Part Ⅰ

Energy supply and demand outlook

1. Framework assumptions

1.1 Model and scenarios

We used a quantitative analysis model, with an econometric approach adopted as the core, to develop an energy outlook and assess energy supply and demand in the world through 2050. The model incorporates the International Energy Agency's (IEA) energy balance tables, along with economic indicators, population data, vehicle ownership statistics, basic materials production and other energy-related information. We divided the world into 44 regions[2] plus international bunkers, as shown in Figure 1-1. We developed a detailed supply and demand analysis model for each region.

Figure 1-1 | Geographical coverage

Source: [map] www.craftmap.box-i.net

We considered two main scenarios for the projections.

Reference Scenario

This is the core scenario for this Outlook. For this scenario, an outlook is developed according to past trends as well as the energy and environmental policies, technologies, etc. that have been in place so far. This scenario incorporates effects expected to appear as a result of traditional and conventional policies—in other words, policies or technologies are not necessarily fixed as they currently are. On the other hand, we assume that no aggressive energy efficiency improvement or policy for a low-carbon transition deviating from past trends will be adopted.

Carbon capture and storage (CCS) is one of the most cutting-edge technologies, and support systems are being established for its commercialisation, primarily in advanced economies. Therefore, the IEEJ Outlook 2026 assumes the introduction of CCS in the relatively near future, around 2030, focusing on projects that are already in operation or under construction. Regarding hydrogen, which is expected to be a clean energy source, it is assumed that its use in power

[2] See Table A1 for a detailed definition.

generation will gradually increase, taking into account the commencement of hydrogen-ammonia co-fired power generation. However, its use in industry and transport is limited.

Advanced Technologies Scenario

In this scenario, all economies in the world are assumed to strongly implement energy and environmental policies contributing to securing stable energy supplies and strengthening measures against climate change and air pollution. These policies are assumed to achieve maximum effectiveness. Specifically, this scenario assumes widespread global implementation of advanced energy technologies as outlined in Figure 1-2, considering both their adoption potential and societal acceptance.

Figure 1-2 | Technology introduction assumptions [Advanced Technologies Scenario]

Introduction and enhancement of environmental regulations and national

Establishment of national strategies and targets, energy efficiency standards, fuel efficiency standards, low-carbon fuel standards, energy efficiency and environmental labelling systems, renewable energy introduction standards, feed-in-tariff systems, subsidy systems, environment tax, emissions trading, etc.

Promoting technology development and international technology cooperation

R&D investment expansion, development of international energy-efficient technologies (steelmaking, cement and other areas), support for establishing energy efficiency standards, etc.

Demand-side technologies

Industry

Global deployment of industrial process technologies at the highest efficiency level (for steelmaking, cement, paper-pulp, etc.);
Introduction of hydrogen reduction iron-making technology

Transport

Further diffusion of clean energy vehicles (highly fuel-efficient vehicles, hybrid vehicles, plug-in hybrid vehicles, electric vehicles, hydrogen fuel cell vehicles)

Buildings

Further diffusion of efficient electric appliances (refrigerators, TVs, etc.), water-heating systems (heat pumps, etc.), air conditioning systems and lighting, as well as enhancement of insulation

Supply-side technologies

Renewable energies

Further diffusion of power generation from wind, solar PV, concentrated solar power (CSP), biomass-fired, marine and biofuels

Enhanced introduction of nuclear power

Acceleration in nuclear power plant construction and improvement in capacity factor

Promotion of highly efficient fossil fuel-fired power generation technologies

Further diffusion of SC, USC, A-USC, coal IGCC (Integrated Gasification Combined Cycle) and natural gas MACC II (More Advanced Combined Cycle II) plants

Next-generation power transmission and distribution technologies

Low-loss substation equipment and voltage regulators

Note: SC stands for supercritical thermal power generation, USC for ultra-supercritical thermal power generation, A-USC for advanced ultra-supercritical thermal power generation, IGCC for integrated coal gasification combined cycle and MACC II for 1 600°C-class combined cycle power generation.

1.2 Major assumptions

The energy supply and demand structure is influenced not only by the above-mentioned energy utilisation technologies and energy and environmental policies, but also by population, economic growth, other social and economic factors and energy prices. The following economic growth and population assumptions are common to both the Reference and Advanced Technologies Scenarios.

Economy

Recent situation

In 2024, despite concerns about stagflation and recession due to rapid global inflation in 2022, the global economy demonstrated solid growth. As we enter 2025, the growth momentum is slowing somewhat due to the growing impact of uncertainty on corporate investment and household consumption, caused by factors such as US trade policies and rising geopolitical risks. The pace of economic recovery remains uneven across regions.

In the United States, with the inflation rate approaching the target of 2% through 2024, the Federal Reserve Board (FRB) announced a 0.5 percentage point cut to the policy interest rate in September 2024, followed by an additional rate cut towards the end of the year. In 2025, the economy has been buffeted by the policies of the new Trump administration. In response to the 'curious balance' of low levels of employment and layoffs (Federal Reserve Chairman Powell) caused by signs of an economic slowdown and increased crackdowns on illegal immigration, the FRB lowered interest rates for the first time in six months in September 2025. So far, the impact of the significant tariff hikes has not been as apparent as previously anticipated. However, this situation is not expected to last forever, and uncertainty remains regarding the future economy.

In Europe, inflation rates, which had remained high, have fallen to target levels. After lowering its policy interest rate in June 2024, the European Central Bank (ECB) implemented a total of eight rate cuts by June 2025, while the Swiss National Bank returned to a zero-interest rate policy in the same month. While the largest economy, Germany, is struggling with economic sluggishness, consumer sentiment is gradually improving in some countries where delayed economic recovery is finally progressing. However, significant risks remain, such as the prolonged Russian invasion of Ukraine and uncertainty surrounding energy supplies, necessitating caution regarding the future.

In China, under the government's 'high-quality development' strategy announced in 2024, exports of high-tech products such as electric vehicles (EVs) and semiconductors are increasing, while also creating trade friction, including over other goods. Nevertheless, growth is slowing due to sluggish domestic demand and a stagnant real estate market. The government continues to implement monetary easing measures, such as cuts to the reserve requirement ratio and the loan prime rate, but these have failed to improve consumer sentiment. Amid structural challenges such as population decline and deflationary pressures, growth is expected to continue slowing.

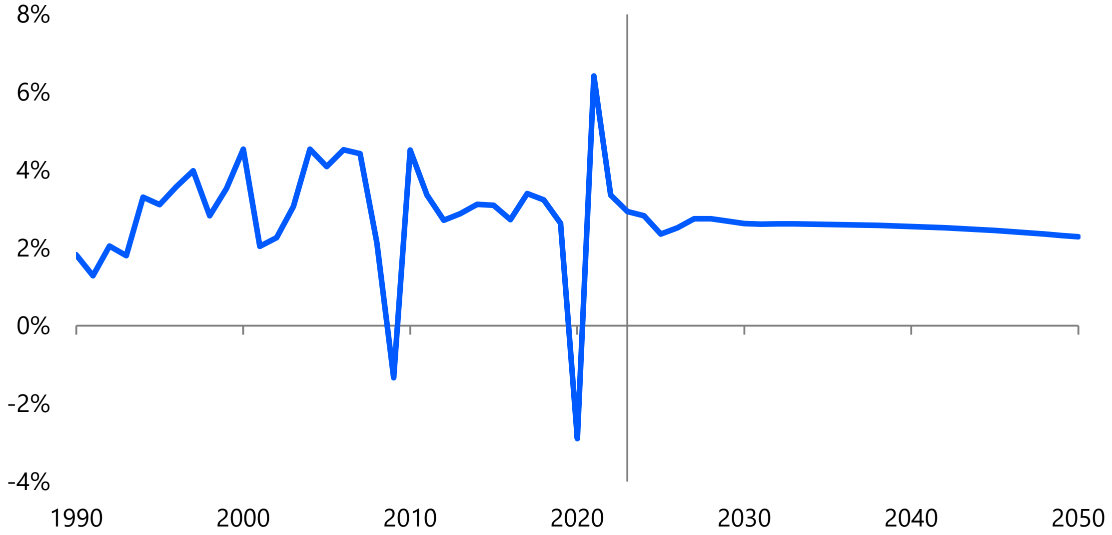
India has maintained a relatively high economic growth rate, supported by strong private consumption, a recovery in exports, higher value added in services and expanded infrastructure investments. Partly due to high tariffs imposed by the United States, India is trying to boost growth by simplifying its value-added tax, effectively lowering the tax rate. With its population growth and progress in digitalisation, India is expected to further strengthen its position as a growth engine for the global economy.

Assumptions for the future

Based on country-by-country economic development plans and economic outlooks prepared by think tanks around the world, we assume economic growth as follows:

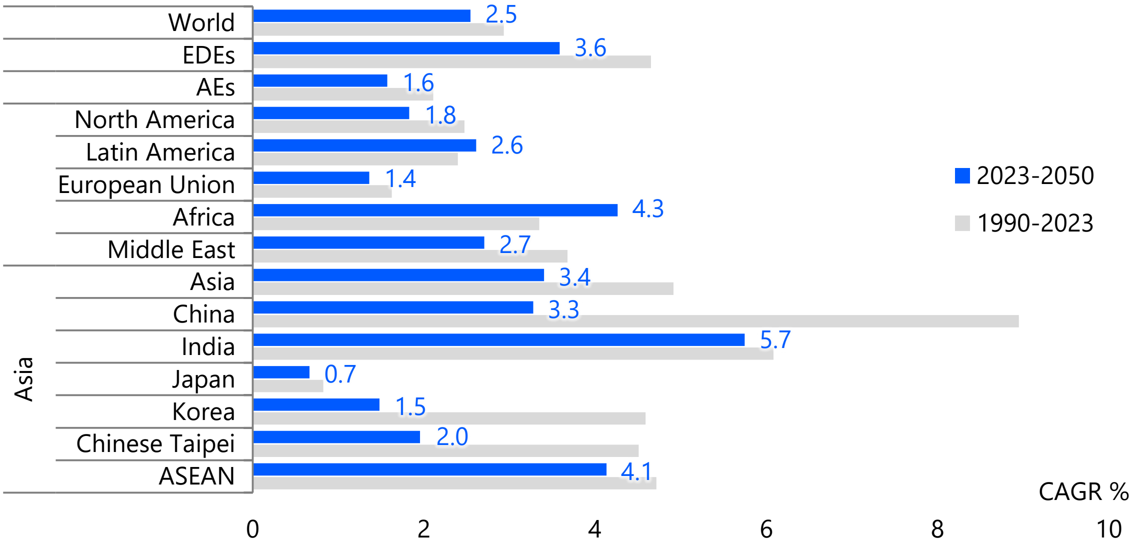
The global economy will slow to a growth rate of 2.4% in 2025, the lowest since the COVID-19 pandemic, driven by factors such as US tariff policies. The growth rate will recover over the next few years, but is expected to gradually decline towards 2050, transitioning from the upper to the lower 2% range (Figure 1-3). Russia's prolonged invasion of Ukraine will not cause significant damage to the global economy as a whole, although it will have localised and short-term effects. Meanwhile, concerns are growing over rising costs and market contraction resulting from supply chain restructuring driven by US policy. For many economies to achieve sustained economic growth, it is essential to enhance productivity, promote technological innovation, implement appropriate fiscal, monetary and redistribution policies, strengthen international cooperation and ensure security.

Figure 1-3 | World economic growth



Advanced Economies will experience slightly weaker growth compared to historical trends, maintaining a growth rate of 1.6% per annum (Figure 1-4). Emerging and Developing Economies will also slow down, but their growth rate will be more than double that of Advanced Economies, at 3.6%. India, in particular, will achieve one of the world's highest growth rates at 5.7%, albeit a slowdown from its post-1990 performance (6.1%). China's slowdown will continue, with the growth rate at 3.3%, below the average for Emerging and Developing Economies. Both Africa and the Association of Southeast Asian Nations (ASEAN) will achieve growth in the low 4% range.

Figure 1-4 | Economic growth in the world and selected economies/regions

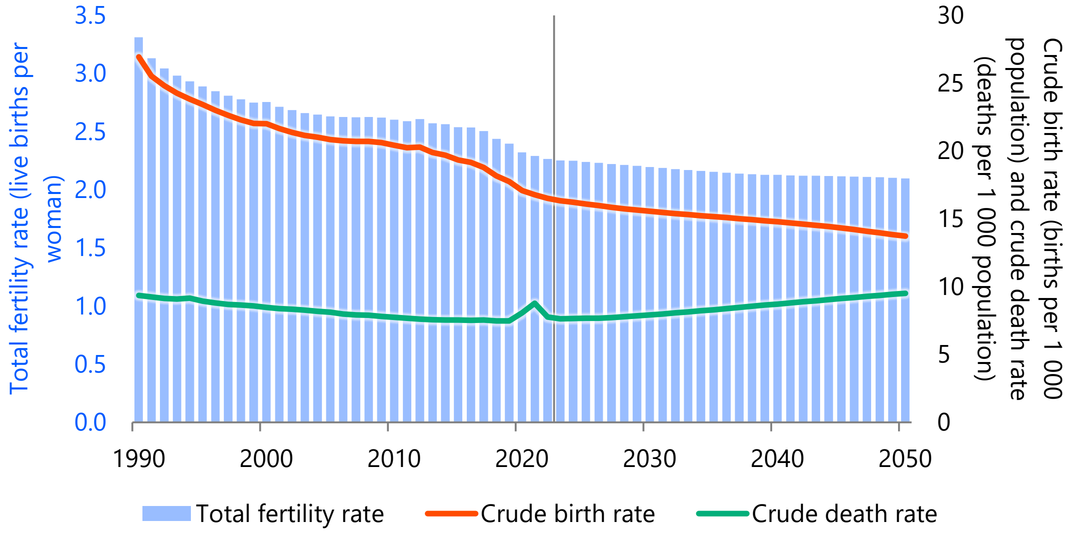


Notes: AEs stands for Advanced Economies. EDEs stands for Emerging and Developing Economies.

Population

For population assumptions, we referenced the United Nations' 'World Population Prospects'. In many Advanced Economies, the total fertility rate (TFR), which is the average number of children born to a woman during her lifetime, has fallen significantly below 1.7. Emerging and Developing Economies are also experiencing declining TFRs, corresponding to income growth and increased female participation in education and the workforce. Thanks to medical technology advancements and improved food and sanitary conditions, the rapid rise in mortality rates observed during the COVID-19 pandemic subsided by 2023, but the rates are expected to increase gradually in the medium to long-term due to the ageing population (Figure 1-5).

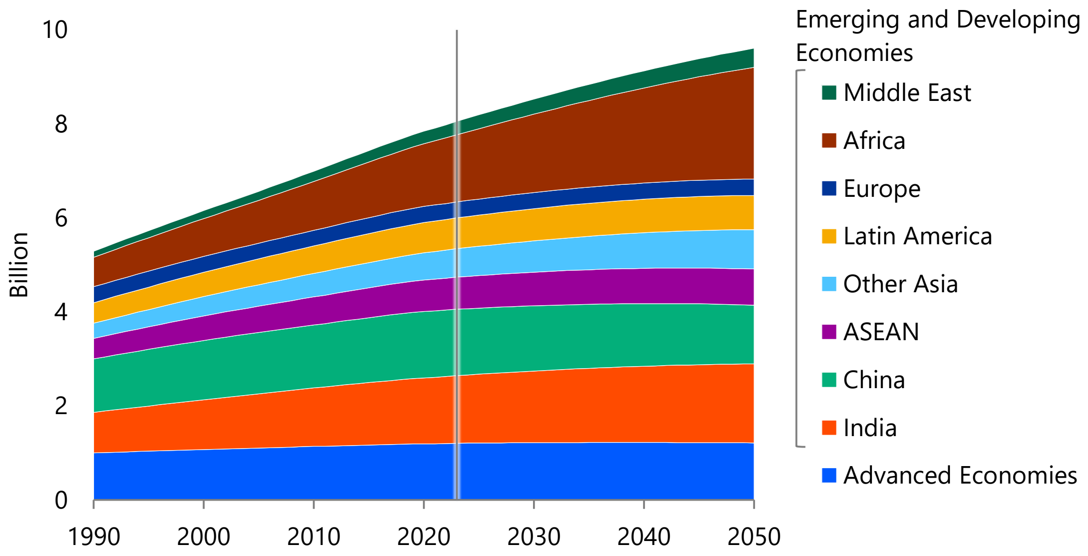
Figure 1-5 | World total fertility rate, crude birth rate and crude death rate



Source: United Nations 'World Population Prospects 2024'

As a result of this global trend toward declining birthrates and population ageing, population growth will continue, but the pace is expected to gradually slow, with the average annual growth rate at 0.7%. As a result, the world population, which was 5.3 billion in 1990 and 8.1 billion in 2023, will reach 9.5 billion by 2050 (Figure 1-6).

Figure 1-6 | Population



Among Advanced Economies, North America, particularly the United States, will experience relatively steady population growth due to substantial immigration and a comparatively high TFR, reaching 417 million by 2050[3]. However, the increase will be moderate, resulting in a slight decline in the United States' share of global population. The European Union's population will peak in the early 2020s, partly due to immigration resulting from the invasion of Ukraine, before beginning to decline, reaching 426 million by 2050. In Asia, Japan's population began decreasing in 2011 and will decline by approximately 15% from 2024 levels to 105 million by 2050. Korea's population, which began gradually declining in 2021, will decrease to 45 million by 2050.

The population of Emerging and Developing Economies will continue to increase substantially, driven by Africa and India. Africa's population will grow by nearly 60% from current levels to 2.378 billion in 2050, as lower mortality rates offset gradually declining birth rates. Nigeria, in particular, is expected to experience rapid population growth to become the third most populous country in the world by 2050. The Middle East's population will expand by 50%, reaching 404 million by 2050, supported by government financial incentives to increase the population and growing immigration from other regions. In Asia, India, which surpassed China in 2023 to become the world's most populous country, will maintain its high growth rate, reaching 1.68 billion in 2050. China's population, which peaked in 2021, has begun to decline and will decrease to approximately 1.250 billion by 2050. ASEAN's population will increase by 10% to 768 million by 2050.

[3] The United Nations' "World Population Prospects 2024" does not reflect the exclusionary policies of the Trump administration, which came into office in 2025.

International energy prices

Recent situation

Brent crude oil prices surged to nearly $130 per barrel (bbl) in March 2022 following Russia's invasion of Ukraine. However, by the end of the year, the prices had declined to around $80/bbl, driven by sustained Russian exports despite sanctions and concerns over weakening global demand. In 2023, they temporarily approached $100/bbl at the end of September. Oil prices were influenced by several factors, including accelerating inflation in the United States and Europe, monetary tightening aimed at controlling inflation and additional production cuts by Organization of the Petroleum Exporting Countries (OPEC) plus members, including Saudi Arabia and Russia. Demand recovery, especially in China, also contributed to price fluctuations.

Thereafter, oil prices continued to decline, and by the end of December, had fallen below $80/bbl. In 2024, the prices rose to over $90/bbl in April as supply concerns grew due to continued production cuts by OPEC+ and attacks on merchant ships in the Red Sea. Oil prices gradually fell to $75/bbl by June and then rose to $85/bbl in July due to rising tensions between the Lebanese militant group Hezbollah and Israel. However, from August onwards, the prices began to decline due to increased production in non-OPEC countries such as the United States and Brazil, and slowing demand in China.

In September, the prices fell to around $70/bbl and remained at that level until December. In 2025, as OPEC+ began gradually lifting production cuts in March, oil prices gradually declined to $60/bbl by May. In June, a tanker collision near the Strait of Hormuz, possibly caused by radio interference, led to the prices temporarily rising to $75/bbl, but they have since fallen gradually. In September, eight OPEC+ member countries completed the lifting of their voluntary production cuts. Brent crude oil prices have fluctuated between $60/bbl and $80/bbl, influenced by macroeconomic conditions in major consuming countries, particularly China and the United States (Figure 1-7).

Figure 1-7 | Brent crude oil prices

Source: Intercontinental Exchange

Regarding natural gas prices, spot liquefied natural gas (LNG) and spot natural gas prices have been on a downward trajectory since late December 2022. The dominance of oil-linked long-term

LNG contracts in the Asian market has diminished, although this situation could fluctuate within a short period. The average Asian spot LNG price for 2022 was $35 per million British thermal unit (MBtu) while the European spot natural gas price (Title Transfer Facility [TTF], front-month delivery) was $43/MBtu. The 2023 average for both ranged from $13/MBtu to $14/MBtu, the 2024 average was also around $11/MBtu to $12/MBtu, with the average for the first half of 2025 ranging from $12/MBtu to $13/MBtu.

Spot LNG and spot natural gas prices (in Europe) have soared since the second half of 2021 after the slump in 2020, intensifying volatility. Under such circumstances, spot LNG and natural gas prices continually exceeded oil prices on a calorific value basis from August 2021 to April 2023. Although natural gas prices have generally remained at lower levels relative to oil prices in the second half of 2024 and have largely moved in line with oil prices, they remain above pre-2021 averages.

From April 2023 onwards, natural gas prices were expected to ease due to improving European supply conditions and stable LNG availability toward 2030. However, potential disruptions could reverse this trend. Factors such as further reductions in Russian pipeline gas to Europe, rising LNG demand from China and unexpected production outages could lead to renewed price volatility. For instance, in July 2024, both Asian spot LNG and European spot natural gas prices remained elevated for the Northern Hemisphere's summer season due to hurricane-induced LNG production halts in the United States.

Japan's average LNG import price reached a record high of $22.71/MBtu in September 2022, reflecting the surge in Japan's average oil prices through June 2022. It then fell below $13/MBtu in early 2024, partly due to the downward trend in oil prices since July 2022, then dropped to $11.45/MBtu in June 2025.

The steam coal market also experienced significant price volatility. Prices exceeded $400 per tonne (t) in 2022, a record high, driven by increased demand following the COVID-19 recovery, intensified efforts by the European Union, Japan and others to switch from Russian coal to alternative sources following Russia's invasion of Ukraine and supply constraints in major coal-producing countries due to adverse weather. Subsequently, coal prices fell as Russian coal was redirected to non-sanctioning countries such as China and India, weather conditions improved in key producing regions, and demand for energy and steel weakened.

From 2024 onward, the prices temporarily dipped below $100/t, but by August 2025, they have been hovering around $110/t. Although the prices remain significantly lower than the 2022 peak, they are still high compared to pre-pandemic levels. However, alongside declining profits from the coal business due to falling market prices, concerns exist over a reduction in supply capacity due to the difficulty of making coal investments amid the trend away from coal. In particular, uncertainty regarding future coal supplies is becoming apparent.

Reference Scenario

In the Reference Scenario, oil demand will continue to be driven by Asia; however, the centre of demand growth will shift from China to India and ASEAN. On the supply side, non-OPEC production will increase until around 2030, after which dependence on OPEC will rise. Oil demand is projected to expand continuously through 2050, with the breakeven oil price expected to rise over the medium to long term. The real oil price (2024 prices) is assumed to be $80/bbl in 2030 and $85/bbl in 2050 (Table 1-1).

Table 1-1 | International energy prices

Real prices			Reference			Advanced Technologies		
		2024	2030	2040	2050	2030	2040	2050
Oil	$2024/bbl	79	80	85	85	75	70	65
Natural gas								
Japan	$2024/MBtu	12.1	8.8	9.2	9.1	8.3	8.1	7.6
Europe (Netherlands)	$2024/MBtu	11.0	8.9	9.8	9.9	8.7	9.0	8.6
United States	$2024/MBtu	2.4	3.0	4.2	4.7	3.0	4.1	4.0
Steam coal	$2024/t	157	105	110	110	100	90	80

Nominal prices			Reference			Advanced Technologies		
		2024	2030	2040	2050	2030	2040	2050
Oil	$/bbl	79	91	131	179	89	112	144
Natural gas								
Japan	$/MBtu	12.1	10.0	14.2	19.1	9.9	12.9	16.8
Europe (Netherlands)	$/MBtu	11.0	10.1	15.0	21.0	10.3	14.4	18.9
United States	$/MBtu	2.4	3.4	6.5	9.9	3.6	6.6	8.8
Steam coal	$/t	157	120	169	232	119	145	177

Note: The annual inflation rate is assumed at about 3%.

Assuming an annual inflation rate of approximately 3%, the nominal oil price would rise to $95/bbl by 2030 and $188/bbl by 2050.

Regarding Japan's natural gas prices, the coefficient of the oil price-sensitive portion of Japan's import prices linked to oil is expected to decline in line with the downward trend in oil consumption in Japan. The sustained increase in LNG exports from the United States is anticipated to diversify procurement sources and eliminate or ease destination restrictions, gradually shifting pricing away from oil-linked contracts. Additionally, Japan's natural gas prices are expected to mutually influence Asian markets, including those in emerging economies. Consequently, the ratio of oil price impact on Japan's import prices is set at 60% in 2030, decreasing to 50% by 2050. Meanwhile, the share of Japan's import prices mainly affected by US natural gas prices, rather than oil prices, will gradually increase from 40% in 2030 to 50% in 2050. In addition, a certain premium will also be applied by multiplying the United States Henry Hub price by a premium factor.

The Henry Hub price is based on projections from the U.S. Energy Information Administration's (EIA) 'Annual Energy Outlook 2025'. US prices will likely remain lower than those in other regions, supported by abundant domestic supply. Taking into account the current development situation, the price will rise gradually toward 2030. Thereafter, it will rise towards 2040 due to a relative increase in development and production costs and rising demand, including exports outside the region, followed by a gradual rise. In Europe, the portion of prices linked to oil is projected to decline, reflecting decreasing crude oil consumption. However, European natural gas prices are expected to remain elevated due to the phasing-out of Russian pipeline gas, which previously contributed to stable prices.

It is assumed that carbon capture and storage (CCS) and electrification will gradually be incorporated into new and existing LNG projects. However, the resulting increases in investment costs and their potential impact on LNG prices are not factored into this scenario. While discussions continue regarding the potential for a premium for cleaner LNG, some producers have stated they will not pass the additional costs of greenhouse gas (GHG) measures onto prices. At the same time, some consumers remain cautious about accepting such premiums.

Coal prices (free on board [FOB], steam coal from Newcastle, Australia) reached a record high in 2022 due to sanctions on Russian coal and supply disruptions. However, global supply concerns have eased, leading to price stabilisation. Over the long term, demand for coal is expected to decline, partly due to the global trend toward carbon neutrality. Nonetheless, as new investments in coal production decrease, supply and demand dynamics will gradually tighten, with the real price assumed to reach $110/t by 2040. While demand for coal for power generation will increase in Asian countries such as India and ASEAN members, on the supply side, the expansion of coal production capacity is expected to become almost non-existent, especially in Advanced Economies, due to tighter environmental regulations and the trend toward decarbonisation. As a result, there is concern that risk of short-term fluctuations due to seasonal factors and supply-demand imbalances will increase.

Advanced Technologies Scenario

In the Advanced Technologies Scenario, fossil fuel demand will decline from around 2030 because of more rapid improvements in energy efficiency and fuel switching to nuclear, renewables and hydrogen. As a result of the sluggish demand, fossil fuel prices generally will be lower compared to the Reference Scenario. Prices may become volatile if a smooth transformation of the energy demand structure and the corresponding supply structure are not coordinated.

Global demand for natural gas will peak in the 2030s followed by a gradual decline. In Japan, the share of import LNG prices linked to oil will decrease further, aligned with reduced crude oil consumption in Japan. Specifically, the ratio affected by oil prices will decline to 50% in 2030 and 40% in 2050, which is lower than in the Reference Scenario. The portion of Japanese import prices influenced by factors other than oil, primarily US natural gas prices, will be 50% in 2030 and 60% in 2050. A premium will continue to be added by multiplying the Henry Hub price by a premium factor. Henry Hub prices assume continued abundant supply capacity, while also referencing the EIA's 'Annual Energy Outlook 2025'. The coefficient for the oil price-sensitive portion of European natural gas prices is lowered in line with the downward trend in crude oil consumption. Meanwhile, with the further downward trend of crude oil consumption in the Advanced Technologies Scenario, the ratio affected by oil prices will be reduced.

2. Energy demand

2.1 Primary energy consumption

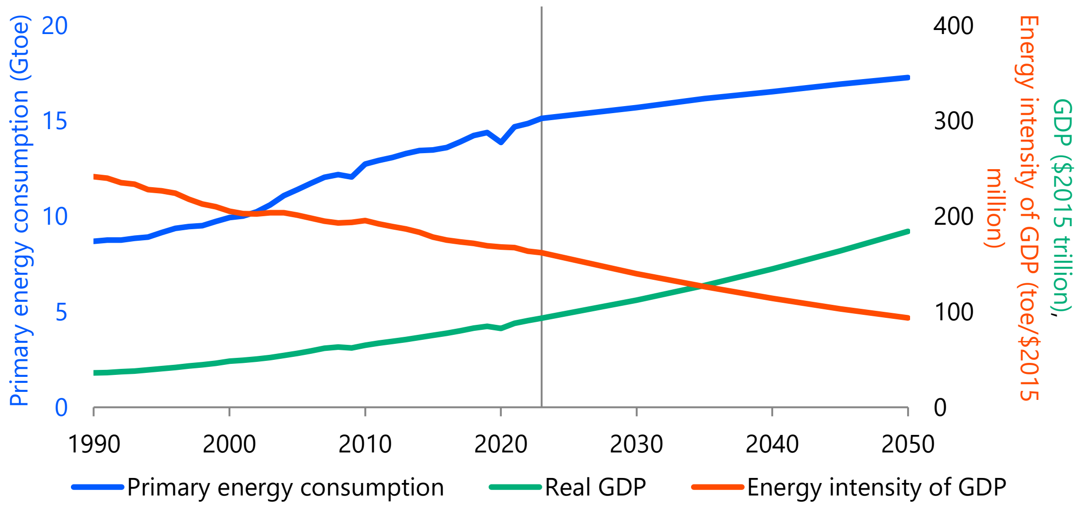
Whilst improvements in energy consumption per unit of GDP are being made from the perspective of climate change countermeasures and energy security, the volume continues to increase.

Even in 2025, the effects of climate change have been evident, with extreme wildfires in California in January, extreme heat waves in India and Pakistan since April, and the worst wildfires on record across Europe, covering an area of over 1 million hectares in the summer. To mitigate the impacts of climate change, each country has set greenhouse gas (GHG) emission reduction targets, and at the 29th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP29), held in Baku, Azerbaijan in November 2024, it was planned to conduct a follow-up, from 2025 until COP33, on the results of the Global Stocktake, which assessed global progress on GHG reductions and was completed at COP28. However, some developing economies claimed that there was no need for monitoring or follow up, while major advanced economies and small island nations called for confirmation of the implementation status of the agreement. This led to a sharp confrontation between the two sides, and further discussions were postponed. In 2025, US President Donald Trump directed the withdrawal of the United States from the Paris Agreement and related international climate commitments, with the withdrawal scheduled to take effect in January 2026, one year after notification. The framework for the 2050 net-zero target is losing momentum, with major banks withdrawing from the Net Zero Banking Alliance (NZBA), an international coalition aiming for decarbonisation, following pressure from some US Republican lawmakers. The European Union (EU) has also been proceeding with an ambitious proposal to reduce emissions by 90% compared with 1990 levels by 2040, but there are moves to allow the use of credits from afforestation and renewable energy deployment outside the European Union to achieve national targets, as well as to delay a final decision due to opposition from member states.

Furthermore, amid heightened tensions in the Middle East, Iran proposed a blockade of the Strait of Hormuz in June 2025. In August, escalating hostilities in Ukraine led to Ukrainian attacks on Russia's Druzhba crude oil pipeline facilities. Additionally, large-scale power outages occurred in Spain and Portugal in May. These developments have heightened concerns regarding energy supply stability and price stabilisation. On the energy demand side, there are growing uncertainties, including potential increased electricity consumption associated with digital transformation driven by generative artificial intelligence (AI) and other technologies. Consequently, while acknowledging diverse energy transition pathways, countries are strengthening policies to promote economic growth and a stable supply through enhanced energy efficiency and reduced fossil fuel dependence via clean technologies.

Global primary energy intensity per gross domestic product (GDP) from 2023 to 2050 will decline faster than from 1990 to 2022 as countries around the world promote higher energy efficiency and energy conservation in the context of economic, climate change and energy security actions (Figure 2-1). Although COP28 set a target to double the annual rates of energy efficiency improvement from 2% to 4% until 2030, the actual improvement is expected to reach only 2.1% annually from 2023 to 2030, decline to 2.0% by 2035 and remain at 2.0% up to 2050. As global GDP will grow faster than improvements in energy intensity, primary energy consumption will continue to rise. Energy consumption growth, which was 1.7% per year from 1990 to 2023, will slow to 0.5% per year from 2023 to 2035 due to continued progress in energy conservation and will remain at the same annual pace through 2050. As a result, global energy consumption will increase by 9% relative to 2023 levels by 2035, reaching 16 164 million tonnes of oil equivalent (Mtoe) and by 16% by 2050, to 17 298 Mtoe. It will be difficult to satisfy the new demand simply by increasing the supply of non-fossil fuels such as nuclear and renewable energies. Therefore, countries must enhance energy efficiency further to reduce global fossil fuel consumption with an eye towards the goals set at COP28.

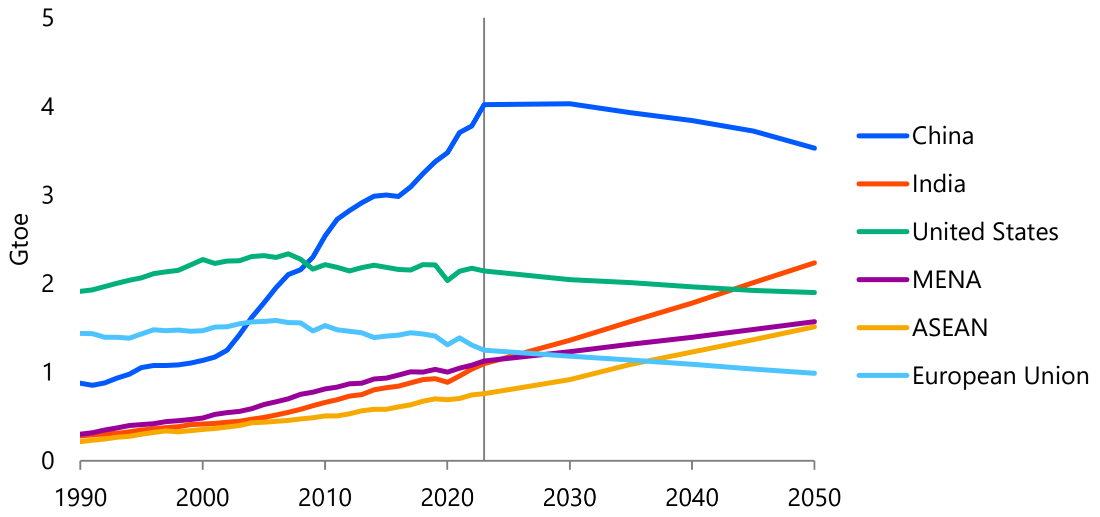
Figure 2-1 | Global primary energy consumption, real GDP and energy intensity of GDP [Reference Scenario]



By region, primary energy consumption in China, which has driven the global increase since 2000, will peak in the early 2030s and begin to decline due to slower economic growth as well as progress in energy efficiency, such as a shift towards services industries and the penetration of electric vehicles (EVs). Meanwhile, primary energy consumption in India, the Association of Southeast Asian Nations (ASEAN) and the Middle East and North Africa (MENA) will continue to increase in line with their rapid economic expansion, despite some progress in energy efficiency. The increase in these three countries/regions will account for 97% of the increase in the world's consumption from 2023 to 2035 and 110% from 2023 to 2050, pushing up global energy consumption, with their share growing from 20% in 2023 to 25% in 2035 and 31% in 2050 (Figure 2-2). Therefore, beyond the need to accelerate energy consumption reductions in Advanced Economies and China, the ability of India, ASEAN and MENA to moderate their energy consumption will determine global consumption trends and ultimately the success of climate change and energy security measures.

India, ASEAN and MENA, respectively, will increase their primary energy consumption by 2.7%, 1.2% and 2.6% per annum from 2023 to 2050 and account for 13%, 9% and 9% of global energy consumption in 2050. This is because their GDP will continue to grow at high annual rates of 5.7%, 4.1% and 3.0% through 2050. From the perspective of curbing global energy consumption, decoupling economic growth from energy consumption in these countries/regions represents a critical global challenge.

Figure 2-2 | Primary energy consumption in selected countries/regions [Reference Scenario]



Advanced Economies, including the United States, the European Union and Japan, as well as China, must continue reducing their energy consumption in light of climate change and energy security concerns. However, in the United States, President Trump has suspended funding allocations under the Inflation Reduction Act and revoked environmental executive orders issued under the previous Biden administration, such as the target for electric vehicles to account for 50% of annual new car sales by 2030. In the European Union, regulations for automotive manufacturers continue to be relaxed through the postponement of targets and increased flexibility, treating the 2025 carbon dioxide (CO_2) emission standards as a three-year average from 2025 to 2027, reflecting the difficulty of achieving them. China's 14th Five-Year Plan, announced in 2021, set a goal of reducing CO_2 emissions per GDP by 18% between 2021 and 2025 compared with 2020 levels, but by 2023, emissions had increased from the previous year, resulting in only a 2% reduction relative to 2020. The United States, Europe, Japan and China will account for 40% and 21% of global GDP in 2035 and 35% and 23% in 2050, respectively, and will continue to hold large shares of energy consumption, at 22% and 24% in 2035 and 18% and 20% in 2050. To restrain global energy consumption in support of climate change and energy security measures, these economies should accelerate their reduction of energy consumption while contributing to stable global economic growth through sustained consumption and investment.

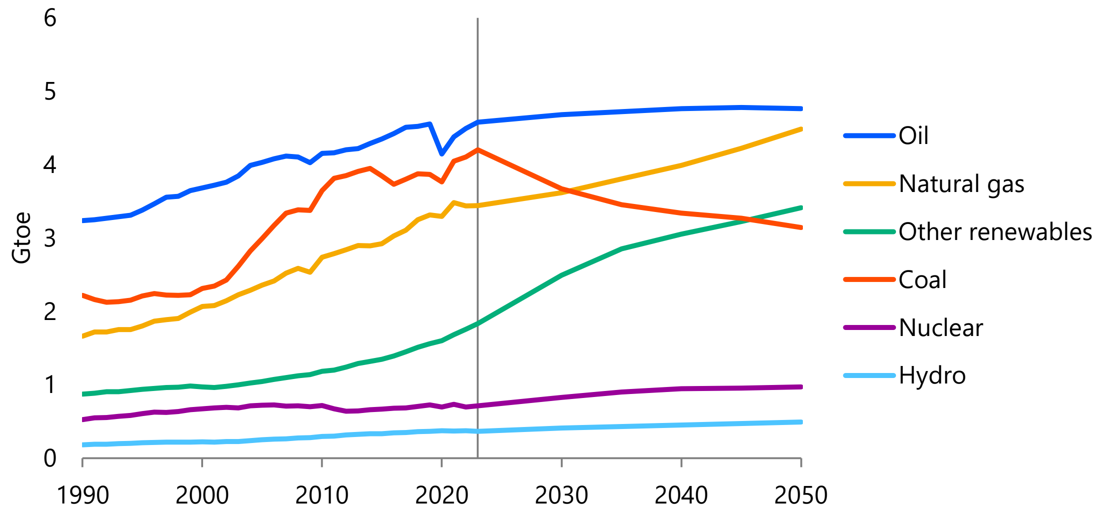
Further reducing global energy consumption will require enhanced international cooperation between advanced economies and emerging and developing economies, as well as among emerging and developing economies, alongside strengthened national policies. Advanced economies such as the United States, Europe and Japan must facilitate efficient technology transfer and support emerging and developing economies to achieve economic growth while limiting energy consumption by utilising Article 6 of the Paris Agreement, adhering to the new joint numerical targets on climate finance agreed at the 29th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP29), and addressing energy security concerns, particularly regarding fossil fuel supply instability.

Fossil fuel consumption continues to expand, with natural gas seeing particularly strong growth, continues to expand amid growing concerns about climate change and energy security.

In addition to the global trend towards carbon neutrality, Russia's invasion of Ukraine has heightened concerns about the stable supply of fossil fuels, particularly in Europe. As part of climate change mitigation efforts, COP28 established ambitious targets to triple global renewable energy installed capacity by 2030 compared with 2022 levels and triple global nuclear power generation installed capacity by 2050 compared with 2020 levels.

However, under current plans, nuclear will only reach 1.4 times the 2020 level by 2050 on a primary energy basis. Although renewables will sustain the growth observed during the 2020s, they will increase by only 1.4 times between 2022 and 2030. Growth will further slow after 2030 due to land availability and grid integration constraints, resulting in a 1.5-fold increase by 2035 and 1.8-fold by 2050 (Figure 2-3). Additionally, the adoption of hydrogen and ammonia will remain limited, as demand is not yet sufficient to justify their high costs.

Figure 2-3 | Global primary energy consumption [Reference Scenario]



Fossil fuel consumption declined significantly in 2020, partly due to the economic downturn and voluntary home confinement (or lockdowns) amid the COVID-19 pandemic. However, consumption rebounded as economies recovered from the pandemic, with coal and oil reaching a record high in 2023. Until 2030, overall fossil fuel consumption will decrease, as a significant reduction in coal offsets increases in oil and natural gas. After 2030, due to a larger increase in natural gas, fossil fuel consumption will resume growth, rising by 1.4% by 2050 compared with 2023 levels. Although the supply concerns have heightened due to Russia's invasion of Ukraine, natural gas, which emits the least carbon among fossil fuels, will be the most actively utilised fossil fuel to support climate change mitigation. Natural gas consumption will grow at an average annual rate of 1.0% through 2050, reaching 1.3 times its 2023 level, primarily driven by demand in the power generation sector. Oil will increase until the mid-2040s due to greater movement of people and goods and expanded use of petrochemical feedstocks. It will then begin to decrease slightly as the penetration of electrified vehicles increases and fuel efficiency improves in the road sector. This marks a departure from the IEEJ Outlook 2025, which projected that oil consumption on a calorie basis would continue to increase throughout the projection period. However, it is essential to recognize that consumption levels in 2050 will remain comparable to current levels and may even exceed them on a volume basis (p.28). Whilst coal will increase in India and ASEAN, where electricity demand is expanding, due to its low cost, it will generally decline due to climate change mitigation measures, mainly in Advanced Economies, and air pollution, mainly in China. Coal will decline at an annual rate of 1.1% by 2050 and will be lower than that of renewable energy sources excluding hydro in the late 2040s.

While non-fossil energy sources will increase, overall energy demand will grow even faster. As a result, non-fossil sources alone will not be sufficient to meet total energy demand over the next three decades. Through 2050, it will remain realistic for the world, especially Emerging and Developing Economies whose energy consumption is increasing, to use both fossil fuels and non-fossil energy (Figure 2-4).

Figure 2-4 | Primary energy consumption changes [2023–2050, Reference Scenario]

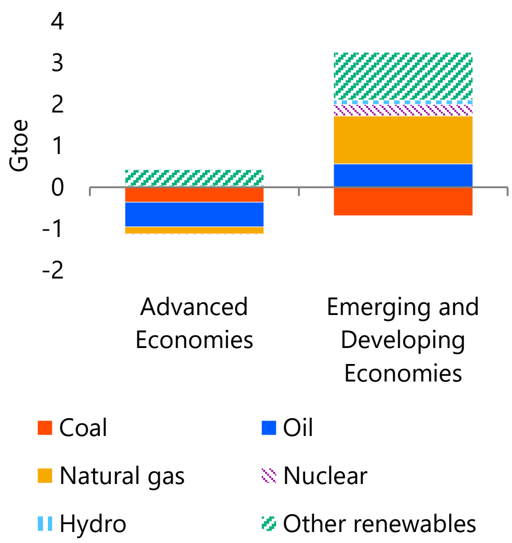
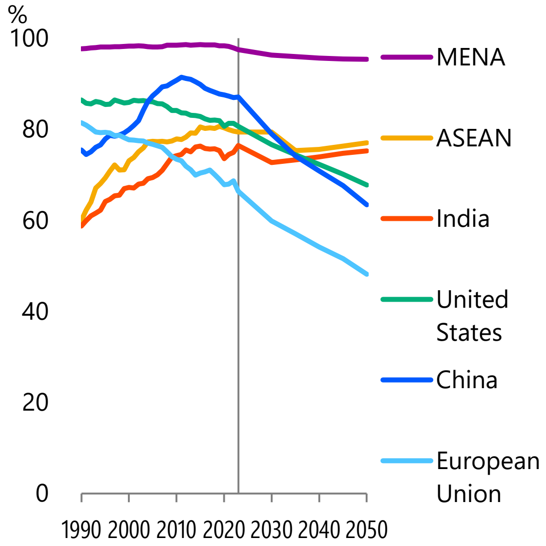


Figure 2-5 | Dependence on fossil fuels in selected economies/regions [Reference Scenario]



Dependence rates on fossil fuels will decrease from 81% in 2023 to 72% by 2050. The United States, the European Union and Japan will see their dependence rates decline from 81%, 66% and 85% in 2023 to 68%, 48% and 64% in 2050, respectively, as the adoption of non-fossil energy sources advances amid declining total energy consumption (Figure 2-5). Meanwhile, Emerging and Developing Economies excluding China will see their dependence rates remain high. Fossil fuel dependence rates in India, ASEAN and MENA will remain high at 75%, 77% and 95%, respectively, due to increasing total energy consumption, with fossil fuels continuing to meet much of this rising demand.

Energy consumption reduction and decarbonisation will not be easy in any sector.

Among sectors, industry will experience the highest energy consumption growth, primarily in Emerging and Developing Economies, followed by the transport sector, the buildings sector and the other transformation sector, with similar increases (Figure 2-6). In the industry sector, production in secondary industries, such as machinery, will expand significantly in Emerging and Developing Economies. The transport sector will see increased consumption by motor vehicles as incomes rise in Emerging and Developing Economies, while consumption by air and sea transport will also grow substantially due to increased passenger movement and international trade. Energy consumption growth in the buildings sector will also be significant. In India, ASEAN and MENA, the continued development of tertiary industries, including global call centres and improved household access to energy will drive demand growth. Rising living standards in these economies will further push up energy consumption in the buildings sector. Given these factors, it will be challenging for these economies to curb energy demand while maintaining economic growth. Furthermore, some point out that data centres are driving up electricity demand globally, including in Advanced Economies.

Figure 2-6 | Contributions to global primary energy consumption changes [Reference Scenario]

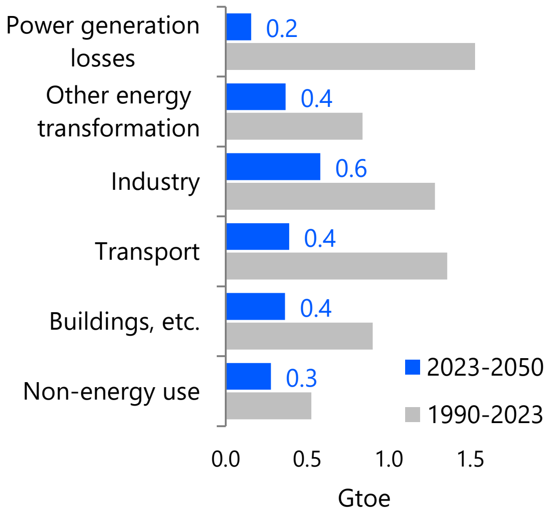
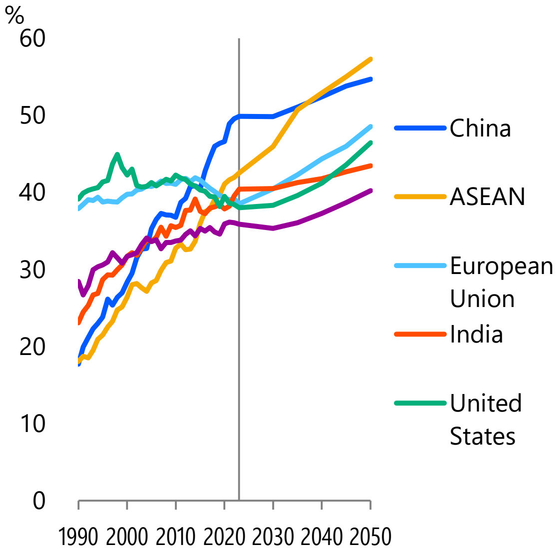


Figure 2-7 | Electrification rates on the supply side in selected economies/regions [Reference Scenario]

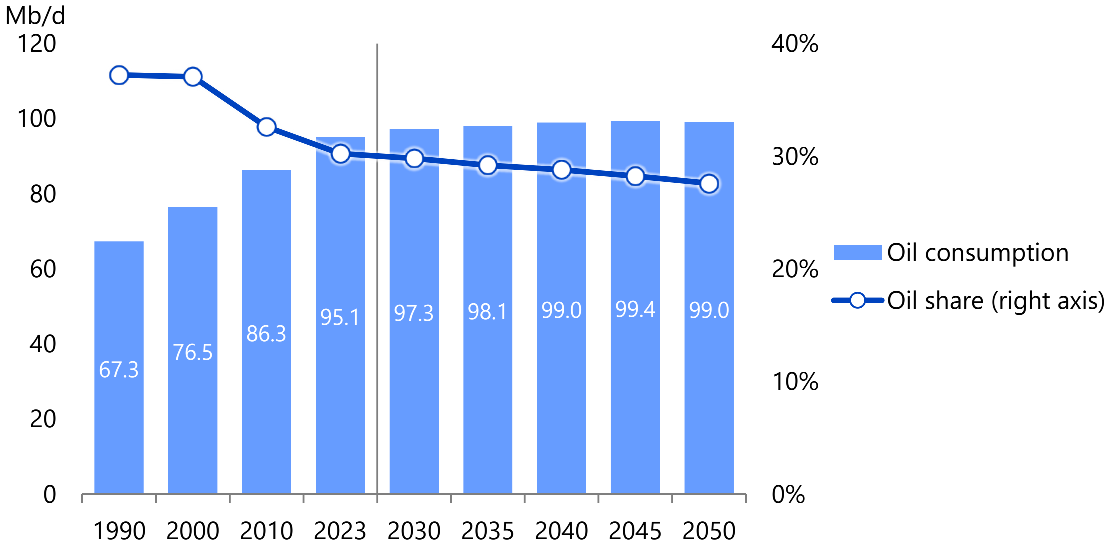


Energy consumption (losses) in the power generation sector will increase due to higher electricity generation resulting from rising electrification rates, although improvements in fossil fuel-fired power generation efficiency and a shift towards non-fossil power sources, which are assumed to have 100% efficiency (no losses), will partly offset this increase (Figure 2-7). As incomes rise and infrastructure development progresses in currently unelectrified regions, electricity consumption in Emerging and Developing Economies will continue to increase due to its convenience and widespread adoption. Furthermore, electricity demand will continue to grow, not only in Emerging and Developing Economies, but also in Advanced Economies, where digitalisation is increasing energy needs. Although the share of non-fossil energy sources is expected to grow, they will likely be insufficient to fully meet the rising electricity demand.

Oil consumption will peak in the late 2040s, while its share of primary energy consumption will decline gradually.

Global oil consumption, which stood at 95.1 million barrels per day (Mb/d) in 2023, will increase gradually, peaking in the mid-2040s before accounting for 99.0 Mb/d in 2050 (Figure 2-8). The oil share of primary energy consumption will continue to decline slightly from 30% in 2023 to 28% by 2050. This rate of decline will remain comparable to that observed between 2010 and 2023. Oil will remain the world's most widely used energy source through 2050.

Figure 2-8 | Global oil consumption and its share of primary energy consumption [Reference Scenario]



In Advanced Economies, oil consumption has already peaked (Figure 2-9). Since reaching its peak in 2005, oil consumption has declined at an annual rate of 1.2%, but from 2023 to 2050, the decline will accelerate at an annual rate of 1.5%. The main factor driving this decline in Advanced Economies is the reduction in automobile fuel consumption, supported by fuel efficiency improvements and the adoption of electrified vehicles, including hybrid vehicles. By contrast, oil consumption in India, ASEAN and MENA will steadily increase at an annual rate of 1.5% from 2023 to 2050. The oil consumption of these economies will grow mainly in the transport, non-energy use and buildings sectors.

Figure 2-9 | Oil consumption in selected economies/regions [Reference Scenario]

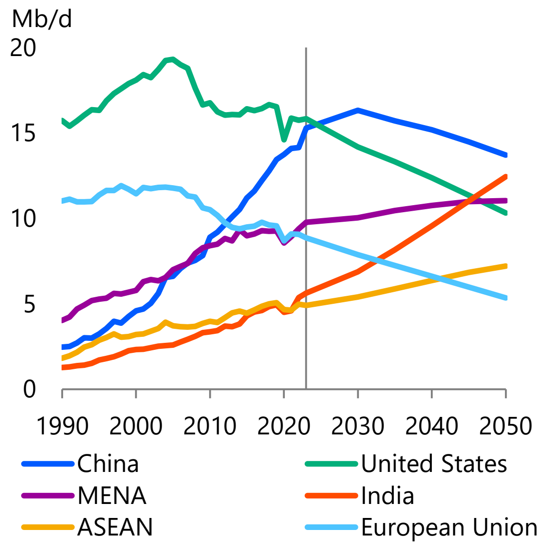
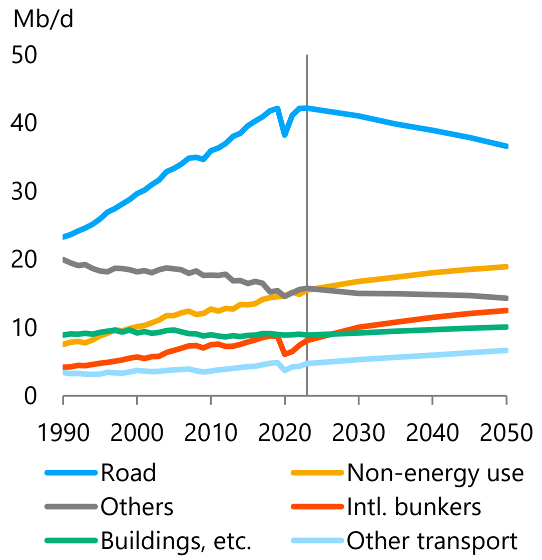


Figure 2-10 | Global oil consumption [Reference Scenario]



By sector, oil consumption in the road sector, which has the largest share, will peak in the 2020s and then decline, as the effects of fuel efficiency improvements and the expansion of electrified vehicles outweigh the impact of increasing vehicle ownership (Figure 2-10). Meanwhile, oil consumption in the other transport sector, including international bunkers, domestic aviation and domestic navigation, is difficult to replace through means such as electrification. Rising trade and passenger mobility will drive growth in this area.

In India, ASEAN and MENA, oil consumption for automobiles will rise from 8.8 Mb/d in 2023 to 13.7 Mb/d in 2050. Vehicle ownership in these countries/regions will increase by 3.4-fold from current levels, supported by rising incomes and improvements in transport infrastructure, such as roads and bridges. To curb oil consumption, it will be necessary to actively promote a transition to electric vehicles and others. In Emerging and Developing Economies, the initial cost of electric vehicles may remain higher compared with conventional cars even in 2050, restricting sales to high-income consumers unless strong climate policies and financial incentives are implemented.

Oil consumption in the non-energy use sector, primarily for petrochemicals, will increase by 2.3 Mb/d from 2023 to 2050 in India, ASEAN and MENA, accounting for 68% of global growth in the sector. While global demand for plastics and other petrochemical products is strong, oil-producing countries hope to foster their petrochemical industries as part of their industrial diversification. This means that both supply-side and demand-side factors will drive oil consumption growth in this sector. To suppress consumption in the sector, regulations on plastics consumption will need to be toughened. However, even from the perspective of addressing plastic waste issues, the reality is that establishing an international prevention treaty, as called for by the United Nations Environment Assembly in 2022, remains as difficult as climate change measures, with the 2025 intergovernmental negotiations failing to reach agreement.

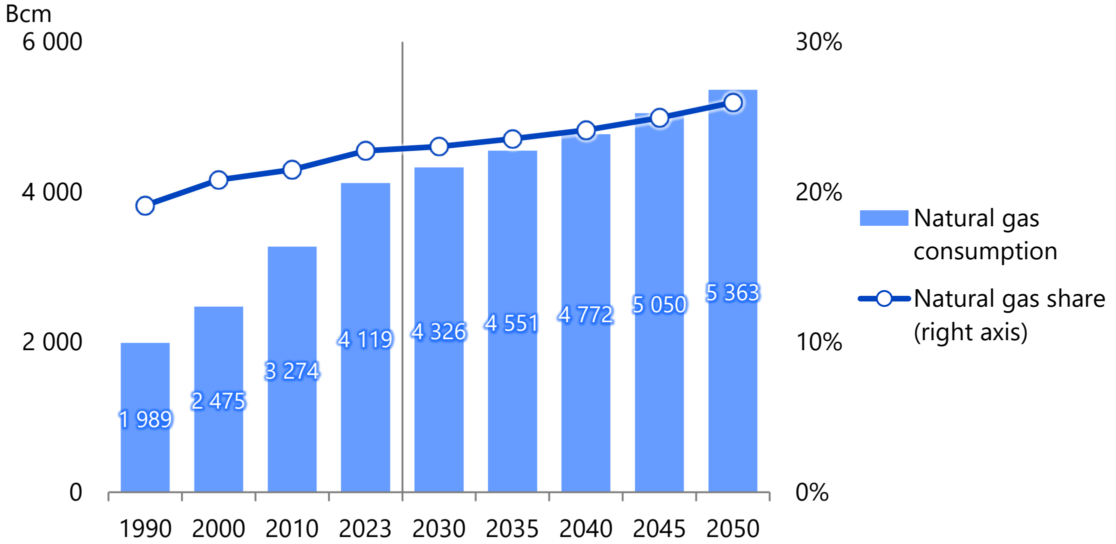
Oil consumption in the buildings sector of India, ASEAN and MENA will increase by 1.5 Mb/d from 2023 to 2050, accounting for 119% of the net global increase in this sector. As incomes rise, consumers in these countries/regions will shift from coal and solid biomass to oil, which is a relatively cleaner alternative in terms of health impacts. It should also be noted that in Sub-Saharan countries other than South Africa, oil consumption by the buildings sector will increase by 0.5 Mb/d during the same period. In those countries, the high initial investment required to switch to and operate electricity or city gas for water heating and cooking leads consumers to choose liquefied petroleum gas for that purpose.

China’s oil consumption is expected to increase mainly in the non-energy use sector, peaking at 16.3 Mb/d around 2030, before declining to 13.7 Mb/d in 2050 due to a decline in the road sector driven by the increase in electric vehicles. Accelerating the reduction of oil consumption in China will be critical to achieving deeper global reductions in oil use.

Demand for natural gas for power generation continues to grow in India, ASEAN and MENA.

Natural gas consumption will see the largest increase of all energy sources through 2050. Global consumption will grow at an annual rate of 1.0%, rising from 4 119 billion cubic metres (Bcm) in 2023 to 5 363 Bcm in 2050 (Figure 2-11). As a result, natural gas will expand its share of primary energy consumption from 23% in 2023 to 26% in 2050, making it the second most consumed energy source after oil. As the European Union reduces its dependence on Russian natural gas and increases imports from other regions, particularly liquefied natural gas (LNG), the question of how to limit global natural gas demand growth remains critical.

Figure 2-11 | Global natural gas consumption and its share of primary energy consumption [Reference Scenario]



India, ASEAN and MENA will account for 77% of the total global increase in natural gas consumption, adding a combined 1 245 Bcm between 2023 and 2050 (Figure 2-12). By 2050, natural gas consumption will reach 215 Bcm in India, 1 134 Bcm in ASEAN and 590 Bcm in MENA. The Middle East is expected to increase domestic natural gas consumption while continuing to prioritise cost-competitive oil exports to generate foreign currency. India and ASEAN will expand natural gas consumption primarily for the power generation sector to meet their rising electricity demand. China will see an increase of 42 Bcm by 2050, driven primarily in the power generation sector, although its level will fall below ASEAN levels in the 2040s. In contrast, the European Union will accelerate its transition away from natural gas, reducing its consumption by 131 Bcm by 2050, falling below India's level.

By sector, natural gas consumption in the buildings sector will decline due to increasing electrification and energy efficiency improvements (Figure 2-13). In contrast, consumption in Emerging and Developing Economies, including China, will rise, particularly in the power generation and industry sectors. In the power generation sector, natural gas demand will remain largely stable until 2030 due to the expansion of renewables and other energy sources. After 2030, demand is expected to rise again as the deployment of alternative power sources fails to keep pace with growing electricity needs. Natural gas consumption for power generation in Emerging and Developing Economies will increase at an annual rate of 2.7% from 2023 to 2050, accounting for 109% of global growth in the sector. This trend is driven by natural gas's lower CO_2 emissions compared with other fossil fuels, its relatively high flexibility in adjusting supply in response to fluctuations in demand, and its ability to support large-scale power generation at lower integration costs than renewables.

Figure 2-12 | Natural gas consumption in selected economies/regions [Reference Scenario]

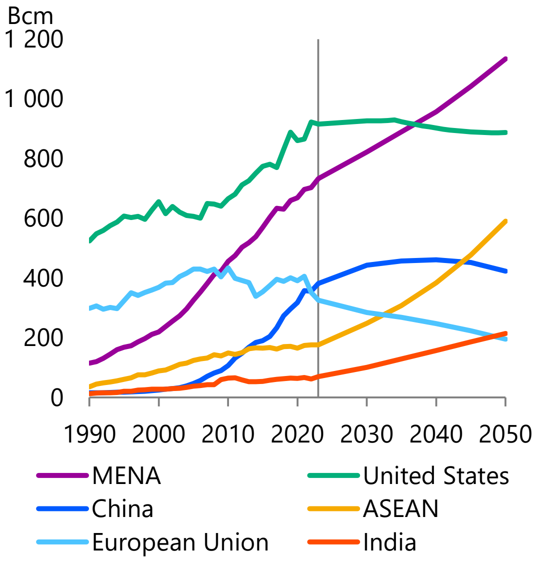
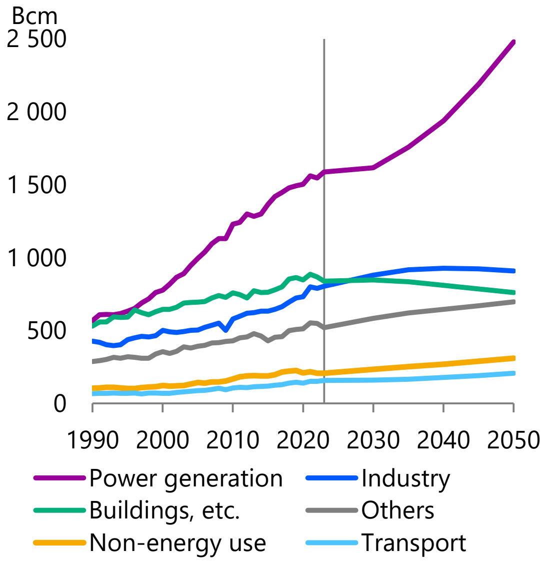


Figure 2-13 | Global natural gas consumption [Reference Scenario]



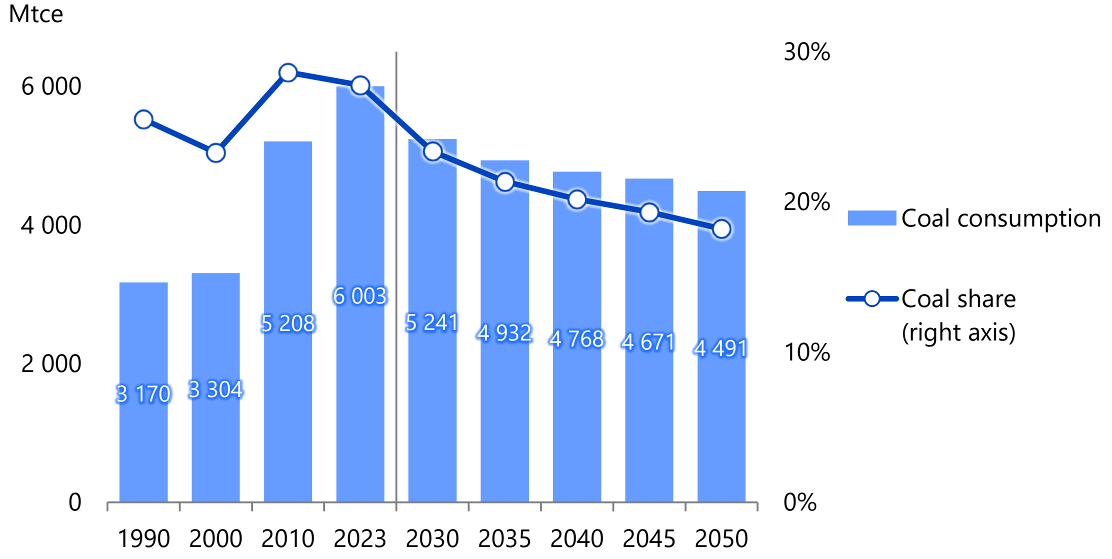
In the industry sector, natural gas consumption in Advanced Economies will decline, while demand in Emerging and Developing Economies will grow at an annual rate of 1.0%, contributing 149% of net global growth. Many industries will shift from oil and coal to natural gas due to its economic and environmental advantages. In the buildings sector, natural gas consumption is expected to decline due to increasing electrification and energy efficiency measures. China will be the primary driver of demand growth as it rapidly transitions from solid fuels such as coal and fuelwood to natural gas to improve air quality and public health.

As India, ASEAN, MENA and China drive the growth in natural gas consumption, they should adopt and widely implement high-efficiency technologies. For example, the power generation sector should fully utilise natural gas-fired combined cycle plants to optimise energy use and reduce consumption.

Coal consumption will peak in the 2020s due to environmental measures.

Global coal consumption, which stood at 6 003 million tonnes of coal equivalent (Mtce) in 2023, will decline at an annual rate of 1.1% due to the impact of environmental policies (Figure 2-14). Coal's share of primary energy consumption will decrease from 28% in 2023 to 18% in 2050. It will cede its position as the second-largest energy source to natural gas in the early 2030s, following oil, and will fall below renewables excluding hydro by the late 2040s.

Figure 2-14 | Global coal consumption and its share of primary energy consumption [Reference Scenario]



In 2023, China accounted for 58% of global coal consumption, while India and ASEAN together made up 17%. The United States, Europe and Japan collectively accounted for 10%. By 2050, coal consumption in China and these three Advanced Economies will decline to 39% and 5% of the global total, respectively, while India and ASEAN will see their combined share rise to 39%, matching China's level (Figure 2-15).

Figure 2-15 | Coal consumption in selected economies/regions [Reference Scenario]

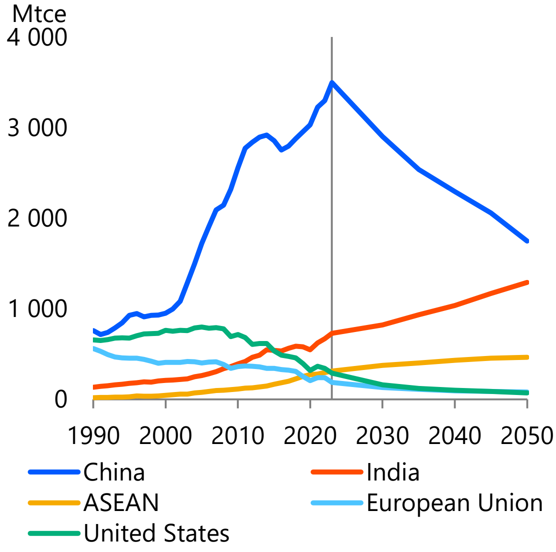
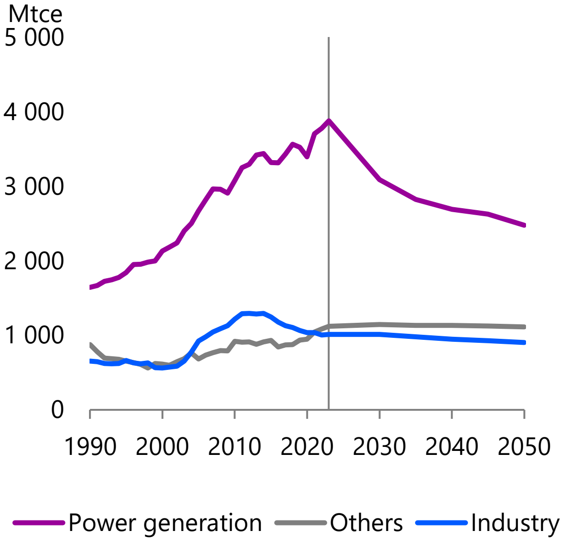


Figure 2-16 | Global coal consumption [Reference Scenario]



In China, coal consumption for industry has been declining since peaking in 2012, while that for power generation will decrease after peaking in the early 2020s due to measures against climate change and air pollution, which will result in a 50% overall decline in coal consumption by 2050. Coal consumption in the United States, Europe and Japan will continue falling in both the power generation and industry sectors, posting a 65% drop by 2050. In contrast, coal consumption in

India and ASEAN will continue to grow. By 2050, coal use for power generation will increase 1.6 times in India and 1.4 times in ASEAN. Industrial coal consumption will expand even more, rising by 2.0 times in India and 1.5 times in ASEAN. Note that MENA consumes limited coal due to the large number of oil- and gas-producing countries.

With growing pressure to address climate change, coal consumption has come under increasing scrutiny worldwide. At the 2024 meeting of environment ministers from the Group of Seven (G7), member countries agreed to phase out coal-fired power plants that lack emission reduction measures by 2035. In Europe, stricter regulations have raised the economic burden on coal-fired power plants while further tightening limits on CO_2 and mercury emissions. As such, restrictions on coal use are being strengthened in both the power generation and industry sectors. Meanwhile, in the United States, the Trump administration is promoting the use of coal to revitalise the domestic coal industry from the perspective of ‘energy dominance’. While governments and financial institutions in Advanced Economies have been actively promoting coal divestment, an increasing number of financial institutions have been changing their policies since the Trump administration took office. Furthermore, many Emerging and Developing Asian Economies, including India and ASEAN, continue to rely on coal as an affordable domestic energy source to support energy self-sufficiency. These countries do not impose particularly strict restrictions on coal consumption. To curb coal consumption, Advanced Economies must accelerate their phase-out efforts, while China, India and ASEAN should prioritise switching from coal to natural gas and to hydrogen and ammonia, for both power generation and industrial use.

Non-fossil energy use, such as solar photovoltaics and wind, will increase, but their share of primary energy consumption will be limited.

As more countries pursue carbon neutrality, expectations for the expansion of non-fossil energy sources continue to rise. In conjunction with COP28, participating nations declared that they would triple the world’s renewable power generation capacity by 2030. Separately, another declaration was issued to triple the world’s nuclear power generation capacity by 2050 compared with 2020 levels.

Non-fossil energy consumption for power generation centred on nuclear and hydro will grow 2.2 times, rising from 1 753 Mtoe in 2023 to 3 864 Mtoe in 2050 (Figure 2-17).

The most rapid growth will come from solar photovoltaics, wind and other renewable sources, which will expand 4.9 times over the same period. In contrast, nuclear and hydro will see slower growth due to policy constraints, environmental concerns and social considerations. Consequently, the share of nuclear and hydro in non-fossil energy for power generation will decline from 62% in 2023 to 38% in 2050.

Meanwhile, non-fossil energy consumption for heating will remain largely reliant on traditional solid biomass, such as fuelwood and manure, which are widely used in rural areas of Emerging and Developing Economies. From 957 Mtoe in 2023, non-fossil energy consumption for heating will decrease to 696 Mtoe by 2050 (Figure 2-18). Its consumption will decline as rural residents switch to modern energy sources in line with improvements in their income and living standards. Liquid biofuel for transport and heating, along with biogas, will grow 1.7 times by 2050, though they will still make up only 23% of total non-fossil energy consumption for heating.-

Non-fossil energy consumption will dramatically increase towards 2050. However, its share of total primary energy consumption will not increase as significantly, since overall energy demand will continue to rise. The share will only increase from 19% in 2023 to 28% in 2050.

Figure 2-17 | Global non-fossil energy consumption for power generation [Reference Scenario]

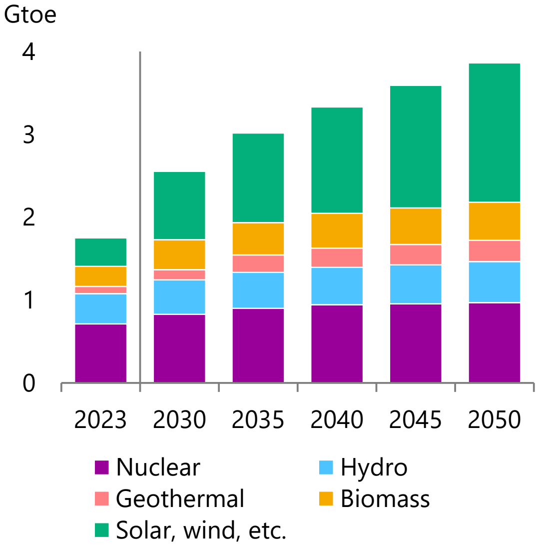
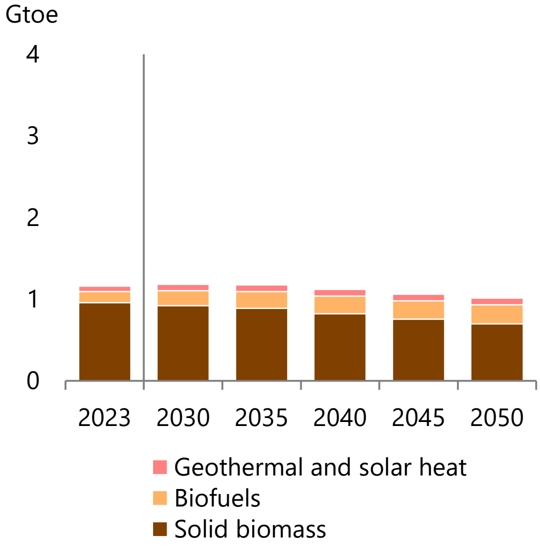


Figure 2-18 | Global non-fossil energy consumption for heating [Reference Scenario]



The centre of Asian energy consumption growth will shift from China to India and ASEAN.

Asia will account for 54% of global energy consumption growth as its share of the global economy increases from 35% in 2023 to 44% in 2050 in real terms (Figure 2-19). China, India and ASEAN will be the primary drivers of this global economic expansion. While these economies share some similarities in energy consumption trends, they also exhibit distinct differences. Energy consumption in China will peak in the late 2020s, whereas in India and ASEAN, it will continue to rise (Figure 2-20). These differences stem from variations in economic and population growth.

Figure 2-19 | Asian primary energy consumption [Reference Scenario]

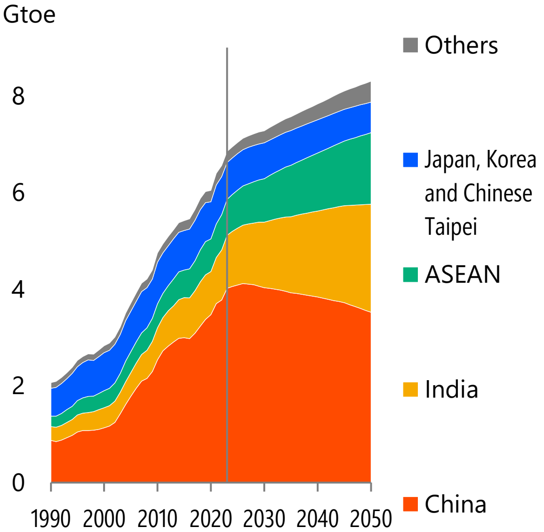
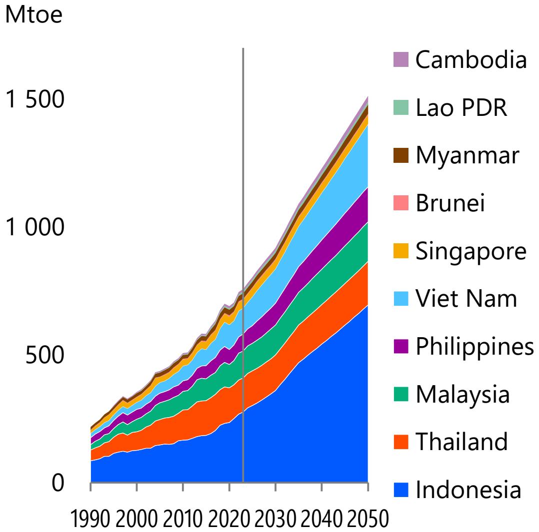


Figure 2-20 | ASEAN's primary energy consumption [Reference Scenario]



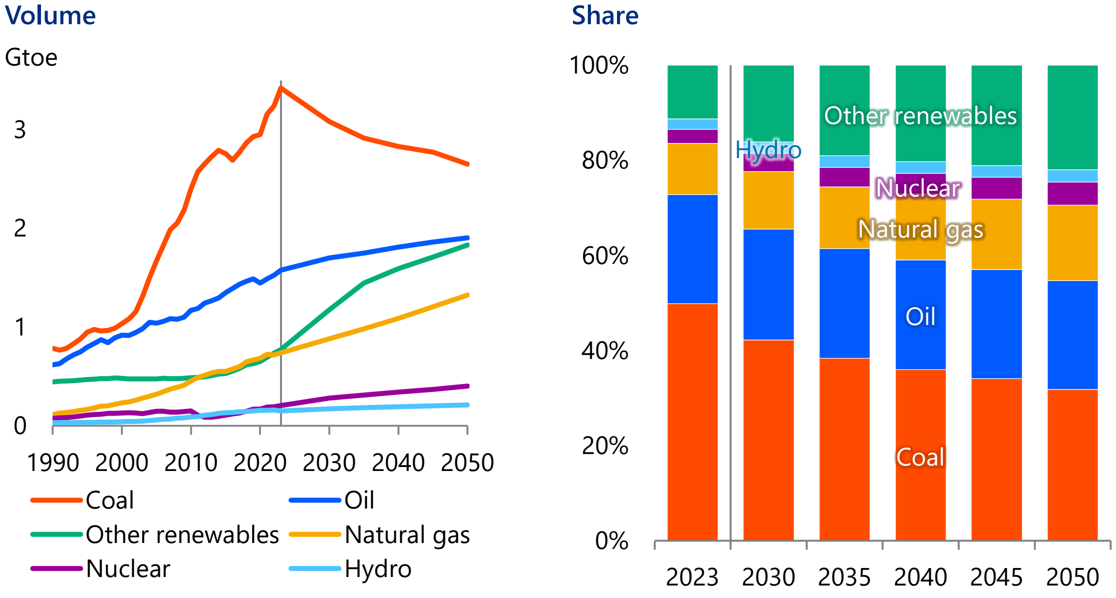
China's economy expanded 16.9-fold, from 1 trillion dollars in 1990 to $17.6 trillion in 2023 and will grow another 2.4-fold to $42 trillion by 2050. In the meantime, its population grew from 1.14 billion in 1990 to a peak of 1.41 billion in 2021 but will decline to below the 1999 level of 1.25 billion by 2050. Under the 14th Five-Year Plan (2021–2025), China has positioned the transition to a green economy as a key growth strategy. From the early 2020s, energy consumption will decline even as economic growth continues, similar to trends observed in advanced economies, driven primarily by energy conservation efforts in industry. After increasing at an average annual rate of 4.7% from 1990 to 2023, China's energy consumption is projected to decline at an annual rate of 0.5% from 2023 to 2050. By 2050, energy consumption will fall below 2023 levels, despite real GDP per capita exceeding $33 000. This marks China's transition to a mature economy, increasingly focused on carbon neutrality. China's share of Asian energy consumption rose from 42% in 1990 to 59% in 2023 but will decline to 42% by 2050.

India's economy expanded 7.0-fold, from $500 billion in 1990 to $3.3 trillion in 2023 and will grow 4.5-fold to $15 trillion in 2050. Its population rose from 860 million in 1990 to 1.44 billion in 2023, surpassing that of China. It will continue growing to reach 1.68 billion by 2050. Consequently, real GDP per capita will rise from $500 in 1990 to $9 000 in 2050, improving incomes and living standards. Although India has committed to achieving carbon neutrality by 2070, its energy consumption will continue growing at an annual rate of 2.7% from 2023 to 2050. As a result, climate change mitigation and energy security measures will become increasingly critical. India's share of Asian energy consumption will surge from 14% in 1990 and 16% in 2023 to 27% by 2050.

ASEAN's economy, valued at $740 billion in 1990, grew to $3.4 trillion in 2023 and will reach $10.1 trillion by 2050. Its population will expand from 440 million in 1990 to 770 million by 2050. As a result, real GDP per capita, which stood at $1 700 in 1990 and $4 900 in 2023, will rise to $13 000 by 2050, further improving income levels. ASEAN's energy consumption will continue to rise at an annual rate of 2.6% from 2023 to 2050, with Asia's share expanding from 11% in 2023 to 18% by 2050. Of that increase in consumption, 60% will be accounted for by Indonesia, which has declared its intention to achieve carbon neutrality by 2060. Within ASEAN, countries that have previously been fossil fuel exporters are facing declining supply capacity due to increased consumption and resource depletion, making energy security measures as important as climate change countermeasures.

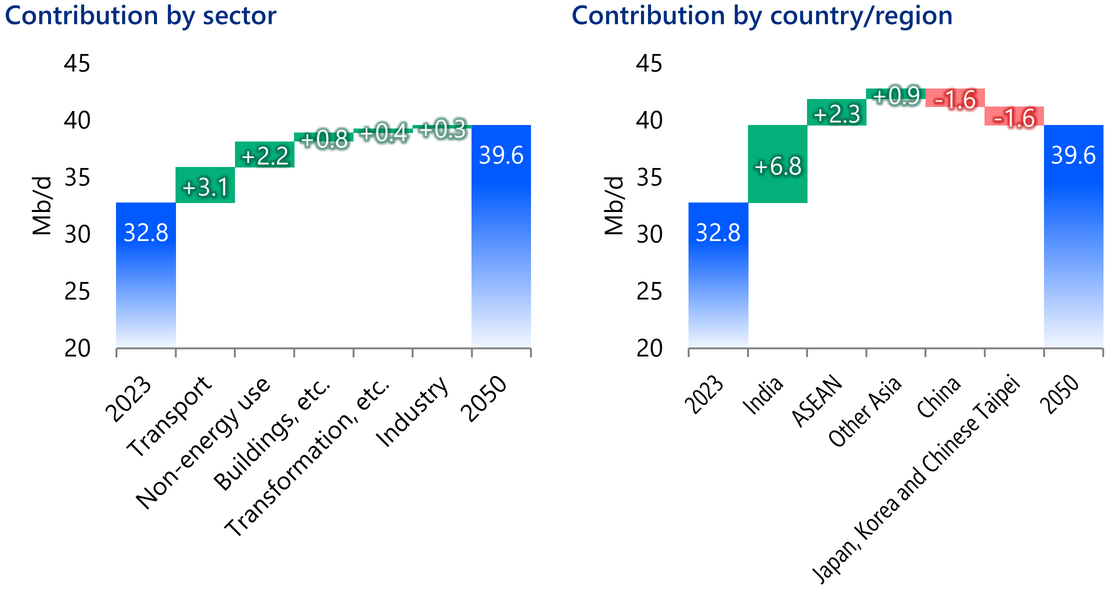
Even by 2050, while energy consumption in India and ASEAN will still be increasing, Asia will remain reliant on fossil fuels. Although this dependency will decrease from 84% in 2023, it will still account for 70% of its energy mix (Figure 2-21). Oil and natural gas consumption will continue to grow, driven primarily by demand from the transport and power generation sectors. Reducing Asia's dependence on fossil fuels will be essential for ensuring global energy stability and meeting climate goals.

Figure 2-21 | Asian primary energy consumption [Reference Scenario]



Asia's oil consumption growth will slow from an annual rate of 2.9% between 1990 and 2023 to 0.7% from 2023 to 2050. The transport sector will drive 46% of this growth by 2050, while the non-energy use sector and the buildings sector will contribute 33% and 11%, respectively (Figure 2-22). By region, India will account for 100% and ASEAN for 34%. The share of India and ASEAN combined exceeds 100% because Japan, Korea and China will cut consumption. To curb oil demand, India and ASEAN must prioritise fuel efficiency improvements in the automobile sector, including vehicle electrification. Given that Asia will account for 175% of global oil consumption growth, developments in the region will significantly impact global oil trends.

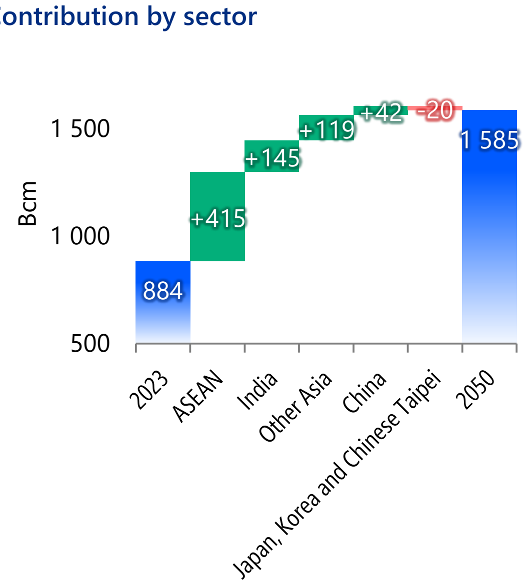
Figure 2-22 | Asian oil consumption [Reference Scenario]

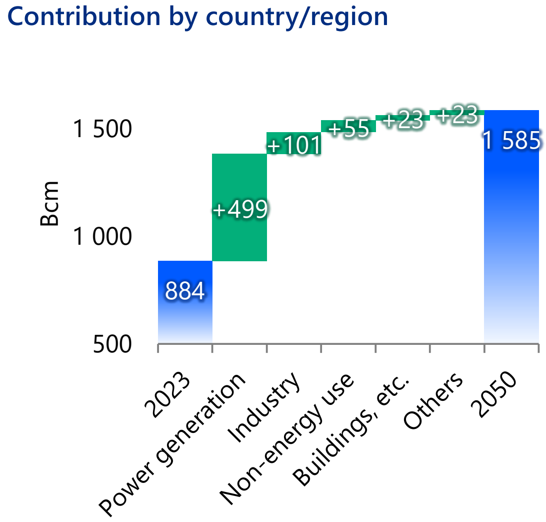


To ensure stable oil supplies while addressing environmental concerns, Asian economies must accelerate the transition to alternative energy sources and enhance oil consumption efficiency.

Asia's natural gas consumption grew at an annual rate of 5.8% between 1990 and 2023 but will slow to 2.2% per year from 2023 to 2050. Of this growth by 2050, the power generation sector will account for 71%, the industry sector for 14% and the non-energy use sector for 8% (Figure 2-23). ASEAN will contribute 59% of the increase, followed by India at 21% and China at 6%. To curb natural gas consumption, China, India and ASEAN will need to improve efficiency, reduce electricity transmission and distribution losses and promote hydrogen co-firing in power generation. Additionally, enhancing insulation and efficiency measures in the buildings sector will be crucial. As Asia's natural gas consumption growth will account for 56% of global growth, limiting demand in these countries/regions will have a direct impact on global natural gas trends.

Figure 2-23 | Asian natural gas consumption [Reference Scenario]





Although natural gas emits less CO_2 than oil and coal, it is still a fossil fuel that emits CO_2 when combusted. Therefore, it is essential for emerging and developing economies to maximise efficiency in natural gas use. This can be achieved by improving skills in equipment operation and maintenance, encouraging the mandatory adoption of natural gas-fired combined cycle systems and hydrogen co-firing in the power generation sector.

LNG imports will play a critical role in meeting Asia's natural gas demand. The region's LNG consumption is expected to rise from 279 million tonnes in 2024 to a 1.4-fold increase reaching 379 Mt in 2035 and further to 591 Mt in 2050, a 2.1-fold increase. Japan and Korea were among the earliest and largest LNG importers, but in 2021 and 2023, China surpassed Japan to become the world's largest LNG importer. In 2024, Japan, Korea and Chinese Taipei combined accounted for 49% of Asia's LNG imports, while China, India, ASEAN and South Asia together accounted for 51%. By 2050, this distribution will shift significantly, with the former group's share falling to 21% and the latter's rising to 79%. Consequently, India, ASEAN and China will play increasingly important roles in securing a stable LNG supply for the region.

Unlike oil or natural gas consumption, coal consumption in Asia will peak in the 2020s before beginning a long-term decline, driven primarily by reductions in coal-fired power generation.

Between 1990 and 2023, coal consumption grew rapidly at an annual rate of 4.6%, but it will decline at an annual rate of 1.0% from 2023 to 2050. Concerns over climate change and air pollution have led to growing global criticism of coal-fired power plants. Across Asia, the adoption of renewable energy is advancing, leading to a decline in coal consumption for power generation. However, coal will remain Asia's dominant energy source in 2050, accounting for 32% of the region's total energy mix. India and Indonesia, among others, will continue expanding coal-fired power generation to meet rising electricity demand. Asian economies must strive to reduce environmental burdens while advancing the effective utilisation of Asia's abundant coal resources. To achieve this, they must avoid constructing new or expanding inefficient coal-fired power plants, and instead pursue the introduction of carbon capture, utilisation and storage (CCUS) involving advanced economies, alongside ammonia co-firing.

Although Asia's non-fossil energy consumption remains lower in volume than oil or natural gas consumption, it will grow at an annual rate of 2.9% from 2023 to 2050. Renewables, excluding traditional biomass, will account for 96% of the region's non-fossil energy consumption growth between 2023 and 2050, followed by nuclear at 15%, while traditional biomass use will decline by 11%. China will account for 54% of the growth in renewable energy consumption (excluding traditional biomass), ASEAN 15% and India 25%. In nuclear, China will account for 62% of the increase, while ASEAN and India will contribute 9% and 24%, respectively. Asia's share of global non-fossil energy consumption will rise by 11 percentage points from 2023 levels, reaching 50% in 2050.

In 2020, China announced its goal of achieving carbon neutrality by 2060, setting a policy to curb fuels with higher CO_2 intensity, such as oil and coal, while promoting the use of natural gas and non-fossil energy sources through 2050. Additionally, China has been advancing industrial policies focused on renewable energy, battery storage and electric vehicles, strengthening its global position in decarbonisation technologies. However, given China's substantial fossil fuel consumption, significant improvements in energy efficiency and decarbonisation efforts will be required. Meanwhile, India, which will drive most of Asia's incremental energy consumption through 2050, has pledged to achieve carbon neutrality by 2070. Many ASEAN nations, including Indonesia, have also committed to carbon neutrality. Under its 'Make in India' initiative, India is promoting domestic solar photovoltaic power generation and the adoption of EVs. In ASEAN, Indonesia has integrated energy conservation and green industry development into its medium-term national development plan. To accelerate energy efficiency and decarbonisation, Asia must take a proactive approach, leveraging continued and enhanced technical and financial assistance from Japan, Korea, China and other economies. These commitments by China, India and ASEAN to address climate change will also contribute to the stability of energy supplies, including LNG.

2.2 Final energy consumption

Global final energy consumption in 2050 will increase 1.2-fold from 2023.

In the Reference Scenario, global final energy consumption will increase 1.2-fold, from 10 249 million tonnes of oil equivalent (Mtoe) in 2023 to 11 857 Mtoe in 2050, representing an average annual growth of 0.5%. The following key trends will define this change in global final consumption between 2023 and 2050.

First, India, the Association of Southeast Asian Nations (ASEAN) and the Middle East and North Africa (MENA) will be the primary drivers of global final energy consumption growth through 2050. As a result, any major developments affecting energy demand in these countries/regions will significantly influence global consumption trends. Therefore, particular attention should be paid to the factors that cause fluctuations in final energy consumption in these countries/regions. Those fluctuating factors include economic growth, the details and strengths of their energy-related policies, the technological development and diffusion of energy-using equipment.

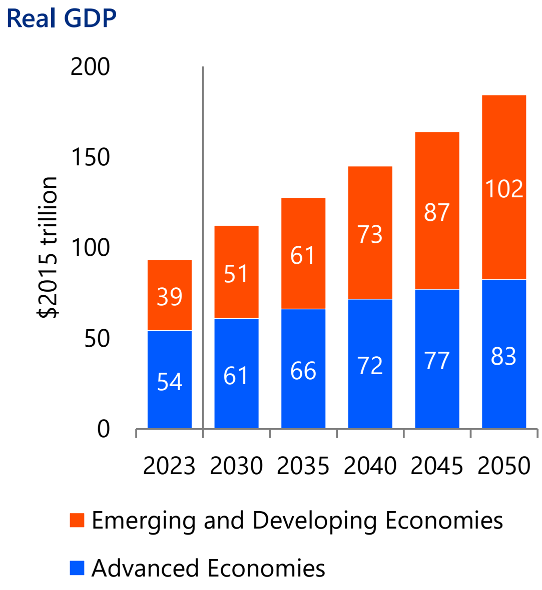
Second, all major energy sources will continue to play a role in global final energy consumption in 2050. While coal consumption will decline from the late 2020s and renewable energy consumption will decline from the 2030s, neither will reach an absolute minimum by 2050. While climate change is a critical global issue, if climate policies and investment strategies aimed at addressing it become overly biased towards specific energy sources, there is a risk of disrupting the overall energy supply-demand balance in the medium to long term. Therefore, it is essential to establish a market where each energy source can be supplied stably in response to demand, while taking into account trends in demand changes and the impact of climate change.

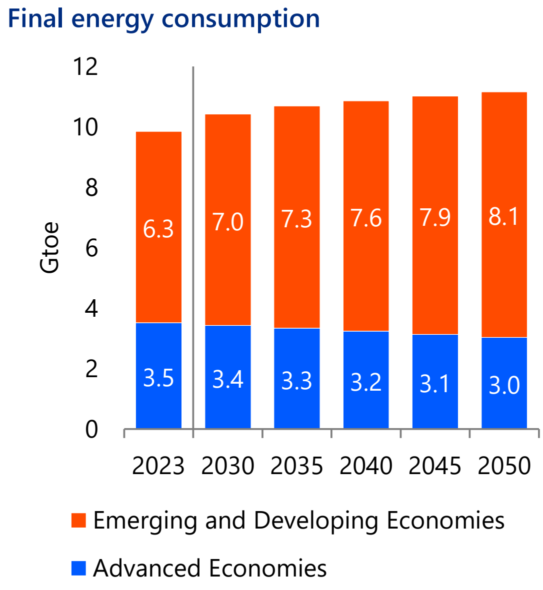
The following provides insights on final energy consumption changes in the Reference Scenario by economy group, region, sector and energy source between 2023 and 2050.

By economy group: Emerging and Developing Economies will drive global consumption growth.

The increase in global final energy consumption from 2023 to 2050 will be driven primarily by Emerging and Developing Economies (Figure 2-24). While final energy consumption in Advanced Economies will decline over the same period, steady growth in Emerging and Developing Economies will more than offset this reduction, leading to an overall increase in global final energy consumption through 2050.

Figure 2-24 | Real GDP and final energy consumption [Reference Scenario]





In Emerging and Developing Economies, final energy consumption is projected to reach 8 123 Mtoe in 2050, a 1.3-fold increase from 2023 (0.9% per year), driven by economic growth and population increase. These economies will follow a growth trajectory in the medium to long term. Improvements in energy efficiency and the expansion of service sectors will slow the rate of increase in final energy consumption. Final energy consumption growth will be significantly lower than real gross domestic product (GDP) growth (3.6% per annum).

In contrast, Advanced Economies will see final energy consumption decline to 3 039 Mtoe by 2050, a 10% reduction from 2023 levels. Even in those economies, real GDP will grow from 2023 to 2050 (1.6% per annum). However, in contrast to the upward trend in real GDP, final energy consumption will continue its downward trend, decreasing at an annual rate of 0.5%. This decline follows a trend that has been evident since the late 2000s, driven by accelerated energy conservation efforts and a structural shift towards service-based economies. As a result, the final energy consumption elasticity against GDP[4] in Advanced Economies will shift from 0.20 between 1990 and 2023 to −0.35 between 2023 and 2050[5].

Improving energy efficiency remains a key strategy for decarbonisation. Both advanced economies and emerging and developing economies will need to implement measures to enhance energy efficiency across all final energy consumption sectors.

By region: India, ASEAN and MENA will drive future final energy consumption growth.

Between 2023 and 2050, final energy consumption growth will be driven primarily by India, ASEAN and MENA (Figure 2-25 and Figure 2-26). Together, these countries/regions will account for more than 70% of the global increase in final energy consumption during this period.

Figure 2-25 | Global final energy consumption and contribution by country/region [Reference Scenario, 2023–2050]

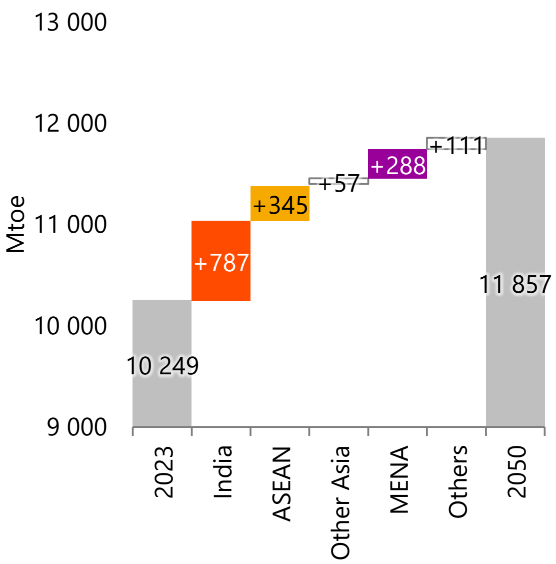
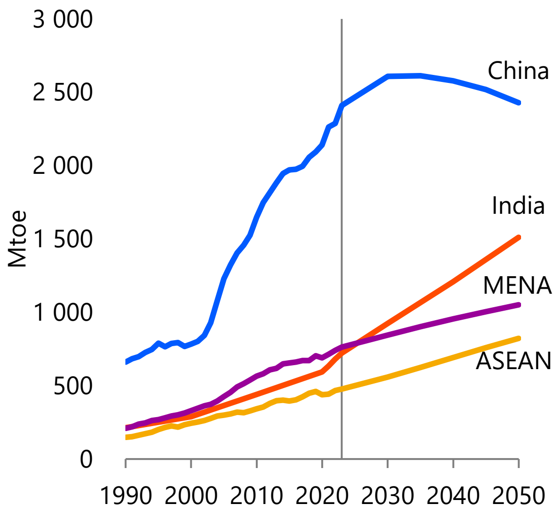


Figure 2-26 | Final energy consumption in China, India, MENA and ASEAN [Reference Scenario]



As a result of the strong demand growth in India and ASEAN, Asia's share of global final energy consumption will widen from 42% in 2023 to 46% in 2050. In the future, Asia will become an even more significant energy consumption centre.

India, which became the world's most populous country in 2022, will see its population exceed 1.6 billion and approach 1.7 billion by 2050. With GDP growing at an annual rate of 5.7% between 2023 and 2050, driven by urbanisation and other factors, India's GDP per capita will increase 3.9-

[4] Final energy consumption elasticity against GDP = final energy consumption growth rate ÷ real GDP growth rate.

[5] Nevertheless, higher economic growth does not necessarily mean less energy consumption.

fold. Backed by population and GDP growth, India's final energy consumption will grow 2.1-fold (2.8% per year) from 724 Mtoe in 2023 to 1 511 Mtoe in 2050. India alone will account for 60% of Asia's incremental final energy consumption, underscoring its rising significance not only within Asia but also globally. India's share of global final energy consumption will expand from 7.1% in 2023 to 12.7% in 2050, highlighting its growing influence on global energy demand.

In ASEAN, final energy consumption will grow at an annual rate of 2.0%, increasing from 477 Mtoe in 2023 to 822 Mtoe in 2050, largely driven by Indonesia and Viet Nam. Of the total 345 Mtoe increase in ASEAN's final energy consumption, Indonesia will contribute 142 Mtoe and Viet Nam 80 Mtoe. This growth reflects both countries' rising populations and expanding economies. In 2023, Indonesia and Viet Nam had populations of 281 million (the largest in ASEAN) and 100 million (the third largest), respectively, with continued growth expected. Between 2023 and 2050, GDP per capita will increase 2.9-fold in Indonesia and 3.6-fold in Viet Nam. Against this backdrop, Indonesia's final energy consumption will surpass that of Japan by the late 2030s.

China's final energy consumption will increase modestly, from 2 410 Mtoe in 2023 to 2 430 Mtoe in 2050. While China will remain the world's largest final energy consumer during this period, its energy demand will begin to decline after the 2030s. This pattern will differ from the constant uptrend in India and ASEAN. A key factor behind China's stabilisation and eventual decline in final energy consumption is the industry sector. The energy-intensive steel and cement industries, in particular, will see significant reductions in energy demand. The impact of efforts to eliminate excess capacity has already begun to materialise, with cement production peaking in the mid-2010s and crude steel production peaking in 2020 before shifting to a downward trend.

Final energy consumption in MENA will increase at an annual rate of 1.4% from 764 Mtoe in 2023 to 1 052 Mtoe in 2050 mainly in Iran, North Africa and Saudi Arabia. They will account for most of the region's total growth of 288 Mtoe. Specifically, Iran's final energy consumption will rise by 62 Mtoe, North Africa's by 86 Mtoe and Saudi Arabia's by 58 Mtoe. Population growth in these economies—at an annual rate of 0.9%—will outpace that of India and ASEAN, while GDP per capita will increase 2.0-fold in North Africa, 1.6-fold in Iran and 1.4-fold in Saudi Arabia.

By sector: Emerging and Developing Economies will drive consumption growth in each sector.

Between 2023 and 2050, global final energy consumption will increase across all sectors, driven primarily by Emerging and Developing Economies. In contrast, final energy consumption in Advanced Economies will decline in all sectors except for the non-energy use sector (Figure 2-27).

In the transport sector, final energy consumption will grow at an annual rate of 0.5%, rising from 2 936 Mtoe in 2023 to 3 324 Mtoe in 2050, supported by growth in the road sector of Emerging and Developing Economies. The increase will reach 388 Mtoe, capturing 24% of the overall global rise in final energy consumption. Economic growth in these economies will lead to a significant expansion of automobile ownership over the same period (Figure 2-28). Consequently, final energy consumption in the transport sector of Emerging and Developing Economies will grow at an annual rate of 1.1%. In contrast, Advanced Economies will see an increase in electricity consumption due to the policy-driven adoption of electric vehicles. However, oil consumption in the road sector will decline significantly due to improvements in fuel efficiency and a reduction in internal combustion vehicle ownership. As a result, final energy consumption in the transport sector of Advanced Economies will decline at an annual rate of 1.5%.

Figure 2-27 | Final energy consumption in Advanced Economies and Emerging and Developing Economies [Reference Scenario]

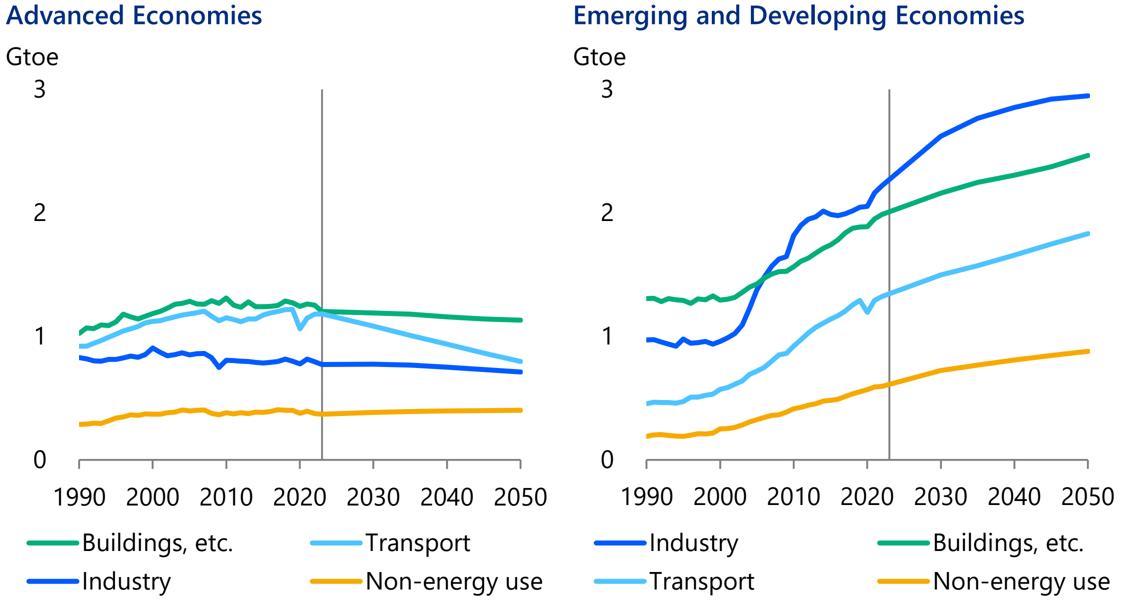
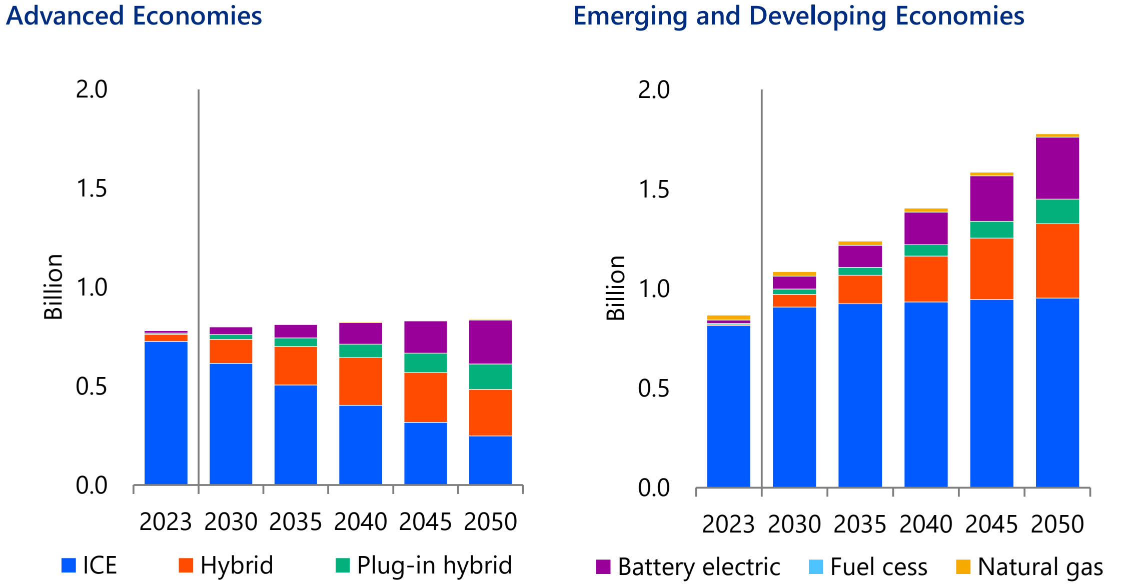


Figure 2-28 | Automobile ownership [Reference Scenario]



In the industry sector, final energy consumption will grow at an annual rate of 0.6%, increasing from 3 080 Mtoe in 2023 to 3 659 Mtoe in 2050. This growth will be driven primarily by increased electricity and natural gas consumption in manufacturing industries of Emerging and Developing Economies. The sector's total consumption growth will reach 580 Mtoe, accounting for 36% of the overall rise in final energy consumption. In general, however, there is a strong incentive in the industry sector, including manufacturing, to reduce the energy consumption of businesses to enhance the cost competitiveness of products. As a result, the growth in final energy consumption in the global industry sector will be slower than the 2.3% annual growth in the value added of the global secondary sector from 2023 to 2050.

In the buildings sector, final energy consumption will grow at an annual rate of 0.4%, increasing from 3 232 Mtoe in 2023 to 3 595 Mtoe in 2050. The growth will be driven by increased consumption of electricity, city gas and petroleum products in the commercial and residential sectors of Emerging and Developing Economies. However, as Advanced Economies increasingly adopt electricity-consuming appliances, the consumption of city gas and petroleum products in the commercial and residential sectors will trend downward worldwide. The total increase in final energy consumption in the buildings sector will reach 363 Mtoe, representing 23% of the overall rise in final energy consumption. As living standards improve in Emerging and Developing Economies, access to modern energy and energy-efficient appliances will increase. In Africa, the share of traditional biomass (fuelwood and manure) in the buildings sector's energy consumption will decline from 73% in 2023 to 32% in 2050, while in Asia, where the share has already fallen to 18%, it will further decline to 5%.

In the non-energy use sector, final energy consumption is expected to grow at an annual rate of 0.9%, increasing from 1 002 Mtoe in 2023 to 1 279 Mtoe in 2050, mainly due to rising oil and natural gas consumption in Emerging and Developing Economies. The sector's total consumption growth will amount to 277 Mtoe, accounting for 17% of the overall rise in final energy consumption. In Emerging and Developing Economies, demand for petrochemical products, including plastics, will increase as living standards improve. In Advanced Economies, consumption will rise slightly between 2023 and 2050. In North America, the petrochemical industry's non-energy use will increase due to the expansion of shale gas production, which enables cost-effective procurement of feedstocks. While plastics are convenient, their massive consumption has caused international issues such as resources and waste constraints, marine plastic waste and impacts on climate change. In response to these issues, plastics made from biomass instead of fossil fuels will be gradually introduced.

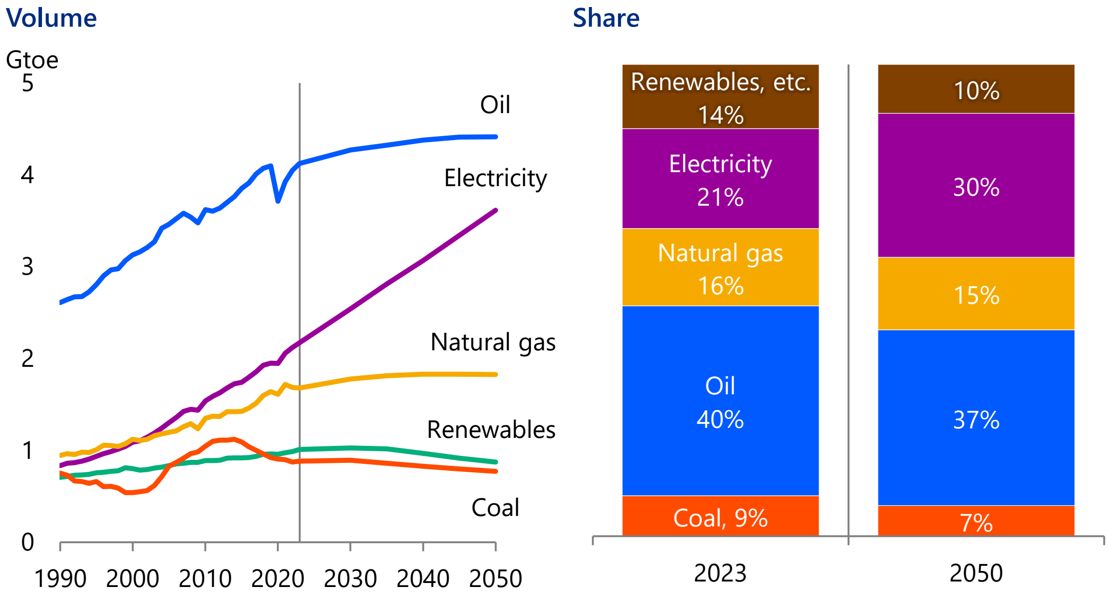
By energy source: Demand for all energy sources will remain.

Changes in global final energy consumption from 2023 to 2050 can be categorised into two trends: energy sources with an increasing share and those with a declining share (Figure 2-29).

While electricity's share of global final energy consumption will rise, the shares of oil, coal, natural gas and other renewables (dominated by the direct use of biomass) will decrease. Despite this shift, demand for coal and renewables and especially natural gas will remain significant in 2050. Fossil fuels (coal, oil and natural gas) will see their combined share of global final energy consumption fall from 65% in 2023 to 59% in 2050, yet they will continue to represent more than half of total consumption.

Final oil consumption will increase at a rate of 0.3% per year from 4 122 Mtoe in 2023 to 4 413 Mtoe in 2050, led by growth in the transport sector including the road sector in Emerging and Developing Economies. While the decline in Advanced Economies is expected to be 525 Mtoe, the increase in Emerging and Developing Economies will be 595 Mtoe. In Asia, where motorisation is accelerating, including in India and ASEAN, oil consumption in the road sector will increase by 151 Mtoe. The non-energy use sector will post the second-highest growth in oil consumption, following transport. In this sector, oil consumption will expand in Asia and the Middle East, where abundant local resources support petrochemical industry development.

Figure 2-29 | Global final energy consumption (by energy source) [Reference Scenario]



Final electricity consumption will grow at an annual rate of 1.9%, increasing from 2 171 Mtoe in 2023 to 3 615 Mtoe in 2050. This growth will be driven by increased electricity use in the buildings and industry sectors. Electricity is the only energy source that will post consumption growth also in Advanced Economies. While the primary drivers of global electricity demand growth will be China, India and ASEAN, the consumption will increase also in North America and Europe. Generally, as people's incomes rise, electricity is preferred for its convenience. Additionally, the increasing penetration of digitalisation will expand the use of electricity-consuming devices and machinery. Electricity's share of global final energy consumption will rise from 21% in 2023 to 30% in 2050. As economies and societies become more reliant on electricity, the consequences of supply disruptions will grow. While decarbonising power sources is a significant issue, it is also important to ensure a stable supply system of electricity from the viewpoint of energy security.

Final natural gas consumption will grow at an annual rate of 0.3%, rising from 1 680 Mtoe in 2023 to 1 827 Mtoe in 2050. Growth will be concentrated in the industry and non-energy use sectors of Emerging and Developing Economies. In India, ASEAN and MENA, where manufacturing industries are expanding, demand for natural gas will increase, particularly for processing and assembly industries. In the non-energy use sector, India and ASEAN, with their growing demand for chemicals, and the Middle East, which is seeking to expand its petrochemical industry using natural gas, will drive the growth of global natural gas consumption.

Final coal consumption will decline at an annual rate of 0.5%, falling from 882 Mtoe in 2023 to 772 Mtoe in 2050, due primarily to reductions in China's industry and buildings sectors. As mentioned in the regional perspective, China's coal-intensive steel and cement manufacturing industries will contract in the medium to long term. By 2050, coal consumption in China's industry sector will be less than half of its 2023 level. In addition, China has pledged its '3060 Goal', which aims to reach peak carbon dioxide (CO_2) emissions by 2030 and become carbon neutral by 2060. Based on this goal, China plans to reduce coal consumption from 2025. This will accelerate the shift to electricity in the industry sector and to natural gas and electricity in the buildings sector.

Final renewable energy consumption will decline at an annual rate of 0.5%, decreasing from 1 009 Mtoe in 2023 to 875 Mtoe in 2050. This decline will be primarily driven by the ongoing energy transition in Emerging and Developing Economies in Asia and Africa. One area of renewable energy in final consumption gaining attention is liquid biofuels for use in automobiles and aircraft. However, traditional biomass, including fuelwood and manure used in Emerging and Developing Economies, accounted for the largest share at 68% in 2023, followed by 14% for fuelwood mainly for space heating in Europe and North America, 13% for liquid biofuels and 4% for others. As mentioned in the perspective by sector, the use of modern energy is gradually replacing the use of traditional biomass in Emerging and Developing Economies in Asia and Africa. As a result, global final consumption of renewables will gradually decline from the 2030s.

3. Energy supply

3.1 Crude oil

Crude oil supply in recent years

Crude oil supply trends since the coronavirus disease 2019 (COVID-19 pandemic have been shaped by factors such as rising geopolitical risks, production cuts by OPEC[6] Plus and increased production by non-OPEC Plus.

Geopolitical risks have persisted and continue to pose serious threats to oil supplies, including the war in Ukraine, attacks on oil tankers in the Middle East and attacks on Iran by Israel and the United States, but large-scale supply disruptions have been avoided as of November 2025. Western countries have imposed sanctions, including embargoes, price caps and the blocking of financing and insurance for tankers and import-export companies, to reduce Russia's and Iran's oil export revenues. Despite these sanctions, however, oil exports from Russia and Iran have remained resilient.

OPEC Plus, which began production cuts in 2017, agreed as a group to reduce output by 2.0 million barrels per day in October 2022. Furthermore, eight additional countries voluntarily agreed to reduce production by 1.66 Mb/d in April 2023 and by 2.2 Mb/d in November 2023, continuing to strengthen production cuts. However, from April 2025, they began to ease their voluntary production cuts, shifting to a strategy of expanding market share. In the meantime, non-OPEC Plus supply has been increasing, particularly in the Americas.

Despite these diverse risks, oil supply has been expanding at a pace that exceeds demand in 2025. According to the International Energy Agency (IEA), liquid fuel supply (including biofuels) in the second quarter of 2025 is projected to reach 105.0 Mb/d, exceeding demand for the same period by 1.8 Mb/d.

Non-OPEC production will decline after 2030, with OPEC's share expanding.

In the Reference Scenario, global oil demand will increase, mainly in Emerging and Developing Economies, such as India, the Association of Southeast Asian Nations (ASEAN) and Africa. However, global demand will remain largely flat from around 2040 onwards, affected by the continued decline in demand in Advanced Economies and the peaking of Chinese demand around 2030. As a result, the demand growth rate between 2023 and 2050 will only be 0.1% per annum.

Production from non-OPEC countries will be sustained until around 2030, underpinned by increased output in the Americas. Meanwhile, production in North America, mainly the United States, will peak around 2030. Production in Europe and Eurasia will not grow, as Russian production, which had remained solid despite sanctions from Western countries, will begin to decline, albeit slowly, with European production also continuing to decline. Production increases in Latin America will be sustained, though output in Africa will remain flat, while production declines will continue in Asia and Oceania. Against this backdrop, production in non-OPEC countries will begin to decline from 2030 onwards.

Meanwhile, OPEC production will remain roughly flat until around 2030, as production levels in non-OPEC countries are maintained. From 2030 onwards, however, production from non-OPEC

[6] The Organization of the Petroleum Exporting Countries

countries will decline, while production from cost-competitive OPEC countries will increase. As a result, the share of OPEC crude oil in the world oil supply will expand from 34% in 2023 to 40% in 2050.

Table 3-1 | Crude oil production [Reference Scenario]

(Mb/d)

	2023	2030	2040	2050	2023-2050	
					Changes	CAGR
Crude oil production	96.3	96.8	99.1	98.6	2.3	0.1%
OPEC	33.9	33.9	38.5	40.0	6.1	0.6%
Middle East	26.7	27.3	31.8	33.4	6.7	0.8%
Others	7.1	6.6	6.8	6.6	-0.6	-0.3%
Non-OPEC	62.4	62.9	60.6	58.6	-3.8	-0.2%
North America	24.0	26.1	25.2	23.7	-0.3	0.0%
Latin America	9.0	9.3	10.0	10.0	1.0	0.4%
Europe and Eurasia	17.6	16.6	15.2	14.6	-3.0	-0.7%
Middle East	2.9	3.3	3.7	4.4	1.5	1.6%
Africa	1.5	1.4	1.4	1.4	0.0	-0.1%
Asia and Oceania	7.5	6.3	5.2	4.4	-3.1	-1.9%
Processing gains	2.4	2.4	2.4	2.4	0.1	0.1%
Oil supply	98.6	99.2	101.6	101.0	2.3	0.1%

Note: Crude oil includes natural gas liquids (NGLs).

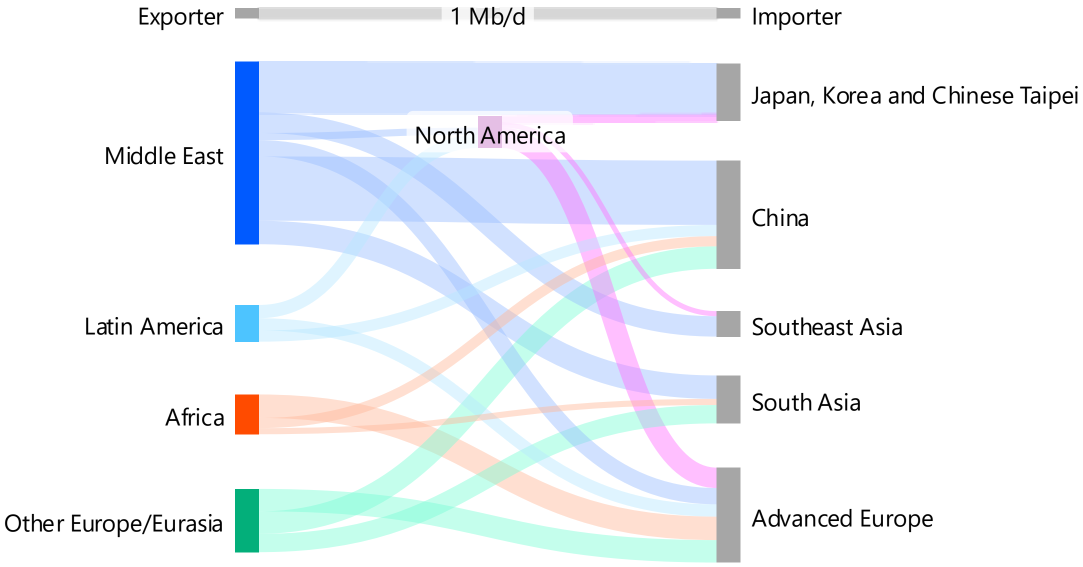
Asia's growing dependence on Middle Eastern crude oil

In 2024, global interregional crude oil trade totalled 43 Mb/d. The Middle East remained the largest exporting region, accounting for approximately 18 Mb/d, or 43% of global exports, followed by North America at 8 Mb/d and Other Europe/Eurasia, which is led by Russia, at 7 Mb/d. Asia is the primary destination for Middle Eastern crude oil, receiving 80% of the region's exports.

In Other Europe/Eurasia, 60% of exports were directed to Asia, largely due to Russia increasing shipments to China and India in response to Western embargoes. North American crude oil trade is predominantly intra-regional, with flows between the United States and Canada making up 50% of total exports. Of the remaining exports, 20% are shipped to Europe and another 20% to Asia.

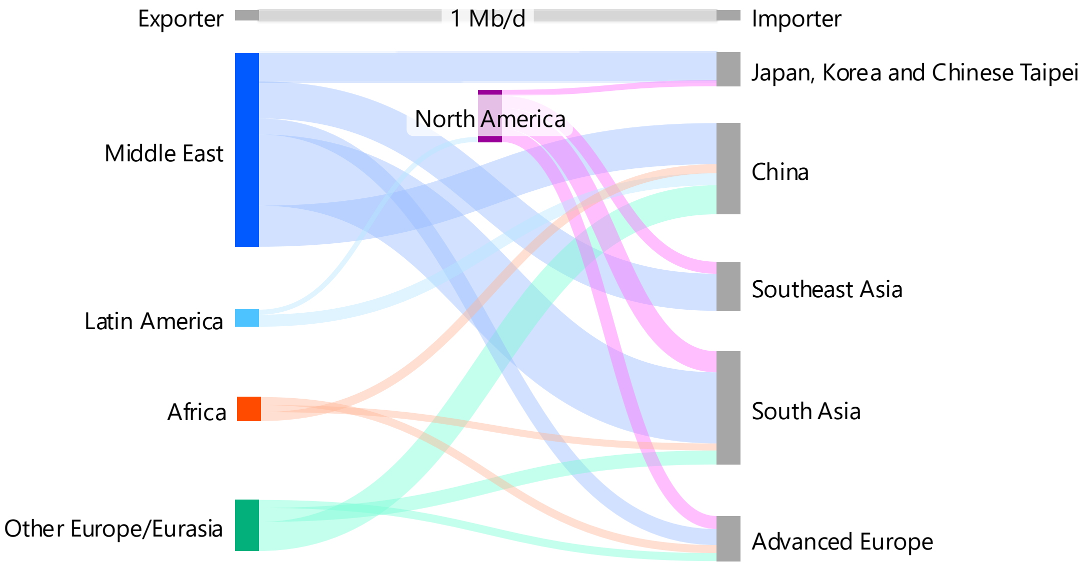
As for imports, Asia is by far the largest importing region with about 25 Mb/d, of which China, the world's largest importer, accounts for about 10 Mb/d. Advanced Europe's imports are also large, at 10 Mb/d. The largest supplier for Asia is the Middle East, with a 60% dependency rate for Asia as a whole. Since the onset of the war in Ukraine, Africa has emerged as the leading crude oil supplier to Advanced Europe, as the region moves away from Russian crude oil. North America and the Middle East have also expanded their exports to Advanced Europe, reducing Advanced Europe's dependence on crude oil from Other Europe/Eurasia. Before the invasion of Ukraine, Advanced Europe sourced 40% of its crude oil imports from this region. By 2024, this dependence had fallen to 24% (with the European Union's reliance on Russian crude oil dropping from 30% to just 4%).

Figure 3-1 | Major interregional crude oil trade flows [2024]



Note: Flows of 0.5 Mb/d or more are covered.
Sources: Energy Institute "Statistical Review of World Energy 2025", national trade statistics

Figure 3-2 | Major interregional crude oil trade flows [Reference Scenario, 2050]



Note: Flows of 0.5 Mb/d or more are covered.

Interregional crude oil trade volume in 2050 will increase due to growing demand and declining regional production in Southeast Asia and South Asia, despite decreased imports from Advanced

Europe and Northeast Asia. There will be a notable decline in exports from Russia and Other Europe/Eurasia and Africa to Advanced Europe, as well as from the Middle East to Northeast Asia. Meanwhile, exports from the Middle East and North America to South Asia and Southeast Asia will grow. Overall, Asia's import dependence will continue to rise, with the Middle East remaining the largest supplier to Asia.

3.2 Natural gas

The liquefied natural gas market is finally entering a major expansion phase, with logistics continuing to fluctuate between east and west.

The year 2025 is characterised by accelerated investment decisions, engineering work, marketing activities to secure long-term sales contracts and financing, alongside increased liquefied natural gas (LNG) shipments coinciding with the completion and start-up of LNG projects currently under construction.

The United States has been central to global LNG production growth over the past eight years or so, and with the commencement of operations at new and expanded LNG production facilities and an increase in export volumes, investment decisions and development activities are accelerating following the end of the pause on export authorisation discussed below. Particularly notable is the advancement of additional facilities and expansion projects by LNG production project developers, who have established a firm foothold in the global LNG market over the past few years. Of the 46 million tonnes per year of final investment decisions (FIDs) on LNG export projects announced globally through September 2025, US projects accounted for 40 Mt.

Also in North America, an export project on the west coast of Canada began operations in mid-2025. Based on cost-competitive Canadian gas sources and direct access to Pacific markets, the project has the potential to become a game-changer in the Asian LNG market. LNG supplies are expected to expand on the west coast of North America, including projects under construction on the west coast of Mexico.

In the first half of 2025, global LNG trade exceeded 200 Mt, following the same period in 2023 and 2024. While the growth rate was modest compared with the same period the previous year, it marked the third record high for a January–June six-month period. However, contrary to the shift from the Atlantic to the Pacific in 2024, LNG imports in Asia, particularly China, decreased, while those in the European Union and the United Kingdom combined increased by around 20%. As a result, the ratio of LNG imports east and west of Suez shifted from 70:30 for the full year 2024 to 64:36 for the first half of 2025, with the Atlantic market gaining greater prominence.

Japan imported 32 Mt, slightly down from the same period in the previous year, for the second consecutive year. China's LNG imports remained at 30 Mt, down 20% year-on-year. In the first half of 2025, Japan was the world's largest LNG importer. China's total imports of pipeline gas and LNG were 60 Mt, down 8% from the same period in the previous year, but it remained the world's largest importer of natural gas. China produced 130.8 billion cubic metres of natural gas in the first half of 2025, up 5.8% year on year. On the other hand, consumption reached 211.97 Bcm, down 0.9% year-on-year. Southeast Asia's LNG imports remained at 11 Mt, down 10% year-on-year.

On the LNG export side, the United States, Qatar and Australia ranked highest, as in the same period from 2022 to 2024. Among these, the United States increased its exports by 8% compared with the same period in the previous year, exceeding 50 Mt for the first time in a six-month period.

Russia, ranked fourth as in the previous year, saw an 8% decrease compared with the same period the previous year.

Since 2022, a combination of the European Union's avoidance of using Russian fossil fuels and Russia's deliberate reduction in energy exports has led to a decline in Russian pipeline gas supply to the European Union. Monthly supply fell from just over 8 Mt in LNG equivalent in December 2021 to below 2 Mt after December 2022. At the beginning of 2025, supplies via Ukraine ceased, with monthly volumes remaining below 1 Mt. On the other hand, the supply of Russian LNG to the European Union increased slightly after 2022, marking a record high of 17 Mt in 2024. However, beyond 2025, alongside the remaining Russian pipeline gas supplies, there are uncertainties surrounding the supply trends for Russian LNG.

Depending on future trends in spot gas prices in Asia and Europe, the ratio of US LNG exports to each region will fluctuate. The ratio of US LNG exports to the European Union and the United Kingdom surged from around 30% in 2021 to over 60% in 2022–2023, then decreased to just under 50% in 2024, but rapidly rebounded to nearly 70% in the first half of 2025. Meanwhile, the share of US LNG exports to Asia declined from nearly half in 2021 to about a quarter from 2022 to 2023, before rising to just over 30% in 2024 and dropping to below 20% in the first half of 2025.

In the LNG market in 2022, the shutdown and postponed restart of a US LNG facility following a fire became a major factor in the decline in supply and the uncertain future outlook. In late 2023, labour disputes at large LNG production facilities in Australia caused market volatility, although they did not lead to supply disruptions. From 2024 to early 2025, restrictions on major LNG marine transport routes resulted in detours and longer shipping distances. If there are any additional troubles with large LNG production facilities or disruptions to transport routes, the market could be significantly disrupted. From late 2025 to 2027, the timely and stable commissioning of new LNG projects in Canada, Mexico, the United States, Australia and Qatar will also be major factors that affect the market.

In the United States, which became the world's largest LNG exporter in 2023, the administration suspended the non-free-trade-agreement (FTA) LNG export authorisation process in late January 2024, and the Department of Energy conducted a study on the economic and environmental impacts of LNG exports that same year. The pause on the LNG export authorisation process has caused delays and uncertainty for some LNG projects while calling into question the reliability of the United States as a long-term, stable LNG supplier. China, the fastest-growing natural gas and LNG market in recent years, experienced a decline in natural gas consumption in 2022 for the first time in the recorded history of China's natural gas market (−1.7% year-on-year), whereas its LNG imports fell by nearly 20% year-on-year. However, natural gas consumption rebounded in 2023 and in 2024, LNG imports, pipeline gas imports and domestic natural gas consumption and production all increased. Natural gas consumption declined slightly again in the first half of 2025. Meanwhile, both pipeline gas imports and domestic natural gas production increased, leading to a significant decrease in LNG imports.

India, another rapidly expanding natural gas market, saw demand recover from a 5% year-on-year decline in 2022 to a 15.5% increase in 2023. In 2024, it increased by 10.1% but dropped by 6.9% in the first half of 2025. While natural gas production by state-owned enterprises declined, private sector production rose by 16% in 2022, 20% in 2023 and 9% in 2024. In the first half of 2025, private sector production fell by 6.4% compared with the same period in the previous year, and overall domestic natural gas production also decreased by 3.8%.

In Southeast Asia and South Asia (excluding India), the impact of price and supply-demand fluctuations in the global LNG market has been varied in recent years. In Southeast Asia, LNG imports increased by 32% year-on-year in 2022, 27% in 2023 and 16% in 2024, reaching 23.83 Mt in 2024. In the first half of 2025, however, imports fell sharply to 11.30 Mt, a 10.3% year-on-year decrease. Southeast Asia contains both LNG-exporting and LNG-importing countries, with varying degrees of impact. In 2023, the Philippines and Viet Nam joined the list of LNG importers, leading to a further increase in LNG imports in Southeast Asia. Bangladesh and Pakistan, on the other hand, significantly reduced LNG imports for natural gas-fired power generation in 2022, with a combined decline of 15% year-on-year. Their imports, however, increased by 8.8% in 2023 and 9.2% in 2024 to reach 13.51 Mt. In the first half of 2025, imports accounted for 6.83 Mt, with a year-on-year increase of 2.4%.

LNG market expansion history and current development status

Since the oil crisis half a century ago, natural gas and LNG have emerged as the cleanest and most essential energy sources among fossil fuels. Today, natural gas accounts for roughly a quarter of global and Japanese primary energy consumption. As a result, the impact of natural gas and LNG on overall energy security has expanded, highlighting the importance of ensuring a stable supply of LNG, especially in Asia, where LNG accounts for a major part of the natural gas supply. Seaborne LNG trade has increased by more than 60% in the 13 years since 2011. In 2022–2023, Germany, the Philippines, Hong Kong, Viet Nam and Mauritania joined the list of importing countries and regions.

As natural gas has become the world's major energy source, LNG holds the key to global energy supply security. On the supply side, the key issue in the long term will be to achieve stable supply from non-Russian sources such as the United States, Australia, Canada and Africa. How Russian natural gas will be handled after the conflict is resolved will also have a major impact on global natural gas supply and demand.

For the time being, the United States will play a pivotal role in LNG supply, particularly through projects with the highest likelihood of being realised based on future investment decisions. Unlike traditional LNG projects in other regions, LNG projects in the United States do not necessarily have upstream gas fields supplying feedstock gas that are vertically integrated. These projects have been developed with relatively loose commitments on LNG purchasing, meaning that final consumption destinations are not always predetermined. However, since 2021, long-term contracts that specify the end-users have gained traction once again, leading to increasing diversity in project structures as global LNG volumes grow.

The rise of US LNG in the global market has driven structural changes in LNG trade. In 2019, the full-scale supply of US LNG to Japan demonstrated its advantage when oil-indexed prices were high, a feature that had previously been the mainstream in trading contracts with the main suppliers of LNG to Asia. On the other hand, in 2020, it demonstrated flexibility in absorbing fluctuations in supply volumes during a period of depressed global natural gas prices and short-term demand weakness. In 2021, as global natural gas prices surged, US LNG reinforced its competitive pricing and adaptability, solidifying its role as a key supplier to various regions. In 2022, the United States became the largest source of additional natural gas for Europe. In 2023 and 2024, it became the world's largest LNG exporter. A further phase of expansion is accelerating from 2025 onwards.

Table 3-2 | Changes in the role of LNG

Major periods and incidents	LNG's roles
Late 20th century Oil crises air pollution	Expanded as an alternative, clean energy source (Japan and Korea) Alternative source of supply for pipeline gas (Europe) Expanded its share among primary energy sources and helped ease the impact of the oil crises
2010s Addressed the nuclear power crisis Increased energy demand	Demonstrated flexibility to respond quickly to baseload power source shortages The number of participating companies across each element of the value chain has broadened, reducing the difficulty of liquefaction, maritime transport and vaporisation operations worldwide and expanding its use. Remarkable flexibility in emergencies
2021–2022 Rebound in post-pandemic energy demand Russian war, natural gas shortages	LNG imports made up for the reduced supply of Russian pipeline gas in Europe compared with before the invasion of Ukraine Decrease in Russian pipeline gas imports due to the crisis and pipeline explosion offset by increase in LNG imports, mainly from the United States
Towards the future Realistic solution for the uncertainties surrounding the energy transition	A core supply source for energy security Underpins economic growth in emerging markets and a stable energy supply in mature markets Combination with new and clean energy sources and transition Could be utilised permanently if LNG can become clean

The growing presence of the United States in the global LNG market has begun to influence LNG procurement contract negotiations, not only for US suppliers but also other LNG-producing countries. Meanwhile, Australia completed the final phase of its LNG production capacity expansion in 2019 and subsequently boosted output in 2020 and 2021, surpassing Qatar—which had been the world's largest LNG exporter since 2006. At the same time, Russia has expanded LNG production from its Arctic region, increasing its share of the European natural gas market despite ongoing geopolitical challenges.

Changing development models for LNG production

Historically, large-scale LNG projects have required four to five years from the investment decision to the start of exports. However, efforts to shorten construction timelines through standardisation and modularisation of engineering and assembly processes are yielding results. In addition, some of the emerging project companies have announced the completion of 1.4 Mt/year floating LNG (FLNG) production facilities in one to two years, which is significantly shorter than conventional methods.

New LNG developments are emerging in frontier regions across East and West Africa, where natural gas production is expanding. For offshore or small and medium-sized natural gas fields, floating LNG production facilities are increasingly seen as viable options. Floating LNG production started in 2018 offshore Cameroon in West Africa, in 2022 offshore Mozambique in East Africa, in 2024 offshore the Republic of the Congo, and in 2025 offshore Senegal and Mauritania in West Africa. Large LNG players with global marketing capabilities have made commitments to take delivery of all LNG produced under these projects to promote them.

Mozambique is planning multiple onshore LNG production projects in addition to its floating LNG production project. An investment decision was made on one of them in June 2019. However, construction has been suspended since 2021, due to the deteriorating local security situation. As of mid-2025, coordination among stakeholders is underway to resume construction. Mozambique, which has large-scale natural gas resources, is close to South Asia including India and is free from maritime transportation chokepoints. Furthermore, its strategic location allows Mozambique to access not only the Asian market but also the European market through the Suez Canal or the Cape of Good Hope. Therefore, Mozambique is well positioned to grow as a major LNG supplier in the future. Tanzania also possesses abundant natural gas resources, which could lead to LNG exports.

In the short term, it is necessary for the global natural gas market to cope with the decline in Russian pipeline gas supply, secure stable production in LNG-producing countries and smoothly launch new LNG production projects. The short-term stabilisation of LNG production through these measures will raise the reliability of LNG and support long-term investment.

The future role of LNG needs to be clarified

LNG and natural gas are expected to play a vital role as a realistic solution for resolving uncertainties in the energy transition. LNG's role has grown with the needs of the times. It will also play a role as a key energy source in energy transitions, contributing to energy security. It will underpin economic growth in emerging markets and stable energy supply in mature markets and contribute to the energy transition of the world in combination with new energy sources. Making LNG and natural gas clean will be a prerequisite.

Both the Reference Scenario and the Advanced Technologies Scenario foresee strong demand for LNG and natural gas mainly in the emerging markets in Southeast Asia. The demand could rise even further if energy efficiency does not improve as anticipated by these scenarios.

In Southeast Asia, regional consumption of natural gas has grown since the 1970s alongside the development of LNG export projects. Natural gas utilisation will continue and expand in traditional gas producer countries, namely Indonesia, Malaysia and Thailand.

Since 2011, seven countries have begun to import LNG, and LNG imports from outside the region, as well as mutual LNG trade within the region, are growing. The share of LNG in Southeast Asia's natural gas consumption is expected to grow from the current one-sixth to around one-third in 2050. There is a particularly large potential for expanding infrastructure for LNG use in the coastal regions and islands.

In the Southeast Asian market, natural gas will play a particularly important role in reducing emissions from the industry sector and in balancing the supply and demand of electricity. It may serve as an economically rational fuel for reducing emissions in the transitional period. Ensuring a stable natural gas market and expanding the supply capability to do so will help reduce energy transition costs.

Recent LNG market trends underline the importance of LNG's role and the long-term stability and security of the market. LNG is providing the flexibility necessary for responding to energy crises, and the recent destabilisation of the supply-demand balance and prices is affirming the importance of taking long-term market stability measures.

On the demand side, it is becoming even more important to respond to fluctuations in the demand outlook due to the impact of long-term decarbonisation initiatives, shifting demand centres to emerging and developing economies, and the demand-side trend towards flexible contracts. In the short term, the market balance will be affected by uncertainties in natural gas demand due to the impact of nuclear and renewable energies, volatility in natural gas demand reductions in Europe and the trend of natural gas demand recovery in China, India and Asian emerging markets.

In terms of prices, in the long term, it is necessary to diversify and optimise the contract pricing schemes and to set prices in a balanced manner that supports stable market growth and investment. In the short term, increased volatility continues to plague the industry.

In this regard, it is important to address policy and investment security issues to stabilise the LNG market. Specific measures to ensure stable growth of the LNG market and stable supply sources, especially for fast-growing emerging markets, are to establish the superiority of LNG projects as investment targets and financing sources, by clarifying standards for transition-compliant LNG, for measuring, reporting and verifying (MRV) greenhouse gas (GHG) emissions, and for equipment for clean measures at the government and international levels.

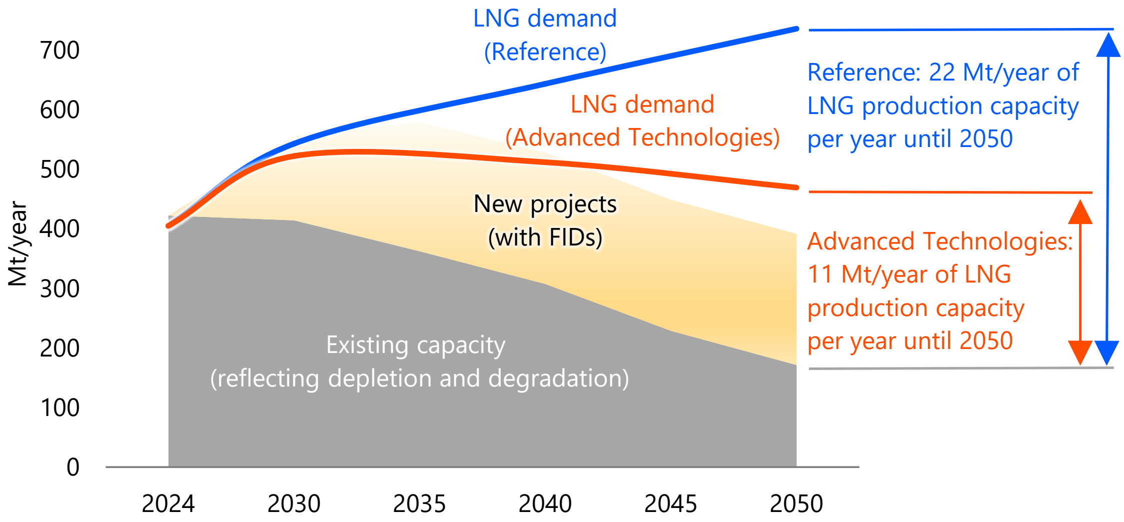
In this regard, the discussion at the 2025 LNG Producer-Consumer Conference on strengthening cooperation among governments and relevant organisations to stabilise the LNG market and promote cleaner LNG production represents progress.

Ongoing investments in LNG and natural gas are required for a stable supply

The LNG production sector needs additional capacity of 11 to 22 Mt/year up to 2050. These figures are based on the difference between the estimated LNG demand and decreased production capacity due to ageing. They include: 1/ investments in new projects, 2/ investments in new gas fields as alternative supplies (backfill), 3/ compensation for declining production in feedstock gas fields, and 4/ rejuvenation and renovation of existing LNG liquefaction facilities and other infrastructure.

The total capacity of new construction decisions in the past four years (projects in FID status) exceeds this amount. However, even the implementation of FID projects is not completely certain, and attention should be paid to the possibility of delays or cancellation. Causes for delay that have emerged include growing uncertainty over new Russian projects, continued suspension of construction in Africa due to political unrest, failure in project owner-contractor negotiations due to increased engineering, procurement and construction (EPC) costs in the United States, and a court decision to halt construction licensing stemming from a US environmental litigation.

Figure 3-3 | Global LNG demand and production capacity



Cost increases alongside technological innovations and evolving development models

Addressing development obstacles for LNG production projects will be key to the long-term use of LNG.

LNG supply has increased rapidly since the 2010s, with supply centres shifting from Qatar to Australia and then to the United States. In the process, the development costs for LNG production projects have been on the rise. In parallel, cost reduction efforts through floating LNG production, small- and medium-sized liquefaction facilities and modular systems have also been made.

The start of LNG exports in the North American west coast, namely in Canada and Mexico, and the progress of LNG development in East Africa are expected to be game changers that diversify supply sources and resolve bottlenecks in marine LNG transport to the Asian market in terms of distance and routes. Among these, LNG exports started from Canada's west coast in 2025.

Long-term commitment from buyers has been key to the steady stream of projects reaching FID in the past few years. In particular, the FID for the 2025 US project was supported by long-term LNG purchase agreements with buyers, including Japanese companies.

While steady growth in production capacity is expected in the medium term, construction delays are becoming a norm. There are views that LNG supply capacity will be in excess around 2030, but forecasts of excess could also spur additional demand. Due to the reasons on both the supply and demand sides, 'excess supply' will likely be an illusion.

Major LNG exporting regions have issues as well as resource potential. Australia's LNG export development has matured, and maintaining stable production through brownfield projects will be a challenge. Qatar is factoring in clean measures into its mega expansion plan, and whether it will be completed as planned is the key concern. East Africa has high resource potential, but full-scale expansion is at a standstill. Russia's supply is currently strong, but the country faces challenges and new development projects are growing even more uncertain.

LNG transport bottlenecks and production equipment problems

With the geographical expansion of the LNG market, ensuring smooth marine transport and stable LNG production is becoming ever more important as long-term challenges. Bottlenecks in key LNG shipping routes, if they occur, are likely to cause serious disruptions when supply is tight. There is a need to establish a long-term LNG transportation strategy.

With the diversification of LNG supply sources, transportation routes and distances vary depending on the source and consumption areas. The completion of expansion of the Panama Canal in 2016 made it possible for LNG carriers to pass through, improving the convenience of transporting US LNG to Asia. Since the shale revolution, the canal has also contributed to increased shipments of liquefied petroleum gas (LPG) to Asia, alongside natural gas. The increase in traffic is causing long waiting times and detours. While passage and reservation systems are being rationalised, drops in water level caused by droughts have led to restrictions on the number of large vessels that can pass through. In 2024 and 2025, it is becoming a norm for US LNG bound for Northeast Asia to go around the Cape of Good Hope. Similarly, Middle Eastern LNG bound for Europe is also routinely shipped via the Cape of Good Hope. Constraints on LNG transportation are growing. Meanwhile, the start of full-scale LNG exports from the North American west coast and East Africa will be a game changer for rationalising and optimising LNG transportation.

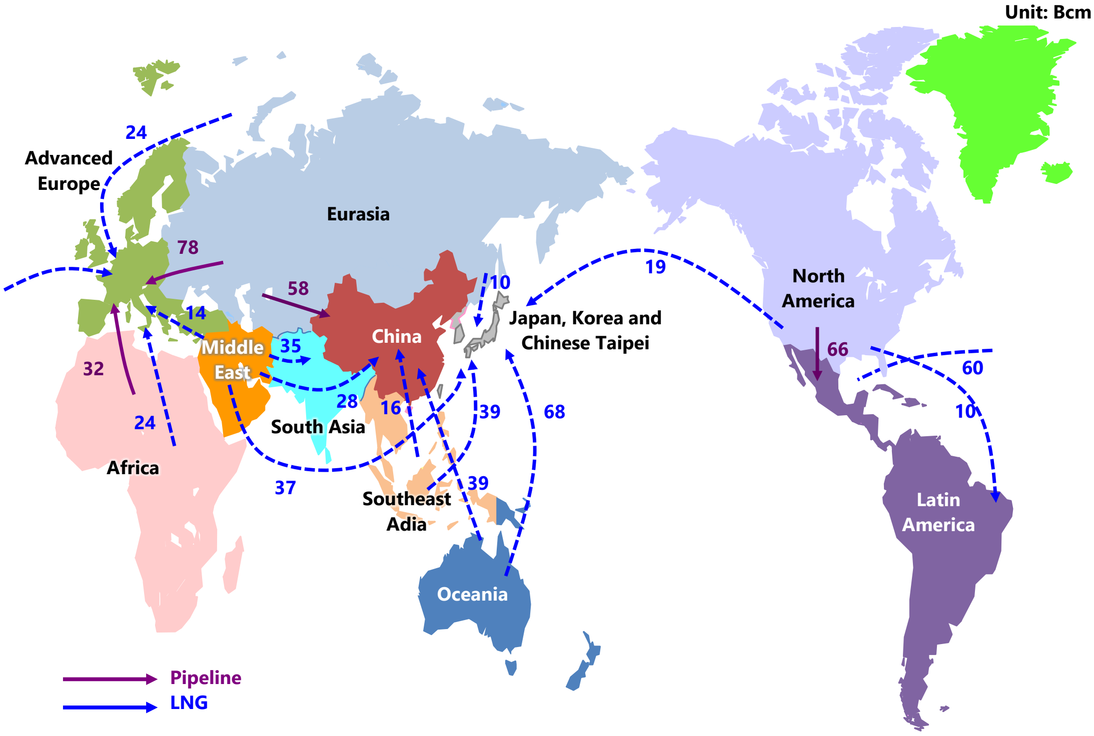
Unplanned shutdowns of LNG production facilities are increasing and are likely to cause serious problems when the supply-demand balance is tight. One example is a large US LNG export facility that shut down for extended periods after a fire in 2022, which coincided with relatively long unplanned shutdowns in other producer countries. Because this occurred when the market balance was tight, it pushed up the already high spot LNG and gas prices.

Table 3-3 | Natural gas production [Reference Scenario]

(Bcm)

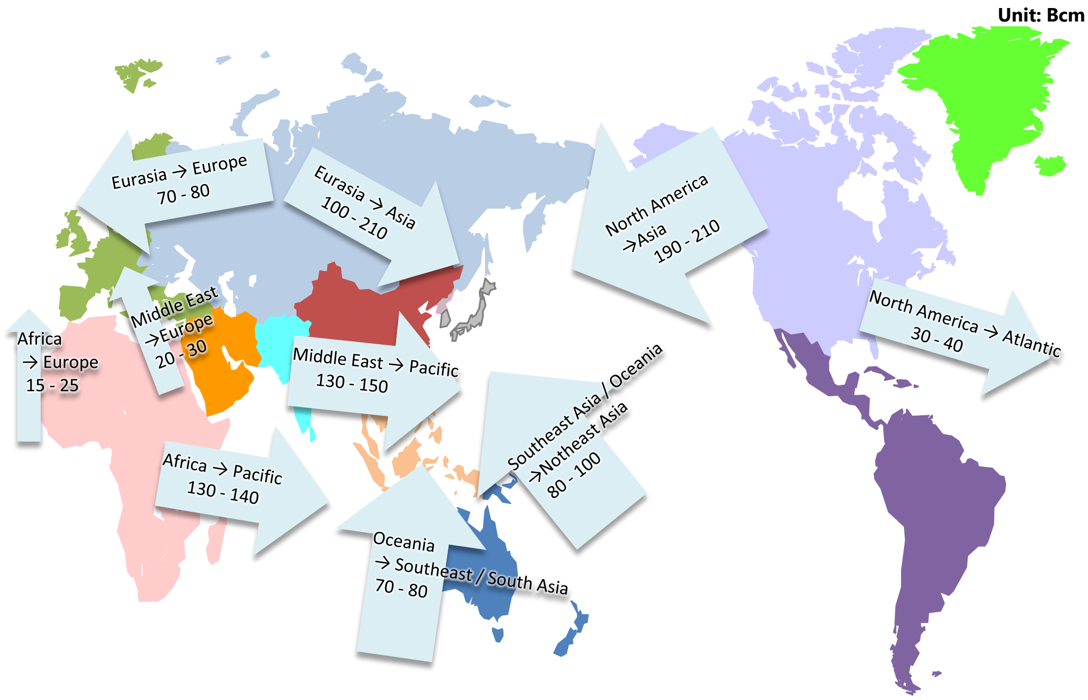
	2023	2030	2040	2050	2023-2050	
					Changes	CAGR
World	4 222	4 322	4 775	5 386	1 165	0.9%
North America and Mexico	1 280	1 292	1 385	1 365	85	0.2%
Latin America excl. Mexico	199	234	289	356	156	2.2%
Europe	196	136	132	106	-90	-2.2%
Eurasia	856	820	839	909	52	0.2%
Russia	638	600	600	609	-29	-0.2%
Middle East	732	770	827	1 049	318	1.3%
Africa	253	256	380	614	361	3.3%
Asia	538	650	738	784	246	1.4%
China	232	260	276	242	10	0.1%
India	36	55	87	90	54	3.5%
ASEAN	204	229	241	252	48	0.8%
Oceania	167	165	185	204	37	0.7%

Figure 3-4 | Major interregional natural gas trade flows [2024]



Note: Major interregional trade flows are indicated.

Figure 3-5 | Major interregional natural gas trade flows [Reference Scenario, 2050]



Notes: Major interregional trade flows are indicated, not encompassing all trade volumes. Supplies from Eurasia, Africa and the Middle East include those through pipelines in addition to LNG.

3.3 Coal

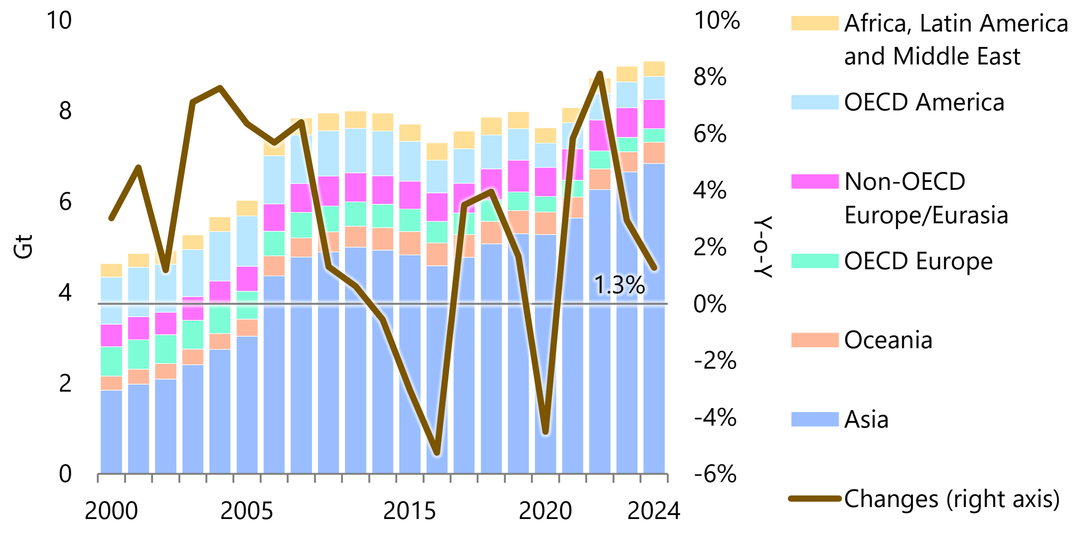
Overview of global supply and demand

In 2024, global coal production hit a record high of 9.1 Gt (Figure 3-6). This was mainly due to increased production in the three major coal-producing countries: China, India and Indonesia. Domestic circumstances, safety measures and export trends in each country contributed to the record-breaking results.

China maintained production at around 4.6 Gt in 2024. Although production in Shanxi Province declined due to strengthened safety management, increased production in the Inner Mongolia and Xinjiang regions more than compensated for this, contributing to sustaining nationwide production levels. Coal production continues to be ramped up as a pillar of the government's energy security strategy centred on domestic coal supply. In India, production increased 5% from the previous year to 1 090 Mt. Coal India Limited (CIL) and other captive (for self-consumption) and private mines also expanded output. Coal production in Indonesia recorded an 8% increase from the previous year to 830 Mt, thanks to expanded domestic demand and increased exports to China. Australia produced 470 Mt of coal, a 7% year-on-year increase, despite heavy rainfall at the start of the year, as operations proceeded smoothly thereafter. Both countries are adapting to weather risks while maintaining their positions as major exporters. Mongolia has also significantly increased production, supported by rising exports to China. South Africa succeeded in maintaining production levels despite the impact of power outages.

The record coal production in 2024 demonstrates that coal remains a central component of the current energy supply and economic activity. Meanwhile, environmental issues such as air pollution and greenhouse gas emissions continue to pose significant challenges. Going forward, greater attention is expected to focus on technological development and policy adjustments aimed at achieving both a stable supply and reduced environmental impact.

Figure 3-6 | Global coal production



Notes: Figures for 2024 are provisional.
Source: International Energy Agency "World Energy Balances July 2025"

Global coal production is expected to reach 9.2 Gt in 2025, recording a new high. By country, China recorded a 6% year-on-year rise in the first half of the year. This growth rate is largely driven by a rebound effect following the large-scale production adjustments implemented in Shanxi Province in 2024. However, domestic inventories remain at high levels and prices are on a downward trajectory, particularly in the northern region. Although the market recovered during the summer, demand is expected to slow in the latter half of the year, raising concerns about potential impacts on production volumes.

In India, the government's drive to boost domestic coal production is expected to strengthen supply capacity for coal-fired power plants. Specifically, government measures to promote mining investment and reforms to the allocation system have borne fruit, leading to increased private sector participation. Production is forecast to reach the 1.1 Gt range, a 3% year-on-year increase. Although domestic demand remains resilient, particularly in the electricity and cement industries, concerns persist that high coal prices will push up power generation costs.

In Indonesia, coal production decreased by 8% year-on-year in the first half of the year. This was affected by low export prices to China as well as operational shutdowns caused by floods and heavy rains. For the full year, production is forecast to fall by 10% to 760 Mt, below the previous year. Attention must also be paid to limited shipping capacity at major ports and the restructuring of mines that fall below the break-even point. Price recovery and progress in infrastructure development are considered key to a production recovery in the latter half of the year and beyond.

In Australia, production is forecast to decline year-on-year to approximately 430 Mt due to operational stoppages caused by coal mine accidents and flood damage. While maintaining its position as a major exporter, there are concerns over its export competitiveness, due to increased vessel layover days caused by reduced supply, and Queensland's royalties being among the highest globally. Amid mounting pressure on coal operations following a period of environmental policy prioritisation, there is uncertainty about the future of coal supply and declining business predictability.

In the United States, production is increasing, thanks in part to policy support for the coal industry under the Trump administration. Demand has also been rising as coal-fired power generation has maintained a price advantage over natural gas-fired power generation. With the price impact on the natural gas market expected to ease in the second half of the year, demand is expected to remain at around 480 Mt overall.

In Russia, a slight production cut is expected due to continued sanctions, while uncertainty remains high and forecasts are fluid, with the possibility of a significant decline. By 2024, more than half of producers were expected to record losses, and the government plans to introduce rail transport subsidies from May 2025. Maintaining exports is key to sustaining production volumes. Going forward, Russia's strategy to shift to markets outside Europe, particularly Asia, will determine the success or failure of its exports.

Mongolia is expected to see a slight decrease in production due to limited railway capacity to China and a decline in demand within China, while South Africa will see a slight increase due to stable growth in domestic demand, mainly for electricity. Colombia is expected to face the risk of a significant decline in production due to labour disputes and changes in tax policy.

Supply and demand balance due to China and India's domestic coal production increase policies

Global coal demand increased by 1.5% compared with 2023, reaching a record high of 8.79 Gt. The growth rate has slowed compared with 2022 (4.4%) and 2023 (2.3%), but the upward trend continues. This growth was driven by Asian emerging economies, with China and India experiencing increases of 82 Mt and 45 Mt, respectively, from the previous year, and Indonesia and Viet Nam also seeing expanded demand. Meanwhile, in advanced economies, demand continues to decline due to reductions in coal-fired power generation, with the European Union declining by 40 Mt and the United States by 14 Mt. As such, China, India and the Association of Southeast Asian Nations (ASEAN) account for 77% of global coal demand. This is more than double the share in the early 21st century, highlighting Asia's growing influence in the global coal market. The increase in coal-fired power generation in Asia is notable, reaching a record high of 10 766 TWh in 2024. Meanwhile, demand for coking coal for steelmaking has remained broadly flat or declined slightly in recent years. China accounts for 50% of global coal demand, with its power generation sector alone accounting for one-third of global coal consumption. As such, global coal demand trends have been heavily influenced by China's policies and electricity demand.

Global coal demand declined slightly in the first half of 2025. While fuel diversification and renewable energy adoption are gradually progressing, the situation is becoming more complex across regions. The coal market is in constant flux, with short-term economic fluctuations and seasonal factors intertwining.

Although China did not experience severe cold during the winter, high temperatures persisted in the summer, accelerating demand for thermal power generation. Annual coal demand for thermal power generation, however, is expected to decrease compared with the previous year. Sluggish electricity consumption and the expanded use of renewable energy will continue to weigh on coal use.

In India as well, demand stagnated in the first half of the year. The earlier-than-normal rainy season and extreme heat in 2024 caused thermal power generation demand to fall by 2.1%. On the other hand, strong demand from the iron and steel industry is boosting coking coal consumption, which is expected to be higher than the previous year on a full-year basis.

In East Asia, Japan's coal demand is gradually declining due to economic uncertainty, while Korea recorded a significant decline in the first half but recovered in the second half and full-year demand is ultimately forecast to be on par with the previous year. In Chinese Taipei, natural gas is filling the gap left by the nuclear phase-out, while coal consumption is expected to decrease in the power generation sector and decline slightly in the non-power-generation sector, resulting in a total decrease compared with the previous year. Meanwhile, Indonesia is performing strongly, with growth expected, primarily in power generation, but also in refining, steelmaking and self-generation.

Both the United States and the European Union expanded their coal consumption in the first half of the year. In the United States, surging natural gas prices and increased electricity demand are boosting production, which is expected to increase by 12% year-on-year in the first half and by 7% for the full year, to reach the 400 Mt range. In the European Union, the electricity sector relied on coal-fired power generation due to sluggish hydro and wind power output, leading to a 5% increase in coal-fired power generation in the first quarter. However, with the trend towards structural decarbonisation remaining unshaken, full-year coal-fired power generation is expected to decline compared with the previous year. The market for coking coal for steelmaking is also facing challenges. The global economic slowdown and sluggish infrastructure investment have dampened demand, while uncertainty over the future flow of steel products and components following the introduction of US tariffs is also contributing to market stagnation. Amid these mixed trends, global coal demand is expected to ultimately remain roughly flat compared with the previous year.

Coal trade

In 2024, global coal trade volume reached a new record high, exceeding 1.5 Gt for the first time. In particular, the trade volume of steam coal reached 1.18 Gt. Import demand in Asia is driving this increase. China, in particular, expanded its imports by 14% from the previous year to 550 Mt, the first time imports exceeded 500 Mt in a single year. China's imports are roughly twice those of India, the world's second-largest importer. As for exports, Indonesia increased its shipments by 6% to 550 Mt, led by those to China. Australia saw modest growth of 3% to 209 Mt. Russia's exports have dropped significantly due to Western sanctions, logistical disruptions and deteriorating profitability.

Meanwhile, global trade of coking coal is also expected to reach a record high of 370 Mt in 2024. Australia remained stable at the same level as the previous year, Mongolia exported its entire 56 Mt to China, recording a 5% increase, the United States saw a slight rise, while Canada experienced a decline.

Global steam coal trade is projected to decrease in 2025 compared with the previous year. China's imports are expected to decline due to slowing demand, robust domestic production and increased inventories. India's dependence on imports will decrease as domestic production expands. Japan and Korea are expected to see a decline in imports due to the recovery of nuclear power generation and economic uncertainty. Viet Nam is expected to increase its imports supported by rising domestic electricity demand. As for trends among major exporting countries, Indonesia is expected to reduce its steam coal exports by at least 10% to act as a supply balancer for Asian markets, including China and India. Colombia's exports will decline due to a worsening market and labour-management issues. South Africa will see a slight increase in trade volume due to tight supply and demand in Europe (low wind power output as backup). Meanwhile, coking coal trade will also decline in volume, reflecting weaker global steel demand. The primary driver is the slowdown in steel demand in China. In particular, exports from Mongolia, which is highly dependent on China, will fall significantly. Australia is also expected to see a slight decrease due to bad weather, while Russia faces a decrease caused by deteriorating corporate finances.

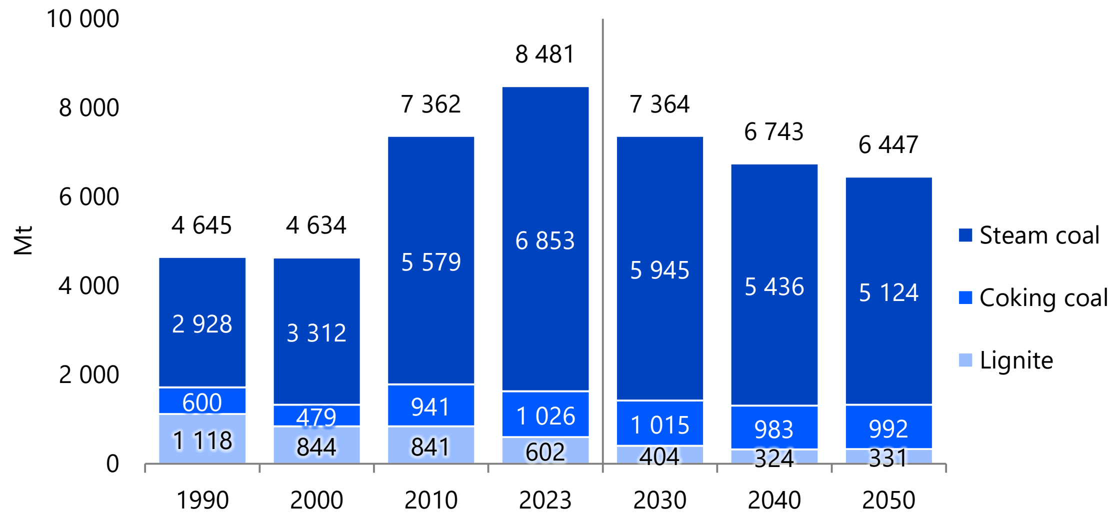
Maintaining a supply system that meets demand

Advanced economies, including the United States and Europe, have been accelerating their decarbonisation efforts, while emerging and developing economies have also declared their commitment to carbon neutrality. Consequently, many countries now share a recognition of the need to strictly limit fossil fuel consumption and production, particularly coal. Coal consumption in Europe and the United States has already been steadily declining. In such an environment, President Donald Trump, who returned to power in the United States in 2025, reversed policies implemented by the previous administration and introduced the 'Energy Dominance' strategy, which emphasises fossil fuels and deregulation. This has also led to the US coal industry receiving substantial support through an executive order dubbed 'Beautiful Clean Coal', making its future trajectory a subject of keen interest. Meanwhile, in China, India and emerging Asian economies, energy demand continues to rise alongside economic development, with coal continuing to play a central role in meeting this demand. However, resource majors have continued to withdraw from, downsize, or restructure their upstream coal operations in alignment with decarbonisation trends. Notably, amid this movement, companies backed by Asian businesses and conglomerates, whose demand continues to grow, have stepped in to bid for the coal assets being divested.

Given the energy situation in each country and current coal demand, the global phase-out of coal is expected to be a long-term effort in practice. Coal consumption in 2024 increased year-on-year, reaching a record high of 8.79 Gt. This surge was driven primarily by emerging Asian economies, including China and India. Looking at global coal demand in the short to medium term, demand will expand in Asia (including China, India and ASEAN countries) and Africa, in line with economic growth. In the long term, demand will increase in Asia (including India and ASEAN, excluding China) and Africa. Traditional upstream coal investment and financing for new mine development and the maintenance and renewal of existing operations have been significantly reduced or restricted amid decarbonisation efforts, raising concerns about future supply capacity. In this context, the aforementioned participation of Asian companies in coal projects is noteworthy. Attention is also focused on how the Trump administration's fossil fuel support policies will influence countries outside the United States.

Global coal production will increase until the late 2020s, then begin to decline in line with demand. Production volume will decrease from 8.481 Gt in 2023 to 7.364 Gt in 2030 and to 6.447 Gt in 2050 (Figure 3-7).

Figure 3-7 | Global coal production [Reference Scenario]



By coal type, steam coal production will peak in the late 2020s and then begin to decline in line with decreasing demand for power generation. Production volume will decrease from 6.853 Gt in 2023 to 5.945 Gt in 2030 and to 5.124 Gt in 2050. Consequently, China will rapidly shift its power sources from coal to renewable energies from the present until around 2030. As a result, coal demand will rapidly decline until around 2030, followed by a slower reduction towards 2050. Meanwhile, production of coking coal, mainly for steelmaking, will gradually decline from 1 026 Mt in 2023 to 992 Mt in 2050. Production of lignite, a locally produced and consumed energy resource, will gradually decrease from 620 Mt in 2023 to 331 Mt in 2050 alongside the decommissioning of existing lignite-fired power plants.

In the future, coal-supplying countries will produce in response to export demand (the international coal market) after meeting their domestic requirements. Conversely, countries that both produce and consume substantial amounts of coal, such as China and India, will expand domestic production to meet internal demand and import any shortfall from other supplying countries. Countries such as Japan, where coal resources are limited and production is not economical, will depend entirely on imports.

Examining the situation in major coal-producing countries and regions, European and North American advanced economies, as well as East European coal-producing European Union members such as Poland, will find it increasingly difficult to develop new coal mines, expand production at existing operations, or invest in transportation infrastructure. In Australia, domestic consumption and export of coal remain a divisive public issue. The federal government is set to strengthen existing greenhouse gas measures following the change of government in 2022, which will significantly affect future production of fossil fuels, including coal. Coal-producing state governments are increasingly seeking alternative sources of foreign currency beyond coal exports while complying with climate change policies. Major importers of Australian coal, such as India and ASEAN, continue to experience increasing coal demand; however, competition from Indonesian exports may constrain supply depending on Indonesian domestic priority policies. Although supplies from Australia (especially steam coal) could potentially expand, this may prove difficult given the current policy and investment environment. The status of mergers and acquisitions of Australian coal assets should be closely monitored.

In Colombia, which has served as a supplier of coal mainly for Europe, companies from advanced economies are withdrawing from coal production. The country is unlikely to increase production significantly in the medium to long term as its political situation grows more unstable. South Africa, whose main markets are domestic supply and India, is also witnessing a transformation of its coal industry, including the withdrawal of companies from advanced economies. Reserves in existing coalfields are being depleted, necessitating a shift to new coalfields. Indonesia, a major exporter of steam coal, has expanded production primarily to meet remarkably strong export demand. Meanwhile, the government has established a basic policy of curbing production and prioritising domestic supply to protect coal resources. However, the coal production quotas announced annually by the government are set to allow for significant production increases, and currently there are no major disruptions to production for either domestic use or export. The rapid expansion of domestic self-generation demand in Indonesia, combined with increased domestic coal production in China and India, has led to a noticeable decline in coal import demand this year. Greater attention must therefore be paid to the government's future actions.

China and India have been increasing domestic coal production alongside their efforts to build new coal-fired power plants. Looking ahead, demand in China will peak in the late 2020s and then decline, while demand in India will grow towards 2050. Both countries have worked to secure supply capacity by increasing domestic coal production but have also utilised imported coal as a valve to adjust domestic supply and demand. The effects of increased production are beginning to be seen, and caution is required regarding the impact on the international market as demand for imported coal declines.

Table 3-4 | Steam coal production [Reference Scenario]

(Mt)

	2023	2030	2040	2050	2023-2050 Changes	2023-2050 CAGR
World	6 962	5 945	5 436	5 124	-1 838	-1.1%
North America	454	214	138	100	-354	-5.4%
United States	391	206	131	95	-296	-5.1%
Latin America	64	55	46	44	-20	-1.4%
Colombia	56	47	39	37	-19	-1.5%
OECD Europe	45	23	16	9	-35	-5.6%
Non-OECD Europe/Eurasia	368	330	298	304	-64	-0.7%
Russia	247	220	191	190	-57	-1.0%
Middle East	0	0	0	0	0	-0.5%
Africa	249	225	238	269	19	0.3%
South Africa	245	201	202	219	-26	-0.4%
Asia	5 529	4 886	4 519	4 233	-1 296	-1.0%
China	3 903	3 092	2 435	1 862	-2 041	-2.7%
India	839	1 002	1 296	1 564	725	2.3%
Indonesia	681	659	642	648	-33	-0.2%
Oceania	252	210	181	165	-87	-1.6%
Australia	251	210	180	164	-87	-1.6%

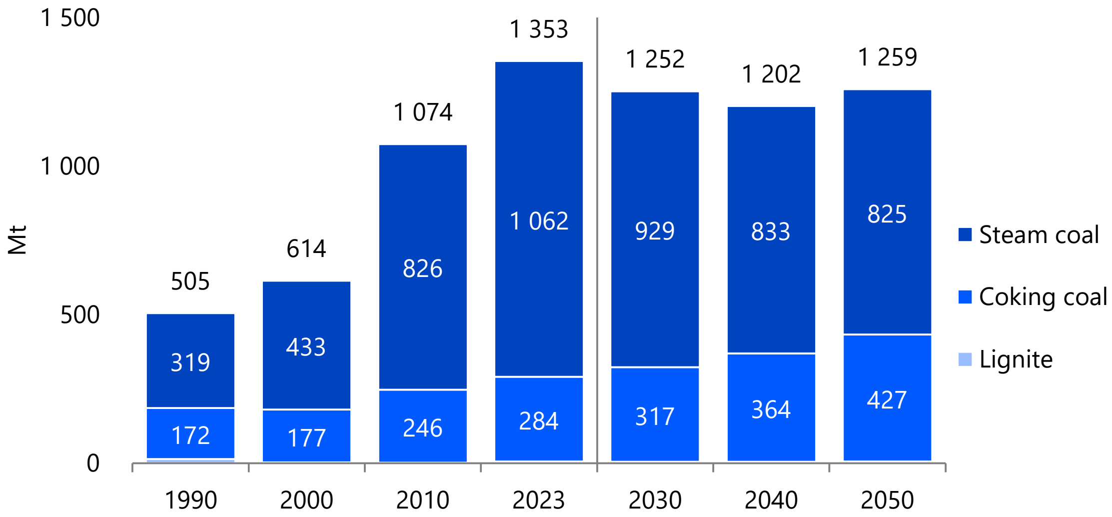
Table 3-5 | Coking coal production [Reference Scenario]

(Mt)

	2023	2030	2040	2050	2023-2050 Changes	2023-2050 CAGR
World	1 021	1 015	983	992	-29	-0.1%
North America	77	63	66	71	-6	-0.3%
United States	52	45	47	50	-2	-0.2%
Latin America	10	10	13	18	8	2.1%
Colombia	9	9	12	17	8	2.5%
OECD Europe	14	13	14	15	1	0.2%
Non-OECD Europe/Eurasia	110	103	108	115	5	0.2%
Russia	105	97	101	109	4	0.1%
Middle East	2	2	3	3	1	1.6%
Africa	8	19	28	38	30	5.8%
Mozambique	4	15	22	32	27	7.6%
Asia	641	621	541	482	-159	-1.1%
China	554	521	408	309	-245	-2.1%
India	57	68	99	136	80	3.3%
Mongolia	24	25	25	25	1	0.1%
Oceania	158	184	212	250	91	1.7%
Australia	157	183	211	249	91	1.7%

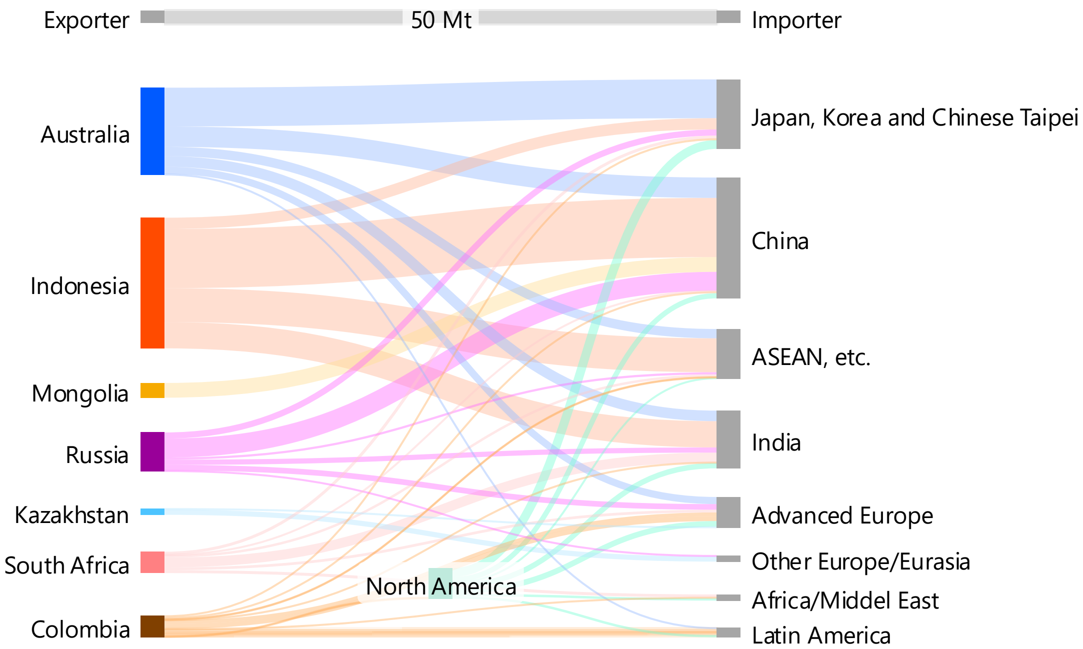
Coal trade volume will decrease from 1 353 Mt in 2023 to 1 202 Mt in 2040 but will then increase slightly to 1 259 Mt in 2050. By type of coal, trade of steam coal will decline significantly from 1 062 Mt in 2023 to 825 Mt in 2050, as China's imports peak in the late 2020s followed by a decline amid decarbonisation efforts. Conversely, demand for coking coal will gradually decrease due to declining steel demand in the European Union, Japan and China, but increasing steel demand in Emerging and Developing Economies, particularly India, will offset these declines, and trade volume will increase from 284 Mt in 2023 to 427 Mt in 2050.

Figure 3-8 | Global coal trade (import volume) [Reference Scenario]



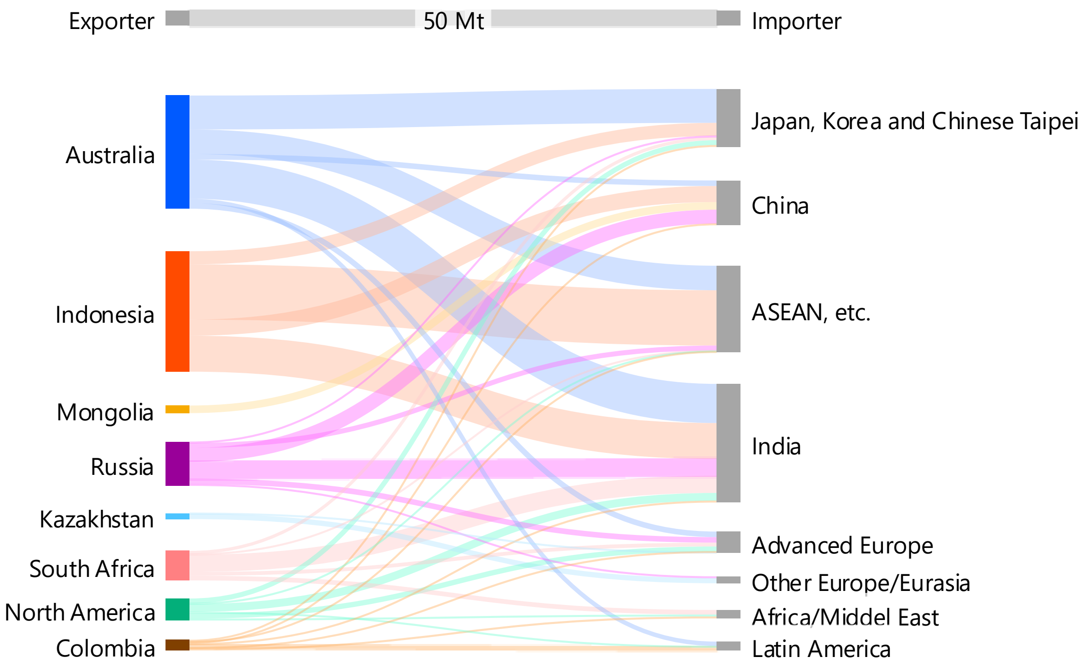
By major exporters, Australia will maintain the current level, but the volume balance will shift in line with demand changes, with steam coal decreasing and coking coal increasing. Indonesia will tend to reduce its export volume while maintaining production to meet increasing domestic demand. This will not significantly impact the market in the near term, partly due to reduced demand in China, but from the 2030s, it may affect the Asian market, depending on the supply balance between domestic and export markets. Russia's exports, following a decline in the short to medium term due to embargoes imposed by the European Union and Japan, will remain flat.

Figure 3-9 | Major interregional coal trade flows [2024]



Notes: Sum of steam coal and coking coal. 2 Mt or more listed. South Africa includes Mozambique.
Source: Estimated based on IEA "Coal Information 2025", TEX Report, etc.

Figure 3-10 | Major interregional coal trade flows [Reference Scenario, 2050]



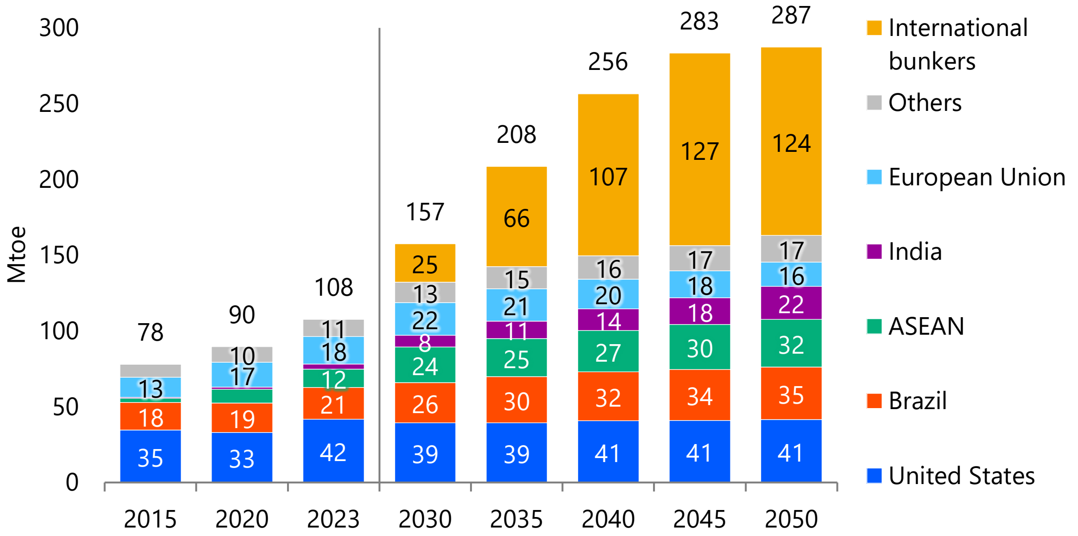
Notes: Sum of steam coal and coking coal. 2 Mt or more listed. South Africa includes Mozambique.

3.4 Biofuels for transport

The penetration of liquid biofuels including bioethanol and biodiesel has progressed as part of measures on climate change, energy security and agriculture promotion. Currently, biofuel use in automobiles is concentrated in the United States, Brazil, Southeast Asia and the European Union.

While biofuel consumption has increased substantially since the 1990s, investment in biofuels has remained stagnant since 2010. The increased introduction of low-cost electric vehicles (EVs), including those made in China, will pose a headwind for the use of liquid biofuels in automobiles. However, the number of internal combustion engine vehicles (ICEs) and hybrid electric vehicles (HEVs) using biofuels will also increase (Figure 2-28), leading to a gradual rise in overall demand[7] (Figure 3-11).

Figure 3-11 | Biofuel consumption for transportation [Reference Scenario]



Note: International bunkers include sustainable aviation fuel (SAF) and marine biofuel.

By region, demand for both liquid fuels and biofuels will grow in emerging and developing economies. In countries producing biofuel feedstocks such as sugarcane, including Brazil, demand for liquid fuels for motor vehicles will remain robust. Increasing liquid fuel demand will be met by raising the ethanol blending ratio. Biofuel demand in the Association of Southeast Asian Nations (ASEAN) will increase sharply but will not reach levels comparable to those in the United States or Brazil. In advanced economies, the introduction of regulations aimed at decarbonisation will reduce demand for liquid fuels, but a certain level of biofuel demand is expected to continue due to policy guidance, such as the setting of phased targets and introduction goals tailored to the circumstances of each country. In the European Union, which is proactive in taking measures against climate change, including the Renewable Energy Directive (RED III), a certain number of vehicles currently in operation will remain. As a result, demand for biofuels at a comparable scale is expected to persist beyond 2030, owing to stockpiles and other factors.

[7] It should be noted that the outlook in terms of calorific value differs from that based on volume because estimates are performed on the basis of the blending ratio (by volume) for liquid fuels such as gasoline and diesel.

Beyond automobiles, biofuel consumption for international aviation and marine transport, currently minimal, will expand in the future. The European Union adopted a bill to promote clean aviation fuel, 'ReFuelEU Aviation', in 2023, and is implementing regulations requiring operators supplying jet fuel to airports in the region to incorporate a certain percentage of sustainable aviation fuel (SAF) in their total fuel supply. While there are prospects for SAF derived from renewable energy or hydrogen, at the current stage, biofuel-derived SAF remains price-competitive. However, it is difficult at this point to foresee the comparative rationality of other decarbonisation measures, such as operational efficiency and the use of credits, and the volume of SAF introduced will depend on factors such as demand-side acceptance of price increases attributable to SAF and the degree of progress in achieving broad societal acceptance.

Regarding biofuels for marine use, while demand for liquid biofuels is expected in the near term, the long-term outlook points to the introduction of hydrogen-based liquid fuels such as ammonia and methanol, as well as hydrogen-based fuels including e-methane derived from liquefied natural gas (LNG) and gaseous biofuels. This shift is expected to align with progress in international regulatory trends, technological development and the advancement of societal implementation, including port infrastructure development. Consequently, liquid biofuels are expected to reach a peak around a transition point in 2040. In the longer term, the proportion of liquid biofuels used in shipping will therefore decrease.

On the supply side, there are growing concerns in some regions about the environmental impact of first-generation biofuels and their competition with food. Initiatives to develop next-generation biofuels, including second-generation cellulosic biofuels and third-generation algae-derived fuels, and to reduce their cost, will be strengthened.

3.5 Power generation

Recent trends

Increase in power generation accelerated in 2024 due to strong demand for data centres.

Total global electricity generated in 2024 amounted to 31.3 PWh, representing a 4.0% increase from the previous year[8]. This growth rate far exceeded the average of 2.6% per year over the past decade. The main factors behind this include continued economic growth and a surge in demand from power-hungry data centres. In particular, the United States, which leads in artificial intelligence (AI) development, saw its power generation growth rate rise by 2.2%, a significant increase compared with the average of 0.6% over the past decade.

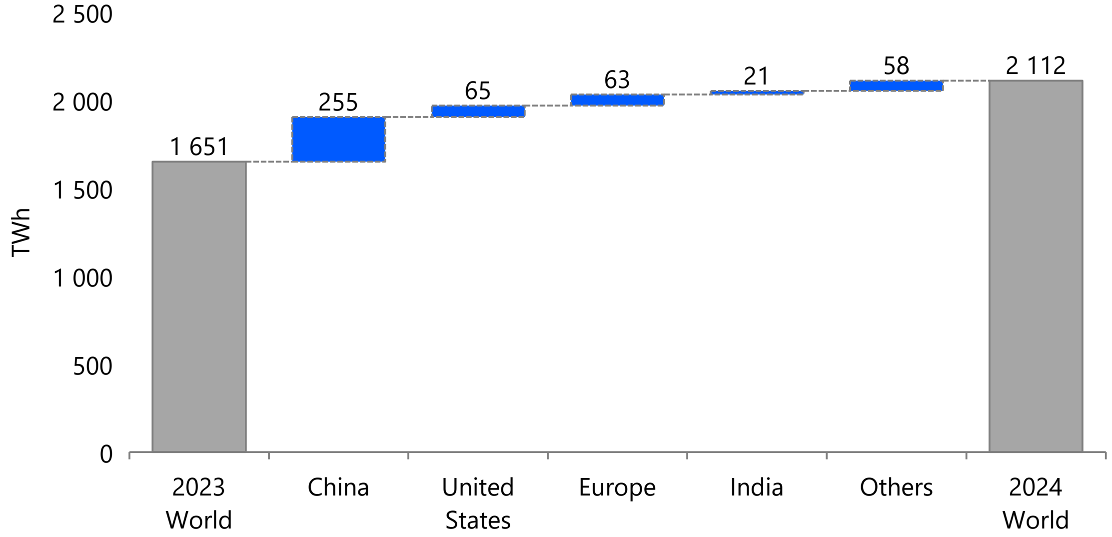
Solar photovoltaics continue to expand drastically, especially in China.

To meet this significant increase in demand, electricity generated from all power sources, including natural gas, coal, nuclear, hydro and other renewables, increased compared with the previous year in 2024. The increase in solar photovoltaics was particularly notable, with power generation reaching 2 112 TWh (up 27.6% year-on-year), exceeding the previous record of 2023.

China has been a strong driver of solar photovoltaic growth to date, and this trend continued into 2024. China alone accounted for 55% of the global increase in solar photovoltaic power generation. Of the remaining 45%, the United States, Europe and other regions each accounted for roughly one-third.

[8] Energy Institute "Statistical Review of World Energy" (2025)

Figure 3-12 | Year-on-year change in solar photovoltaic power generation [2024]

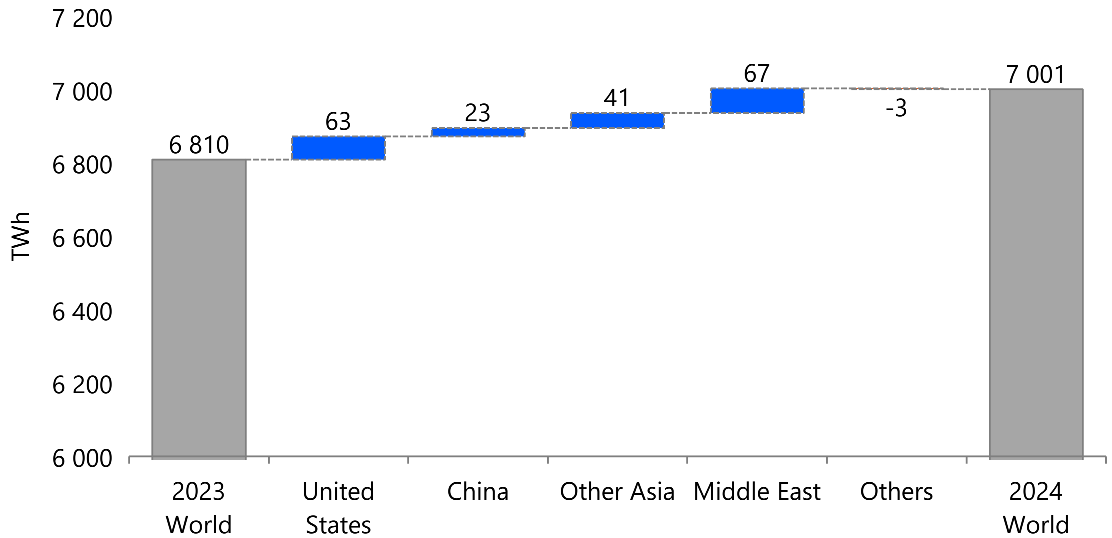


Source: Energy Institute "Statistical Review of World Energy" (2025)

Natural gas-fired power generation increased in the United States, Asia and the Middle East.

Following solar photovoltaics, the sectors that saw significant growth in 2024 were hydro and natural gas-fired power generation. Natural gas-fired power generation increased 2.8% to 7 001 TWh, accounting for 22.4% of total electricity generated. By region, there was a decrease in Europe, while a notable increase was seen in the United States, Asia and the Middle East. In the United States, natural gas is meeting the rapidly increasing demand for electricity from data centres along with renewable energy and is expected to maintain its position as a major power source under President Donald Trump's policy of promoting fossil fuels. In Asia, whilst it declines in Japan, new construction of natural gas-fired plants is steadily progressing in emerging and developing economies such as China, India and Indonesia, increasing its importance as a power source that combines emission reduction with load-following capability.

Figure 3-13 | Year-on-year change in natural gas-fired power generation [2024]



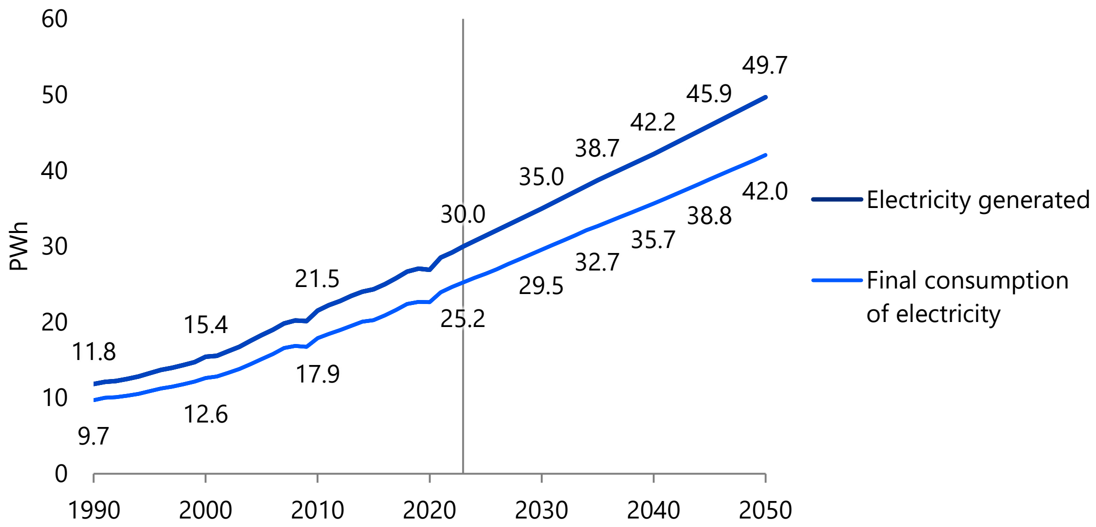
Source: Energy Institute "Statistical Review of World Energy" (2025)

Outlook

Electricity generated: Rapidly expanding in Asia and Africa while continuing to increase in Advanced Economies

Global electricity consumption will continue expanding at an annual rate of 1.8% until 2050, driven by conventional factors such as continued economic growth and ownership of electricity-consuming devices due to improved living standards, particularly in emerging and developing economies, as well as by factors such as recent accelerating electrification as a result of climate change countermeasures and increased consumption due to digital technology. This will result in global electricity generated increasing to 49 701 TWh in 2050, a 1.7-fold rise from the 2023 level (Figure 3-14). Of the 19 723 TWh increase, 82% will derive from Emerging and Developing Economies, with demand growth being particularly significant in India and the Association of Southeast Asian Nations (ASEAN). Furthermore, even in Advanced Economies where overall energy demand is declining, power generation will continue to increase at an annual rate of 1.0%, making new investment in power generation and transmission facilities a major challenge worldwide.

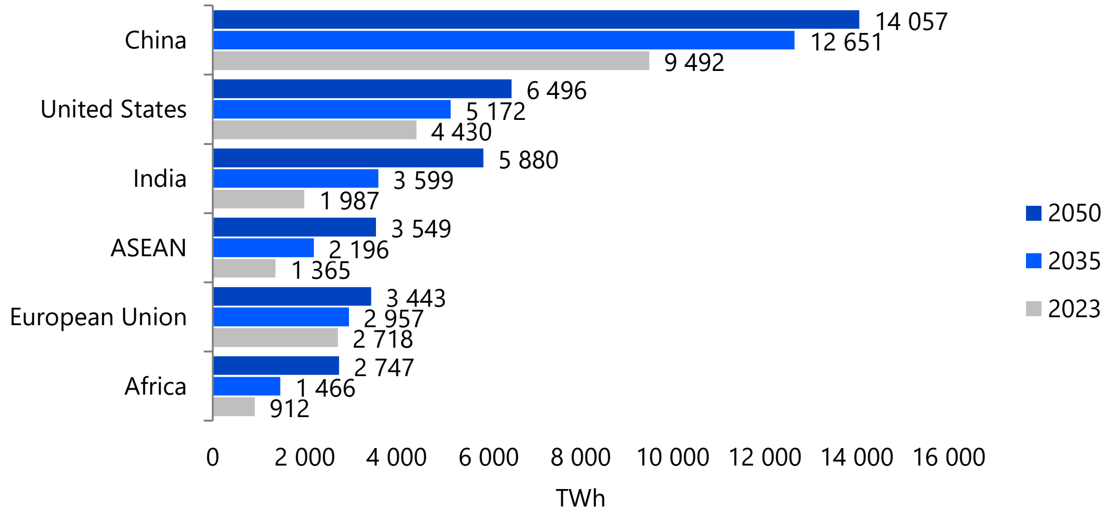
Figure 3-14 | Global electricity generated and final consumption of electricity [Reference Scenario]



Electricity generated in rapidly growing Asia will expand at an annual rate of 2.1% from 15 098 TWh in 2023 to 26 633 TWh in 2050, accounting for about half of the global total. China, which has expanded its electricity generated at a remarkable pace, will continue increasing its demand, albeit at a slower pace, and will account for 28% of the global electricity generated in 2050, the largest in the world (Figure 3-15).

Moreover, just as China increased its electricity generated alongside its economic growth in the past, India and ASEAN, both experiencing rapid economic expansion, are projected to see their electricity generated rise by 3.0 times and 2.6 times, respectively, by 2050. India will significantly surpass the European Union, while ASEAN's electricity generated will grow to a level comparable to that of the European Union. Similarly, electrification in Africa will progress significantly, with electricity generated in 2050 exceeding three times that of 2023.

Figure 3-15 | Electricity generated in selected countries/regions [Reference Scenario]

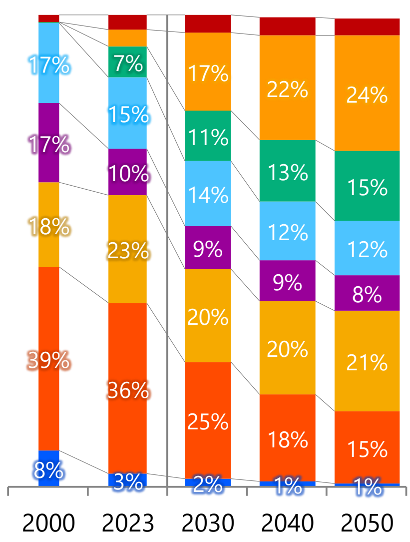


Power generation mix: Natural gas will become the largest power source.

Coal dominated the global power generation mix in 2023, accounting for 36% of electricity generated. Towards 2050, coal's share will continue to decline, with solar photovoltaics taking its place as the largest power source (Figure 3-16). Solar photovoltaics has recently been introduced at an overwhelming pace of over 20% per year, primarily in China, and is expected to account for 17% of electricity generated in 2030 and 24% in 2050. Meanwhile, wind will see significant expansion, accounting for 15% of electricity generated by 2050.

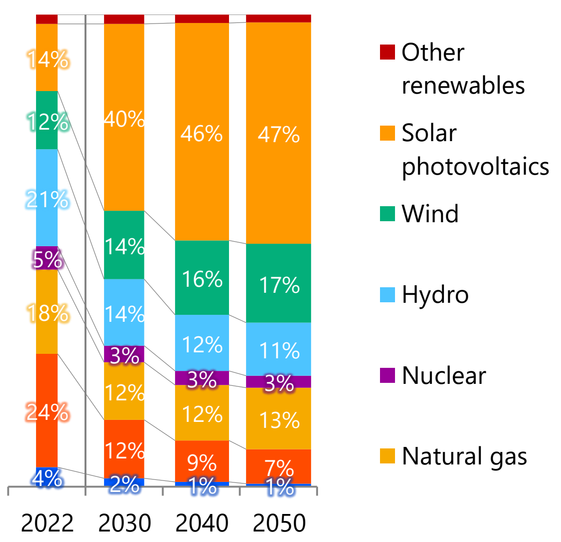
Figure 3-16 | Global power generation mix [Reference Scenario]

Electricity generated



Note: Bar widths are proportionate to total electricity generated.

Installed capacity



Note: Bar widths are proportionate to total power generation installed capacity.

Natural gas, which will have the second-largest share after solar photovoltaics in 2050, is expected to see its share increase again through 2050 as the market stabilises following the significant price spike in 2022 and its high load-following capability allows it to serve as a backup power source for solar photovoltaics and wind. In Southeast Asia, it serves as a transitional stable power source to replace coal, while in the United States and the Middle East, underpinned by overwhelmingly low costs, it forms the core of power generation. Securing affordable and stable natural gas supplies will remain an important medium- to long-term priority for both advanced economies and emerging and developing economies.

Regarding coal, in addition to the United Kingdom, which phased out coal-fired power generation in 2024, advanced economies including Italy, Canada, France and Germany have announced plans to phase out coal-fired power generation, while others have committed to eliminating low-efficiency coal-fired power plants. These policies are generally expected to be achieved close to their target dates. In recent years, emerging and developing economies have also begun setting limits on new coal-fired power generation capacity and shifting to alternatives such as natural gas, solar photovoltaics and wind to address climate change and air pollution. Given this global trend, coal's share will decline, but it will continue to serve as an affordable and stable power source, particularly in emerging and developing economies, with about 70% of current electricity generated levels remaining by 2050. The United States and Europe, which are currently moving towards decarbonisation, have seen a sharp decline in coal-fired power generation. By contrast, the pace of new coal-fired power plant construction in China and India has been remarkable, with the increase in power generation in China and India in 2024 being greater than the decrease recorded in Europe and the United States.

Nuclear power plant construction will make progress mainly in Asia as a measure to ensure energy security and help mitigate climate change, causing nuclear power generation to increase by 25% from the current level. However, the growth of nuclear power generation will fail to exceed that of electricity demand through 2050, leading the nuclear share of electricity generated to fall to 7% in 2050.

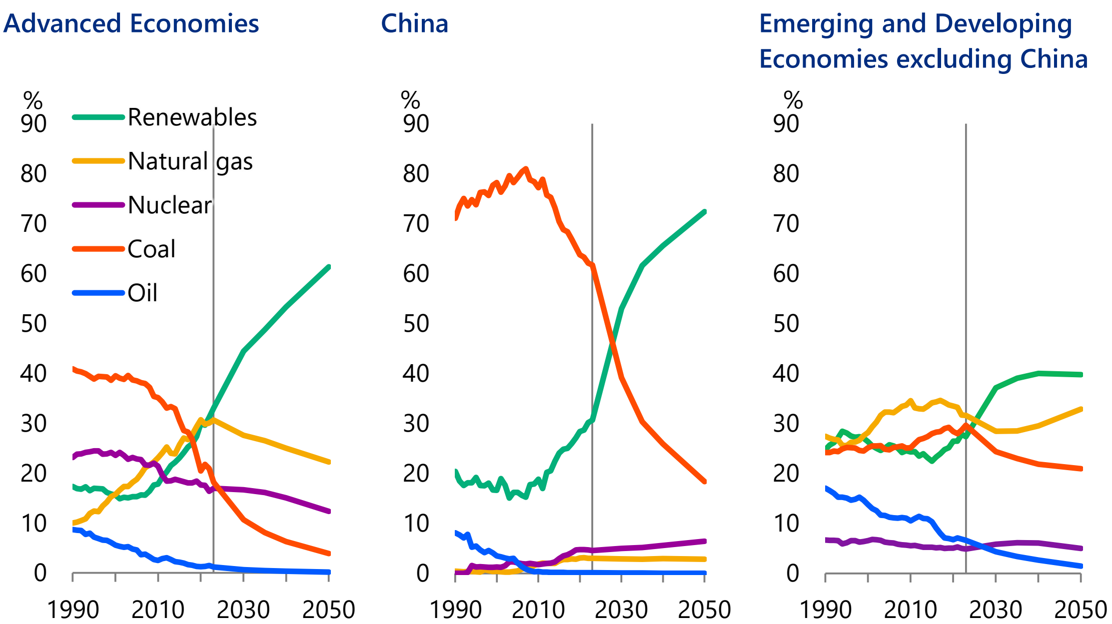
Power generation mix (overview by region)

In Advanced Economies, the shift from existing thermal power generation to renewables, primarily solar photovoltaics and wind, is already underway, and this trend is expected to continue in the future. However, given that suitable locations are limited and that measures to address output fluctuations require greater integration costs as the share of variable renewable energy in power sources increases, the current pace of deployment is likely to slow slightly after 2030. Nevertheless, variable-output solar photovoltaics and wind will account for 44% of electricity generated in 2050, making them potential future mainstay power sources. Addressing output fluctuations and expanding grid infrastructure to connect suitable generation areas with demand centres will become challenges that must be overcome as renewables strengthen their presence. As part of this, natural gas-fired power generation, in particular, will maintain a certain share, even as its volume decreases.

Even among Emerging and Developing Economies, the situation in China differs significantly from that in other regions. In China, where renewables have been actively developed, they will surpass coal to become the largest power source by 2030, keeping the recent rapid pace of adoption due to low costs. They are expected to continue increasing through 2050, albeit at a slower pace, to account for approximately 70% of the electricity generated. Of this, variable solar photovoltaics and wind will account for 58% and, as in Advanced Economies, measures to address output fluctuations will become an increasingly important issue.

In Emerging and Developing Economies excluding China, renewables, including wind, will increase and replace coal and natural gas as the largest power source by around 2030. However, a major difference from Advanced Economies is that their share will remain in the high 30% range, with thermal power generation maintaining a certain proportion. To meet the rapidly increasing demand for electricity, coal will account for approximately 22% of electricity generated in 2050, with natural gas accounting for 33%. To achieve both a stable supply of electricity and a reduction in carbon dioxide (CO_2) emissions, it is important to invest in efficient grid operation and high-efficiency equipment in the short term, and to explore options such as co-firing with hydrogen and ammonia, and carbon capture and storage (CCS) in the long term. Variable renewable energy is a promising power source that can simultaneously address the strong increase in electricity demand in Emerging and Developing Economies and the reduction of carbon dioxide emissions. Meanwhile, it is necessary to secure a certain amount of dispatchable thermal and hydro power sources, which are essential for an environment where electricity demand continues to grow against the backdrop of rapid economic growth, thus requiring the maintenance and expansion of installed capacity.

Figure 3-17 | Power generation mix in Advanced Economies and in Emerging and Developing Economies [Reference Scenario]

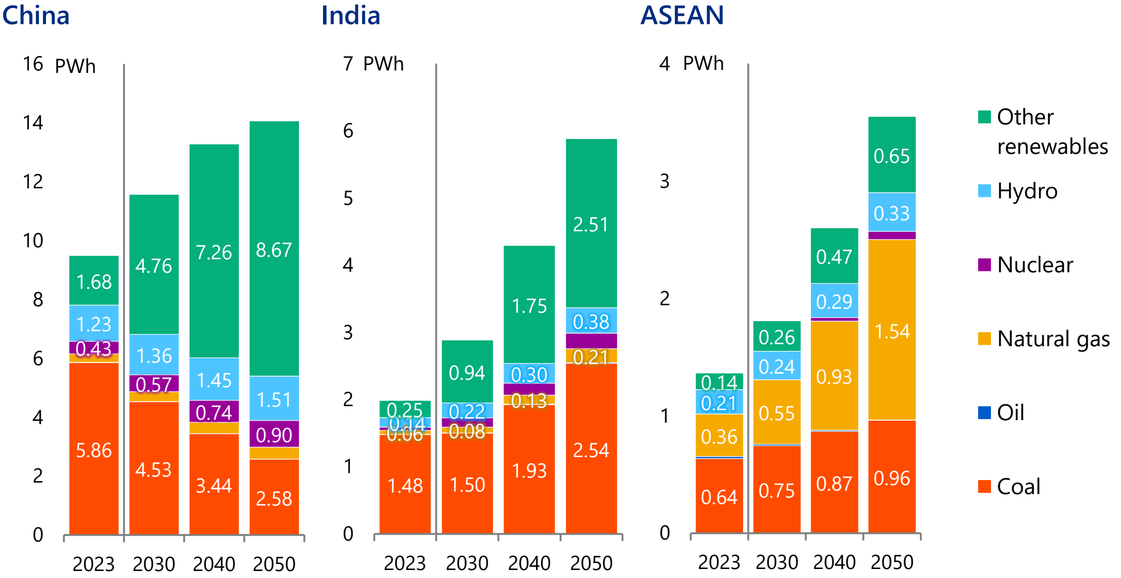


Diverging prospects for coal and renewable energies in three emerging areas in Asia

Across Asia, coal-fired power generation accounted for the largest share of electricity generation in 2023 in China, India and ASEAN. Going forward, a shift to natural gas and renewables will progress, reducing coal's share from 57% of power generated in 2023 to 25% by 2050. However, this power source transition varies significantly across countries and regions (Figure 3-18).

In China, renewable energy capacity has been rapidly expanding in recent years, as stated above, and electricity generated from solar photovoltaics, wind and other sources will increase more than fivefold from 2023 levels by 2050, establishing renewables as the dominant power generation source. Nevertheless, China continued to build new coal-fired power plants even in 2024, and despite its decreasing share, coal-fired power generation will be comparable to that of India by 2050.

Figure 3-18 | Chinese, Indian and ASEAN power generation mix [Reference Scenario]



India is also expanding its renewable power generation from both solar photovoltaics and wind, which is projected to overtake coal as the largest power source by 2050. However, unlike China, coal-fired power generation will continue to increase in the future and is expected to increase 1.7-fold compared with 2023. To meet the strong growth in electricity demand, a key issue will be how to mobilise a variety of options, including nuclear, hydro and natural gas, to satisfy the demand expansion that is expected to nearly triple compared with 2023.

In contrast to these two countries, ASEAN is substantially expanding its use of natural gas, which will reclaim its position as the largest power source alongside growing renewable energies. The situation varies considerably across ASEAN countries. In Thailand, strong public and private sector movements to phase out coal-fired power generation are driving a shift towards natural gas and renewables. Meanwhile, Indonesia and the Philippines are expected to continue to rely on coal as their main power source due to a rapidly increasing electricity demand. Another feature of the ASEAN region is the diverse range of supply forms, such as Lao People's Democratic Republic advancing the decarbonisation of power sources through the development of abundant hydro, and Viet Nam leveraging its potential for variable renewable energy, including offshore wind. Maintaining low-cost and stable electricity supply in this region, where demand continues to soar, presents significant challenges and necessitates diverse approaches tailored to each country's supply and demand characteristics.

Renewable power generation

In recent years, renewable energies have been increasingly adopted worldwide from the perspectives of stable supply and economic efficiency. Particularly in Europe, the Ukraine crisis that began in early 2022 has created strong pressure to reduce dependence on Russian natural gas. The use of renewable energy is now positioned as an urgent priority, with active deployment being pursued.

Meanwhile, in the United States, the second Donald Trump administration, which took office in January 2025, continues to shift policies from the previous administration. This turning point has led to market instability, causing the review and postponement of planned projects. The impact will not be limited to the United States, and some European businesses and manufacturers may be temporarily affected. However, China remains the current driver of the rapid expansion of global installed capacity. China has been introducing solar photovoltaics and wind at an accelerated pace since 2022 and is expected to lead the way in renewable energy deployment going forward.

From 2015 to 2019, global renewable power generation capacity increased by just under 200 GW annually, but this figure exceeded 250 GW in 2020 and 300 GW in 2022 and ultimately surpassed 570 GW in 2024. This growth will peak towards 2030 (a simple average of approx. 700 GW per year).

Among them, solar photovoltaics, which have achieved substantially lower generation costs, have shown particularly remarkable growth and are expected to maintain their position accounting for 70% of new renewable power generation capacity additions. Moreover, as naturally variable power sources, including solar photovoltaics and wind, represent more than 90% of new renewable power generation capacity additions, their impact on electricity grids will inevitably increase.

Although the installation costs of solar panels and wind turbines have temporarily risen due to higher resource prices since 2021, the International Renewable Energy Agency (IRENA) estimates that the global weighted average levelised cost of electricity (LCOE) fell to $43/MWh for solar photovoltaics in 2024 and $34/MWh for onshore wind power. This is 41% lower for solar photovoltaics and 53% lower for onshore wind than the cheapest new fossil fuel power sources, maintaining their relative economic viability as new power sources. Furthermore, as thermal power generation costs are susceptible to fluctuations in fuel prices, as well as emissions regulations, carbon costs and environmental investment, making overall cost reductions difficult, the relative economic advantage of solar photovoltaics and onshore wind is expected to persist from the perspective of new construction.

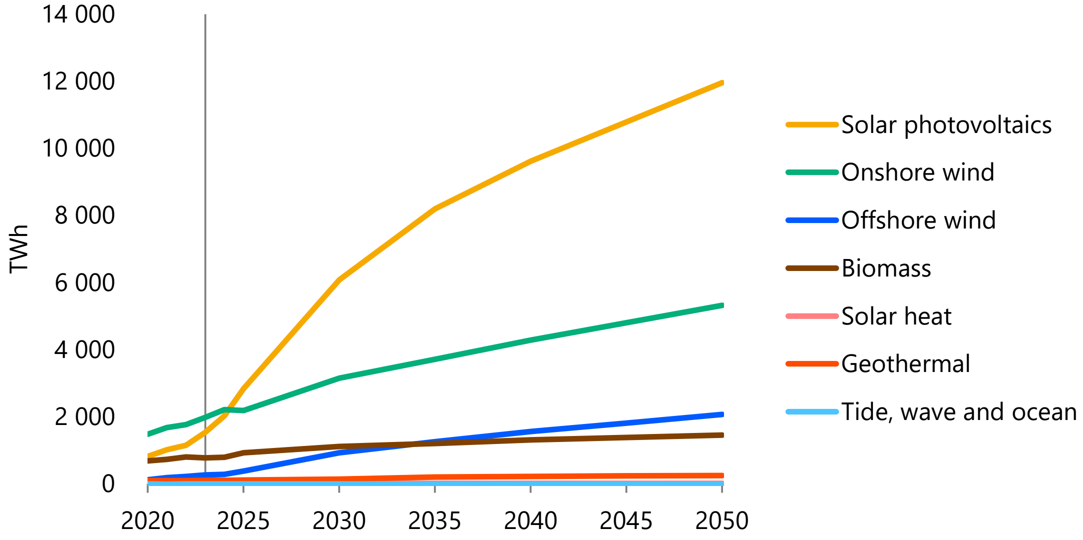
Beyond economic benefits, an increasing number of countries and regions are committing to renewable energy introduction targets (Table 3-6). Whilst regional variations in deployment approaches may emerge in response to developments such as the second Donald Trump administration, the overall global growth rate is expected to remain largely unchanged, partly due to China's strong role as a growth driver.

Table 3-6 | Renewable energy policies and targets in selected countries and regions

Country or region	Main policies and targets
United States	Announcement of a rollback of energy policies from the Joe Biden administration. Not setting decarbonisation targets, prioritising affordable and reliable energy through strengthened regulations for solar photovoltaics and wind power generation. Declaring a National Energy Emergency in January 2025 (The White House). One Big Beautiful Bill Act, July 2025 (Public Law No:119-21).
European Union	42.5% share of renewables in final energy consumption by 2030 (45% as an effort target). Renewable Energy Directive III (issued in November 2023) (European Parliament, Council of the European Union).
Japan	40% to 50% share of renewables in total electricity generated by 2040. The Seventh Strategic Energy Plan, Cabinet Decision in February 2025 (Ministry of Economy, Trade and Industry).
China	Share of non-fossil fuels in primary energy consumption to 25% by 2030 (including installed capacity of wind and solar photovoltaic power generation of 1 200 GW). Action Plan for Carbon Dioxide Peaking before 2030, publicised in October 2021 (State Council)
India	50% of electricity consumption to be supplied by renewables by 2030 (500 GW of non-fossil power generation capacity). Declaration by Prime Minister Narendra Modi at the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP26), November 2021 (Ministry of External Affairs).
ASEAN	23% of primary energy supply and 35% of installed power generation capacity to be from renewables by 2025. ASEAN Plan of Action and Energy Cooperation Phase II, announced in November 2020 (adopted at the 38th ASEAN Senior Officials of Meeting on Energy).

Figure 3-19 shows the trend in renewable power generation up to 2050. Solar photovoltaics will increase nearly six-fold from 2 030 TWh in 2024 to 11 960 TWh in 2050. Wind (both onshore and offshore) will expand 3.0-fold from 2 500 TWh in 2024 to 7 390 TWh in 2050. As a result, variable renewables will significantly increase their share of global electricity generated from 13.1% in 2023 to 39.0% in 2050, strengthening their presence in the electricity system.

Figure 3-19 | Global renewable power generation excluding hydro [Reference Scenario]



China, Europe, the United States and India currently account for 80% of the cumulative installed wind (both onshore and offshore) power generation capacity, and this trend is expected to continue (Figure 3-20). Among these, China's share will continue to grow. The share will expand to the level above 50% by 2040 and its intense concentration in China will be even more pronounced than for solar photovoltaics, which will be discussed later. This suggests that while the increase in Europe, North America and elsewhere is slowing due to stricter location and grid constraints, there remains a relatively large amount of room for expansion in China.

Figure 3-20 | Global installed wind power generation capacity [Reference Scenario]

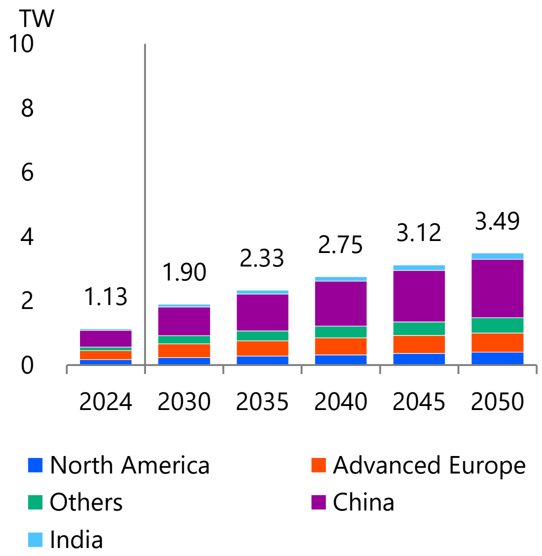
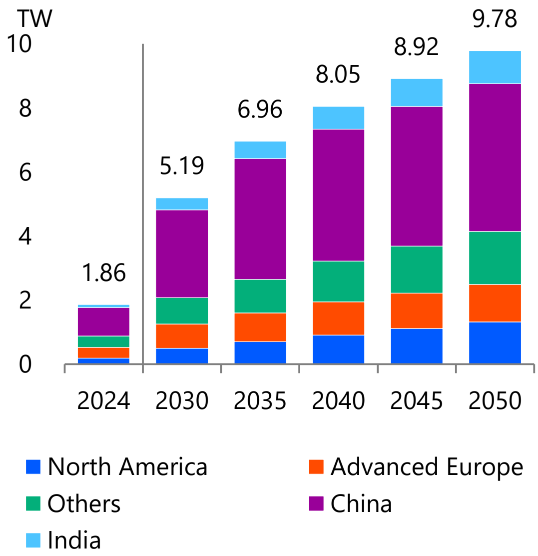


Figure 3-21 | Global installed solar photovoltaic power generation capacity [Reference Scenario]



Onshore wind power generation will grow relatively slowly towards 2050 compared with solar photovoltaics and offshore wind, primarily due to early-emerging site and grid constraints, such as limited suitable land for development. By 2050, installed capacity of onshore wind power generation will reach 2 850 GW, representing only about 2.7 times the 2024 capacity of 1 050 GW. Nevertheless, the cumulative installed capacity in 2050 will remain 4.4 times larger than offshore wind, maintaining its significant presence in renewables.

In contrast, offshore wind, although inferior to onshore wind in scale, is expected to grow at an extremely high rate. Installed capacity of offshore wind power generation worldwide increased drastically from 3 GW in 2010 to 79 GW in 2024. Europe is the world's most mature offshore wind power generation market, with supply chains developed for wind farms. However, China has accelerated large-scale project development since 2020, and by the end of 2023, China's cumulative generation capacity of 37 GW surpassed Europe's 34 GW. This establishes China as one of the world's two largest offshore wind markets, alongside Europe, both nominally and in practice. China's further expansion is projected towards 2050.

The United States has minimal offshore wind capacity, though the former Joe Biden administration had actively promoted offshore wind projects, including a policy targeting 30 GW of offshore wind power generation capacity by 2030. However, following the inauguration of the second Donald Trump administration in January 2025, there has been a growing trend towards planning revisions, including development delays or cancellations, making the introduction of offshore wind power highly uncertain. In July 2025, the One Big Beautiful Bill Act (OBBBA) will partially reduce the tax credits for renewable energy, including wind, that were introduced in the Inflation Reduction Act (IRA). Further slowdown in introduction is expected in the future due to policy changes.

Asia other than China will hold offshore wind markets formed in Chinese Taipei, Korea and Viet Nam. In Japan, the Act on the Utilization of Marine Renewable Energy of 2019 has taken effect, and in 2025, the law was amended to allow project development including in exclusive economic zones (EEZs). As such, further efforts are being made to promote the introduction of offshore wind. The Japanese government has explicitly committed to supporting not only project development but also the expansion of domestic supply chains and industry development. With this policy support, global offshore wind power generation capacity is projected to grow approximately eight-fold from 79 GW in 2024 to 640 GW in 2050. However, affected by location and grid constraints, the speed of deployment will gradually slow down after 2030.

Solar photovoltaic power generation is spreading not only in China, Europe, the United States and Japan, which experienced early adoption, but also all over the world, benefiting from significant reduction in power generation costs (Figure 3-21). China will maintain and expand its dominant position, representing 48% of global cumulative installed capacity in 2024, and is projected to remain so by 2050. However, compared with wind, the share of solar photovoltaics in the United States, Europe, India and others is relatively high, with somewhat less concentration on China. This reflects the versatility of solar photovoltaic power generation, which can produce electricity wherever sufficient sunlight exists, whereas wind power generation is geographically constrained by specific wind conditions.

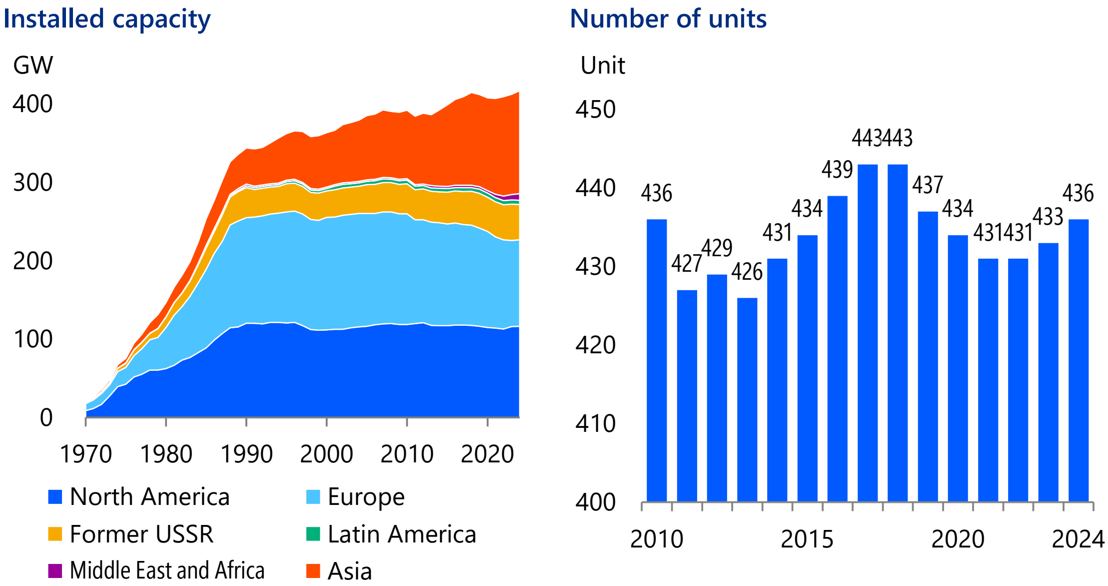
Global installed capacity of solar photovoltaic power generation is projected to increase approximately eight-fold from 1 859 GW in 2024 to 9 785 GW in 2050. However, from 2030 onwards, grid constraints and the impact of the increasing share of variable power sources on power system stability will become increasingly apparent. Consequently, the net increment of global installed capacity of solar photovoltaic power generation, estimated to reach 4 490 GW in the decade from 2020 to 2030, will gradually decrease to 2 860 GW from 2030 to 2040 and 1 730 GW in the following decade. To overcome this slowing trend and maintain high growth in renewable power generation capacity through 2050, it will be critically important to integrate variable power sources, address grid constraints appropriately, and overcome location limitations through technological innovation. The Advanced Technologies Scenario described below assumes a situation where these challenges have been partially, though not completely, alleviated through policy measures addressing location constraints, integration technologies for variable power sources and grid development.

Nuclear

Recent trends: Movements towards expanded use of nuclear underway in various countries

The installed capacity of global nuclear power generation shows a long-term upward trend. After declining for three consecutive years from 2019 to 2021, capacity has been increasing through 2024 (Figure 3-22). From the 1970s to the 1980s, Japan and Western countries built numerous nuclear power plants, resulting in a rapid increase in cumulative installed capacity, but new constructions subsequently decelerated.

Figure 3-22 | Global nuclear power generation capacity and number of units



In recent years, however, as many countries have established ambitious greenhouse gas emission reduction targets, nuclear's role as a low-carbon baseload power source has gained renewed attention. Following the rise in global energy prices since 2021 and Russia's invasion of Ukraine in 2022, the importance of affordable, fossil fuel-free energy for energy security has increased, with nuclear increasingly recognised as a means to achieve this. In recent years, various organisations have begun forecasting that the growing proliferation of data centres and other facilities may lead to higher demand for electricity than previously anticipated, and in response, some countries and companies have taken steps to secure additional power sources. Against this background, there have been both moves to construct new nuclear reactors and to make effective use of existing reactors over the long term.

While ageing management and safety assurance remain prerequisites, the long-term operation of existing nuclear reactors is positioned as a low-carbon power source option with high economic efficiency and is being actively pursued, particularly in Western countries with numerous ageing reactors.

In the United States, reactors that have operated for more than 40 years have been permitted by the Nuclear Regulatory Commission (NRC) to operate for a further 20 years, extending their total operational lifespan to 60 years. Some reactors have received approval for a second extension, allowing them to operate for 80 years. Additionally, there have been recent initiatives to restart reactors previously scheduled for closure. Examples include the Palisades Nuclear Plant in Michigan and Three Mile Island Unit 1 in Pennsylvania. The latter is a prime example of the relationship between nuclear power and data centre electricity demand, as it was a power purchase agreement signed with Microsoft, a major information and communication technology (ICT) company, that led to its efforts to restart the plant.

Belgium, which had planned to complete nuclear phasing-out by 2025, announced in 2022 a 10-year extension for two reactors, Doel Unit 4 and Tihange Unit 3, and reached a final agreement with the owner, Engie S.A. In May 2025, the Parliament passed a resolution to repeal the nuclear phase-out policy. Similarly, in Sweden, the owner of the Forsmark and Ringhals nuclear power plants announced in June 2024 the decision to extend their operating periods from 60 to 80 years. These extensions will enable the country to supply low-carbon electricity until the 2060s.

In Japan, the 'GX Decarbonisation Power Source Act' enacted in May 2023 and enforced in June 2025 allows nuclear power plants' operating periods to be extended by excluding prolonged shutdown periods following the Fukushima Daiichi Nuclear Power Station accident from the prescribed operating timeframe. However, regardless of this provision, plants must undergo a Nuclear Regulation Authority review of ageing management measures every 10 years after their 30th year of operation to receive continued operation approval. As various scenarios emerge for different plants, tracking both the chronological age since startup and the actual operational lifetime of each facility will become increasingly important from a safety perspective.

As such, moves towards the effective utilisation of existing reactors are under way in various countries, while there are moves to construct new plants in some countries. China is particularly active, with Zhangzhou Unit 1 beginning commercial operation in January 2025. Further development is also proceeding, with the construction of about four units starting between February and August 2024. Furthermore, with the State Council's approval of plans to build a total of 10 reactors at five sites in April 2025, the expanded use of nuclear in China is likely to continue. In the United States, President Donald Trump signed several executive orders regarding nuclear in May 2025. Among these was a highly ambitious goal of increasing nuclear power generation capacity from approximately 100 GW in 2024 to 400 GW by 2050. Regardless of whether this goal is achievable, it can be said that the United States' policy towards the expanded use of nuclear has become even clearer. In France as well, progress is underway to build a total of six new reactors at three existing sites, while in the United Kingdom, the government made a final investment decision on the Sizewell C construction plan in July 2025. Both countries are also taking steps to increase the feasibility of new construction, such as nationalising power companies and amending laws to accelerate licensing procedures (France) and introducing an investment recovery scheme known as the Regulated Asset Base (RAB) model (the United Kingdom). In Sweden, where location restrictions were abolished through legal reform, a new support system for new construction was established in May 2025, combining low-interest loans and contracts for difference (CfD). In Europe and the United States, where new construction had stagnated for a long period, several recent new construction projects have seen significant delays compared with their initial schedules. It will be necessary to fully utilise lessons learned from these construction projects to avoid similar delays in the future.

Russia continues to dominate the global nuclear market. Russia has started building nuclear reactors in countries such as China, Turkey, Iran, India, Bangladesh and Egypt, holding a significant share of the export market. Furthermore, in June 2025, Kazakhstan, a uranium-producing country, selected Russia's state-owned nuclear company, Rosatom, as the prime contractor for the construction of the country's first nuclear power station. One reason for this is that Russia not only builds power plants but also provides comprehensive services including fuel supply and the collection of spent fuel, which meets the needs of emerging and developing economies. Meanwhile, Western countries have also been moving towards nuclear exports. In June 2025, Korea Hydro & Nuclear Power (KHNP) awarded an order for an expansion project (two reactors) at the Dukovany Nuclear Power Station in the Czech Republic. The United States is also pursuing exports to Bulgaria and India. In February 2025, Indian Prime Minister Narendra Modi visited the United States and issued a joint statement with President Donald Trump, in which the two leaders announced their intention to build US-made nuclear reactors in India. India is also reviewing its Civil Liability for Nuclear Damage Act (CLNDA) to mitigate uncertainty over the entry of private US operators.

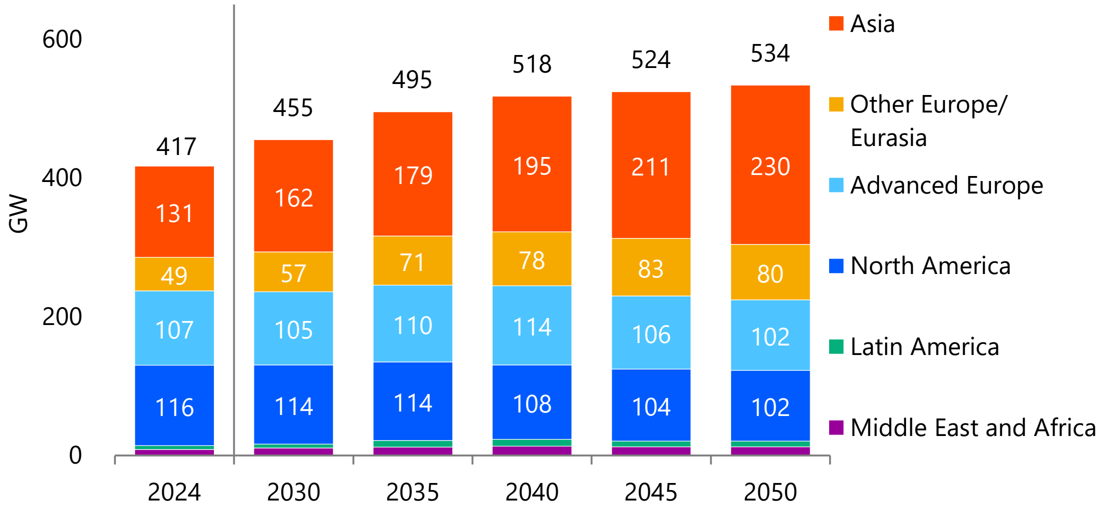
Attention must also be maintained on developments beyond conventional large-scale light water reactors, including small modular reactors (SMRs) and Generation IV reactors. In the United States, both Republican and Democratic Parties have implemented aggressive support measures, with numerous private companies initiating advanced reactor development. In Canada, the regulatory authority issued a construction permit in April 2025 to Ontario Power, which is pursuing plans to introduce a light-water reactor SMR manufactured by GE Vernova Hitachi Nuclear Energy. Several other countries, including Korea, Bulgaria, Romania and Estonia, are also moving towards introducing SMRs. Concerning Generation IV reactors in the United States, X-energy, which is developing the high-temperature gas-cooled reactor 'Xe-100', applied to regulators in March 2025 for a construction licence in Texas alongside major chemical manufacturer Dow. Furthermore, in May of the same year, Kairos Power commenced full-scale construction of the 'Hermes' fluoride salt-cooled high-temperature demonstration reactor in Tennessee. Amazon is supporting the introduction and commercialisation of Xe-100, and Google plans to purchase electricity from Kairos Power's fluoride salt-cooled high-temperature reactor (a power generation reactor succeeding Hermes) in the future to supply its own data centres.

Thus, efforts are under way in many countries towards expanded use of nuclear as its role attracts increasing attention. However, in many cases, the final success or failure of the introduction will depend not only on governments' policies, but also on developers' ability to offer customers acceptable conditions in terms of costs and other factors. Customer responses to various nuclear initiatives worldwide merit close observation.

Outlook: Nuclear will increase particularly in Asia and reaffirm its role in Europe and the United States

The Fukushima Daiichi Nuclear Power Station accident changed public perception about nuclear, and some construction expertise has been lost during the subsequent hiatus in new projects. Consequently, Japan, Europe and the United States now face greater challenges in constructing new nuclear reactors as originally planned. With existing reactors built in the 1970s or 1980s approaching closure, nuclear power generation may decline in many countries. Nevertheless, recognising nuclear's value as a competitive, low-carbon baseload power source that enhances energy security and provides valuable business assets for electric utilities, these countries will maintain a significant nuclear presence. Meanwhile, several countries including China are actively expanding their nuclear power generation capacity, and some nations may introduce nuclear for the first time. As a result, global installed nuclear power generation capacity will increase through 2050, reaching 534 GW (Figure 3-23).

Figure 3-23 | Installed nuclear power generation capacity [Reference Scenario]



The United States, still the world's largest user of nuclear energy with 94 reactors as of 2024, includes states where economic considerations have led to decisions for early closure of existing reactors. Market liberalisation has exposed nuclear to direct competition from natural gas-fired power generation and renewable power generation. As a result, the installed capacity will decrease by 2050. However, the United States will maintain its policy of treating nuclear as a strategic energy source. With both major political parties recognising nuclear's significance, substantial policy shifts are unlikely. Furthermore, due to rising demand for low-carbon, stable power sources, power purchase agreements are increasingly being concluded, either preventing closures for economic reasons or enabling plants to pursue restarts after closure. Against this backdrop, maintaining existing reactors and some new construction will continue, contingent upon favourable market conditions and investment climate.

In France, Europe's foremost nuclear advocate, the Energy Transition Law of July 2015 originally aimed to reduce nuclear's share of power generation to 50% (approximately 75% in 2015) by 2025. In view of its greenhouse gas (GHG) emission reduction goal, however, France concluded that it was difficult to attain this reduced target for nuclear, and the target year was later extended to 2035. In addition, the target itself was dropped by a law promulgated in June 2023. France announced plans in February 2022 to construct at least six new reactors (with the possibility of eight more) and has identified three construction sites (Penly, Gravelines and Bugey), which are all locations of existing reactors. Given these developments, the installed capacity in France will either be maintained at its current level or decline slightly for the time being. After 2035, decommissioning of ageing reactors will accelerate, continuing the overall downward trend. However, with initiatives underway to extend operational lifespans, utilities will optimise their nuclear–renewable balance and maintain nuclear power generation capacity where profitability permits.

In the United Kingdom, despite government support for nuclear, total installed power generation capacity will decline until the 2030s due to the decommissioning of older reactors. However, new construction plans aligned with the energy security strategy are in development, supported by measures to enhance the business environment, such as the Regulated Asset Base (RAB) model, which offers greater investment return certainty. If this supportive approach continues, the temporary decline in installed capacity will reverse, recovering to approximately current levels in the late 2030s, before increasing thereafter.

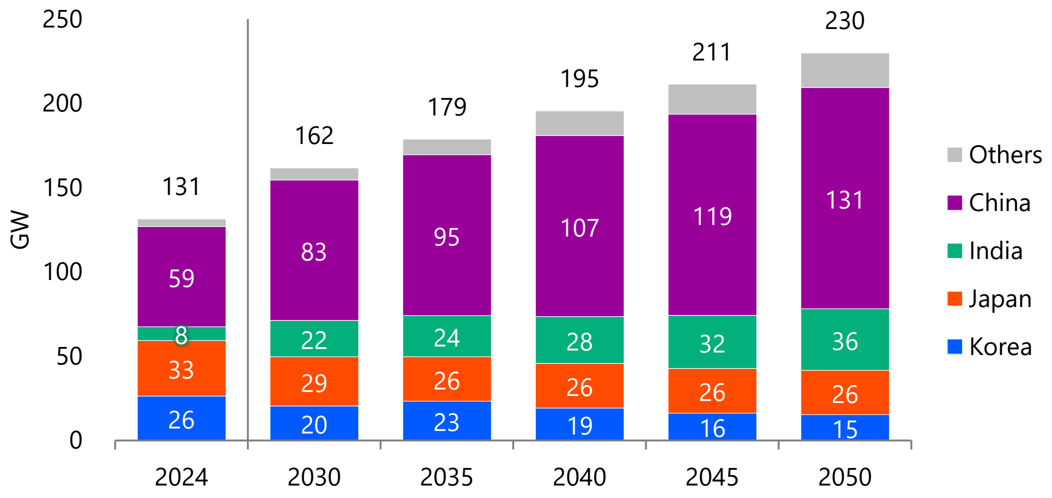
Switzerland has clearly established nuclear phase-out plans following the Fukushima Daiichi Nuclear Power Station accident and will cease nuclear power generation by 2035 under the government's decommissioning schedule. Belgium had originally planned to close all reactors by 2025, but following the reversal of its nuclear phase-out policy, it will maintain a certain number of reactors until 2050. Germany completed its nuclear phase-out in April 2023 with the closure of its last three reactors. The country is not expected to resume nuclear power generation under current circumstances. Other European OECD[9] countries will experience reduced installed capacity through 2050, despite some new construction initiatives, as economically unviable reactors are decommissioned.

Russia has committed to proactively utilise nuclear both domestically and internationally. Its domestic installed nuclear power generation capacity will increase to approximately 40 GW by 2035. Around 2030, Russia will overtake Japan as the world's fourth-largest nuclear power generation capacity holder. Given its aggressive reactor export strategy, Russia's influence in the global nuclear market will exceed that suggested by its domestic capacity alone. Beyond promoting its existing large light-water reactors, Russia has introduced the world's first floating nuclear power station and possesses a demonstration sodium-cooled fast reactor. Possessing such diverse technologies is important to enhance the infrastructure of the nuclear industry.

Asia, particularly China and India, will continue to increase its nuclear prominence. Emerging and developing economies in Asia, experiencing substantial economic growth, are highly motivated to deploy nuclear as a low-carbon, stable large-scale power source. China will expand its installed nuclear power generation capacity to 107 GW by 2040, surpassing the United States to become the world's largest nuclear user. Asia's total installed nuclear power generation capacity will exceed the combined capacity of OECD Europe and North America around 2040, reaching 230 GW by 2050. China and India together will account for more than 70% of this capacity (Figure 3-24).

[9] Organisation for Economic Co-operation and Development

Figure 3-24 | Asia's installed nuclear power generation capacity [Reference Scenario]



3.6 Hydrogen, etc

Hydrogen and low-carbon fuels made from hydrogen (such as ammonia, synthetic methane and synthetic fuels [e-fuels]) could be effective means of decarbonisation in hard-to-abate sectors including steel and chemicals, where alternative technologies such as electrification are limited, as well as in the transport sector and for fuel substitution in thermal power generation, which primarily serves as a balancing power source. In recent years, efforts have been made worldwide to set goals, provide policy support, and develop projects to expand hydrogen use.

Recently, there have been moves to cancel or postpone some projects on hydrogen, mainly due to difficulties in reducing costs, raising funds and securing markets (off-takers). While some view the movement towards hydrogen utilisation as stalling, support and legal frameworks are being developed, particularly in Europe, and the number of projects that have passed the final investment decision (FID) is steadily increasing. Therefore, the trend towards expanding hydrogen use appears set to continue. At present, projects that have secured economic viability and reliable off-takers, including government support, are proceeding. The question going forward is whether these challenges can be overcome through appropriate market design that accounts for policies and environmental values, alongside technological development and cost reduction.

Below is an overview of hydrogen support trends in each country. The European Union is increasingly promoting the use of renewable energy-derived hydrogen (green hydrogen) as part of its shift away from Russia since the Ukraine crisis. REPowerEU announced in March 2022 that it had set a target of supplying 10 Mt/year of renewable energy-derived hydrogen through domestic production and 10 Mt/year through imports by 2030. In addition, the European Union established the European Hydrogen Bank (EHB), a mechanism designed to support the intra-EU distribution and import of renewable-derived hydrogen. Following the first round of bidding, six projects signed grant agreements in October 2024, with a total expected support of 720 million euros. The second round of bidding closed in February 2025, with grant agreements expected to be signed by November 2025. In the United Kingdom, support for bridging the price gap between hydrogen and existing fuels (CfD support) has been promoted, with the total amount of CfD expected to be 2.3 billion pounds over 15 years. Round 1 was completed, with five contracts signed in October 2024. Completion of the Round 2 review and the start of Round 3 are planned for 2025. In July 2024, Germany announced the results of the first tender for H2Global[10], an international hydrogen and hydrogen-derived fuel procurement mechanism. Germany launched its second bidding round in February 2025.

The United States launched a 10-year tax credit for clean hydrogen production through the Inflation Reduction Act (IRA), which was passed in August 2022. In addition, with a $7 billion support scheme under the Bipartisan Infrastructure Law, the United States selected seven Regional Clean Hydrogen Hubs (H2Hubs) aiming to create a clean hydrogen network encompassing hydrogen production and use. However, since President Donald Trump took office, support for hydrogen has become more uncertain. Amendments to the Inflation Reduction Act (IRA) also show moves to scale back support, such as limiting hydrogen production tax credits to projects that begin construction before 2027, rather than before 2032. Future developments warrant close monitoring.

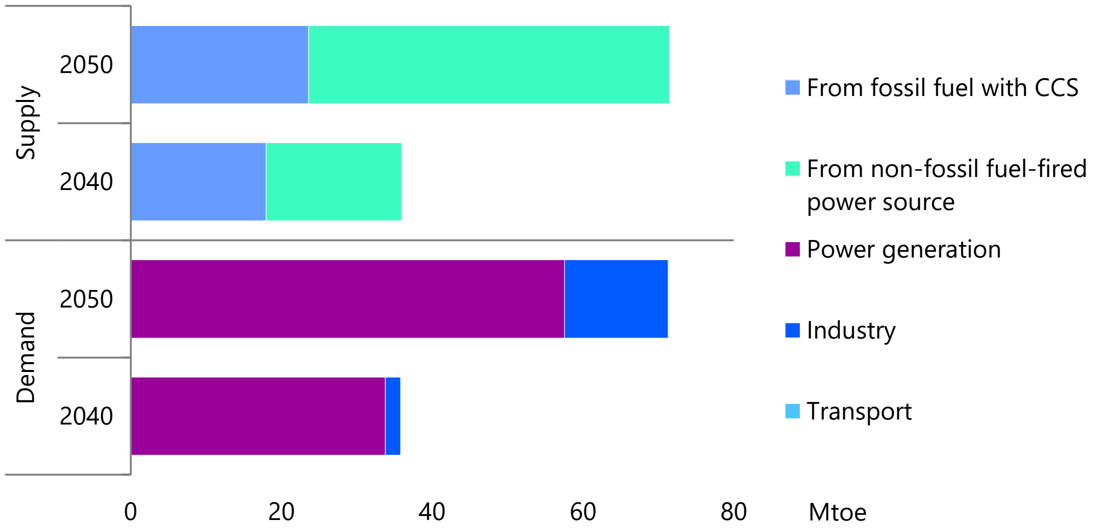
China has become the world's largest consumer of hydrogen. Its hydrogen production and consumption in 2024 were reported to be 36.5 Mt. China announced its 'Medium- and Long-Term Development Plan for the Hydrogen Energy Industry' in March 2022, with the goal of producing 100 kt/year–200 kt/year of renewables-derived hydrogen and holding 50 thousand fuel cell vehicles by 2025. As of 2025, green hydrogen production projects with a capacity of 20 kt/year have already begun operation, and sales of fuel cell vehicles, primarily commercial vehicles, are rapidly increasing (at a pace of more than 10 thousand units in two years), indicating that the social implementation of hydrogen is progressing rapidly. Korea has established the world's first hydrogen-fired power generation bidding system, aiming to expand the use of hydrogen- and ammonia-fired power generation.

In Japan, based on the Hydrogen Society Promotion Act enacted in May 2024, preparations are underway to provide price-differential support and hub development support for clean hydrogen and ammonia. Regarding price-differential support, 27 project applications have been submitted by the March 2025 deadline and are expected to be reviewed in fiscal 2025. In addition, in the long-term decarbonised power source auction, a total of 920 MW of ammonia and hydrogen co-firing has been won in the first and second rounds. Through this support, hydrogen and ammonia use is expected to expand.

In the Reference Scenario, it is assumed that the current trend of ammonia co-firing in power generation will expand at a similar pace. In this scenario, hydrogen use is expected to remain at a limited level in power generation, industry and parts of the transport sector. However, for hydrogen to be widely used across various sectors in the future, policy support, appropriate market design and technological development, including cost reduction, will need to advance further. These assumptions will be reflected in the Advanced Technologies Scenario.

[10] The winning bid was for the export of green ammonia produced in Egypt to the Netherlands, with a contract price of €1 000/t.

Figure 3-25 | Supply and demand of clean hydrogen [Reference Scenario]



3.7 Carbon capture and storage

Carbon capture and storage (CCS) is a technology that captures carbon dioxide (CO_2) from a variety of emission sources and stores it in underground formations. This technology has already been widely commercialised in the United States, Canada, Norway, Australia and others, and has attracted much attention in recent years as a technology that can greatly contribute to future decarbonisation. CCS does not simply capture CO_2 generated from fossil fuel use; it is also an essential enabling technology for so-called carbon dioxide removal technologies such as direct air capture and carbon storage (DACCS). CCS is thus indispensable for keeping atmospheric CO_2 concentrations stable over the long term.

Aiming to achieve net-zero emissions by mid-century, advanced economies are developing support systems for CCS. In the United States, companies implementing CCS previously received a tax credit of $20 per tonne of CO_2 captured and stored, but the Inflation Reduction Act enacted in 2022 increased this to $85/t. Subsequently, under the Donald Trump administration that took office in 2025, while decarbonisation policies introduced under the Biden administration were abolished or scaled back across the board, tax incentives for CCS have been maintained. Canada, Australia and others provide subsidies for initial CCS investments as well as emissions trading credits for the CO_2 captured and stored. In the United Kingdom, although no commercial CCS projects exist yet, four sites have been identified as potential hubs for the intensive implementation of CCS. To achieve this, a system has been introduced whereby the government compensates for the difference between CCS implementation costs and the emission credit price that would apply without CCS.

In this context, in June 2025, the Japanese government presented a proposed support framework for CCS commercialisation. As in the UK system, the government will cover the difference between CCS implementation costs and the emissions credit price, based on the annual average price of the emissions trading scheme (GX-ETS) scheduled for introduction from fiscal year 2026. Specific budgetary measures will be taken in due course, and the extent to which projects may qualify remains uncertain. However, it is expected to become a major driving force for CCS commercialisation in Japan. The government aims to commercialise domestic CCS projects by

FY2030, with a decision on support under this system expected as early as fiscal 2026. The CCS projects currently undergoing feasibility studies with government support in Japan comprise two types: those transporting captured CO_2 via pipeline to storage sites and those transporting it by ship (Table 3-7). However, this support framework applies only to pipeline-based projects. A framework for ship-based projects is expected to follow.

Table 3-7 | Selected advanced CCS projects

Storage location	Storage amount (kt/year, approximate)	Capture source	Major transport means
Tomakomai region, Japan (marine aquifers)	1 500–2 000	Refinery, thermal power plants in Tomakomai region	Pipeline
Tohoku region along the Sea of Japan, Japan (marine aquifers)	1 500–1 900	Steel mills, cement plants, local emitters	Ships
East Niigata region, Japan (existing oil and gas fields)	1 400	Chemical plants, paper mills, power plants	Pipeline
Capital region, Japan (marine aquifers)	1 400	Steel mills, etc.	Pipeline
Western Kyushu, Japan (marine aquifers)	1 700	Refineries, thermal power plants	Ships
North off the coast of the Malay Peninsula, Malaysia (depleted oil and gas fields)	3 000	Steel, chemicals, oil refining, etc.	Ships
Off the coast of Sarawak, Malaysia (offshore depleted oil and gas fields)	1 900–2 900	Steel mills, power plants, chemical plants, etc.	Ships
South off the coast of the Malay Peninsula, Malaysia (Offshore declining oil and gas fields, aquifers)	5 000	Power generation, chemicals, cement, oil refining, etc.	Ships
Oceania (Offshore declining oil and gas fields, aquifers)	2 000	Steel mills, etc.	Ships

Source: Ministry of Economy, Trade and Industry

Nine projects are currently undergoing feasibility studies in Japan, while in Europe and the United States, investment and construction are already underway for commercial CCS projects that have passed final investment decisions (FID) (Table 3-8).

Table 3-8 | Ongoing CCS business investment projects in Europe and the United States

Project	Country	Annual storage amount ($kt\text{-}CO_2$)	Start of operation
Longship	Norway	750	2025 (Under construction)
Aramis	Netherlands	Expanded to 22 000	2029 (FID scheduled for 2026)
Greensand	Denmark	Expanded to 400–8 000	2026 (FID completed)
Teesside	United Kingdom	Expanded to 4 000–23 000	2028 (FID completed)
Eastern Louisiana	United States	5 000	2028 (Under construction)
Yazoo	United States	500	2028 (Under construction)

Source: Created based on press releases from each company

In terms of storage scale, some of the larger projects are expected to store more than 10 Mt per year, and if realised, they would represent highly effective emission reduction measures. The Norwegian and Dutch projects envisage capturing and storing CO_2 from industrial emission sources, whereas the US project targets ammonia production and the UK project targets natural gas-fired power stations, indicating that a diverse range of capture sources is being considered.

Regarding CCS in the Reference Scenario, near-term implementation volume, up to around 2030, is based on projects already in operation or those for which investment decisions have been made and construction has begun. As CCS represents a purely additional cost for operators, its deployment will not progress without sufficient government support. Therefore, it is assumed that even after 2030, deployment will progress mainly in developed countries where CCS support systems are already in place.

CCS is anticipated to become more widespread in so-called ‘hard-to-abate sectors’, such as industries that generally require high-temperature heat and where emissions reduction through electrification is difficult. However, given the comparatively easier recovery of additional costs in the power generation sector, a certain level of deployment is also anticipated there. Therefore, it is assumed that CCS will be introduced not only in the industry sector but also in the power generation sector. Among the industry sectors, the steelmaking sector is expected to see increased adoption, as CO_2 can be captured intensively from blast furnaces. On the other hand, in the cement sector, factories are geographically dispersed, making it difficult to transport captured CO_2, while in the chemical sector, multiple emission sources exist. Therefore, adoption is expected to remain limited in these sectors.

4. Advanced Technologies Scenario

4.1 Major measures

In the Advanced Technologies Scenario, measures to maximise the reduction of carbon dioxide (CO_2) emissions and to ensure energy security will be enhanced with consideration given to their application opportunities and societal acceptability. Each country and region will actively implement aggressive energy efficiency and decarbonisation policies that contribute to securing a stable energy supply, enhancing climate change measures and accelerating the development and introduction of innovative technologies globally. Supported by the introduction of environmental regulations and national targets, by the enhancement of technological development and by the promotion of international technological cooperation, the demand side will actively diffuse energy efficient equipment and the supply side will further promote renewables, nuclear, hydrogen, and carbon capture and storage (CCS) (Table 4-1). Note that this outlook is a forecast-type analysis, calculated based on assumptions such as the introduction of technologies, not a backcast-type analysis, which first sets a future 'landing point' and then charts a path to get there.

Table 4-1 | Assumed technologies [Advanced Technologies Scenario]

2023 → 2050 (Reference, 2050)

	Advanced Economies	Emerging and Developing Economies
Thermal power generation	Developing an initial investment finance scheme	
	Installing CCS for new plants from 2030 (Countries with carbon storage potential excluding aquifers)	
[Natural gas-fired efficiency (stock basis)]	50.0% → 66.1% (54.5%)	37.8% → 51.8% (40.5%)
[Coal-fired efficiency (stock basis)]	36.8% → 43.9%[11] (41.2%)	33.3% → 38.5% (37.5%)
[IGCC share of newly installed plants]		0% → 60% (20%)
Nuclear power generation	Maintaining appropriate wholesale electricity prices	Developing an initial investment finance framework
[Installed capacity]	281 GW → 359 (245) GW	125 GW → 492 (289) GW

[11] In the Advanced Technologies Scenario for Advanced Economies, most coal-fired power plants to be introduced in the future will be accompanied by CCS, which will increase energy consumption for CCS, resulting in reduced efficiency from the current level.

2023 → 2050 (Reference, 2050)

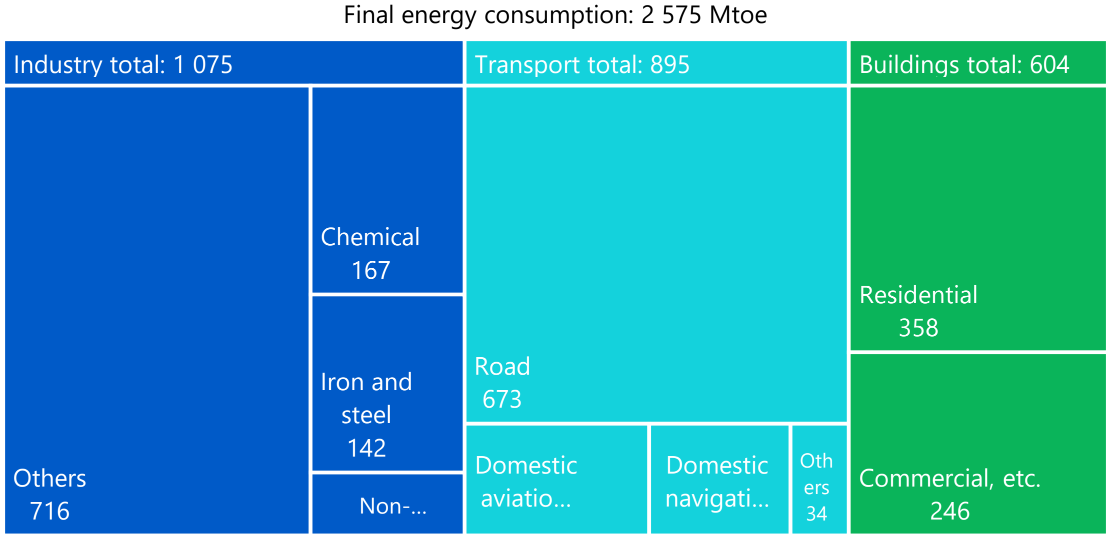
	Advanced Economies	Emerging and Developing Economies
Renewables power generation	System cost reduction	
	Grid stabilisation technology cost reduction	Low-cost finance
	Efficient grid operation	Advancing power systems
[Wind installed capacity]	421 GW → 1 807 (1 134) GW	541 GW → 3 277 (2 356) GW
[Solar photovoltaics installed capacity]	490 GW → 3 534 (2 996) GW	618 GW → 7 668 (6 789) GW
Biofuels for automobiles	Developing next-generation biofuels	Biofuel cost reduction
	Expanded use of flexible-fuel vehicles (FFVs)	Agricultural policy position
[Consumption]	69 Mtoe → 88 (65) Mtoe	43 Mtoe → 114 (92) Mtoe
Industry	100% penetration of the best available technology (BAT) in 2050	
Transport	Reducing fuel-efficient vehicle costs	
	Doubling zero-emission vehicle (ZEV) travel distances	
[New passenger car fuel efficiency]	19.0 km/L → 53.5 (37.7) km/L	16.6 km/L → 41.6 (26.7) km/L
[ZEV share of new passenger car sales]	9.0% → 94.0% (58.8%)	11.6% → 74.4% (36.8%)
Buildings	1.6 times faster improvement in appliance and equipment efficiency and insulation efficiency on a stock basis (approx. 22% improvement in 2050 relative to the Reference Scenario).	
	Electrifying space/water heating and cooking equipment, clean cooking	

Note: IGCC stands for integrated coal gasification combined cycle.

Energy efficiency

Final energy consumption in the Advanced Technologies Scenario will be 355 million tonnes of oil equivalent (Mtoe) or 3% less in 2030 and 2 575 Mtoe or 22% less in 2050 than in the Reference Scenario. These savings in 2050 are equivalent to 25% of final energy consumption in 2023. Of the energy savings, the industry sector will account for 1 075 Mtoe, the transport sector for 895 Mtoe, and the buildings sector for 604 Mtoe (Figure 4-1).

Figure 4-1 | Energy savings through technology development (compared with Reference Scenario) [Advanced Technologies Scenario, 2050]



The road sector will be responsible for 673 Mtoe in the transport sector and the residential sector for 358 Mtoe in the buildings sector. This is because vehicles and energy-consuming home appliances offer huge potential for improving energy efficiency. The Emerging and Developing Economies will capture more than 50% of the energy savings in all final energy consumption sectors, including the industry sector where they will account for over 80% of energy savings. Whether or not the Emerging and Developing Economies realise the potential energy savings is key to the progress of global energy savings.

By employing already available highly efficient technologies for steel, cement, chemicals, pulp and paper, and other energy-intensive industries, these sectors will improve their energy intensity in 2030 by several percentage points compared with the Reference Scenario (Table 4-2). Furthermore, by accelerating the adoption of highly efficient technologies, energy intensity will improve by more than 20% by 2050. Through these energy intensity improvements, the industry sector in Emerging and Developing Economies will reduce energy consumption by 872 Mtoe compared with the Reference Scenario. Asia, where raw materials industries account for a large share of production, will contribute to about 80% of the global energy savings. These technologies will contribute significantly to improving energy efficiency in Emerging and Developing Economies. The global development and proactive dissemination of energy efficiency improvement technologies, particularly in Emerging and Developing Economies, are therefore essential.

Table 4-2 | World energy indicators

		2023	Reference 2030	Reference 2050	Advanced Technologies 2030	Advanced Technologies 2050
Industry	Intensity (2023=100)					
	Iron and steel	100	100.4	97.9	96.7	74.3
	Non-metallic minerals	100	93.8	77.5	92.0	67.5
	Chemical	100	98.2	66.9	91.0	42.3
	Paper and pulp	100	95.9	88.0	92.5	69.6
	Others	100	98.4	75.5	94.1	50.5
Transport	New passenger vehicle fuel efficiency (km/L)	19.7	22.4	37.7	30.4	53.5
	ZEV's share of new vehicle sales	8.4%	15%	56%	44%	92%
	Natural gas's share in intl. marine bunkers	0.4%	3.7%	22%	5.9%	40%
	Biofuel's share of intl. aviation bunkers	0.1%	1.5%	5.2%	4.5%	42%
Buildings	Overall energy efficiency (2023 = 100)					
	Residential	100	90.7	66.9	88.1	55.2
	Commercial	100	99.0	64.3	97.8	52.3
	Electrification rate					
	Residential	29%	32%	47%	34%	55%
	Commercial	55%	58%	70%	59%	77%

Note: Energy intensity is energy consumption per unit of production, and overall energy efficiency is energy consumption per energy service.

In the transport sector, fuel efficiency and vehicle fleet mix changes make further progress. By type of vehicle, in addition to hybrid vehicles, electric vehicles (EVs), plug-in hybrid vehicles (PHEVs) and fuel cell vehicles will diffuse further. These zero-emission vehicles (ZEVs) will increase their share of new vehicle sales by 29 percentage points in 2030 and 36 percentage points in 2050 compared with the Reference Scenario. Due to changes in vehicle fleet composition and fuel efficiency improvements, the global average new vehicle fuel efficiency in 2050 will improve by 15.7 km/L from the Reference Scenario to 53.5 km/L (1.9 L/100 km). The transport sector will see the largest energy savings among sectors in the Advanced Economies as the share of ZEVs in those economies increases faster than in Emerging and Developing Economies. International bunkers will make progress in energy conservation through technological innovation and operational improvements. At the same time, given the significant potential for fuel switching, natural gas will account for 5.9% of international marine bunkers in 2030 and 40% in 2050. In international aviation, biofuel will comprise 4.5% of fuel use in 2030 and 42% in 2050.

It is more challenging for energy conservation incentives to work in the buildings sector than in the industry sector, where economic considerations drive energy conservation awareness. Consequently, the buildings sector presents significant potential for reducing energy consumption. The overall global residential energy efficiency will improve by 3% in 2030 and by 17% in 2050 compared with the Reference Scenario. Similarly, the overall efficiency of the commercial sector will improve by 1% in 2030 and 19% in 2050. Energy efficiency improvements for space and water heating systems in cold regions and enhanced insulation in Emerging and Developing Economies will contribute substantially to energy savings. Since city gas, liquefied petroleum gas (LPG), kerosene and other fuels are used for water and space heating in various ways depending on national conditions, fuel consumption for these applications will be greatly reduced. Traditional biomass use, including inefficient fuelwood and manure, will see the greatest reduction through increased electrification and the adoption of modern cooking equipment in rural areas. Electricity consumption will decline substantially as energy efficiency improvements across various applications such as space cooling, power, and lighting more than offset the impact of appliance electrification.

Renewable energies

In the Advanced Technologies Scenario, variable renewables such as wind and solar photovoltaics will be introduced at a faster pace. The share of variable renewables in total global electricity generated will expand from 13.1% in 2023 to 51.9% in 2050.

If the share of variable renewables increases to this level, challenges in power system operations are likely to emerge in some countries and regions. For example, challenges attributable to the time variability of wind and solar photovoltaic power generation include rapid output fluctuations (frequency fluctuations), surplus electricity, and extreme generation shortfalls during cloudy or windless periods that occur once or twice a year. One of the challenges regarding the uneven spatial distribution is power transmission capacity shortages. Other challenges include a decrease in grid inertia accompanying an increase in asynchronous power sources[12], as well as the negative impacts on the natural environment, ecosystems and economic activities around renewable power source locations. Such impacts include adverse effects of large-scale solar photovoltaic facilities on forest development, those of onshore wind power facilities on birds, and the increasingly severe impact of offshore wind power generation on fishing.

Considering these challenges, technological, institutional, and political measures will be required to integrate variable renewable power sources into the electricity system. The Advanced Technologies Scenario assumes progress in the commercialisation of technologies for integrating variable renewable power sources into the electricity system, policy support for their implementation in society, growing environmental awareness among business operators, investors and consumers, and improved social acceptance of electricity infrastructure construction. Technologies supporting the spread of variable renewables will include power generation prediction, output control, energy storage (mainly pumped storage hydro and batteries), output adjustments by backup power sources, power supply adjustments using EVs, grid enhancement, and interregional power supply and smart grid systems combining these with information and communication technologies. For these technologies to diffuse, policies and legal systems to promote the harmony of power sources with the environment and the regional acceptance of renewables will be required to support their sustainable deployment.

Installed capacity for onshore and offshore wind power generation will increase in all regions faster than in the Reference Scenario, reaching 2 230 GW in 2030 and 5 080 GW in 2050 (Figure 4-2). Onshore wind power generation will expand remarkably in China and India as enhanced power transmission infrastructure and cost reduction for energy storage technologies ease the spatial and temporal unevenness of wind resource distribution. Offshore wind power generation will increase in China, Chinese Taipei, and Japan, as well as in Europe, which has so far led the world in offshore power generation. In particular, the increase in China will be significant. In addition to continuous technological development and cost-cutting efforts, policy support for wind power generation—including enhanced economic assistance, national institution-building efforts for ocean development, and smoother development processes based on better understanding with fishery business operators and other traditional ocean users—will help the diffusion of offshore wind power generation in these regions. China will retain the largest share of global onshore and offshore wind power generation capacity, remaining a major wind power generation market. China will account for 45% of the world's installed capacity in 2030 and 50%

[12] Synchronous power sources with rotation energy have the inertial power of rotating turbines, as well as a synchronising power that leads turbines to rotate at the same speed, contributing to stabilising the power grid. They include thermal, hydro and nuclear power generation. In contrast, asynchronous (inverter) power sources have no such function, including solar photovoltaic and wind power generation.

in 2050. Overcoming location and grid constraints through advanced technologies will contribute to further expansion of wind power generation in Europe, the United States, India, and elsewhere but also in China. As a result, China's presence in 2050 will not differ significantly from the Reference Scenario.

Figure 4-2 | Global installed wind power generation capacity [Advanced Technologies Scenario]

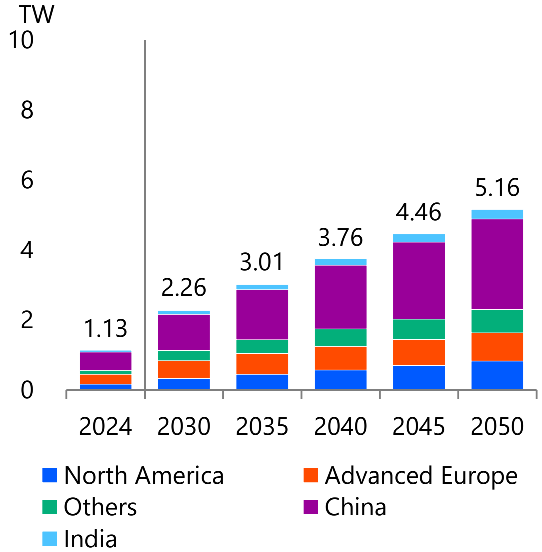
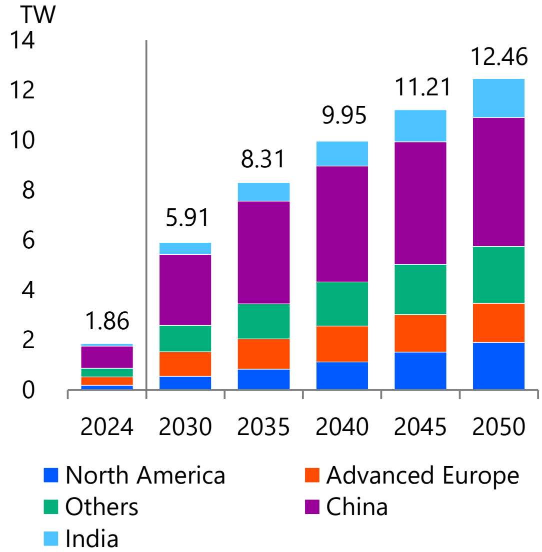


Figure 4-3 | Global installed solar photovoltaic power generation capacity [Advanced Technologies Scenario]



Solar photovoltaic power generation is also being introduced ambitiously, with global installed capacity reaching 5 850 GW in 2030 and 12 460 GW in 2050 (Figure 4-3). As a result of technological advances, which have, to a certain extent, overcome grid constraints and the effects of variable power sources on grid stability, as well as location constraints, wind and solar photovoltaics will increase by 1.5 times and 1.3 times, respectively, in 2050, compared with the Reference Scenario. While the current major solar photovoltaic power generation markets are dominated by China, Europe and the United States, India's presence will grow as a solar photovoltaic power generator due to falling costs for solar panels and storage batteries. Furthermore, the growth of solar photovoltaic power generation will accelerate in the Sun Belt, which has abundant sunlight resources, including the Middle East, Africa, and Latin America. In the Advanced Technologies Scenario, while solar photovoltaics show a 1.3-fold increase compared with the Reference Scenario in Europe, there is a 1.5-fold increase in India and a 1.4-fold increase in countries and regions other than China, North America and Europe (i.e. Middle East, Africa, Latin America, etc.), with no significant differences among them. This suggests that technological advances could make solar photovoltaic markets even more promising in countries and regions that are not currently major markets. As mentioned in the Reference Scenario, in the United States, the introduction of renewable energies such as wind and solar photovoltaics is expected to slow down due to policy changes under the second administration of Donald Trump, which was inaugurated in January 2025.

Meanwhile, initiatives towards a carbon-neutral society will continue to progress globally, and the current surge in electricity demand in the artificial intelligence (AI) industry could dramatically change the electricity supply and demand situation. Looking towards the middle of this century, it remains crucial to select technologies aligned with the large-scale introduction of variable renewables, as envisaged in the Advanced Technologies Scenario.

In addition to using lithium-ion and sodium-sulphur (NAS) batteries to store electricity for several hours, technologies to store electricity for a far longer time may be required to respond to weekly, monthly and seasonal fluctuations in output from variable renewable power sources. Recent market trends indicate that batteries utilising lithium iron phosphate (LFP), which offer greater safety and longer-term usability than lithium-ion batteries, are becoming increasingly mainstream. Since they do not use nickel or cobalt, reductions in procurement costs are also expected. Meanwhile, long-term storage technologies include redox flow batteries and hydrogen. Redox flow batteries, whose output and storage capacities can be designed separately, may be able to store massive amounts of electricity for a long time by increasing the amount of electrolytic solution. Regarding hydrogen, capacities for water electrolysis, hydrogen storage and hydrogen-fired power generation technologies can be chosen separately. Energy storage technology is also expected to be used to provide ancillary services such as power system frequency regulation. Storage batteries have already entered the ancillary services market in Europe and the United States. Water electrolysis technology is also being tested, mainly in Europe, aiming at the institutional design for practical use in ancillary services. Energy storage should be pursued to achieve optimal combinations, by comprehensively considering and combining the characteristics of each technology, such as technical features, economy, safety and economic security, including the procurement of mineral resources as raw materials such as lithium, nickel, cobalt, vanadium and platinum.

Nuclear

Nuclear power generation is useful for multiple policy objectives including climate change mitigation, air pollution control, and energy security. Nuclear power generation in the Advanced Technologies Scenario will therefore expand more than in the Reference Scenario. Obstacles to the introduction of traditional large light-water reactors will be reduced through the accumulation of know-how and more efficient construction. Additionally, advanced reactor types, such as small module reactors (SMRs) and Generation IV reactors, which have been actively developed in recent years, will also benefit from strong policy measures supporting their commercialisation. Despite decades of development, these advanced reactors have yet to be put into practical use on a commercial scale; however, in recent years, specific potential users in the United States, Europe and other countries are moving forward with introducing them, with many countries around the world expressing interest. Consequently, the future deployment of these advanced reactors will depend on whether planned or current demonstration reactor projects sufficiently satisfy the requirements of potential users worldwide.

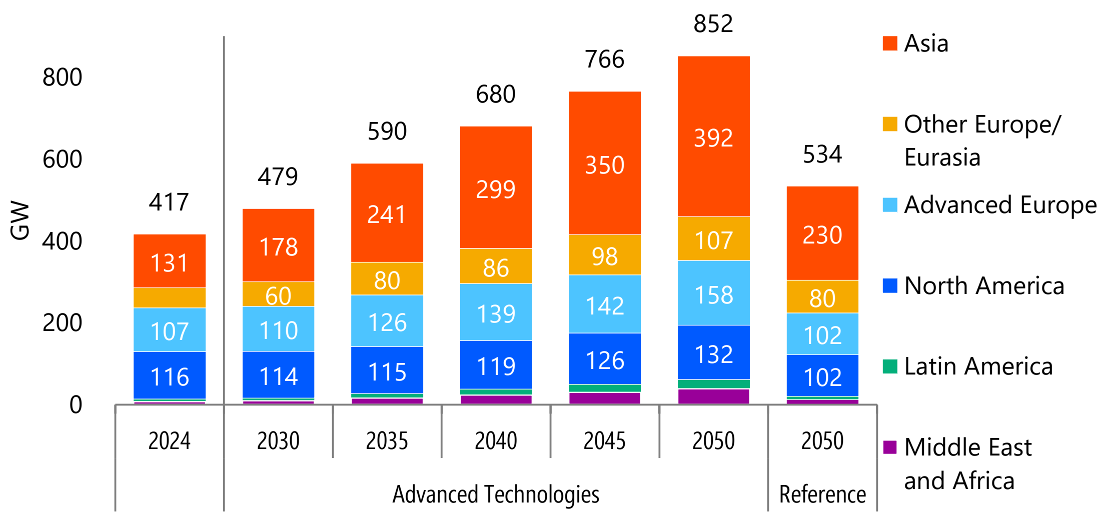
Efforts in non-power sectors will also be important for substantial decarbonisation throughout society. As a result, nuclear technology is expected to be used not only for power generation but also for multiple other purposes such as district and industrial heat supply, hydrogen production, and seawater desalination. However, nuclear is currently used primarily as a baseload power source, and this will not change even in 2050, as large amounts of energy demand will continue to be electrified. The effective use of surplus electricity and heat will be considered only after nuclear's primary role of supplying electricity is fulfilled.

Among countries that have proactively promoted nuclear power generation, the United States and France will see their nuclear power generation capacity decline towards 2050 in the Reference Scenario as most existing reactors become outdated. In the Advanced Technologies Scenario where climate change measures will be implemented more powerfully, more new nuclear power plant construction projects than in the Reference Scenario will be realised to narrow the reduction in France while the projects will even increase in the United States. In the United Kingdom, even in the Reference Scenario, new nuclear power generation capacity exceeding its current level will be added by 2050, but in the Advanced Technologies Scenario, new construction will be even greater. Some of the countries that announced nuclear phase-out policies following the Fukushima Daiichi Nuclear Power Station accident will change those policies and postpone closure of their nuclear power plants, or replace decommissioned capacity, to promote decarbonisation and maintain their industrial competitiveness.

Not only Advanced Economies that have announced ambitious decarbonisation initiatives, but also some Emerging and Developing Economies will expand nuclear power generation to promote decarbonisation and meet their rapidly growing electricity demand. While the basic motive for introducing nuclear is to acquire large stable power sources to meet energy demand, Emerging and Developing Economies with remote territories such as islands are expected to introduce small nuclear reactors for small grids in these areas.

In the Advanced Technologies Scenario under these assumptions, global installed nuclear power generation capacity will increase from 417 GW in 2024 to 852 GW in 2050 (Figure 4-4). This is equivalent to approximately 1.6 times the amount of 534 GW in the Reference Scenario.

Figure 4-4 | Installed nuclear power generation capacity [Advanced Technologies Scenario]



In North America, installed capacity will decline slightly from 2025 to 2030, but will increase to around 132 GW in 2050, through long-term operation of existing reactors and construction of new reactors. In the United States, both Democratic and Republican administrations have shown a commitment to nuclear, and policies have been implemented by the federal government and some state governments to support new construction and maintenance of existing reactors. In the Advanced Technologies Scenario, it is assumed that these policies will be maximally successful; thus, installed capacity will remain above that of the Reference Scenario. In addition, information and communication technology (ICT) companies that own data centres are expected to more actively secure nuclear-derived electricity and invest in development of advanced reactors. However, the impact of SMRs on those countries' total installed capacity will be limited due to the small capacity per unit.

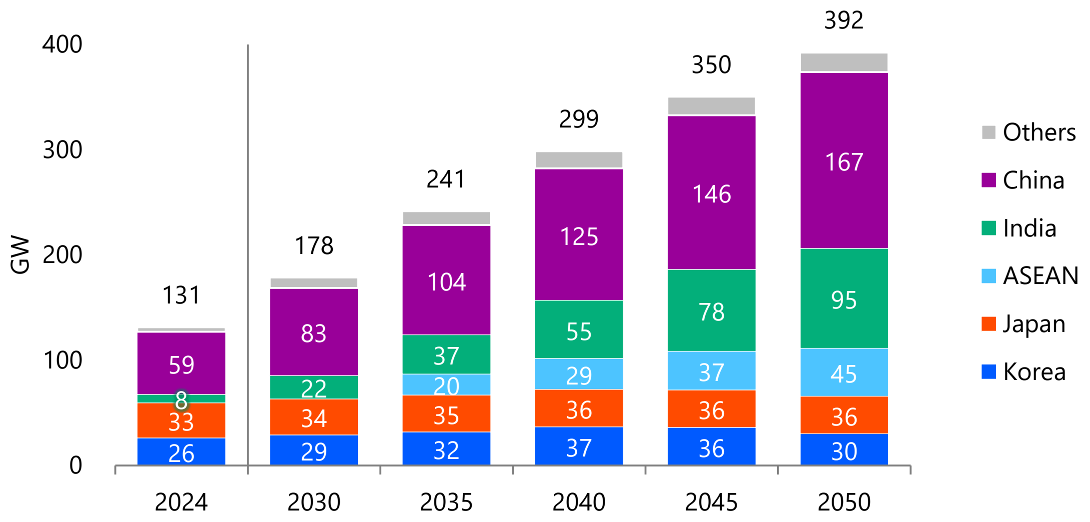
In Advanced Europe, countries aiming at ambitious targets for reducing greenhouse gas (GHG) emissions will politically promote the construction of additional nuclear power plants and the replacement of outdated reactors. As a result, installed nuclear power generation capacity will expand from 107 GW in 2024 to 158 GW in 2050. In France, the largest nuclear user in Europe, installed nuclear power generation capacity will decline more slowly than in the Reference Scenario through 2050, as the number of nuclear power plant construction projects increases. The construction of state-of-the-art large light-water reactors will be further promoted in the United Kingdom, and by 2050 the maximum target set by the Energy Security Strategy, 24 GW cumulatively (including existing plants), will be realised. In Western countries, the construction of large-scale light-water (Generation III+) reactors has been substantially delayed due to the loss of construction know-how for new reactors and design modifications after construction starts. These problems will be corrected for future nuclear power plant construction projects to reduce the risks related to new plant construction and improve the investment climate for operators. This will drive the expansion of nuclear power generation capacity.

Russia will accelerate construction of new nuclear power plants, continuing to expand its installed capacity from 29 GW in 2024 to 54 GW in 2050. Furthermore, Russian exports will actively proceed against the backdrop of economic growth and growing energy demand in Emerging and Developing Economies. Russia has already been promoting cooperative relations with many Emerging and Developing Economies to help them develop nuclear and other industrial infrastructure, as well as human resources, paving the way for exporting its nuclear power plants in the future.

The Middle East, Africa and Latin America, known as emerging nuclear energy markets, will commence operation of new reactors from around 2030 and steadily expand installed nuclear power generation capacity thereafter. As of 2024, the total installed capacity in these regions is approximately 14 GW but is projected to reach 62 GW by 2050.

As in the Reference Scenario, Asia will have the world's largest installed nuclear power generation capacity in 2050 in the Advanced Technologies Scenario. Asia's installed capacity will exceed the total combined capacity of OECD Europe and North America around 2035 and reach 392 GW in 2050 (Figure 4-5). The increase will be driven by China and India, as in the Reference Scenario. In addition, Southeast Asian countries, now just planning to introduce nuclear power generation, will also make progress in introducing nuclear capacity as they require stable and economically efficient low-carbon power sources to meet their growing power demand. As many of these countries need to achieve stable electricity supply on their islands, the introduction of SMRs or floating nuclear reactors is being considered. With this background, the Association of Southeast Asian Nations (ASEAN)'s installed capacity, though zero as of 2024, will reach 45 GW in 2050 as commercial nuclear power generation starts after 2030. That figure will exceed Japan's installed capacity of 36 GW at that year.

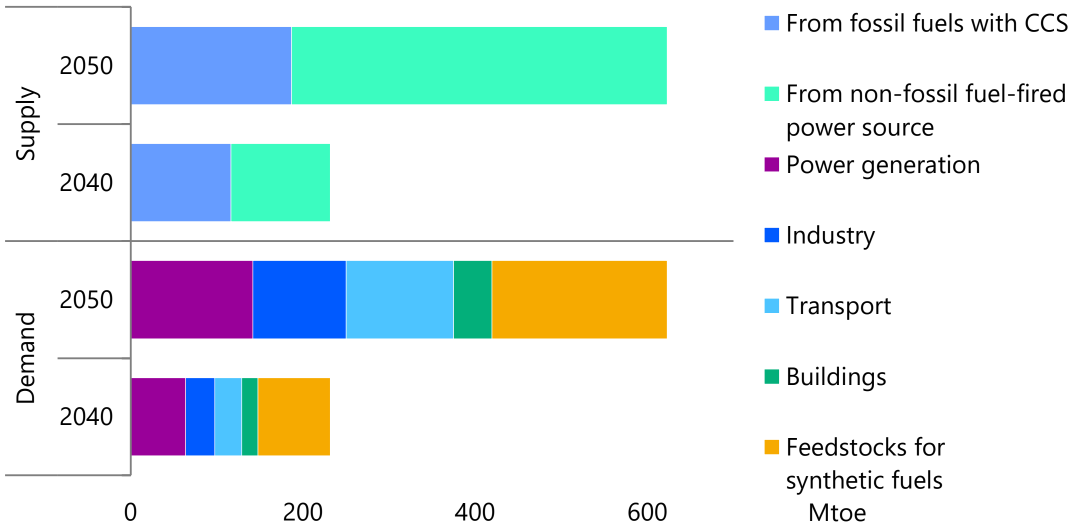
Figure 4-5 | Asia's installed nuclear power generation capacity [Advanced Technologies Scenario]



Hydrogen, etc.

In the Advanced Technologies Scenario, it is assumed that policy support, appropriate market design and technological development will progress steadily, with hydrogen and other technologies being used effectively as a means of decarbonisation. Specific uses of hydrogen include the power generation sector, the industry sector, the transport sector, and the buildings sector, encompassing its use as synthetic methane (e-methane) and synthetic fuels (e-fuels) (Figure 4-6). Uses of hydrogen and other technologies in each sector are described below.

Figure 4-6 | Supply and demand for clean hydrogen [Advanced Technologies Scenario]



In the power generation sector, the total amount of thermal power generation will decrease due to the expansion of renewable energy; however, remaining thermal power generation will be decarbonised by adding CCS or using fuels such as hydrogen. These power sources will provide adjustment capacity and contribute to CO_2 reduction in countries and regions with relatively little renewable energy potential. In the transport sector, hydrogen is currently used mainly in fuel cell passenger vehicles; however, over time, its primary application will shift to commercial vehicles such as buses and trucks that have high annual mileage and present electrification challenges. Hydrogen and hydrogen-derived products including ammonia, synthetic methanol (e-methanol), and synthetic kerosene (e-kerosene) will serve as critical options for decarbonising shipping and aviation. Another application of hydrogen and hydrogen-derived low-carbon fuels will be in the industrial sector, especially for high-temperature heat demand, where electrification is difficult. In some regions, synthetic methane will increasingly replace part of the current natural gas demand. Regarding steelmaking, which accounts for a relatively large share of CO_2 emissions, current hydrogen-based technologies, such as blast furnace reduction and direct reduction using hydrogen, are still at the demonstration stage, but their introduction will proceed in 2050 as an important means of decarbonisation. In the buildings sector, hydrogen will be used only to a limited extent as an alternative to current fossil fuels. It will be introduced in areas where it is relatively easy to develop distribution infrastructure such as hydrogen pipelines and piping. Furthermore, as in the industry sector, some of the natural gas demand will be replaced by synthetic methane.

For hydrogen production, fossil fuel-derived hydrogen with CCS (blue hydrogen) will advance in the short term in light of its price competitiveness. However, future cost reductions in renewable power generation and water electrolysis systems will enhance hydrogen derived from non-fossil power sources such as renewable energy (green hydrogen). By 2050, green hydrogen will account for approximately 70% of clean hydrogen supply. Other promising sources of clean hydrogen production and supply will include countries or regions with abundant renewable energy resources such as Latin America, Australia and Africa, in addition to traditional energy-producing areas such as the Middle East and North America. The main destinations for clean hydrogen and low-carbon fuels will include Europe, North America, East Asia and India.

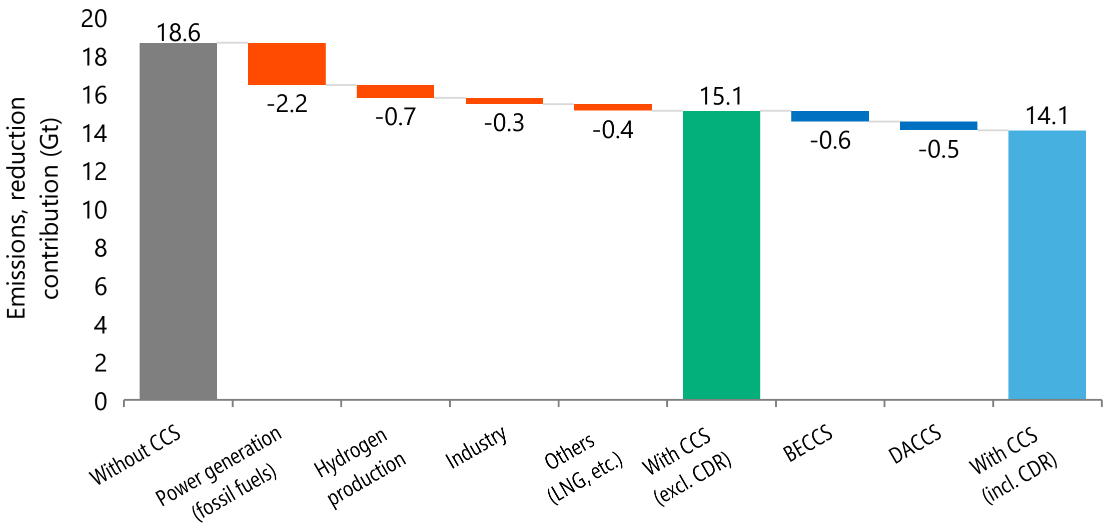
The Advanced Technologies Scenario assumes the establishment of a supply chain capable of importing and exporting hydrogen. For long-distance hydrogen transport by ship, hydrogen needs to be converted into a hydrogen carrier. As large-scale capital investment and additional energy inputs are required, it is desirable for hydrogen production and demand to be geographically close to each other. However, for countries or regions such as Europe, Japan and Korea, where demand for hydrogen is large, but the supply potential of inexpensive clean hydrogen seems limited, long-distance transport of hydrogen from abroad will be necessary. To establish an economical international supply chain, it is necessary to significantly reduce the cost of hydrogen carriers, such as liquefied hydrogen, methylcyclohexane (MCH), ammonia, synthetic methane and synthetic fuels.

Carbon capture and storage

As stated in Section 3.7, CCS is expected to play a major role in sectors where decarbonisation through electrification is difficult, as the world moves towards decarbonisation. In the Reference Scenario, we assumed that CCS would be increasingly introduced primarily in advanced economies where policy support systems are already in place. However, in the Advanced Technologies Scenario, we envisioned a picture where CCS would be introduced to the maximum extent possible, including in emerging economies where CCS can be implemented relatively inexpensively.

First, in the power generation sector in Advanced Economies, CCS is expected to be applied to all newly built coal- and liquefied natural gas (LNG)-fired power plants that are not expecting ammonia or hydrogen co-firing, while in Emerging and Developing Economies, CCS is expected to be increasingly applied to thermal power plants in China, India, Southeast Asia, the Middle East and other regions where CO_2 storage reservoirs and companies capable of implementing CCS exist. In the industry sector, also in Advanced Economies and some Emerging and Developing Economies, CCS is assumed to be actively applied in the steel, cement and chemical sectors where electrification is difficult. Furthermore, in the fossil fuel production sector, it was assumed that all new LNG projects will be equipped with facilities to capture and store the CO_2 generated during production.

Figure 4-7 | Amount of CCS implemented [Advanced Technologies Scenario, 2050]

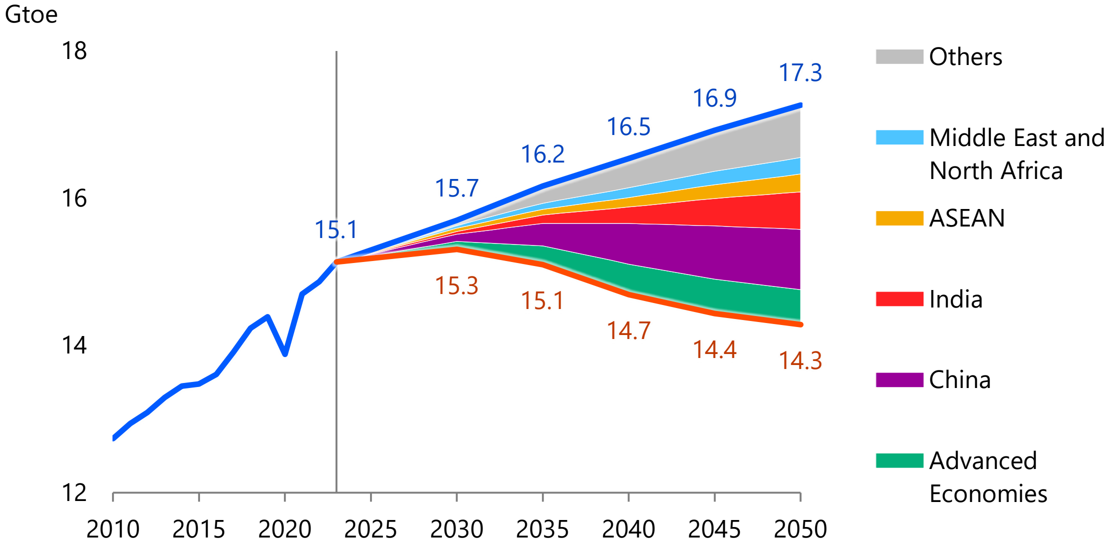


4.2 Energy supply and demand

Even in the Advanced Technologies Scenario, the world will fall far short of reaching carbon neutrality in 2050. All means should be mobilised to further promote energy efficiency improvements and climate change countermeasures.

The Advanced Technologies Scenario assumes higher improvements in the energy efficiency and climate change countermeasures. Primary energy consumption will increase until 2030, partly due to increased power demand in data centres and the time required to replace energy-saving equipment and technologies (Figure 4-8). However, it will begin to decline after 2030 as energy-saving equipment becomes more widely used. In 2035, primary energy consumption in the Advanced Technologies Scenario will be 1 065 million tonnes of oil equivalent (Mtoe) lower (−6.6%) than in the Reference Scenario but will remain nearly flat compared with 2023 at −36 Mtoe (−0.2%). Although the pace of decline will gradually slow after 2040 due to energy demand increases in carbon capture and storage (CCS), the decline will continue until 2050, resulting in a reduction in primary energy consumption of 2 984 Mtoe (20.1%) compared with the Reference Scenario. Cumulative energy savings by 2050 will be 38.3 Gtoe due to progress in energy efficiency improvement. Emerging and Developing Economies such as India, the Association of Southeast Asian Nations (ASEAN), and the Middle East and North Africa (MENA) will play a crucial role in realising the Advanced Technologies Scenario, as they have significant potential to save energy and expand the use of non-fossil energy sources.

Figure 4-8 | Global primary energy consumption and energy savings (relative to Reference Scenario) [Advanced Technologies Scenario]

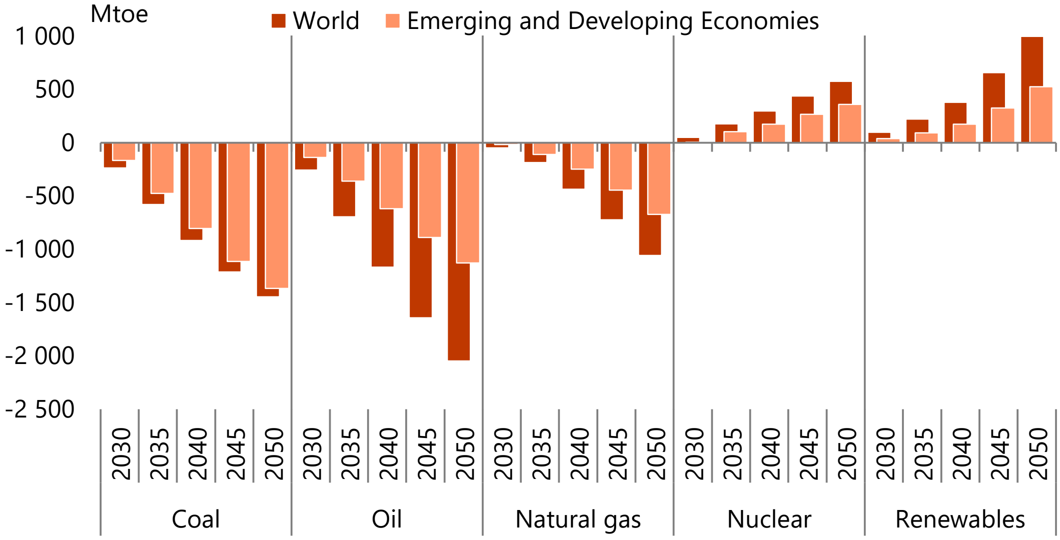


Emerging and Developing Economies will account for 80% of global energy savings in the Advanced Technologies Scenario in 2050. In particular, India, ASEAN and MENA will account for a combined share of 33%. Extraordinary efforts to boost energy efficiency and decarbonisation will be key to global energy security and climate change countermeasures.

By energy source, fossil fuels will decrease by only 4.6 Gtoe (37%) in 2050 compared with the Reference Scenario, with a cumulative reduction of 54.2 Gtoe (Figure 4-9), partly because fuel switching will also progress. Coal for power generation is being replaced in Emerging and Developing Economies, with these economies accounting for 80% in 2035 and 90% in 2050. Led by the spread of electrified vehicles, oil consumption will decrease by 0.7 Gtoe in 2035 and by 2.0 Gtoe in 2050, achieving the highest energy savings. Natural gas consumption will decline by only 0.2 Gtoe in 2035 and 1.1 Gtoe in 2050. The small saving in natural gas consumption in 2050, however, might partly result from increased use of feedstock for hydrogen production. Non-fossil energy consumption will increase by 0.4 Gtoe in 2035 and by 1.6 Gtoe in 2050. Nuclear and renewable energy consumption will rise by 59% and 26%, respectively, from the Reference Scenario in 2050. Even in the Advanced Technologies Scenario featuring strong growth in non-fossil energy consumption, the world will not be able to maintain or improve economic, social and living conditions without fossil fuels.

Realisation of the Advanced Technologies Scenario is challenging. Emerging and Developing Economies will account for 95% of the coal consumption savings in 2050, with India, ASEAN and MENA accounting for a combined 41%. Emerging and Developing Economies will account for 62% and 53% of the growth of nuclear and renewables, respectively, with India, ASEAN and MENA accounting for 31% and 25%, respectively. The Advanced Technologies Scenario thus requires Emerging and Developing Economies to achieve such reductions in coal consumption and growth in nuclear and renewables consumption within less than 30 years. During the process of realising the Advanced Technologies Scenario, the Emerging and Developing Economies will need to implement their energy transition far faster than the Advanced Economies did in the past.

Figure 4-9 | Primary energy consumption changes (relative to Reference Scenario) [Advanced Technologies Scenario]

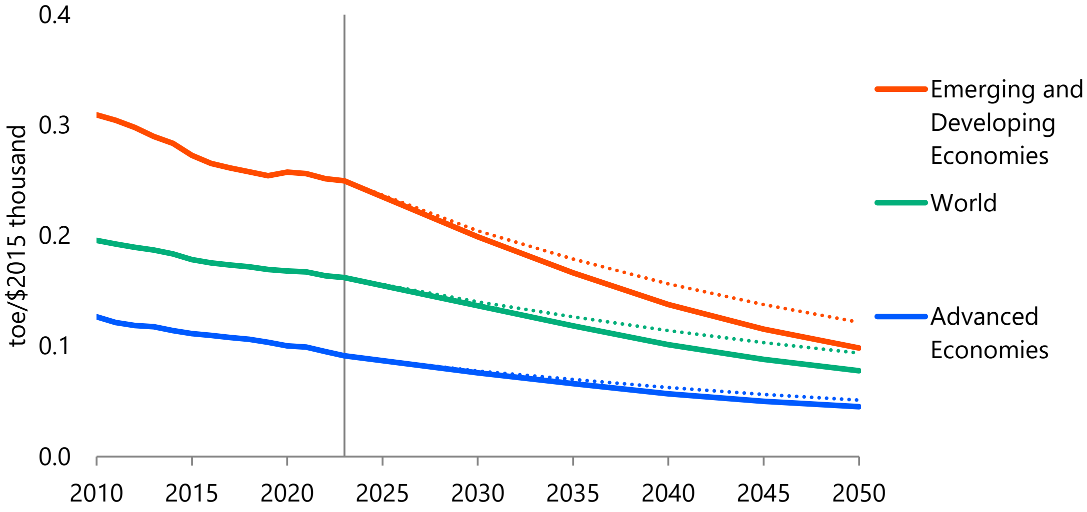


For the world to achieve the 1.5°C target, an average annual improvement in energy efficiency of more than 4% is necessary by 2030. However, in the Advanced Technologies Scenario, energy intensity per unit of gross domestic product (GDP) declines by an average of 2.6% per year in Advanced Economies and 3.2% in Emerging and Developing Economies from 2023 to 2030, which are not sufficient (Figure 4-10). In 2050, the Advanced Economies will post a decline of 55% in energy intensity from 2023 to 2050, compared with a fall of 62% for the Emerging and Developing Economies which have greater potential to improve energy efficiency. The global energy intensity per unit of GDP will have to decrease by 78% from 2023 if the global energy consumption of 6.7 Gtoe in 2050 in the Advanced Technologies Scenario is covered by only nuclear, renewables and fossil fuels for blue hydrogen[13] to achieve carbon neutrality. The decrease would be far steeper than the declines in the Emerging and Developing Economies and in China, demonstrating the considerable difficulty of achieving global carbon neutrality by 2050.

If the Advanced Technologies Scenario is realised and further carbon dioxide (CO_2) emission reductions are made, both the Advanced Economies and the Emerging and Developing Economies will need to improve energy efficiency at a high pace and promote the decarbonisation of energy sources. This will require Advanced Economies to develop energy efficiency technologies, transfer them to Emerging and Developing Economies, enhance international fundraising capabilities, and eliminate barriers to energy savings, including insufficient awareness. Each country will need to adopt appropriate energy conservation and decarbonisation approaches tailored to urban and rural areas, while introducing incentives for energy-efficient appliances accessible to low-income households focused on day-to-day survival. Improving national and regional education programmes will also be essential to raise long-term awareness of energy efficiency.

[13] Hydrogen produced by decomposing fossil fuels and capturing carbon dioxide emitted in the process

Figure 4-10 | Primary energy intensity per GDP [Advanced Technologies Scenario]



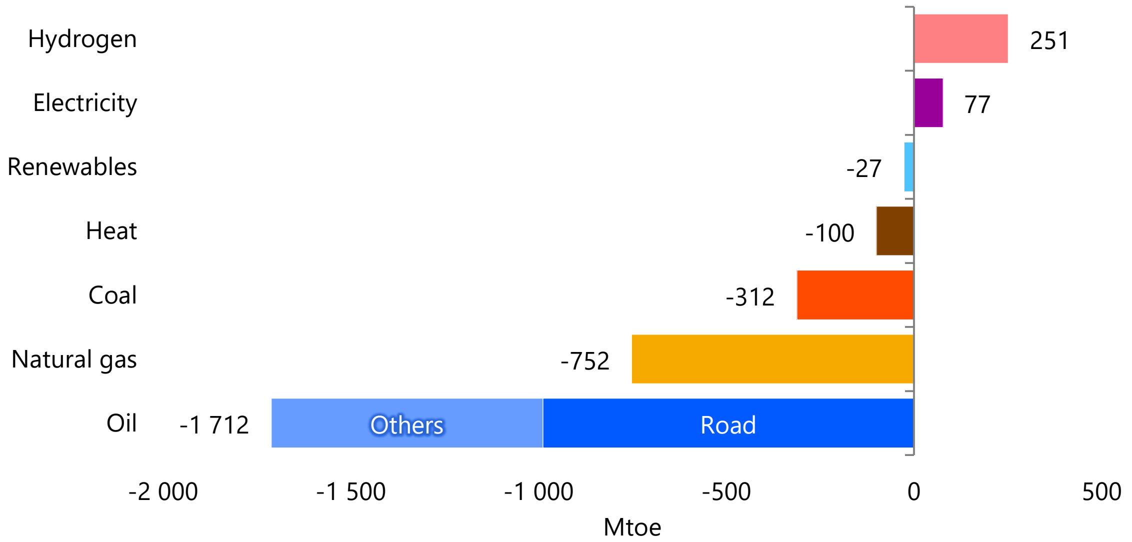
Note: Dotted lines represent the Reference Scenario.

All policy tools must be mobilised to plan and implement these CO_2 emission reduction measures, including subsidies, taxes, regulations and other public policies that can be leveraged by private businesses. Success will require Advanced Economies' bilateral cooperation with Emerging and Developing Economies, multilateral cooperation through frameworks such as the ASEAN+3, Asia-Pacific Economic Cooperation (APEC) forums, and Asia Zero Emission Community (AZEC) in Asia, as well as support from international financial institutions such as the International Monetary Fund (IMF) and the World Bank.

Vehicle fuel efficiency improvements and electrification hold the key to reducing final energy consumption

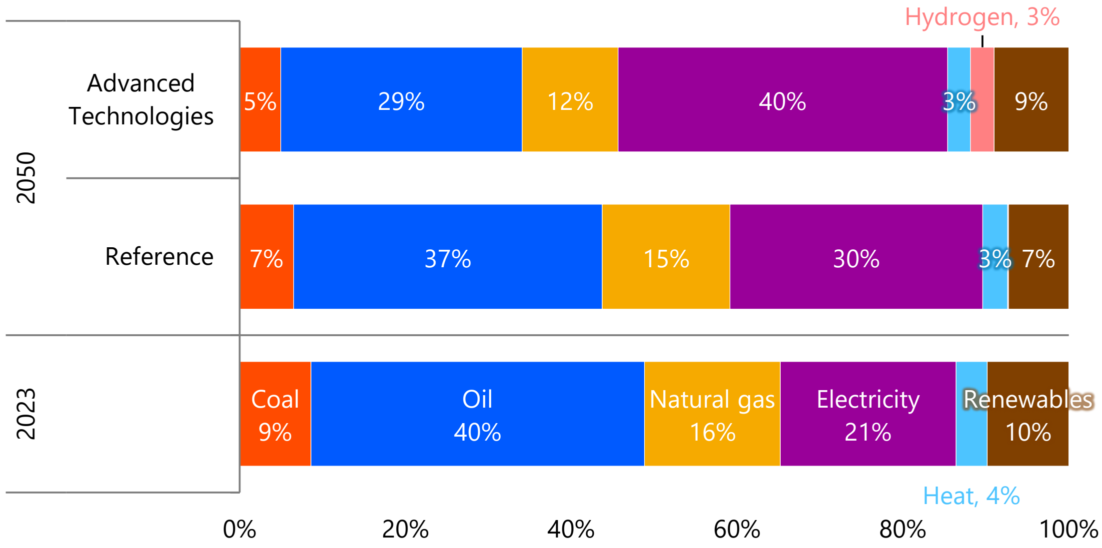
In the Advanced Technologies Scenario, oil will account for about 70% of net final energy consumption savings in 2050 (Figure 4-11). Factors behind oil consumption savings include a decrease in the road sector's oil consumption due to vehicle fuel efficiency improvements and fleet mix changes. Steady implementation is one of the key elements for bringing final energy consumption closer to the path of the Advanced Technologies Scenario. To further diffuse electrified vehicles, various policy incentives will have to be combined with the acceleration of charging facility expansion, battery production capacity enhancement, and relevant cost cuts.

Figure 4-11 | Global final energy consumption changes (relative to Reference Scenario) [Advanced Technologies Scenario, 2050]



The final energy consumption in the Advanced Technologies Scenario will be reduced compared with the Reference Scenario for all fossil fuels such as oil, natural gas, and coal due to progress in energy conservation. On the other hand, electricity consumption will increase due to promoted electrification with the aim of saving energy and reducing CO_2 emissions through high-efficiency and low-carbon electricity. In 2050, the share of electricity will be 9 percentage points higher than in the Reference Scenario (Figure 4-12). Hydrogen, expected to be a low-carbon solution for applications where electrification is difficult, is barely introduced in the Reference Scenario but will experience the greatest proportional increase among energy sources in the transition to the Advanced Technologies Scenario. Renewable energy volumes will decline as traditional biomass such as firewood and livestock manure is replaced with cleaner alternatives, but at a slower rate than fossil fuels, resulting in a share 2 percentage points higher than in the Reference Scenario. Despite these variations from the Reference Scenario, demand will persist for all major energy sources even in the Advanced Technologies Scenario. Therefore, also in this scenario, ensuring stable supply of each energy source will remain important as in the Reference Scenario.

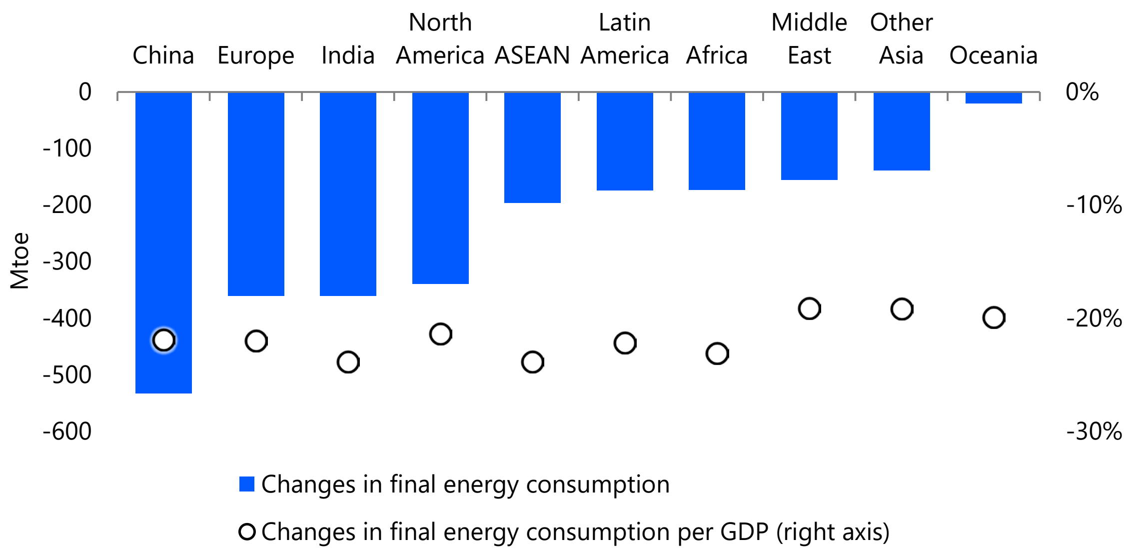
Figure 4-12 | Global final energy consumption mix



Steady progress in energy efficiency improvements in China, India, the United States, and Europe will be important.

Asia, including China and India, will account for the largest share of final energy consumption savings in 2050, followed by North America, Europe and Africa (Figure 4-13). Steady progress in energy efficiency improvements in China, India, the United States, Europe and other economies that are expected to achieve great energy consumption savings will be important for realising the final energy consumption path in the Advanced Technologies Scenario.

Figure 4-13 | Final energy consumption savings and changes in final energy consumption per GDP (relative to Reference Scenario) [Advanced Technologies Scenario, 2050]



Asia's final energy consumption savings in 2050 will total 1 229 Mtoe, accounting for as much as 48% of global savings. China with 533 Mtoe in savings and India with 360 Mtoe will account for a combined 30% of global savings, highlighting their significant influence. Progress in these two countries' energy savings will affect not only the countries themselves but also global climate change and energy security in other regions. They will substantially reduce oil consumption in the road sector, and coal and natural gas consumption in the industry sector, reflecting the effects of various technologies assumed in the Advanced Technologies Scenario. Achieving steady progress in energy efficiency improvements in these two countries through various measures, such as the transfer of highly efficient technologies from Advanced Economies, will be essential.

Final energy consumption savings in Europe will total 361 Mtoe, accounting for 14% of global savings. Notably, the buildings sector will account for 33% of these savings. Led primarily by the Organisation for Economic Co-operation and Development (OECD) countries, more efficient equipment for household and commercial use will be actively deployed, resulting in significant reductions in natural gas consumption. Final energy consumption savings in North America will total 340 Mtoe, accounting for 13% of global savings. The decline in oil consumption, primarily in the road sector, will account for approximately 60% of its savings. As automobiles are frequently used for mobility and transportation in North America, the combined oil demand in the road sector in the United States and Canada is the second largest in the world after Asia. Consequently, oil consumption in the road sector will decline substantially, driven by improvements in vehicle fuel efficiency and changes in vehicle fleet composition.

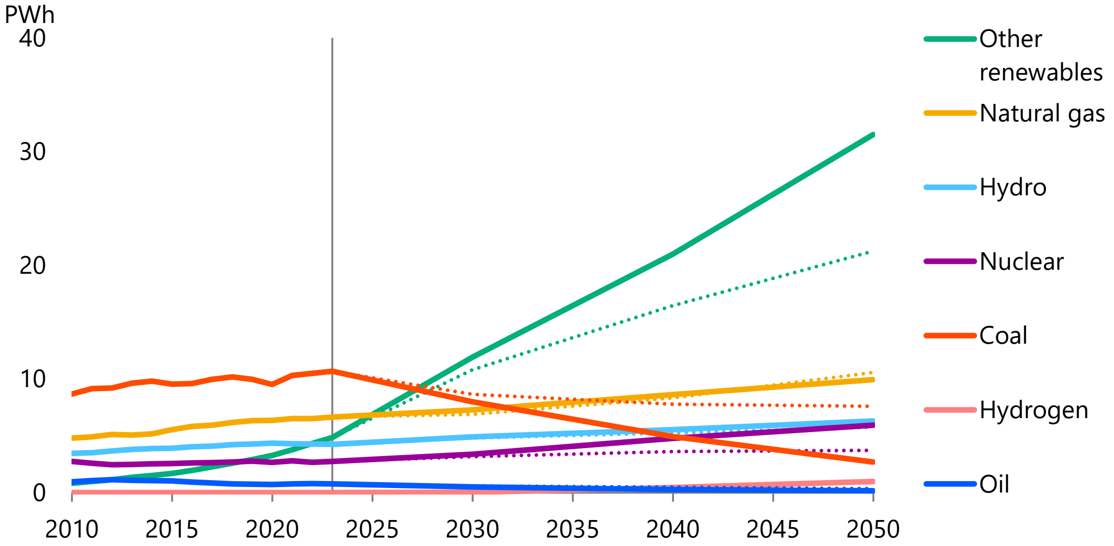
Africa presents unique characteristics in terms of sectoral savings. Of Africa's 173 Mtoe net final energy consumption savings, about 20% will come from reduced renewable energy consumption in the residential sector, leading to a 23% decline in final energy consumption per GDP—the largest reduction in energy consumption across all countries and regions. The savings in renewable energy consumption will be driven by the modernisation of energy use and the adoption of highly efficient appliances. To steadily implement residential sector energy savings, it will be essential to make highly efficient energy-consuming appliances available at affordable prices to a wider range of consumers and to develop infrastructure for supplying modern energy sources.

Power generation mix

In the Advanced Technologies Scenario, factors reducing electricity demand—such as maximisation of energy efficiency improvements—coexist with factors increasing demand, including accelerated electrification as a climate change countermeasure and additional electricity consumption arising from hydrogen production and CCS. As a result, electricity generated in 2050 will be 57 579 TWh, 14% higher than in the Reference Scenario. Although there is uncertainty about how global climate change countermeasures will progress, the electricity generated in 2050 under either scenario will be 1.7 to 2 times higher than the current level. Securing continuous investment in power generation facilities and transmission and distribution infrastructure that support this enormous increase in demand will be an unavoidable challenge for future energy supply.

The power generation mix will greatly change from the current one. Regarding coal, as Advanced Economies take the lead in promoting policies to phase it out, coal-fired power generation will decline substantially from the present to about a quarter of the current level in 2050 (Figure 4-14). In contrast, renewables including solar photovoltaics, wind, and biomass will become the largest power source. In the Reference Scenario, the pace of renewable energy growth will slow after 2030 due to land constraints and the difficulty of addressing output fluctuations. In the Advanced Technologies Scenario, the current pace of rapid deployment will be maintained. This outcome, however, cannot be achieved through deployment alone. It will be possible only with appropriate institutional design to harness the potential anticipated in the Advanced Technologies Scenario across the world, continuous cost reductions and support for measures to address output fluctuations, such as thermal power generation, storage batteries and demand-side load adjustment (demand response).

Figure 4-14 | Global electricity generated [Advanced Technologies Scenario]



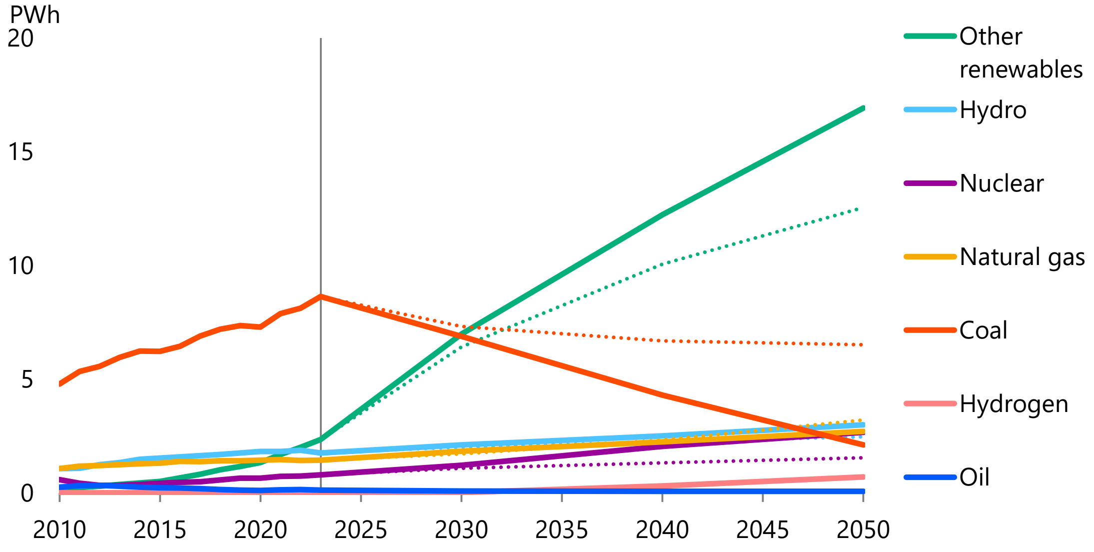
Note: Dotted lines represent the Reference Scenario.

As part of these efforts, to substitute for coal- and natural gas-fired power plants, thermal power generation equipped with CCS as well as hydrogen/ammonia-fired power plants will be introduced in earnest from around 2040. In policy formulation, rather than making a binary choice between thermal power and renewable energy, it is desirable to combine both options at appropriate scales tailored to regional circumstances, thereby achieving both supply stability and environmental objectives. In addition, storage batteries for both grid and consumer use will expand rapidly, contributing to the adjustment of the balance between electricity supply and demand alongside demand response measures utilising electric vehicles.

In Asia, coal, currently the largest power source, will begin declining, yielding its position as the largest power source to renewables (other than hydro) by around 2030 (Figure 4-15). This decline will be seen in Advanced Economies such as Japan and Korea, as well as in China, where renewable energy is already growing significantly. In Emerging and Developing Economies, a certain number of coal-fired power plants will be constructed. Ensuring more efficient coal-fired power generation and air pollution countermeasures is important, and it is also desirable to reduce CO_2 emissions in the future by adopting CCS and co-firing of hydrogen, ammonia and biomass. The introduction of renewables, which has accelerated in recent years, will increase even faster from 2030, particularly in China and India. As these economies sustain strong growth, their challenge will be to harmonise renewable energy expansion with affordable and stable electricity supply. It is necessary to consider all power generation options, not only variable renewable energies, but also dispatchable renewables such as hydro and geothermal, as well as nuclear and emissions-controlled thermal power.

In Asia, natural gas-fired power generation will increase steadily until 2050 in both scenarios, serving as a key tool for managing fluctuations in renewable energy output. Hydrogen-fired power generation will also be introduced in earnest after 2040, progressing from Advanced Economies to Emerging and Developing Economies, supporting supply-demand balance adjustments in a manner similar to natural gas.

Figure 4-15 | Asia's electricity generated [Advanced Technologies Scenario]



Note: Dotted lines represent the Reference Scenario.

Crude oil production

In the Advanced Technologies Scenario, oil demand growth will be suppressed due to rapid progress in the electrification of automobiles and other fuel switching measures in final energy consumption sectors, as well as further progress in energy efficiency. Oil demand will peak by 2030 and reach 57.8 million barrels per day (Mb/d) in 2050, 43% less than in the Reference Scenario. This decline in demand will cause non- Organization of the Petroleum Exporting Countries (OPEC) production to fall by 2030, with OPEC production also beginning to decline by 2040. However, the OPEC countries in the Middle East, which are more cost competitive, will maintain production at 24.2 Mb/d in 2050. As a result, OPEC's market share will increase slightly from the Reference Scenario, reaching 42% in 2050.

Table 4-3 | Crude oil production [Advanced Technologies Scenario]

(Mb/d)

	2023	2030	2040	2050	2023-2050	
					Changes	CAGR
Crude oil production	96.3	91.6	74.4	56.2	-40.1	-2.0%
OPEC	33.9	33.9	29.4	24.2	-9.6	-1.2%
Middle East	26.7	27.5	24.7	20.9	-5.8	-0.9%
Others	7.1	6.4	4.7	3.3	-3.8	-2.8%
Non-OPEC	62.4	57.7	45.0	31.9	-30.5	-2.5%
North America	24.0	24.2	19.2	14.6	-9.4	-1.8%
Latin America	9.0	8.3	7.4	5.4	-3.6	-1.9%
Europe and Eurasia	17.6	14.6	10.5	6.4	-11.2	-3.7%
Middle East	2.9	3.1	3.0	2.7	-0.2	-0.2%
Africa	1.5	1.3	1.1	0.8	-0.7	-2.2%
Asia and Oceania	7.5	6.2	3.8	2.1	-5.4	-4.7%
Processing gains	2.4	2.3	1.8	1.4	-1.0	-2.0%
Oil supply	98.6	93.8	76.2	57.6	-41.1	-2.0%

Note: Crude oil includes natural gas liquids (NGLs).

Natural gas supply

As improvements in energy efficiency and other energy utilisation technologies reduce natural gas consumption in the Advanced Technologies Scenario, natural gas production will be 12% lower in 2040 and 25% lower in 2050 than in the Reference Scenario. However, better management of greenhouse gas (GHG) emissions may lead to a greater proportion of greener natural gas production capacity.

Table 4-4 | Natural gas production [Advanced Technologies Scenario]

(Bcm)

	2023	2030	2040	2050	2023-2050	
					Changes	CAGR
World	4 222	4 259	4 223	4 067	-154	-0.1%
North America and Mexico	1 280	1 221	1 153	1 006	-274	-0.9%
Latin America excl. Mexico	199	214	243	222	23	0.4%
Europe	196	94	71	63	-133	-4.1%
Eurasia	856	840	776	724	-132	-0.6%
Russia	638	590	525	465	-173	-1.2%
Middle East	732	777	810	938	207	0.9%
Africa	253	330	425	412	159	1.8%
Asia	538	593	559	517	-21	-0.1%
China	232	230	160	87	-145	-3.6%
India	36	54	42	23	-13	-1.6%
ASEAN	204	203	243	253	49	0.8%
Oceania	167	190	185	185	18	0.4%

There will be a wide production gap between the Reference and Advanced Technologies Scenarios in North America which has a large production scale. The region's natural gas production in 2050 in the Advanced Technologies Scenario will be nearly 30% less than in the Reference Scenario. Production in Eurasia, including Russia, will be 20% lower than in the Reference Scenario. In the Middle East, Qatar and Iran will see large increases in production even in the Advanced Technologies Scenario, but production in the region in 2050 will be 10%–20% lower than in the Reference Scenario.

In the Advanced Technologies Scenario, production changes will depend on progress in policies and regulations to support the advancement of technologies for monitoring and cutting CO_2 and methane emissions during natural gas production and transportation.

Net natural gas-importing regions will reduce their imports by 40%–70% from the Reference Scenario in 2050. Among net natural gas-exporting regions, Eurasia including Russia will cut exports slightly while the Middle East will reduce its net exports (excluding intra-regional trade) by about 50% from the Reference Scenario. In North America, production will be lower than in the Reference Scenario, but demand will also decline significantly. Despite declining international prices, net exports in 2050 will remain only 20% below the Reference Scenario.

In the Advanced Technologies Scenario, changes in natural gas trade will depend on progress in relevant companies' cooperation and efforts to rationalise and optimise the trading of natural gas and liquefied natural gas (LNG). Such changes will also depend on progress in relevant countries' cooperation and support policies and regulations (monitoring and regulating fuel efficiency and emissions in marine transportation). For LNG transportation in particular, relevant parties will be able to reduce transportation costs, transportation distances and GHG footprints while maintaining equivalent transport volumes through cooperation optimisation measures, including destination changes and cargo swapping.

Policy and securing investment issues leading to stabilisation of the LNG market and measures to make LNG cleaner

As a realistic solution to address the uncertainties of energy transition, it is necessary to set clear roles for LNG, as well as to establish clear LNG standards to fulfil those roles. At the company level, the key will be strengthening countermeasures and setting targets for methane and GHG emissions, as well as disclosing such information accurately and promptly. International forums such as the Group of Seven (G7) have recognised the importance of natural gas and LNG; however, it is also essential to establish standards defining which types of LNG are acceptable in the energy transition. The importance of strengthening methane and GHG emission measurement and international standardisation, as well as of international cooperation in emission reduction measures, is increasingly being recognised. In this regard, it is significant that the LNG Producer-Consumers Conference in June 2025 agreed on further cooperative efforts among governments and relevant international organisations to reduce and manage methane emissions.

Table 4-5 | Challenges to clean LNG production

	Electrification by clean electricity	CCS
Summary Benefit	Electrification of LNG production process Improvement of operational reliability and reduction of maintenance cost Improvement of GHG control and reduced natural gas consumption in the process	Capture of CO_2 in feedstock gas and in the process Improvement of economy through collaboration with surrounding industrial facilities
Challenge	Securing appropriate clean electricity Securing backup electricity Load fluctuation adjustment with neighbouring industrial facilities	Securing suitable site for CCS Cost and time required for integration in case of existing LNG facilities More difficult to capture CO_2 in the process than in feedstock gas

These planned LNG projects are increasingly adopting CCS to reduce GHG emissions and electric drivers powered by renewable energy. In the Advanced Technologies Scenario, the incorporation of these measures is expected to increase in both new LNG projects and existing LNG production facilities. Such incorporation will highlight the economic and environmental advantages of LNG projects, leading to the development of various financial instruments that meet the financing needs of LNG project development.

In the Advanced Technologies Scenario, building links between domestic and foreign buyers, including joint procurement arrangements, will be effective for securing clean LNG during market transitions. This approach considers the demand for flexibility and shorter contract terms by buyers, including those in developing economies, and the expanding base of buyers with relatively lower credit ratings. Such collaboration will also help Japan secure its required LNG supply stability, including through long-term contracts.

Table 4-6 | Long-term challenges to stabilising the LNG market

Realisation of new LNG projects in the United States, Canada, Australia, East Africa, etc. Maintenance and expansion of existing LNG production facilities (incorporating appropriate climate change measures)
Clarification of LNG's role during the transition and beyond Need for LNG buyers to take measures to ensure stable demand and long-term commitments, among flexibility requirements (long-term and short-term transactions combined)
Changes in long-term contract pricing methods: Diversification of pricing schemes, from mainstream crude oil-indexed pricing to more natural gas hub pricing, more complex composite factors, etc.
Development of financing methods also taking into account the trend of shortened contracts (addressing the gap between the requirements for shorter contracts and needs for long-term commitments) Response to the expanded base of less creditworthy buyers (buyer-to-buyer alliances)

Coal supply

As efforts to replace coal with other fuels and increase the efficiency of coal use are enhanced towards carbon neutrality, initiatives to minimise coal use will progress in various sectors including power generation, steelmaking, and other industries. Coal's share in the power generation mix will decline in many countries as the proportions of renewables and nuclear expand. However, a certain level of coal-fired power generation will be maintained to secure reserve generation capacity and grid inertia to stabilise the electricity system. Additionally, some coal-fired power generation will be required for economic reasons in countries and regions where renewable energy implementation is challenging.

Advanced Economies will suspend or terminate inefficient coal-fired power plants. Even when some coal-fired power plants are replaced, technologies to minimise coal consumption will be adopted, such as high-thermal-efficiency technologies like integrated coal gasification combined cycle (IGCC) and co-firing with ammonia or hydrogen. The installation of CCS equipment is also being examined commercially. By improving the efficiency of coal use at individual power plants and industrial facilities, CO_2 emissions intensity will be reduced.

Emerging and Developing Economies will be strongly urged to adopt low-carbonisation or decarbonisation technologies when replacing aged or inefficient coal-fired power plants or constructing large new power plants. Coal demand will be suppressed as other fuels and power sources become more viable options due to lower costs through technological progress.

Consequently, coal production will decrease from 8.481 Gt in 2023 to 3.336 Gt in 2050 (Figure 4-16). By coal type, steam coal production will decline from 6.853 Gt in 2023 to 2.324 Gt in 2050, coking coal production from 1.026 Gt to 0.811 Gt, and lignite production from 620 Mt to 210 Mt. Compared with the Reference Scenario, overall coal production will decrease by 3.110 Gt in 2050. By coal type, steam coal will decrease by 2.8 Gt, coking coal by 181 Mt and lignite by 130 Mt.

Figure 4-16 | Global coal production [Advanced Technologies Scenario]

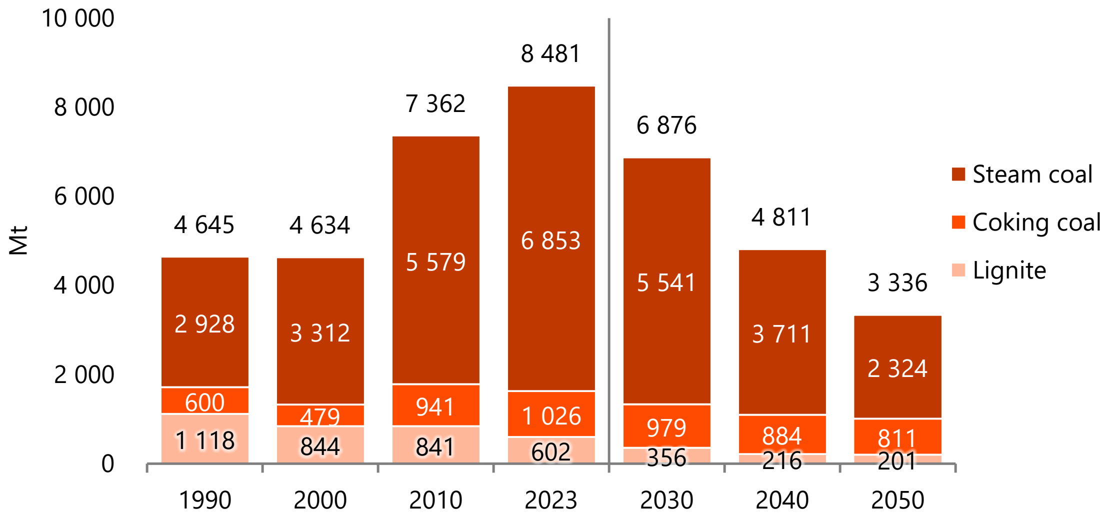


Table 4-7 | Steam coal production [Advanced Technologies Scenario]

(Mt)

	2023	2030	2040	2050	2023-2050	
					Changes	CAGR
World	6 962	5 541	3 711	2 324	-4 638	-4.0%
North America	454	156	48	42	-412	-8.5%
United States	391	149	43	38	-353	-8.3%
Latin America	64	47	24	17	-47	-4.8%
Colombia	56	40	20	12	-44	-5.5%
OECD Europe	45	21	9	5	-40	-7.6%
Non-OECD Europe/Eurasia	368	302	217	177	-191	-2.7%
Russia	247	199	133	102	-145	-3.2%
Middle East	0	0	0	0	0	-2.2%
Africa	249	206	163	132	-117	-2.3%
South Africa	245	185	141	110	-136	-2.9%
Asia	5 529	4 612	3 114	1 846	-3 683	-4.0%
China	3 903	2 961	1 662	735	-3 168	-6.0%
India	839	932	917	689	-151	-0.7%
Indonesia	681	594	421	304	-377	-2.9%
Oceania	252	197	137	105	-147	-3.2%
Australia	251	196	136	104	-146	-3.2%

Table 4-8 | Coking coal production [Advanced Technologies Scenario]

(Mt)

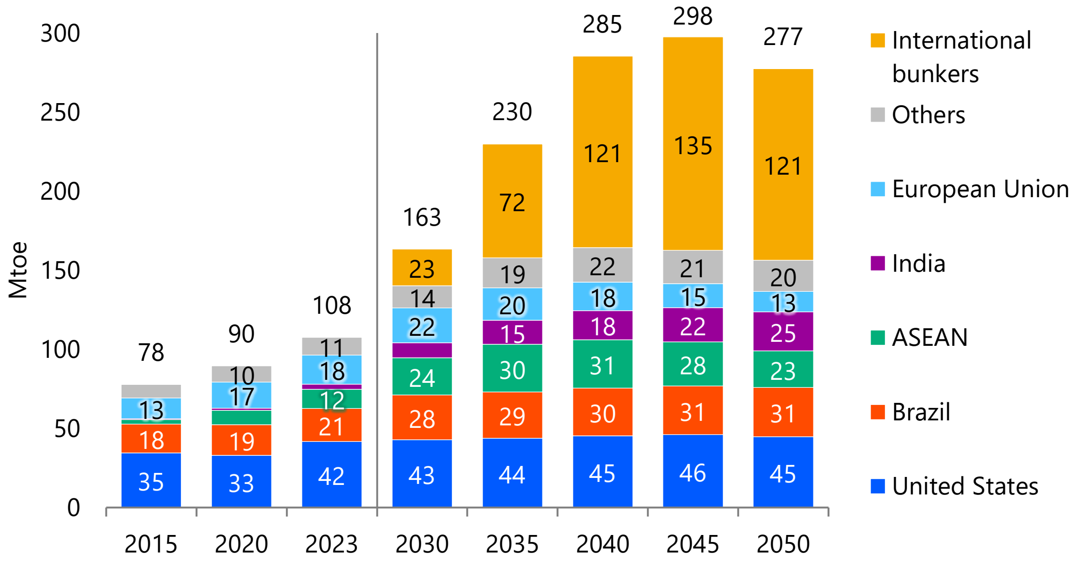
	2023	2030	2040	2050	2023-2050	
					Changes	CAGR
World	1 021	979	884	811	-210	-0.8%
North America	77	61	61	61	-16	-0.8%
United States	52	43	43	43	-9	-0.7%
Latin America	10	10	12	16	5	1.6%
Colombia	9	9	12	15	6	2.0%
OECD Europe	14	13	14	15	0	0.0%
Non-OECD Europe/Eurasia	110	96	86	80	-30	-1.2%
Russia	105	90	81	74	-31	-1.3%
Middle East	2	2	2	3	1	1.4%
Africa	8	17	21	24	15	4.0%
Mozambique	4	12	16	18	14	5.4%
Asia	641	601	490	395	-246	-1.8%
China	554	505	376	268	-286	-2.7%
India	57	64	83	98	41	2.0%
Mongolia	24	24	23	21	-3	-0.5%
Oceania	158	180	198	218	60	1.2%
Australia	157	179	197	217	60	1.2%

Most countries will see coal production decline, partly due to falling demand. For steam coal in particular, production in 2050 will be reduced compared with 2023 due to decreased domestic demand, with China, the United States and Australia experiencing the largest declines. India will also see a decline in steam coal production. On the other hand, coking coal production will decrease in China and the United States but increase in India, as steel demand varies greatly from country to country. In Australia and Mozambique, where exports dominate coal transactions, production will increase along with expanded exports due to increased steel production in Emerging and Developing Economies.

Biofuels for transport

In the Advanced Technologies Scenario, although electrification of the road sector will progress, demand for biofuels will increase beyond the Reference Scenario due to the spread of flexible-fuel vehicles (FFVs) that can run on high biofuel blends (Figure 4-17). Furthermore, if large-scale, low-cost supply of feedstocks, including advanced biofuels such as third-generation algae-based fuels, can be achieved, demand for biofuels is expected to increase not only in the United States and Brazil but also in India and ASEAN. I In contrast, Europe is expected to see little change in its electrification trajectory. Regulations on conventional biofuels, which are currently available, are anticipated to be maintained or strengthened from sustainability and environmental protection perspectives such as land use change (LUC) and indirect land use change (ILUC). Consequently, biofuel demand is not expected to increase as much as it would in the Reference Scenario. Based on these factors, the share of biofuels in total road sector energy demand will be approximately 15% by 2050.

Figure 4-17 | Biofuel consumption for transport [Advanced Technologies Scenario]



In the aviation sector, the use of bio-based sustainable aviation fuels (SAFs) will increase significantly, reaching 25% to 30% of global aviation fuel in 2050. There is little difference between the two scenarios in the amount of SAF introduced in 2050, but in the transition period leading up to that point, the Advanced Technologies Scenario will see greater deployment due to cost improvements and increased supply. On the other hand, bunker oil use for ships will fall below the Reference Scenario as hydrogen-based liquid and gaseous fuels are actively introduced through technological innovation under the Advanced Technologies Scenario.

4.3 India and ASEAN

This section focuses on India, a key driver of growth in global final energy consumption, and Malaysia, which will serve as the chair of the Association of Southeast Asian Nations (ASEAN) in 2025, to outline their efforts to achieve both decarbonisation and economic development, as well as future prospects.

Pursuing both economic development and decarbonisation

India

Having set 'Viksit Bharat 2047' (Developed India 2047) as its national vision, India aims to become one of the advanced economies by 2047 (the 100th anniversary of its independence). Viksit Bharat 2047 outlines multiple strategic pillars—economic growth and development, infrastructure development, social progress, governance and security, innovation, science and technology, environmental sustainability, and India in the world. In particular, regarding economic growth and development, it sets an ambitious goal of raising gross domestic product (GDP) to over $30 trillion by 2047, stating that achieving this goal will require maintaining an average growth rate of 7% to 10% over the coming decades[14].

Meanwhile, regarding decarbonisation, India declared at the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP26), held in November 2021, that it will aim to achieve carbon neutrality by 2070. In the Nationally Determined Contribution (NDC) announced in August 2022, India has committed to reducing greenhouse gas (GHG) emissions per unit of GDP by 45% compared with 2005 levels by 2030. It also set a conditional target of increasing cumulative installed power generation capacity from non-fossil fuel-based energy sources to approximately 50% by 2030[15]. The goal of increasing non-fossil fuel power generation capacity to 500 GW by 2030, announced by Prime Minister Narendra Modi at COP26, was not included in the text of the NDC, but continues to be mentioned in Indian government documents. India had installed 242.8 GW of non-fossil fuel power generation capacity by June 2025 (233.99 GW from renewables and 8.8 GW from nuclear). This accounts for 50.07% of the total installed capacity (484.82 GW), achieving the goal announced at COP26 five years ahead of schedule[16]. The long-term strategy, announced at COP27 in November 2022, focuses on seven areas (electricity, transport, adaptation in urban design, industry, carbon removal, forests and vegetation, and finance), outlining the elements that should be addressed to achieve low-carbon development in each area.

In terms of simultaneous achievement of economic development and decarbonisation, India has been implementing the National Action Plan on Climate Change (NAPCC), a comprehensive framework, since 2008. The NAPCC consists of national missions in eight areas (solar photovoltaics, energy efficiency, living environment, water resources, Himalayan ecosystems, forests and other ecosystems, agriculture, and strategic knowledge dissemination on climate

[14] Viksit India, "Viksit India: Bold Vision. Brighter Future", https://viksitindia.com/

[15] Government of India, "India's Updated First Nationally Determined Contribution Under Paris Agreement (2021–2030)", August 2022. https://unfccc.int/sites/default/files/NDC/2022-08/India%20Updated%20First%20Nationally%20Determined%20Contrib.pdf

[16] Press Information Bureau, Government of India, "The Solar Surge: India's Bold Leap Toward a Net Zero Future", 19 August 2025. https://www.pib.gov.in/PressNoteDetails.aspx?id=155063&NoteId=155063&ModuleId=3

change), which are being reviewed to align with the NDCs[17]. The government is implementing sectoral policies in line with the NAPCC strategy while supporting each state and union territories (UTs) in formulating the State Action Plans for Climate Change (SAPCCs).

Malaysia

In terms of economic development, Malaysia has set a goal of achieving an average annual GDP growth rate of 4.5% to 5.5% between 2026 and 2030 in its 3rd Five-Year Plan (13MP), with development expenditure of approximately $130 billion[18]. Through this economic growth, Malaysia aims to become one of the high-income countries, ranking among the world's top 30 economies by 2030.

Regarding decarbonisation, Malaysia's NDC was submitted in 2021 and reaffirmed at COP29. The country pledged to reduce its GHG emissions intensity by 45% by 2030 from 2005 levels, with the goal of achieving net-zero emissions by 2050[19].

Malaysia's energy transition is driven by the National Energy Transition Roadmap (NETR) and the Malaysia Renewable Energy Roadmap (MyRER), which promote energy efficiency, renewable energies, green mobility, hydrogen, bioenergy, and carbon capture. While the clean energy transition is still in its early stages, Malaysia is progressing towards its goal of increasing the share of renewable energies in installed capacity to 40% by 2035 and 70% by 2050[20]. As of 2022, renewables accounted for 24% (9 GW) of installed power generation capacity. This is primarily due to hydro and solar photovoltaics (e.g. large-scale solar photovoltaics and rooftop solar photovoltaics).

Malaysia's MADANI economic framework integrates climate change measures with inclusive development, innovation and infrastructure development. Making use of green finance and carbon market mechanisms, the National Decarbonisation Committee oversees the implementation of the framework. This strategy reflects a balanced and pragmatic approach to energy security, economic competitiveness, and sustainability, and lays the foundations for a fair and low-carbon society.

Outlook

In both the Reference Scenario and the Advanced Technologies Scenario, energy consumption in Emerging and Developing Economies will continue to grow steadily, with India and ASEAN seeing particularly large increases in energy consumption due to robust economic growth. As shown in Figure 4-18, India's average income will approach $10 000, and energy consumption per capita will nearly double from the current level by 2050. Malaysia's GDP per capita is at the same level as China's, and robust growth and rising demand are expected to continue.

In China, from the 1990s to the 2000s, there was an explosive increase in energy demand, due partly to the rapid expansion of the secondary industry. Although a similar pace of

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[17] Press Information Bureau, Government of India, "National Action Plan on Climate Change (NAPCC)", 1 December 2021.
https://static.pib.gov.in/WriteReadData/specificdocs/documents/2021/dec/doc202112101.pdf

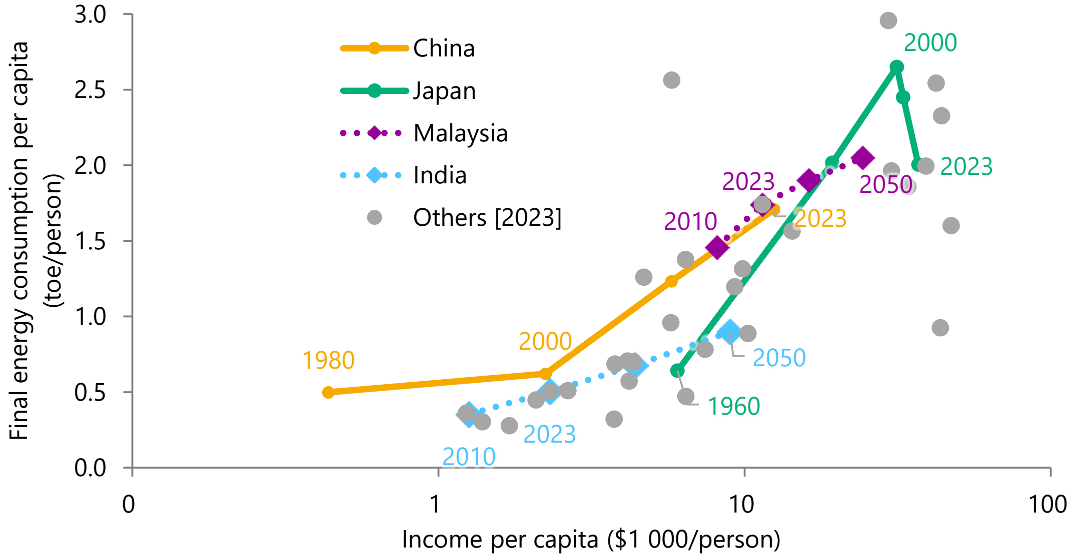
[18] Ministry of Economy, "Thirteenth Malaysia Plan 2026-2030", https://rmk13.ekonomi.gov.my/wp-content/uploads/2025/09/120925-Main-Document-e-Book.pdf

[19] UNFCCC, "Malaysia's Update of its First Nationally Determined Contribution", 30 July 2021.
https://unfccc.int/sites/default/files/NDC/2022-06/Malaysia%20NDC%20Updated%20Submission%20to%20UNFCCC%20July%202021%20final.pdf

[20] Ministry of Economy, "National Energy Transition Roadmap",
https://www.investmalaysia.gov.my/media/w1la4c2k/national-energy-transition-roadmap.pdf

industrialisation is unlikely in India or Malaysia, steady growth in demand is expected in the industry sector. This is because India continues to promote industrialisation as a policy direction, while Malaysia is expected to maintain a high industrialisation ratio by upgrading its industrial sector and strengthening its industrial base, thereby expanding into more advanced activities such as semiconductor design and cloud services. In addition, rising energy demand in non-industry sectors, such as the buildings and transport sectors, in both countries cannot be ignored.

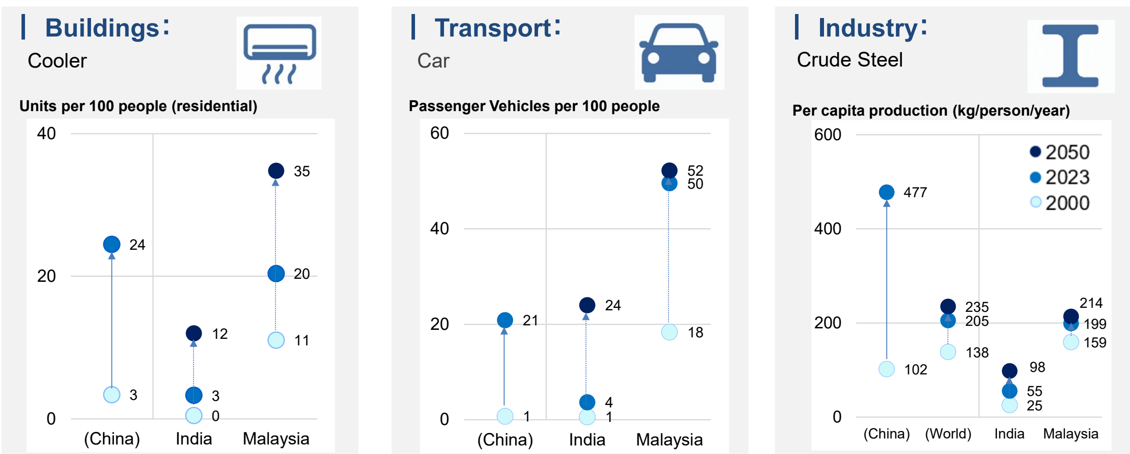
Figure 4-18 | Annual income and final energy consumption per capita



Note: Income per capita is in real terms, at 2015 prices.

Typical examples of energy consumption in each sector include the so-called '3Cs', that is, air conditioning (coolers), passenger cars (cars) and crude steel production (crude steel). Rising income levels among the population directly lead to an increase in air conditioning and passenger cars owned, while causing demand for materials, such as crude steel, to grow. Such trends can be observed in the spread of the '3Cs' in Japan in the 1960s and China in the 2000s, and a similar change is now occurring in Malaysia. Going forward, India is also expected to see progress in stimulating energy consumption in the industry, transport, and buildings sectors through the '3Cs'.

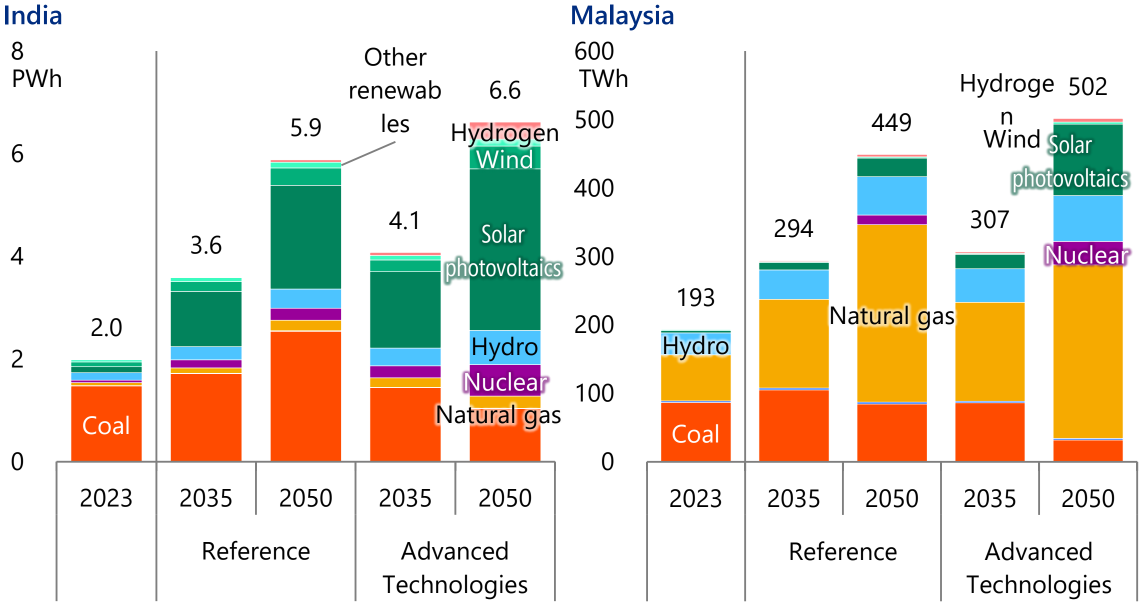
Figure 4-19 | Number of units owned and crude steel production per capita



Due to the significant expansion of energy consumption, the electricity generation required in 2050 will increase sharply, to more than triple the current level in India and to approximately 2 to 2.5 times the current level in Malaysia.

India is expected to see a notably large increase in solar photovoltaic power generation, reaching 17 times the current level (2 020 TWh) under the Reference Scenario in 2050 and 27 times (3 146 TWh) under the Advanced Technologies Scenario. While India has great potential for solar photovoltaics, competition with agricultural land is a major challenge for large-scale development. Coal currently plays an important role in India's power generation sector, and in the Reference Scenario, coal-fired power generation will continue to increase, accounting for 43% of electricity generated in 2050. Although coal-fired power generation will decrease in the Advanced Technologies Scenario, it will still account for 16% of electricity generated in 2050. As shown in Figure 4-20, it will be necessary to expand the power supply system that utilises a variety of power sources, not only coal and renewable energy.

Figure 4-20 | Power generation mix in India and Malaysia



In Malaysia, natural gas will continue to play a dominant role in the country's electricity supply. The share of natural gas-fired power generation in electricity generated in 2050 will remain high at 58% in the Reference Scenario and 51% in the Advanced Technologies Scenario. In the Advanced Technologies Scenario, solar photovoltaics will increase dramatically to 30 times the current level (104 TWh). To achieve its decarbonisation goals, Malaysia is aiming to significantly expand its solar photovoltaic installations through its Large-Scale Solar (LSS) programme and rooftop solar photovoltaics. However, with little potential for renewables (solar photovoltaics and hydro) on the Malay Peninsula, connecting power lines to Borneo will be a key issue for large-scale deployment.

Implication

To further utilise India's abundant renewable energy potential (particularly solar photovoltaics), it will be necessary to develop transmission and distribution infrastructure and resolve land constraints, such as competition with agricultural land and complex land acquisition. Regarding the former, in addition to securing sufficient investment, infrastructure development plans must be formulated that balance local production and consumption of renewables with interregional exchange, taking into account the difficulty of building a power grid to cover India's vast territory, the world's seventh largest. On the other hand, as for the latter, it is necessary, while taking into account trends in changes to the agricultural population accompanying economic growth (shifts to other industries), to undertake long-term efforts such as simplifying regulations on land acquisition, harmonising systems across states, and increasing administrative involvement in negotiations with landowners, which present significant hurdles for private companies. As India's coal-fired power generation is believed to continue to play an important role in 2050, the gradual decarbonisation of existing coal-fired power plants through the co-firing of ammonia and biomass, and the decarbonisation of coal through carbon capture, utilisation and storage (CCUS) will likely become important options. India is currently developing a comprehensive policy on CCUS, and its early formulation and concrete implementation are expected. Given the large number of mining workers in the country, achieving a fair transition is a major challenge. As India continues to grow its economy and develop its infrastructure, it is necessary to assess the long-term and broad impact of this on whether new industries can adequately absorb employment from traditional industries.

In Malaysia, natural gas-fired power generation will continue to play a pivotal role in electricity supply. Against this backdrop, carbon capture and storage (CCS) is expected to play a significant role in achieving both decarbonisation and economic development. Furthermore, the development of an interconnector linking the Malay Peninsula and Sarawak will be an important component of the ASEAN Power Grid and will also contribute to the decarbonisation and stable supply of energy systems across Malaysia by utilising Sarawak's abundant renewable energy potential, such as hydro and solar photovoltaics. This will also be important in terms of regional economic development. At the same time, from a land use perspective, thorough examination will be needed to determine to what extent Sarawak's potential can actually be utilised. After the 13MP was submitted, the Ministry of Energy Transition and Water Transformation launched a feasibility study on nuclear power generation led by MyPower, a subsidiary of the ministry. Considering the development of nuclear, including small modular reactors, to complement renewable energy and natural gas-fired power sources, is an important option as a carbon dioxide (CO_2)-free power source that can meet rapidly expanding electricity demand, diversify energy sources and reduce emissions.

5. Carbon dioxide emissions

5.1 Current trends: Correcting the course of climate change measures and strengthening the competitiveness of Europe and the United States

In recent years, global efforts to combat climate change and reduce carbon dioxide emissions have reached a turning point. In particular, the announcement by the second Donald Trump administration, which took office in January 2025, to withdraw from the Paris Agreement, has triggered a backlash against US climate change policies. This sudden change in policy not only shook the domestic policy foundations but also seriously impacted the international cooperative system, casting uncertainty over policy decisions in various countries and the future direction of markets. Therefore, this section will focus on the current situation in the United States since the inauguration of the second Trump administration, as well as policy trends in the United States and Europe, and developments in climate change countermeasures.

On 20 January 2025, Mr Trump took office as president and signed an executive order that included withdrawing from the Paris Agreement[21]. The order covered five items, including: 1/ unleashing US energy; 2/ declaring a national energy emergency; and 3/ placing the United States first in international environmental agreements. One consequence of signing this executive order is that the United States, which had been contributing approximately $11 billion[22] annually to the United Nations Framework Convention on Climate Change (UNFCCC), will cease these contributions. Furthermore, the US withdrawal has made it even more difficult to provide developing countries with at least $300 billion a year in climate finance (public and private) by 2035 as funding for global warming countermeasures, as agreed at the 29th Conference of the Parties to the UNFCCC (COP29).

Within the United States, since the inauguration of the second Trump administration, the Environmental Protection Agency announced on 12 March that it would ease 31 regulations to advance President Trump's first executive order. This deregulation includes a reconsideration of power plant regulations, a reconsideration of motor vehicle regulations, and a reconsideration of the 2009 endangerment finding and regulations and actions that rely on that finding. Mr Trump also signed the executive order 'Protecting American Energy From State Overreach' on 8 April. The document declared that 'state overreach in energy regulation would undermine the economy and national security of the United States' and called for suspending enforcement of domestic emissions trading systems and carbon taxes (the so-called Superfund Act). Following this signing, the U.S. Department of Justice set a 7 July deadline for filing lawsuits against states participating in these initiatives, but no lawsuits have been filed.

In July, the Inflation Reduction Act (IRA)/Infrastructure Investment and Jobs Act (IIJA) tax credit funding suspension (including the suspension of wind and solar photovoltaic tax credits) was enacted. In addition, the bill rescinded the 2009 Endangerment Finding, which found that greenhouse gas (GHG) emissions have adverse effects on health and welfare, and proposed the repeal of automobile GHG emission standards. The government also plans to propose the

[21] The White House, "Putting America First In International Environmental Agreements", 20 January 2025. https://www.whitehouse.gov/presidential-actions/2025/01/putting-america-first-in-international-environmental-agreements/

[22] U.S. Department of State, "COP 29 Update: U.S. International Public Climate Finance", 18 November 2024. https://2021-2025.state.gov/cop-29-update-u-s-international-public-climate-finance/

complete abolition of GHG emission criteria, on the grounds that GHGs from thermal power plants do not contribute to air pollution.

Table 5-1 | Major energy and environment-related policies of the United States and the European Union

	United States	European Union
September 2024		Publication of Draghi Report (highlighting lack of investment, high energy costs and strategic dependency as key issues)
January 2025	Mr Trump took office as the 47th President of the United States. Direction to review energy regulations and speed up and licensing procedures. National energy emergency declared Withdrawal from and review of international environmental agreements (the Paris Agreement, etc.) directed.	Indication of the path to improving Europe's competitiveness presented
February 2025		Investments that boost both clean manufacturing and competitiveness. Simplification proposed for the Corporate Sustainability Reporting Directive (CSRD), the Corporate Sustainability Due Diligence Directive (CSDDD) and the Carbon Border Adjustment Mechanism (CBAM) (Omnibus Simplification).
March 2025	Review of the legal basis for GHG regulations commenced	
April 2025	Judicial decisions on state carbon pricing and emissions trading systems (ETS) supported	
May 2025		Amendments adopted to postpone compliance with vehicle GHG emission criteria until 2027
July 2025	Reduction of renewable energy tax credits and support for fossil fuels (One Big Beautiful Bill Act passed). Proposal to abolish Endangerment Finding + Proposal to abolish automobile GHG emission regulations.	

Such sceptical movements regarding climate change in the United States are affecting all areas of markets, policy and diplomacy outside the country. Particularly notable were the gains made by right-wing and centre-right parties in elections across various countries, as well as the increase in policies prioritising the international competitiveness of domestic industries.

Meanwhile, on 9 January 2025, the European Union announced its Competitiveness Compass[23], outlining three priority areas, including decarbonising the EU economy, and five cross-cutting support policies, including deregulation. It pledged to simplify regulations and support clean industries to address the stagnation of innovation and hollowing out of manufacturing within the region. Furthermore, on 26 February, the European Union proposed the 'Omnibus Package'[24] to simplify the Corporate Sustainability Reporting Directive (CSRD), the Corporate Sustainability Due Diligence Directive (CSDDD), and the Carbon Border Adjustment Mechanism (CBAM). The package aims to reduce the compliance burden on businesses, such as European Sustainability Reporting Standards (ESRS) disclosure and supply chain audits, by reducing the number of target businesses. This is intended to enhance the Union's international competitiveness and is seen as a response to investment competition with the United States and China. Additionally, on 27 May, the European Union announced the relaxation of automobile exhaust gas regulations (changing the target value achievement from a single year in 2025 to an average over the period from 2025 to 2027)[25].

Examples of specific policies and documents calling for strengthening competitiveness in the European Union include the Clean Industrial Deal[26] and the Draghi Report[27]. The Clean Industrial Deal is a comprehensive package announced by the European Commission on 26 February to make decarbonisation an engine for 'industrial competitiveness'. It aims to address high energy costs and global competition by simultaneously advancing industry electrification and the renewable energy transition while reducing costs. The main pillars include: 1/ an affordable energy action plan (developing power grids and promoting electrification); 2/ creating demand for clean products (introducing sustainability and European resilience standards into procurement rules); 3/ mobilising funds (channelling more than €100 billion through an industrial decarbonisation bank and innovation fund); 4/ resource circulation and joint procurement of critical minerals; 5/ skills development; and 6/ simplifying regulations. The background to these developments is the Draghi Report, published in September 2024, in which former European Central Bank (ECB) President Mario Draghi summarised 'The Future of European Competitiveness' at the request of the European Commission. Taking into account the future transition costs of energy-intensive industries, the report analyses factors such as lack of investment in growth, persistently high energy prices, and lack of competitiveness. Thus, within the European Union as well, the need to enhance competitiveness across multiple fronts is being asserted, and these phenomena—which can be seen as actions based on such assertions—represent a gradual shift away from the previous overemphasis on climate change countermeasures.

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[23] European Commission, "Competitiveness compass", https://commission.europa.eu/topics/eu-competitiveness/competitiveness-compass_en. Retrieved 20 August 2025

[24] European Commission, "Commission simplifies rules on sustainability and EU investments, delivering over €6 billion in administrative relief", 6 February 2025

[25] European Union, "CO_2 emissions in cars: Council gives final approval to additional flexibility for carmakers", https://www.consilium.europa.eu/en/press/press-releases/2025/05/27/co2-emissions-in-cars-council-gives-final-approval-to-additional-flexibility-for-carmakers/pdf/, 27 May 2025

[26] European Commission, "Clean Industrial Deal", https://commission.europa.eu/topics/eu-competitiveness/clean-industrial-deal_en, Retrieved 8 August 2025

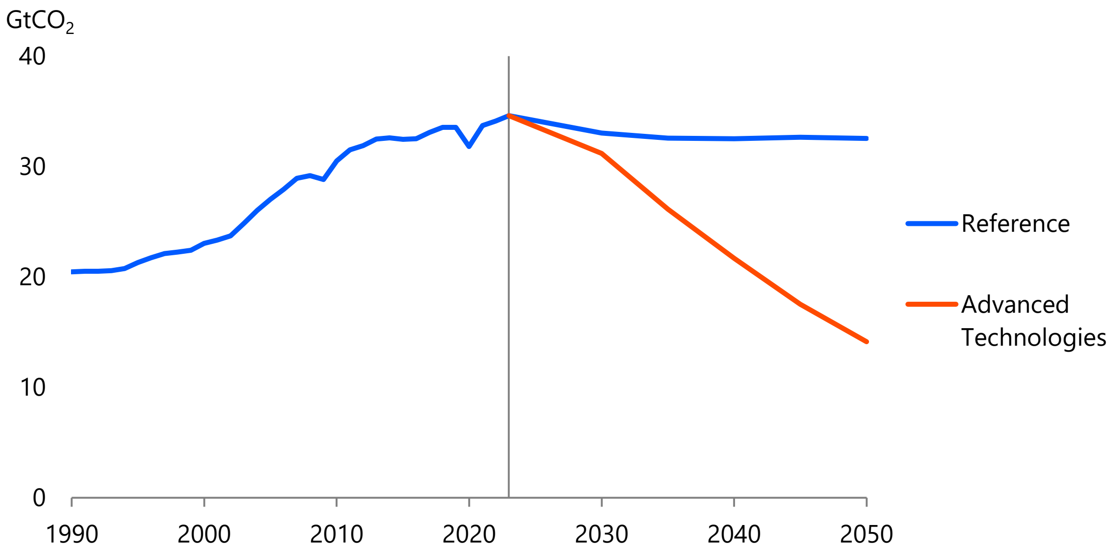
[27] European Commission, "The Draghi report on EU competitiveness", https://commission.europa.eu/topics/eu-competitiveness/draghi-report_en, Retrieved 8 August 2025

Compared with the past, climate change measures have clearly shown a softening trend since around the start of the second Trump administration. On the other hand, renewable energies, particularly solar photovoltaics and wind, will likely see increased adoption in line with market principles as power generation costs fall.

5.2 Outlook for emissions

Figure 5-1 shows the world's carbon dioxide (CO_2) emissions[28]. In the Reference Scenario, emissions will peak in the mid-2020s, followed by a continuous decline towards 2035. However, the rate of decline will slow from 2035 onwards and remain roughly flat until 2050. On the other hand, in the Advanced Technologies Scenario, emission reductions will proceed smoothly towards 2050. Comparing CO_2 emissions between the two scenarios, the Advanced Technologies Scenario shows a significant reduction of 22% in 2035, 35% in 2040, and 57% in 2050 compared with the Reference Scenario. Meanwhile, according to the Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report (AR6), to achieve the 1.5°C target, greenhouse gas (GHG) emissions need to be reduced by 43% by 2030 compared with 2019 levels, 60% by 2035, and 69% by 2040. However, the reductions under the Advanced Technologies Scenario will be only 7% in 2030, 22% in 2035, 35% in 2040 and 58% in 2050. This comparison reveals a significant gap with the 1.5°C target, highlighting that current measures alone are far from sufficient and that additional actions are essential. In addition, the latest assessment shows that the carbon budget has shrunk significantly since AR6, making the 1.5°C target unrealistic and necessitating a more realistic target of 2°C. This point is discussed in Section 9.2

Figure 5-1 | Global CO_2 emissions

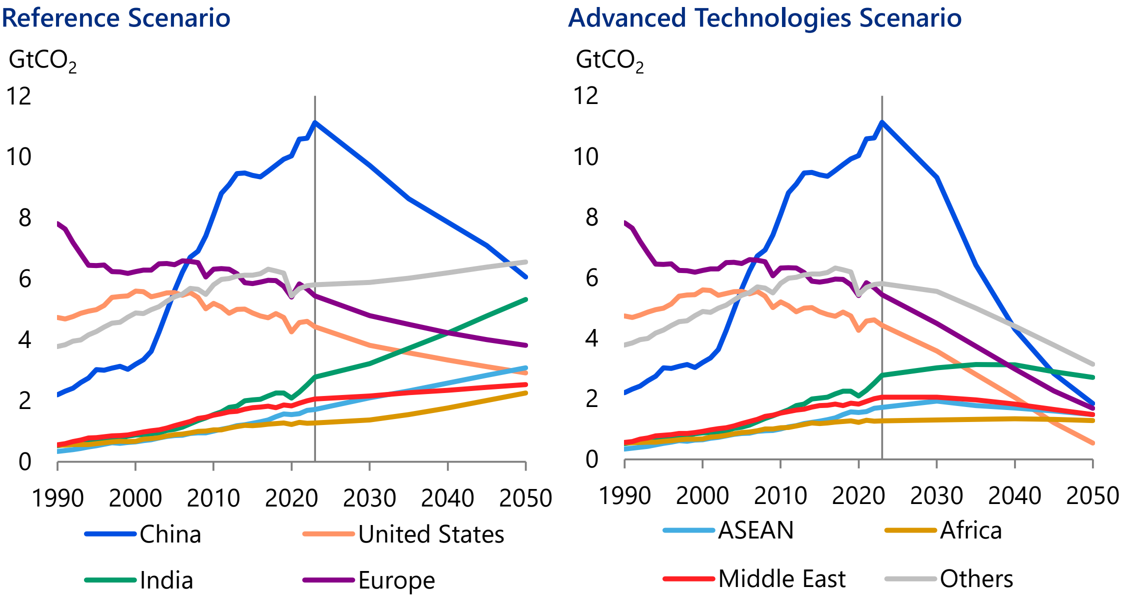


In 2023, China accounted for 32% of CO_2 emissions and the United States for 13%, with these two countries accounting for roughly half of global emissions. Looking at future emissions by region, emissions in the Reference Scenario will continue to decline in China, the United States and Europe (Figure 5-2). Emissions will continue to increase in India, the Association of Southeast

[28] Energy-related CO_2 emissions minus removals by direct air capture and carbon storage (DACCS). The same applies throughout this chapter.

Asian Nations (ASEAN), Africa and the Middle East, while in the Advanced Technologies Scenario, emissions will decrease in all eight countries/regions.

Figure 5-2 | CO_2 emissions

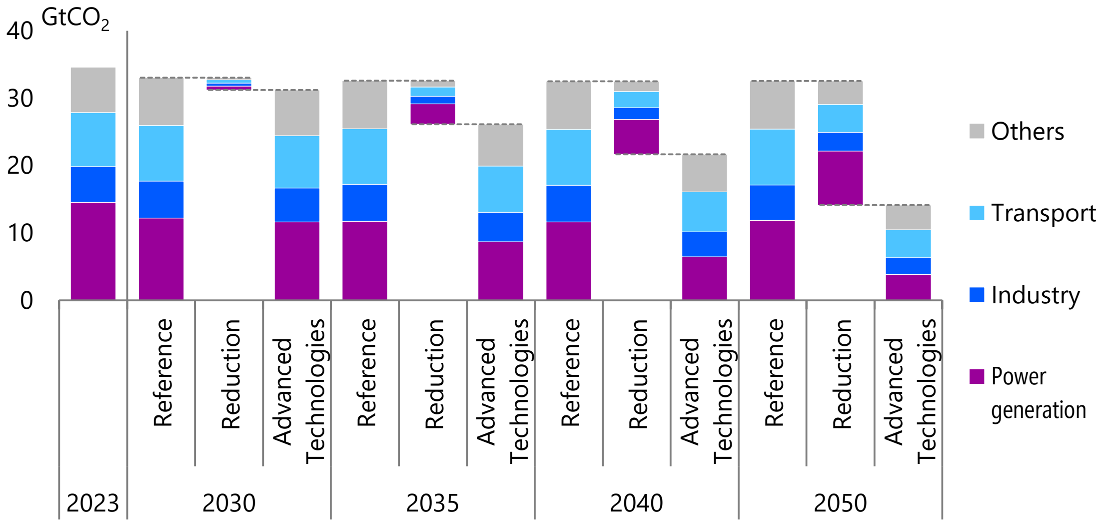


In the Advanced Technologies Scenario for 2050, the largest reduction from the Reference Scenario will be achieved by the United States (82% reduction), followed by China (70% reduction). These outstanding reductions by the two countries, as shown in Figure 3-12, will be attributable to the marked decrease in carbon emissions intensity in the power generation sector due to the expanded introduction of solar photovoltaics and wind. Emissions reductions in ASEAN and India will be around 50% compared with the Reference Scenario, while reductions in Africa and the Middle East will remain in the low 40% range. As stated above, while overall carbon emissions intensity in China and the United States is relatively low, intensity levels in the power generation sector remain high in ASEAN, India, the Middle East and Africa. This is attributable to significant increases in gross domestic product (GDP) in ASEAN and India, coupled with persistently high energy consumption per unit of GDP (indicating that economic growth and environmental impacts will not be decoupled).

In the Advanced Technologies Scenario, India's emissions decline only slowly from 2040 to 2050, and at this rate, it will be difficult for the Indian government to achieve its target of net zero by 2070. Therefore, policies and investments that contribute to emissions reduction, along with the promotion of clean power sources, are required.

The sectoral share of global CO_2 emissions in 2023 was approximately 42% for power generation, 15% for industry, and 23% for transport (Figure 5-3). In the Reference Scenario, CO_2 emissions from the power generation, industry, and transport sectors will decline only marginally between 2023 and 2030. From 2030 onwards, each sector will experience a slight decrease or stagnation, followed by no significant change in emission shares in 2050. On the other hand, in the Advanced Technologies Scenario, emissions from the power generation sector will decrease year by year, falling sharply to 26% by 2050 compared with 2023. Similarly, emissions from the industry and transport sectors will continue to decline, with the former reducing emissions by 46% and the latter by 52% in 2050 compared with 2023.

Figure 5-3 | Global CO_2 emissions



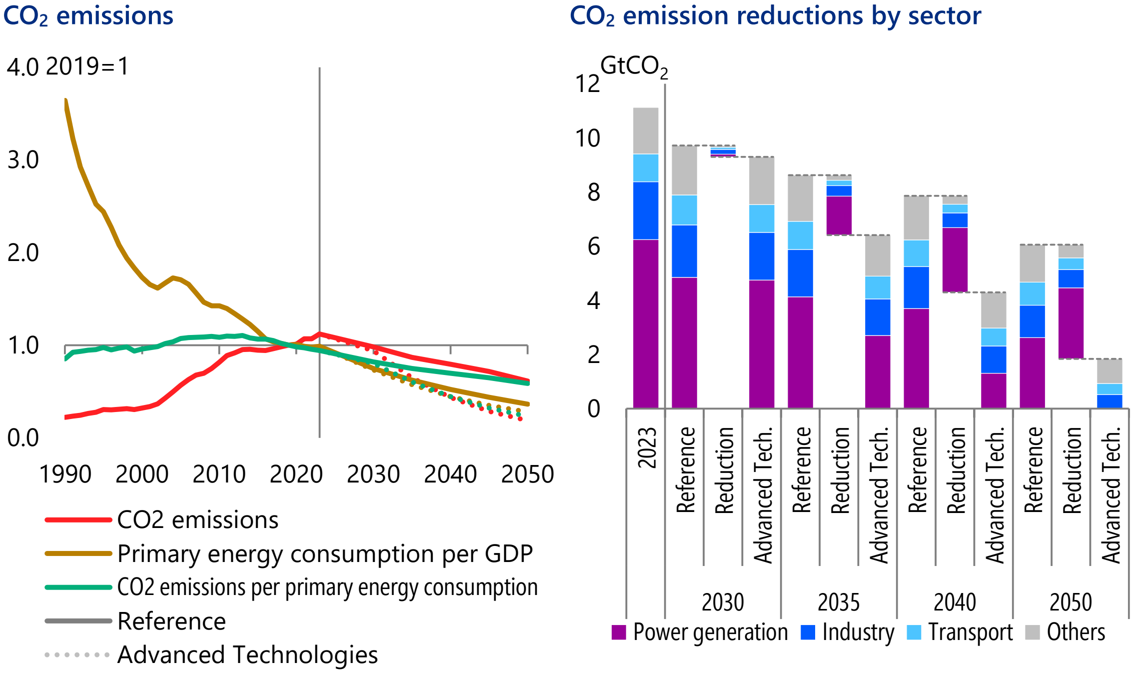
Note: Removals through the direct air capture and storage (DACCS) and bioenergy with carbon capture and storage (BECCS) are excluded from Other and Power Generation, respectively.

In the decomposition of factors affecting CO_2 emissions, two key indicators are considered: the reduction in CO_2 emissions per unit of primary energy consumption (CO_2 emissions/primary energy consumption) and the reduction in primary energy consumption per unit of GDP (primary energy consumption/GDP). Taking these factors into account, China, ASEAN, India, and the United States, where future CO_2 emissions are projected to fluctuate significantly, are analysed. Figure 5-4 to Figure 5-7 show the breakdown of CO_2 emissions, primary energy consumption per unit of GDP, CO_2 emissions per unit of primary energy consumption and CO_2 emission reductions by sector.

China's CO_2 emissions will peak in the mid-2020s in both the Reference Scenario and the Advanced Technologies Scenario, before continuing to decline. CO_2 emissions per unit of primary energy consumption reached their peak in 2013 and have been on a downward trend since then. One of the reasons for this decline was the introduction of renewable energies. As shown in Table A25, as of 2013, renewables accounted for only a small portion of China's power generation mix, with coal-fired power generation accounting for the majority. However, the introduction of renewables continued to expand, increasing their share by 2023.

Even after 2023, the introduction of solar photovoltaics and wind continues. In the Advanced Technologies Scenario, in particular, solar photovoltaics and wind will account for approximately 70% of total electricity generated in 2050, a proportion that is extremely high even by international standards. Looking at CO_2 emissions by sector, those from the power generation sector will decrease year-on-year in both the Reference Scenario and the Advanced Technologies Scenario. In addition, primary energy consumption per unit of GDP has been declining every year since 1990, with the exception of certain periods. The downward trend will continue from 2023 onwards, with emissions by 2050 projected to be 64% lower than 2019 levels in the Reference Scenario and 72% lower in the Advanced Technologies Scenario.

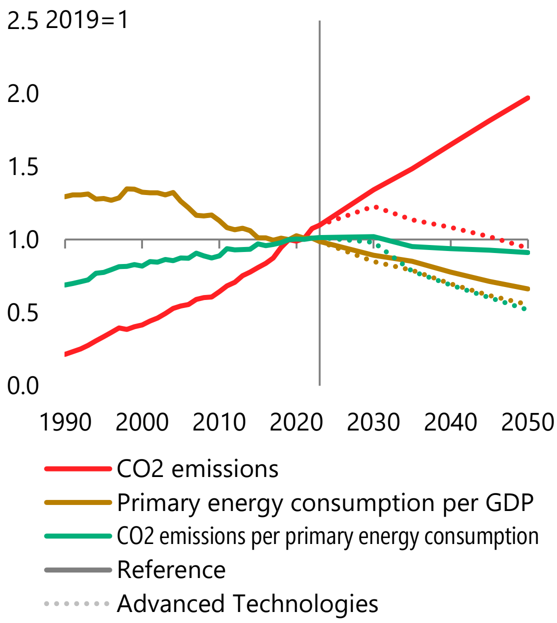
Figure 5-4 | Primary energy consumption per GDP and emission reductions in China



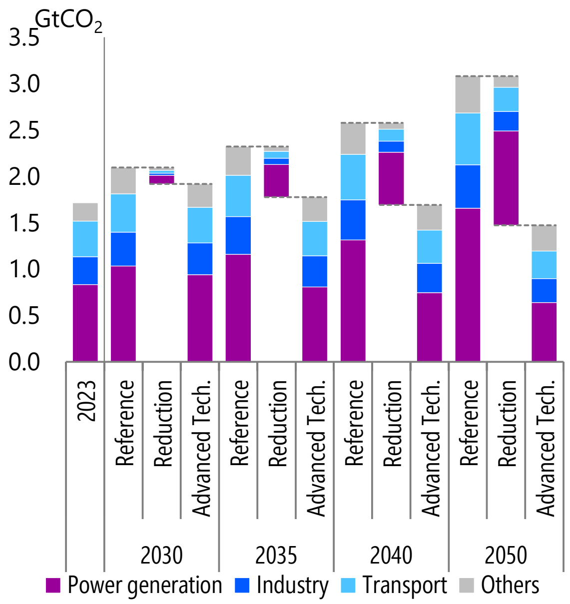
In ASEAN, CO_2 emissions keep increasing along with economic growth and will continue to grow due to strong growth in the future. In the Reference Scenario, CO_2 emissions will increase year by year towards 2050, while in the Advanced Technologies Scenario, they will peak around 2030. During the same period (2030), CO_2 emissions per unit of primary energy consumption will reverse their previous stagnant trend and begin to decline. Furthermore, primary energy consumption per unit of GDP, which was almost stagnant until 2004, began to decline, followed by a year-on-year decrease from 2023 onwards. On the other hand, in terms of CO_2 emissions by sector in 2050, they will double in the power generation sector compared with 2023 levels, increase 1.5 times in the industry sector, and increase approximately 1.5 times in the transport sector. In the Advanced Technologies Scenario, emissions will fall by 20% in the power generation sector, by 14% in the industry sector, and by 20% in the transport sector. Thus, to reduce CO_2 emissions during economic growth, both primary energy consumption per unit of GDP and CO_2 emissions per unit of primary energy consumption must be lowered, presenting significant hurdles on the path towards decarbonisation and carbon neutrality.

Figure 5-5 | Primary energy consumption per GDP and emission reductions in ASEAN

CO_2 emissions



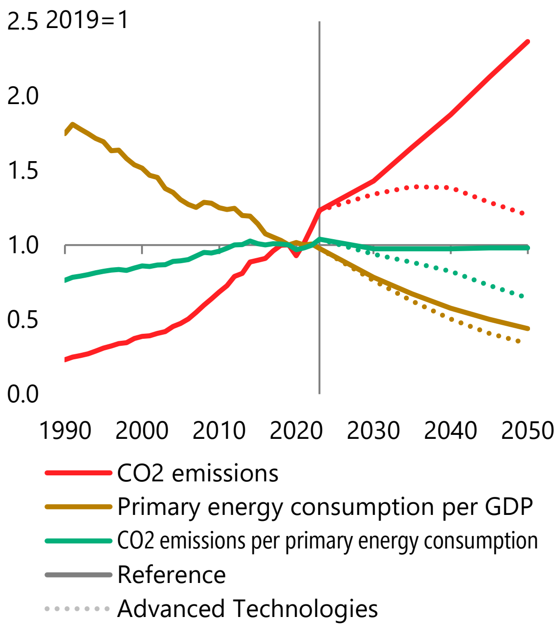
CO_2 emission reductions by sector



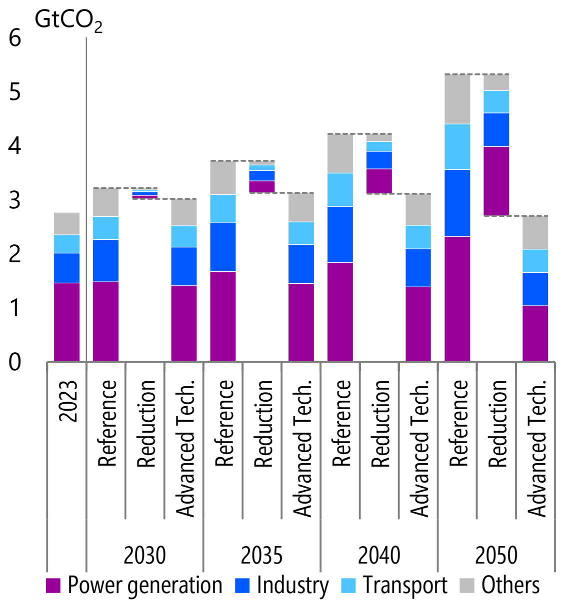
India will follow a path very similar to that of ASEAN, although the scale of its emissions may differ. However, even in the Advanced Technologies Scenario, CO_2 emissions will peak in 2040, and given that CO_2 emissions in 2050 are roughly equivalent to those in 2023, achieving a decarbonised society is becoming increasingly challenging.

Figure 5-6 | Primary energy consumption per GDP and emission reductions in India

CO_2 emissions



CO_2 emission reductions by sector



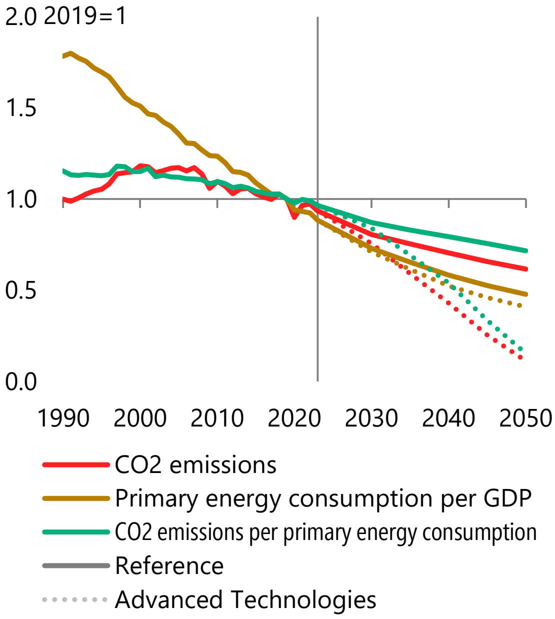
In the United States, CO_2 emissions, which already peaked in the 2000s, will decline in the long term under both the Reference Scenario and the Advanced Technologies Scenario. However, it is necessary to closely monitor the situation as the pace of decline may slow depending on future policy trends. On the other hand, CO_2 emissions per unit of primary energy consumption and primary energy consumption per unit of GDP show a broadly decreasing trend under both scenarios. In 2050, CO_2 emissions from the transport and power generation sectors will decline by 42% compared with 2023 levels in the Reference Scenario, while they will decrease by 81% in the transport sector and by 99% in the power generation sector in the Advanced Technologies Scenario. Unlike China, India and ASEAN, the United States has a large transport sector, which accounts for a substantial share of its CO_2 emissions. However, as mentioned above, in the Advanced Technologies Scenario, significant decarbonisation is also achieved in the transport sector, necessitating technology transfer to other countries.

In the Advanced Technologies Scenario, as stated above, China and the United States will have made significant reductions in emissions from their current levels by 2050, while the reduction rates of ASEAN and India will fall short of those of China and the United States. Comparing these two groups, it is notable that China and the United States will achieve near-zero emissions from the power generation sector. At the same time, CO_2 emissions per unit of primary energy consumption will decline substantially. As shown in Table A25, Table A26, Table A30 and Table A38,

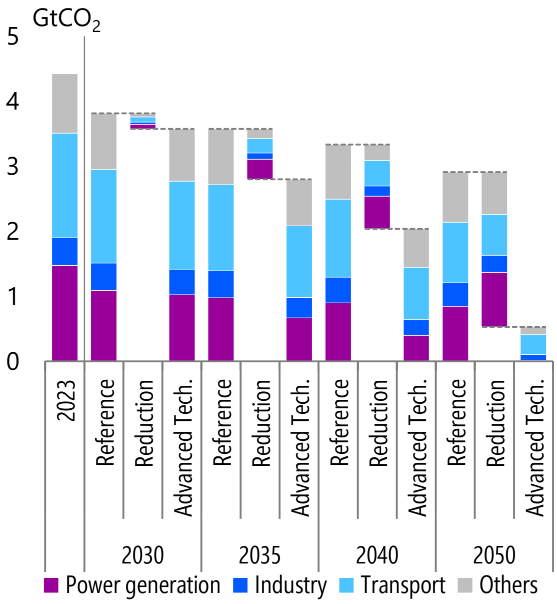
China and the United States will significantly expand the introduction of renewable energies and power sources with carbon capture and storage (CCS) (including bioenergy with CCS [BECCS]). In other words, promoting the transfer of these technologies to developing countries such as ASEAN and India is essential for decarbonising the entire world.

Figure 5-7 | Primary energy consumption per GDP and emission reductions in the United States

CO_2 emissions



CO_2 emission reductions by sector



6. Energy-related investments

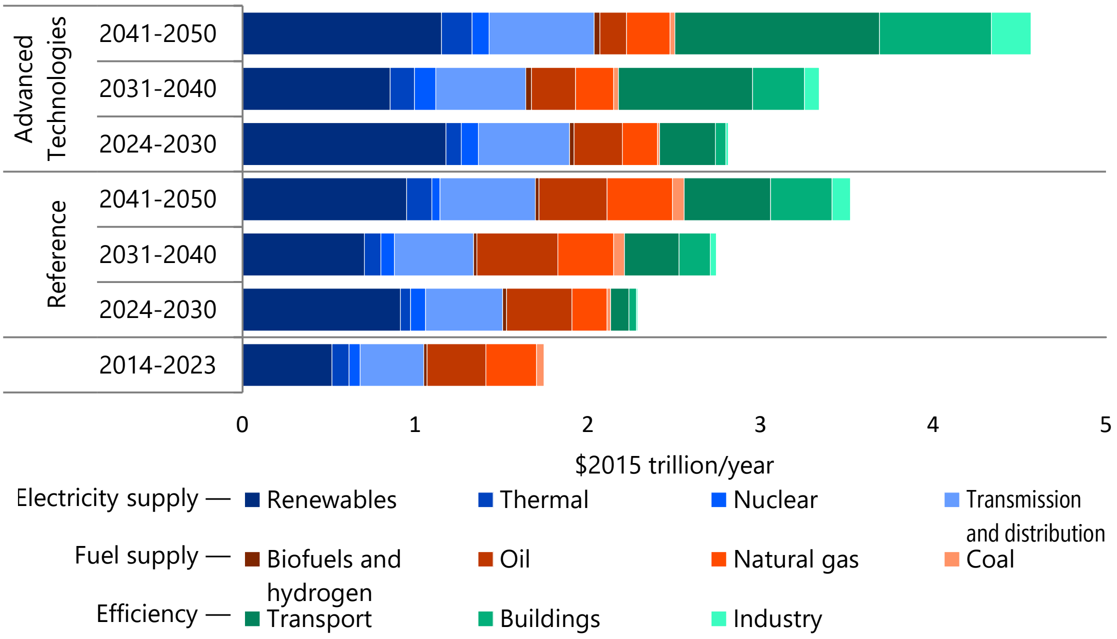
6.1 Recent trends and outlook

Most energy-related investments are made in oil production, natural gas production, and renewables. In the last decade (2014–2023, same hereafter), investments have targeted primarily electricity infrastructure such as renewables and transmission and distribution facilities, followed by facilities related to oil and natural gas production. From the 2020s (2024–2030, same hereafter), accelerated moves towards carbon neutrality will lead to significantly lower capital costs (unit prices) for renewable energy facilities, thus encouraging investments in renewables. In particular, at the 29th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP29), pledges were put forward to expand power grids and energy storage facilities in pursuit of the international goal of tripling global renewable energy capacity by 2030, with over 60 countries endorsing these commitments. Such international agreements are expected to further accelerate the expansion of renewable energy investments. Investments in energy-saving facilities will also increase to break away from dependence on fossil fuels. However, investment in fossil fuels will still need to continue to ensure stable supplies, not only in the Reference Scenario, where demand increases in Emerging and Developing Economies, but also in the Advanced Technologies Scenario.

In the Reference Scenario, energy-related investments[29] will double from an annual average of \$1.8 trillion (2015 real prices, same hereafter) in the last 10 years to an annual average of \$3.5 trillion in the 2040s (Figure 6-1). In the Advanced Technologies Scenario, investments in fossil fuels will be less than in the Reference Scenario. On the other hand, further investments in renewables and energy efficiency will be required, with average annual investment in the 2040s reaching \$4.6 trillion, up \$2.8 trillion from the last 10 years. As a result, cumulative global energy investments required by 2050 will reach \$98.7 trillion.

[29] The investment amounts are estimated based on the amount of newly introduced energy technologies and capital costs in each year, while the historical investments are calculated values.

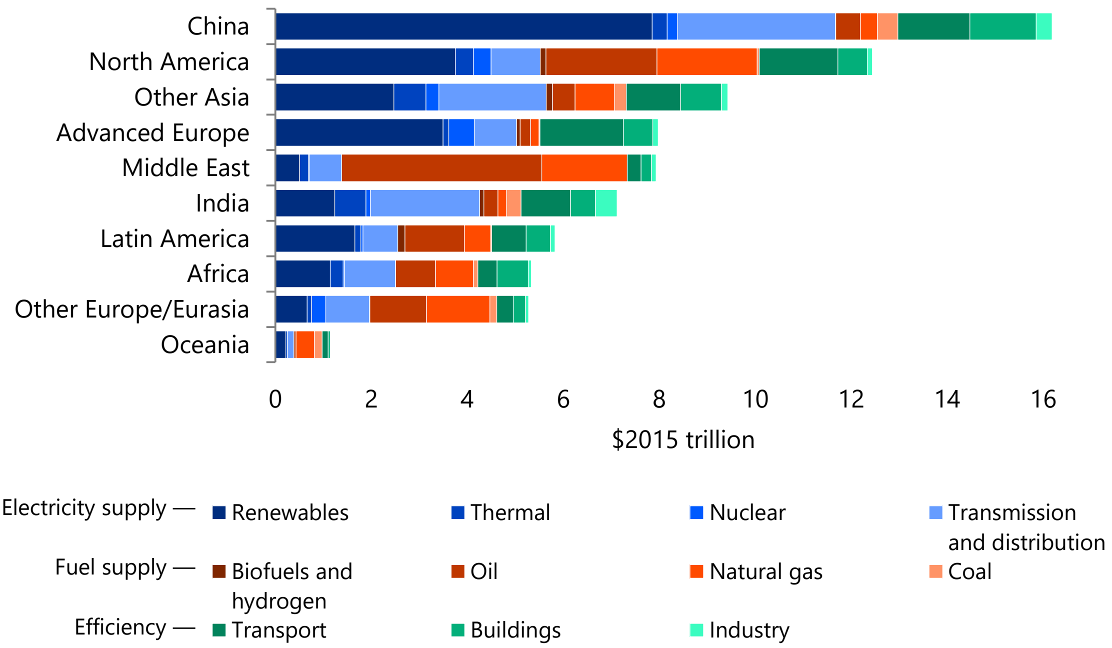
Figure 6-1 | Global energy-related investments



Note: Values of 2014–2023 are estimates.

The amount of energy-related investment varies by region (Figure 6-2).

Figure 6-2 | Energy-related investments [Reference Scenario, cumulative total for 2024–2050]



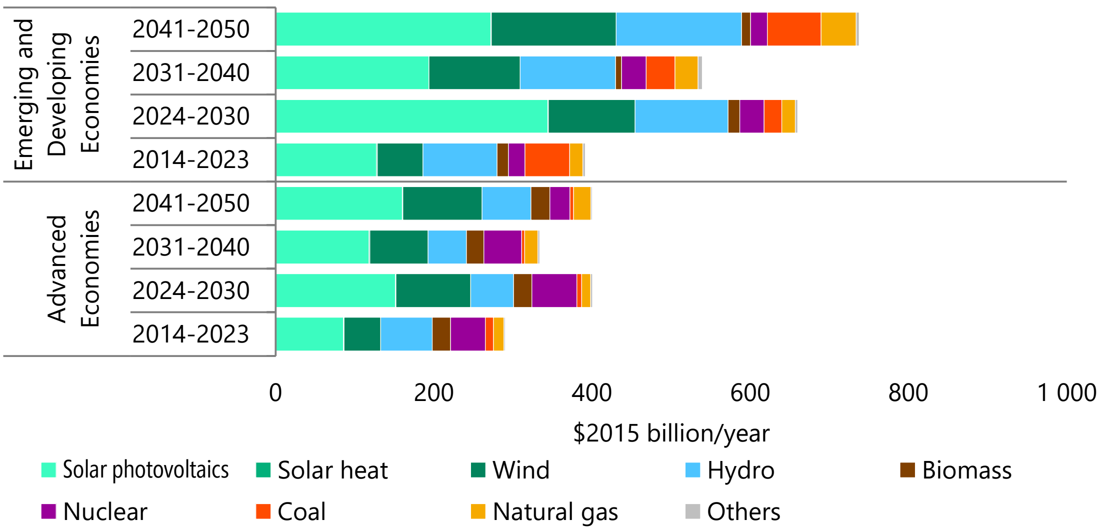
In Advanced Europe, which is moving away from dependence on fossil fuels, investments in renewables and energy efficiency will account for more than 70% of total investment. On the other hand, in Oceania, which is also a fossil fuel supply region among other Advanced Economies, investments in oil and natural gas will account for about half of total investment, with renewable energy investments remaining at less than 20%. In the Middle East, another fossil fuel supply region, investments in oil and natural gas production will exceed 70%, while investments in renewables and energy efficiency will account for around 10%. In North America, investments in renewables will account for 30% of total investment, while those in the production of fossil fuels, such as the development of shale oil and gas, will account for a similar proportion. In China, investment in renewable energy facilities is accelerating, accounting for nearly half of the total, as China aims to achieve the '3060 Target', a national strategy to reach peak carbon dioxide (CO_2) emissions by 2030 and achieve carbon neutrality by 2060. In addition, China is investing heavily in power transmission and distribution, making its cumulative investment the largest of any country or region. India, a fast-growing country, will have the largest share of investment in power transmission and distribution due to the installation of new networks to meet the growing demand for electricity, while investment in energy efficiency will be under 30% and renewables will be under 20%.

6.2 Electricity investments

Increased investment in renewable energy, especially in Emerging and Developing Economies

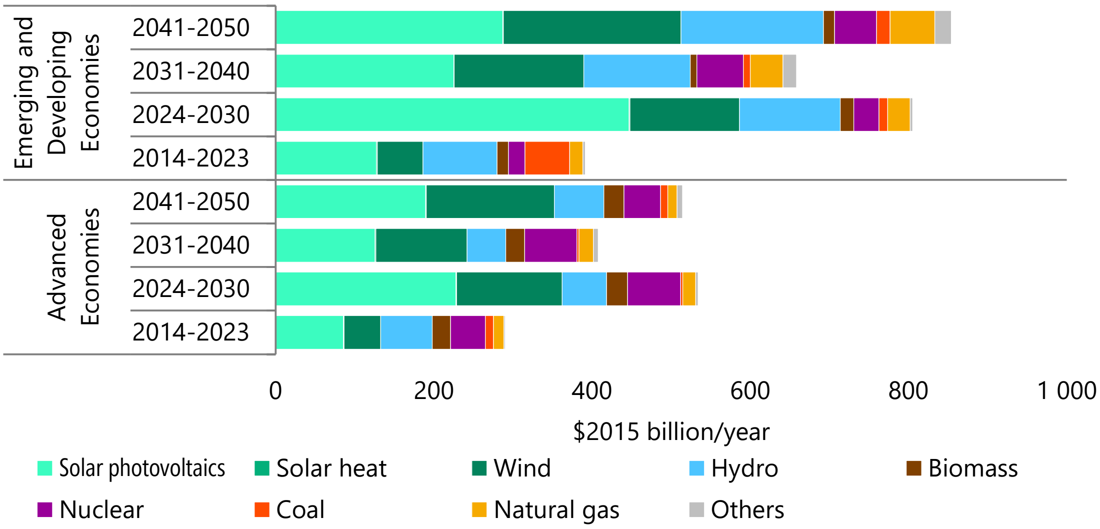
Of the investments in power generation equipment, those in renewable energy facilities account for the largest share (Figure 6-3 and Figure 6-4).

Figure 6-3 | Power generation equipment investment [Reference Scenario]



Note: Values of 2014–2023 are estimates.

Figure 6-4 | Power generation equipment investment [Advanced Technologies Scenario]



Note: Values of 2014–2023 are estimates.

In the last decade, feed-in tariffs and net metering systems contributed to active investments in renewable energy facilities in many regions. From the 2020s onwards, investments in Emerging and Developing Economies will increase significantly in both the Reference and Advanced Technologies Scenarios.

In the Reference Scenario, investments after the 2020s will be higher than in the last 10 years, both in Advanced Economies and Emerging and Developing Economies. In the 2020s, countries will continue to expand investment, particularly in renewables such as solar photovoltaics and wind, to achieve their Nationally Determined Contributions (NDCs). As a result, the average annual investment will increase significantly compared with the last 10 years, approximately 1.4 times in Advanced Economies and 1.7 times in Emerging and Developing Economies. In the 2030s, the average annual investment will decline in both Advanced Economies and Emerging and Developing Economies due to lower capital costs, such as cheaper solar panels and larger wind turbines, but will begin to increase again in the 2040s as more capacity is installed. Advanced Economies will mainly invest in solar photovoltaics, wind, and nuclear. Among fossil fuel power sources, the average annual investment in natural gas-fired power generation will continue to expand through the 2040s. Emerging and Developing Economies will continue to invest in hydro in addition to solar photovoltaics and wind. Among fossil fuel power sources, investment in coal-fired power generation will be notable, exceeding that in natural gas-fired power generation in average annual terms in the 2040s.

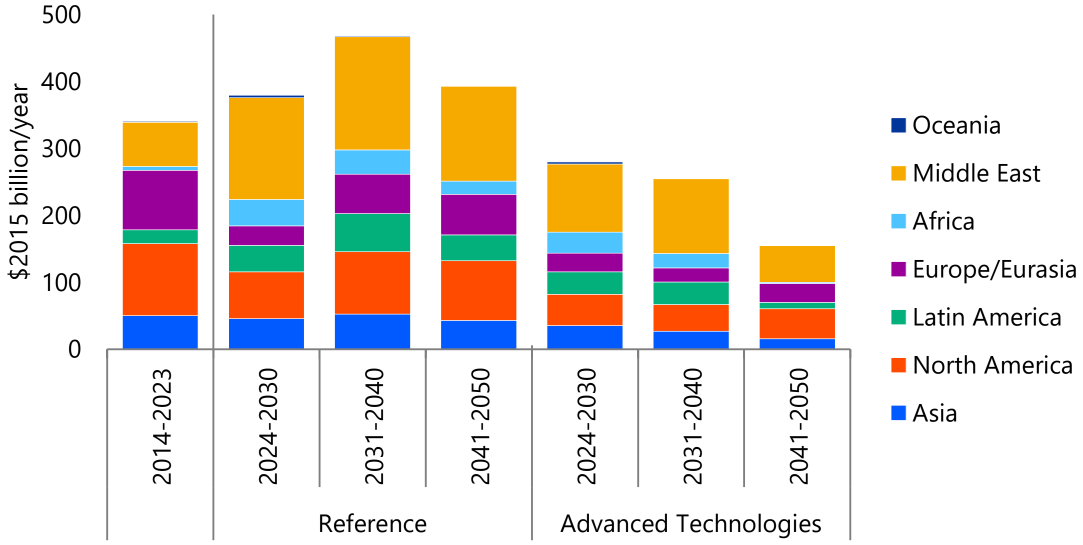
In the Advanced Technologies Scenario, solar photovoltaics and wind will be more actively introduced compared with the Reference Scenario. In addition, there will be a marked increase in nuclear in Advanced Economies, while nuclear and natural gas will be actively introduced in Emerging and Developing Economies. Increased investment in these areas will drive the overall increase in average annual investment under the Advanced Technologies Scenario.

6.3 Investments in oil and natural gas

Although there are moves towards carbon neutrality and a shift from dependence on certain regions (such as Russia for fossil fuel supply), investments in oil and natural gas will not necessarily decline, particularly as demand continues to increase in Emerging and Developing Economies.

In the Reference Scenario, average annual investment in oil will increase in the Middle East and North America due to expanding demand, reaching about 1.4 times the level of the past 10 years in the 2030s. Although declining in the 2040s, average annual investment will remain higher than in the last decade due to persistent demand, especially from Emerging and Developing Economies (Figure 6-5). In contrast, in the Advanced Technologies Scenario, progress in transportation fuel efficiency and accelerated energy substitution with biofuels and other sources will result in average annual investment from the 2020s falling below the level of the past 10 years and continuing to drop. As a result, investments in the 2040s will be about half of those in the last 10 years.

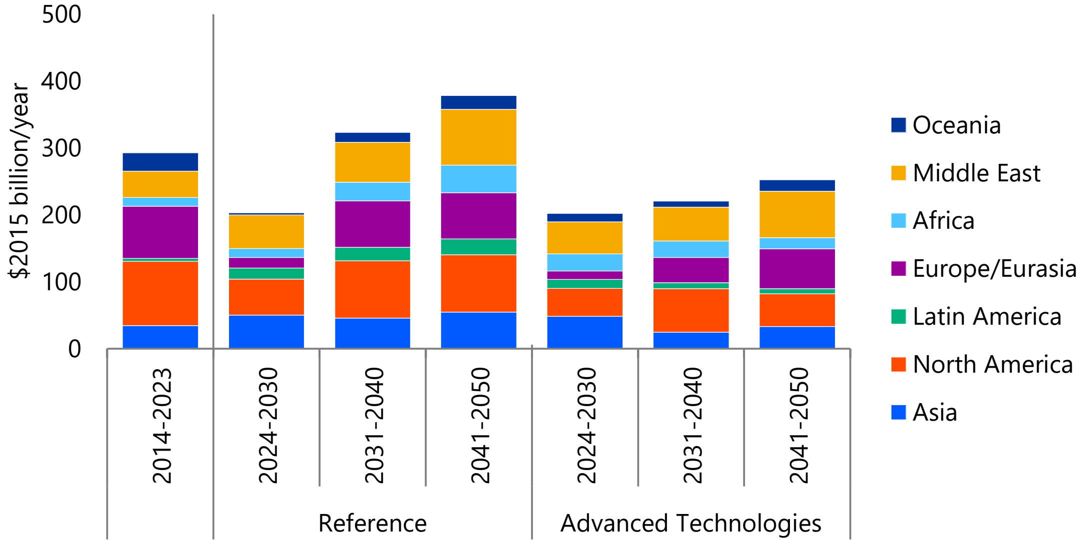
Figure 6-5 | Investment in the oil sector



Note: Values of 2014–2023 are estimates.

In the Reference Scenario, average annual investment in natural gas will continue to expand in light of growing demand, primarily in North America, the Middle East, Russia and Europe/Eurasia, and will increase by approximately 1.3 times in the 2040s compared with the most recent decade (Figure 6-6). However, in the Advanced Technologies Scenario, where renewables and nuclear increase further, from the 2020s, the average annual investment will remain lower than in the most recent decade. Even after this initial decline, a gradual increase will continue until the 2040s due to expanded demand in Emerging and Developing Economies, with investments in North America, the Middle East and Europe/Eurasia driving the increase.

Figure 6-6 | Investment in the natural gas sector

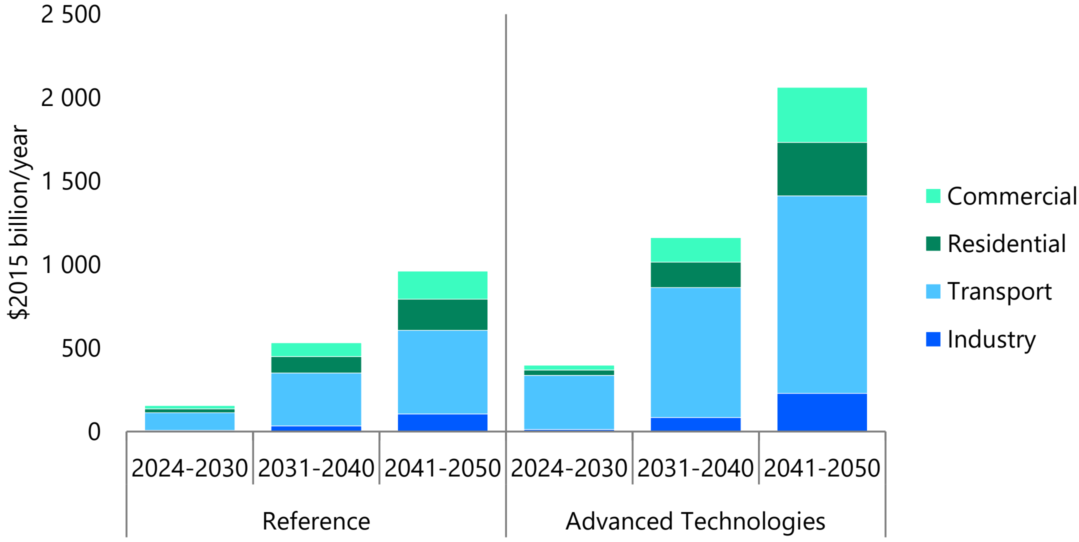


Note: Values of 2014-2023 are estimates.

6.4 Energy efficiency investments

In terms of average annual investment for introducing energy-efficient[30] equipment on the demand side, the transport sector will account for more than half, followed by the buildings sector with about 30% (Figure 6-7).

Figure 6-7 | Global energy efficiency investments



In the Reference Scenario, the transport sector will see increased average annual investment due to the shift from conventional internal combustion engine vehicles such as gasoline- and diesel-fuelled vehicles to zero-emission vehicles such as electric vehicles. In the Advanced Technologies

[30] Energy efficiency levels in 2023 are considered as the baseline.

Scenario, average annual investment will increase due to accelerated electrification driven by the expanded use of electric vehicles and the introduction of fuel cell vehicles that use hydrogen.

In the buildings sector, investments in the commercial sector will exceed those in the residential sector. Furthermore, particularly in the Advanced Technologies Scenario, the average annual investment will increase due to accelerating improvements in the efficiency of newly installed home appliances and equipment and their insulation performance, as well as the shift to electrifying space- and water-heating and cooking equipment and clean cooking solutions.