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).

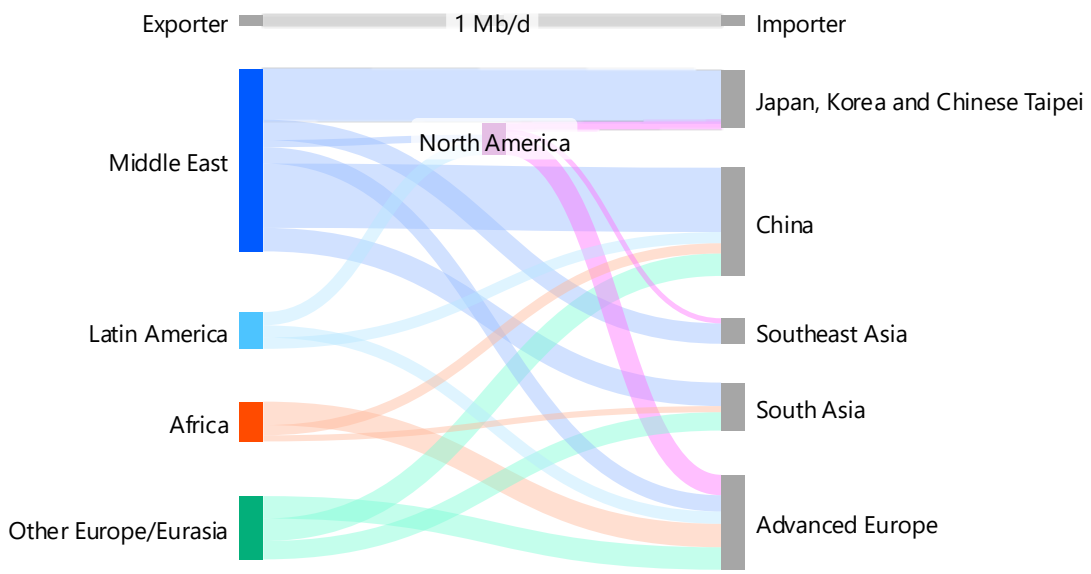
Asia's growing dependence on Middle Eastern crude oil

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.

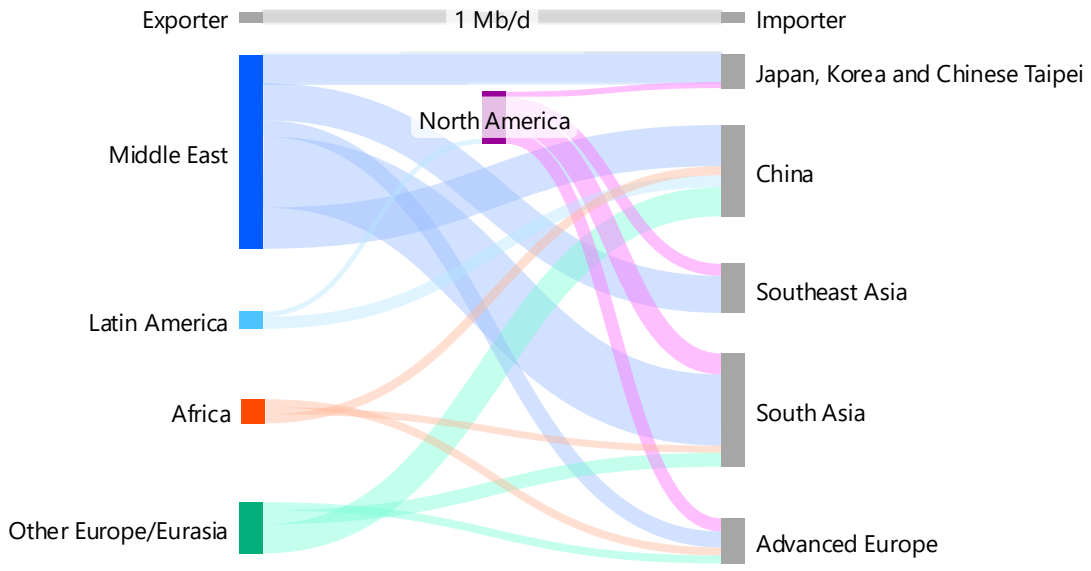
As for imports, Asia is by far the largest importing region with about 25 Mb/d, of which China, the world's largest importer, accounts for about 10 Mb/d. Advanced Europe's imports are also large, at 10 Mb/d. The largest supplier for Asia is the Middle East, with a 60% dependency rate for Asia as a whole. 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.

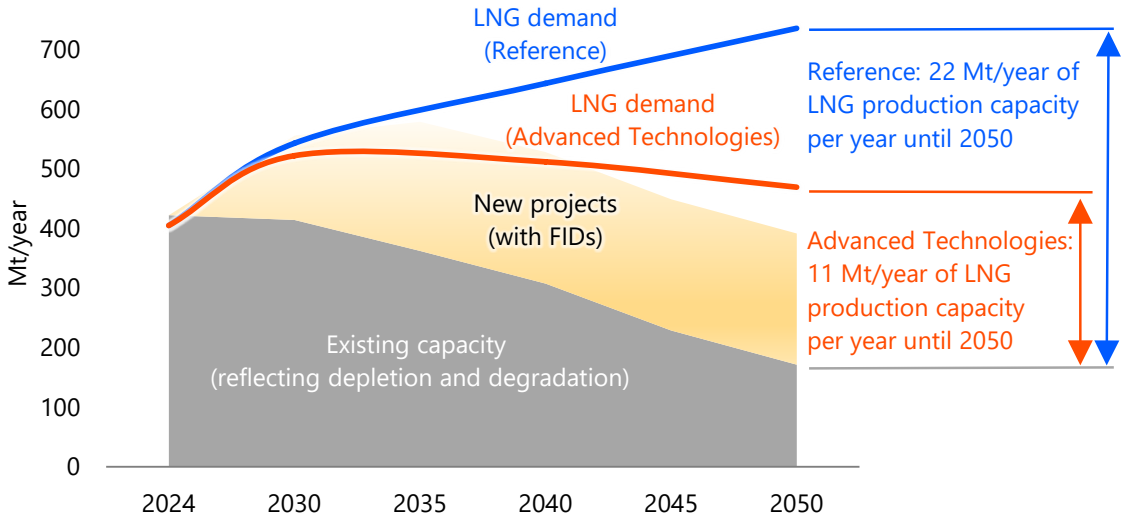
In this regard, the discussion at the 2025 LNG Producer-Consumer Conference on strengthening cooperation among governments and relevant organisations to stabilise the LNG market and promote cleaner LNG production represents progress.

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.

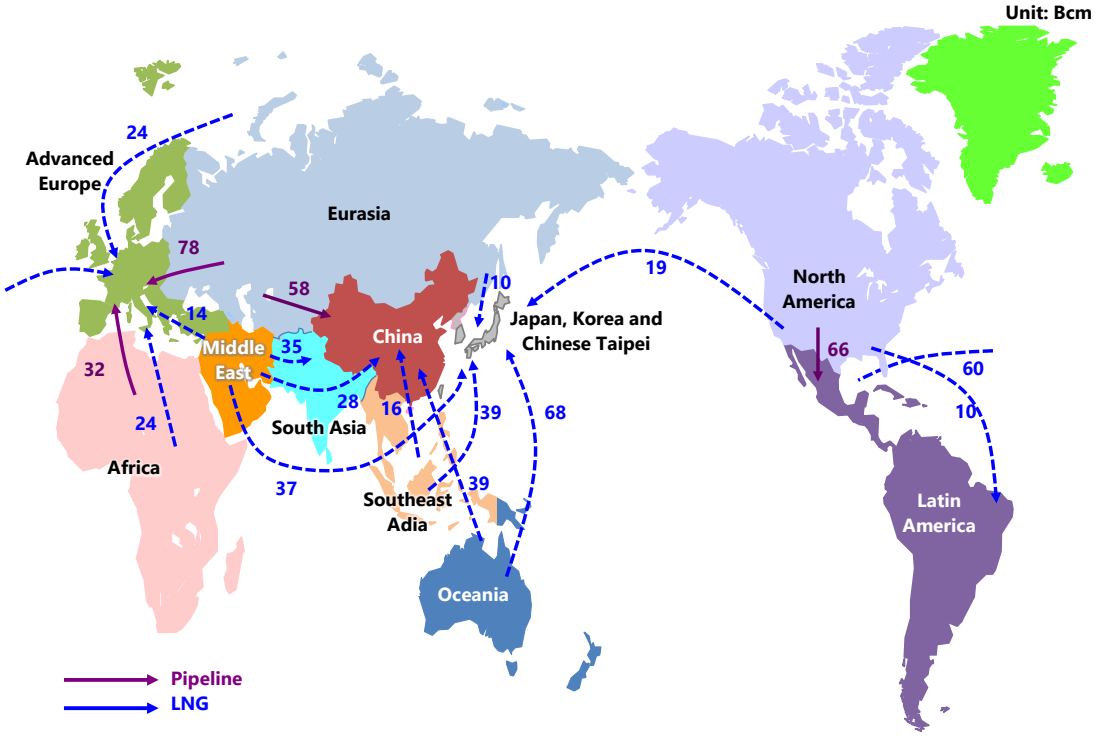
Unplanned shutdowns of LNG production facilities are increasing and are likely to cause serious problems when the supply-demand balance is tight. One example is a large US LNG export facility that shut down for extended periods after a fire in 2022, which coincided with relatively long unplanned shutdowns 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)

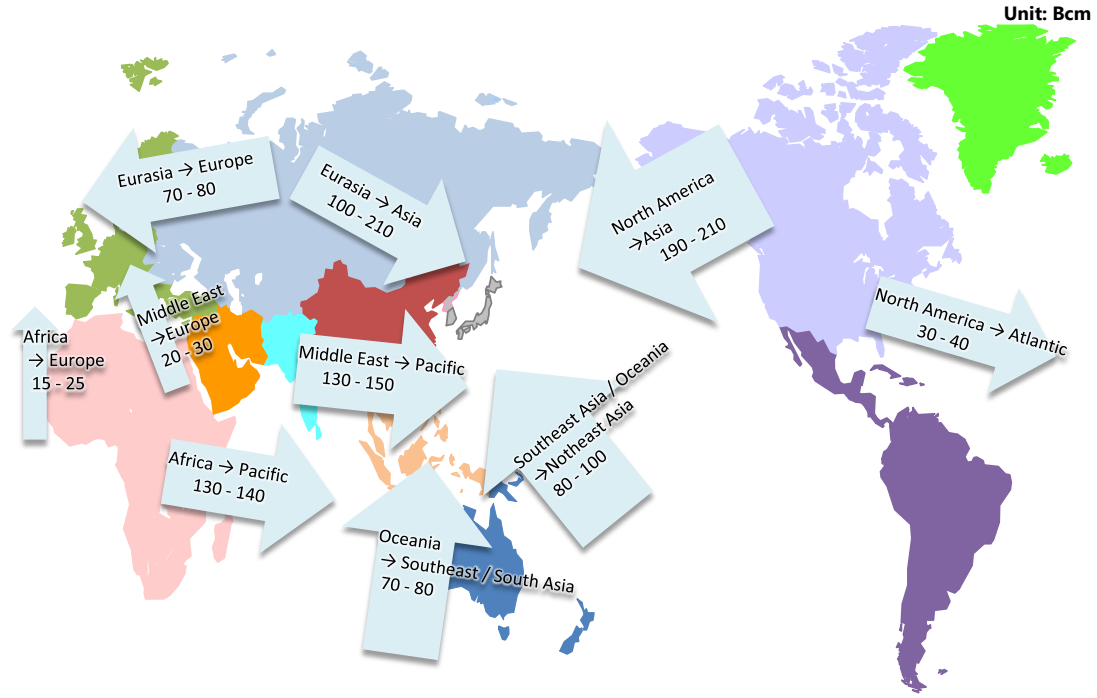
	2023	2030	2040	2050	2023-2050	
					Changes	CAGR
World	4 222	4 322	4 775	5 386	1 165	0.9%
North America and Mexico	1 280	1 292	1 385	1 365	85	0.2%
Latin America excl. Mexico	199	234	289	356	156	2.2%
Europe	196	136	132	106	-90	-2.2%
Eurasia	856	820	839	909	52	0.2%
Russia	638	600	600	609	-29	-0.2%
Middle 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

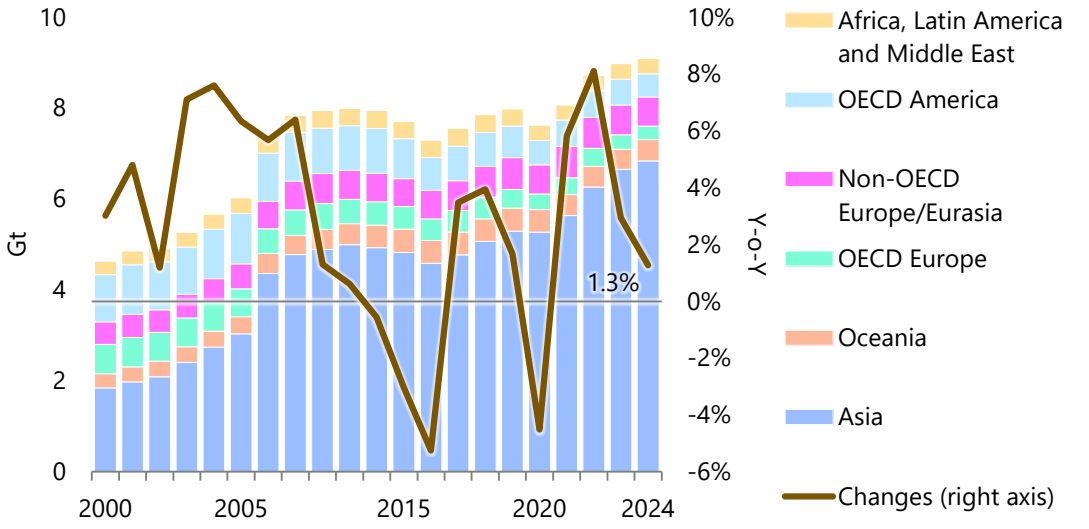
Overview of global supply and demand

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.

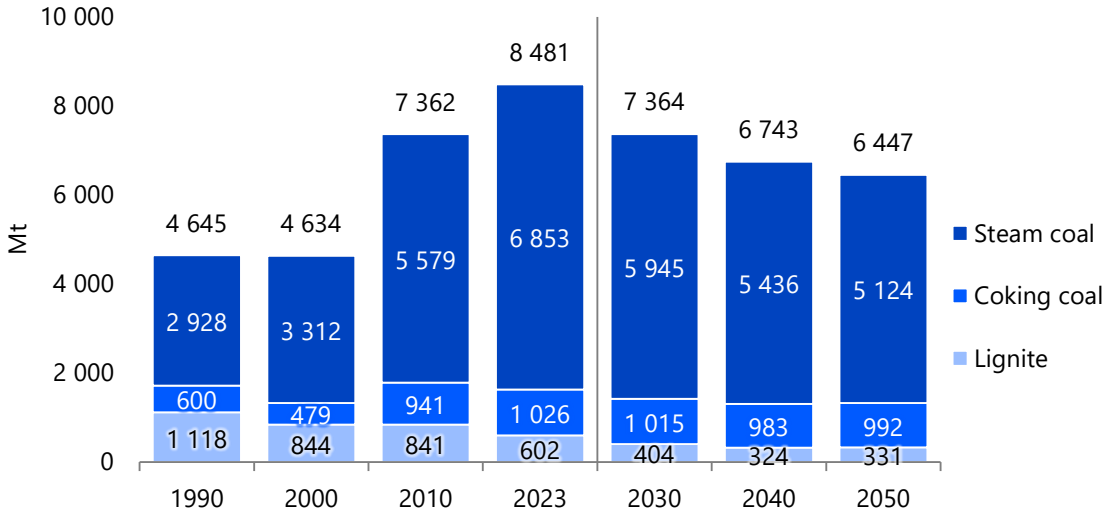
Maintaining a supply system that meets demand

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	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%

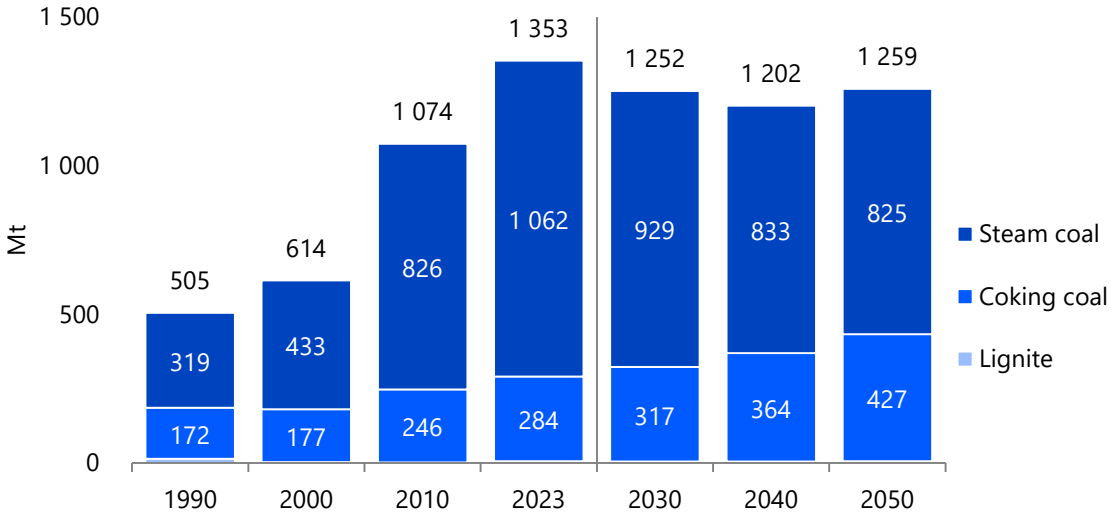
Table 3-5 | Coking coal production [Reference Scenario]

(Mt)

	2023	2030	2040	2050	2023-2050	
					Changes	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%

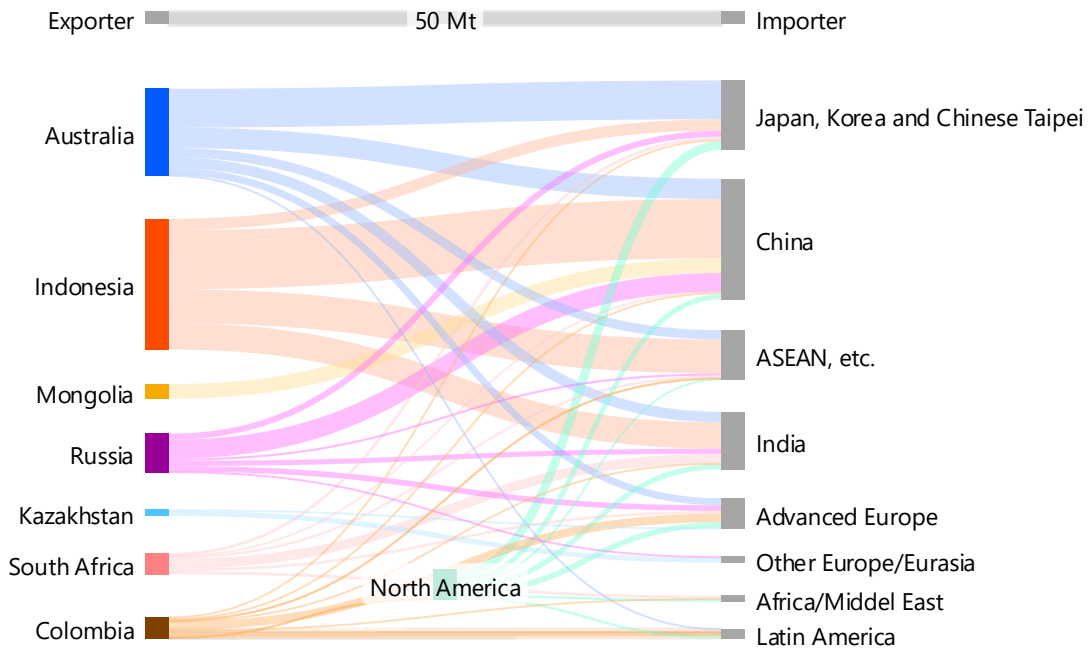
Coal trade volume will decrease from 1 353 Mt in 2023 to 1 202 Mt in 2040 but will then increase slightly to 1 259 Mt in 2050. By type of coal, trade of steam coal will decline significantly from 1 062 Mt in 2023 to 825 Mt in 2050, as China's imports peak in the late 2020s followed by a decline amid 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]



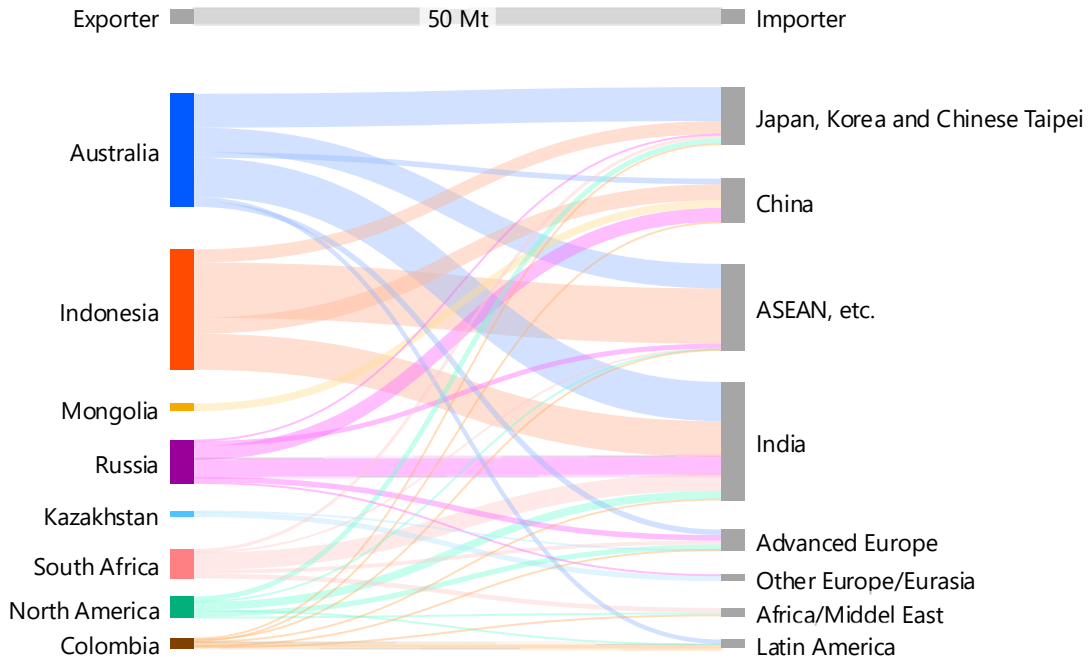
By major exporters, Australia will maintain the current level, but the volume balance will shift in line with demand changes, with steam coal decreasing and coking coal increasing. Indonesia will tend to reduce its export volume while maintaining production to meet increasing domestic demand. This will 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 [2023]



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]



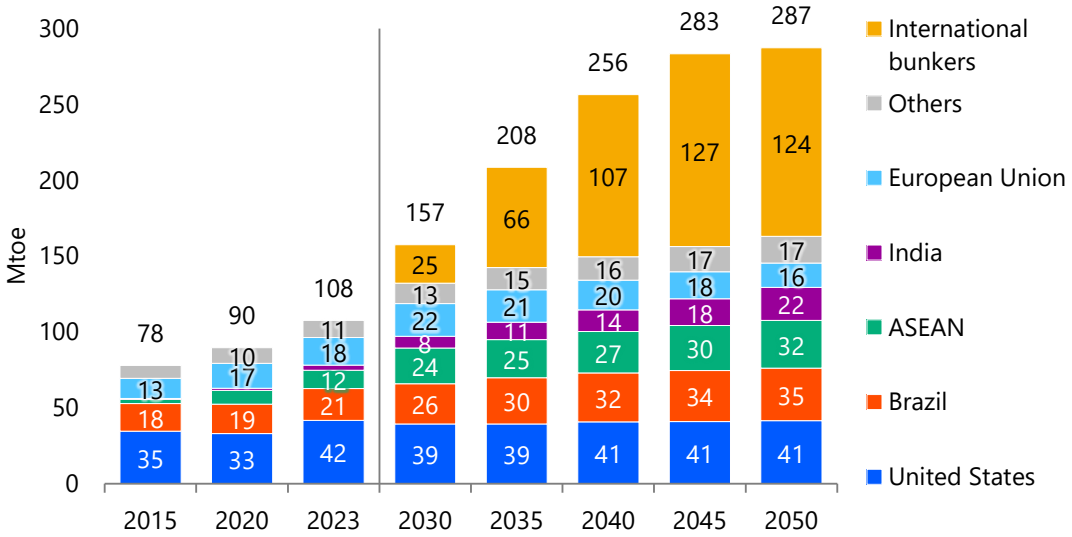
Notes: Sum of steam coal and coking coal. 2 Mt or more listed. South Africa includes Mozambique.

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.

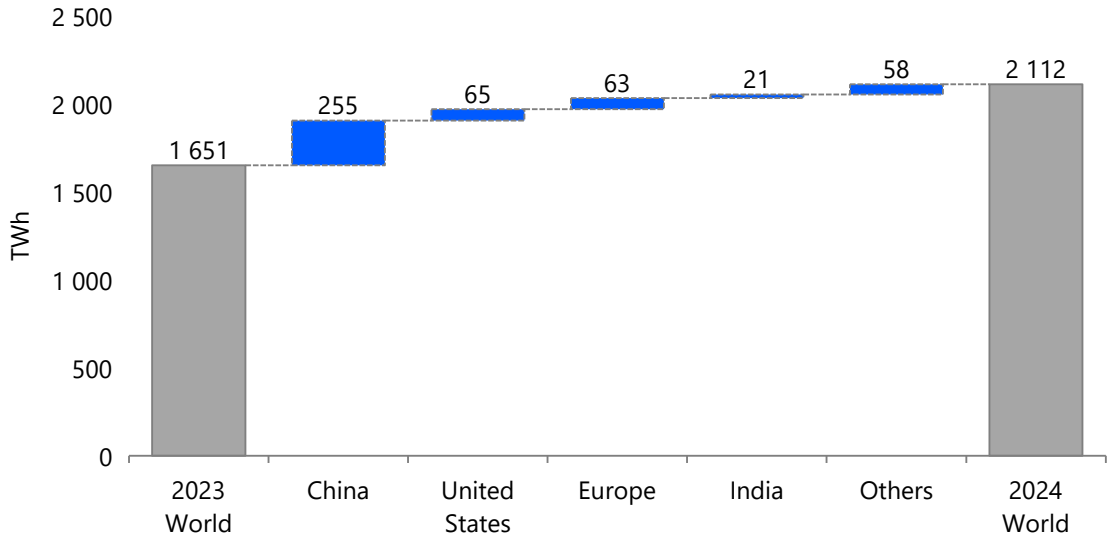
Solar photovoltaics continue to expand drastically, especially in China.

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]

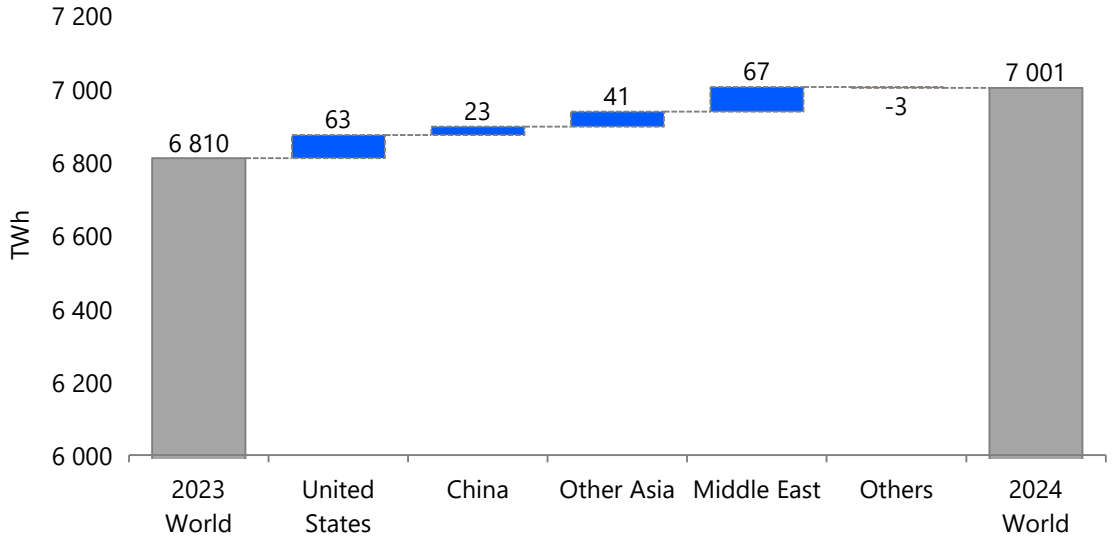


Source: Energy Institute "Statistical Review of World Energy" (2025)

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]



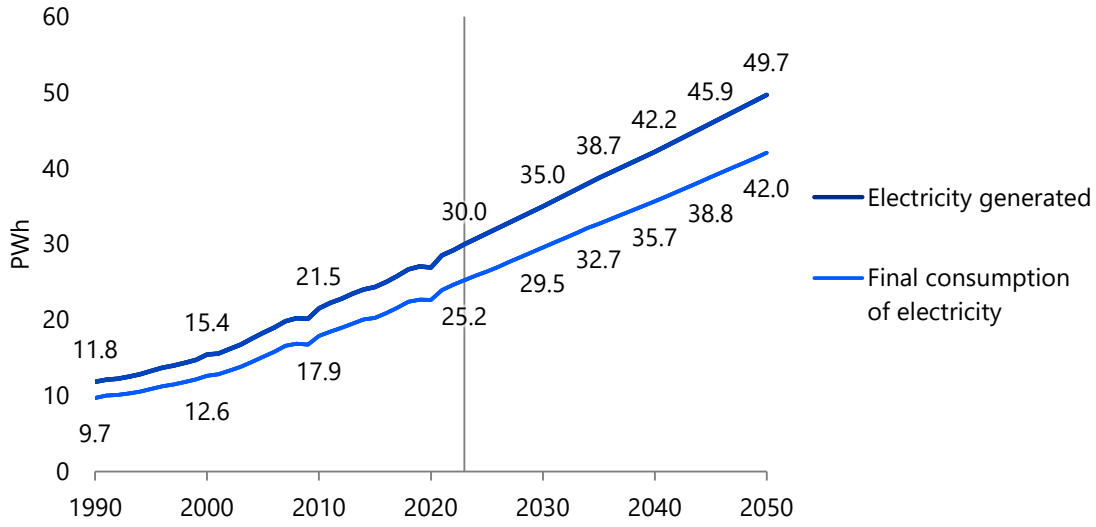
Source: Energy Institute "Statistical Review of World Energy" (2025)

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.

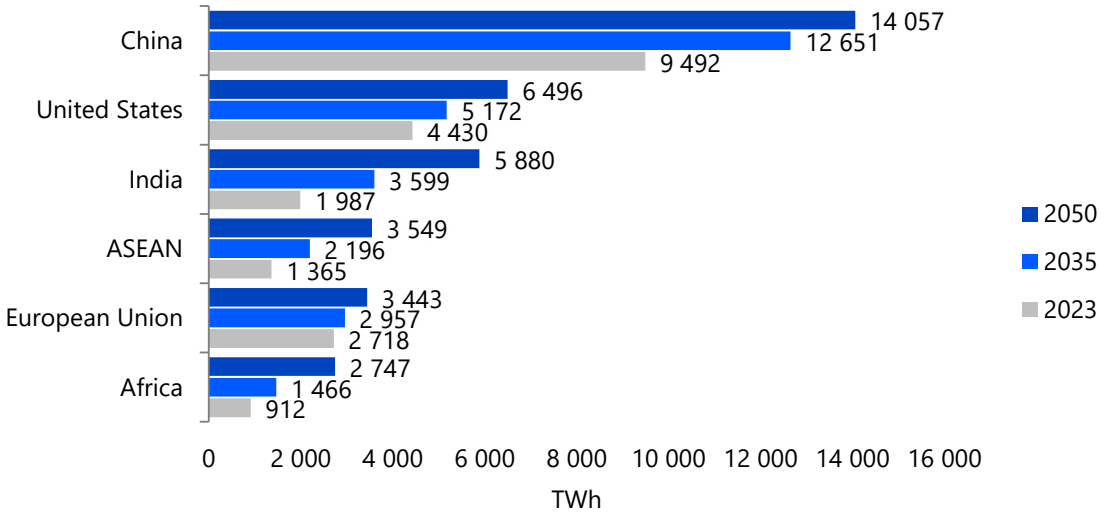
Figure 3-14 | Global electricity generated and final consumption of electricity [Reference Scenario]



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]

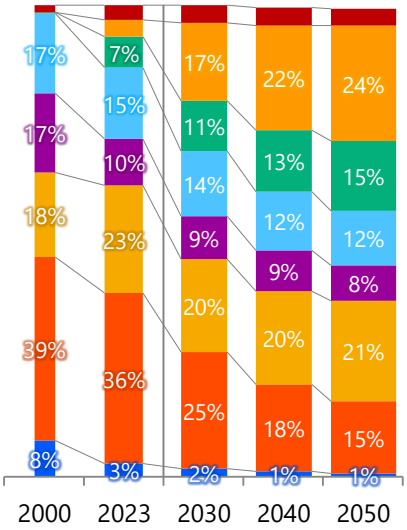


Power generation mix: Natural gas will become the largest power source.

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.

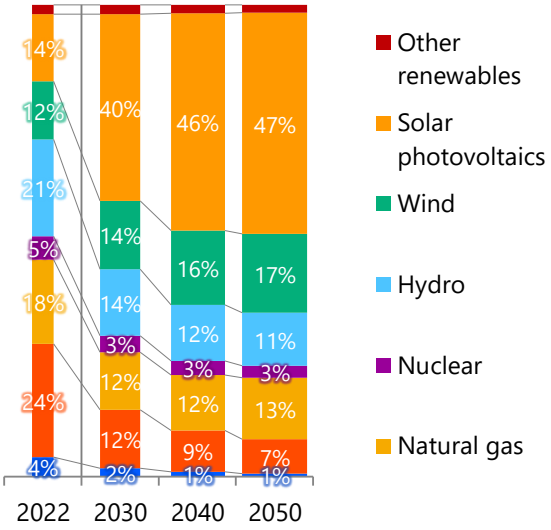
Figure 3-16 | Global power generation mix [Reference Scenario]

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.

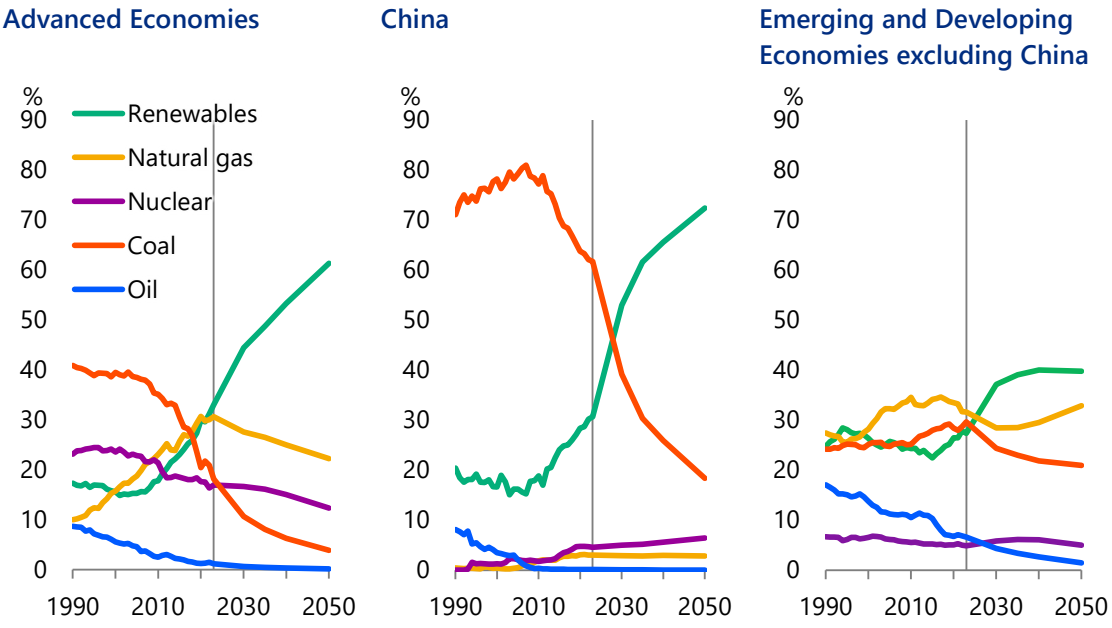
Power generation mix (overview by region)

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]

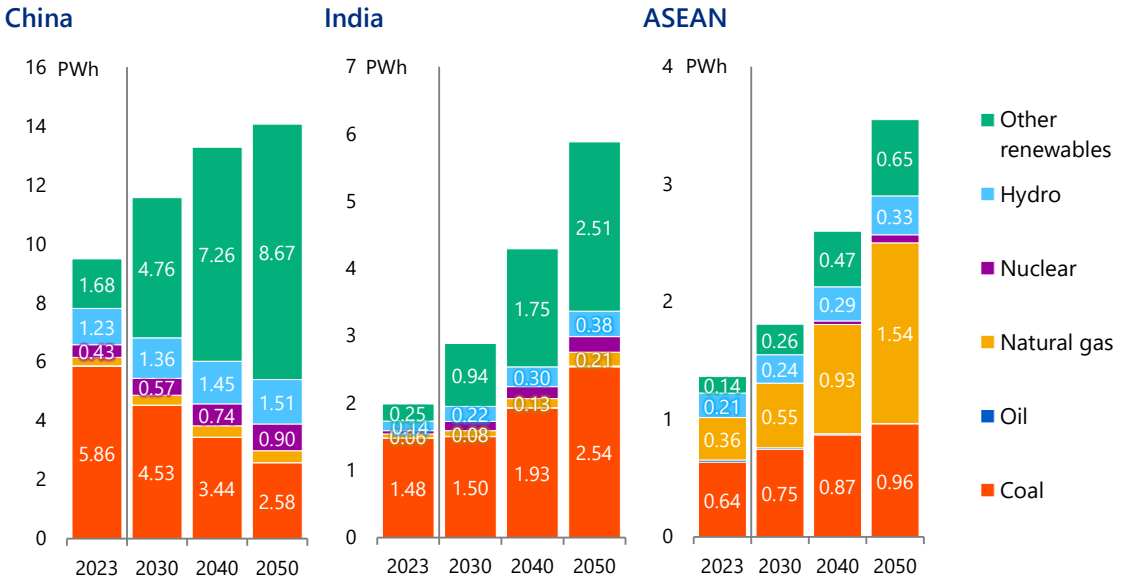


Diverging prospects for coal and renewable energies in three emerging areas in Asia

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.

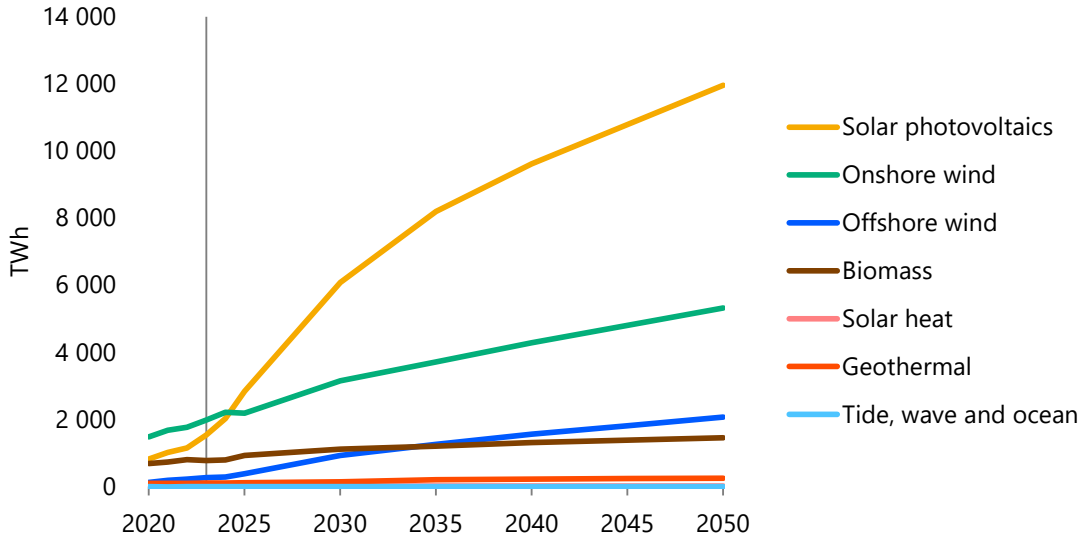
Beyond economic benefits, an increasing number of countries and regions are committing to renewable energy introduction targets (Table 3-6). Whilst regional variations in deployment approaches may emerge in response to developments such as the second Donald Trump administration, the overall global growth 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]

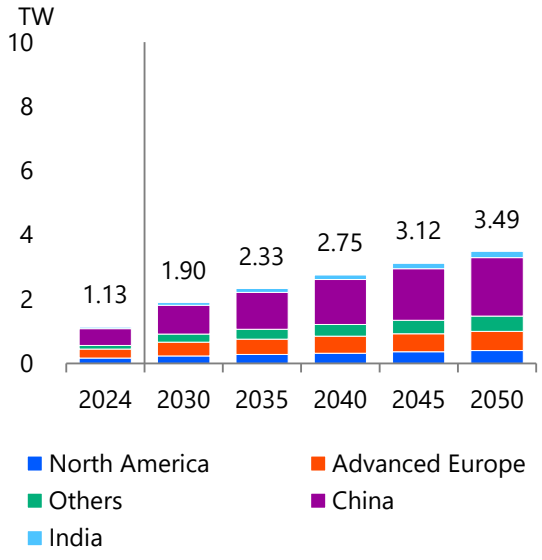
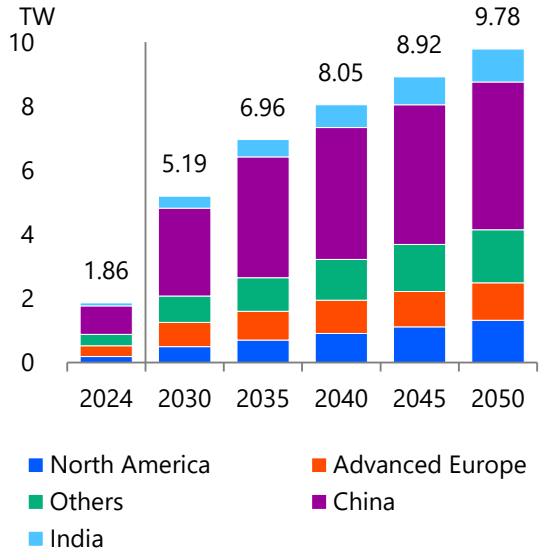


Figure 3-21 | Global installed solar photovoltaic power generation capacity [Reference Scenario]



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

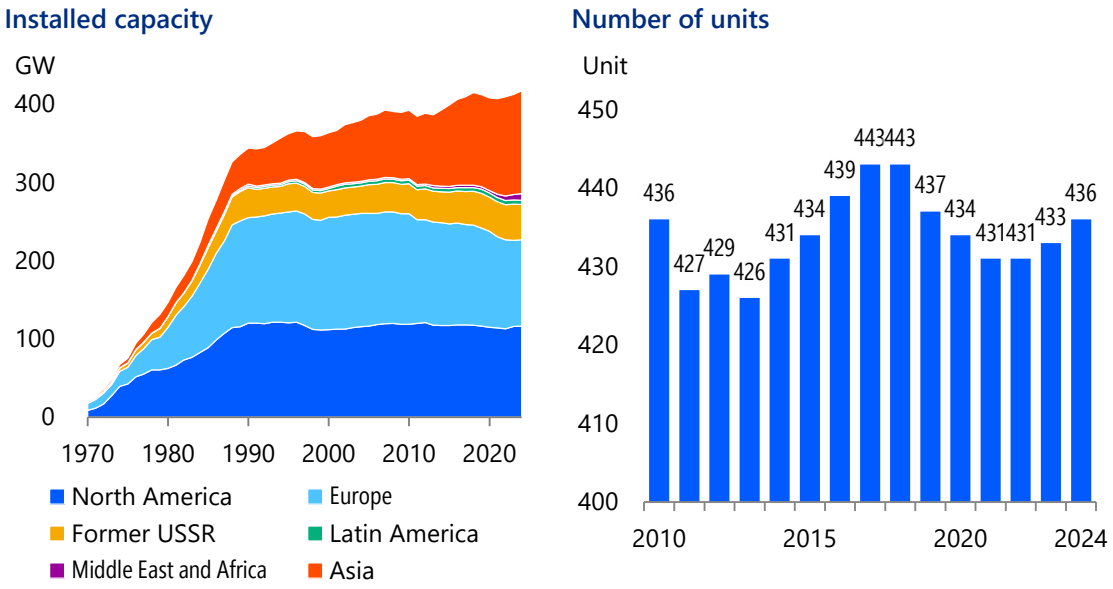
variable power sources, address grid constraints appropriately, and overcome location limitations through technological innovation. The Advanced Technologies Scenario described below assumes a situation where these challenges have been partially, though not completely, alleviated through policy measures 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.

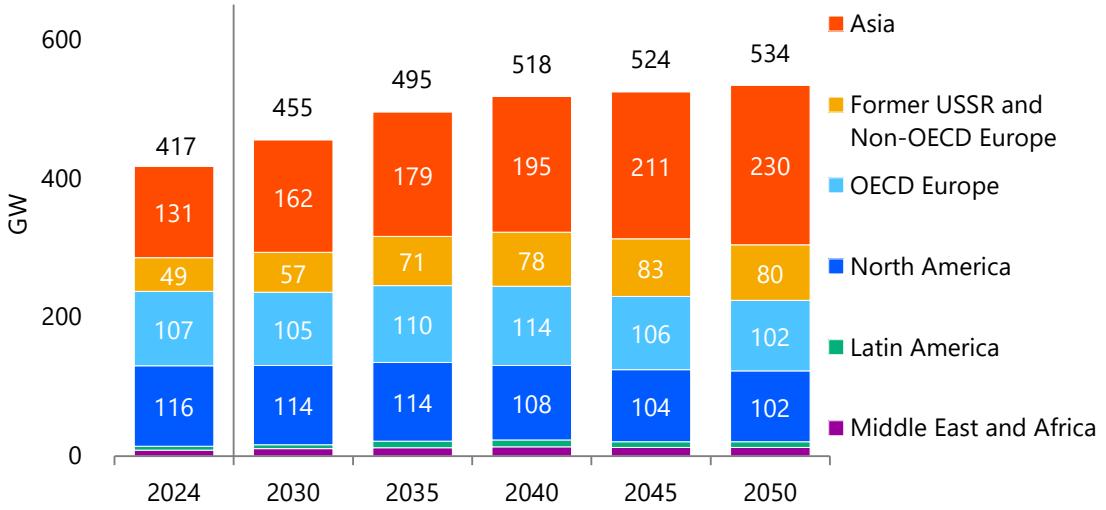
Thus, efforts are under way in many countries towards expanded use of nuclear as its role attracts increasing attention. However, in many cases, the final success or failure of the introduction will depend not only on governments' policies, but also on developers' ability to offer customers acceptable 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.

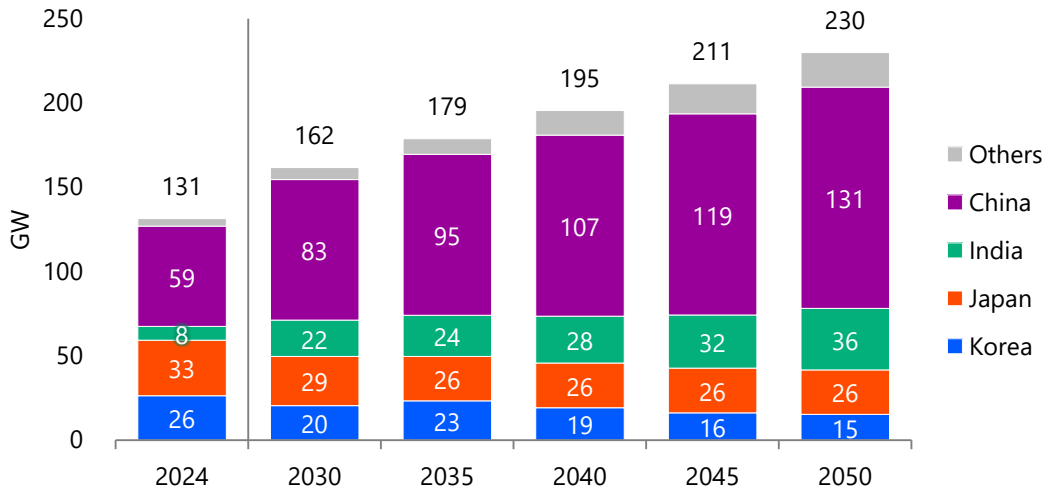
Switzerland has clearly established nuclear phase-out plans following the Fukushima Daiichi Nuclear Power Station accident and will cease nuclear power generation by 2035 under the government's decommissioning schedule. Belgium had originally planned to close all reactors by 2025, but following the reversal 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.

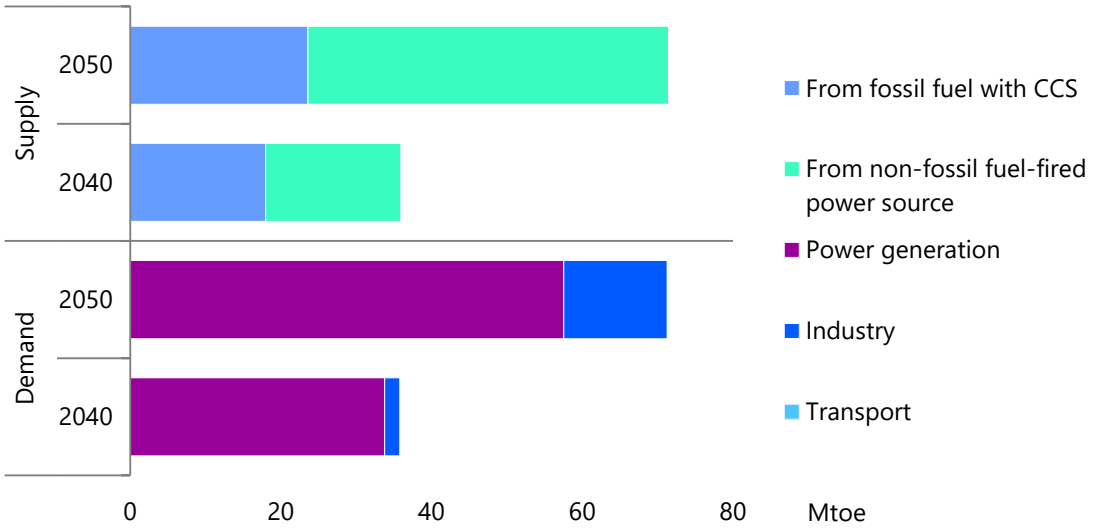
China has become the world's largest consumer of hydrogen. Its hydrogen production and consumption in 2024 were reported to be 36.5 Mt. China announced its 'Medium- and Long-Term Development Plan for the Hydrogen Energy Industry' in March 2022, with the goal of producing 100 kt/year–200 kt/year of renewables-derived 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) and bioenergy with carbon capture and storage (BECCS). 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 (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-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.