IEEJ Outlook 2025

Energy, Environment and Economy

How to address the uncertainties surrounding the energy transition

IEE JAPAN

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Summary

Global energy supply and demand outlook through 2050

Future primary energy: India and ASEAN drive demand expansion

- Our analysis presents two scenarios[1] for global energy supply and demand through 2050. Following current trends, the Reference Scenario projects a 14% increase in global primary energy demand from 2022 to 2050. In contrast, the Advanced Technologies Scenario, which assumes the ambitious deployment of energy and environmental technologies, shows demand will peak by 2030 and fall 6% below 2022 levels by 2050.
- Both scenarios indicate declining energy demand in Advanced Economies and China, while Emerging and Developing Economies—particularly India and the Association of Southeast Asian Nations (ASEAN)—emerge as the primary growth drivers.

Key CO_2 reduction pathways: focus on efficiency, renewables and CCUS

- The Reference Scenario shows global energy-related carbon dioxide (CO_2) emissions plateauing at 32.7 Gt by 2050, as efficiency gains offset demand growth. The Advanced Technologies Scenario projects a significant 62% reduction to 12.9 Gt. The massive reduction requires the convergence of various technologies and mainly relies on three key pillars: energy efficiency improvements, renewable energy expansion (primarily solar photovoltaics and wind), and carbon capture, utilisation and storage (CCUS) deployment.
- Energy efficiency improvements could deliver 6.2 Gt-CO_2 in reductions between the scenarios. The greatest potential lies in Emerging and Developing Economies, where implementing proven technologies from Advanced Economies is crucial. This is especially critical for China, India and ASEAN, where industrial energy consumption is set to surge.
- However, efficiency measures have a lag time—it often takes over a decade for improvements in new equipment to significantly impact overall stock efficiency. Meeting the Advanced Technologies Scenario's 2050 targets require immediate action for efficiency improvement.
- Renewable energy shows dramatic growth potential, reaching nearly 60% of global electricity generated in the Advanced Technologies Scenario (excluding hydro). At this level of penetration many regions will have variable renewable power generation capacity exceeding average load, requiring significant investments in grid-scale storage, transmission infrastructure, demand response systems integration with existing pumped storage hydro and thermal power generation backup.
- Overall electricity generated is projected to increase 1.6 times (Reference Scenario) to twice (Advanced Technologies Scenario) from 2022 levels by 2050, requiring substantial grid infrastructure expansion.

[1] The scenarios in IEEJ Outlook represent forward-looking projections based on current trends and technology pathways, distinct from backward-planning approaches that start with specific targets (e.g. net zero emissions by 2050) and work backward.

- CCUS emerges as a critical technology, capturing 5.1 Gt-CO_2 annually by 2050. While particularly important for power generation, CCUS—alongside hydrogen—becomes essential for hard-to-abate industrial sectors like steel and cement production, where electrification alone cannot achieve complete decarbonisation.

Fossil fuel outlook: significant uncertainty

- The scenarios reveal widely divergent paths for fossil fuels. The Reference Scenario shows increased oil and natural gas demand through 2050, while the Advanced Technologies Scenario projects declines of 40% for oil and 7% for natural gas from 2022 levels. Key variables for oil demand include the road sector, electric vehicle (EV) penetration, hybrid vehicle uptake and improvements in internal combustion engine (ICE) vehicle efficiency. Natural gas and coal demand largely depends on power generation and industry sectors.
- Despite this uncertainty, fossil fuels will remain significant in the global energy mix for decades. Given natural production declines in existing fields, maintaining adequate investment in fossil fuel infrastructure remains critical for energy security, even as we accelerate the clean energy transition.

The critical role of LNG

LNG plays an important role—demand is expected to grow further

- Liquefied natural gas (LNG) is expected to play an important role as a realistic solution toward the energy transition—as a pragmatic and reliable energy source—enhancing energy security and contributing to decarbonisation at the same time. In its history, LNG has expanded and demonstrated its role in response to the demands of each era.
- Global LNG demand in 2050 is projected to increase by 74% from the present level in the Reference Scenario. Even in the Advanced Technologies Scenario, global LNG demand is projected to expand until around 2040 and then decline, but demand in 2050 is projected to be at the same level as of today. One of the focal points of increasing demand is Southeast Asia's emerging markets, notably the power generation sector. If the energy efficiency improvements assumed in these scenarios are not realised, LNG demand would increase further.
- The Ukraine crisis has heightened the importance of stable energy supply and controlling energy costs, increasing expectations for LNG's long-term role. Recognising the value of the LNG is crucial, as its flexibility has played a key role in responding to the latest energy crisis. The recent instability of supply-demand balances and prices shows the importance of measures to stabilise the market from a long-term perspective.

LNG supply stability requires sustaining investment

- The LNG production sector requires additions of 10-20 million-tonne-per-year capacity each year until 2050. These include brand-new LNG production projects, back-fill gas supply development to existing LNG plants and the rejuvenation of existing facilities, to meet incremental demand and to supplement reductions of productivity of existing gas fields and processing facilities.
- The capacity for which final investment decisions (FIDs) were made during the past three years apparently exceeded the above-mentioned required capacity. However, uncertainty should be noted over realisation and timely implementation of those sanctioned projects.

Long-term agenda toward a stable LNG market

- As expectations are high for LNG's role as a viable solution to transition uncertainty, efforts of the LNG market and industry players are necessary to meet these expectations. Companies should make efforts to better manage methane and other greenhouse gas (GHG) emissions, set higher goals and disclose appropriate and timely information. It is important to make the entire LNG value chain even cleaner. Additionally, making LNG a more attractive investment and financing option will further support long-term market stability.
- To expand and sustain LNG production in gas producing countries/regions, including North America and Australia, consuming countries must support regulatory and project development. Governments and companies should also actively participate in these developments to ensure long-term supply security.
- Medium- to long-term demand aggregation and market development support, including those in emerging markets in Southeast Asia, will lead to expansion of the global LNG market and support for LNG production development.

Issues surrounding LNG production project development

- Since the early 2010s, he rapid expansion of LNG supply has shifted its focus from Qatar to Australia and then to the United States. While development costs have risen, efforts to reduce expenses including floating LNG production, small- and medium-scale liquefaction and modular construction.
- Imminent LNG export from the West Coast of North America should be a gamechanger in LNG marine transportation—avoiding transportation bottlenecks, shortening and diversifying transportation routes.
- LNG export capacity in the United States is expected to grow steadily over the next few years, although long-term development is uncertain due to the non-free trade agreement (FTA) export authorisation pause and regulatory uncertainty. No FIDs were made on new LNG production projects in the United States in 2024. Some projects under construction or development face court-challenge risks and completion risks. Proactive participation in LNG production projects from an LNG importing country, as well as visible expressions of expectation of increasing LNG supply, would be even more important.
- The steady realisation of FIDs over the past few years was driven by long-term commitments by LNG buyers. Portfolio players have become increasingly important in these commitments, while commitments of Japan LNG buyers represent a smaller portion than in the past.
- A steady increase of LNG production capacity is expected in the medium-term, although construction delays are now the norm. As the increasing supply is likely to be absorbed by markets in Asia and elsewhere, widely touted 'oversupply' around the end of the decade is unlikely.
- Major LNG exporting regions with gas resource potential face their respective challenges. Australia should maintain stable LNG production by further developing gas fields surrounding existing LNG development areas. Qatar is implementing mega expansion projects while incorporating value-chain cleaning measures and ramping up marketing activities. Despite its vast resource potential, East Africa has yet to advance into full-scale LNG development.

Bottlenecks of LNG transportation and troubles at LNG production plants have impacts on the balance of the market

- Bottlenecks on important shipping routes are likely to be a major obstacle in times of tight supply and demand. It is necessary to develop a long-term LNG transportation strategy.
- Unplanned outages at LNG production facilities are likely to exacerbate supply-demand imbalances, which also necessitate countermeasures with long-term perspectives.

Risk scenarios for energy security

- Securing the necessary amount of energy at an affordable price is essential for society and the economy. However, history has shown that a stable energy supply is vulnerable to various risks. Understanding these risks, their potential impacts and the necessary countermeasures is essential. The following section highlights five key risks that are particularly relevant in today's global energy landscape.

Risks of fossil fuel underinvestment

- According to the Reference Scenario, fossil fuels will still satisfy 73% of global energy demand in 2050. Asia will play a more significant role as a demand centre, while the Middle East and North America will account for a larger share of oil and natural gas supply, and Asia will have a higher share of coal supply. Stable investments, especially in these supply regions, are of vital importance for the stable supply of fossil fuels. During the long transitional period, fossil fuel supply and demand will become tight if sufficient investments are not made.
- Some argue that new fossil fuel investments are unnecessary, assuming demand will decline rapidly in an 'ideal' carbon neutral society. However, the growing gap between the 'ideal world' and reality has highlighted the risk of underinvestment. Without additional investment, oil and natural gas production could decline to just one-tenth of current levels by 2050 due to natural production declines. This shortfall would create a large gap between supply and real-world fossil fuel demand.
- Underinvestment in oil and natural gas is likely to tighten the supply-demand balance, leading to higher prices. A hypothetical 50% increase in oil and natural gas import prices would increase the share of net oil and natural gas imports in the GDP of major Asian importing countries and regions by 1-3 percentage points. The impact would be particularly concerning for developing economies such as India and in ASEAN.

More serious and diverse geopolitical risks

- Geopolitical risks continue to be a major concern for energy security. As Japan's dependence on the Middle East for crude oil imports reached a historical high 95% in 2023, the geopolitical risks for Japan are becoming more serious due to the escalation of the situation in Gaza and the deepening conflict between Iran and Israel.
- Beyond the risk of political instability in resource-exporting countries and regions, policy changes in advanced economies have also emerged as a risk factor in recent years. Japan relies heavily on advanced economies for its coal (81%) and LNG (50%) imports as of 2023. However, policy changes in the United States and Australia, driven by domestic climate change concerns, have increased uncertainty about future resource development and exports. This could pose a challenge for market stability in the medium to long-term.

Risks of electricity supply instability

- The advancement of digitalisation and electrification is increasing society's reliance on electricity. In particular, the deployment of electric vehicles and the expansion of data centres are driving higher electricity demand. Decarbonisation efforts will further accelerate electrification of demand.
- The energy transition is pushing solar photovoltaic and wind power, whose output fluctuates with weather and seasons, to become major sources of electricity supply. It is necessary to ensure a stable electricity supply as the share of these variable power sources increases.
- On the supply side, risks of instability include supply shortages, input fossil fuel price fluctuations, geopolitical risks and variable output from renewable power sources. On the demand side, there is the risk of an increase in demand and uneven distribution of electricity demand. To address these risks, it will be necessary to secure fossil fuel procurement and baseload power sources such as nuclear, secure supply capacity and optimise the power system. Pursuing a balanced supply mix is crucial for ensuring stability.

Risks of critical mineral supply

- Manufacturing capacity of some decarbonisation technologies and critical minerals, which are essential for and raw materials for clean energy investments, have high market concentration and are increasingly recognised as a new risk in the energy transition.
- The critical minerals market is smaller and less mature than the fossil fuel market, making it more susceptible to market dominance, supply-demand imbalances and price volatility. Uncertainty about future demand for clean technologies, along with the long development time of more than a decade for new resources, complicates investment in supply diversification. Additionally, intensifying international competition to secure strategic commodities and the rise of resource nationalism should further heighten risks.
- Risk mitigation is possible through combining various technologies with different risk profiles. The development and commercialisation of these technologies must be promoted.

Increasing risks of cyber-attacks

- Since mid-2010s, the number of critical cyberattacks has increased significantly worldwide. The energy transition, with accompanying electrification, digitalisation and network connectivity, has increased the severity of cyberattacks, making them a growing risk factor.
- Cyberattacks take various forms, involving different actors, objectives and targets. In looking at the future international energy landscape, cyberattacks against fundamental energy infrastructure will become a key issue for energy security. Geopolitical risks should not be underestimated, and the potential weaponisation of cyber threats against energy supply should be considered.

Part Ⅰ

Energy supply and demand outlook

1. Framework and assumptions

1.1 Model and scenarios

We used a quantitative analysis model with an econometric methodology foundation to develop a global energy outlook and assess energy supply and demand through 2050. The model incorporates the International Energy Agency's (IEA) energy balance tables, along with economic indicators, population data, vehicle ownership statistics, basic materials production and other energy-related information. In this edition, we expanded our regional analysis by separating Cambodia and Lao PDR from the rest of Asia, dividing the world into 44 regions plus international bunkers[2], as shown in Figure 1-1. We developed a detailed supply and demand analysis model for each region.

Figure 1-1 | Geographical coverage

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

We considered two main scenarios for the projections.

Reference Scenario

This is the core scenario for the Outlook. It builds on historical trends and existing energy and environmental policies, technologies and other factors. While this scenario accounts for the expected impacts of traditional and conventional policies, it does not assume aggressive energy efficiency improvements or low-carbon policy adoption beyond established trends.

Advanced Technologies Scenario

In this scenario, all economies worldwide are assumed to strongly implement energy and environmental policies that contribute to securing stable energy supplies and enhancing measures against climate change and air pollution. These policies are assumed to achieve maximum effectiveness. Specifically, this scenario assumes widespread global implementation of

[2] See Table A1 for a detailed definition.

advanced energy technologies, as outlined in Figure 1-2, considering both their adoption potential and societal acceptance.

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

Introduction and enhancement of environmental regulations and national targets	**Promoting technology development and international technology cooperation**
Establishment of national strategies and targets, energy efficiency standards, fuel efficiency standards, low-carbon fuel standards, energy efficiency and environmental labelling systems, renewable energy introduction standards, feed-in-tariff systems, subsidy systems, environment tax, emissions trading, etc.	R&D investment expansion, development of international energy-efficient technologies (steelmaking, cement and other areas), support for establishing energy efficiency standards, etc.

Demand-side technologies	**Supply-side technologies**
Industry Global deployment of industrial process technologies at the highest efficiency level (for steelmaking, cement, paper-pulp, etc.); Introduction of hydrogen reduction iron-making technology **Transport** Further diffusion of clean energy vehicles (highly fuel-efficient vehicles, hybrid vehicles, plug-in hybrid vehicles, electric vehicles, hydrogen fuel cell vehicles) **Buildings** Further diffusion of efficient electric appliances (refrigerators, TVs, etc.), water-heating systems (heat pumps, etc.), air conditioning systems and lighting, as well as enhancement of insulation	**Renewable energies** Further diffusion of power generation from wind, solar PV, concentrated solar power (CSP), biomass-fired, marine and biofuels **Enhanced introduction of nuclear power** Acceleration in nuclear power plant construction and improvement in capacity factor **Promotion of highly efficient fossil fuel-fired power generation technologies** Further diffusion of SC, USC, A-USC, coal IGCC (Integrated Gasification Combined Cycle) and natural gas MACC II (More Advanced Combined Cycle II) plants **Hydrogen-related technologies** Thermal power generation fuelled by hydrogen and ammonia, and synthetic methane and synthetic fuels using hydrogen **Next-generation power transmission and distribution technologies** Low-loss substation equipment and voltage regulators **Carbon capture and storage (CCS) and carbon dioxide capture, utilisation and storage (CCUS)**

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

1.2 Major assumptions

The energy supply and demand structure is influenced by population, economic growth, other social and economic factors, energy prices, the above-mentioned energy utilisation technologies, and energy and environmental policies. The following economic growth and population assumptions are common to both the Reference and Advanced Technologies Scenarios.

Economy

Recent situation

In 2023, despite concerns about stagflation and recession due to rapid global inflation in 2022, the global economy demonstrated solid growth. This was primarily attributed to faster-than-expected moderation of inflation, expanded supply partly due to increased labour participation, and stronger demand from higher private consumption and government spending. However, economic recovery in 2023 varied across countries and regions. Among Advanced Economies, the United States showed exceptional growth, while Europe performed below the Advanced Economies average. Among Emerging and Developing Economies, India demonstrated remarkable growth, while China's growth matched the average for Emerging and Developing Economies.

The US economy grew robustly despite rapid monetary tightening, supported by strong private consumption fuelled by the utilisation of excess savings accumulated during COVID-19 restrictions and capital expenditures driven by aggressive industrial policies such as the Inflation Reduction Act (IRA). The Federal Reserve Board ended its zero-interest rate policy in March 2022 to address inflation, raising the policy interest rate to a range of 5.25% to 5.5%. This interest rate level, the highest in 23 years since 2001, was maintained throughout 2023. This helped curb price increases, leading to a substantial 0.5% cut announced in September 2024. The ability of the United States to emerge from monetary tightening without stalling the economy will significantly impact the direction of the global economy. As the outcome of the presidential election in November may also be an influencing factor, the outlook for the global economy remains uncertain.

In Europe, although high inflation is subsiding, economic weakness persists due to declining purchasing power from worsened consumer confidence, increased saving tendencies, and monetary tightening. Germany's economy, the largest in the eurozone and dependent on Russian energy supplies, experienced a particular slump. Inflation has been moderating due to multiple interest rate hikes in 2023 by the European Central Bank and the Bank of England, leading to a rate cut in 2024. While economic weakness is expected to continue, activity is projected to recover gradually with improving consumption, supported by lower inflation and a robust labour market. However, significant uncertainty remains due to Russia's prolonged invasion of Ukraine and abnormal weather conditions, with some analysts predicting continued economic sluggishness.

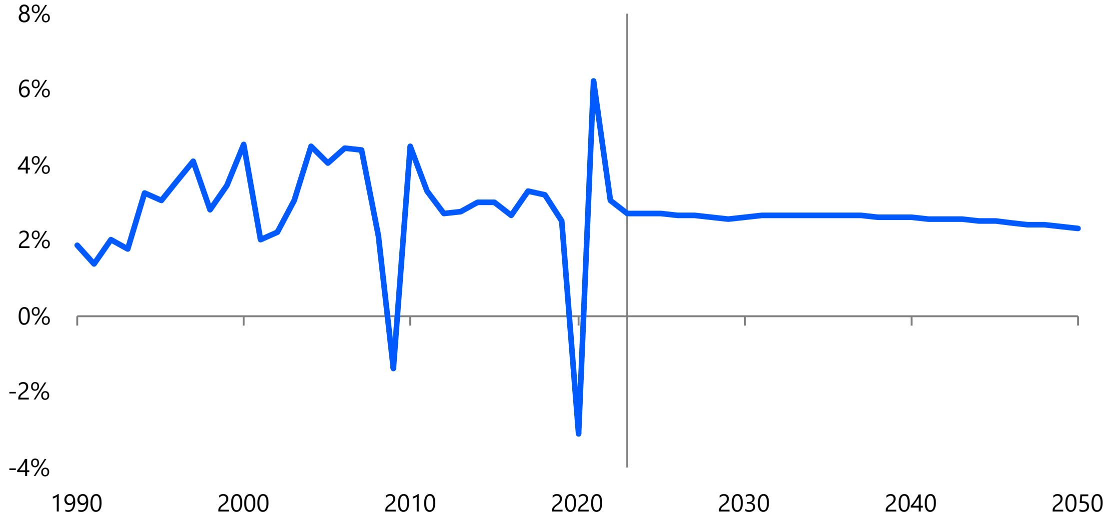
China's economy showed signs of recovery following the end of its zero-Covid policy, mainly in consumption. However, a stagnant property market, impacted by 2020 regulations to prevent a housing bubble, continued to weigh on growth. The government has responded with additional bonds and policies aimed at boosting domestic demand. However, with China's working-age population projected to decline from 60% to 50% by 2050, the downward economic trend is expected to persist.

India maintained high economic growth from 2022, supported by strong domestic demand. While the service sector has shown a marked increase in value-added ratio, the manufacturing sector has experienced sluggish growth, though production activity remains vigorous. The economy is forecast to maintain robust growth due to export recovery and strong domestic demand.

Assumptions for the future

While referring to country-by-country economic development plans and economic outlooks prepared by think-tanks around the world, global economic growth is expected to continue, albeit at a gradually slowing pace. In 2024, global economic growth is expected to continue at a rate of 2.7%, maintaining the momentum from 2023. This growth rate will gradually decline from 2024 to 2050, transitioning from the upper to lower 2% range (Figure 1-3). Although Russia's prolonged invasion of Ukraine will have localised and short-term effects, it is not expected to significantly impact the global economy in the long-term. Over the medium to long-term, most economies will continue to grow. However, sustained growth will require countries to enhance productivity, achieve technological innovation, implement appropriate fiscal, monetary and redistribution policies, strengthen international cooperation, and ensure security.

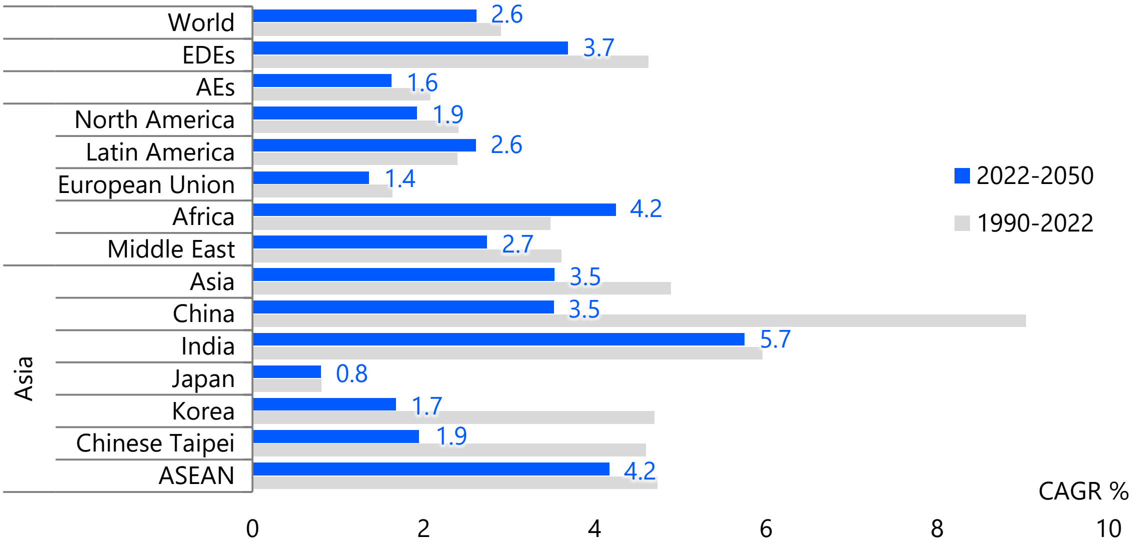
Figure 1-3 | World economic growth



Advanced Economies will experience slightly weaker growth compared to historical trends, maintaining a growth rate of 1.6% per annum. Emerging and Developing Economies will continue growing at 3.7% annually. India is projected to achieve the world's highest growth rate at 5.7% annually, matching its historical performance since 1990. While China will continue to be a significant contributor to global growth with an annual rate of 3.5%, its deceleration trend will persist. Both Africa and the Association of Southeast Asian Nations (ASEAN) will outpace the overall growth rate of Emerging and Developing Economies, each achieving 4.2% annual growth.

Based on these projections, we estimate the world's annual economic growth rate will average 2.6% throughout the projection period (Figure 1-4).

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

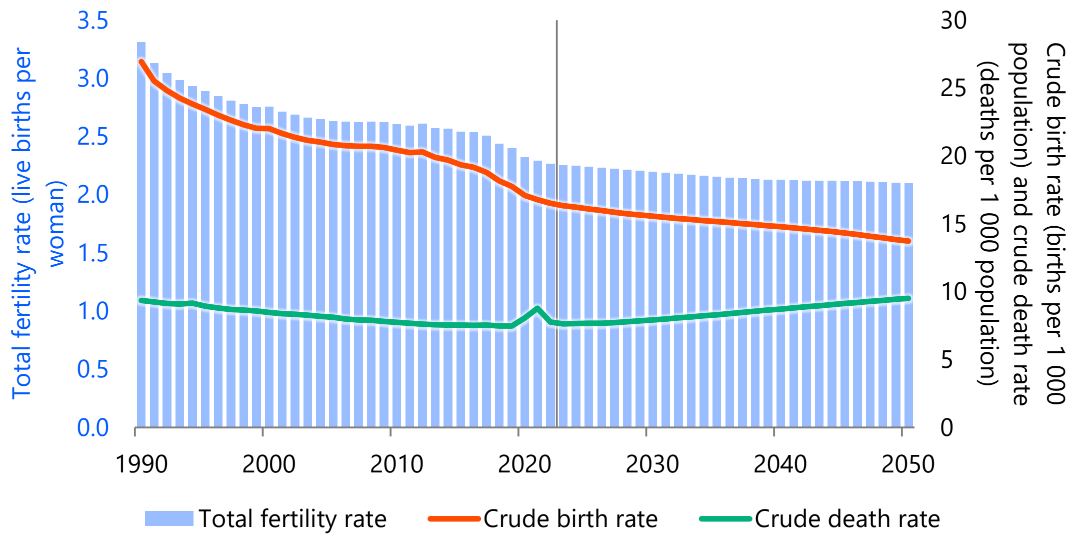


Notes: AEs stands for Advanced Economies. EDEs stands for Emerging and Developing Economies.

Population

For population projections, we referenced the United Nations' "World Population Prospects". In many Advanced Economies, the total fertility rate (TFR), which is the average number of children born to a woman during her lifetime, has fallen significantly below two. Emerging and Developing Economies are also experiencing declining TFRs, corresponding with income growth and increased female participation in the workforce. Mortality rates, which had been decreasing due to medical technology advancements and improved food and sanitary conditions, are expected to increase in the medium to long-term after 2022, following the subsidence of the temporary spike during the COVID-19 pandemic.

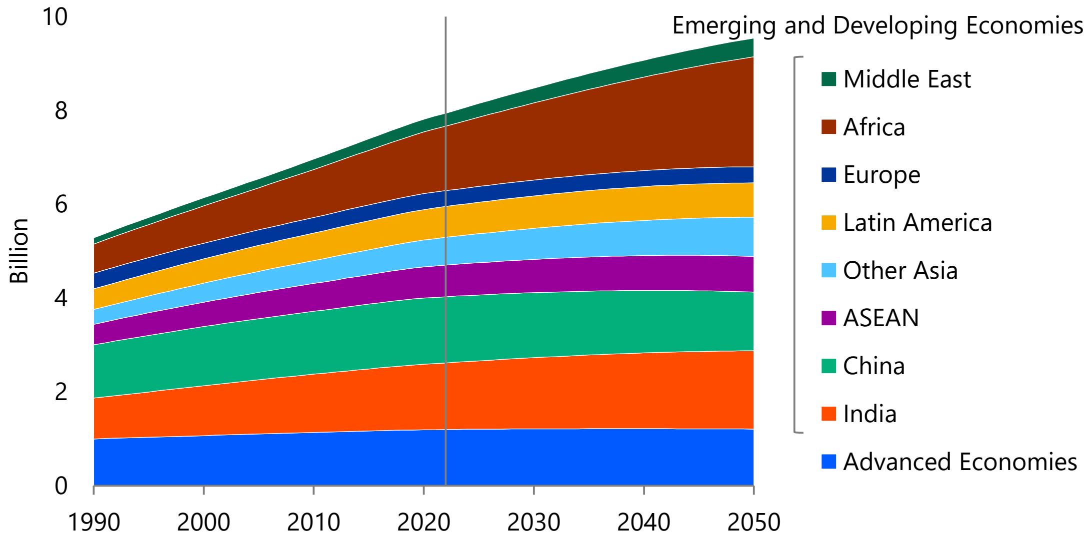
Figure 1-5 | World total fertility rate, crude birth rate and crude death rate



Source: United Nations "World Population Prospects 2024"

Global population will continue to grow, though at a decelerating pace due to declining birth rates and population aging worldwide. The world population will grow at an average annual rate of 0.7%. Consequently, the global population, which stood at 5.3 billion in 1990 and 7.9 billion in 2022, will reach 9.5 billion by 2050 (Figure 1-6).

Figure 1-6 | Population



Among Advanced Economies, North America, particularly the United States, will experience relatively steady population growth due to substantial immigration and a comparatively high TFR, reaching 417 million by 2050. However, this increase will be moderate, resulting in a slight decline in the United States' share of global population. The European Union's population is projected to peak in the early 2020s, partly due to immigration resulting from the Ukraine invasion, before beginning to decline, reaching 426 million by 2050. In Asia, Japan's population began decreasing in 2011 and will decline by approximately 20% from 2022 levels to 105 million by 2050. Korea's population, which began declining in 2021, will decrease to 45 million by 2050 despite a slight increase in 2023.

The population of Emerging and Developing Economies will continue to increase substantially, driven primarily by Africa and India. Africa's population will grow by nearly 70% from current levels to 2.344 billion in 2050, as lower mortality rates offset gradually declining birth rates. The Middle East's population will expand by 50%, reaching 398 million by 2050, supported by government financial incentives to increase population and growing immigration from other regions.

In Asia, India, which surpassed China in 2023 to become the world's most populous country, will maintain its high growth rate, reaching 1.67 billion in 2050—the largest population globally. China's population, which peaked in 2021, has begun to decline and will decrease to approximately 1.249 billion by 2050. ASEAN's population will increase by 10% to 768 million by 2050.

International energy prices

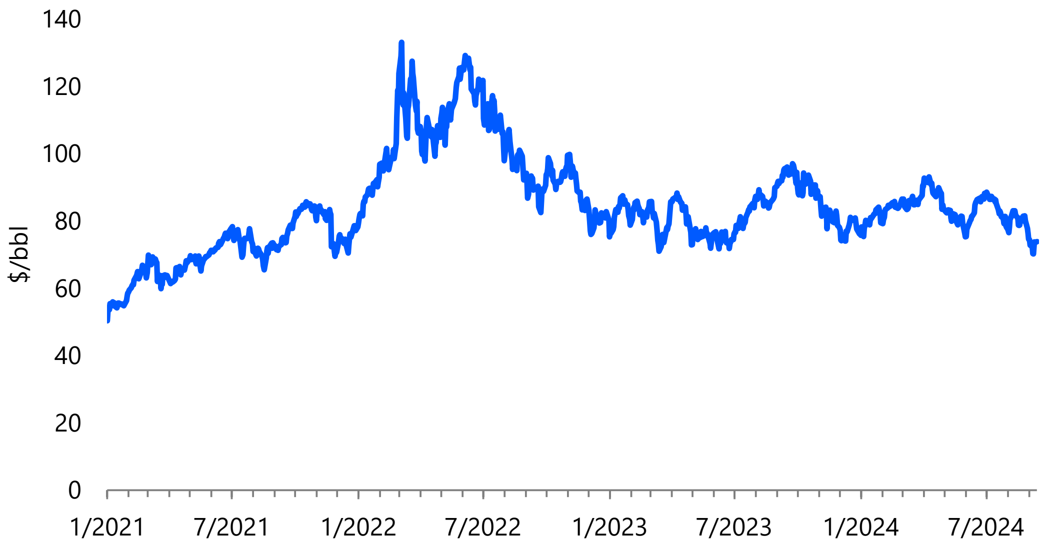
Recent situation

Brent crude oil prices surged to nearly $130 per barrel (bbl) in March 2022 following Russia's invasion of Ukraine. However, by the end of the year, prices had declined to around $80/bbl, driven by sustained Russian exports despite sanctions and concerns over weakening global demand. In 2023, Brent prices began in the low $80/bbl range and fluctuated before reaching nearly $100/bbl at the end of September.

Oil prices were influenced by several factors, including accelerating inflation in the United States and Europe, monetary tightening aimed at controlling inflation and additional production cuts by OPEC+ members[3], including Saudi Arabia and Russia. Demand recovery, especially in China, also contributed to price fluctuations. Despite military conflicts between Israel and Hamas in October, the impact on oil prices remained modest. In November, OPEC+ failed to reach a consensus on further production cuts, with only Saudi Arabia and seven other member countries agreeing to voluntary reductions. This led to a price drop below $80/bbl by the end of December.

In 2024, Brent prices have fluctuated between $70/bbl and $90/bbl, influenced by continued OPEC+ production cuts, geopolitical tensions in the Middle East and macroeconomic conditions in major consuming countries, particularly China and the United States (Figure 1-7).

Figure 1-7 | Brent crude oil prices



Source: Intercontinental Exchange

Regarding natural gas prices, spot liquefied natural gas (LNG) and spot natural gas prices have been on a downward trajectory since late 2022. The dominance of oil-linked long-term LNG contracts in the Asian market has diminished, although short-term fluctuations remain possible. The average Asian spot LNG price for 2023 ranged from $13 to $14 per million British thermal units (MBtu), dropping to $9/MBtu–$10/MBtu in the first half of 2024. This represents a significant decrease from the 2022 average of $35/MBtu for Asian spot LNG and $43/MBtu for European spot gas (Title Transfer Facility [TTF], front-month delivery).

The premium at which European TTF prices traded relative to Asian spot LNG prices in 2022 led to a redirection of LNG supplies toward Europe. Spot LNG and European natural gas prices had soared from the second half of 2021 after the COVID-19 slump, surpassing oil prices on a calorific basis between August 2021 and April 2023. Although natural gas prices have generally returned to lower levels relative to oil prices, they remain above pre-2021 averages.

[3] Organization of the Petroleum Exporting Countries

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

Japan's average LNG import price reached a record high of $22.71/MBtu in September 2022, reflecting the surge in oil prices earlier that year. By June 2024, the price had decreased to $11.46/MBtu, following the broader decline in oil prices since mid-2022.

The steam coal market also experienced significant price volatility. Prices exceeded $400 per tonne (t) in 2022, a record high, driven by increased demand following the COVID-19 recovery, disruptions caused by Russia's invasion of Ukraine and supply constraints in major coal-producing countries due to adverse weather.

Subsequently, coal prices fell as Russian coal was redirected to non-sanctioning countries such as China and India, weather conditions improved in key producing regions, and demand for energy and steel weakened. By 2024, prices briefly dropped below $100/t but recovered to approximately $130/t by June. Although prices remain significantly lower than the 2022 peak, they are still high compared to pre-pandemic levels.

Structural instability is becoming apparent in the coal market. With global efforts to transition away from coal and declining investments in new coal projects, supply flexibility has diminished. This lack of flexibility raises concerns about short-term price volatility, especially in response to seasonal demand fluctuations and supply disruptions.

Reference Scenario

In the Reference Scenario, oil demand will continue to be driven by Asia; however, the centre of demand growth will shift from China to India and ASEAN. On the supply side, non-OPEC production will increase until around 2030, after which dependence on OPEC will rise. Oil demand is projected to expand continuously through 2050, with the breakeven oil price expected to rise over the medium to long-term. The real oil price (in 2023 dollars) is projected to reach $85/bbl in 2030 and $95/bbl in 2050 (Table 1-1). Assuming an annual inflation rate of approximately 3%, the nominal oil price is forecast to rise to $105/bbl by 2030 and $225/bbl by 2050.

Regarding Japan's natural gas prices, the portion of import prices linked to oil is expected to decrease in line with the declining trend in crude oil consumption. The sustained increase in LNG exports from the United States is anticipated to diversify procurement sources and ease destination restrictions, gradually shifting pricing away from oil-linked contracts. Additionally, Japan's natural gas prices are expected to influence Asian markets, including those in emerging economies. Consequently, the ratio of oil price impact on Japan's import prices is set at 70% in 2030, decreasing to 50% by 2050. Meanwhile, the portion linked to natural gas prices will increase from 30% in 2030 to 50% in 2050. A certain premium will also be applied by multiplying the US Henry Hub price by a premium factor.

Table 1-1 | International energy prices

Real prices			Reference			Advanced Technologies		
		2023	2030	2040	2050	2030	2040	2050
Oil	$2023/bbl	82	85	90	95	80	75	70
Natural gas								
Japan	$2023/MBtu	13.7	9.3	8.8	8.5	9.0	8.1	7.6
Europe (Netherlands)	$2023/MBtu	13.1	9.8	9.7	9.5	9.7	9.2	8.8
United States	$2023/MBtu	2.5	3.0	4.0	4.0	3.4	4.1	4.0
Steam coal	$2023/t	243	105	110	110	100	95	90

Nominal prices			Reference			Advanced Technologies		
		2023	2030	2040	2050	2030	2040	2050
Oil	$/bbl	82	105	153	225	98	125	160
Natural gas								
Japan	$/MBtu	13.7	11.5	14.8	20.1	11.0	13.4	17.3
Europe (Netherlands)	$/MBtu	13.1	12.0	16.4	22.4	12.0	15.2	20.0
United States	$/MBtu	2.5	3.7	6.8	9.5	4.2	6.8	9.1
Steam coal	$/t	243	130	186	260	123	158	206

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

The United States Henry Hub price is based on projections from the U.S. Energy Information Administration's (EIA) "Annual Energy Outlook 2023[4]. US prices will likely remain lower than those in other regions, supported by abundant domestic supply. Prices are expected to decline toward 2030 but rise again by 2040 due to increasing development and production costs and higher demand, including exports. After 2040, prices are expected to stabilise.

In Europe, the portion of prices linked to oil is projected to decline, reflecting decreasing crude oil consumption. However, European natural gas prices are expected to remain elevated due to the phasing-out of Russian pipeline gas, which previously contributed to stable prices.

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

Coal prices (free on board [FOB], steam coal from Newcastle, Australia) reached a record high in 2022 due to sanctions on Russian coal and supply disruptions. However, global supply concerns have eased, leading to price stabilisation. Over the long-term, demand for coal is expected to decline, partly due to the global trend toward carbon neutrality. Nonetheless, as new investments in coal production decrease, supply and demand dynamics will gradually tighten, with the real coal price projected to reach $110/t by 2050. Demand for coal in Asian countries such as India and ASEAN members will remain robust, but limited capacity expansion—particularly in Advanced

[4] Not scheduled for publication in 2024.

Economies—due to stricter environmental regulations will create risks of short-term price fluctuations driven by seasonal demand and supply imbalances.

Advanced Technologies Scenario

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

In the Advanced Technologies Scenario, fossil fuel demand will begin to decline around 2030, driven by accelerated improvements in energy efficiency and a shift toward nuclear, renewables and hydrogen. Due to sluggish demand, fossil fuel prices are projected to be generally lower than in the Reference Scenario. However, price volatility may arise if supply structures fail to adjust in line with shifting demand patterns.

Global natural gas demand will peak in the 2030s before entering a gradual decline. In Japan, the share of import prices linked to oil will decrease further, aligned with reduced crude oil consumption. Specifically, the ratio affected by oil prices will decline to 50% in 2030 and 40% in 2050, which is lower than in the Reference Scenario. The portion of prices linked to natural gas will increase to 50% in 2030 and 60% in 2050. A premium will continue to be added by multiplying the US Henry Hub price by a premium factor.

US Henry Hub prices will remain competitive compared to other regions, benefiting from abundant domestic supply, with forecasts again based on the EIA's "Annual Energy Outlook 2023". In Europe, oil-linked pricing will decline further as crude oil consumption decreases. However, regional prices are expected to remain higher than in the United States due to the continued reduction of Russian pipeline gas.

2. Energy demand

2.1 Primary energy consumption

The amount of energy consumption continues to increase although the energy intensity of GDP is improving thanks to climate change countermeasures and energy security.

The Working Group I report of the Sixth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) states that 'it is unequivocal that human influence has warmed the atmosphere, ocean, and land'. In response, more than 150 countries have announced carbon neutrality policies, aiming to achieve net-zero carbon dioxide (CO_2) emissions by 2050 or alternative target years.

However, the first Global Stocktake conducted at the 28th Conference of the Parties (COP28) to the United Nations Framework Convention on Climate Change (UNFCCC) in Dubai, United Arab Emirates, in December 2023, revealed that progress toward the goal of limiting global temperature increases to 1.5°C remains insufficient. It was emphasised that urgent action and support are required to meet the 1.5°C target. The conference also highlighted the need to peak greenhouse gas (GHG) emissions by 2025 and achieve reductions of 43% by 2030 and 60% by 2035 to stay on track.

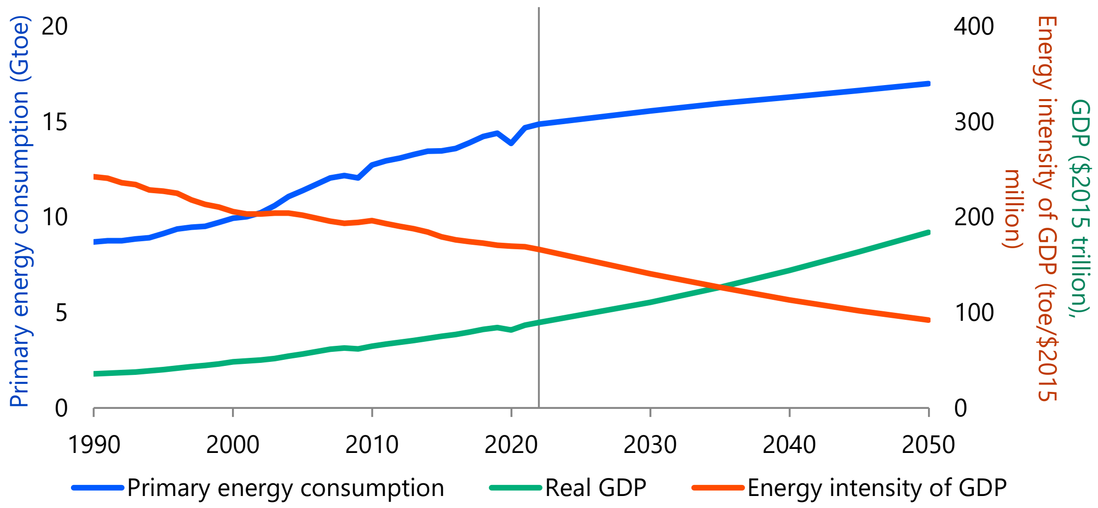
Russia's invasion of Ukraine in February 2022 has highlighted fossil fuel supply instability and price volatility, threatening energy security. Although the 2022 peak in fossil fuel import prices has subsided, geopolitical instability persists in the Middle East, including unrest caused by Russia and anti-Israeli/anti-American forces. Both the Group of Seven (G7) and Group of 20 (G20) have emphasised the need for stable energy supply and price stability. While acknowledging diverse energy transition pathways, countries are strengthening policies to promote economic growth through enhanced energy conservation and reduced fossil fuel dependence via clean technologies. This context has increased uncertainties surrounding energy demand, including potential increased electricity consumption associated with digital transformation through generative artificial intelligence (AI) and other technologies.

From 2022 to 2050, global primary energy intensity per gross domestic product (GDP) will decline more rapidly than it did from 1990 to 2022. This decline is driven by worldwide efforts to improve energy efficiency and conservation in response to economic, climate and energy security challenges (Figure 2-1). Although COP28 set a target to double the average annual improvement rate in energy efficiency from 2% to 4% by 2030, the actual improvement is expected to reach only 2.0% annually from 2022 to 2030 and 2.1% from 2035 onward.

As global GDP is projected to grow faster than energy intensity improvements, primary energy consumption will continue to rise. From 1990 to 2022, global primary energy consumption grew at an annual rate of 1.7%. This growth rate will slow to 0.5% annually between 2022 and 2035 and further to 0.4% annually through 2050 due to progress in energy conservation. Despite this slowdown, total global primary energy consumption will increase by 7%, reaching 15 956 million tonnes of oil equivalent (Mtoe) by 2035, and by 14%, reaching 16 984 Mtoe by 2050.

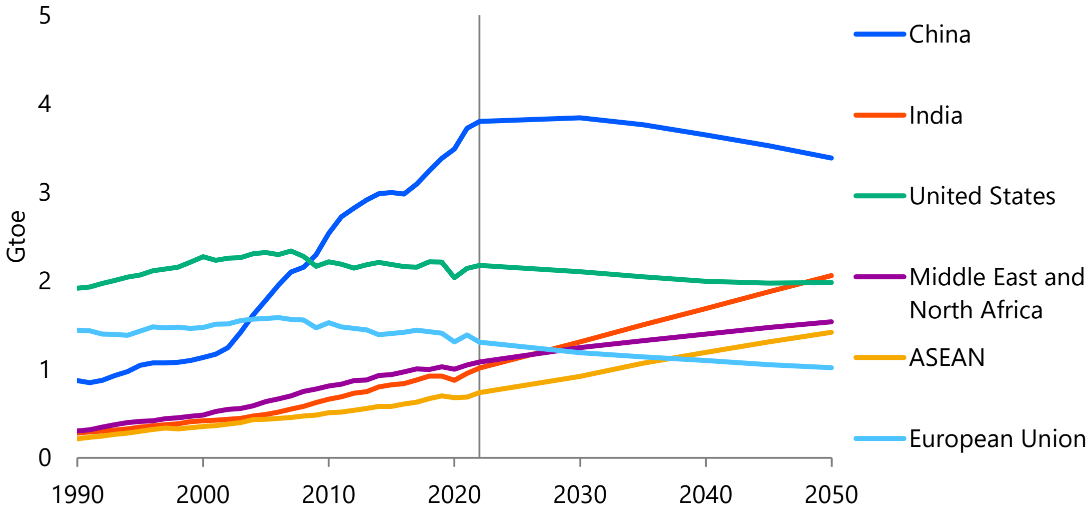
Meeting this growing demand solely through non-fossil energy sources such as nuclear and renewables will be challenging. Therefore, countries must enhance energy efficiency further to reduce fossil fuel consumption in alignment with COP28 goals.

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



China, which has driven global energy consumption growth since 2000, will see its primary energy consumption peak in the early 2030s before beginning a gradual decline due to slower economic growth and energy conservation efforts. Conversely, primary energy consumption in India, the Middle East and North Africa (MENA), and the Association of Southeast Asian Nations (ASEAN) will continue to grow. The increase in these three countries and regions will account for 97% of the increase in the world's consumption from 2022 to 2035 and 103% to 2050, pushing up global primary energy consumption, with their share growing from 19% in 2022 to 24% in 2035 and 30% in 2050 (Figure 2-2). Therefore, beyond accelerating energy consumption reduction in Advanced Economies and China, the ability of India, MENA and ASEAN to moderate their energy consumption will determine global energy consumption trends and ultimately the success of climate change and energy security measures.

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



India, MENA and ASEAN will increase their primary energy consumption by annual rates of 2.6%, 1.3% and 2.4% respectively from 2022 to 2050, ultimately accounting for 12%, 9% and 8% of global energy consumption in 2050. This growth corresponds with projected high annual GDP growth rates of 5.8%, 3.1% and 4.2% through 2050. Decoupling energy consumption from economic growth in these regions represents a critical global challenge.

Advanced Economies, including the United States, the European Union (EU) and Japan, as well as China, must continue reducing their energy consumption in light of climate change and energy security concerns. Climate policies supporting energy conservation are being implemented globally, including the US Inflation Reduction Act, the European Union's Net Zero Industry Act and Carbon Border Adjustment Mechanism and China's Action Plan for Carbon Peaking by 2030. By 2035, the United States, Europe and Japan will collectively account for 40% of global GDP, while China will account for 21%. Their share of global primary energy consumption will be 22% and 24%, respectively. By 2050, these shares will adjust to 35% of global GDP for the United States/Europe/Japan group and 23% for China, with each group accounting for 20% of global primary energy consumption. Given their significant share of global consumption, these economies must accelerate energy reduction efforts through robust climate change and energy security measures. Simultaneously, they should continue driving global economic stability through consumption and investment.

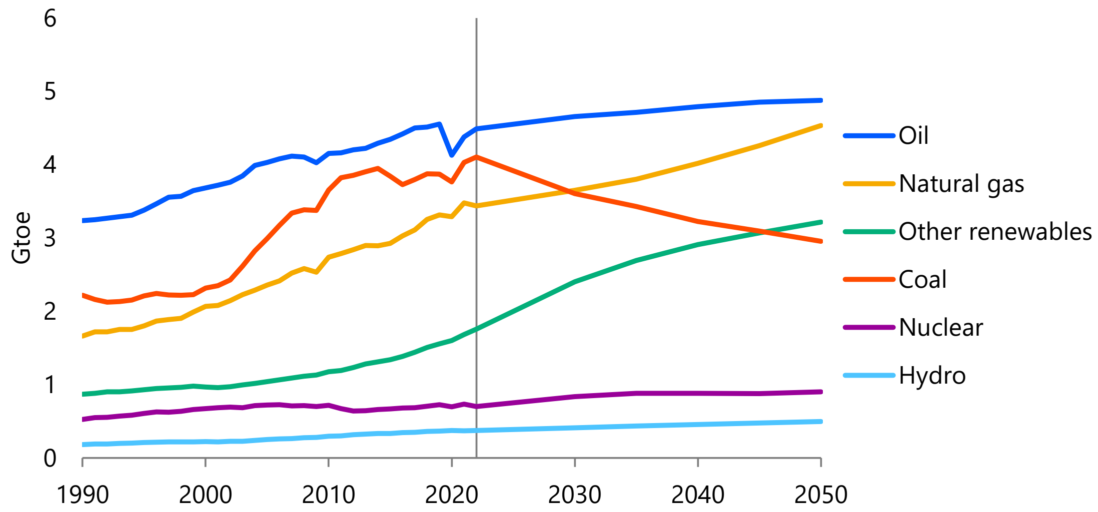
Further reducing global energy consumption will require enhanced international cooperation between Advanced Economies and Emerging and Developing Economies, as well as among Emerging and Developing Economies, alongside strengthened national policies. Advanced Economies such as the United States, Europe and Japan must facilitate efficient technology transfer and support Emerging and Developing Economies to achieve economic growth while limiting energy consumption by utilising Article 6 of the Paris Agreement and addressing energy security concerns, particularly regarding fossil fuel supply instability.

Fossil fuel consumption, especially of natural gas, continues to expand amid growing concerns about climate change and energy security

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

However, under current plans, nuclear power generation will only reach 1.3 times the 2020 level by 2050 on a primary energy basis. Although renewable energy will sustain the growth observed during the 2010s into the 2020s, it is projected to increase by only 1.3 times between 2022 and 2030. Growth will further slow after 2030 due to land availability and grid integration constraints, resulting in a 1.5-fold increase by 2035 and a 1.7-fold increase by 2050 (Figure 2-3). Additionally, the adoption of hydrogen and ammonia will remain limited, as demand is not yet sufficient to justify their high costs.

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



Fossil fuel consumption experienced a sharp decline in 2020 due to the economic slowdown and widespread lockdowns during the COVID-19 pandemic. However, consumption rebounded as economies recovered, reaching a record high in 2022. Until 2030, overall fossil fuel consumption will decrease, as a significant reduction in coal usage offsets increases in oil and natural gas consumption. After 2030, fossil fuel consumption will resume growth, rising by 3% in 2050 compared to 2022 levels.

Natural gas, which emits the least carbon among fossil fuels, will be the most actively utilised fossil fuel to support climate change mitigation. Consumption of natural gas is expected to grow at an average annual rate of 1.0% through 2050, reaching 1.3 times its 2022 level, primarily driven by demand in the power generation sector. Oil consumption will see the second-largest growth, expanding at an average annual rate of 0.3%, mainly for use in transportation sectors such as automobiles, aircraft and shipping. Coal consumption, by contrast, is projected to decline at an average annual rate of 1.2% through 2050. This decrease will result from global initiatives to limit coal use, including the G7's commitment to phase out coal-fired power generation without emission reduction measures by 2035 and efforts to reduce air pollution, particularly in China. By the late 2040s, coal consumption will be lower than that of renewable energy sources, excluding hydro.

While non-fossil energy sources will increase their share in the global energy mix through 2050, overall energy demand is expected to grow even faster. As a result, non-fossil sources alone will not be sufficient to meet total energy demand over the next three decades. Therefore, continued reliance on a combination of fossil fuels and non-fossil energy will remain a realistic scenario, especially for Emerging and Developing Economies, where energy consumption is rising (Figure 2-4).

Figure 2-4 | Primary energy consumption changes [2022-2050, Reference Scenario]

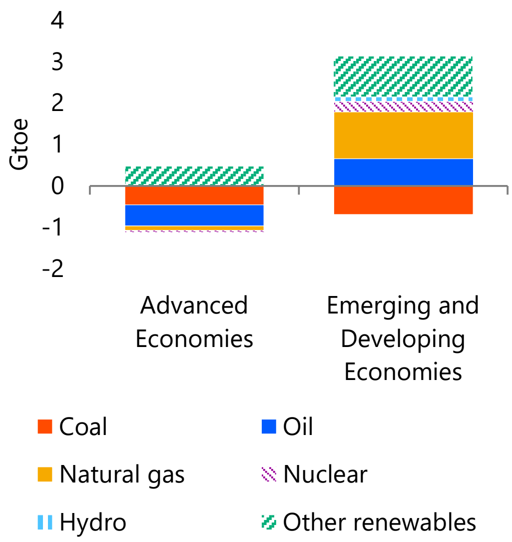
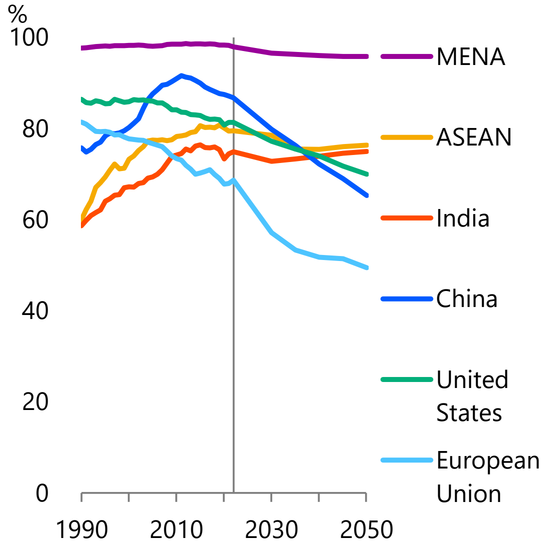


Figure 2-5 | Dependence on fossil fuels in selected economies/regions [Reference Scenario]



Dependence on fossil fuels is projected to decrease from 81% in 2022 to 73% by 2050. However, this dependence will remain high in Emerging and Developing Economies, excluding China (Figure 2-5). In the United States, fossil fuel dependence will decline from 81% in 2022 to 70% in 2050. The European Union will see a more substantial reduction, from 69% to 49%, while Japan's dependence will decrease from 87% to 68%. In contrast, fossil fuel dependence in India, MENA and ASEAN will remain high at 75%, 96% and 76%, respectively, due to increasing total energy consumption, with fossil fuels continuing to meet much of this rising demand.

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

Among sectors, industry is expected to experience the highest energy consumption growth, primarily in Emerging and Developing Economies, followed by the transport sector (Figure 2-6). Industrial energy demand will be driven by the expansion of energy-intensive secondary industries, such as heavy manufacturing and chemical production, in these economies.

In the transport sector, the increase in automobile use due to rising incomes in Emerging and Developing Economies will far exceed the energy savings from improved fuel efficiency and the adoption of next-generation vehicles. Additionally, aviation and shipping will see substantial growth in energy consumption due to the rising movement of people and expanding international trade.

Figure 2-6 | Contributions to global primary energy consumption growth [Reference Scenario, 2022-2050]

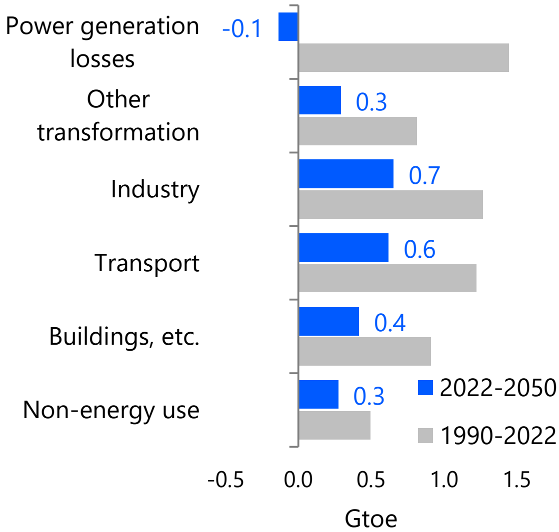
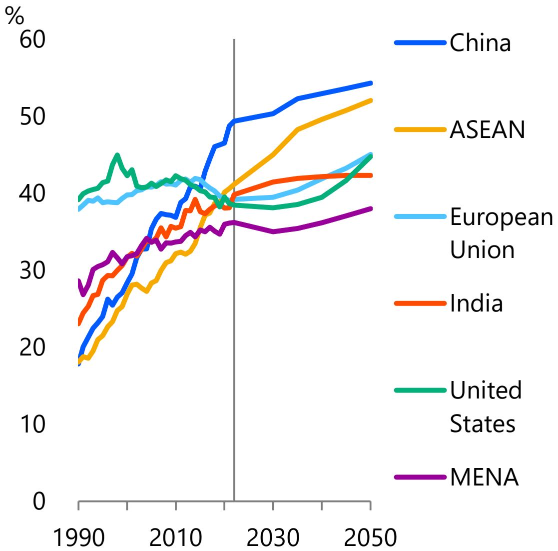


Figure 2-7 | Electrification rates on the supply side in selected economies/regions [Reference Scenario]



The buildings sector will also contribute significantly to increased energy consumption. In India, MENA and ASEAN, the continued development of tertiary industries, including global call centres and improved household access to energy will drive demand growth. Rising living standards in these economies will further push up energy consumption in the buildings sector. Given these factors, it will be challenging for these economies to curb energy demand while maintaining economic growth. Furthermore, the impact of generative artificial intelligence (AI) on energy consumption is emerging as a potential concern, as AI-driven digital infrastructure is expected to increase electricity demand.

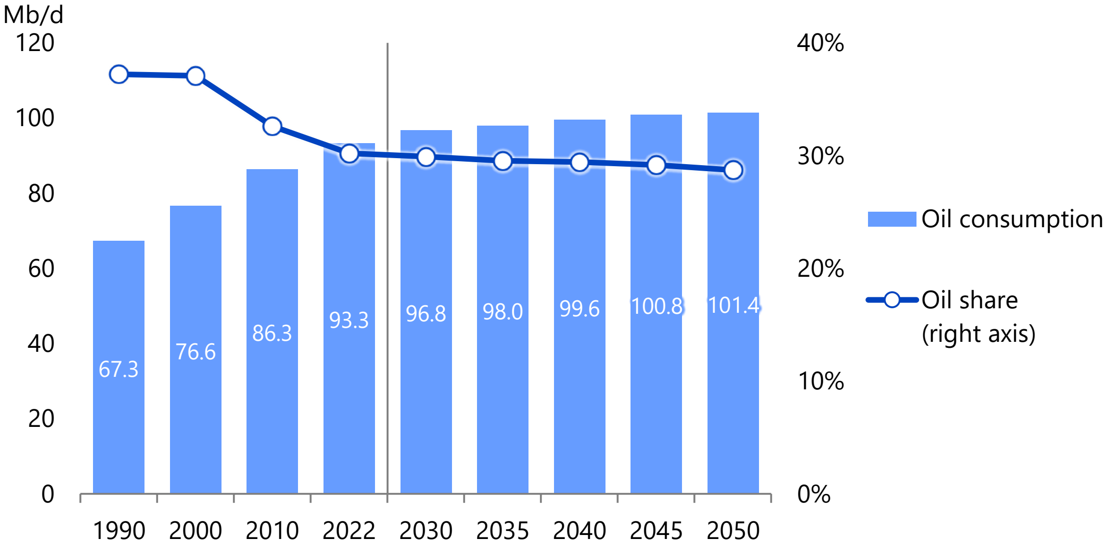
Contrary to historical trends, energy consumption in the power generation sector is expected to decline due to improvements in fossil fuel power generation efficiency and a shift toward non-fossil power sources, which are assumed to have 100% efficiency (no losses) (Figure 2-7). However, the rising electrification rate will offset some of these efficiency gains.

Electricity demand will continue to grow, not only in Emerging and Developing Economies, where electrification is expanding, but also in Advanced Economies, where digitalisation is increasing energy needs. Although the share of non-fossil energy sources is expected to grow, they will likely be insufficient to fully meet the rising electricity demand. As incomes rise and infrastructure development progresses in currently unelectrified regions, electricity consumption will continue to increase due to its convenience and widespread adoption across sectors.

Oil consumption growth curbed but its share in primary energy consumption unchanged

Global oil consumption, which stood at 93.3 million barrels per day (Mb/d) in 2022, is expected to increase gradually, reaching 101.4 Mb/d in 2050 (Figure 2-8). Oil's share in primary energy consumption rose to 30% in 2022, driven by the recovery from the COVID-19 pandemic. However, this share will decline slightly to 29% by 2050. Despite this decline, oil will remain the world's most widely used energy source in 2050 under the Reference Scenario.

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



In Advanced Economies, oil consumption has already peaked (Figure 2-9). Since reaching its peak in 2005, oil consumption has declined at an annual rate of 1.2%, a trend that will continue through 2050. The main factor driving this decline is the reduction in automobile fuel consumption, supported by fuel efficiency improvements and the adoption of electrified vehicles, including hybrid vehicles.

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

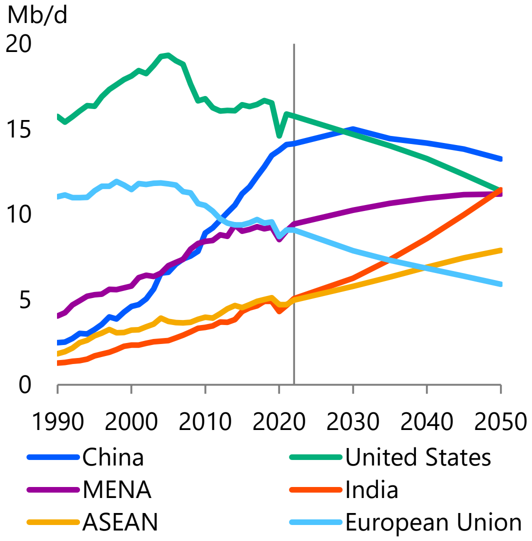
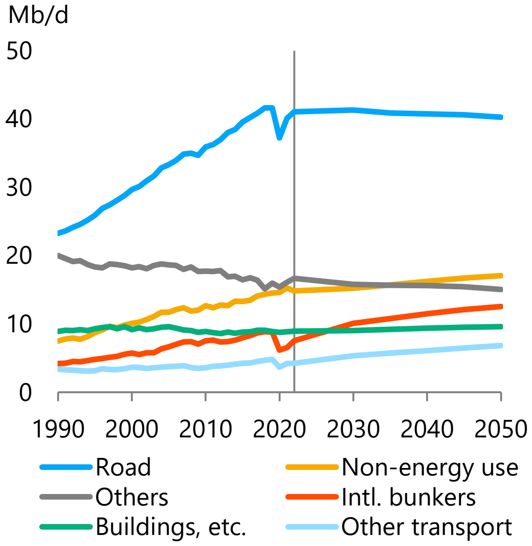


Figure 2-10 | Global oil consumption [Reference Scenario]



By contrast, oil consumption in India, MENA and ASEAN will steadily increase at an annual rate of 1.6% from 2022 to 2050. Growth in these economies will be driven primarily by the transport, non-energy use and buildings sectors.

Oil consumption will continue to grow in the road transport sector, which has the largest share of oil use, until 2030 as vehicle ownership expands. After 2030, however, oil consumption in this sector will peak and then decline, as the impact of fuel efficiency improvements and the adoption of electrified vehicles outweighs the effects of increasing vehicle ownership (Figure 2-10). However, oil consumption in other transport sectors—such as international bunkers, domestic aviation and internal navigation—will continue to grow, driven by rising global trade and increased passenger mobility.

In India, MENA and ASEAN, oil consumption for automobiles is projected to rise sharply from 8.3 Mb/d in 2022 to 14.0 Mb/d in 2050. Vehicle ownership in these regions will increase 3.5 times from current levels, supported by rising incomes and improvements in transport infrastructure, such as roads and bridges. To curb oil consumption, these economies will need to actively promote a transition to electric vehicles. In Emerging and Developing Economies, the initial cost of electric vehicles may remain high even in 2050, restricting sales to high-income consumers unless strong climate policies and financial incentives are implemented.

Oil consumption in the non-energy use sector, primarily for petrochemical production, is projected to increase by 2.4 Mb/d from 2022 to 2050 in India, MENA and ASEAN. These regions will account for 108% of the total global oil consumption growth in this sector. Global demand for plastics and other petrochemical products remains strong, and oil-producing countries are actively fostering their petrochemical industries as part of their industrial diversification strategies. This means that both supply-side and demand-side factors will drive oil consumption growth in this sector. To suppress this growth, stronger regulations on plastics consumption will be required.

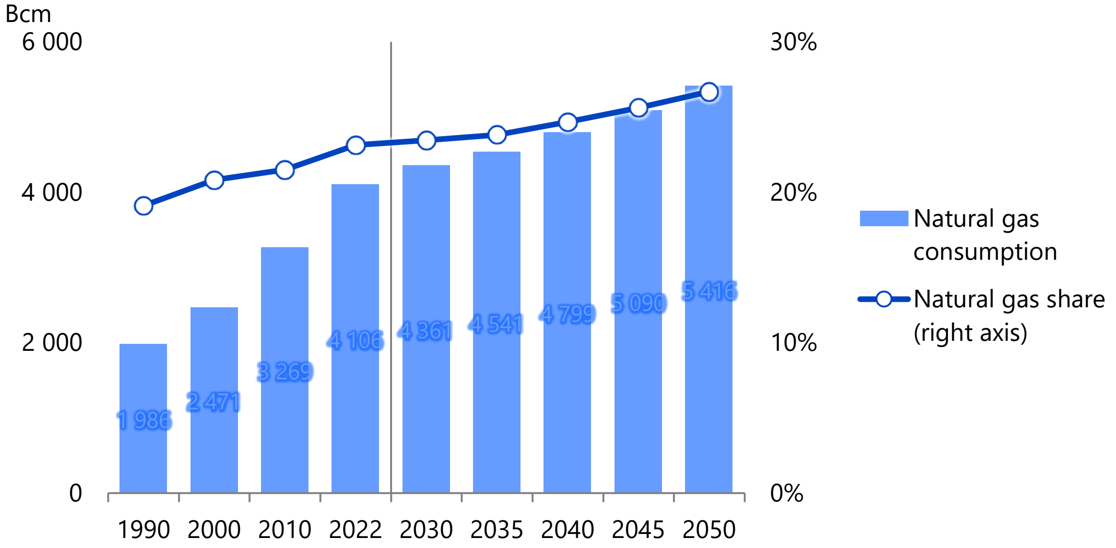
Oil consumption in the buildings sector of India, MENA and ASEAN is expected to increase by 1.2 Mb/d from 2022 to 2050, accounting for 181% of the net global increase in this sector. As incomes rise, consumers in these regions will shift from coal and solid biomass to oil, which is a relatively cleaner alternative in terms of health impacts. In Sub-Saharan Africa (excluding South Africa), oil consumption in the buildings sector is projected to increase by 0.4 Mb/d during the same period. The high initial investment costs for switching to electricity or natural gas for water heating and cooking will drive many consumers to opt for liquefied petroleum gas instead.

China's oil consumption is expected to peak at 15.0 Mb/d around 2030 before declining to 13.2 Mb/d in 2050. In the transport sector, oil consumption will decrease as vehicle ownership saturates, fuel efficiency improves, and electric vehicles become more widespread. The buildings sector will also see a reduction in oil consumption as more consumers switch to electricity and natural gas. Given China's significant share of global oil demand, accelerating the reduction of oil consumption in China will be critical to achieving deeper global reductions in oil use.

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

Natural gas consumption will see the largest increase of all energy sources through 2050. Global consumption is projected to grow at an annual rate of 1.0%, rising from 4 106 billion cubic metres (Bcm) in 2022 to 5 416 Bcm in 2050 (Figure 2-11). As a result, natural gas will expand its share of primary energy consumption from 23% in 2022 to 27% in 2050, making it the second most consumed energy source after oil. The shift in natural gas trade patterns will be a major global challenge. As the European Union reduces its dependence on Russian natural gas and increases imports from other regions, particularly liquefied natural gas (LNG), the question of how to limit global natural gas demand growth remains critical.

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



India, MENA and ASEAN will account for 66% of the total global increase in natural gas consumption, adding a combined 1 310 Bcm between 2022 and 2050 (Figure 2-12). By 2050, natural gas consumption is projected to reach 253 Bcm in India, 1 092 Bcm in MENA and 470 Bcm in ASEAN. The Middle East is expected to increase domestic natural gas consumption while continuing to prioritise cost-competitive oil exports to generate foreign currency. India and ASEAN will expand natural gas consumption primarily for power generation to meet their rising electricity demand. In contrast, the European Union will accelerate its transition away from natural gas, reducing its consumption by 159 Bcm by 2050. China will see an increase of 123 Bcm, mainly for power generation.

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

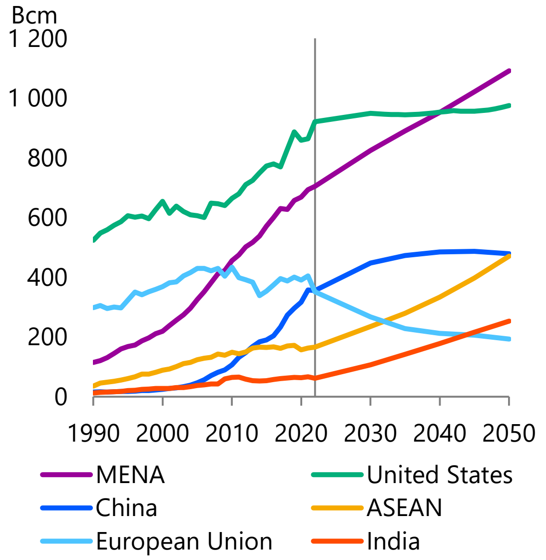
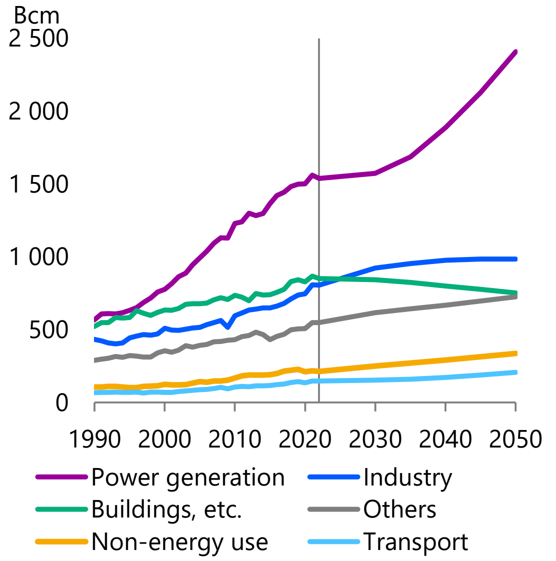


Figure 2-13 | Global natural gas consumption [Reference Scenario]



By sector, natural gas consumption in the buildings sector is expected to decline due to increasing electrification and energy efficiency improvements (Figure 2-13). In contrast, demand in Emerging and Developing Economies, including China, will rise, particularly in the power generation and industry sectors. In the power generation sector, natural gas demand will remain largely stable until 2030 due to the expansion of renewables and other energy sources. After 2030, demand is expected to rise again as the deployment of alternative power sources fails to keep pace with growing electricity needs. Natural gas consumption in power generation within Emerging and Developing Economies will increase at an annual rate of 2.5% from 2022 to 2050, accounting for 99% of the global growth in this sector. This trend is driven by natural gas's lower CO_2 emissions compared to other fossil fuels and its ability to support large-scale power generation at lower integration costs than renewables.

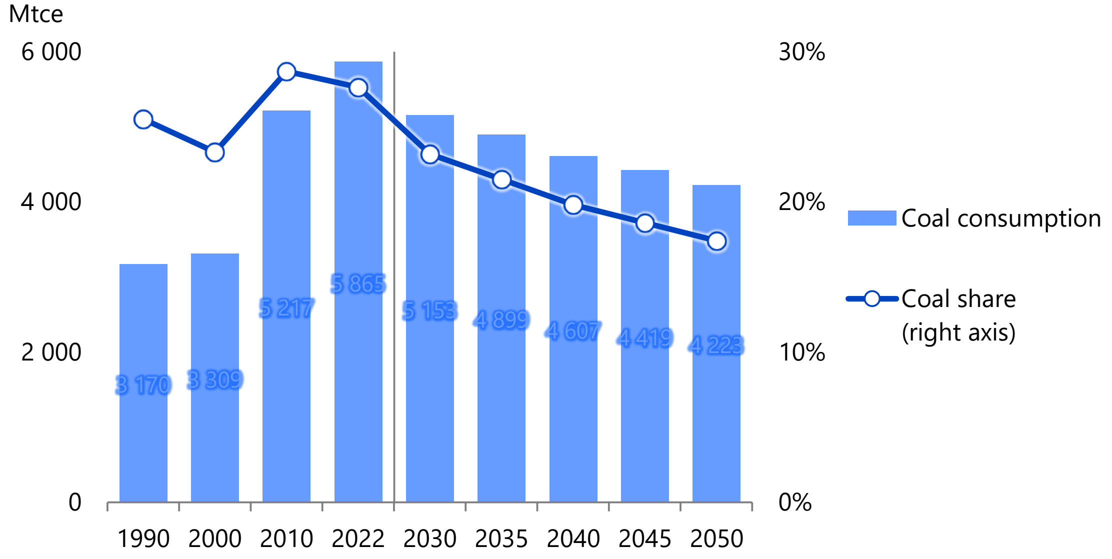
In the industry sector, natural gas consumption in Advanced Economies will decline, while demand in Emerging and Developing Economies will grow at an annual rate of 1.3%, contributing 114% of net global growth. Many industries will shift from oil and coal to natural gas due to its economic and environmental advantages. In the buildings sector, China will be the primary driver of demand growth as it rapidly transitions from solid fuels such as coal and fuelwood to natural gas, improving air quality and public health. However, in other regions, natural gas use in the buildings sector is expected to decline due to increasing electrification and energy efficiency measures.

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

Coal consumption peaks in the 2020s due to environmental measures

Global coal consumption, which stood at 5 865 million tonnes of coal equivalent (Mtce) in 2022, is projected to decline at an annual rate of 1.2% due to the impact of environmental policies (Figure 2-14). As a result, coal's share of primary energy consumption will decrease from 28% in 2022 to 17% in 2050. By the late 2040s, coal will fall below non-hydro renewables in global energy consumption and will be replaced by natural gas as the second most consumed energy source after oil.

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



In 2022, China accounted for 56% of global coal consumption, while India and ASEAN together made up 16%. The United States, Europe and Japan collectively accounted for 13%. By 2050, coal consumption in China and these three Advanced Economies is expected to decline to 40% and 5% of the global total, respectively, while India and ASEAN will see their combined share rise to 37% (Figure 2-15).

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

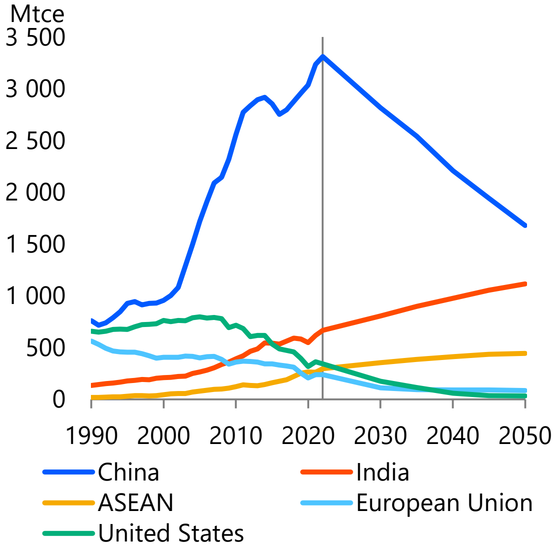
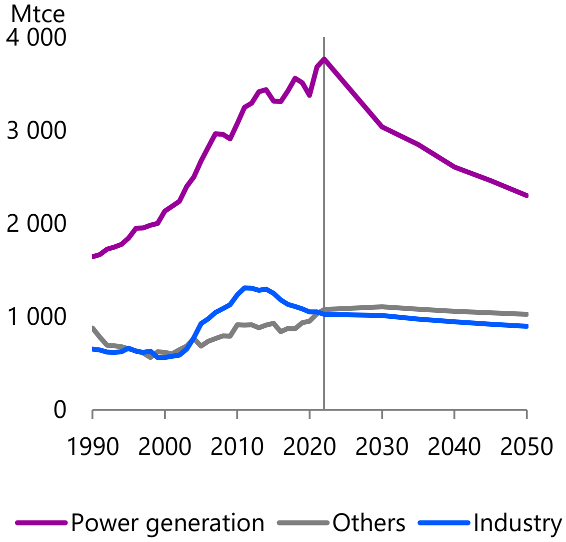


Figure 2-16 | Global coal consumption [Reference Scenario]



In China, coal consumption for industry has been declining after peaking in 2012, while that for power generation will begin to decrease after peaking in the early 2020s due to measures against climate change and air pollution, which will result in a sharp decline of overall coal consumption by 49% by 2050. Coal consumption in the United States, Europe and Japan will continue falling both for power generation and industry sectors, posting a 72% drop by 2050.

In contrast, coal consumption in India and ASEAN will continue to grow. By 2050, coal use for power generation is expected to increase 1.4 times in India and 1.5 times in ASEAN. Industrial coal consumption will expand even more, rising by 2.1 times in India and 1.5 times in ASEAN. MENA, in contrast, consumes minimal coal due to the large number of oil- and gas-producing countries.

With growing pressure to address climate change, coal consumption has come under increasing scrutiny worldwide. At a meeting of G7 environment ministers, member countries agreed to phase out coal-fired power plants that lack emission reduction measures by 2035. In Europe, stricter regulations have raised the economic burden on coal-fired power plants while further tightening limits on CO_2 and mercury emissions.

However, many Emerging and Developing Asian economies, including India and ASEAN, continue to rely on coal as an affordable domestic energy source to support energy self-sufficiency. These countries do not impose particularly strict restrictions on coal consumption. Additionally, while governments and financial institutions in Advanced Economies are actively promoting coal divestment, financial institutions in China and India are not necessarily aligned with this trend.

To curb global coal consumption, the United States, Europe and Japan must accelerate their phase-out efforts, while China, India and ASEAN should prioritise switching from coal to cleaner alternatives such as natural gas, hydrogen and ammonia for both power generation and industrial use.

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

As more countries pursue carbon neutrality, expectations for the expansion of non-fossil energy sources continue to rise. At COP28, world leaders agreed to triple global renewable power generation capacity by 2030 and nuclear power generation capacity by 2050 compared to 2020 levels. However, despite this push, the share of non-fossil energy in total primary energy consumption is projected to increase only modestly, from 19% in 2022 to 27% in 2050.

Non-fossil energy consumption for power generation—mainly from nuclear and hydro—will grow 2.1 times, rising from 1 666 Mtoe in 2022 to 3 600 Mtoe in 2050 (Figure 2-17). The most rapid growth will come from solar photovoltaics, wind and other renewable sources, which are expected to expand 5.1 times over the same period. In contrast, nuclear and hydro will see slower growth due to policy constraints, environmental concerns and social considerations. Consequently, their share of non-fossil energy consumption for power generation will decline from 41% in 2022 to 25% in 2050.

Meanwhile, energy consumption for heating will remain largely reliant on traditional solid biomass, such as firewood and manure, which are widely used in rural areas of Emerging and Developing Economies. While this form of energy accounted for 941 Mtoe in 2022, its use is expected to decline to 708 Mtoe by 2050 as rural populations transition to modern energy sources with rising incomes and improved living standards (Figure 2-18). Its consumption will decline as rural residents switch to modern energy sources in line with improvements in their income and living standards. Liquid biofuels for transport and heating, along with biogas, will grow 1.8 times by 2050, though they will still make up only 22% of total non-fossil energy consumption for heating.

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

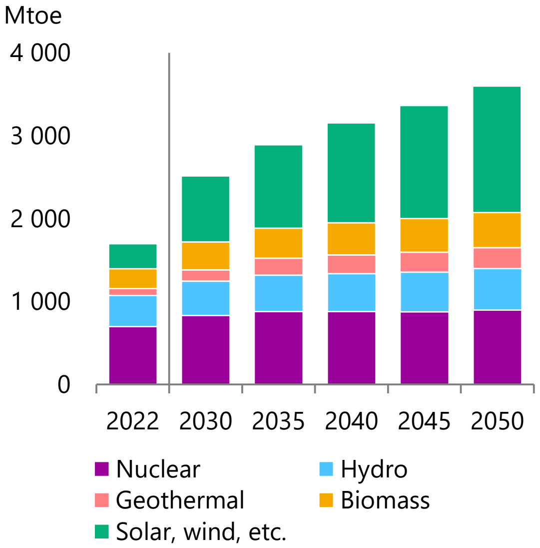
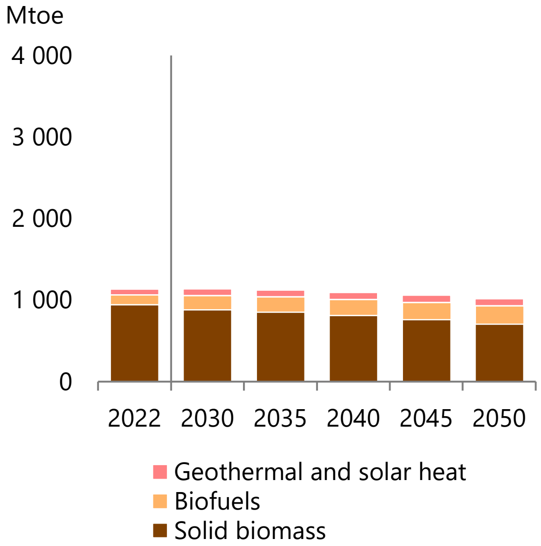


Figure 2-18 | Non-fossil energy consumption for heating [Reference Scenario]



Although non-fossil energy consumption will grow substantially toward 2050, its share of total primary energy consumption will not increase as significantly, since overall energy demand will continue to rise. However, solar photovoltaics, wind and other renewables are expected to expand rapidly due to substantial cost reductions, capturing 84% of the global primary energy consumption growth by 2050.

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

Asia will account for 66% of global energy consumption growth as its share of the global economy increases from 34% in 2022 to 44% in 2050 in real terms (Figure 2-19). China, India and ASEAN will be the primary drivers of this economic expansion. While these economies share some similarities in energy consumption trends, they also exhibit distinct differences. Energy consumption in China will peak in the 2020s, whereas in India and ASEAN, it will continue to rise (Figure 2-20). These differences stem from variations in economic and population growth.

China's economy expanded 15.9-fold, from $1 trillion in 1990 to $16 trillion in 2022 and is projected to grow another 2.6-fold to $42.9 trillion by 2050. Its population grew from 1.14 billion in 1990 to a peak of 1.41 billion in 2021 but is expected to decline to below the 1999 level of 1.25 billion by 2050. Under the 14th Five-Year Plan (2021–2025), China has positioned the transition to a green economy as a key growth strategy. By the early 2020s, energy consumption will begin to decline even as economic growth continues, similar to trends observed in advanced economies, driven primarily by energy conservation efforts in industry. After increasing at an average annual rate of 4.7% from 1990 to 2022, China's energy consumption is projected to decline at an annual rate of 0.4% from 2022 to 2050. By 2050, energy consumption will fall below 2022 levels, despite real GDP per capita exceeding $34 000. This marks China's transition to a mature economy, increasingly focused on carbon neutrality. China's share of Asian energy consumption rose from 42% in 1990 to 58% in 2022 but will decline to 42% by 2050.

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

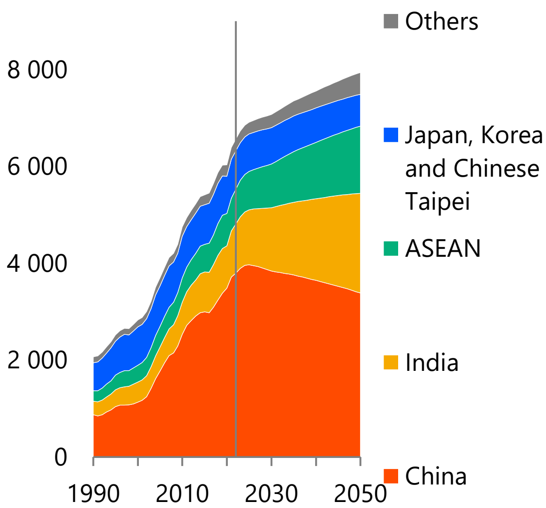
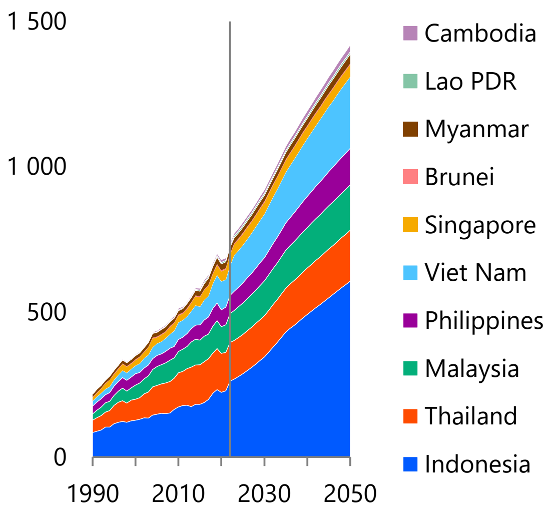


Figure 2-20 | ASEAN's primary energy consumption [Reference Scenario]

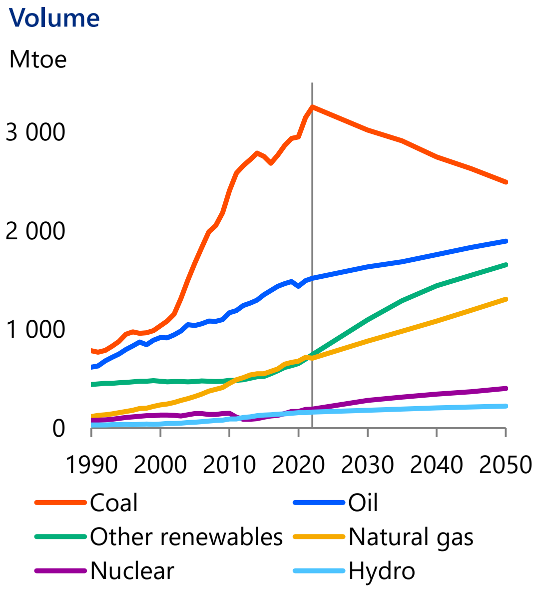


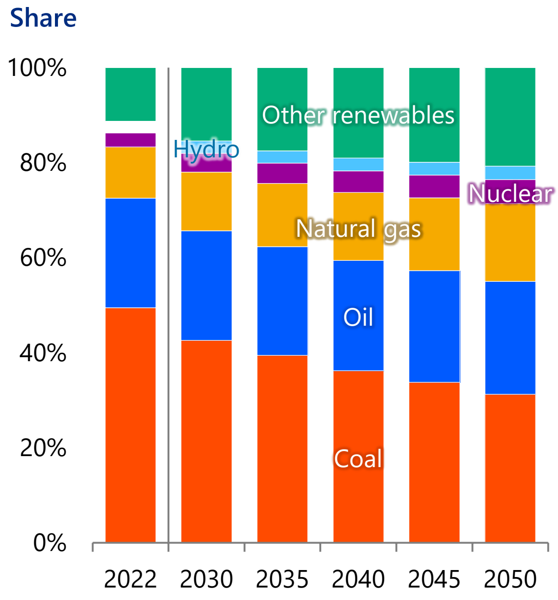
India's economy expanded 6.4-fold, from $500 billion in 1990 to $3 trillion in 2022 and is projected to grow 4.8-fold to $14.4 trillion by 2050. Its population, which surpassed China's in 2022 at 1.42 billion, will continue growing to 1.67 billion by 2050. Consequently, real GDP per capita will rise from $500 in 1990 to $8 600 in 2050, improving incomes and living standards. Although India has committed to achieving carbon neutrality by 2070, its energy consumption will continue growing at an annual rate of 2.6% from 2022 to 2050. As a result, climate change mitigation and energy security measures will become increasingly critical. India's share of Asian energy consumption will grow from 14% in 1990 and 15% in 2022 to 26% by 2050.

ASEAN's economy, valued at $700 billion in 1990, grew to $3.2 trillion in 2022 and is expected to reach $10.1 trillion by 2050. Its population will expand from 440 million in 1990 to 770 million by 2050. As a result, real GDP per capita, which stood at $1 700 in 1990 and $4 800 in 2022, will rise to $13 200 by 2050, further improving income levels. ASEAN's energy consumption will grow steadily at an annual rate of 2.4% from 2022 to 2050, with Indonesia accounting for half of the increase. Despite Indonesia's commitment to achieving carbon neutrality by 2060, its energy consumption continues to rise, underscoring the growing importance of climate change policies and energy security. ASEAN's share of Asia's energy consumption will expand from 10% in 1990 and 11% in 2022 to 17% by 2050.

By 2050, while energy consumption in India and ASEAN will still be increasing, Asia will remain reliant on fossil fuels, which will account for 71% of its energy mix, down from 83% in 2022 (Figure 2-21). Oil and natural gas consumption will continue to grow, driven primarily by demand from the transport and power generation sectors. Reducing Asia's dependence on fossil fuels will be essential for ensuring global energy stability, achieving carbon neutrality and meeting climate goals.

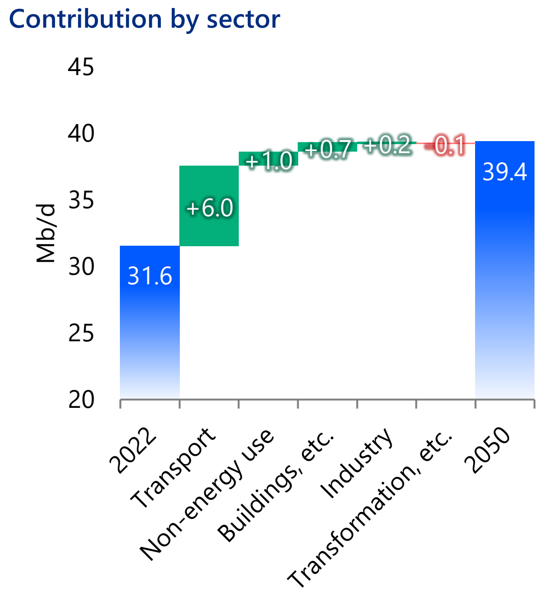
Figure 2-21 | Asian primary energy consumption [Reference Scenario]

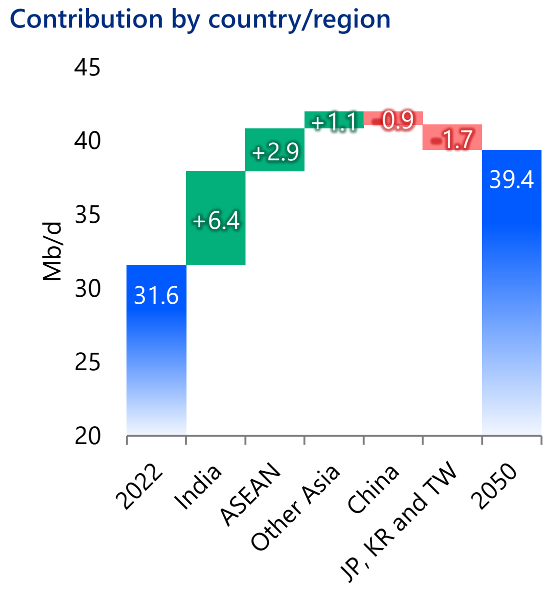




Asia's oil consumption growth is projected to slow from an annual rate of 2.8% between 1990 and 2022 to 0.8% from 2022 to 2050. The transport sector will drive 77% of this growth, while the non-energy use sector and the buildings sector will contribute 13% and 9%, respectively. India will account for 81% of the growth and ASEAN for 37% (Figure 2-22) with their combined share exceeding 100% due to declining oil consumption in Japan, Korea and China. To curb oil demand, India and ASEAN must prioritise fuel efficiency improvements in the transport sector, including vehicle electrification. Given that Asia will account for 97% of global oil consumption growth, developments in the region will significantly impact global energy trends.

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



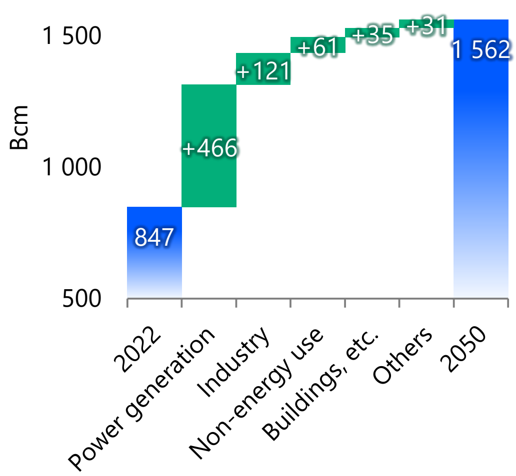


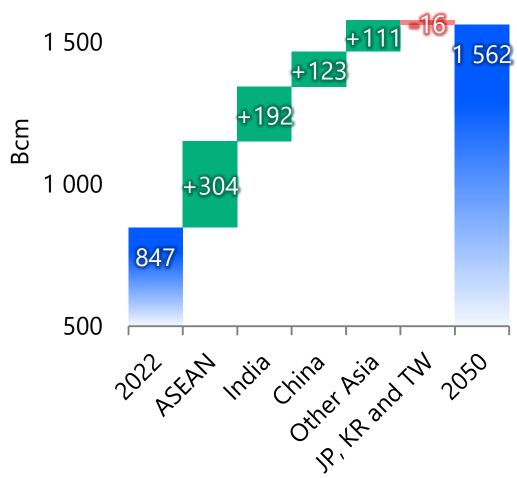
Note: JP, KR and TW stands for Japan, Korea and Chinese Taipei

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

Asia's natural gas consumption grew at an annual rate of 5.8% between 1990 and 2022 but will slow to 2.2% per year from 2022 to 2050. Of this growth, the power generation sector will account for 65%, the industry sector for 17% and the non-energy use sector for 9%. ASEAN will contribute 43% of the increase, followed by India at 27% and China at 17% (Figure 2-23). To curb natural gas consumption, China, India and ASEAN will need to improve efficiency, reduce electricity transmission and distribution losses and promote hydrogen co-firing in power generation. Additionally, enhancing insulation and efficiency measures in the buildings sector will be crucial. As Asia's natural gas consumption growth will account for 55% of global growth, limiting demand in these three economies will have a direct impact on global energy trends.

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





Note: JP, KR and TW stands for Japan, Korea and Chinese Taipei

Although natural gas emits less CO_2 than oil and coal, it remains a fossil fuel that produces CO_2 when combusted. Therefore, it is essential for Emerging and Developing Economies to maximise efficiency in natural gas use. This can be achieved by improving engineers' skills in equipment operation and maintenance, encouraging the construction of natural gas-fired combined-cycle power plants and adopting hydrogen co-firing in the power generation sector.

LNG imports will play a critical role in meeting Asia's natural gas demand. The region's LNG consumption is expected to rise from 257 Mt in 2023 to 392 Mt in 2035, a 1.5-fold increase and further to 569 Mt in 2050, a 2.2-fold increase. Japan and Korea were among the earliest and largest LNG importers, but in 2021 and 2023, China surpassed Japan to become the world's largest LNG importer. In 2023, Japan, Korea and Chinese Taipei accounted for 51% of Asia's LNG imports, while China, India, ASEAN and South Asia together accounted for 49%. By 2050, this distribution will shift significantly, with the former group's share falling to 23% and the latter's rising to 77%. Consequently, India, ASEAN and China will play increasingly important roles in securing a stable LNG supply for the region.

Unlike oil and natural gas consumption, coal consumption in Asia will peak in the 2020s before beginning a long-term decline, driven primarily by reductions in coal-fired power generation. Between 1990 and 2022, coal consumption grew rapidly at an annual rate of 4.5%, but it is projected to decline at an annual rate of 0.9% from 2022 to 2050. The phase-out of coal-fired power plants is being accelerated by concerns over climate change and air pollution, as well as the expansion of renewable energy sources. However, coal will remain Asia's dominant energy source in 2050, accounting for 31% of the region's total energy mix. India and Indonesia, among others, will continue expanding coal-fired power generation to meet rising energy demand.

To mitigate environmental impacts while meeting energy needs, Asian economies should avoid constructing new inefficient coal-fired power plants and focus on optimising the use of existing coal resources. This includes implementing carbon capture, utilisation and storage (CCUS) technologies and promoting ammonia co-firing in collaboration with Advanced Economies.

Although Asia's non-fossil energy consumption remains lower in volume than oil or natural gas consumption, it is projected to grow at an annual rate of 2.6%. Renewables, excluding traditional biomass, will account for 96% of the region's non-fossil energy consumption growth between 2022 and 2050, followed by nuclear at 18%, while traditional biomass use will decline by 13%. China will account for 52% of the growth in renewable energy consumption (excluding traditional biomass), India 25% and ASEAN 16%. In nuclear energy, China will account for 61% of the increase, while India will contribute 23%. Asia's share of global non-fossil energy consumption will rise by 11 percentage points from 2022 levels, reaching 49% in 2050.

In September 2020, China announced its goal of achieving carbon neutrality by 2060, setting a policy to curb fuels with higher CO_2 emissions intensity, such as oil and coal, while promoting the use of natural gas and non-fossil energy sources through 2050. Additionally, China has been advancing industrial policies focused on renewable energy, battery storage and electric vehicles (EVs), strengthening its global position in decarbonisation technologies. However, given China's substantial fossil fuel consumption, significant improvements in energy efficiency and decarbonisation efforts will be required.

Meanwhile, India, which will drive most of Asia's incremental energy consumption through 2050, has pledged to achieve carbon neutrality by 2070. Many ASEAN nations, led by Indonesia, have also committed to carbon neutrality. Under its 'Make in India' initiative, India is promoting domestic solar photovoltaic power generation and the adoption of EVs. In ASEAN, Indonesia has integrated energy conservation and green industry development into its medium-term national development plan.

To accelerate energy conservation and decarbonisation, Asia must take a proactive approach, leveraging continued and enhanced technical and financial assistance from Japan, Korea, China, and other economies. These commitments by China, India and ASEAN to addressing climate change will also contribute to the stability of energy supplies, including LNG.

2.2 Final energy consumption

Global final energy consumption in 2050 will increase 1.2-fold from 2022

In the Reference Scenario, global final energy consumption is projected to increase 1.2-fold, from 10 076 Mtoe in 2022 to 12 043 Mtoe in 2050, representing an average annual growth rate of 0.6%. Two key trends will define this change in global final energy consumption between 2022 and 2050.

First, India, ASEAN and MENA will be the primary drivers of global final energy consumption growth through 2050. As a result, any major developments affecting energy demand in these regions will significantly influence global consumption trends. Key factors contributing to fluctuations in final energy consumption include economic growth, the scope and effectiveness of energy policies, and the advancement and adoption of energy-efficient technologies. Close attention should be paid to these variables to better understand potential shifts in global energy demand.

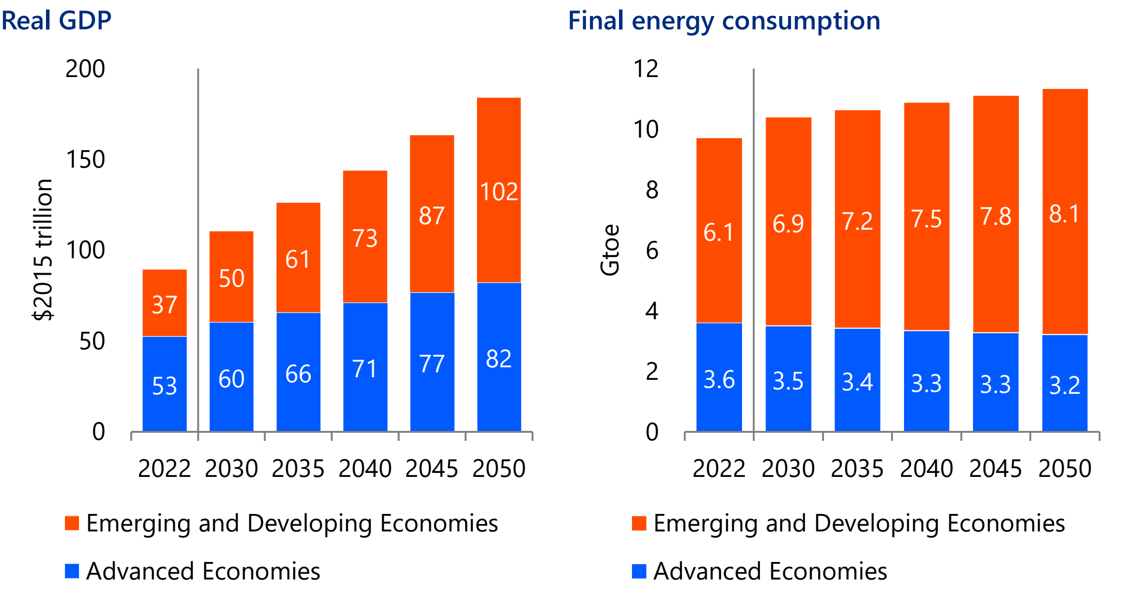
Second, all major energy sources will continue to play a role in global final energy consumption in 2050. While coal consumption is expected to decline from the late 2020s and renewables from the 2030s, neither will reach an absolute minimum by 2050. If climate policies and investment strategies become overly biased toward specific energy sources, there is a risk of disrupting the overall energy supply-demand balance in the medium to long-term. To ensure a stable and diversified energy market, it will be essential to maintain adequate supply across all energy sources while considering demand trends and their implications for climate change.

The following provides insights on final energy consumption changes in the Reference Scenario by economy group, region, sector and energy source between 2022 and 2050.

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

The increase in global final energy consumption from 2022 to 2050 will be driven primarily by Emerging and Developing Economies (Figure 2-24).While final energy consumption in Advanced Economies is expected to decline over the same period, steady growth in Emerging and Developing Economies will more than offset this reduction, leading to an overall increase in global final energy consumption through 2050.

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



In Emerging and Developing Economies, final energy consumption is projected to reach 8 123 Mtoe in 2050, a 1.3-fold increase from 2022 (1.0% per year). Although these economies will continue to follow a growth trajectory in the medium to long-term, improvements in energy efficiency and the expansion of service sectors will slow the rate of increase in final energy consumption. Between 2022 and 2050, final energy consumption growth (1.0% per year) will be significantly lower than real GDP growth (3.7% per year), reflecting a gradual decoupling of economic growth from energy demand.

In contrast, Advanced Economies will see final energy consumption decline to 3 216 Mtoe by 2050, a 10% reduction from 2022 levels. Despite projected real GDP growth of 1.6% per year from 2022 to 2050, final energy consumption will continue its downward trend, decreasing at an annual rate of 0.4%. This decline follows a trend that has been evident since the late 2000s, driven by accelerated energy conservation efforts and a structural shift toward service-based economies. As a result, the final energy consumption elasticity against GDP [5] in the Advanced Economies will shift from 0.25 between 1990 and 2022 to −0.25 between 2022 and 2050[6].

Improving energy efficiency remains a key strategy for decarbonisation. Both Advanced Economies and Emerging and Developing Economies will need to implement measures to enhance energy efficiency across all final energy consumption sectors to support their respective climate goals and ensure sustainable economic growth.

By region: India, ASEAN and Middle East and North Africa will drive final energy consumption growth

Between 2022 and 2050, final energy consumption growth will be driven primarily by India, ASEAN and MENA (Figure 2-25 and Figure 2-26). Together, these regions will account for more than 70% of the global increase in final energy consumption during this period.

Figure 2-25 | Global final energy consumption and contribution by country/region [Reference Scenario, 2022-2050]

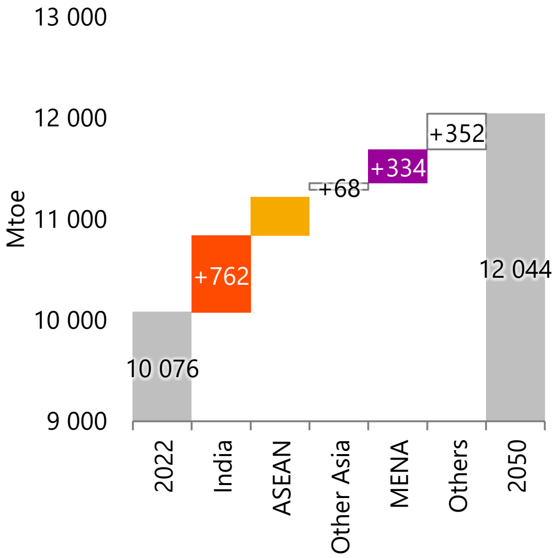
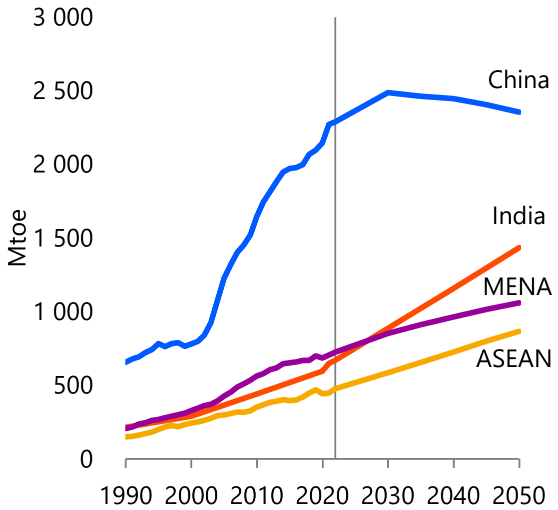


Figure 2-26 | Final energy consumption in China, India, Middle East and North Africa and ASEAN [Reference Scenario]



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

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

Due to strong demand growth in India and ASEAN, Asia's share of global final energy consumption will expand from 41% in 2022 to 45% in 2050, reinforcing its position as a major global energy consumption hub.

India, which became the world's most populous country in 2023, will see its population exceed 1.6 billion and approach 1.7 billion by 2050. With GDP projected to grow at an annual rate of 5.7% between 2022 and 2050, India's GDP per capita will increase 4.1-fold, driven by urbanisation and economic expansion. As a result, India's final energy consumption will grow 2.1-fold (2.7% per year), from 672 Mtoe in 2022 to 1 434 Mtoe in 2050. India alone will account for 60% of Asia's incremental final energy consumption, underscoring its rising significance not only within Asia but also globally. India's share of global final energy consumption will increase from 6.7% in 2022 to 11.9% in 2050, highlighting its growing influence on global energy demand.

In ASEAN, final energy consumption is projected to grow at an annual rate of 2.1%, increasing from 478 Mtoe in 2022 to 866 Mtoe in 2050, largely driven by Indonesia and Viet Nam. Of the total 387 Mtoe increase in ASEAN's final energy consumption, Indonesia will contribute 154 Mtoe and Viet Nam 101 Mtoe. This growth reflects both countries' rising populations and expanding economies. In 2022, Indonesia and Viet Nam had populations of 275 million (the largest in ASEAN) and 98 million (the third largest), respectively, with continued growth expected. Between 2022 and 2050, GDP per capita will increase 3.1-fold in Indonesia and 3.9-fold in Viet Nam. By the late 2030s, Indonesia's final energy consumption is projected to surpass that of Japan.

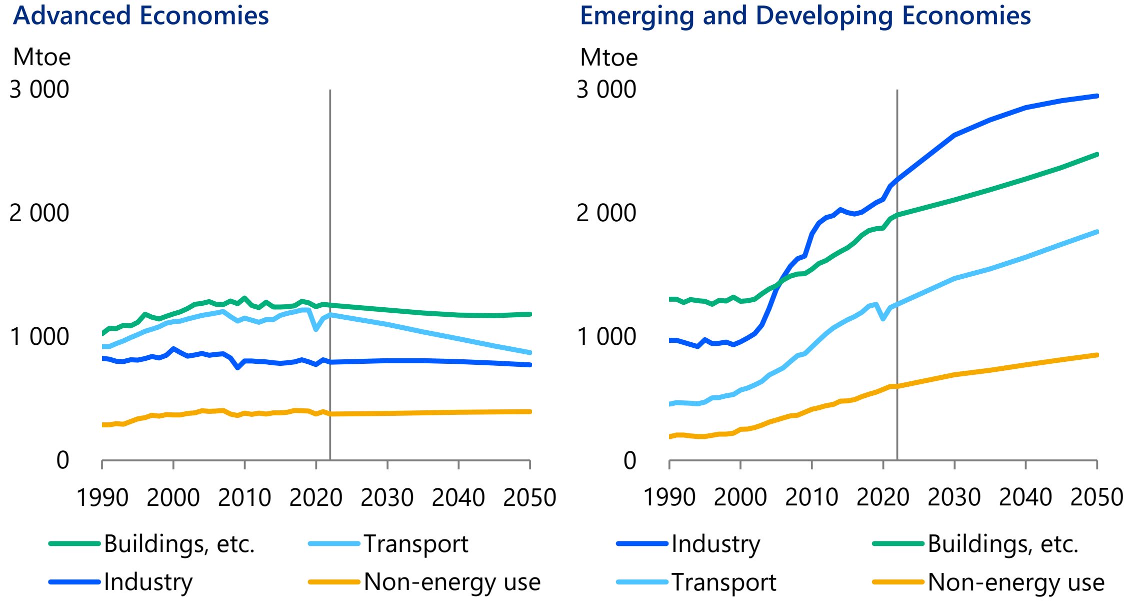
China's final energy consumption is expected to increase modestly, from 2 290 Mtoe in 2022 to 2 355 Mtoe in 2050. While China will remain the world's largest final energy consumer during this period, its energy demand will begin to decline after the 2030s, diverging from the continuous upward trends in India and ASEAN. A key factor behind China's stabilisation and eventual decline in final energy consumption is the industry sector. The energy-intensive steel and cement industries, in particular, will see significant reductions in energy demand. The impact of efforts to eliminate excess capacity has already begun to materialise, with cement production peaking in the mid-2010s and crude steel production peaking in 2020 before shifting to a downward trend.

Final energy consumption in the Middle East and North Africa will grow at an annual rate of 1.4%, rising from 727 Mtoe in 2022 to 1 060 Mtoe in 2050. The main contributors to this increase will be Iran, North Africa and Saudi Arabia, which will account for most of the region's total growth of 334 Mtoe. Specifically, Iran's final energy consumption will rise by 87 Mtoe, North Africa's by 82 Mtoe and Saudi Arabia's by 80 Mtoe. Population growth in these economies—at an annual rate of 1.2%—will outpace that of India and ASEAN, while GDP per capita will increase 1.7-fold in Iran, 2.1-fold in North Africa and 1.4-fold in Saudi Arabia.

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

Between 2022 and 2050, final energy consumption will increase across all sectors, driven primarily by Emerging and Developing Economies. In contrast, final energy consumption in Advanced Economies will decline in all sectors except for the non-energy use sector (Figure 2-27).

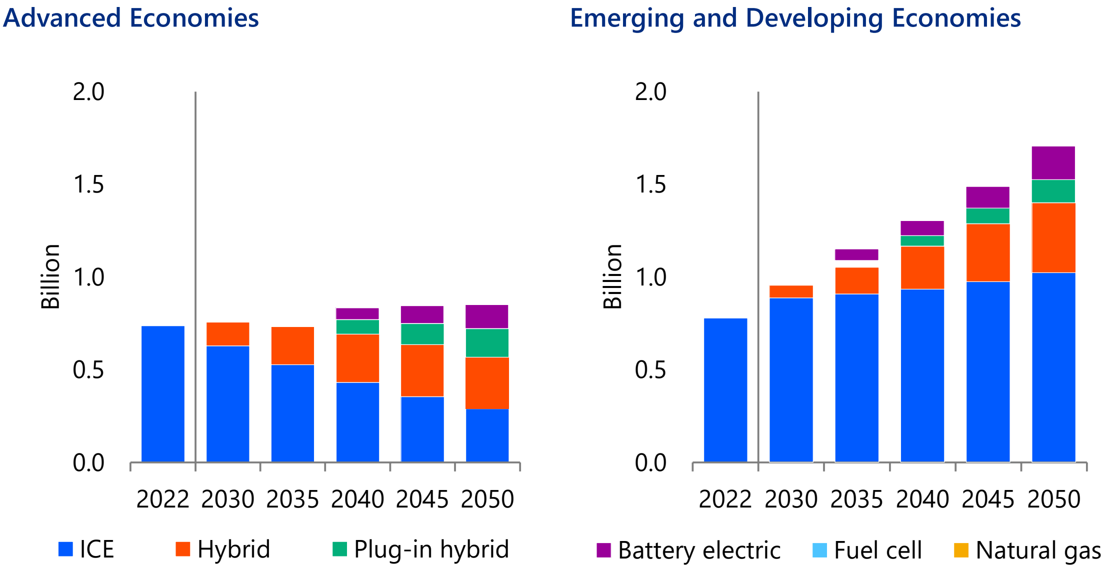
Figure 2-27 | Final energy consumption in the Advanced Economies, and the Emerging and Developing Economies [Reference Scenario]



In the transport sector, final energy consumption is projected to grow at an annual rate of 0.7%, rising from 2 802 Mtoe in 2022 to 3 423 Mtoe in 2050, supported by growth in the road sector of the Emerging and Developing Economies. The growth will reach 621 Mtoe, capturing 28% of the overall global rise in final energy consumption. Economic growth in these economies will lead to a significant expansion in the ownership of internal combustion, hybrid and electric vehicles (Figure 2-28). Consequently, final energy consumption in the transport sector of Emerging and Developing Economies will grow at an annual rate of 1.4%. In contrast, Advanced Economies will see an increase in electricity consumption due to the policy-driven adoption of electric vehicles. However, oil consumption in the road transport sector will decline significantly due to improvements in fuel efficiency and a reduction in internal combustion vehicle ownership. As a result, final energy consumption in the transport sector of Advanced Economies will decline at an annual rate of 1.1%.

In the industry sector, final energy consumption is expected to grow at an annual rate of 0.7%, increasing from 3 064 Mtoe in 2022 to 3 720 Mtoe in 2050. This growth will be driven primarily by increased electricity and natural gas consumption in the manufacturing industries of Emerging and Developing Economies. The sector's total consumption growth will reach 655 Mtoe, accounting for 31% of the overall rise in final energy consumption. However, there is a strong incentive for industrial sectors, including manufacturing, to reduce energy consumption to enhance the cost competitiveness of products. As a result, the growth in final energy consumption in the global industry sector will be slower than the 2.3% annual growth in the value-added output of the global secondary sector from 2022 to 2050.

Figure 2-28 | Vehicle ownership [Reference Scenario]



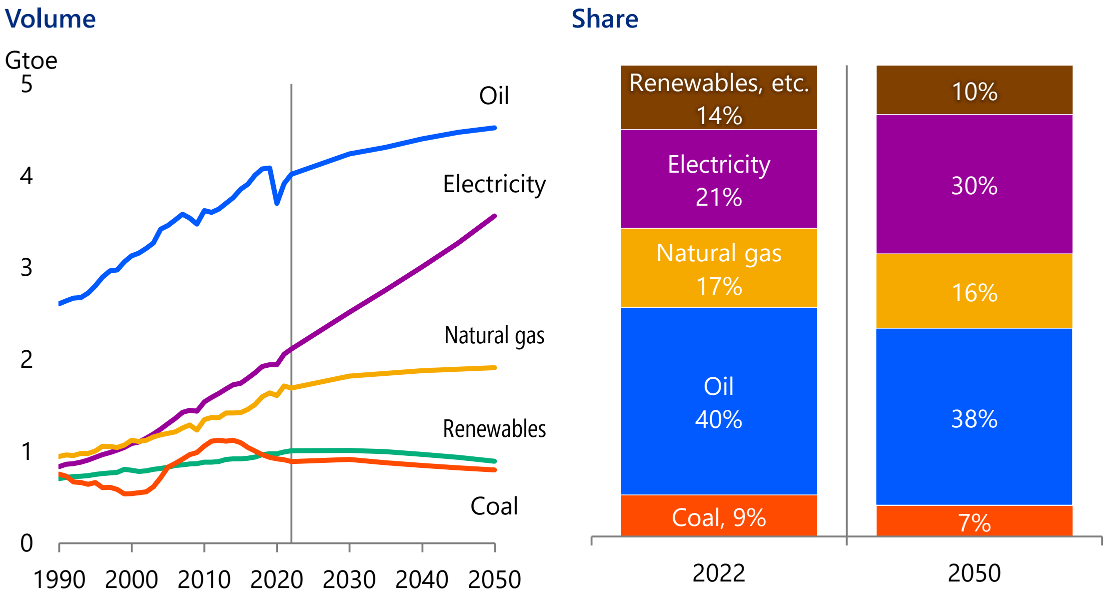
In the buildings sector, final energy consumption is projected to grow at an annual rate of 0.4%, increasing from 3 238 Mtoe in 2022 to 3 655 Mtoe in 2050. Growth will be driven by increased consumption of electricity, natural gas and petroleum products in the commercial and residential sectors of Emerging and Developing Economies. However, as Advanced Economies increasingly substitute electricity-consuming appliances, the consumption of natural gas and petroleum products in the commercial and residential sectors will trend downward worldwide. The total increase in final energy consumption in the buildings sector will reach 417 Mtoe, representing 21% of the overall rise in final energy consumption. As living standards improve in Emerging and Developing Economies, access to modern energy and energy-efficient appliances will increase. In Africa, the share of traditional biomass (fuelwood and manure) in the buildings sector's energy consumption will decline from 73% in 2022 to 35% in 2050, while in Asia, where the share has already fallen to 19%, it will further decline to 5%.

In the non-energy use sector, final energy consumption is expected to grow at an annual rate of 0.9%, increasing from 972 Mtoe in 2022 to 1 246 Mtoe in 2050, mainly due to rising oil and natural gas consumption in Emerging and Developing Economies. The sector's total consumption growth will amount to 274 Mtoe, accounting for 14% of the overall rise in final energy consumption. In Emerging and Developing Economies, demand for petrochemical products, including plastics, will increase as living standards improve. In Advanced Economies, consumption will rise slightly between 2022 and 2050. In North America, the petrochemical industry's non-energy use will increase due to the expansion of shale gas production, which enables cost-effective procurement of feedstocks. While plastics are convenient, their massive consumption has caused international issues such as resources and waste constraints, marine plastic waste and impacts on climate change. In response to these issues, plastics made from biomass instead of fossil fuels will be gradually introduced.

By energy source: Demand for all energy sources will remain

Changes in global final energy consumption from 2022 to 2050 can be categorised into two trends: energy sources with an increasing share and those with a declining share (Figure 2-29). While electricity's share of global final energy consumption will rise, the shares of oil, coal, natural gas and renewables (dominated by the direct use of biomass) will decline. Despite this shift, demand for coal, renewables and especially natural gas will remain significant in 2050. Fossil fuels (coal, oil and natural gas) will see their combined share of global final energy consumption fall from 65% in 2022 to 60% in 2050, yet they will continue to represent more than half of total consumption.

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



Final oil consumption will increase at a rate of 0.4% per year from 4 014 Mtoe in 2022 to 4 520 Mtoe in 2050, led by growth in the transport sector including the road sector in the Emerging and Developing Economies. In Asia, where motorisation is accelerating, including in India and ASEAN, oil consumption in the road transport sector will increase by 382 Mtoe—offsetting the 444 Mtoe decline in Advanced Economies. The non-energy use sector will post the second-highest growth in oil consumption, following transport. In this sector, oil consumption will expand in Asia and the Middle East, where abundant local resources support petrochemical industry development.

Final electricity consumption will grow at an annual rate of 1.9%, increasing from 2 113 Mtoe in 2022 to 3 561 Mtoe in 2050. This growth will be driven primarily by increased electricity use in the buildings and industry sectors. Electricity will be the only energy source to see consumption growth in Advanced Economies, with increases in North America and Europe. However, the primary drivers of global electricity demand will be China, India and ASEAN. Generally, as incomes rise, electricity is preferred for its convenience. Additionally, the increasing penetration of digitalisation will expand the use of electricity-consuming devices and machinery. Electricity's share of global final energy consumption will rise from 21% in 2022 to 30% in 2050. As economies and societies become more reliant on electricity, the consequences of supply disruptions will grow. While decarbonising power sources is a significant issue, it is also important to ensure a stable supply system of electricity from the viewpoint of energy security.

Final natural gas consumption is projected to grow at an annual rate of 0.4%, rising from 1 690 Mtoe in 2022 to 1 910 Mtoe in 2050. Growth will be concentrated in the industry and non-energy use sectors of Emerging and Developing Economies. In India, ASEAN and MENA, where manufacturing industries are expanding, demand for natural gas will increase, particularly processing and assembly activities. Additionally, the petrochemical industry in the Middle East, which relies on natural gas as a feedstock, will drive further consumption growth.

Final coal consumption is expected to decline at an annual rate of 0.4%, falling from 890 Mtoe in 2022 to 799 Mtoe in 2050. As mentioned in the regional perspective, China's energy-intensive steel and cement industries, which are major coal consumers, are expected to contract in the medium to long-term. By 2050, coal consumption in China's industry sector will be less than half of its 2022 level. In addition, China has pledged its '3060 Goal', which aims to reach peak CO_2 emissions by 2030 and become carbon neutral by 2060. Based on this goal, China plans to reduce coal consumption from 2025, which will accelerate the shift to electricity in its industry sector and to natural gas and electricity in the industry and buildings sectors.

Final renewable energy consumption is projected to decline at an annual rate of 0.4%, decreasing from 1 008 Mtoe in 2022 to 892 Mtoe in 2050. This decline will be primarily driven by the ongoing energy transition in Emerging and Developing Economies in Asia and Africa. One area of renewable energy in final consumption that is gaining attention is liquid biofuels for use in automobiles and aircraft. An example of renewable energy in the final consumption sector which is attracting attention is liquid biofuels for automobiles and aircraft. However, traditional biomass, including fuel wood and manure used in the Emerging and Developing Economies, accounted for the largest share at 67% in 2022, followed by 14% for fuel wood mainly for space heating in Europe and North America, 12% for liquid biofuels and 7% for others. As mentioned in the perspective by sector, the use of modern energy is gradually replacing the use of traditional biomass in Emerging and Developing Economies in Asia and Africa. As a result, global final consumption of renewables will gradually decline from the 2030s.

3. Energy supply

3.1 Crude oil

Crude oil supply in recent years

Despite oil supply risks, such as the Western sanctions on Russian oil, attacks on oil tankers by the Houthis and the conflict between Israel and Iran, the current crude oil supply is relatively stable. OPEC[7]+ has maintained production cuts of 2 million barrels per day (Mb/d) through 2025, alongside additional voluntary reductions of 1.65 Mb/d and 2.2 Mb/d. Although global oil demand recovered to pre-pandemic levels in 2023, OPEC+ has struggled to sustain prices through coordinated production cuts, in part due to increased output from non-OPEC+ countries, particularly the United States. Despite Western embargoes, price caps and Ukrainian attacks on its oil infrastructure, Russia has maintained production at approximately 10 Mb/d. This resilience is largely supported by continued oil imports from countries such as India and China. Meanwhile, production in the United States, which is the world's largest oil producer, is robust, exceeding 20 Mb/d in the second quarter of 2024.

Middle Eastern oil producers taking advantage of low production costs to lead the global supply of crude oil

In the Reference Scenario, global oil demand will continue to increase until 2050, mainly in Emerging and Developing Economies, such as India, the Association of Southeast Asian Nations (ASEAN) and Africa, on the back of economic growth.

Until 2030, global oil demand will increase at an annual rate of 0.5%, prompting both OPEC and non-OPEC producers to increase output. OPEC member countries, led by the Middle East Gulf countries, will drive the increase in the world's supply during this period. Europe and Eurasia will continue to reduce their oil production as Russia's lack of upstream investment worsens, partly due to embargoes and sanctions imposed by Western countries.

Meanwhile, production in North America, mainly the United States, will peak around 2030. In addition, production in Latin America will increase slightly, while production in Africa will remain flat, with that in Asia and Oceania continuing to decline. Although production in North America will decline moderately from 2030s, the United States will continue to be the world's largest oil producer in 2050. While production in Latin America will continue to increase, production in non-OPEC regions such as Europe and Eurasia and Asia will decrease, highlighting the increased presence of Middle East OPEC countries with their overwhelming cost competitiveness.

As a result, the share of OPEC crude oil in the world oil supply will expand from 36% in 2022 to 42% in 2050.

[7] Organization of the Petroleum Exporting Countries

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

(Mb/d)

	2022	2030	2040	2050	2022-2050	
					Changes	CAGR
Crude oil production	95.4	99.0	101.9	103.5	8.1	0.3%
OPEC	35.0	37.8	41.5	44.6	9.6	0.9%
Middle East	28.3	31.0	34.3	36.8	8.5	0.9%
Others	6.8	6.7	7.2	7.9	1.1	0.5%
Non-OPEC	60.3	61.2	60.3	58.9	-1.5	-0.1%
North America	22.4	25.9	25.6	24.7	2.3	0.3%
Latin America	8.2	8.4	9.6	9.8	1.6	0.6%
Europe and Eurasia	17.7	15.1	14.1	13.2	-4.4	-1.0%
Middle East	2.9	3.7	3.8	4.6	1.7	1.6%
Africa	1.6	1.4	1.4	1.5	-0.1	-0.2%
Asia and Oceania	7.6	6.7	5.7	5.1	-2.5	-1.4%
Processing gains	2.3	2.4	2.6	2.8	0.5	0.7%
Oil supply	97.7	101.4	104.5	106.3	8.6	0.3%

Note: Crude oil includes natural gas liquid (NGL).

Asia growing dependent on Middle Eastern crude oil

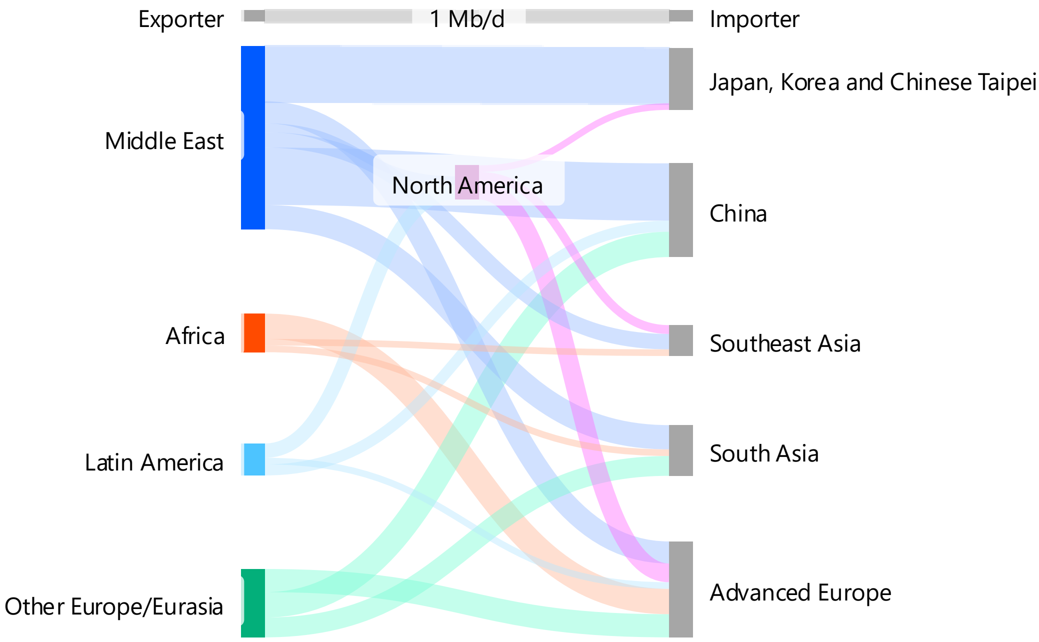
In 2023, global interregional crude oil trade totalled 44 Mb/d. The Middle East remained the largest exporting region, accounting for approximately 18 Mb/d, or 42% of global exports, followed by North America with 8 Mb/d and Other Europe and Eurasia, which is led by Russia, with 7 Mb/d.

Asia is the primary destination for Middle Eastern crude, receiving 70% of the region's exports. In Other Europe and Eurasia, 80% of exports were directed to Asia, largely due to Russia increasing shipments to China and India in response to Western embargoes. North American crude 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 29 Mb/d, of which China, the world's largest importer, accounts for about 11 Mb/d. Advanced Europe's imports are also large, at 10 Mb/d. The largest supplier for Asia is the Middle East, with 60% dependency for Asia as a whole.

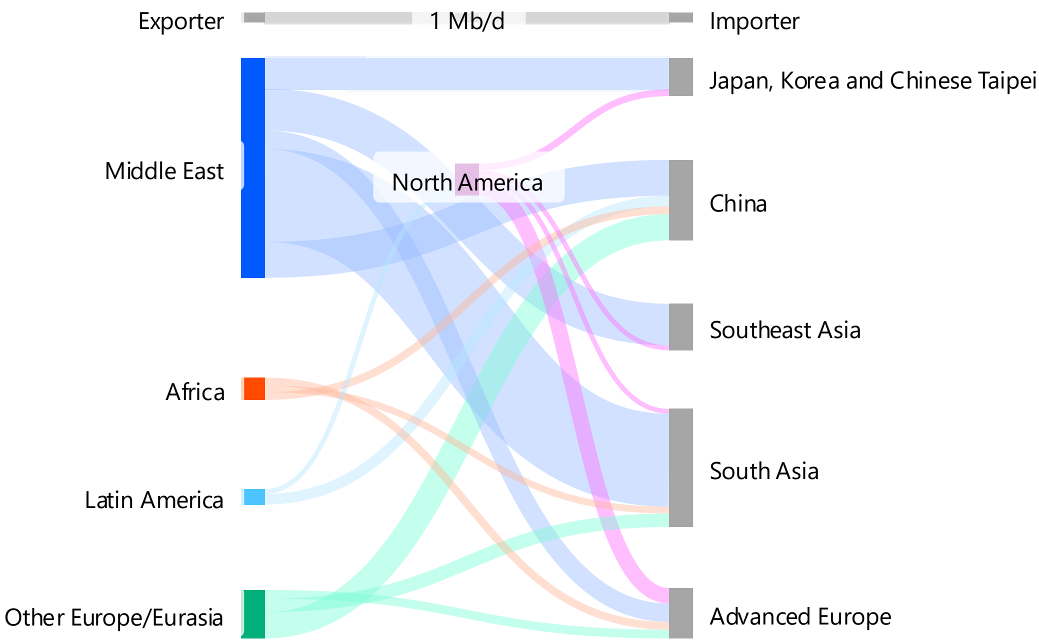
Since the onset of the war in Ukraine, Africa has emerged as the leading crude oil supplier to Advanced Europe, as the region moves away from Russian oil. North America and the Middle East have also expanded their exports to Europe, reducing Advanced Europe's dependence on crude oil from Other Europe and Eurasia. Before the invasion of Ukraine, Advanced Europe sourced 40% of its crude oil imports from this region, including 30% from Russia. By 2023, this dependence had fallen to 24% (with the European Union's reliance on Russian oil dropping to just 4%).

Figure 3-1 | Major interregional crude oil trade flows [2023]



Note: Flows of 0.5 Mb/d or more are covered
Sources: Energy Institute "Statistical Review of World Energy 2024", 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

Global crude oil trade will increase as demand grows in non-oil-producing countries. In Organisation for Economic Co-operation and Development (OECD) countries, declining demand will continue to reduce imports. However, crude oil imports by non-OECD countries will expand at a faster pace. As China's import growth slows, India and ASEAN will emerge as the main drivers of demand, further increasing Asia's reliance on crude oil imports. While import flows from Europe, Eurasia (led by Russia) and the Americas to Asia will continue to rise, the Middle East will remain the region's dominant crude oil supplier.

3.2 Natural gas

The liquefied natural gas market continues to see moderate growth in trading volume ahead of a major expansion period

In the first half of 2024, global liquefied natural gas (LNG) trade exceeded 200 million tonnes (Mt), marking a slight increase from the previous year. While the growth rate was modest, it set a new record for the highest volume traded in a six-month period. A notable trend was the shift in LNG imports from the Atlantic to the Pacific, with the Asia-Pacific region (excluding the Middle East) increasing its share of global imports from 62% in the previous year to 68%.

The European Union and the United Kingdom imported 48 Mt, well below the 59 Mt in the same period previous year. Japan imported 32 Mt, slightly down from the same period previous year. China imported 38 Mt, up from the same period previous year (33 Mt), but fell short of the record high of 40 Mt for the same period in 2021. However, China's pipeline gas and LNG imports totalled 65 Mt, a 14.3% year-on-year increase, setting a new record. Meanwhile, China's domestic natural gas production reached 123.6 billion cubic metres (Bcm) in the first half of 2024, up 6.0% year on year, while its total natural gas consumption rose to 213.75 Bcm, a 10.1% increase, also a new high. Southeast Asia's LNG imports surged by 21% year on year to 12 Mt.

On the export side, the United States, Australia and Qatar remained the top LNG suppliers in the first half of 2024, each exporting approximately 40 Mt. Among them, the United States recorded a slight increase in exports. Russia, the fourth-largest exporter, saw an increase after a notable decline the previous year. Smaller growth was also recorded in Mozambique, Nigeria, Malaysia and Indonesia.

Since 2022, a combination of Western embargoes and Russia's deliberate reduction in energy exports has led to a sharp decline in Russian pipeline gas supply to the European Union. Monthly supply fell from just over 8 Mt of LNG equivalent in December 2021 to below 2 Mt after December 2022, a trend that continued through at least June 2024. On the other hand, the supply of Russian LNG to the European Union increased slightly in 2022 and 2023. However, uncertainties remain regarding the future availability of both Russian LNG and pipeline gas from 2025 onward.

Furthermore, depending on future trends in spot gas prices in Asia and Europe, the ratio of US LNG to Asia and Europe will fluctuate. The ratio of US LNG exports to the European Union and the United Kingdom increased from around 30% in 2021 to over 60% in 2022–2023 and nearly over 50% in the first half of 2024. Meanwhile, the share of US LNG exports to Asia declined from nearly half in 2021 to about a quarter in 2023, before rising slightly to around 30% in early 2024.

Disruptions to global LNG supply have impacted the market in recent years. In 2022, a fire at a major US LNG facility led to a prolonged outage, limiting global supply growth. In late 2023, labour disputes at large LNG production facilities in Australia caused market volatility, although they did not lead to supply disruptions. In early 2024, restrictions on major LNG marine transport routes resulted in detours and longer transport distances. If there are any additional troubles with large LNG production facilities or disruptions to transport routes in the future, the market balance could be significantly disrupted. From late 2024 to early 2026, the timely and stable commissioning of new LNG projects in Canada, Mexico, the United States and Mauritania/Senegal 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 announced at the end of January 2024 that it would suspend non-FTA[8] LNG export authorisation process and update its study on the economic and environmental impacts of LNG exports. The authorities announced that the updated study would be completed in a few months, but objections and opposition continued. In early July, an injunction suspending the pause on export authorisation process was issued. Also in late July, the US Senate Committee on Energy and Natural Resources adopted a licence approval reform bill. If enacted, the bill would impose a 90-day deadline for LNG export application reviews, oblige expedited processing, and not allow for measures to halt future LNG export authorisations. The pause of 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 the first half of 2024, LNG imports, pipeline gas imports, and domestic natural gas consumption and production all increased.

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. While natural gas production by state-owned enterprises declined, private sector production rose by 16% in 2022 and 20% in 2023.

In Southeast Asia and South Asia (excluding India), the impact of fluctuations in prices and supply and demand on the LNG global market has been varied in recent years. In Southeast Asia, LNG imports increased 28% year on year in 2022 and 25% in 2023, reaching 20.20 Mt in 2023. In the first half of 2024, imports increased by 21.2% year on year to 12.12 Mt. 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 of LNG imports in Southeast Asia. On the other hand, Bangladesh and Pakistan significantly reduced LNG imports for natural gas-fired power generation in 2022, with a combined decline of 18% year on year or 2.55 Mt. In 2023, their imports increased by 8.8% year on year to 12.39 Mt in 2023 and by 7.7% to 6.68 Mt in the first half of 2024.

Aiming at stabilising the LNG market: supply, demand and prices

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. LNG traded by sea has increased by more than 60% in the 12 years since 2011. In 2022–2023, Germany, the Philippines, Hong Kong, and Viet Nam joined the list of importing countries and regions.

[8] Free trade agreement

Table 3-2 | Changes in the role of LNG

Major periods and incidents	LNG s roles
Late 20th century Oil crisis Air pollution	Expanded as an alternative, clean energy source (Japan, Korea) Alternative source of supply to pipeline gas (Europe) Expanded its share among primary energy supply 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 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	Combination with new and clean energy sources and transition Could be utilised permanently if LNG can become clean

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.

For the time being, the United States will play a pivotal role in LNG supply, particularly through projects with strong investment potential. Unlike traditional LNG projects, which are vertically integrated with upstream gas fields, US LNG projects operate under a more flexible structure. 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 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, US LNG exports to Japan expanded, highlighting a price advantage over most traditional long-term contracts for Asian LNG supply. In 2020, US LNG demonstrated its flexibility by absorbing fluctuations in global demand amid weak natural gas prices. 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. By 2023, it became the world's largest LNG exporter.

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 for 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.

Shift of LNG logistics to Europe and continuation of high global natural gas prices

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 liquefaction facilities in one to two years, which is significantly faster than those with larger liquefaction capacities.

New LNG developments are emerging in frontier regions across East and West Africa, where natural gas production is expanding. For offshore or small-to-medium-sized natural gas fields, floating LNG (FLNG) production facilities are increasingly seen as viable options. In West Africa, Cameroon has already commissioned an FLNG project, while investment decisions were made in 2017 for a similar project off Mozambique in East Africa, in 2018 for a project off Senegal and Mauritania in West Africa, and in 2022 for another off the Republic of Congo. 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 in June 2019. However, as of 2024, construction has been suspended for four years due to the deteriorating local security situation. 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. Backed by those LNG projects, natural gas production is expected to increase steadily.

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.

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 cutting or decreasing natural gas demand in Europe, and the trend of recovering natural gas demand 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, dealing with increased volatility will continue 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: establishing the superiority of LNG projects as investment targets and financing sources by clarifying standards for transition-compliant

LNG; clarifying standards for measuring, reporting and verifying (MRV) greenhouse gas (GHG) emissions standards; and clarifying standards for equipment for clean measures at the government and international levels.

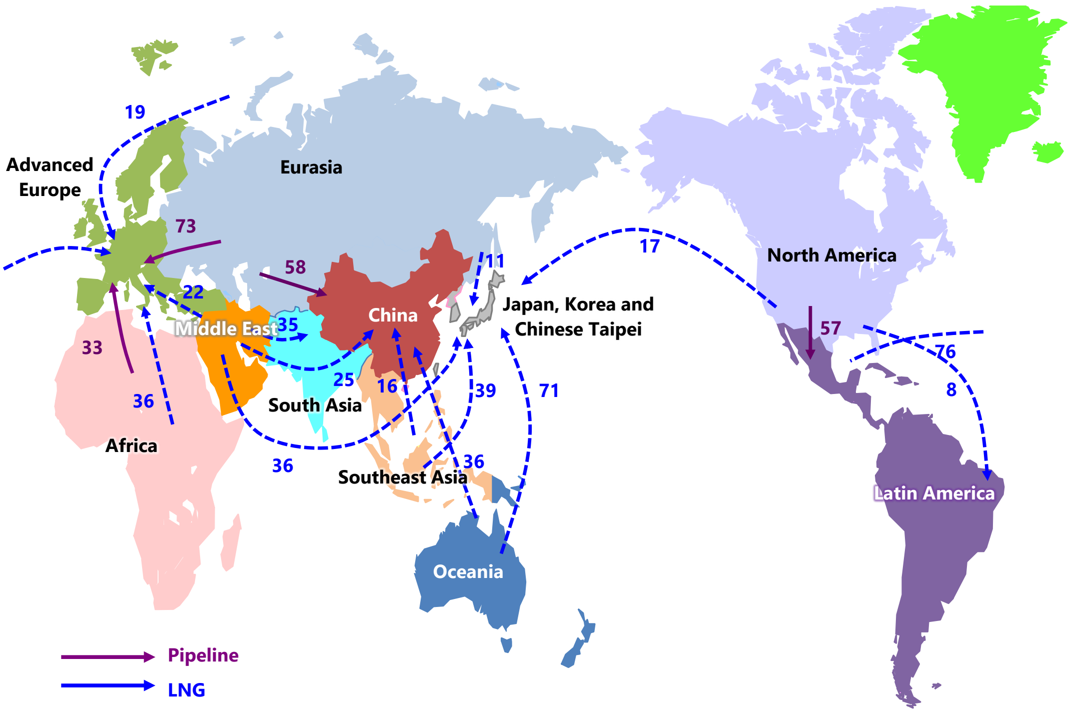
Progress in this regard was made in 2023 and 2024, when the Group of Seven (G7) and LNG Producer-Consumer Conference discussed strengthening the role of the government and the International Energy Agency (IEA) to stabilise the LNG market.

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

(Bcm)

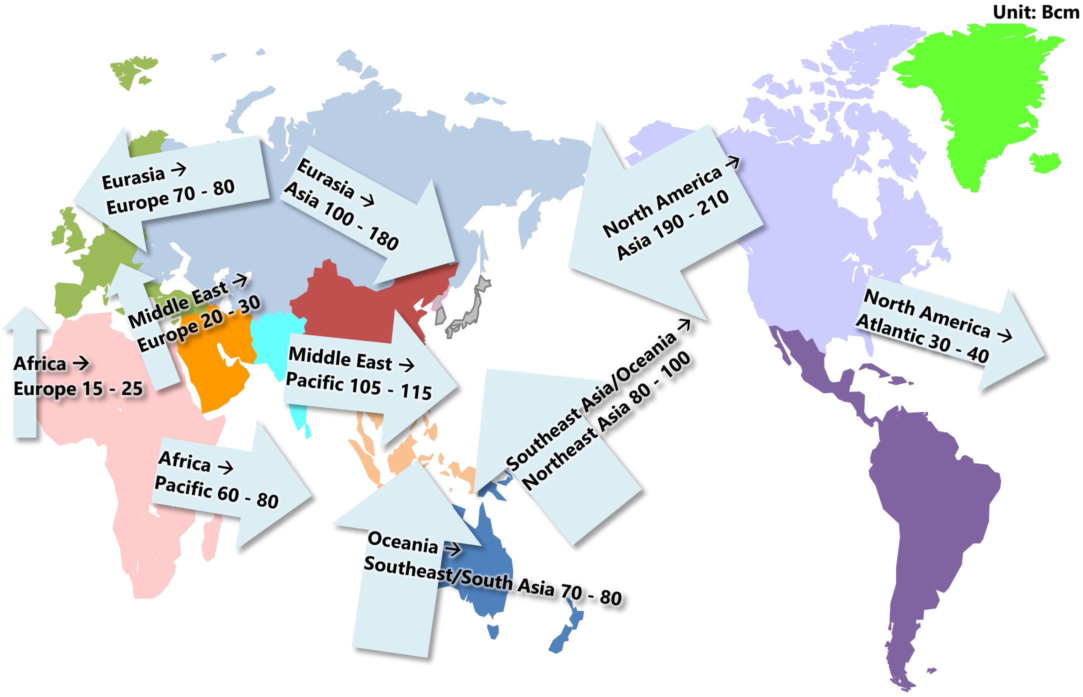
	2022	2030	2040	2050	2022-2050	
					Changes	CAGR
World	4 210	4 364	4 797	5 407	1 197	0.9%
North America and Mexico	1 272	1 337	1 426	1 497	225	0.6%
Latin America excluding Mexico	161	174	225	313	153	2.4%
Europe	214	143	130	100	-113	-2.7%
Europe/Central Asia	914	848	864	909	-5	0.0%
Russia	689	618	610	609	-80	-0.4%
Middle East	709	777	860	1 013	304	1.3%
Africa	254	279	386	548	294	2.8%
Asia	521	642	722	823	302	1.6%
China	220	240	248	251	31	0.5%
India	34	45	71	100	66	4.0%
ASEAN	196	220	249	269	73	1.1%
Oceania	166	165	185	204	38	0.7%

Figure 3-3 | Major interregional natural gas trade flows [2023]



Note: Major trade flows are covered.

Figure 3-4 | Major interregional natural gas trade flows [Reference Scenario, 2050]



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

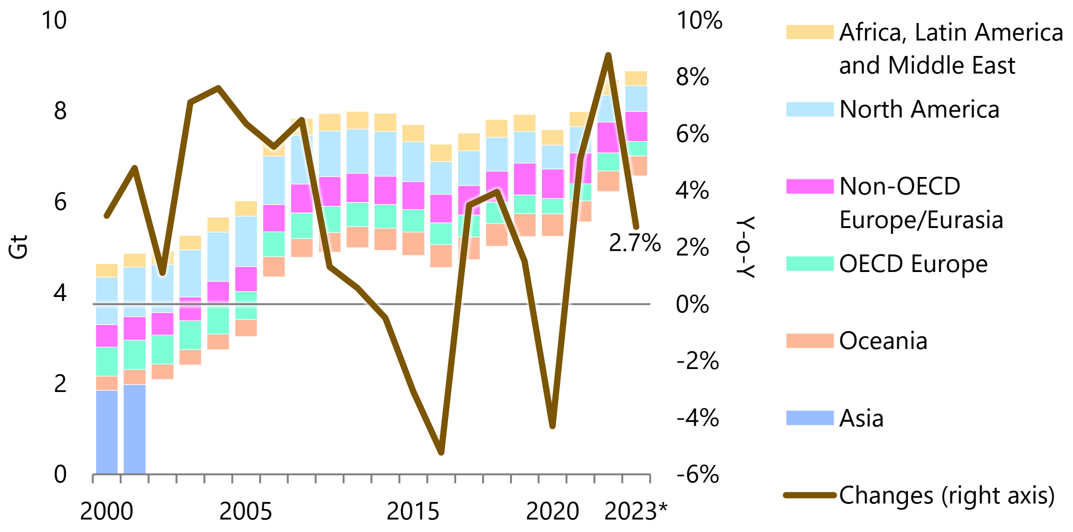
3.3 Coal

Increasing regional fragmentation of supply and demand in the world

In 2023, global coal demand hit a record high, driven by a significant increase in coal demand in China and India due to their continued economic recoveries from the previous year from the impacts of the COVID-19 pandemic. In addition to the large production increases in China and India, where domestic demand grew, production in Indonesia also increased significantly due to growing demand in Emerging and Developing Economies in Asia, boosting global coal production to an all-time high.

Looking at this situation in numbers, global coal consumption in 2023 is expected to reach 8 688 Mt (+2.4% or +200 Mt year on year). Particularly, China and India have accelerated the growth of consumption. Consumption in China increased to 4 876 Mt (+6.0% or +276 Mt YoY), while that in India grew to 1 272 Mt (+10.4% or +120 Mt YoY). Meanwhile, the United States and the European Union significantly reduced consumption to 417 Mt (−10.7% or −50 Mt YoY) and to 358 Mt (−22.8% or −106 Mt YoY), respectively. In Europe, demand recovered due to a temporary return to coal-fired power generation in the wake of Russia's invasion of Ukraine due to increased coal-fired power generation; however, once immediate supply issues subsided, European countries resumed their planned phase-out of coal as part of their decarbonisation efforts, leading to a substantial reduction in coal demand. This seemingly caused a significant decrease in coal demand for electricity. However, overall global demand volume has grown over the previous year as increased demand in China, India, and other countries exceeded the declines. Global coal production also increased in line with demand, reaching 8 954 Mt (+2.7% or +237 Mt YoY) in 2023 (Figure 3-5).

Figure 3-5 | Global coal production



Note: Figures for 2023 are provisional.
Source: IEA "World Energy Statistics and Balances 2024"

Regional production exhibited significant variations. In Asia, production expanded substantially to meet robust demand, with China's production rising to 4 610 Mt (+3.4% or +153 Mt YoY), India's to 1 050 Mt (+11.6% or +109 Mt YoY) and Indonesia's to 775 Mt (+12.6% or +87 Mt YoY). Overall, Asia's total coal production reached 6 831 Mt (+5.7% or +370 Mt YoY). Other regions experienced declines: OECD Americas produced 625 Mt (−4.6% or −30 Mt YoY), OECD Europe

316 Mt (−18.9% or −74 Mt YoY), non-OECD Europe/Eurasia 658 Mt (−4.1% or −28 Mt YoY) and the combined regions of Africa, Latin America, and the Middle East 322 Mt (−3.8% or −13 Mt YoY). The increase in Asia far exceeded these declines, resulting in a year-on-year increase for overall the world.

Looking at production trends for major exporting countries in 2023, Australia's coal production declined to 439 Mt (−4.1% or −19 Mt YoY) due to adverse weather conditions from the La Niña phenomenon earlier in the year, as well as delays in labour availability following COVID-19 disruptions. In contrast, Indonesia's coal production significantly increased, surpassing 700 Mt for the first time, reaching 775 Mt (+12.6% or +87 Mt YoY) to meet growing demand from Asian countries. Colombia, primarily serving the European market, experienced a sharp decline to 49 Mt (−23.7% or −15 Mt YoY) due to political unrest, labour protests and adverse weather. South Africa, which exports mainly to India and ASEAN countries, halted its production decline since 2020 (caused by COVID-19 impacts, railroad disruptions and weaker domestic demand), with production stabilising at 232 Mt (+0.7% or +2 Mt YoY). Meanwhile, in Russia, despite the embargoes imposed by Western countries due to the invasion of Ukraine and bottlenecks along the Trans-Siberian Railway, production slightly declined to 425 Mt (−1.1% or −5 Mt YoY).

As in 2022, global coal trade flows in 2023 were affected by sanctions on Russian coal exports due to the ongoing invasion of Ukraine. Consequently, Western countries sought alternative coal suppliers, while China and India, not participating in the sanctions, continued importing Russian coal. These trade disruptions maintained coal prices at elevated levels, especially for steam coal, though prices declined slightly from the peaks of 2022. With coal prices remaining high, China and India have strengthened their response to growing domestic demand through policies to significantly raise domestic production. As a result, their domestic production increased remarkably. However, imports are being maintained to fill the supply-demand gap, with the volume imported also increasing. As both countries have large demand for coal, the role (share) of imported coal in domestic demand is small, but since it accounts for a large amount in global coal trade, the coal supply and demand in both countries warrants continued attention. In this environment, China's coal imports rose significantly to 474 Mt (+55.7% or +122 Mt YoY). Previously, China's import volumes had declined sharply due to the import ban on Australian coal and preference for domestic coal. In 2023, however, China increased coal imports markedly, importing substantial volumes from Russia (whose export markets were constrained by Western sanctions) and lifting its embargo on Australian coal. Similarly, India significantly boosted domestic coal production, but also actively procured Russian coal, resulting in imports of 246 Mt (+9.5% or +21 Mt YoY). Due to these developments, total international coal trade (imports of steam and coking coal) reached 1 486 Mt (+8.9% or +120 Mt YoY), comprising 1 156 Mt of steam coal (+7.9% or +84 Mt YoY) and 322 Mt of coking coal (+11.2% or +36 Mt YoY), both increasing from the previous year.

Supply-demand balance amid the continuing invasion of Ukraine

Coal demand in 2024 is expected to maintain a similar composition to the previous year, with strong growth primarily in the power generation sector in Asia, while demand weakens in the United States, the European Union and Japan. The situation in Asian countries during the first half of the year is as follows:

In China, despite steady growth in electricity demand, coal-fired power generation is expected to slow due to the recovery of hydro power generation and expansion of renewable power generation. Additionally, demand in steel and cement manufacturing has weakened due to economic slowdown, although coal gasification applications are increasing. In India, demand has grown in both electricity and non-electricity sectors. Increased consumption in coal-fired power generation has been driving overall demand growth, particularly as hydro power generation remains sluggish, similar to the previous year. In Indonesia, in addition to strong exports, domestic power generation and consumption in the nickel-based refining industry have increased. In Viet Nam and others, strong electricity demand combined with sluggish hydro power generation has necessitated compensation through thermal power generation using imported coal, resulting in significantly increased coal demand. Thus, in Emerging and Developing Economies in Asia, coal demand continues to grow as it did in the previous year.

On the other hand, the United States and European Union, where coal demand is declining, have experienced notable decreases in the power sector due to a combination of sluggish electricity demand and renewable energy expansion. In the United States, inexpensive natural gas has further contributed to declining coal demand. Japan and Korea also experienced continuing consumption decreases from 2023 due to reduced coal-fired power plant operations, influenced by lower LNG prices compared to the previous year. Based on this balance, demand in 2024 is projected to remain level relative to the previous year.

As for global coal production, while production in India and Indonesia will continue to increase, China is expected to experience a slight decline compared to the previous year due to strengthened operational maintenance in the coal-producing province of Shanxi. The United States and European Union will also experience continued production decreases. As for other countries, Australia suffered production declines due to severe weather damage caused by the La Niña phenomenon in 2022–2023. Although current production is no longer affected by these weather events, it is expected to remain at the depressed 2023 level due to reduced demand from Japan, a major export destination, as well as domestic labour shortages. Russia's coal production is not expected to decline significantly despite being affected by Western countries' import bans as in previous years. However, production may be influenced by the war situation with Ukraine or changes in import policies of countries not participating in sanctions, such as China and India.

In coal trade, moves by China and India, the two largest importers, have a major impact. China had been restricting imports to approximately 300 Mt/year to protect its domestic coal industry, but in 2023 it relaxed these restrictions in response to rising domestic demand, resulting in a substantial year-on-year increase in imported coal to 474 Mt. Regarding import sources, in addition to Indonesia and Russia, China is diversifying its procurement by resuming imports from Australia in January 2023, which had been suspended due to political friction. Imports of coking coal from Mongolia have also increased significantly. In 2024, imports in the first half of the year exceeded the previous year, partly due to reduced production in Shanxi province, where the government has tightened environmental and operational safety measures. However, imports are not expected to grow significantly in the latter half, partly due to declining coal-fired power plant operations. In India, imports are expected to remain high in 2024, as coal-fired power generation continues to operate at a high level while hydro power generation remains weak due to drought. While India aims to increase coal-fired power generation through local production and consumption, it is also committed to decentralisation and diversification of its import sources. For example, India appears to be working to increase stability and sustainability of coal procurement by importing Russian coal via Iran and trialling Mongolian coal imports. Viet Nam expanded imports in the first half of 2024 due to a significant increase in coal-fired power generation to compensate for poor hydro power generation performance. Although future developments depend on hydro power conditions, the current situation is stabilising. In contrast to increasing import demand from Emerging and Developing Economies in Asia, imports by the

European Union, Japan, Korea and Chinese Taipei are expected to continue declining in 2024 due to lower coal demand.

On the supply side, Indonesia, the world's largest coal exporter, is expected to respond to robust import demand from Asian countries by increasing production. The Indonesian government has raised its coal production quota for 2024 to 922 Mt, approximately 30% higher than the previous year. This provides producers with an incentive to increase production, allowing them to comply with domestic market supply regulations while increasing production for export. Production has already increased by over 8.0% year-on-year from January to April 2024. Australia, though recovering from COVID-19 impacts and adverse weather conditions, is experiencing sluggish export volumes due to reduced demand from major export markets such as Japan, Korea and Chinese Taipei, which is expected to remain flat in 2024 compared to 2023.

Thus, the global coal trade volume in 2024 is projected to remain level compared to the previous year, with increased imports by Emerging and Developing Economies in Asia offset by decreased imports from the European Union, Japan, Korea and Chinese Taipei. However, it should be noted that disruptions to the coal supply and demand balance in China and India could have significant implications for the global market.

Coal market conditions

Coal prices soared due to the energy crisis caused by Russia's invasion of Ukraine in February 2022, with the Australian steam coal/FOB[9] price from Newcastle (6 000 NAR[10]) hitting a historic high of over $400/t. These high prices continued until the first quarter of 2023. However, the mild winter in the northern hemisphere has helped ease supply and demand for coal and LNG/natural gas, and the price of steam coal plummeted to below $150/t in the second quarter. Thereafter, market prices temporarily rose during the summer demand season but fell below $150/t in early autumn and have remained at a similar level in the first half of 2024.

As substitution of Australian steam coal is limited due to its high calorie quality compared to Indonesian coal and others, the price is likely to soar if the supply-demand balance becomes remarkably tight as in 2022. Under normal market conditions, the price of coking coal is higher than that of steam coal. However, amid the supply-demand environment following the invasion of Ukraine, this gap was reversed, with Australian steam coal prices continuing to exceed coking coal prices from July 2022 to January 2023. Since the end of China's embargo in 2023, coking coal prices have risen while the steam coal market has eased, restoring the normal price relationship where coking coal is more expensive than steam coal.

The FOB price of Indonesian coal (4 200 NAR), which also increased due to the effects of the Ukraine invasion in 2022, did not rise as sharply as Australian coal, as its specifications were not comparable to the coal used in Europe as an alternative to natural gas. Indonesian coal prices have stabilised below $100/t since the second quarter of 2023. Nevertheless, even at this level, prices remain historically high, strengthening Indonesia's motivation to increase production and exports.

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 common

[9] Free on board

[10] Net calorific value (Net as received) 6 000 kcal/kg

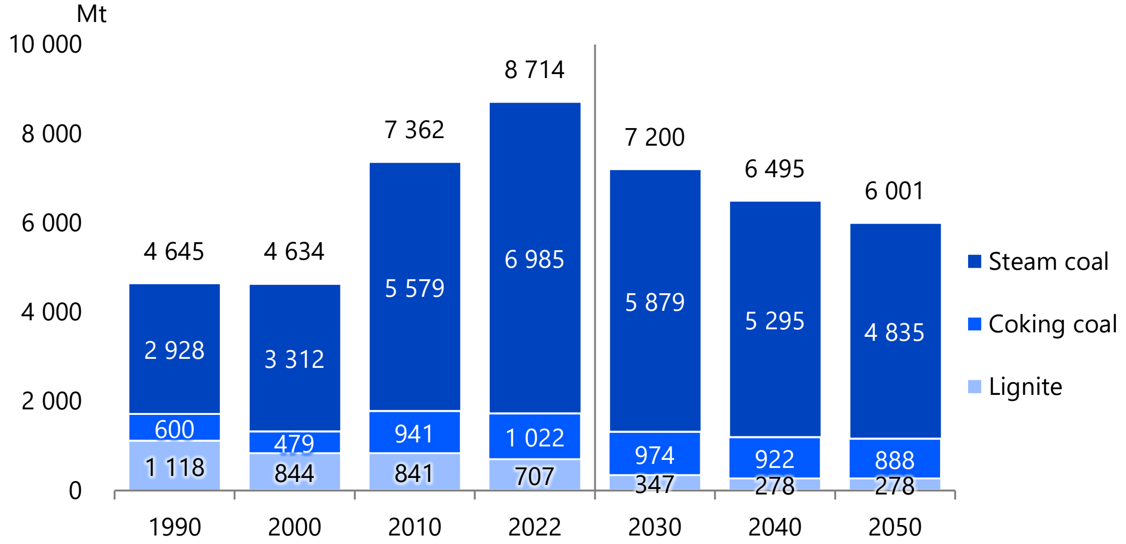
recognition of the need to strictly curb fossil fuel consumption and production, particularly coal. Coal consumption in Europe and the United States has already been steadily declining. Meanwhile, China, India, and emerging Asian countries have experienced increases in energy demand as their economies have recovered from the impact of COVID-19. A temporary shift in demand towards coal occurred due to natural gas shortages resulting from Russia's invasion of Ukraine, but this subsided by 2023. In recent years, 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 steadily, have stepped forward to bid for coal assets being divested.

Given the energy status in each country and the current coal demand situation, the global phase-out of coal is expected to be a long-term process in practice. Coal consumption in 2023 increased from the previous year and reached a historical high. However, the drivers of global demand growth were primarily China and India, and the ban on Russian coal imports as part of economic sanctions may lead to changes in coal trade flows, affecting production in supplier countries in the short to medium-term. Looking at global coal demand in the short to medium-term, demand will expand in Asia (including China, India and ASEAN countries) and Africa, following 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.

World coal production will increase until the mid-2020s, then begin to decline, continuing a downward trend thereafter in line with demand. Production volume will decrease from 8 714 Mt in 2022 to 7 200 Mt in 2030 and to 6 001 Mt in 2050 (Figure 3-6). By coal type, steam coal production will peak in the mid-2020s and then begin to decline in line with decreasing power generation demand. Production volume will decrease from 6 985 Mt in 2022 to 5 879 Mt in 2030 and to 4 835 Mt in 2050. Under these circumstances, 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, coking coal production mainly for steelmaking will gradually decline from 1 022 Mt in 2023 to 888 Mt in 2050. Production of lignite, a locally produced and consumed energy resource, will gradually decrease from 707 Mt in 2022 to 278 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.

Figure 3-6 | Global coal production [Reference Scenario]



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 remains 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 impact 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 Australian coal importing countries such as India and ASEAN continue to experience increasing coal demand; however, exports from Indonesia, with which they currently compete, may constrain supply depending on Indonesian government policies. Although supply 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 becomes more unstable. South Africa, whose main markets are domestic supply, India and ASEAN, is also witnessing a transformation of its coal industry, including the withdrawal of companies from Advanced Economies. Reserves in existing South African coalfields are being depleted, necessitating a shift to new coalfields. Indonesia, a major exporter of steam coal, has expanded production primarily to meet the remarkably growing export market. Meanwhile, the government has established a basic policy of curbing production and prioritising domestic supply to protect coal resources. However, as mentioned previously, 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. With domestic demand also expanding, future government actions should continue to be monitored.

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

(Mt)

	2022	2030	2040	2050	2022-2050 Changes	2022-2050 CAGR
World	6 985	5 879	5 295	4 835	2 150	1.3%
North America	456	239	91	61	-395	-6.9%
United States	391	230	85	56	-335	-6.7%
Latin America	67	57	51	49	-18	-1.1%
Colombia	59	49	43	41	-18	-1.3%
OECD Europe	45	16	11	9	-36	-5.5%
Non-OECD Europe/Eurasia	376	322	303	299	-77	-0.8%
Russia	254	201	182	175	-79	-1.3%
Middle East	0	0	0	0	0	-0.1%
Africa	248	229	241	268	19	0.3%
South Africa	245	206	209	221	-24	-0.4%
Asia	5 531	4 796	4 403	3 975	-1 556	-1.2%
China	3 903	3 047	2 406	1 850	-2 053	-2.6%
India	840	977	1 204	1 317	477	1.6%
Indonesia	682	656	668	674	-8	0.0%
Oceania	261	221	195	174	-87	-1.4%
Australia	260	220	194	173	-87	-1.4%

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

(Mt)

	2022	2030	2040	2050	2022-2050 Changes	2022-2050 CAGR
World	1 022	974	922	888	134	0.5%
North America	77	66	67	68	-9	-0.5%
United States	53	48	48	48	-4	-0.3%
Latin America	10	12	13	14	4	1.2%
Colombia	9	11	12	14	5	1.6%
OECD Europe	14	14	15	16	1	0.3%
Non-OECD Europe/Eurasia	109	115	115	115	6	0.2%
Russia	105	107	107	108	3	0.1%
Middle East	2	2	2	2	0	0.2%
Africa	8	18	24	31	23	5.1%
Mozambique	5	14	20	27	22	6.6%
Asia	641	567	485	416	-224	-1.5%
China	554	463	351	253	-301	-2.8%
India	57	71	99	128	72	3.0%
Mongolia	24	24	23	22	-2	-0.3%
Oceania	161	181	201	225	64	1.2%
Australia	160	180	200	224	64	1.2%

Meanwhile, China and India have rapidly constructed coal-fired power plants and consume their domestic coal resources. Looking ahead, demand in China will peak in the mid-2020s and then decline, while demand in India will grow towards 2050. These two countries will continue to play an important role in the international market by using imported coal as a domestic supply-demand adjustment mechanism, while maintaining domestic coal as their primary supply source.

Coal trade volume will decline from 1 366 Mt in 2022 to 1 234 Mt in 2040, before remaining relatively stable thereafter, with a volume of 1 231 Mt in 2050. By type of coal, trade of steam coal will decline significantly from 1 072 Mt in 2022 to 841 Mt in 2050, as China's imports peak in the 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, causing trade volume to increase from 286 Mt in 2022 to 385 Mt in 2050.

By major exporters, Australia will maintain its current supply 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 at a lower level. Colombia will also gradually decrease its supply from the mid-2020s.

Figure 3-7 | Global coal trade (import volume) [Reference Scenario]

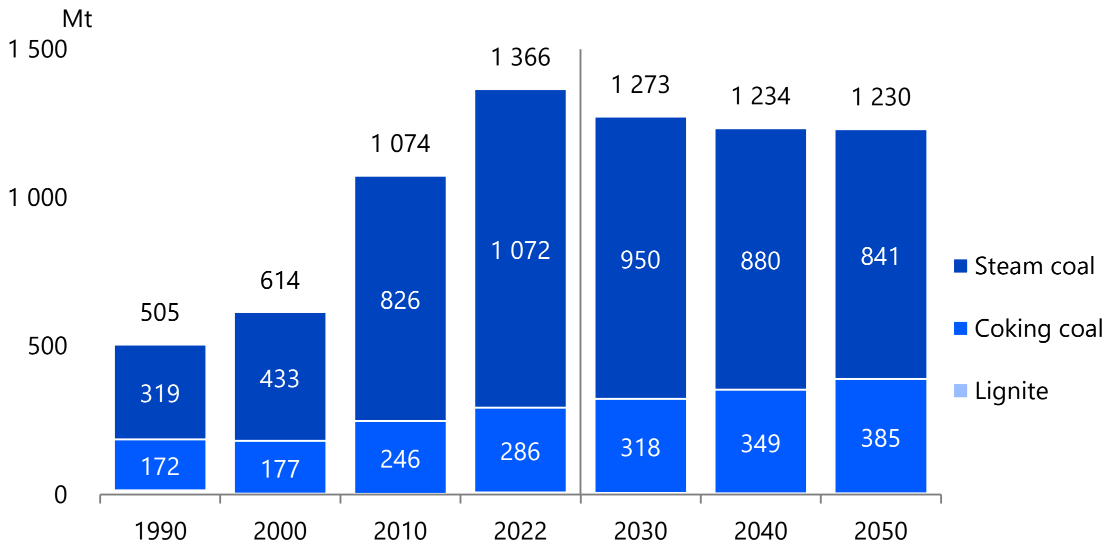
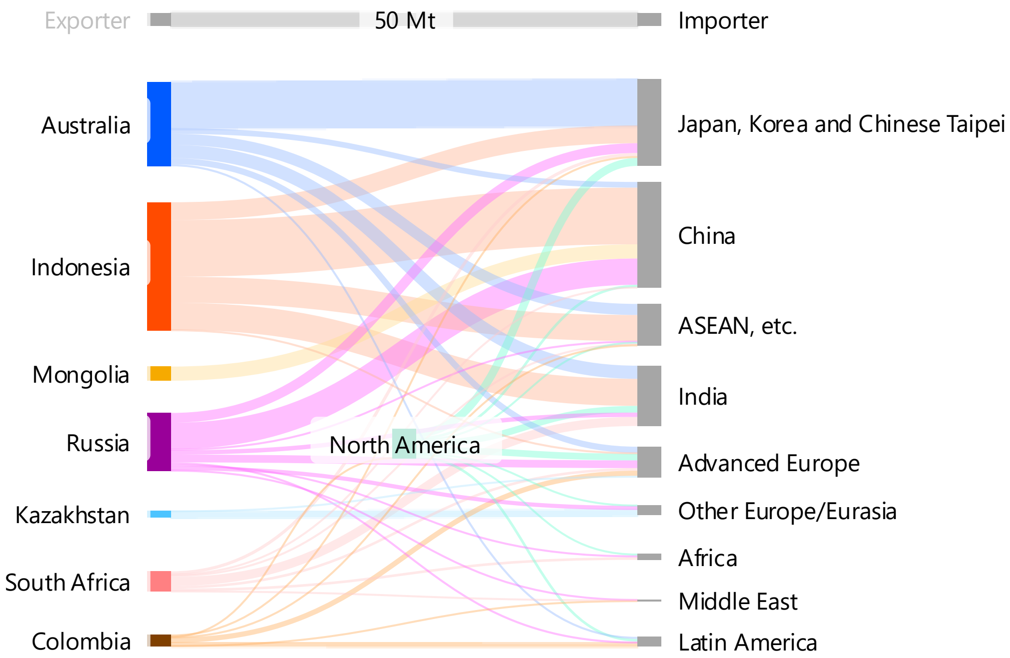
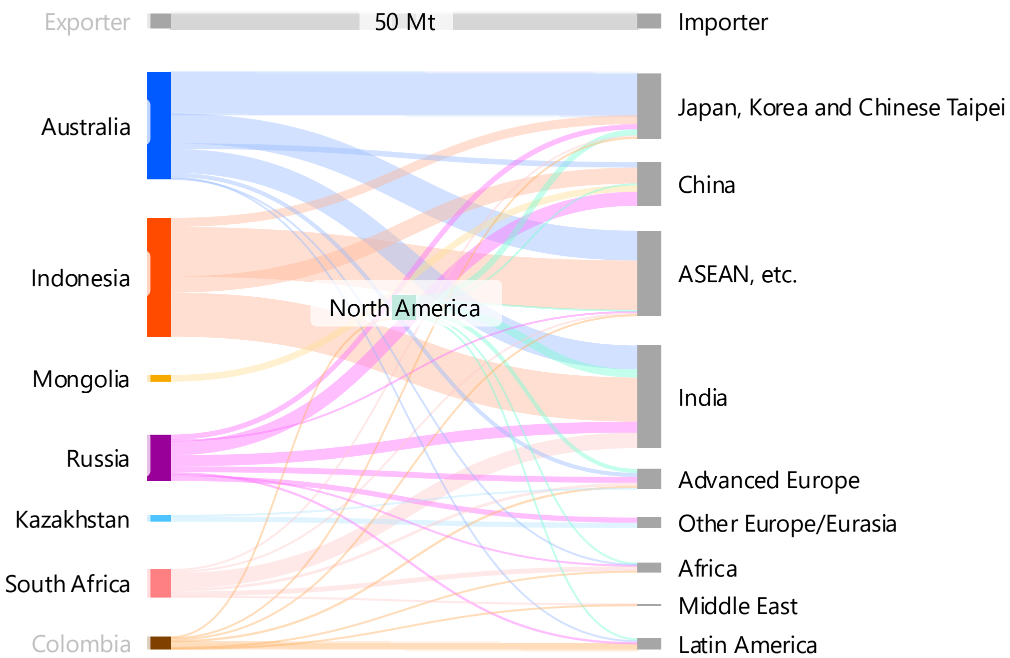


Figure 3-8 | Major interregional coal trade flows [2023]



Notes: Sum of steam coal and coking coal. 2 Mt or more listed. South Africa includes Mozambique.
Sources: Estimated based on IEA "Coal Information 2024", TEX Report, etc.

Figure 3-9 | 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.

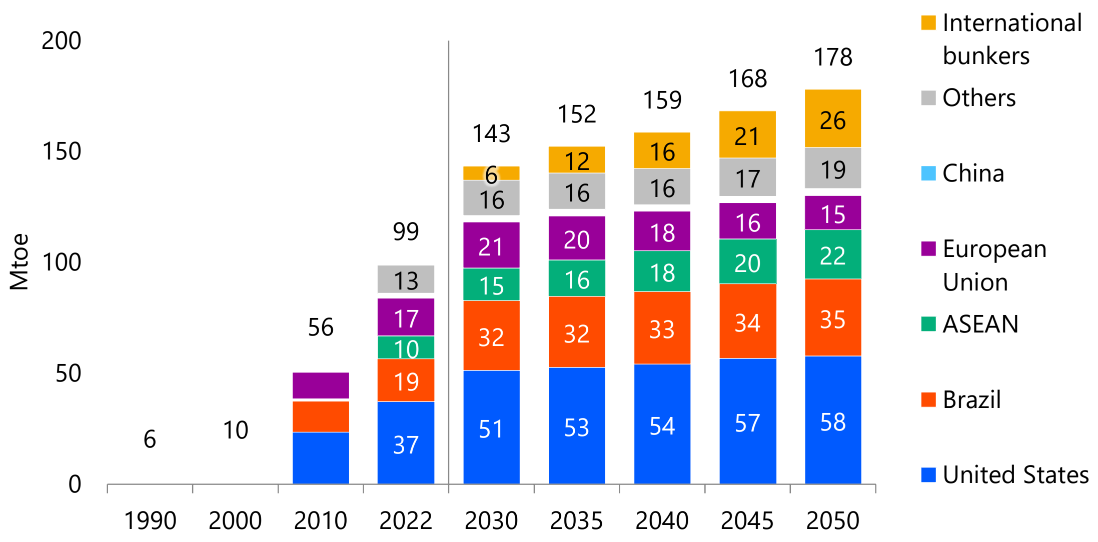
3.4 Biofuels for transport

The penetration of liquid biofuels, including bioethanol and biodiesel, has progressed as part of measures addressing climate change, energy security and agricultural promotion. Currently, biofuel use for 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. Nevertheless, consumption of biofuels for automobiles will expand by 2050 (Figure 3-10). As concerns grow regarding the environmental impact of first-generation biofuels and their competition with food production, initiatives for developing next-generation biofuels, including cellulosic and algae-derived fuels, and reducing their costs will be enhanced. Although biofuel demand in ASEAN will increase sharply, biofuel consumption in Asia will not reach levels comparable to those in the United States or Brazil.

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 will implement 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[11].

Figure 3-10 | Biofuel consumption for transportation [Reference Scenario]



[11] World Economic Forum (WEF), "Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation" (Nov 2020), https://jp.weforum.org/publications/clean-skies-for-tomorrow-sustainable-aviation-fuels-as-a-pathway-to-net-zero-aviation/

3.5 Power generation

Recent trends

Demand for electricity continues to increase

Global electricity generation has grown at a rate of 2.5% per year over the past decade (2013–2023), driven by global economic growth, recovery from the COVID-19 pandemic and increased demand from data centres. The increase in 2023 matched this decade-long average at 2.5% year on year[12]. Progress in electrification across various demand sectors and rising computing requirements from digital technologies are likely to continue fuelling electricity demand growth.

Meanwhile, these same digital technologies are expected to enhance grid management efficiency and improve the operation of both power generation and demand-side facilities, potentially contributing to greater energy efficiency and cost reduction.

Polarisation of coal-fired power generation

Global coal-fired power generation in 2023 was 10 513 TWh, up 1.8% from the previous year. The trends surrounding coal-fired power generation differ between Advanced Economies and Emerging and Developing Economies.

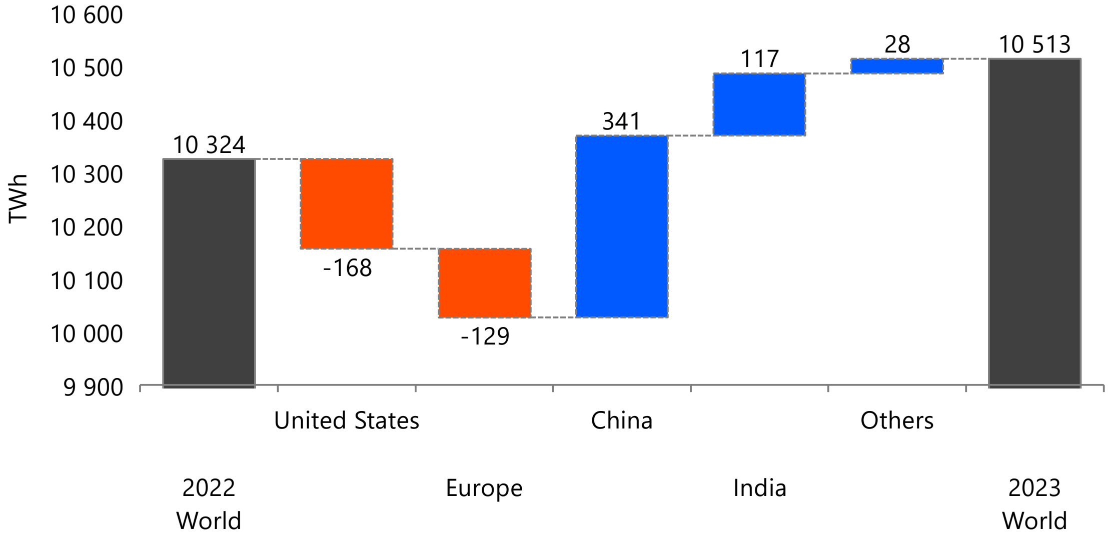
In OECD countries, efforts to phase out coal-fired power generation have progressed steadily, with generation falling substantially by 13.9%. This decrease is partly due to the easing of natural gas supply shortages, which were exacerbated by the Ukraine crisis in 2022, and also results from the large-scale deployment of renewable energy sources, which is expected to drive the continued shift away from coal.

Meanwhile, coal-fired power generation in emerging countries increased significantly by 6.1% year on year. Two-thirds of this increase occurred in China and one-sixth in India. The strong growth in electricity demand in these emerging countries necessitates expanded use of fossil fuel-fired power generation. Additionally, the potential for increased electricity demand from data centres in Advanced Economies may lead to caution regarding the early retirement of existing fossil fuel-fired power generation facilities. It is essential to maintain sufficient capacity to address growing electricity demand while incorporating co-firing technologies with hydrogen or ammonia.

These divergent trends are clearly reflected in recent international agreements. At the G7 Environment Ministers' Meeting held in Italy in April 2024, members agreed to phase out unabated coal-fired power generation by 2035, and this goal was incorporated into the joint statement. In contrast, the Group of 20 (G20), which includes emerging and developing economies, agreed at its energy ministers' meeting in July 2023 to pursue a decarbonised society, but failed to reach consensus on concrete steps to reduce fossil fuel use or targets for renewable energy deployment. Emerging and developing economies do not necessarily align with the decarbonisation and coal-free movements promoted by advanced economies, highlighting the need for 'diverse pathways' that account for each country's unique economic and energy circumstances.

[12] Energy Institute, "Statistical Review of World Energy" (2024)

Figure 3-11 | Coal-fired power generation and contribution to changes



Source: Energy Institute, "Statistical Review of World Energy" (2024)

Solar photovoltaics soar in China while wind decelerates amid inflation

Renewable energy sources, particularly solar photovoltaics and wind are growing remarkably. Solar photovoltaic power generation in 2023 increased by 24.2% year on year, while wind grew by 10.3%, with these two sources together accounting for 13.2% of total electricity generated. In solar photovoltaics, China has experienced dramatic growth in recent years, contributing half of the global increase. Under its 14th Five-Year Plan (2021–2025), China has intensively expanded its capacity to produce solar photovoltaic equipment, resulting in significant growth not only in domestic energy supply but also in overseas equipment exports. Meanwhile, wind, though continuing to grow, has not matched the expansion rate of solar photovoltaics and has slowed over the past two years (+17% and +13% year on year, respectively). This deceleration has been largely due to soaring material prices amid prolonged inflation.

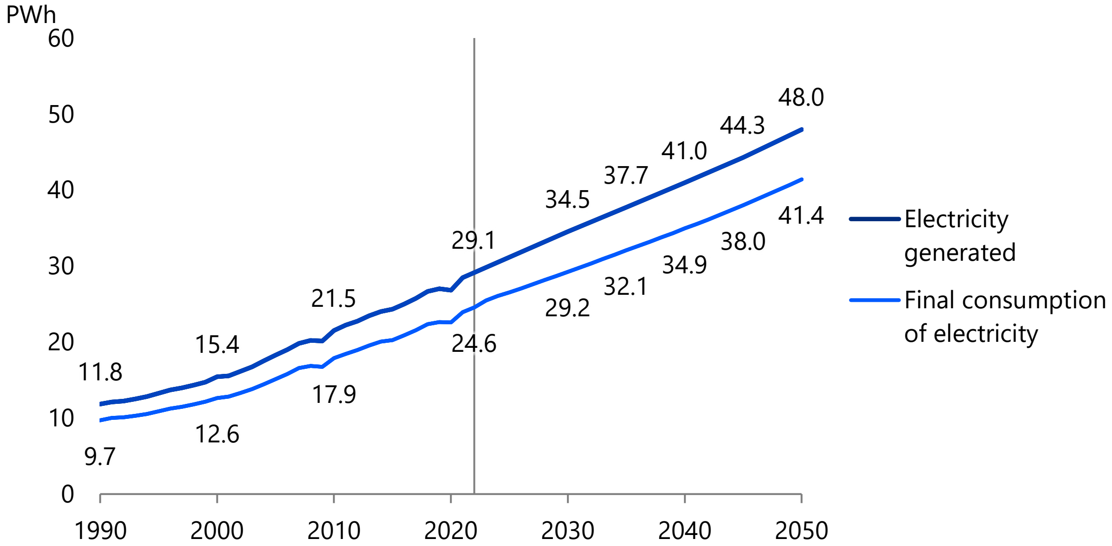
In recent years, more ambitious renewable energy targets and implementation measures have been established across major economies, including the Inflation Reduction Act in the United States, the REPowerEU plan in the European Union, and Japan's Strategic Energy Plan, Basic Policy for the Realisation of Green Transformation (GX) and Sector-specific Investment Strategies. Investments in this field are expected to continue strengthening, primarily in advanced economies and China.

Outlook

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

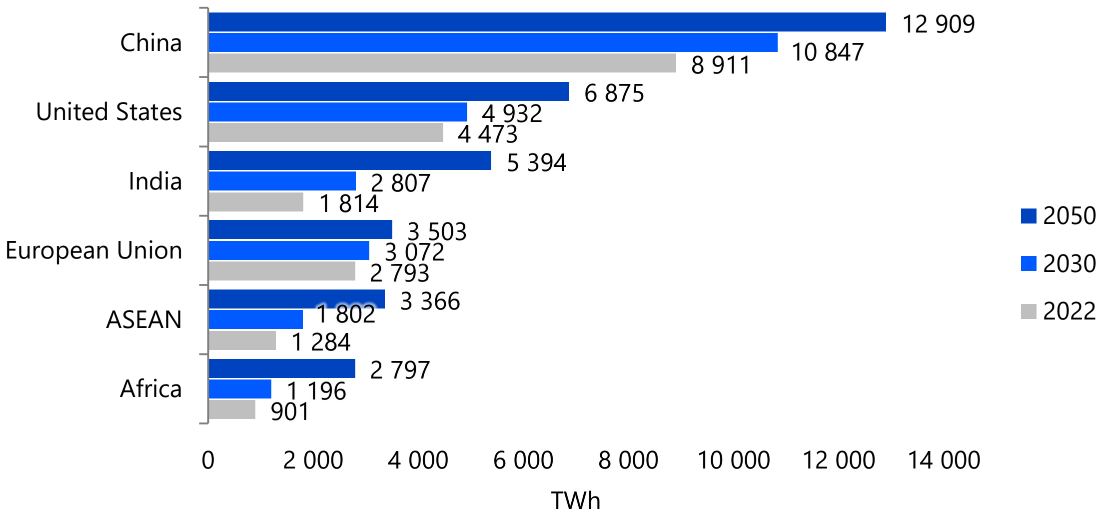
Electricity consumption is expected to continue expanding at an annual rate of 1.6% until 2050, driven by the rise of digital technology as well as traditional factors such as continued global economic growth and electrification. This will result in global electricity generation increasing to 47 956 terawatt-hours (TWh) in 2050, a 1.8-fold rise from the 2022 level (Figure 3-12). Of the incremental 18 813 TWh, 80% will come from Emerging and Developing Economies, while electricity generation will continue to grow at 1.1% per year even in Advanced Economies where overall energy demand is declining. New investment in power generation and transmission facilities will be a major challenge worldwide.

Figure 3-12 | Global electricity generated and final consumption of electricity [Reference Scenario]



Electricity generation in rapidly growing Asia will expand at an annual rate of 2.0% from 14 310 TWh in 2022 to 24 913 TWh in 2050, accounting for about half of the global total. China, which has been driving demand growth in Asia, will see its pace of increase slow down but will still maintain its position as the world's largest power generator in 2050 (Figure 3-13). India and ASEAN, in line with their rapid economic growth, will increase their power generation by 3.0 times and 2.6 times respectively by 2050, reaching a scale far greater than or comparable to that of the European Union. Outside Asia, Africa will see significant progress in electrification, with electricity generation expanding strongly to 2 797 TWh by 2050, more than three times the 2022 level.

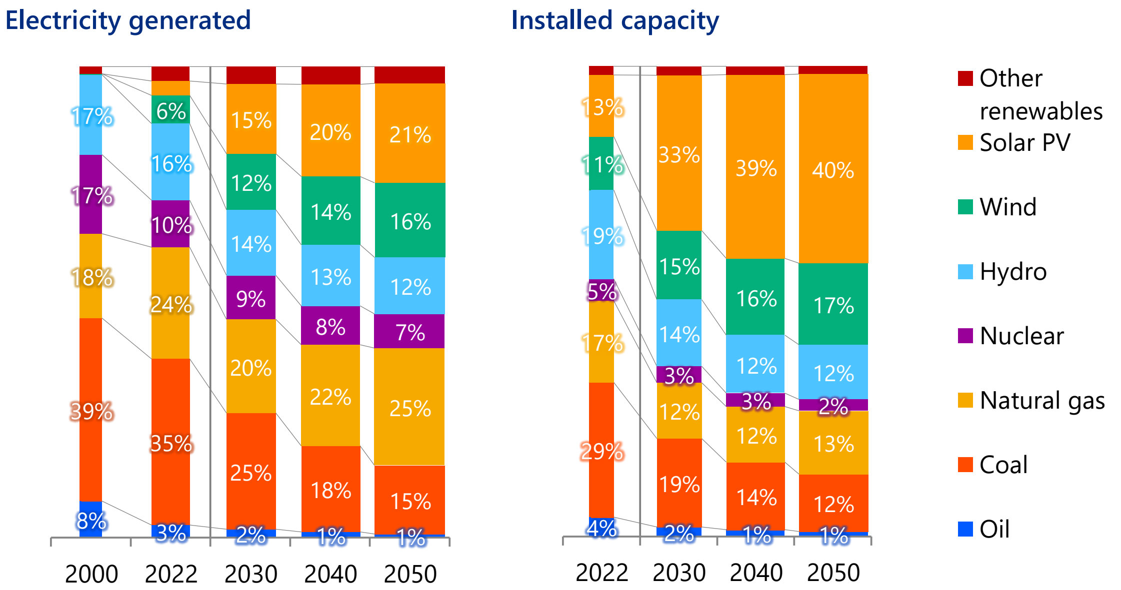
Figure 3-13 | Electricity generated in selected economies/regions [Reference Scenario]



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

In 2022, coal accounts for the largest share of the global power generation mix, but natural gas will replace it as the largest power source by 2050 (Figure 3-14). Natural gas prices rose significantly following the Ukraine crisis in 2022 due to supply-demand imbalances, but are expected to stabilise with expanding supply capacity, leading to growth in natural gas's share of the global power generation mix by 2050. Securing affordable and stable natural gas supplies will remain an important mid- to long-term priority for both Advanced Economies and Emerging and Developing Economies.

Figure 3-14 | Global power generation mix [Reference Scenario]



Note: Bar widths are proportionate to total electricity generated.

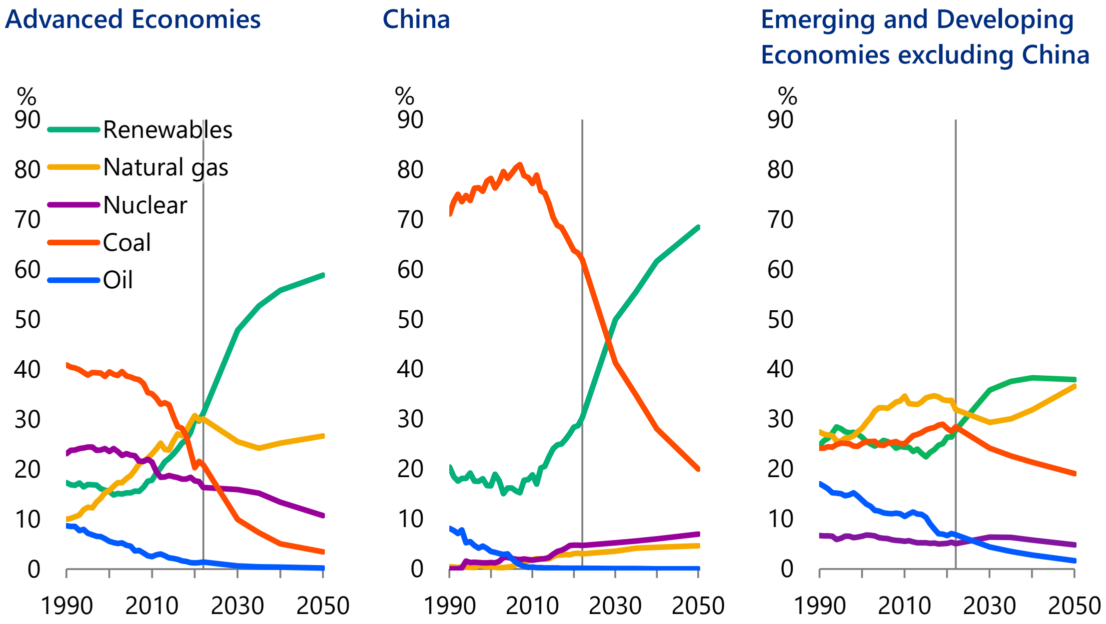
Note: Bar widths are proportionate to total power generation installed capacity.

Regarding coal, Advanced Economies including Italy, Canada, the United Kingdom, France and Germany have announced plans to phase out coal-fired power generation, while others have committed to eliminating low-efficiency coal 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 two-thirds of current generation levels remaining by 2050. Some of these will be new installations, and to minimise CO_2 emissions over their 25–40-year operational lifespans, key strategies will include technical cooperation with Emerging and Developing Economies, biomass utilisation and long-term adoption of ammonia co-firing.

Wind, solar photovoltaics, geothermal and other renewable power generation will expand rapidly at 5% annually through 2050, supported by policy measures and cost reductions, increasing their share in the power generation mix to 41%. In Advanced Economies, these renewables will overtake natural gas as the largest power source around 2030. Even in China, where renewables have been actively deployed, they will surpass coal to become the largest power source by 2035 if recent rapid adoption continues. Renewables will account for 48% of total electricity generated in Advanced Economies by 2030 and 59% by 2050, with variable sources such as solar photovoltaics and wind comprising 45% of generation in 2050. Addressing output fluctuations and expanding grid infrastructure to connect suitable generation areas with demand centres will become increasingly critical challenges as renewables strengthen their position as primary power sources. Nuclear power plant construction will advance primarily in Asia as a measure to enhance energy security and mitigate climate change, increasing nuclear power generation by 25% from current levels. However, nuclear growth will not keep pace with electricity demand through 2050, reducing its share of electricity generated to 7% by 2050.

In Emerging and Developing Economies (excluding China), renewables including wind will increase and replace coal and natural gas as the largest power source around 2030. However, their share will remain in the high 30% range, significantly lower than in Advanced Economies. To meet growing electricity demand, coal will still account for approximately 22% of electricity generated in 2050 despite its decreasing share, while natural gas will continue expanding long-term after a short-term decline, becoming the second-largest energy source and approaching renewable energy levels. Ensuring stable fossil fuel supplies, improving efficiency to reduce CO_2 emissions, and exploring long-term options such as co-firing and carbon capture and storage (CCS) will remain important. Meanwhile, it is necessary to secure a certain amount of dispatchable thermal and hydro power source, 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 3-15 | Power generation mix in Advanced Economies and in Emerging and Developing Economies [Reference Scenario]

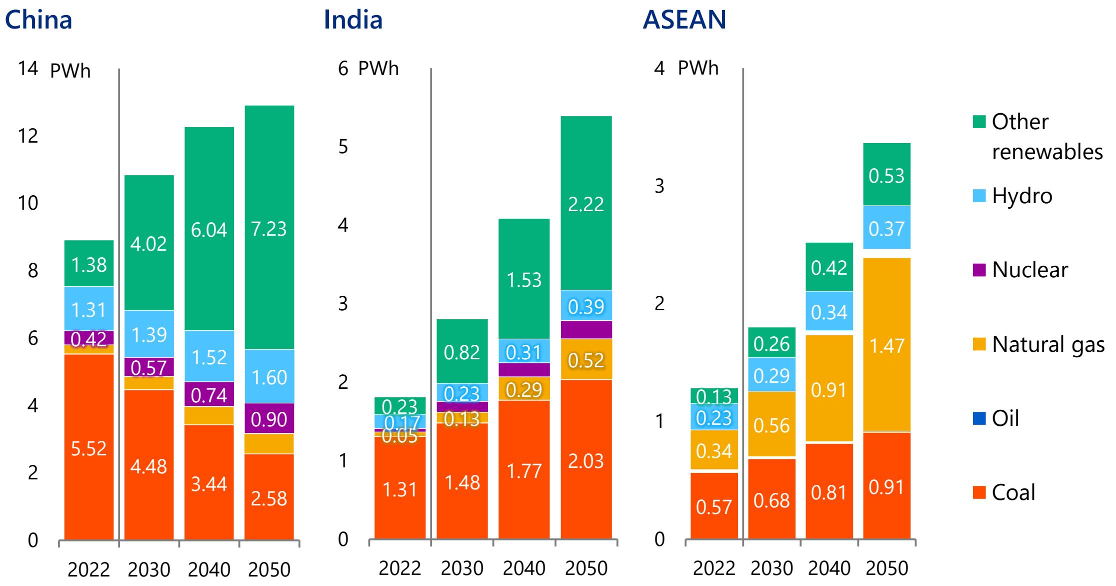


Diverging prospects for coal and renewable energies in three emerging areas in Asia

In Asia, coal-fired power generation accounted for the largest share at 57% in 2022, but the transition to natural gas and renewable energies will reduce this to 24% by 2050. However, this power source transition varies significantly across countries and region (Figure 3-16). In China, which has been rapidly expanding its renewable energy capacity in recent years, electricity generated from solar photovoltaics, wind and other sources will increase more than fivefold from

2022 levels by 2050, establishing renewables as the dominant power generation source. Nevertheless, China continued to build new coal-fired power plants even in 2023, and despite its decreasing share, coal-fired power generation will maintain a significant presence.

Figure 3-16 | Chinese, Indian and ASEAN power generation mix [Reference Scenario]



India is also expanding its renewable energy capacity, with both solar photovoltaics and wind projected to overtake coal as the largest power source by 2050. Unlike China, however, India's coal-fired power generation will continue to grow. A key challenge for India will be mobilising all available options, including nuclear, hydro and natural gas, to meet robust electricity demand, which is expected to nearly triple compared to 2022 levels.

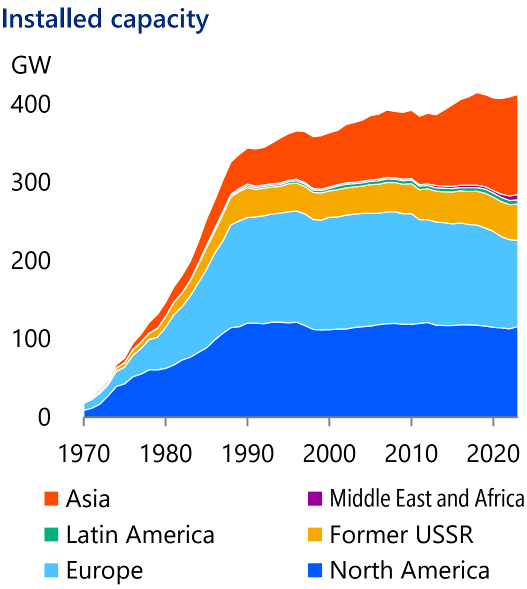
In contrast to these two countries, ASEAN is substantially expanding its use of natural gas, which will reclaim its position as the largest power source alongside growing renewable energy capacity. The situation varies considerably across ASEAN countries. In Thailand, strong public and private sector movements to phase out coal-fired power generation are driving a shift toward natural gas and renewables. Meanwhile, countries like Indonesia and the Philippines continue to rely on coal as their main power source due to rapidly increasing electricity demand, while Lao People's Democratic Republic and Viet Nam are promoting power sector decarbonisation by leveraging their renewable energy potential, including abundant hydro power resources. Achieving low-cost power supply in this region, where demand continues to soar, presents significant challenges and necessitates diverse approaches tailored to each country's unique supply and demand characteristics.

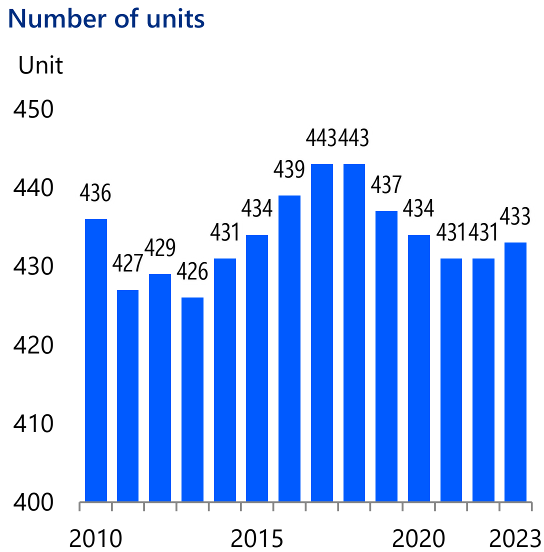
Nuclear

Recent trends: The role of nuclear is emphasised; customer action is key to its introduction

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 increased in both 2022 and 2023 (Figure 3-17). 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 construction subsequently decelerated. In recent years, however, as many countries have established ambitious greenhouse gas emission reduction targets, nuclear's role as a low-carbon energy source has gained renewed attention. Furthermore, 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. Against this backdrop, there have been moves both to construct new nuclear reactors and to extend the operational lifespans of existing ones.

Figure 3-17 | Global nuclear power generation capacity and number of units





While ageing management and safety assurance remain prerequisites, the long-term operation of existing nuclear reactors is positioned as a low-carbon power option with high economic efficiency and is being actively pursued, particularly in Western countries with numerous ageing reactors. In the United States, many reactors have operated for more than 40 years and 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. Belgium, which had planned to complete its nuclear phase-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. 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 both countries to supply low-carbon electricity until the 2060s.

In Japan, the 'GX Decarbonisation Electricity Act' enacted in May 2023 allows nuclear power plant operating periods to be extended by excluding prolonged shutdown periods following the Fukushima Daiichi 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. In June 2024, Kansai Electric Power's Ohi Units 3 and 4 secured approvals under this latter system. 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 long-term operation of existing reactors are under way in each country, while there are moves to construct new plants in some countries. China is particularly active, with Fangchenggang Unit 4 beginning commercial operation in May 2024. Further development is also under way, with the construction of about five units starting between February and July 2024. Furthermore, with the State Council's approval of plans to build 11 reactors at five sites in August 2024, the expanded use of nuclear in China is likely to continue. In the United States, Vogtle Units 3 and 4, which had been under construction in Georgia, began commercial operation in August 2023 and April 2024, respectively. Although construction of both units began in 2013, the construction period and costs significantly exceeded those initially expected. Olkiluoto 3 in Finland, which began commercial operation in April 2023, and Flamanville 3 in France, which obtained a commissioning licence from the regulator in May 2024, have also experienced delays from their original schedules. While it is noteworthy that new reactors have started operation one after another in Europe and the United States, where new construction had long been stagnant, the lessons learned from these construction projects must be fully utilised to avoid similar delays in the future.

In Korea, where nuclear policy was reaffirmed under President Yoon Suk-yeol's administration, Shin Hanul Unit 2 began commercial operation in April 2024, followed by the issuance of construction licences in September for Units 3 and 4, which had been suspended during the previous administration. Korea is also advancing its export initiatives, with Barakah Unit 4 in the United Arab Emirates beginning commercial operation in September 2024, completing all planned units at that site. In July 2024, Korea Hydro & Nuclear Power Co., Ltd. secured preferred negotiation rights for a new construction project in the Czech Republic, outcompeting France's EDF in the bidding process.

It should also be noted that Russia continues to dominate the global nuclear export market. Following Russia's invasion of Ukraine in February 2022, Finland terminated new construction contracts with Russian companies, while Russian reactors continue to be developed in China, Turkey, Iran, India and Bangladesh. In July 2022, Russia began constructing Egypt's first nuclear power plant, El Dabaa. This facility consists of four reactors, with construction of Unit 4 having commenced in January 2024. Neighbouring Belarus has also deployed Russian-built reactors, with the country's first and second units entering commercial operation in June 2021 and November 2023, respectively. Russian companies, having steadily accumulated construction experience, have avoided significant delays and offer comprehensive services covering not only power plant construction but also fuel supply and spent fuel management. For emerging and developing economies—the primary importers—seeking rapid deployment of stable, large-scale power sources without extensive nuclear experience, Russian proposals may effectively address their requirements. Western nuclear industries aiming to recapture global market share must fully comprehend Russia's strategic approach.

Attention must also be maintained on developments beyond conventional large-scale light water reactors, including small modular reactors (SMRs) and Generation IV designs. In the United States, both Republican and Democratic parties have implemented aggressive support measures, with numerous private companies initiating advanced reactor development. However, plans for a NuScale-developed light-water SMR at the Idaho National Laboratory site were cancelled in November 2023. This reportedly resulted from difficulties in maintaining the contract with Utah Associated Municipal Power Systems (UAMPS), the intended electricity purchaser, due to factors including escalating construction costs. Nevertheless, other SMR projects continue in the United States, the United Kingdom and Ontario, Canada, while several countries including Korea, Bulgaria, Romania and Estonia are advancing towards SMR deployment. Regarding Generation

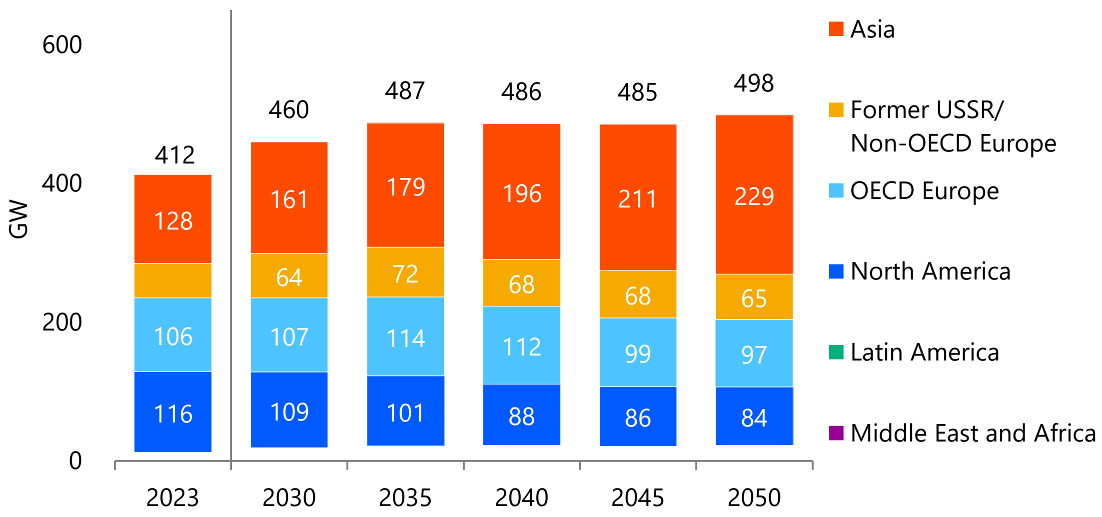
IV reactors, TerraPower began constructing its demonstration sodium-cooled fast reactor 'Natrium' in Wyoming in June 2024, while Kairos Power commenced construction of its molten salt-cooled high-temperature reactor 'Hermes' in Tennessee in July. The former project, in particular, offers potential benefits including effective utilisation of existing transmission infrastructure and employment preservation in the host community by being sited near a coal-fired power plant scheduled for closure.

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' capability to meet acceptable conditions for customers in terms of costs and other factors. The cancellation of the NuScale-UAMPS SMR project clearly illustrates this reality. Customer responses to various nuclear initiatives worldwide merit close observation.

Outlook: Nuclear will increase particularly in Asia and continue to be used as a key low-carbon, stable power source 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 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 498 GW (Figure 3-18).

Figure 3-18 | Installed nuclear power generation capacity [Reference Scenario]



The United States, still the world's largest nuclear power producer with 93 reactors as of 2023, includes states where economic considerations have led to decisions for early closure of existing reactors. Market liberalisation has exposed nuclear power plants to direct competition from natural gas-fired power generation and renewable sources, leading to a projected decrease in installed capacity by 2050. However, the United States will maintain its policy of treating nuclear as a strategic energy source. The Trump administration emphasised nuclear from an energy security perspective, while the Biden administration has highlighted its importance for addressing climate change. With both major political parties recognising nuclear's significance, substantial policy shifts are unlikely. Against this backdrop, operating period extensions 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 from approximately 75% to 50% by 2025. This target was subsequently deferred to 2035 due to incompatibility with greenhouse gas reduction objectives and was ultimately abandoned in legislation 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 facilities. Given these developments, nuclear's share in France will likely remain stable or decrease slightly in the near term, as reactor closures are balanced by new construction. 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 capacity where profitability permits.

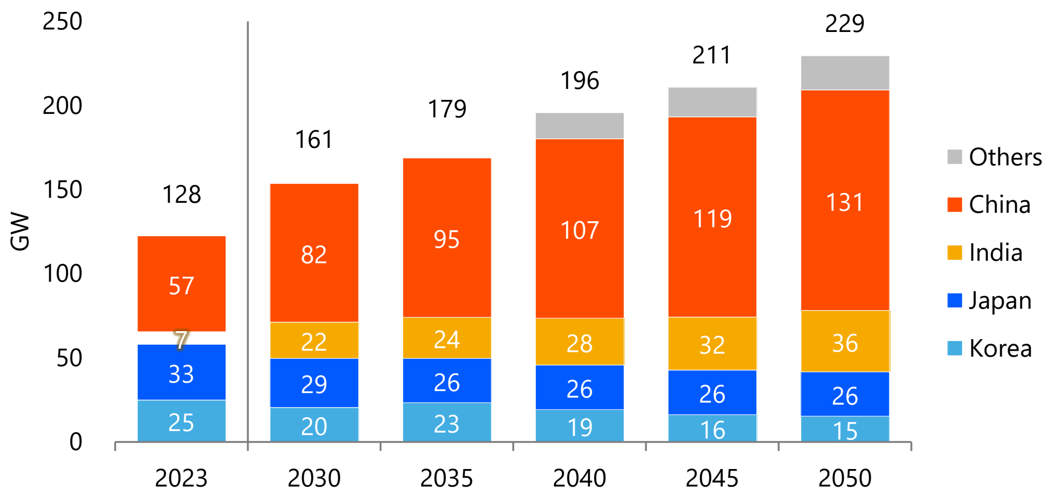
In the United Kingdom, despite government support for nuclear, total installed capacity will decline until the late 2020s due to the decommissioning of older reactors. However, new construction plans aligned with the energy security strategy are in development, supported by measures to enhance the business 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 around 2035 before continuing to increase thereafter.

Switzerland has clearly established nuclear phase-out plans following the Fukushima Daiichi accident and will cease nuclear power generation by 2035 under the government's decommissioning schedule. Belgium, which initially planned to close all reactors by 2025, has decided to extend operations of at least two reactors by 10 years in light of recent developments, thereby delaying its nuclear exit. Germany completed its nuclear phase-out in April 2023 with the closure of its final three reactors and is not expected to resume nuclear power generation under current circumstances. Other OECD European 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 41 GW by 2035, with Russia overtaking Japan as the world's fourth-largest nuclear power generation capacity holder around 2030. 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 began constructing a demonstration lead-cooled fast reactor in June 2021. In addition, it began to construct a demonstration version of a lead-cooled fast reactor in June 2021. It is important to possess such a wide range of technologies 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 energy source. China will expand its installed nuclear power generation capacity to 95 GW by 2035, surpassing the United States to become the world's largest nuclear power generator. Asia's total installed nuclear capacity will exceed the combined capacity of OECD Europe and North America around 2040, reaching 229 GW by 2050. China and India together will account for more than 70% of this capacity (Figure 3-19).

Figure 3-19 | Asia's installed nuclear power generation capacity [Reference Scenario]



Renewables

In recent years, the growth in installed renewable power generation capacity has accelerated significantly. From 2015 to 2019, global renewable power generation capacity increased by just under 200 GW annually, but this figure exceeded 250 GW in 2020, 300 GW in 2022 and ultimately surpassed 450 GW in 2023. This growth momentum is expected to continue, reaching approximately 500 GW annually by 2030. Solar photovoltaics, which have achieved substantially lower generation costs, have shown particularly remarkable growth and are expected to maintain their position accounting for approximately 70% of new renewable capacity additions. Moreover, as naturally variable power sources, including solar photovoltaics and wind, represent more than 90% of new renewable capacity, their impact on power grids will inevitably increase.

For the first time, solar photovoltaic and wind power generation costs have begun to rise as installation costs for equipment such as solar panels and wind turbines have increased alongside higher resource prices since 2021. Nevertheless, renewables maintain their relative economic advantage due to the concurrent rise in thermal power generation costs. The long-term declining cost trend for solar photovoltaics and wind is expected to continue, preserving their economic advantage over thermal power generation.

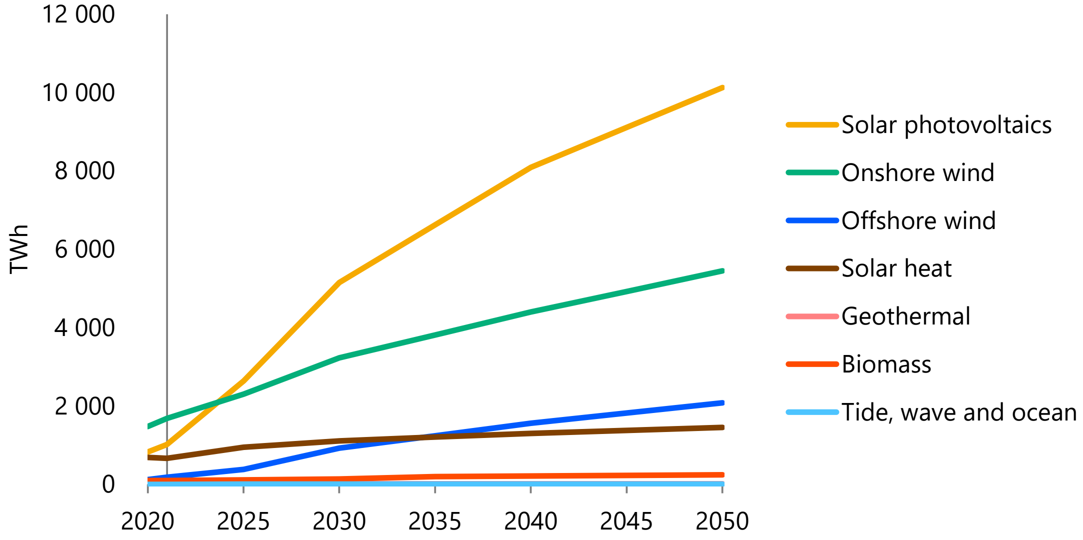
Beyond economic benefits, an increasing number of countries and regions are committing to long-term carbon neutrality targets while strengthening their renewable expansion goals and supporting measures. This will ensure continued growth in renewable power generation capacity (Table 3-6). In Europe, the Ukraine crisis that began in early 2022 has created strong pressure to reduce dependence on Russian natural gas, further stimulating renewable energy adoption. An even more significant development has been China's accelerated deployment of solar photovoltaic and wind power generation, which has intensified since 2022. This rapid expansion has important implications for the long-term trajectory of global renewable energy deployment towards 2050.

Table 3-6 | Goals for introducing renewables in selected countries and regions

Country or region	Main goals
United States	Decarbonisation of the entire electricity sector by 2035 (renewables, nuclear, hydrogen, CCS, etc.) Biden Administration's decarbonisation goals, April 2021 (The White House)
European Union	42.5% share of renewables in final energy consumption by 2030 (45% as an effort target) Review of the Renewable Directive (adopted by the European Parliament in September 2023)
Japan	36% to 38% share of renewables in total electricity generated by 2030 The Sixth Strategic Energy Plan, Cabinet Decision in October 2021 (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 COP26, November 2021 (Ministry of External Affairs)
ASEAN	23% of primary energy supply and 35% of installed generation capacity to be 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 3-20 shows the projected growth in renewable power generation up to 2050. Solar photovoltaics will increase nearly eight-fold from 1 295 TWh in 2022 to 10 110 TWh in 2050. Wind (both onshore and offshore) will expand 3.6-fold from 2 120 TWh in 2022 to 7 595 TWh in 2050. As a result, variable renewables will significantly increase their share of global electricity generation from 11.7% in 2022 to 36.9% in 2050, strengthening their role in the electricity system.

Figure 3-20 | Global renewable (non-hydro) power generation [Reference Scenario]



China, Europe, the United States and India currently account for 80% of cumulative installed wind power generation capacity (both onshore and offshore) and will continue to dominate the market (Figure 3-21). China's share will grow progressively, exceeding 50% by 2050, with its concentration becoming even more pronounced than for solar photovoltaics, as discussed later. This pattern suggests that while growth in Europe, North America and other regions slows due to stricter siting and grid constraints, China still possesses substantial room for expansion.

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

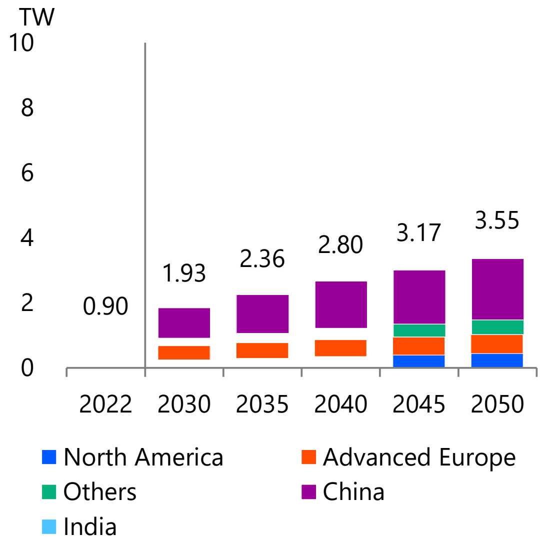
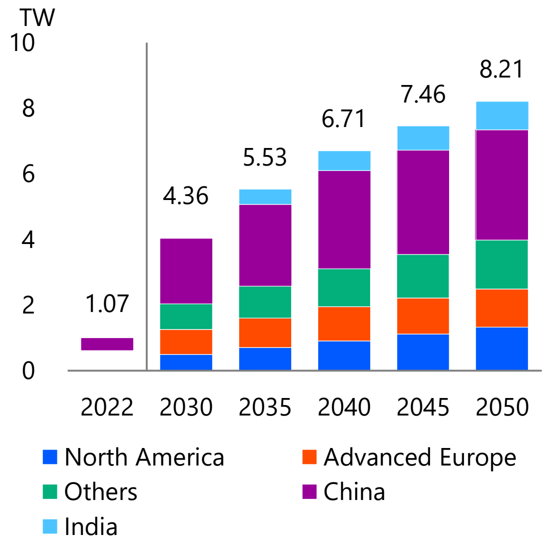


Figure 3-22 | Global installed solar photovoltaic power generation capacity [Reference Scenario]



Onshore wind power generation will grow relatively slowly towards 2050 compared to solar photovoltaic and offshore wind, primarily due to early-emerging site and grid constraints, such as limited suitable land for development. By 2050, onshore wind installed capacity will reach 2 900 GW, representing only about 3.5 times the 2022 capacity of 840 GW. Nevertheless, the cumulative installed capacity in 2050 will remain 4.5 times larger than offshore wind, maintaining its significant presence in the renewable energy mix.

In contrast, offshore wind, despite its smaller scale compared with onshore wind, is expected to grow rapidly. Historically, global installed capacity of offshore wind power generation increased dramatically from 3 GW in 2010 to 73 GW in 2023. Europe remains the world's most mature offshore wind market, with well-developed supply chains 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 32 GW. This establishes China as one of the world's two largest offshore wind markets, alongside Europe, both nominally and in practice. China's expansion is projected to continue through to 2050.

The United States has minimal offshore wind capacity, though the Biden administration has actively promoted offshore wind projects, including a policy targeting 30 GW of offshore wind power generation capacity by 2030. However, increasing project costs due to rising global material prices and interest rates have led to growing project modifications, including postponements and cancellations after 2023. While the United States remains promising for offshore wind in the long-term, significant uncertainty exists in the short to medium-term.

In Asia outside China, offshore wind markets are expected to develop in Chinese Taipei, Korea and Viet Nam. In Japan, the Act on the Utilization of Marine Renewable Energy of 2019 has taken effect, and the designation of promotion zones for offshore wind projects under this legislation is progressing. 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 nine-fold from 73 GW in 2023 to 650 GW in 2050. However, due to location and grid constraints, deployment rates will gradually decrease after 2030.

Solar photovoltaic power generation is expanding globally, not only in established markets like China, Europe, the United States and Japan, but worldwide, benefiting from substantial cost reductions Figure 3-22). China will maintain and expand its dominant position, representing 37% of global cumulative installed capacity in 2022 and approximately 40% even by 2050. However, compared to wind power generation, solar photovoltaics show relatively higher shares in the United States, Europe, India and other regions, with somewhat less concentration in 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.

The global weighted average levelised cost of electricity (LCOE) for large-scale solar photovoltaics in 2022 is estimated at $49/MWh (≈ ¥7/kWh), making it the lowest-cost power generation source in many countries. Particularly noteworthy are large-scale solar photovoltaic auctions in countries with favourable sunshine conditions, such as Chile, the United Arab Emirates and Saudi Arabia, which recorded remarkably low selling prices of $10/MWh (≈ ¥1.4/kWh) in 2021. Costs for distributed solar photovoltaic systems installed on rooftops and commercial facilities have also fallen to competitive grid parity levels in many countries and regions, especially when considered alongside rising electricity prices. This situation is expected to further enhance the competitiveness of solar photovoltaic power generation.

Global installed solar photovoltaic capacity is projected to increase approximately eight-fold from 1 067 GW in 2022 to 8 210 GW in 2050. However, from 2030 onwards, grid constraints and the impact of variable power sources on power system stability will become increasingly apparent. Consequently, the net increment of global installed solar photovoltaic capacity, estimated to reach

3 630 GW in the decade from 2020 to 2030, will gradually decrease to 2 350 GW from 2030 to 2040 and 1 500 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.

4. Advanced Technologies Scenario

4.1 Major measures

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

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

2022 → 2050 (Reference Scenario, 2050)

	Advanced Economies	Emerging and Developing Economies
Thermal power generation	Developing an initial investment finance scheme	
	Installing CCS for new plants from 2030 (Countries with CO_2 storage potential excluding aquifers)	
[Natural gas-fired efficiency (stock basis)]	50.3% → 63.6% (56.8%)	38.3% → 55.3% (47.9%)
[Coal-fired efficiency (stock basis)]	37.4% → 41.1%[13] (44.7%)	33.3% → 40.4% (36.7%)
[IGCC share of newly installed plants]	0% → 60% (20%)	
Nuclear power generation	Maintaining appropriate wholesale electricity prices	Developing an initial investment finance framework
[Installed capacity]	264 GW → 331 (223) GW	123 GW → 483 (275) GW

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

2022 → 2050 (Reference Scenario, 2050)

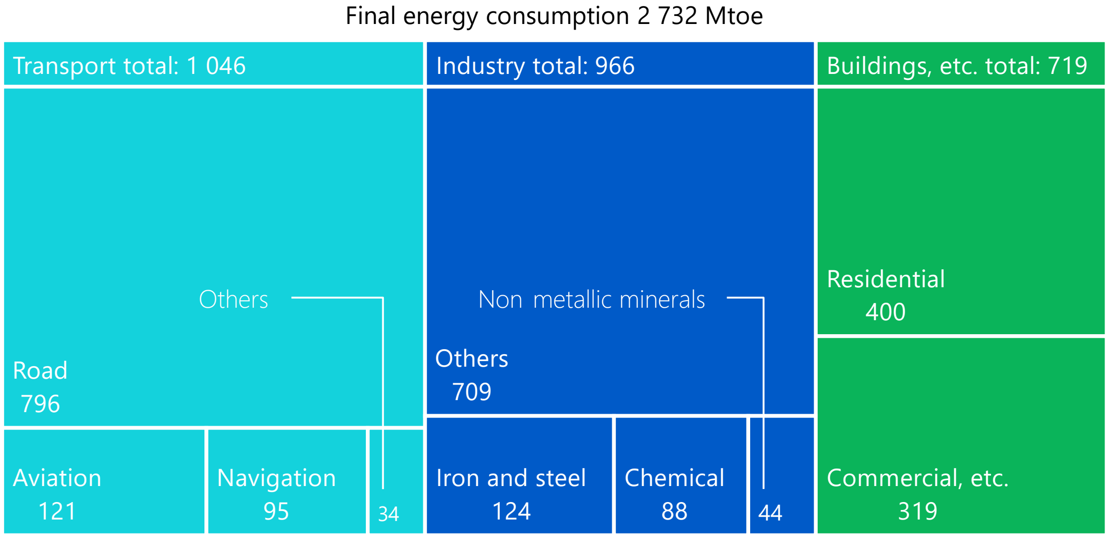
	Advanced Economies	Emerging and Developing Economies
Renewables power generation	System cost reduction	
	Grid stabilisation technology cost reduction	Low-cost finance
	Efficient grid operation	Advancing power systems
[Wind installed capacity]	407 GW → 1 751 (1 113) GW	543 GW → 3 335 (2 390) GW
[Solar photovoltaics installed capacity]	460 GW → 3 665 (2 793) GW	617 GW → 6 877 (5 290) GW
Biofuels for automobiles	Developing next-generation biofuels	Biofuel cost reduction
	Expanded use of flexible-fuel vehicles (FFVs)	Agricultural policy position
[Consumption]	60 Mtoe → 108 (79) Mtoe	39 Mtoe → 104 (72) Mtoe
Industry	100% penetration of the best available technologies (BATs) in 2050	
Transport	Reducing fuel-efficient vehicle costs	
	Doubling zero-emission vehicle (ZEV) travel distances	
[New passenger car fuel efficiency]	19.0 km/L → 48.4 (33.2) km/L	16.8 km/L → 45.2 (25.2) km/L
[ZEV share of new passenger car sales]	7.3% → 93.9% (48.3%)	12.6% → 86.0% (30.4%)
Buildings	1.7 times faster improvement in appliance and equipment efficiency and insulation efficiency on a stock basis (approx. 26% improvement in 2050 relative to the Reference Scenario).	
	Electrifying space/water heating and cooking equipment, clean cooking	

Note: IGCC stands for integrated coal gasification combined cycle.

Energy efficiency

Final energy consumption in the Advanced Technologies Scenario will be 486 million tonnes of oil equivalent (Mtoe) or 4% less in 2030 and 2 732 Mtoe or 23% less in 2050 than in the Reference Scenario. Savings in final energy consumption in 2050 are equivalent to 27% of final energy consumption in 2022. Of the energy savings, the transport sector will account for 1 046 Mtoe, the industry sector for 966 Mtoe and the buildings sector for 719 Mtoe (Figure 4-1).

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



The road sector will be responsible for 796 Mtoe in the transport sector and the residential sector for 400 Mtoe in the buildings sector. This is because vehicles and energy-consuming home appliances offer huge potential for improving energy efficiency. The Emerging and Developing Economies will capture more than 50% of the energy savings in all final energy consumption sectors, including the industry sector where they will account for over 80% of energy savings. Whether or not the Emerging and Developing Economies actually realise the potential energy savings is key to the progress of global energy savings.

By employing already available highly efficient technologies for steel, cement, chemical, pulp and paper, and other energy-intensive industries, these sectors will improve their energy intensity in 2030 by several percentage points from the Reference Scenario (Table 4-2). Furthermore, by accelerating the adoption of highly efficient technologies, energy intensity will improve by about 20% by 2050. Through these energy intensity improvements, the industry sector in Emerging and Developing Economies will reduce energy consumption by 772 Mtoe compared to the Reference Scenario. Asia, where basic materials industries account for a large share of production, will contribute about 80% of the global energy savings. The introduction of highly efficient technologies will significantly enhance energy efficiency in Emerging and Developing Economies. The global development and proactive dissemination of energy efficiency improvement technologies, including in Emerging and Developing Economies, is therefore essential

Table 4-2 | World energy indicators

			Reference		Advanced Technologies	
		2022	2030	2050	2030	2050
Industry	Intensities (2022=100)					
	Iron and steel	100	101.5	96.3	95.7	74.5
	Non-metallic minerals	100	93.0	77.6	89.6	68.6
	Chemical	100	97.1	75.7	91.3	61.8
	Paper and pulp	100	94.9	84.8	90.9	66.2
	Other industries	100	99.8	75.4	93.9	51.7
Transport	New passenger vehicle fuel efficiency (km/L)	19.0	21.9	33.2	29.4	48.4
	ZEVs' share of vehicle sales	5.5%	12%	45%	45%	93%
	Natural gas's share in intl. marine bunkers	0.2%	4.6%	23%	7.5%	44%
	Biofuel's share of intl. aviation bunkers	0.0%	1.8%	5.9%	6.9%	28%
Buildings	Overall energy efficiency (2022 = 100)					
	Residential	100	89.0	70.7	85.1	57.2
	Commercial	100	86.5	55.2	84.4	42.2
	Electrification rate					
	Residential	28%	33%	48%	35%	57%
	Commercial	55%	59%	71%	60%	78%

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

In the transport sector, fuel efficiency improvements and vehicle fleet composition changes will make further progress. By vehicle type, in addition to hybrid vehicles (HEVs), there will be greater adoption of electric vehicles (EVs), plug-in hybrid vehicles (PHEVs) and fuel cell vehicles (FCVs). These zero-emission vehicles (ZEVs) will increase their share of new vehicle sales by 32 percentage points in 2030 and 48 percentage points in 2050 compared to the Reference Scenario. Due to changes in vehicle fleet composition and fuel efficiency improvements, the global average new vehicle fuel efficiency in 2050 will improve by 15.2 km/L from the Reference Scenario to 48.4 km/L (2.1 L/100 km). The transport sector will see the largest energy savings among sectors in Advanced Economies as the share of ZEVs in those economies increases faster than in Emerging and Developing Economies. International transport will make progress in energy conservation through technological innovation and operational improvements. At the same time, given the significant potential for fuel switching, natural gas will account for 7.5% of international marine bunkers in 2030 and 44% in 2050. In international aviation, biofuel will comprise 6.9% of fuel use in 2030 and 28% in 2050.

It is more challenging for energy conservation incentives to work in the buildings sector than in the industry sector, where economic considerations drive energy conservation awareness. Consequently, the buildings sector presents significant potential for reducing energy consumption. The overall global residential energy efficiency will improve by 4% in 2030 and by 19% in 2050 compared to the Reference Scenario. Similarly, the overall efficiency of the commercial sector will improve by 2% in 2030 and 24% in 2050. Energy efficiency improvements for space and water heating systems in cold regions and enhanced insulation in Emerging and Developing Economies will contribute substantially to energy savings. Since natural gas, liquefied petroleum gas (LPG), kerosene and other fuels are used for water and space heating in various ways depending on national circumstances, fuel consumption for these applications will be significantly reduced. Traditional biomass use, including inefficient fuel wood and manure, will see the greatest reduction through increased electrification and the adoption of modern cooking equipment in rural areas. Electricity consumption will decline substantially as energy efficiency improvements across various applications such as space cooling, power and lighting more than offset the impact of appliance electrification.

Box 4-1 | Life cycle analysis of vehicles: Right selection of powertrain by country and region

Global sales of battery electric vehicles (BEVs) are expected to slow down in October 2024, compared to the rapid growth seen in previous years. In Europe, Germany, the largest EV market, suspended EV subsidies in December 2023 in response to spending cuts after its initial budget was ruled unconstitutional. France has also made Chinese-produced EVs ineligible for subsidies, causing BEV registrations in the European Union (EU) to fall by 43.9% from January to August 2024. The United States is expected to see a slowdown in sales in 2024, with a 20% year-on-year increase, compared to the approximately 40% growth recorded in 2023, as ‘Early Adopters’, who purchase new products at an initial stage, have apparently completed their purchases. In China, the world’s largest EV market, BEV/PHEV sales in 2024 are expected to grow 25% year on year—still expanding but at a slower pace—compared to the 82% growth in 2022 and 35% growth in 2023, with consumers’ tendency to save money being identified as an underlying factor.

In this context, discussions are also underway on making liquid fuels carbon neutral to reduce greenhouse gas (GHG) emissions from automobiles. Lower carbon emissions can be achieved by increasing the proportion of carbon-neutral (CN) fuels, such as biofuels and hydrogen-related synthetic fuels (e-fuels), in liquid fuels. Brazil has mandated a 27% bioethanol blend (E27) while E100 is also available. Indonesia plans to mandate the introduction of a 40% biodiesel blend (B40) and E10 by 2025, while Thailand and India have set targets of E10 or higher. Additionally, the India-led Global Biofuels Alliance was launched in 2023, focusing on securing the supply of biofuels and their sustainable production at reasonable prices. In May 2024, the leaders of Japan and Brazil agreed to launch the Initiative for Sustainable Fuels and Mobility (ISFM) to promote global decarbonisation on both supply and demand sides by combining sustainable fuels with highly efficient mobility equipment. Regarding e-fuels, projects are underway in South America, Northern Europe, the United States and elsewhere.

Although BEVs do not emit GHGs when driven, it is necessary to analyse their potential and limitations as a climate change countermeasure from a broader perspective. When estimating GHG emissions from automobiles, a comprehensive life cycle assessment (LCA) should be conducted that includes vehicle production and disposal, in addition to the supply (well to tank) and consumption (tank to wheel) of energy used in automobiles, known as the ‘well to wheel’ (WtW) approach. Furthermore, since the availability of carbon-neutral fuels, power generation mix, energy infrastructure and social conditions vary significantly by country and region, LCA analysis specific to each country and region is required.

LCA analysis of passenger cars by powertrain

In this Box analysis, the Carbon Neutral Fuel Promotion Case was developed by combining the Reference Scenario and the Advanced Technologies Scenario. GHG emissions per passenger car from well to tank, tank to wheel, production and disposal, were estimated in both the Carbon Neutral Fuel Promotion Case and the Advanced Technologies Scenario across Advanced Europe, the Association of Southeast Asian Nations (ASEAN), India, and Brazil.

Table 4-3 | Cases in Box analysis

	Carbon neutral fuel ratio (Biofuels + synthetic fuels)	Power generation mix and other energy transformation, fuel prices, fuel efficiency, etc.
Carbon Neutral Fuel Promotion Case	Equivalent to Advanced Technologies Scenario	Equivalent to Reference Scenario
Advanced Technologies Scenario	Advanced Technologies Scenario	Advanced Technologies Scenario

Note: For Brazil, the carbon neutral fuel ratio is assumed to be E100.

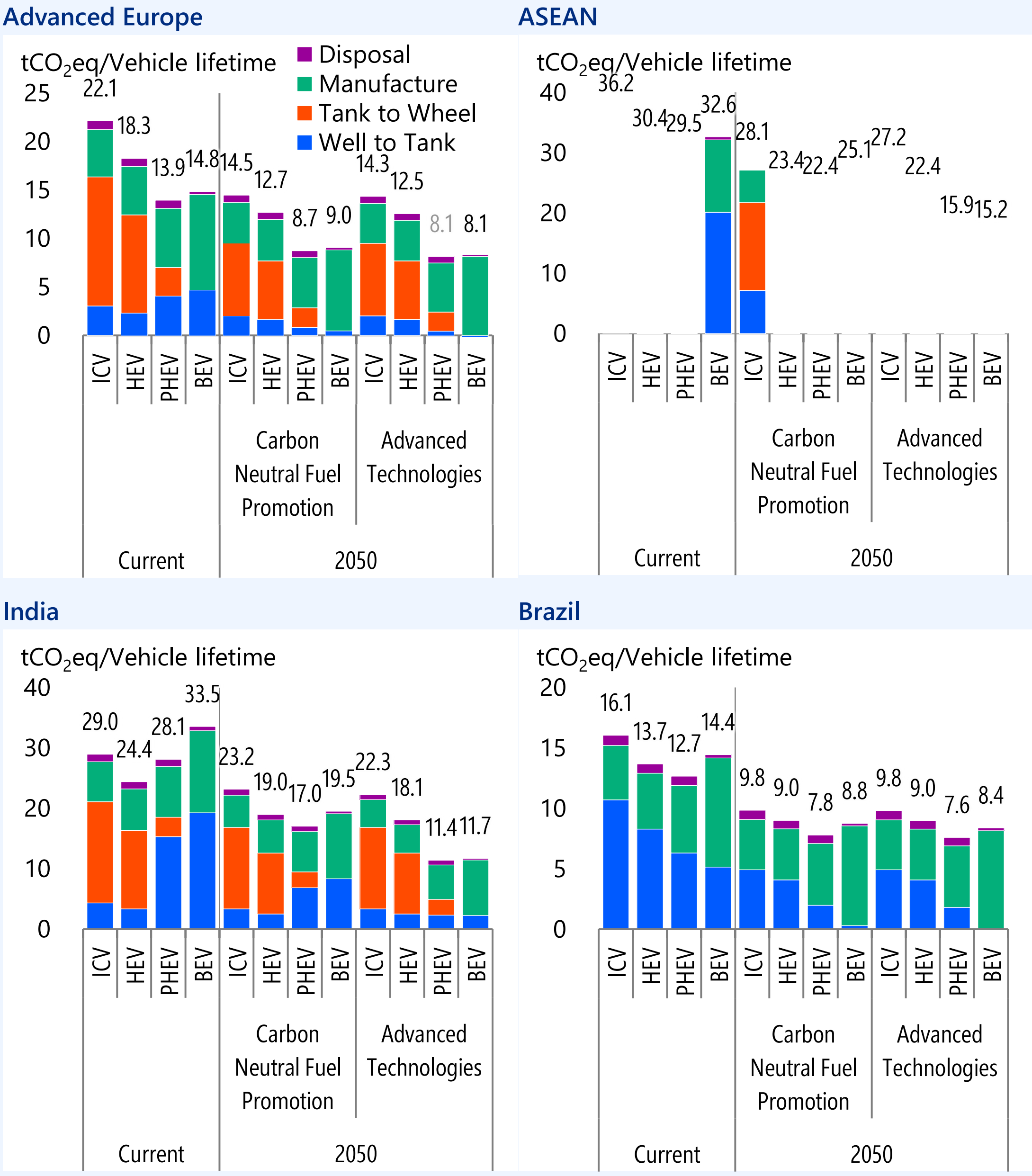
When examining LCA-based GHG emissions, the relative performance of HEVs, PHEVs and BEVs varies by country, region and timeframe. In Advanced Europe, PHEVs currently have the lowest GHG emissions, with BEVs at roughly equivalent levels. This relationship will remain unchanged in 2050 in both the Carbon Neutral Fuel Promotion Case and the Advanced Technologies Scenario. On the other hand, in ASEAN, where power generation decarbonisation has progressed relatively slowly, HEVs and PHEVs currently have comparable GHG emissions, which are lower than those of BEVs. In India, HEVs currently produce the lowest GHG emissions. In the Carbon Neutral Fuel Promotion Case, even by 2050, the combination of HEVs, PHEVs and carbon-neutral fuels will continue to have lower LCA-based GHG emissions than BEVs in both ASEAN and India. In the Advanced Technologies Scenario, where power sources also undergo significant decarbonisation, the LCA-based GHG emissions of PHEVs and BEVs will be roughly equivalent by 2050.

As such, there are significant differences in power generation mix decarbonisation between countries and regions. In countries and regions with a high proportion of low-carbon power sources, such as Advanced Europe, both the combination of carbon-neutral fuels with PHEVs and BEVs will result in lower LCA-based GHG emissions, making these approaches key to achieving carbon neutrality. Conversely, in ASEAN and India, where power source decarbonisation is progressing more slowly, the combination of carbon-neutral fuels and PHEVs represents a more promising option.

In Brazil, many vehicles are already capable of running on E100, and even now, the LCA-based GHG emissions of HEVs and PHEVs using E100 are lower than those of BEVs. Furthermore, even by 2050, when power sources are expected to be completely decarbonised, both HEVs and PHEVs are projected to have comparable LCA-based GHG emissions to BEVs. Therefore, in Brazil, which has substantial biofuel supply potential, the combination of carbon-neutral fuels with HEVs and PHEVs, alongside BEVs, will provide effective pathways towards achieving carbon neutrality.

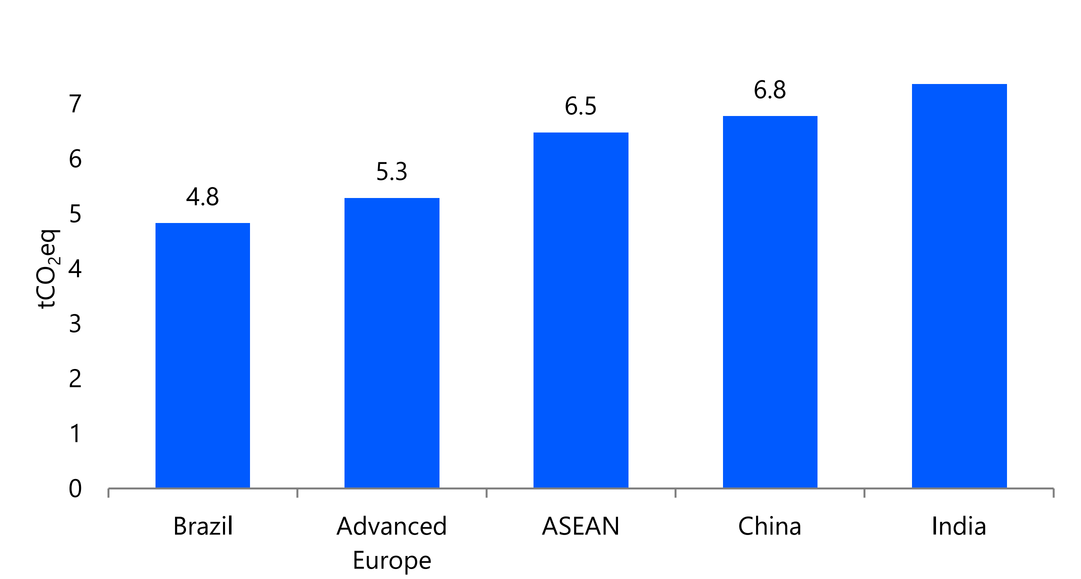
It should be noted, however, that when batteries, which generate higher emissions during manufacturing than other components, are produced in other countries and imported, the LCA-based GHG emissions may differ. Brazil, in particular, has already made significant progress in power source decarbonisation. If batteries were imported from China, where the electricity emission coefficient is relatively high, rather than being produced domestically in Brazil (as assumed in this analysis), emissions associated with battery manufacture would increase by 40% under current circumstances.

Figure 4-2 | GHG emissions per passenger car (LCA basis)



Note: As for well to tank, CO_2 emissions during fuel transport are excluded. As for the manufacture and disposal of vehicles, the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) Model 2021 version issued by Argonne National Laboratory was used, assuming all such works are implemented within a country or region. Since the calculation was made under the assumption that the CO_2 capture effect (negative emissions) of e-fuel feedstock belongs to downstream users (vehicle users), emissions during e-fuel production (well to tank) were set at zero.

Figure 4-3 | GHG emissions from battery manufacture per BEV [current]

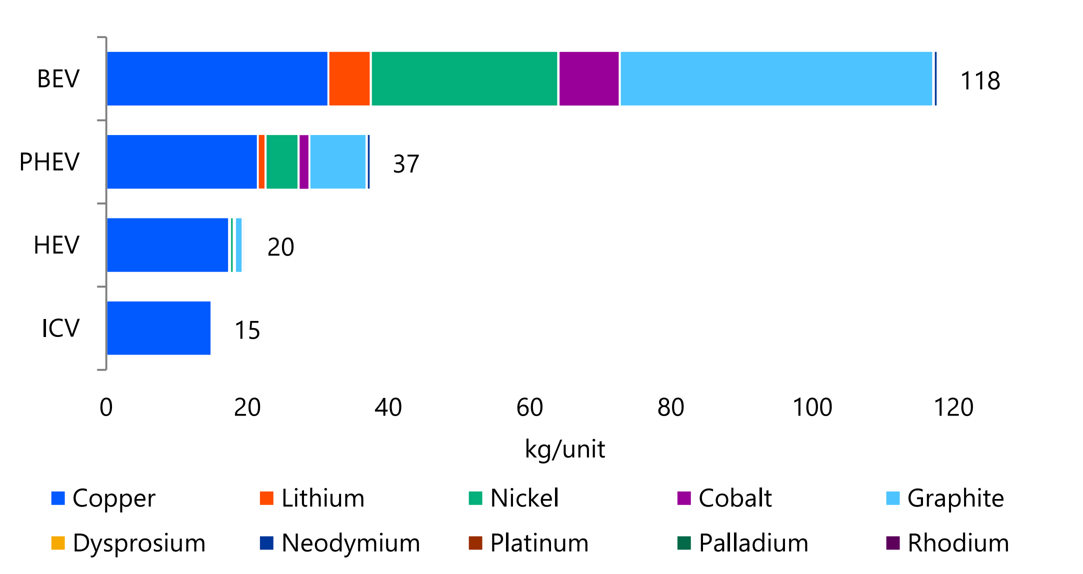


Note: Corresponding to manufacture in Figure 4-2

Critical mineral usage by passenger car powertrain

One advantage of combining HEVs and PHEVs with carbon-neutral fuels such as biofuels and e-fuels is the potential for reduced use of critical minerals compared to BEVs. BEVs contain large-capacity drive batteries that use critical minerals such as nickel and graphite as raw materials. The quantity of critical minerals used in BEVs is substantial: approximately six times higher than in HEVs and three times higher than in PHEVs (see IEEJ Outlook 2024 for details). In recent years, the capacity of on-board batteries has been increasing to extend the driving range per charge. If BEV numbers continue to rise significantly, the supply and demand balance of mineral resources may be disrupted, potentially increasing the manufacturing cost of BEVs.

Figure 4-4 | Amount of minerals used per passenger car



Source: Japan Organization for Metals and Energy Security[14]

Usage cost analysis of passenger cars by powertrain

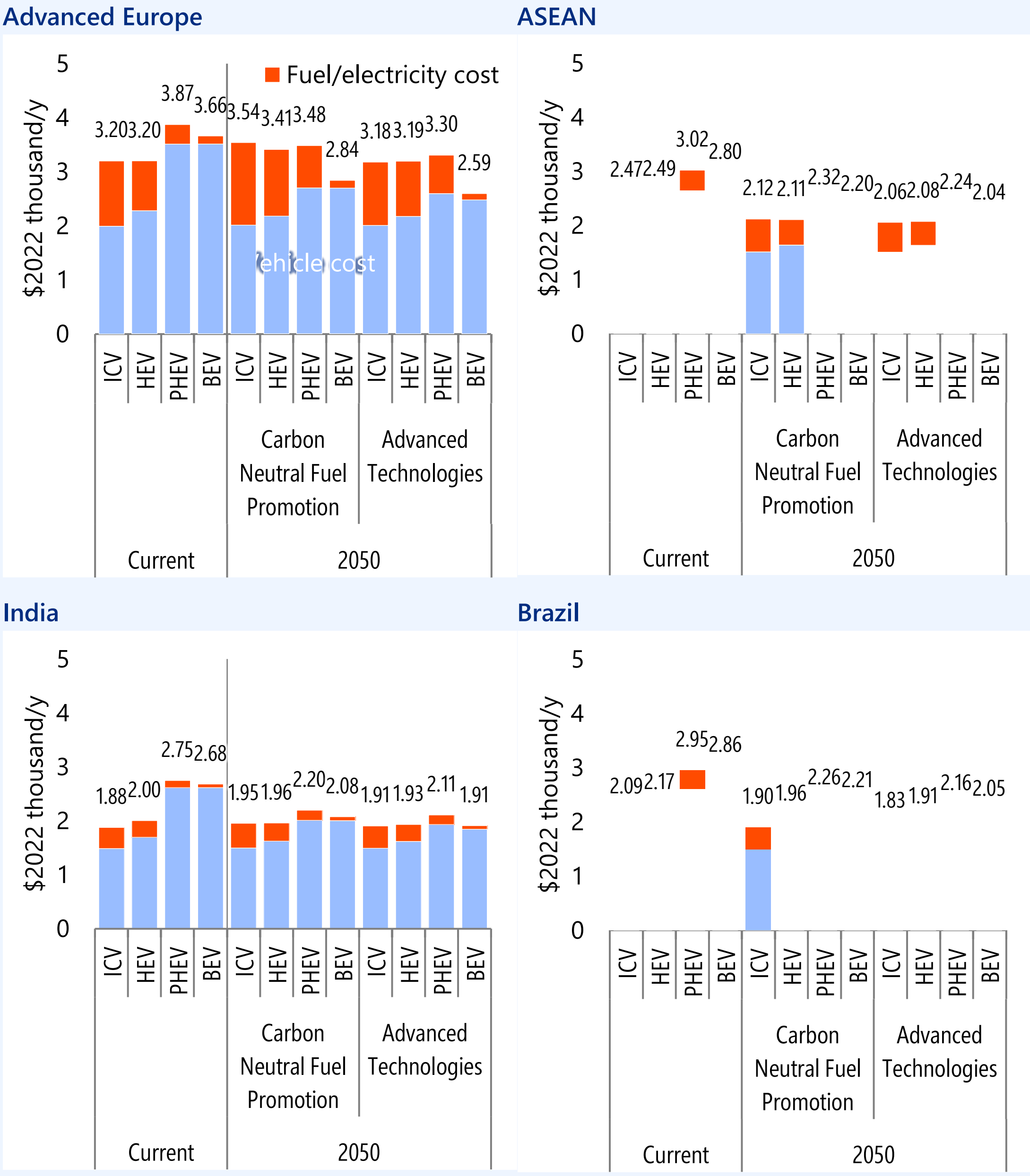
One current challenge is that the vehicle costs of PHEVs and BEVs exceed those of internal combustion engine vehicles (ICVs) and HEVs. To address this, we compared the total cost of ownership across different powertrains in passenger cars, projecting vehicle costs, and fuel and electricity prices through 2050, incorporating future battery price estimates.

In Advanced Europe, ICVs and HEVs currently offer lower running costs than PHEVs and BEVs. By 2050, however, BEVs will become the most economical option due to their reduced vehicle cost and the higher price of oil relative to electricity (electricity being cheaper than petrol). Similarly, in non-Organisation for Economic Co-operation and Development (OECD) countries such as ASEAN, India and Brazil, ICVs and HEVs are presently more affordable than PHEVs and BEVs. Even with projected cost reductions for PHEVs and BEVs by 2050, HEVs are likely to remain more economical than BEVs in the Carbon Neutral Fuel Promotion Case and comparable in cost in the Advanced Technologies Scenario in ASEAN and India, where oil prices are lower than in Advanced Europe. In Brazil, HEVs will maintain a cost advantage over BEVs due to cheaper biofuels. In essence, beyond vehicle costs, oil prices, carbon-neutral fuel prices and electricity prices will significantly influence consumers' powertrain choices[15].

[14] Japan Organization for Metals and Energy Security, "FY2022 Mineral Resource Supply and Demand Survey Report for Achieving Carbon Neutrality" (2022)

[15] BEVs require battery replacement according to mileage and age, and this is especially true in cold climates. In addition, if the use of BEVs is expanded, it will be necessary to consider how to share the tax burden fairly among powertrains and how to cover road maintenance and other costs. In addition to the costs to consumers, it is also necessary to consider social burdens such as power generation capacity and the construction of transmission and distribution systems. This analysis assumes that battery prices are the same worldwide, however, it is estimated that the price of lithium iron phosphate batteries varies greatly depending on the country of production (around 10% higher in the United States and 20% higher in

Figure 4-5 | Usage cost per passenger car



Notes: Cost of vehicle is calculated by dividing the cost by the number of years of usage. For oil and electricity prices, it is assumed that taxes, subsidies, etc. do not change. Biofuels are assumed to have the same ratio to oil in 2023, and Brazil is assumed to continue its existing subsidies. The price of synthetic fuel is assumed to be ¥300/L in the case of Japan's overseas production in 2050, and the ratio with Japanese oil is applied to other countries as well.

Implication

Limiting the global temperature rise to 1.5°C requires a holistic and flexible approach. In doing so, the carbon neutrality of automobiles must take into account various regional factors,

Europe than Chinese-made batteries). It should be noted that battery prices, which have a significant impact on the price of BEVs, also vary by country of production and there are other items to be considered besides this analysis that take into account future technological advances and other factors.

such as the availability of resources, the country's stage of development and consumer purchasing power, fuel and electricity prices related to automobile use and the decarbonisation of power sources.

As the LCA analysis results show, when considering GHG emissions not only during powertrain use, but also in the production of energy and in the manufacture and disposal of passenger cars, the assessment varies greatly depending on regional characteristics. When the proportion of low-carbon power sources is high, as in Advanced Europe, the combination of carbon-neutral fuels and PHEVs will have smaller GHG emissions, on par with BEVs. On the other hand, in ASEAN and India, where decarbonisation of power sources is relatively slow, the combination of carbon-neutral fuels and PHEVs is a promising option, whereas in Brazil, which has abundant biofuels, the combination of carbon-neutral fuels with HEVs and PHEVs is a viable option for carbon neutrality of automobiles.

In addition, as the LCA results show, in a country like Brazil where the power sector is already substantially decarbonised, importing batteries manufactured in countries with higher electricity carbon emission factors could increase battery-related emissions by up to 40% compared to domestic production. Therefore, a comprehensive LCA must evaluate GHG emissions by powertrain type, accounting for both domestic and international battery production.

The supply of critical minerals is currently dominated by certain countries, particularly China. An important implication of this is that combining carbon-neutral fuels with HEVs and PHEVs offers greater energy security benefits compared to BEVs, which depend more heavily on critical minerals.

When pursuing automobile carbon neutrality, it is crucial, especially in Emerging and Developing Economies, to determine whether proposed measures can be implemented in an 'affordable' manner regarding consumer costs. For example, as demonstrated in the analysis of ASEAN, India and Brazil, the use of HEVs powered by biofuels and other carbon-neutral fuels may remain an 'affordable' option even in 2050. Moving forward, in addition to forecasting vehicle costs based on the critical mineral resource supply-demand balance and the impact of technological developments on battery prices, detailed examination is needed of policy frameworks (tax systems, subsidies, etc.) that will influence the relative relationships between future oil prices, carbon-neutral fuel prices and electricity prices.

Renewable energies

In the Advanced Technologies Scenario, variable renewables such as wind and solar photovoltaics will be introduced at a faster pace. The share of variable renewables in total global electricity generated will expand from 11.7% in 2022 to 53.1% in 2050.

If the share of variable renewables increases to this level, challenges in power system operations are likely to emerge in some countries and regions. For example, challenges attributable to the time variability of wind and solar photovoltaic power generation include rapid output fluctuations (frequency fluctuations), surplus electricity and extreme generation shortfalls during cloudy or windless periods that occur once or twice a year. One of the challenges regarding the uneven spatial distribution is power transmission capacity shortages. Other challenges include a decrease in grid inertia accompanying an increase in asynchronous power sources[16], as well as the negative impacts on the natural environment, ecosystems and economic activities near renewable power source locations. Such impacts include the adverse effects of large-scale solar photovoltaic facilities on forest development, those of onshore wind power facilities on birds and increasingly severe impact of offshore wind power generation on fishing.

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

Installed capacity for onshore and offshore wind power generation will increase in all regions faster than in the Reference Scenario, reaching 2 260 GW in 2030 and 5 160 GW in 2050 (Figure 4-6). Onshore wind power generation will expand remarkably in China and India as enhanced power transmission infrastructure and cost reduction for energy storage technologies ease the spatial and temporal unevenness of wind resources distribution. Offshore wind power generation will increase in China, Chinese Taipei, Japan and the United States as well as in Europe, which has so far led the world in offshore power generation. In particular, the increase in China will be significant. In addition to continuous technological development and cost-cutting efforts, policy support for wind power generation—including enhanced economic assistance, national institution-building efforts for ocean development and smoother development processes based on better understanding with fishery business operators and other traditional ocean users—will help the diffusion of offshore wind power generation in these regions. China will retain the largest share of global onshore and offshore wind power generation capacity, remaining a major wind power generation market. China will account for 45% of the world's installed capacity in 2030 and 50% in 2050. Overcoming location and grid constraints through advanced technologies will contribute to further expansion of wind power generation in Europe, the United States, India and elsewhere, but also in China. As a result, China's presence in 2050 will not significantly differ from the Reference Scenario.

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

Figure 4-6 | Global installed wind power generation capacity [Advanced Technologies Scenario]

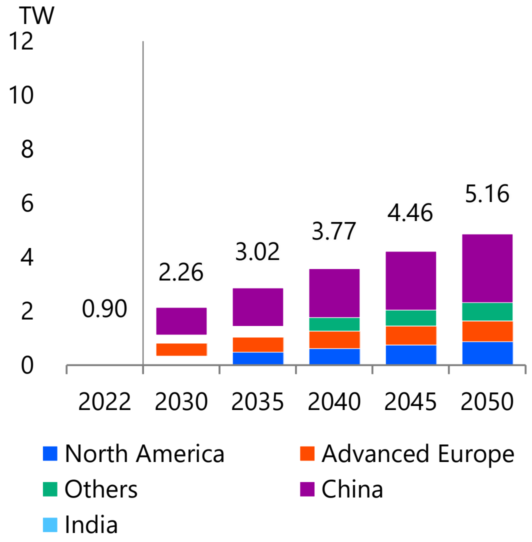
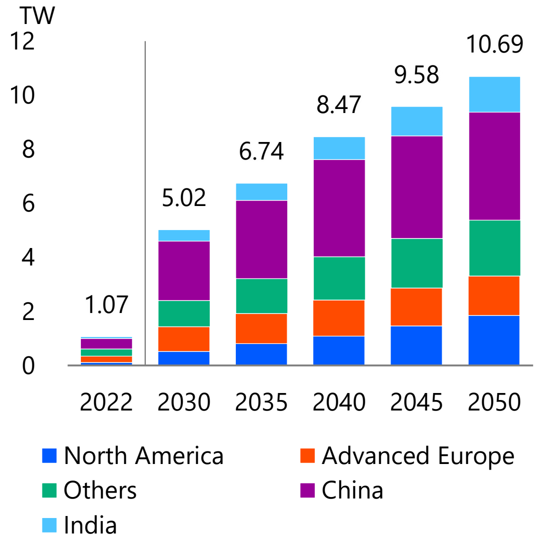


Figure 4-7 | Global installed solar photovoltaic power generation capacity [Advanced Technologies Scenario]



Solar photovoltaic power generation is also being introduced ambitiously, with global installed capacity reaching 5 020 GW in 2030 and 10 690 GW in 2050 (Figure 4-7). As a result of technological advances, which have, to a certain extent, overcome grid constraints, the effect of variable power sources on grid stability and location constraints, wind and solar photovoltaics will increase by 1.5 times and 1.3 times, respectively, compared to the Reference Scenario for 2050. In addition to the current major solar photovoltaic power generation markets such as China, Europe and the United States, India's presence will increase as a solar photovoltaic power generator due to falling costs for solar panels and storage batteries. Furthermore, the growth of solar photovoltaic power generation will accelerate in the Sun Belt which has abundant sunlight resources, including the Middle East, Africa and Latin America. Comparing the Reference Scenario and the Advanced Technologies Scenario for solar photovoltaics, the latter shows a 1.3-fold increase in Europe, a 1.5-fold increase in India and a 1.4-fold increase in countries and regions other than China, North America and Europe (i.e., Middle East, Africa, Latin America, etc.), with no significant differences among them. This suggests that technological advances could make solar photovoltaic markets even more promising in countries and regions that are not currently major markets.

Carbon neutrality initiatives have grown globally in recent years. The diffusion of naturally variable renewable power sources will have to accelerate much faster than in the Advanced Technologies Scenario to realise carbon neutrality by around the middle of this century. As the electricity supply and demand structure is expected to change drastically in a carbon neutral society, technology choices will have to adapt to the change. In addition to using lithium-ion and sodium-sulphur (NAS) batteries to store electricity for several hours, technologies to store electricity for a far longer time may be required to respond to weekly, monthly and seasonal fluctuations in output from variable renewable power sources. Such technologies include redox flow batteries and hydrogen. Redox flow batteries, whose output and storage capacities can be designed separately, may be able to store massive amounts of electricity for a long time by increasing the amount of electrolytic solution. Regarding hydrogen, capacities for water electrolysis, hydrogen storage and hydrogen-fired power generation technologies can be chosen separately. Energy storage technology is also expected to be used to provide ancillary services such as power system frequency regulation. Storage batteries have already entered the ancillary services market in Europe and the United States. Water electrolysis technology is also being tested, mainly in Europe, aiming at the institutional design for practical use in ancillary services. Energy storage should be pursued to achieve optimal combinations, by comprehensively considering and combining the characteristics of each technology, such as technical features, economy, safety and economic security including the procurement of mineral resources as raw materials, such as lithium, nickel, cobalt, vanadium and platinum.

Nuclear

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

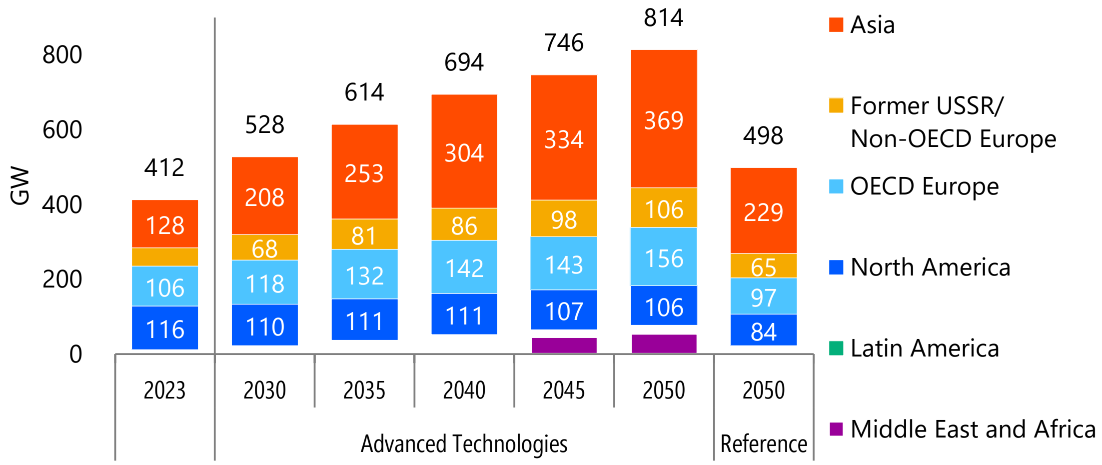
Efforts in non-power sectors will also be important for substantial decarbonisation throughout society. Therefore, nuclear technology is expected to be used not only for power generation but also for multiple other purposes such as district and industrial heat supply, hydrogen production and seawater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

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

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

In the Advanced Technologies Scenario under these assumptions, global installed nuclear power generation capacity will increase from 412 GW in 2023 to 814 GW in 2050 (Figure 4-8). This is equivalent to 1.6 times the amount of 498 GW in the Reference Scenario.

Figure 4-8 | Installed nuclear power generation capacity [Advanced Technologies Scenario]



In North America, the installed capacity will slightly decline after 2025, but will remain around 106 GW until 2050, by carrying out maintenance of essential existing reactors and by constructing new reactors. In the United States, both Democratic and Republican administrations have shown a commitment to nuclear, and policies have been implemented by the federal government and some state governments to support new construction and maintenance of existing reactors. In the Advanced Technologies Scenario, it is assumed that these policies will be maximally successful; thus, installed capacity will remain above that of the Reference Scenario. Furthermore, the United States and Canada are proactively promoting the development of SMRs and Generation IV reactors, which are expected to be commercialised in or after the 2030s. However, the impact of SMRs in those countries' total installed capacity will be limited due to the small installed capacity per unit.

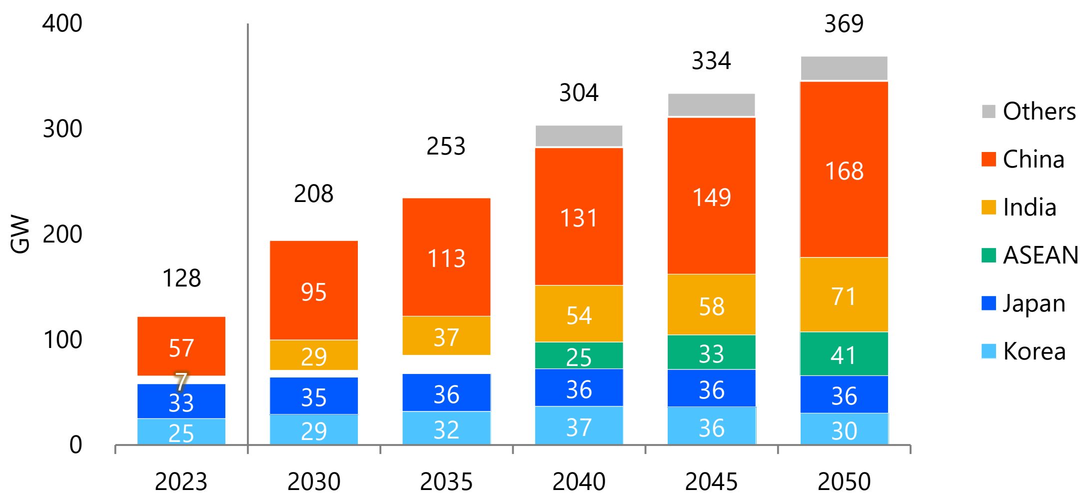
In Advanced Europe, countries aiming at ambitious targets for reducing greenhouse gas emissions will politically promote the construction of additional nuclear power plants and the replacement of outdated reactors. As a result, installed nuclear power generation capacity will expand from 106 GW in 2023 to 156 GW in 2050. In France, the largest nuclear user in Europe, installed nuclear power generation capacity will decline more slowly than in the Reference Scenario through 2050, as the number of nuclear power plant construction projects increases. The construction of state-of-the-art large light-water reactors will be further promoted in the United Kingdom, and by 2050 the maximum target set by the Energy Security Strategy, 24 GW cumulatively (including existing plants), will be realised. In Western countries, the construction of large-scale light-water (Generation III+) reactors has been substantially delayed due to the loss of construction know-how for new reactors and design modifications after construction starts. These problems will be corrected for future nuclear power plant construction projects to reduce the risks related to new plant construction and improve the investment climate for operators. This will drive the expansion of nuclear power generation capacity.

Russia will accelerate construction of new nuclear power plants, continuing to expand its installed capacity from 30 GW in 2023 to 53 GW in 2050. Furthermore, exports from Russia will actively proceed against the backdrop of economic growth and growing energy demand in Emerging and Developing Economies. Russia has already been promoting cooperative relations with many Emerging and Developing Economies to help them develop nuclear and other industrial infrastructure and human resources, paving the way for exporting its nuclear power plants in the future.

The Middle East, Africa and Latin America, known as emerging nuclear markets, will commence operation of new reactors from around 2030 and steadily expand installed nuclear power generation capacity thereafter. In the Middle East, where policy priority will be placed on breaking away from heavy dependence on fossil fuels, installed nuclear power generation capacity will reach 11 GW in 2030 and 29 GW in 2050. New nuclear reactors will be built one after another, mainly in the United Arab Emirates, which has already launched plant construction, and in Saudi Arabia, which has announced plans to construct nuclear power plants.

As in the Reference Scenario, Asia will have the world's largest installed nuclear power generation capacity in 2050 in the Advanced Technologies Scenario. Asia's installed capacity will exceed the total combined capacity of Advanced Europe and North America around 2035 and reach 369 GW in 2050 (Figure 4-9). The increase will be driven by China and India, as in the Reference Scenario. In addition, Southeast Asian countries, now just planning to introduce nuclear power generation, will also make progress in introducing nuclear as they require stable and economically efficient low-carbon power sources to meet their growing electricity demand. As many of these countries need to achieve stable electricity supply on their islands, the introduction of SMRs or floating nuclear reactors is being considered. With this background, ASEAN's installed capacity, though zero as of 2023, will reach 41 GW in 2050 as commercial nuclear power generation starts around 2030. That figure will exceed Japan's installed capacity of 36 GW at that year.

Figure 4-9 | Asia's installed nuclear power generation capacity [Advanced Technologies Scenario]



Hydrogen

Clean hydrogen and low-carbon fuels made from clean hydrogen (ammonia, synthetic methane, synthetic fuels [e-fuel], etc.) are attracting attention as a decarbonisation measure for applications where electrification is difficult, and as an alternative to thermal power generation primarily as a balancing power source.

The United States launched a 10-year tax credit for clean hydrogen production through the Inflation Reduction Act, which was passed in August 2022. In addition, with the $7 billion support scheme based on the Bipartisan Infrastructure Law, the United States will select seven Regional Clean Hydrogen Hubs (H2Hubs) and aim to create a clean hydrogen network, including the use of hydrogen. 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. Additionally, the European Hydrogen Bank (EHB), which was created to establish the intra-EU market distribution of renewable energy-related hydrogen and to support the import of such hydrogen into the union, adopted seven subsidy projects for the production of renewable energy-derived hydrogen within the European Union in April 2024, with subsidies ranging from €0.37/kg-H_2 to €0.48/kg-H_2. In July 2024, Germany announced the results of the first tender [17] for H2Global, the international hydrogen and hydrogen-derived fuel procurement mechanism.

In Asia, 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 50 000 fuel cell vehicles by 2025. In addition, a series of large-scale renewables-derived hydrogen production projects have commenced in regions where wind and sunlight resources are abundant and can be procured inexpensively. The Chinese government, in its action plan for decarbonising coal-fired power generation published in July 2024, specified co-firing with green ammonia as one of the measures for decarbonising coal-fired power generation[18]. South 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. Meanwhile, Japan revised its Basic Hydrogen Strategy in June 2023 for the first time in six years, setting clean hydrogen and low-carbon fuel introduction targets of up to 3 Mt/year by 2030, 12 Mt/year by 2040 and 20 Mt/year by 2050. In May 2024, the Hydrogen Society Promotion Act [19] was enacted, which provides supports for differential pricing and for the development of bases for clean hydrogen and ammonia, raising hopes for expanded use of hydrogen and ammonia in the future.

In the Advanced Technologies Scenario, the main applications of clean hydrogen are in power generation, synthesis of low-carbon fuels, industry and transport sectors (Figure 4-10). Currently, hydrogen in the transport sector mainly serves fuel cell vehicles, particularly for heavy-duty applications such as buses and trucks that have high annual mileage and present electrification challenges. Hydrogen and hydrogen-derived products including ammonia, synthetic methanol

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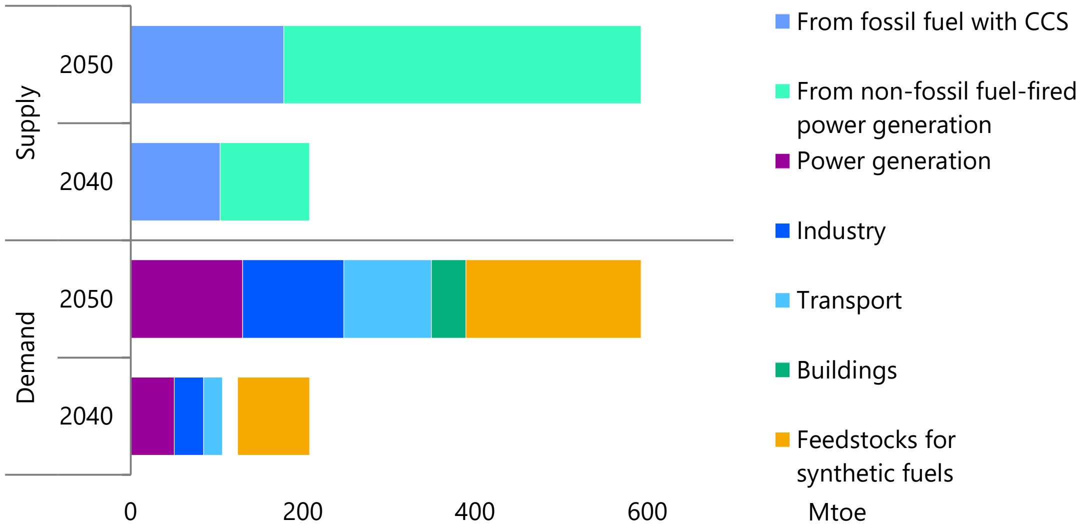
[17] The winning bid was for green ammonia produced in Egypt, with the contract price being €1 000/t.

[18] Decarbonisation measures other than green ammonia co-firing are biomass co-firing and CCS.

[19] Act on Promotion of Supply and Utilization of Low-Carbon Hydrogen and its Derivatives for Smooth Transition to a Decarbonized, Growth-Oriented Economic Structure

(e-methanol) and synthetic kerosene (e-kerosene) will serve as crucial options for decarbonising shipping and aviation.

Figure 4-10 | Supply and demand of clean hydrogen [Advanced Technologies Scenario]



Another application of hydrogen and hydrogen-derived low-carbon fuels will be in the industry sector, especially for high-temperature heat demand. In addition, steelmaking technologies using hydrogen, such as hydrogen-based blast furnace reduction and hydrogen-based direct reduction, are still at the demonstration stage, but their introduction will expand in the future as an important means of decarbonising the iron and steel sector. The use of hydrogen in the buildings sector will be introduced in a limited manner in areas where it is relatively easy to develop distribution infrastructure such as hydrogen pipelines and piping.

For hydrogen production, fossil fuel-derived hydrogen with CCS (blue hydrogen) will advance in the short term due to its price competitiveness. However, future cost reductions in renewables power generation and water electrolysis systems will enhance alternative production methods. Countries such as France and the United States are simultaneously developing nuclear-based hydrogen production. By 2050, approximately 70% of clean hydrogen supply will come from non-fossil fuel sources such as renewables (Figure 4-10). Other promising sources of clean hydrogen production and supply will include countries or regions with abundant renewable energy resources such as Latin America, Australia and Africa, in addition to traditional energy-producing areas such as the Middle East and North America. The main destinations for clean hydrogen and low-carbon fuels will include Europe, North America, East Asia and India.

Transforming hydrogen into a hydrogen carrier for the purpose of hydrogen transport requires large capital investment and additional energy input, which will lead to increased costs. Therefore, such transformation and transport should be kept to a minimum, so the production and demand for hydrogen should be geographically close to each other. However, for countries or regions such as Europe, Japan and Korea, where demand for hydrogen is large, but the supply potential of inexpensive clean hydrogen seems limited, long-distance transport of hydrogen from abroad will also be necessary. To establish an economical international supply chain for clean hydrogen, it is necessary to significantly reduce the cost of hydrogen carrier synthesis such as liquefied hydrogen, methylcyclohexane (MCH), ammonia, synthetic methane and synthetic fuels. Controlling CO_2 emissions throughout the supply chain is another important issue, which will require the establishment of a carbon footprint certification scheme for clean hydrogen and low-carbon fuels.

Carbon capture and storage

Carbon capture and storage (CCS) refers to a technology that captures CO_2 from a variety of emission sources and stores it stably in underground formations. This technology has already been widely commercialised in the United States, Canada, Norway, Australia and others, and has been attracting much attention in recent years as a technology that will greatly contribute to decarbonisation in the future. CCS does not simply capture CO_2 generated when fossil fuels are used; it is also an essential elemental technology for so-called carbon dioxide removal technologies such as direct air capture with carbon storage (DACCS), which captures CO_2 directly from the atmosphere and stores it underground, and bioenergy with carbon capture and storage (BECCS), which captures CO_2 generated by biomass use and stores it underground. Thus, CCS is an indispensable technology for humankind to keep the CO_2 concentration in the atmosphere stable over the long-term.

Aiming to achieve net-zero emissions by mid-century, support systems are being developed for the introduction of CCS, especially in Advanced Economies. Since CCS implementation represents a pure additional cost for companies, its adoption requires incentives. In the United States, companies that have implemented CCS have previously been given a tax credit of $20 per tonne of CO_2 captured and stored, but the Inflation Reduction Act enacted in 2022 introduced a policy to encourage the adoption of CCS by rapidly increasing this tax credit to $85/t. Canada, Australia and others have systems in place to provide subsidies for initial investments to businesses implementing CCS, as well as providing emissions trading credits in their respective countries for the CO_2 captured and stored through CCS. In the United Kingdom, although there are no commercial CCS projects yet, four sites have already been identified as potential hubs for the intensive implementation of CCS. To achieve the plan, a system has been introduced whereby the government will compensate for the difference between the actual costs of implementing CCS and the emissions trading credits that can be obtained by implementing CCS.

In Japan, efforts towards CCS commercialisation are progressing steadily in response to global trends. In May 2024, the Act on Carbon Dioxide Storage Business was enacted, which stipulates the legal rights and obligations for implementing CCS. In June of the same year, the Ministry of Economy, Trade and Industry and the Japan Organization for Metals and Energy Security (JOGMEC) announced policies to provide targeted financial support to capture and storage plans at nine locations in Japan and overseas as 'advanced CCS projects' that will provide integrated support for the entire value chain, from CO_2 separation and capture to transportation and storage (Table 4-4). Domestic projects, in particular, which have diverse characteristics in terms of storage locations, recovery sources and transportation means, are selected as targets for support. The Japanese government has set a CCS implementation target of 120 Mt/year to 240 Mt/year for 2050, and to achieve this target, it is calling for the advanced CCS projects selected this time to begin actual storage by 2030.

Table 4-4 | Selected advanced CCS projects

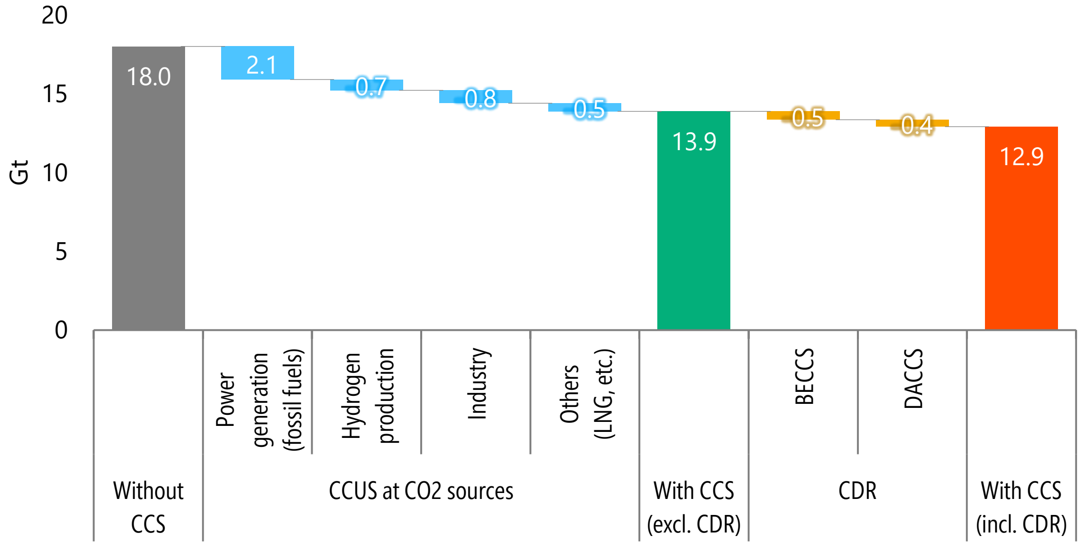
Storage location	Storage amount (approximate)	Capture source	Transport means
Tomakomai region (aquifers)	1.5 Mt/year–2 Mt/year	Refinery, thermal power plants in Tomakomai region	Pipeline
Tohoku Region along the Sea of Japan (marine aquifers)	1.5 Mt/year–1.9 Mt/year	Steel mills, cement plants, local emitters	Ships and pipelines
East Niigata region (existing oil and gas fields)	1.4 Mt/year	Chemical plants, paper mills, power plants	Pipeline
Capital Region (marine aquifers)	1.4 Mt/year	Steel mills, etc.	Pipeline
Western Kyushu (marine aquifers)	1.7 Mt/year	Refineries, thermal power plants	Ships and pipelines
Malaysia North off the coast of the Malay Peninsula (declining oil and gas fields)	3 Mt/year	Steel, chemicals, oil refining, etc.	Ships and pipelines
Off the coast of Sarawak, Malaysia (offshore depleted oil and gas fields)	1.9 Mt/year–2.9 Mt/year	Steel mills, power plants, chemical plants, etc.	Ships and pipelines
Malaysia South off the coast of the Malay Peninsula (offshore declining oil and gas fields, aquifers)	5 Mt/year	Power generation, chemicals, cement, oil refining, etc.	Ships and pipelines
Oceania (offshore declining oil and gas fields, aquifers)	2 Mt/year	Steel mills, etc.	Ships and pipelines

Source: Ministry of Economy, Trade and Industry

In the Advanced Technologies Scenario, CCS implementation is anticipated across various sectors, particularly power generation and industry. In the power generation sector in Advanced Economies, CCS is expected to be applied to all newly built coal- and liquefied natural gas (LNG)-fired plants that are not expecting ammonia or hydrogen co-firing, while in Emerging and Developing Economies, CCS is expected to be increasingly applied to thermal power plants in China, India, Southeast Asia, the Middle East and other regions where CCS reservoirs and companies capable of implementing CCS exist. In the industry sector, also in Advanced

Economies and some Emerging and Developing Economies, CCS is assumed to be actively applied in the steel, cement and chemical sectors. Furthermore, in the fossil fuel production sector, it was assumed that all new LNG projects in the LNG production sector will be equipped with facilities to capture and store CO_2 generated during LNG production.

Figure 4-11 | Amount of CCS implemented [Advanced Technologies Scenario, 2050]



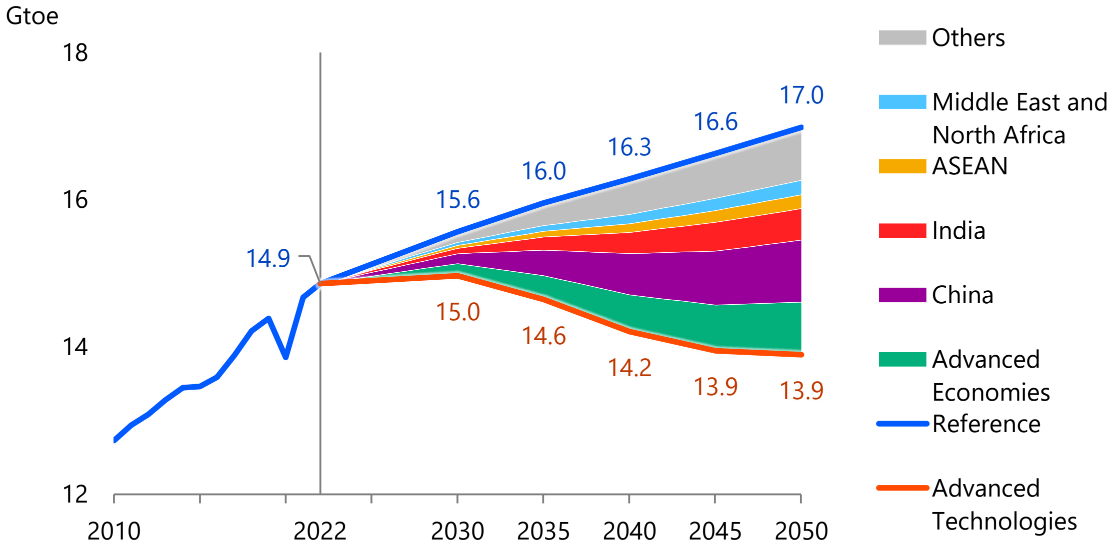
4.2 Energy supply and demand

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

The Advanced Technologies Scenario assumes the enhancement of energy efficiency improvements and climate change countermeasures. Primary energy consumption will increase until 2030, partly due to increased electricity demand in data centres, but will decline after 2030 due to accelerated energy conservation. Primary energy consumption in 2035 in the Advanced Technologies Scenario will be −1 311 Mtoe (−8.2%) compared with the Reference Scenario and −215 Mtoe (−1.4%) compared with 2022 (Figure 4-12). Although the pace of decline will slow after 2040 along with increases in CCS and other technologies, the decline will continue until 2050, resulting in a reduction in primary energy consumption of 3 091 Mtoe (20.8%) compared to the Reference Scenario. Cumulative savings by 2050 will be 43.5 Gtoe. Emerging and Developing Economies such as India, the Middle East and North Africa (MENA) and ASEAN will play a crucial role in realising the Advanced Technologies Scenario, as they have significant potential to save energy and introduce non-fossil energy sources.

Emerging and Developing Economies will account for 72% of global energy savings from the Advanced Technologies Scenario in 2050. Particularly, India, MENA and ASEAN will capture a combined share of 26%. Extraordinary efforts to boost energy efficiency improvements and decarbonisation in these countries as quickly as possible will be key to global energy security and climate change countermeasures.

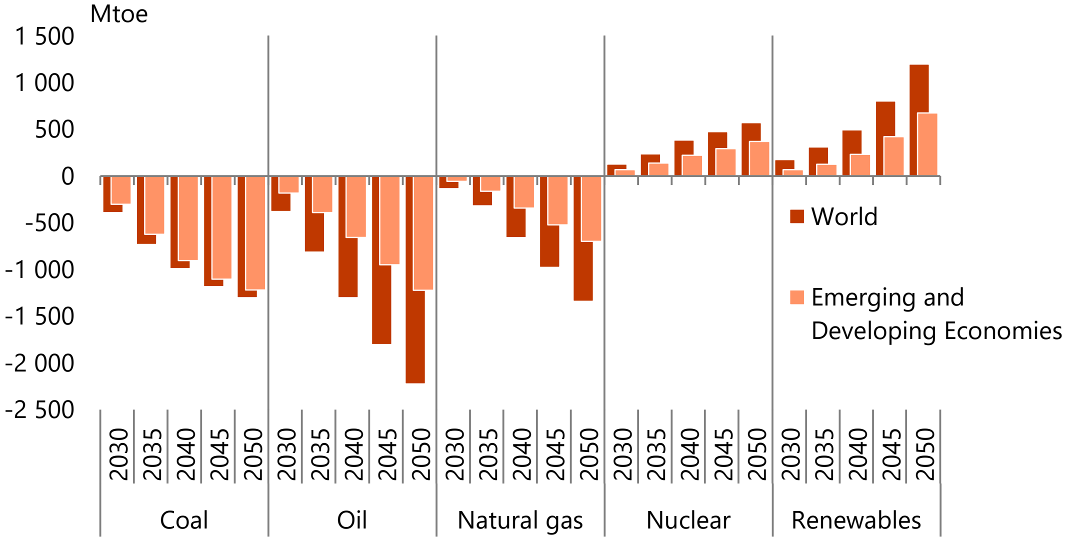
Figure 4-12 | Global primary energy consumption and energy savings (relative to Reference Scenario) [Advanced Technologies Scenario]



By energy source, fossil fuels will decrease by 4.9 Gtoe (39%) in 2050 compared to the Reference Scenario, with a cumulative reduction of 63.2 Gtoe (Figure 4-13), partly due to progress in fuel switching. Coal for power generation is being replaced in Emerging and Developing Economies, with these economies accounting for 90% in 2035 and 2050. Led by the spread of electrified vehicles, oil consumption will decrease by 0.8 Gtoe in 2035 and by 2.2 Gtoe in 2050, achieving the highest energy savings. Natural gas consumption will decline only by 0.3 Gtoe in 2035 and by 1.3 Gtoe in 2050. The small saving in natural gas consumption in 2050, however, might partly result from an increase in the use for feedstocks for hydrogen production. Non-fossil energy consumption will increase by 0.5 Gtoe in 2035 and by 1.8 Gtoe in 2050. Nuclear and renewables consumption will rise by 63% and 32%, respectively, from the Reference Scenario in 2050. Even in the Advanced Technologies Scenario featuring great growth in non-fossil energy consumption, the world will not be able to maintain or improve economic, social and living conditions without fossil fuels.

Realisation of the Advanced Technologies Scenario is challenging. Emerging and Developing Economies will account for 94% of the coal consumption savings from the Reference Scenario in 2050, with India, MENA and ASEAN capturing a combined 33%. Emerging and Developing Economies will account for 65% and 56% of the growth of nuclear and renewables, respectively, with India, MENA and ASEAN accounting for 27% each. The Advanced Technologies Scenario thus urges Emerging and Developing Economies to realise such contributions to coal consumption savings and nuclear and renewables consumption growth in a short period of less than 30 years. During the process of realising the Advanced Technologies Scenario, Emerging and Developing Economies are required to implement their energy transition far faster than Advanced Economies did in the past.

Figure 4-13 | Primary energy consumption changes (relative to Reference Scenario) [Advanced Technologies Scenario]

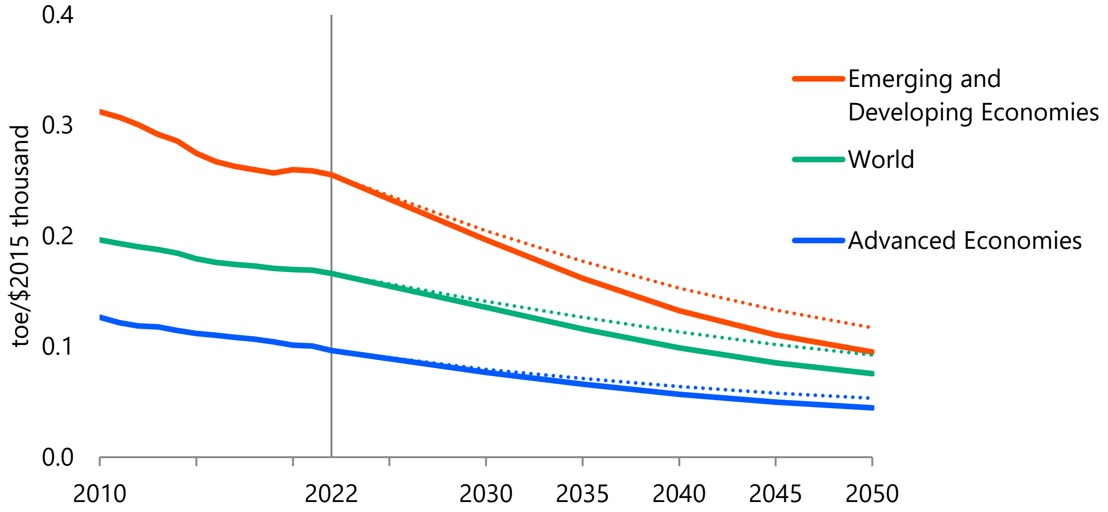


For the world to achieve the 1.5°C target, an average annual improvement in energy efficiency of more than 4% is necessary by 2030. However, in the Advanced Technologies Scenario, the decline in global intensity per gross domestic product (GDP) from 2022 to 2030 is an average of 2.8% per year in Advanced Economies and 3.2% in Emerging and Developing Economies, which are not sufficient (Figure 4-14). In 2050, the Advanced Economies will post a decline of 56% in their energy intensity from 2022 to 2050, compared with a fall of 63% for the Emerging and Developing Economies which have greater potential to improve energy efficiency. The global energy intensity per unit of GDP will have to decrease by 78% from 2022 if the global energy consumption of 6.7 Gtoe in 2050 in the Advanced Technologies Scenario is covered by only nuclear, renewables and fossil fuels for blue hydrogen[20], and achieve carbon neutrality. The decrease would be far steeper than the declines in the Emerging and Developing Economies and in China, demonstrating the considerable difficulty for the world to realise global carbon neutrality in 2050.

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

[20] Hydrogen produced by decomposing fossil fuels and capturing CO_2 emitted in the process

Figure 4-14 | Primary energy intensity per GDP [Advanced Technologies Scenario]



Note: Dotted lines represent the Reference Scenario.

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

Box 4-2 | Current energy conservation trends and future challenges: The importance of 'stock efficiency'

What does doubling the pace of energy efficiency improvements mean?

At the 28th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28), an agreement was reached to strengthen the global commitment to doubling the current pace of energy efficiency improvements by 2030. Specific studies and policy formulation are under way in each country to strengthen domestic energy conservation measures and support by advanced economies to developing economies, while taking into account the burden on consumers.

The goal of doubling the pace[21] of energy efficiency improvements by 2030 is based on an analysis of the Net Zero Roadmap developed by the International Energy Agency (IEA) as a backcast to achieve net zero global CO_2 emissions by 2050. The analysis implies a worldwide improvement in primary energy intensity per unit of GDP per year[22] from now to 2030 at 4% annually, doubling from 2% in 2022.

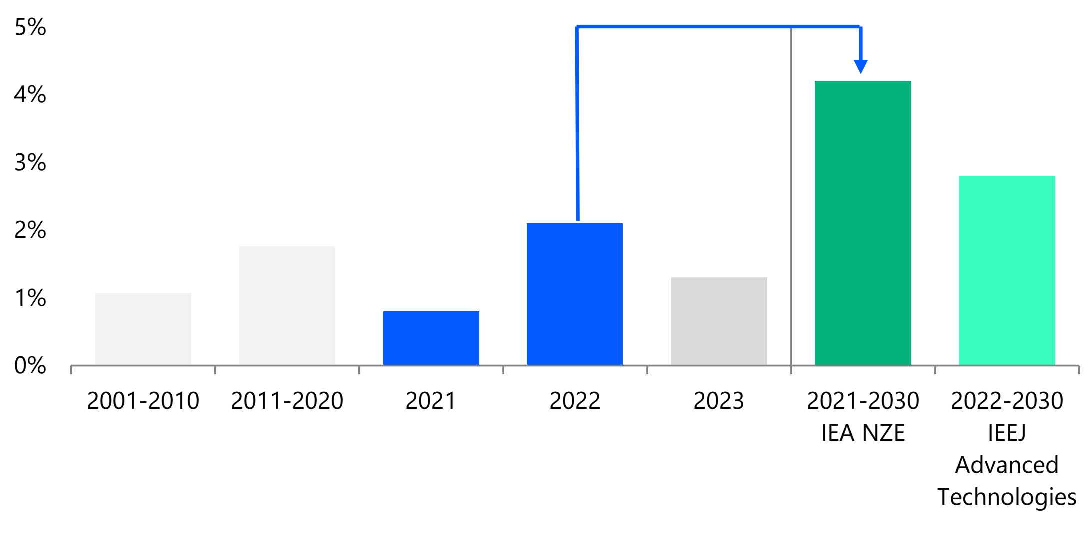
As shown in Figure 4-15, energy intensity improved more significantly in 2022 than in previous years, at a rate of 2% year on year. This improvement was driven by production

[21] Although the term 'energy efficiency improvements' in the COP28 agreement is not clearly defined, in Box 4-2 it refers to primary energy intensity per unit of GDP.

[22] The IEA utilises purchasing power parity-based GDP, but the IEEJ uses exchange rate-based GDP for its analysis.

adjustments in the industry sector due to the global rise in energy prices, progress in changing behaviour related to electricity and natural gas conservation in many countries and decreased demand for space heating in Europe due to the warm winter. The average improvement rate in energy intensity for the period 2010–2020 was 1.5%, slowing to 0.8% in 2021, then 1.3% in 2023, indicating a high pace of improvement in 2022.

Figure 4-15 | Improvement rate of global energy intensity



Sources: IEA (2024). Energy Balances., IEEJ, and IEA (2023). Net Zero Roadmap.

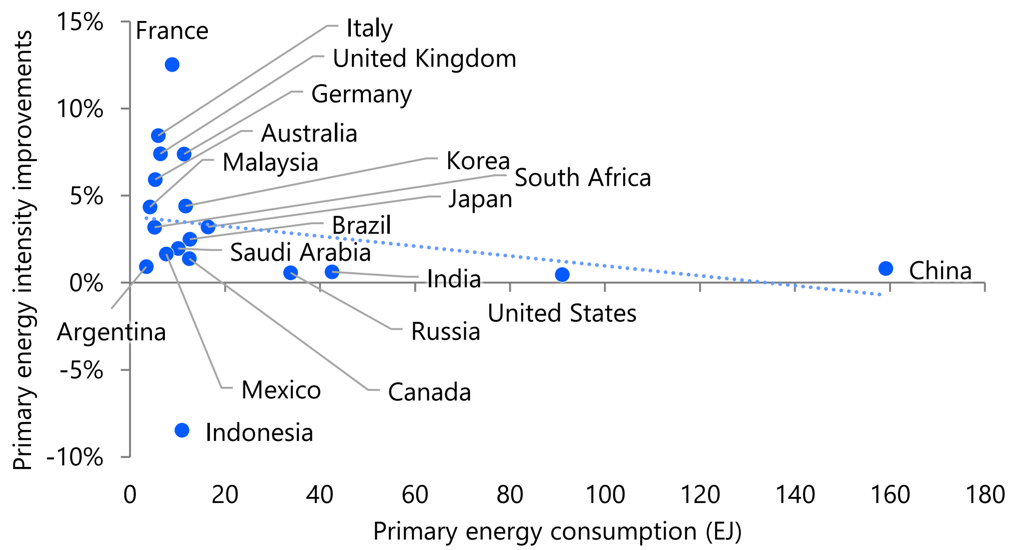
As shown in Figure 4-16, the energy intensity improvement rate in 2022 varied greatly from country to country among Group of 20 member states. Germany and the United Kingdom each saw a 7% improvement, Italy recorded 8% and France[23] demonstrated 13%.

In China, the United States, India and Russia, which are major energy consumers, year-to-year improvements in energy intensity in 2022 were much more modest, ranging between 0.5% and 0.8%. Compared to the high improvement rates in Europe and other regions, the rates were significantly lower in countries with large energy consumption, resulting in an average global improvement rate of 2%. China's energy intensity improvement rate slowed to 0.8% in 2022 compared to 3.2% in 2020–2021, primarily due to increased demand for oil as a feedstock for its expanding petrochemical industry, while China's economic growth rate decelerated to 3%. ASEAN has seen little improvement in energy intensity since 2015, with a 2% deterioration in 2022. This regression likely stems from increasing ownership of automobiles, air conditioners and other home appliances as living standards improve across the region.

The improvement in energy intensity in Europe was particularly remarkable in 2022, reaching 2%. However, in India and ASEAN, which will drive global energy demand in the future, as well as in other major countries (both advanced and developing economies), improvement rates are slowing down. This trend suggests that achieving the 4% target will be challenging, considering historical performance.

[23] The double-digit improvement in France is attributed to savings in energy input to the power generation sector, as the country relied on imports for electricity due to the shutdown of domestic nuclear power plants in the year.

Figure 4-16 | Relationship between GDP intensity improvement rate of primary energy and primary energy consumption [2022]



Source: Compiled from IEA (2024). Energy Balances

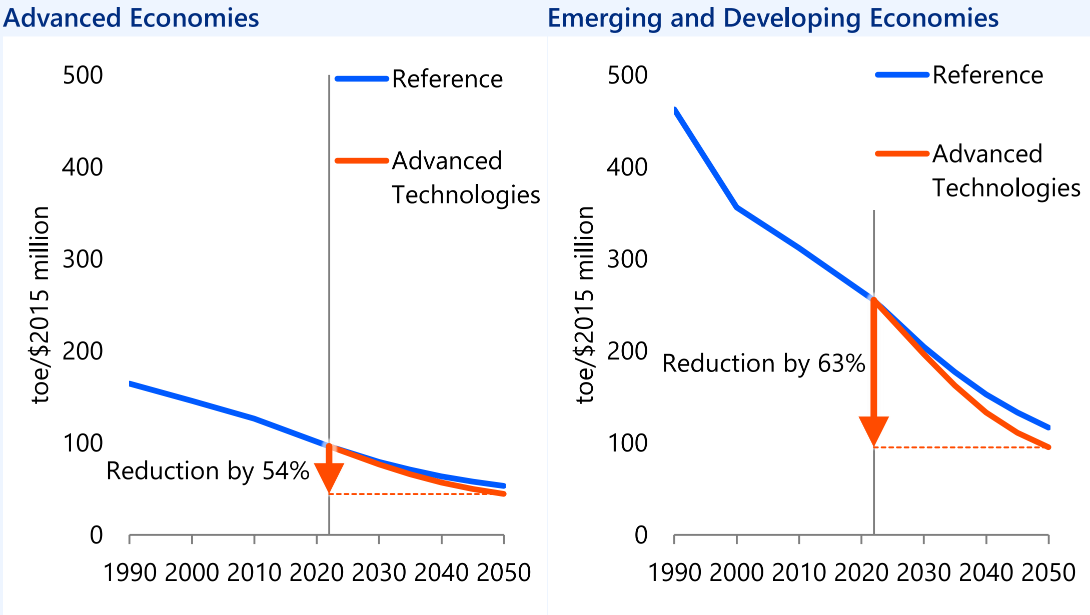
Outlook

Looking to the future, in the Advanced Technologies Scenario, which leads to expanded adoption of highly efficient technologies, primary energy consumption intensity per GDP will improve at an annual rate of 2.8% until 2030 in Advanced Economies and at 3.2% in Emerging and Developing Economies (Table 4-5). In both Advanced Economies and Emerging and Developing Economies, the pace of improvement in intensity is fastest between 2030 and 2040, at 3.0% and 3.8%, respectively, followed by 2.6% and 3.3% between 2040 and 2050, respectively. In terms of energy intensity, Advanced Economies will see a 54% reduction in 2050 compared to 2022, while Emerging and Developing Economies will see a 63% reduction (Figure 4-17). Looking at the global picture, the improvement rate is expected to be 2.5% between 2022 and 2030, falling short of the 4% target even in the Advanced Technologies Scenario, which assumes maximum introduction of efficient technologies.

Table 4-5 | Primary energy consumption intensity per GDP and improvement rate

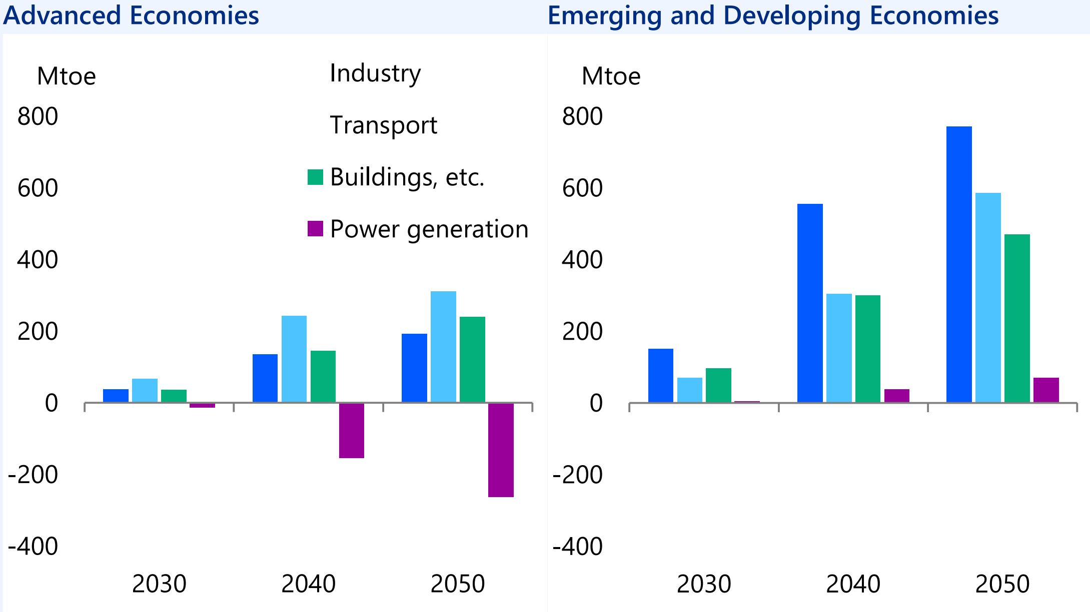
		Reference						Advanced Technologies					
	2022	2030	2040	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2040	2050	2022/ 2030	2030/ 2050	2022/ 2050
Advanced Economies	96	79	64	53	-2.4%	-2.0%	-2.1%	77	57	45	-2.8%	-2.6%	-2.7%
Emerging and Developing Economies	255	205	153	117	-2.7%	-2.8%	-2.7%	197	133	95	-3.2%	-3.6%	-3.5%

Figure 4-17 | Primary energy consumption intensity per GDP



When the difference between the Reference Scenario and the Advanced Technologies Scenario is defined by energy savings, the scale of the energy conservation amount differs by sector and time axis in Advanced Economies and Emerging and Developing Economies, as shown in Figure 4-18. In Advanced Economies, BEVs for passenger vehicles will be more widely used after 2035, when they are estimated to offer cost advantages over internal combustion engine vehicles, contributing to energy conservation in the transport sector. In contrast, in Advanced Economies, the energy input for power generation will be higher in the Advanced Technologies Scenario than in the Reference Scenario due to a demand-side shift from fossil fuels to electricity. In Emerging and Developing Economies, the industry sector will see significant progress in energy conservation due to China's transition to a service industry and the higher efficiency of newly installed facilities. Energy conservation in the transport sector in Emerging and Developing Economies will progress after 2040, with electrification lagging 5 to 10 years behind Advanced Economies.

Figure 4-18 | Energy conservation by sector



Note: Regarding the difference between the Reference Scenario and the Advanced Technologies Scenario, positive values represent energy conservation and negative values represent energy increases.

As the results of the Advanced Technologies Scenario show, it will be difficult to achieve a 4% annual improvement rate in energy intensity from now to 2030, the early stage of the projection period, without 'discontinuous' actions in technology introduction and operational improvements. Accelerating energy efficiency improvements requires consideration of various factors related to equipment use and technology adoption. Specifically, these include the timing of cost reductions in high-efficiency technologies, electrification in the demand sector. Specifically, these include the speed and scale of progress of various factors, such as the timing of cost reductions in high-efficiency technologies, electrification in the demand sector and expanded introduction of renewable energy[24] in the power generation sector, and the service-oriented industrial structure of developing countries that will be the driving force of the future global economy. However, the key factor that determines the pace of energy efficiency improvement is that replacing equipment and technologies progresses continuously and takes time.

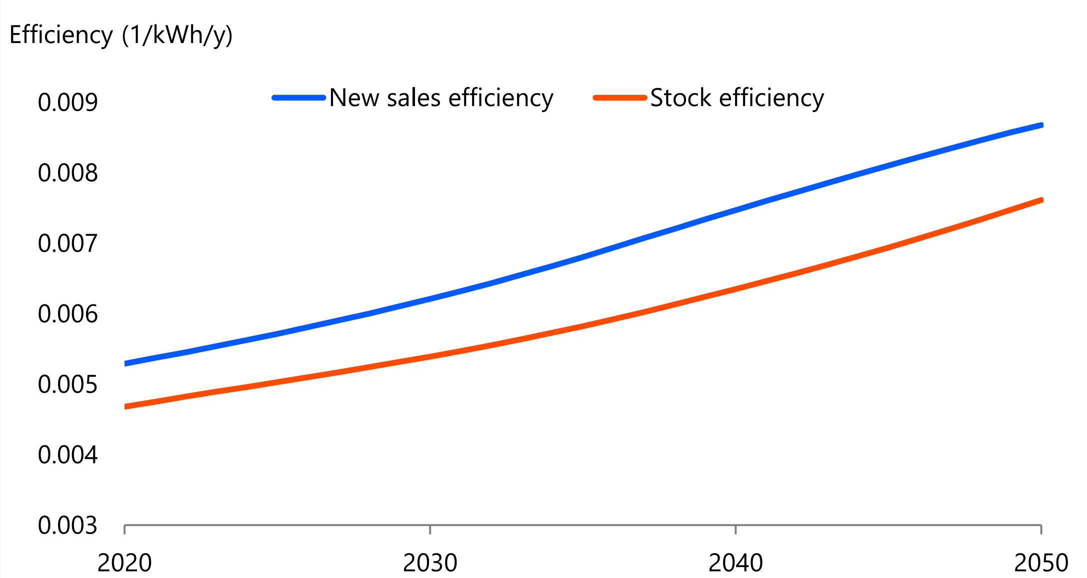
As Figure 4-18 shows, in terms of quantity, the difference in energy conservation between the scenarios up to 2030 is relatively small, but the gap in energy conservation between the scenarios widens after the 2040s. In terms of pace, energy efficiency improvements will accelerate in both Advanced Economies and Emerging and Developing Economies between 2030 and 2040, followed by a slight deceleration thereafter (Table 4-5).

This means that equipment and technology replacement inherently requires time. Household appliances and passenger cars typically take 10 to 20 years to replace, while large buildings and industrial equipment require 30 to 50 years or more, with periodic

[24] The conversion factor to primary energy per kWh for solar photovoltaics and wind is 3.6 MJ, while that for thermal power generation is around 8 MJ to 9 MJ, reflecting different efficiency levels by countries. In improving primary energy intensity, increasing the share of renewable energy in the power generation mix works advantageously.

maintenance extending their lifespans. Taking air conditioners as an example, with an average service life of 15 years, even if efficiency standards for new units are raised to optimal levels, it will take approximately 10 years for these improvements to be reflected in a country's average stock efficiency (Figure 4-19). In other words, policies such as strengthening standards implemented today will only yield significant results about 10 years from now, highlighting the urgency of implementing measures to accelerate the adoption of highly efficient technologies immediately.

Figure 4-19 | Comparison of new sales efficiency and stock efficiency (example of air conditioners)



Notes: The efficiency here indicates the inverse of the power consumption during space cooling by the air conditioner, and the higher the value, the higher the efficiency. New sales efficiency is the efficiency at the time of sale, while stock efficiency represents the efficiency of the entire air conditioner stock in a country, taking into account a 15-year service life.

Implication

Based on the long service life of equipment and technology, it is essential to accelerate measures and policies to promote the introduction of high-efficiency technology so that its energy-saving effects will bear fruit in the future. Also taking into consideration the 'lock-in effect', which means that once equipment or technology is selected, it continues to be used for 10 years or more, the improvement of efficiency should be prioritised within the energy conservation system, as well as the establishment of standards.

The amount of energy conservation from improved efficiency of equipment and technology is an accumulation of small effects. On the other hand, to achieve 'discontinuous' energy conservation effects that are not simply an extension of past efforts, packaged technologies and the approach as a system are required. For example, it is necessary to provide incentives as well as regulatory approaches to promote the introduction of Net Zero Energy Buildings (ZEB), which are an aggregation of highly efficient technologies.

Emerging and Developing Economies have significant potential for energy conservation. Furthermore, compared to Advanced Economies, they still have access to relatively inexpensive energy conservation options. However, this potential often remains unrealised due to the lack of standards, systems, incentives and information provision, as well as the high initial costs involved in introducing high-efficiency technologies. The formation of effective standards requires the thorough implementation of lighting and building standards, air conditioning regulations, automobile fuel efficiency regulations, motor standards and regulations related to energy management. However, many of these standards may not be in place in Emerging and Developing Economies due to insufficient human resources and technical know-how.

To address these issues, it is essential that developed countries provide support for the formulation of systems, transfer of know-how and implementation of energy conservation projects. Energy conservation projects may not be preferentially selected by investors in terms of profitability, given their smaller project size compared to other carbon-neutral projects, such as renewables. Taking these circumstances into account, it is also necessary to package multiple energy conservation projects.

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

Oil will account for about 70% of the net final energy consumption savings in 2050 in the Advanced Technologies Scenario (Figure 4-20). Factors behind oil consumption savings include a decrease in the road sector's oil consumption due to vehicle fuel efficiency improvements and fleet mix changes. To further promote electrified vehicles, various policy incentives will have to be combined with the acceleration of charging facility expansion, battery production capacity enhancement and relevant cost cuts.

Figure 4-20 | Global final energy consumption changes (relative to Reference Scenario) [Advanced Technologies Scenario, 2050]

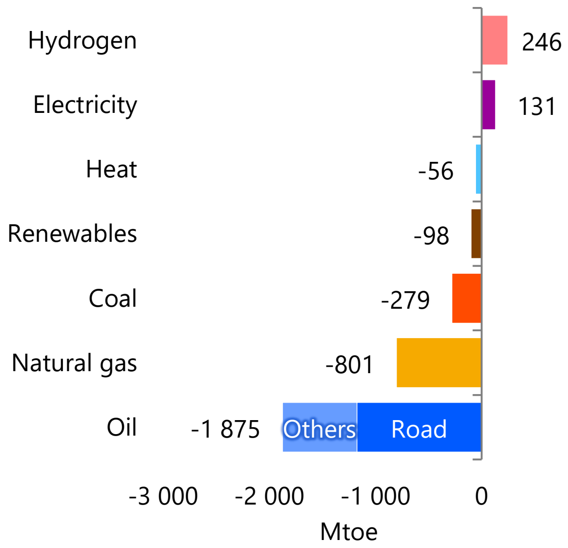
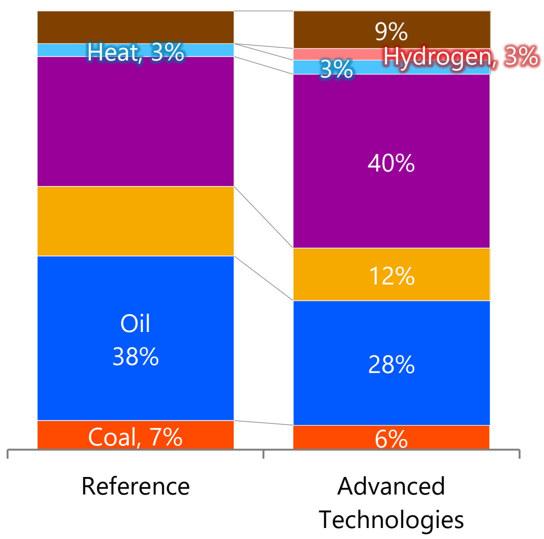


Figure 4-21 | Global final energy consumption mix [2050]



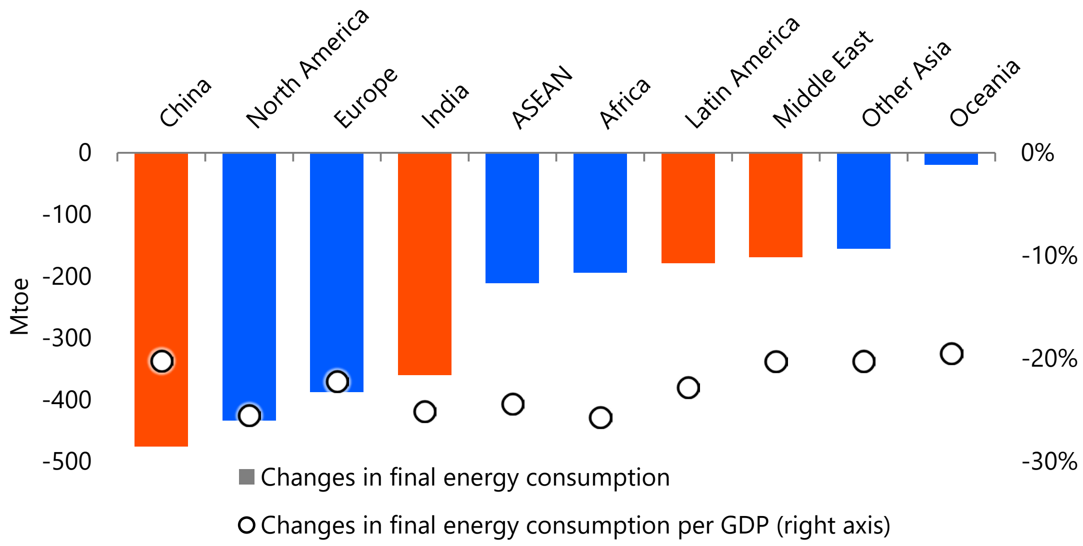
Given oil's large share of total energy savings, steady fuel efficiency improvements and vehicle fleet mix changes will become a key contributor to bringing final energy consumption closer to the Advanced Technologies Scenario path.

The final energy consumption in the Advanced Technologies Scenario will be reduced compared to the Reference Scenario for all fossil fuels such as oil, natural gas and coal due to progress in energy conservation. On the other hand, electricity consumption will increase due to promotion of electrification with the aim of saving energy and reducing CO_2 emissions through high-efficiency and low-carbon electricity. In 2050, the share of electricity will increase by 10 percentage points higher than in the Reference Scenario (Figure 4-21). Hydrogen, expected to be a low-carbon solution for applications where electrification is difficult, is barely introduced in the Reference Scenario but will experience the greatest proportional increase among energy sources in the transition to the Advanced Technologies Scenario. Renewable energy volumes will decrease as traditional biomass such as firewood and livestock manure is replaced with cleaner alternatives, but at a slower rate than fossil fuels, resulting in a share 2 percentage points higher than in the Reference Scenario. Despite these variations from the Reference Scenario, demand will persist for all major energy sources even in the Advanced Technologies Scenario. Therefore, ensuring stable supply of each energy source will remain important in both scenarios.

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

Asia, including China and India will account for the largest share of final energy consumption savings in 2050, followed by North America, Europe and Africa (Figure 4-22). Steady progress in energy efficiency improvements in China, India, the United States, Europe and other economies that are expected to achieve great energy consumption savings will be important for realising the final energy consumption path in the Advanced Technologies Scenario.

Figure 4-22 | Final energy consumption savings and changes in final energy consumption per GDP (relative to Reference Scenario) [Advanced Technologies Scenario, 2050]



Asia’s final energy consumption savings in 2050 will total 1 202 Mtoe, accounting for 44% of global savings. China with 476 Mtoe in savings and India with 360 Mtoe will account for a combined 30% of global savings, highlighting their significant influence. Progress in these two countries’ energy savings will affect not only the countries themselves but also global climate change and energy security in other regions. They will substantially reduce oil consumption in the road sector, and coal and natural gas consumption in the industry sector, reflecting the effects of various technologies assumed in the Advanced Technologies Scenario. Achieving steady progress in energy efficiency improvements in these two countries through various measures, such as the transfer of highly efficient technologies from Advanced Economies, will be essential.

Final energy consumption savings in Europe will total 388 Mtoe, accounting for 14% of global savings. Notably, the buildings sector will account for 35% of these savings. Led primarily by OECD countries, more efficient equipment for household and commercial use will be actively deployed, resulting in significant reductions in natural gas consumption. Final energy consumption savings in North America will total 434 Mtoe, accounting for 16% of global savings. The decline in oil consumption, primarily in the road sector, will account for approximately 60% of North America's savings. As automobiles are frequently used for mobility and transportation in North America, the combined oil demand in the road sector in the United States and Canada is the second largest in the world after Asia. Consequently, oil consumption in the road sector will decline substantially, driven by improvements in vehicle fuel efficiency and changes in vehicle fleet composition.

Africa presents unique characteristics in terms of sectoral savings. Of Africa's 169 Mtoe net final energy consumption savings, about one-third will come from reduced renewable energy consumption in the residential sector, leading to a 26% decline in final energy consumption per GDP—the largest reduction in energy consumption across all countries and regions. The savings in renewable energy consumption will be driven by the modernisation of energy use and the adoption of highly efficient appliances. For Africa to steadily implement residential sector energy savings, it will be essential to make highly efficient energy consumption appliances available at affordable prices to a wider range of consumers and to develop infrastructure for supplying modern energy sources.

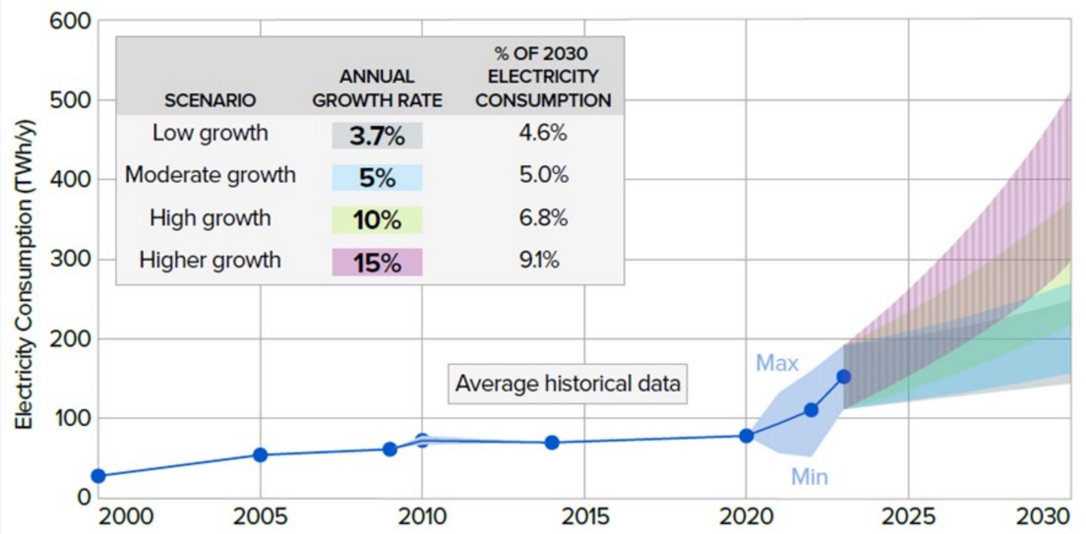
Box 4-3 | Solutions to issues arising from increased electricity demand at data centres, etc.

The electricity demand at data centres in the United States is expected to increase significantly in the future with the spread of generative artificial intelligence [AI] (AI that automatically generates content). In particular, with the release of OpenAI's ChatGPT in November 2022, the use of AI technology is expanding rapidly, which will greatly affect electricity consumption. For example, while a single Google search consumes 0.3 Wh of electricity, a single inquiry to ChatGPT consumes 2.9 Wh, about 10 times as much. Thus, the spread of AI-based services will cause electricity demand in data centres to continue to increase, but the extent of the increase remains uncertain.

In a report released in May 2024, the Electric Power Research Institute (EPRI) in the United States estimated the share of data centre electricity consumption in 2030 under four growth scenarios. The low growth scenario assumes an annual growth rate in data centre electricity consumption of 3.7%, the moderate growth scenario 5.0%, the high growth scenario 10% and the higher growth scenario 15%, with the share of electricity consumption under each scenario increasing to 4.6% for the low growth, 5.0% for the moderate growth, 6.8% for the high growth and 9.1% for the higher growth scenario. In addition, a January 2023 McKinsey & Company's report projected that annual electricity consumption growth in data centres in the United States will reach about 10% through 2030. As such, advances in AI technology are expected to accelerate electricity demand in data centres, which in the future will occupy an important position in overall energy consumption in the United States.

Data centre demand in the United States is concentrated in certain regions, and this uneven distribution has a significant impact on the amount of electricity consumed by each state. In particular, the proportion of electricity consumption by data centres varies widely from state to state. EPRI estimates that approximately 80% of the country's total data centre electricity consumption in 2030 will be concentrated in 15 specific states, including Virginia, Texas and California. In particular, Virginia's data centre consumption is prominent, reaching 33.9 TWh in 2023. This is significantly higher than the next largest state, Texas, at 21.8 TWh and the third largest, California, at 9.3 TWh. In 2030, Virginia's data centre electricity consumption is projected to account for 31% of the state's total electricity consumption, while Texas's is expected to reach about 6%.

Figure 4-23 | Projection of data centre electricity consumption in the United States [2023–2030]



Source: Electric Power Research Institute (2024) "Powering Intelligence: Analyzing Artificial Intelligence and Data Center Energy Consumption". Retrieved on 2 September 2024, from https://restservice.epri.com/publicdownload/000000003002028905/0/Product

The concentration of data centres in Northern Virginia, particularly in the area known as 'Data Centre Alley', is attributed to several historical and geographic factors. First, the world's first network connection point, Metropolitan Area Exchange, East (MAE-East), was established there in the early 1990s. Through this point, internet traffic from around the world started flowing, leading to the concentration of data centres.

Another major factor was the development of fibre optic cables and electricity infrastructure when AOL, a major Internet service provider, established its base in Virginia in the 1990s. In addition, the introduction of tax incentives for data centres in Virginia in 2009 and lower electricity prices than the United States average also encouraged the concentration of data centres. The concentration of data centres in certain states, including Virginia, will continue to be a major factor affecting energy consumption in the United States.

The issue of increased electricity demand due to the deployment of data centres is extremely important in future energy policies and electricity infrastructure planning. In particular, the main issues that need to be considered to meet the increasing electricity demand include ensuring supply capacity, procuring thermal fuel/securing baseload power sources and optimising the electricity system.

Figure 4-24 | Issues arising from increased electricity demand at data centres, etc. and their countermeasures

Issue	Challenge	Countermeasure
➢ Newly introducing power sources need more time than establishing demand facilities	➢ Ensuring supply capacity	➢ Introducing systems that promote power source introduction ➢ Owning and operating backup power sources by demand facilities
➢ Need for thermal power generation to compensate for the intermittency of renewables power generation ➢ Difficulty in procuring fossil fuels, risk of price hikes	➢ Procuring thermal fuel ➢ Securing baseload power sources	➢ Including a fuel security clause in PPA ➢ Developing geothermal and nuclear power sources
➢ Demand facilities being built in concentrated areas ➢ Insufficient transmission and distribution capacities ➢ Increased cost for grid enhancement	➢ Optimising power systems	➢ Publicising the welcome zones ➢ Promoting co-located loads ➢ Using dynamic line rating

First, the challenge is to secure sufficient supply capacity in the short term, given that it is uncertain how quickly electricity demand from data centres and other sources will grow in the future. Generally, the construction period for power generation facilities is longer than that for data centres. Therefore, there is concern that if data centre demand increases rapidly, there will be a growing risk of supply shortages over the medium to long-term. In Japan, although mechanisms are in place to secure supply capacity for a certain period of time in advance, such as the capacity market system and the long-term decarbonised power source auction system, securing supply capacity may be difficult if the timing of these systems does not coincide with the increase in demand from data centres. The capacity market system has a mechanism that allows additional auctions to be conducted one year in advance of the target period, making it possible to secure additional supply capacity in the short term if necessary. However, the limited supply capacity that can be secured in the short term may not be enough to fundamentally solve a supply shortage.

Therefore, it is necessary to have a system that ensures supply capacity so as to respond quickly to increased demand. Specifically, capacity markets and capacity addition auctions could be introduced, but as these alone would be insufficient, there is a need for systems to promote the construction of new power sources (such as Japan's long-term decarbonised power source auction and the long-term, low-interest loan programme in Texas, United States) and systems to maintain idle power sources as reserves (Japan's reserve power source system). It is also important for demand facilities to own backup generation equipment and use them as a demand response resource; one approach for this purpose might be widely sharing best practices. Furthermore, a mechanism could be put in place to give grid connection priority to companies that have signed long-term power purchase agreements (PPAs) with power generation companies.

Next, procuring thermal fuel and securing baseload power sources is another important issue. Data centres have a baseload that requires constant, stable electricity consumption. With the rapid increase in renewable power generation such as solar photovoltaic and wind power, natural gas-fired power generation may be required to compensate for the intermittency of these sources. Relying on natural gas-fired power generation necessitates stable procurement of natural gas; if any problem with the fuel supply occurs, it could seriously impact electricity supply. In particular, if international fuel market fluctuations or supply chain problems arise, rising fuel prices and supply shortages would increase risks to electricity supply. Furthermore, alongside the progress of global decarbonisation, the risk of supply-demand tightening for natural gas cannot be ignored.

Therefore, to mitigate these risks, it is important to include long-term provisions on fuel procurement in the PPA. There is also a need to consider developing clean base power sources such as geothermal power generation, as well as introducing new nuclear power generation technologies such as small modular reactors (SMRs).

Lastly, optimising the power system should also be addressed. If data centres are built in concentrated areas, power transmission and distribution capacities in those areas will be insufficient, making it necessary to enhance the grid. Because of the high cost and lengthy time required to upgrade the transmission system, it may sometimes be difficult to keep pace with the plans for data centres. For example, in the state of Virginia, United States, a rapid increase in data centre connections caused power supply constraints, resulting in a temporary halt of new connections. To avoid such a situation, it is necessary to expand the power transmission network as well as accurately forecast the electricity demand in each region in advance and enhance the grid at the appropriate timing. In addition, the costs of enhancing the power transmission system may be concentrated on local consumers, which could result in higher electricity bills and economic impacts on local residents.

Therefore, it is important to locate demand facilities close to power sources and to select areas with sufficient transmission capacity (welcome zones). It is also necessary to actively coordinate with power transmission and distribution companies to suppress electricity rates and avoid unnecessary grid enhancement. An effective measure would be for transmission companies to disclose data on transmission availability and promote appropriate siting for demand facilities. Also, when connecting a demand facility to the grid in a region with insufficient transmission capacity, giving priority to facilities willing to bear the grid enhancement costs should be considered. Furthermore, promoting ‘co-located loads’, which receive electricity directly from a power source, is important as one way to curb grid enhancement. It is a prerequisite, however, that the impact of these efforts on the power system be carefully examined, and that arrangements regarding the burden of grid operation costs be made. Japan is also promoting the use of dynamic line rating (dynamically optimising transmission capacity according to weather conditions), which deserves attention as a way to help expand transmission capacity.

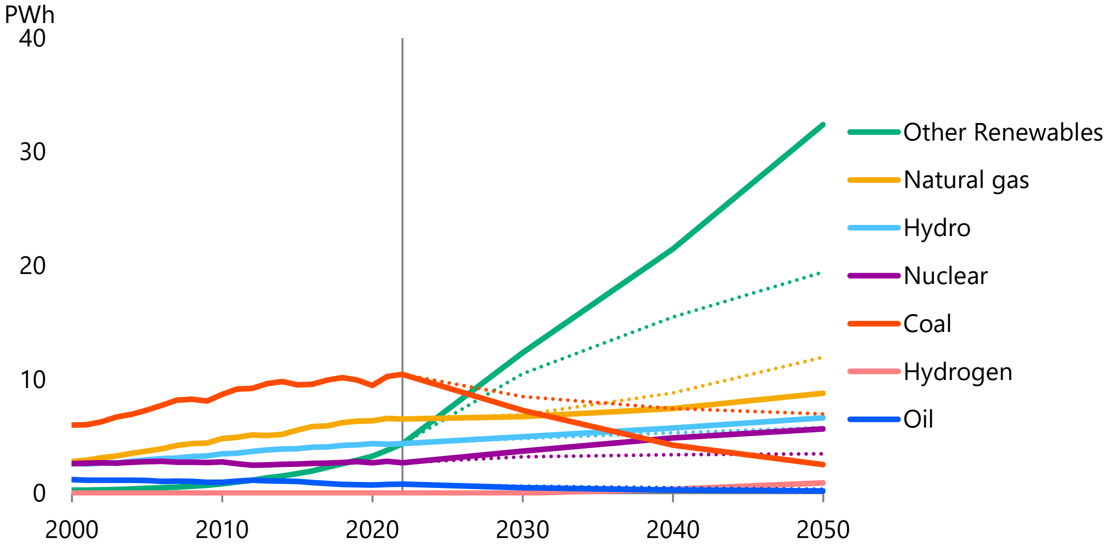
While the above mainly focuses on measures on the supply and grid sides, it goes without saying that the demand side, such as data centres, should also take measures to conserve energy.

Power generation mix

Electricity generated in 2050 will reach 57 091 TWh, approximately double the level in 2022. This demand level is 9 134 TWh higher than in the Reference Scenario, and the increase is due to the progress of electrification, which has increased the share of electricity in final demand by 10 percentage points from 30% in the Reference Scenario, as well as additional demand for hydrogen production. While energy efficiency efforts are progressing in the world where climate change measures are being implemented, the impact of increased electricity demand from electrification and hydrogen production will be more significant, further boosting the required amount of power generation. Although there is uncertainty about how global climate change measures will progress, the electricity generated in 2050 under either scenario will be 1.6 to 2 times greater than the current level, suggesting that it will be essential to ensure a reasonable supply capacity for the future energy supply.

The power generation mix will greatly change from the current one. Regarding coal, as Advanced Economies take the lead in promoting policies to phase out it, coal-fired power generation will decline substantially from the present to about a quarter of the current level in 2050 (Figure 4-25). In contrast, renewables including solar photovoltaics, wind and biomass will become the largest power source. Variable renewables will account for 53% of total electricity generated, making the handling of variable output a key challenge in each region. In this context, as a dispatch power source to substitute for coal- and natural gas-fired power plants, thermal power generation with CCS will be introduced in areas where storage potential for CCS exists, whereas hydrogen-fired power generation will be introduced in earnest from around 2040 in areas where there is no such potential. In addition, storage batteries for both grid and consumer use will rapidly spread, contributing to the adjustment of the balance between electricity supply and demand.

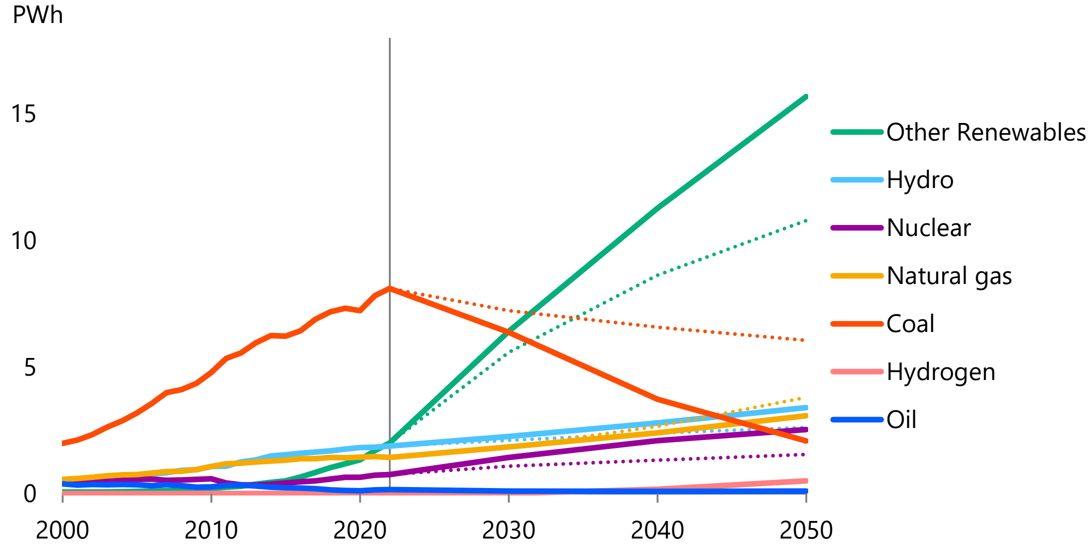
Figure 4-25 | Global electricity generated [Advanced Technologies Scenario]



Note: Dotted lines represent the Reference Scenario.

In Asia, coal, currently the largest power source, will similarly decline, yielding its position as the largest power source to renewables (other than hydro) by around 2030 (Figure 4-26). This decline will be seen in Advanced Economies such as Japan and Korea. In Emerging and Developing Economies a certain number of coal-fired power plants will be constructed. Needless to say, ensuring more efficient coal-fired power generation and air pollution countermeasures is important, and it is also desirable to prepare for reducing CO_2 emissions in the future by adopting CCS and co-firing of hydrogen, ammonia and biomass. The introduction of renewables, which has accelerated in recent years, will increase even faster from 2030, particularly in China and India. As these economies sustain growth, their challenge will be to harmonise renewable energy expansion with affordable and stable electricity supply. It is necessary to consider all power generation options, not only variable renewable energies but also other renewables such as hydro, geothermal, nuclear and emissions-controlled thermal power, in order to meet the strong growth in demand.

Figure 4-26 | Asia's electricity generated [Advanced Technologies Scenario]



Note: Dotted lines represent the Reference Scenario.

Natural gas-fired power generation will increase steadily until around 2040, serving as a promising regulator for fluctuations in renewable energy output. In addition, hydrogen-fired power generation will be introduced in earnest through the 2050s and will support supply-demand adjustment as with natural gas.

Crude oil production

In the Advanced Technologies Scenario, oil demand growth will be suppressed due to rapid progress in the electrification of automobiles and other fuel switching measures in final energy consumption sectors, as well as further progress in energy efficiency. Oil demand will peak by 2030, and the demand will be 56.0 million barrels per day (Mb/d) in 2050, 46% less than in the Reference Scenario. This decline in demand will lead to lower production in all regions. However, the Organization of the Petroleum Exporting Countries (OPEC) countries in the Middle East, which are more cost competitive, will maintain production at 25.3 Mb/d in 2050. As a result, OPEC's market share will increase slightly from the Reference Scenario, reaching 44% in 2050.

Table 4-6 | Crude oil production [Advanced Technologies Scenario]

(Mb/d)

	2022	2030	2040	2050	2022-2050	
					Changes	CAGR
Crude oil production	95.4	90.8	74.0	56.1	39.3	1.9%
OPEC	35.0	34.0	30.1	25.3	-9.8	-1.2%
Middle East	28.3	27.5	25.0	21.4	-6.9	-1.0%
Others	6.8	6.5	5.2	3.9	-2.9	-2.0%
Non-OPEC	60.3	56.8	43.8	30.8	-29.5	-2.4%
North America	22.4	23.9	18.1	13.3	-9.1	-1.8%
Latin America	8.2	7.8	7.4	5.5	-2.6	-1.4%
Europe and Eurasia	17.7	14.5	10.5	6.4	-11.3	-3.6%
Middle East	2.9	3.1	3.0	2.7	-0.2	-0.3%
Africa	1.6	1.3	1.1	0.8	-0.8	-2.4%
Asia and Oceania	7.6	6.2	3.8	2.1	-5.5	-4.5%
Processing gains	2.3	2.4	2.1	1.7	-0.6	-1.1%
Oil supply	97.7	93.2	76.0	57.8	39.9	1.9%

Note: Crude oil includes natural gas liquid (NGL).

Natural gas supply

As improvements in energy efficiency and other energy utilisation technologies reduce natural gas consumption in the Advanced Technologies Scenario, natural gas production will be 16% lower than in the Reference Scenario in 2040 and 29% lower in 2050. However, better management of GHG emissions may lead to a greater proportion of greener natural gas production capacity.

There will be a wide production gap between the Reference and Advanced Technologies Scenarios in North America which has a large production scale. The region's natural gas production in 2050 in the Advanced Technologies Scenario will be 30%–40% less than in the Reference Scenario. Production in non-OECD Europe, including Russia, will also be 20% lower than in the Reference Scenario. In the Middle East, Qatar and Iran will see large increases in production even in the Advanced Technologies Scenario, but production in the region in 2050 will be 10%–20% lower than in the Reference Scenario.

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

Table 4-7 | Natural gas production [Advanced Technologies Scenario]

(Bcm)

	2022	2030	2040	2050	2022-2050	
					Changes	CAGR
World	4 210	4 205	4 040	3 857	353	0.3%
North America and Mexico	1 272	1 278	1 195	943	-329	-1.1%
Latin America excluding Mexico	161	160	144	140	-21	-0.5%
Europe	214	96	71	63	-151	-4.3%
Europe/Central Asia	914	795	725	724	-190	-0.8%
Russia	689	545	474	465	-224	-1.4%
Middle East	709	736	743	855	146	0.7%
Africa	254	316	405	411	157	1.7%
Asia	521	634	571	536	15	0.1%
China	220	230	160	87	-133	-3.3%
India	34	54	42	23	-11	-1.4%
ASEAN	196	215	245	272	76	1.2%
Oceania	166	190	185	185	19	0.4%

Net natural gas-importing regions will reduce their imports by 30%–80% from the Reference Scenario in 2050. Among net natural gas-exporting regions, non-OECD Europe including Russia will cut exports slightly while the Middle East will reduce its net exports (excluding intra-regional trade) by about 60% from the Reference Scenario. In North America, production will be lower than in the Reference Scenario, but this is outweighed by the decline in demand. Despite declining international prices, net exports in 2050 will be on par with the Reference Scenario.

In the Advanced Technologies Scenario, changes in natural gas trade will depend on progress in relevant companies' cooperation and efforts to rationalise and optimise the trading of natural gas and LNG. Such changes will also depend on progress in support policies and regulations (monitoring and regulating fuel efficiency and emissions for marine transportation). For LNG transportation in particular, relevant parties will be able to increase transportation with the same footprint through cooperation in optimisation including changing destinations and swapping cargoes.

Policy and securing investment issues leading to stabilisation of the LNG market and clean energy measures

The importance of natural gas and LNG was recognised at the Group of Seven (G7) Ministers' Meeting on Climate, Energy and Environment in April 2023 and at the Summit meeting in the following May. This principle was maintained at the G7 Ministers' Meeting and the Summit Meeting in 2024. It will be important to establish standards for LNG that are 'abated', i.e. acceptable for transitions. In this context, the G7 ministerial meetings and the LNG Producer-Consumer Conference emphasised the importance of strengthening methane and GHG emission measurement, international standardisation and international cooperation in emission reduction measures.

Table 4-8 | Challenges to clean LNG production

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

From March 2022, with the increase in procurement commitments based on long-term contracts in the international LNG market, LNG-related investments and construction activities have increased, especially in the United States and the Middle East. These planned LNG projects are increasingly adopting carbon capture and storage (CCS) to reduce GHG emissions and electric drivers powered by renewable energy. In the Advanced Technologies Scenario, these measures are expected to be increasingly incorporated in both new LNG projects and existing LNG production facilities. Such incorporation will highlight the economic and environmental advantages of LNG projects, leading to the development of various financial instruments that meet the financing needs of LNG project development.

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

These developments will be supported by government policies and concrete measures that clearly define the important role of LNG and natural gas during the transition period and beyond, while establishing clear definitions of clean LNG and natural gas to fulfil this role.

Table 4-9 | Long-term challenges to stabilising the LNG market

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

Coal supply

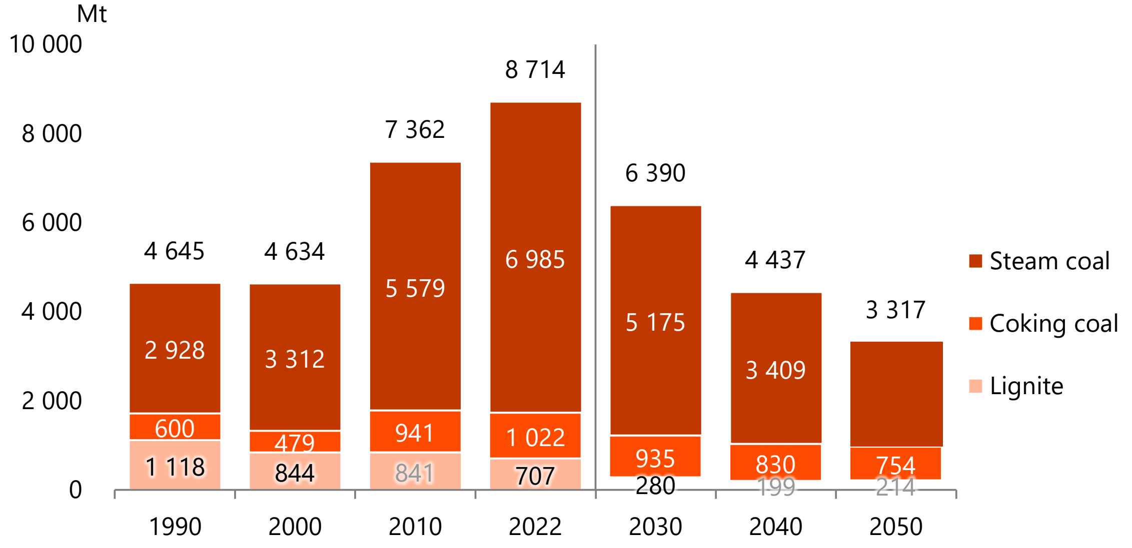
As efforts to replace coal with other fuels and increase the efficiency of coal use are enhanced toward carbon neutrality, initiatives to minimise coal use will progress in various sectors including power generation, steelmaking and other industries. Coal's share in the power generation mix will decline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

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

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

Consequently, coal production will decrease from 8 714 million tonnes (Mt) in 2022 to 3 317 Mt in 2050 (Figure 4-27). By coal type, steam coal production will decline from 6 985 Mt in 2022 to 2 349 Mt in 2050, coking coal production from 1 022 Mt to 754 Mt and lignite production from 707 Mt to 214 Mt. Compared to the Reference Scenario, overall coal production will decrease by 2 684 Mt in 2050. By coal type, steam coal will decrease by 2 486 Mt, coking coal by 134 Mt and lignite by 64 Mt.

Figure 4-27 | Global coal production [Advanced Technologies Scenario]



Most countries will reduce coal production partly due to falling demand. For steam coal in particular, production in 2050 will be significantly reduced compared to 2022 due to decreased domestic demand, with the United States seeing a 352 Mt decrease to 39 Mt, and China seeing a 3 235 Mt decrease to 668 Mt. By 2050, India will also see a decrease of 43 Mt in steam coal to 797 Mt, but an increase in coking coal by 47 Mt to 104 Mt due to increased domestic steel demand. In Australia, where exports dominate coal transactions, steam coal production is expected to fall sharply by 144 Mt to 116 Mt, but coking coal will increase by 37 Mt to 197 Mt, showing variation by coal type.

Table 4-10 | Steam coal production [Advanced Technologies Scenario]

(Mt)

	2022	2030	2040	2050	2022-2050	
					Changes	CAGR
World	6 985	5 175	3 409	2 349	4 636	3.8%
North America	456	161	48	43	-413	-8.1%
United States	391	153	43	39	-352	-7.9%
Latin America	67	44	26	20	-47	-4.2%
Colombia	59	37	21	15	-43	-4.7%
OECD Europe	45	11	8	7	-38	-6.6%
Non-OECD Europe/Eurasia	376	274	193	159	-218	-3.0%
Russia	254	168	109	86	-168	-3.8%
Middle East	0	0	0	0	0	-0.2%
Africa	248	195	149	123	-125	-2.5%
South Africa	245	176	128	98	-147	-3.2%
Asia	5 531	4 291	2 836	1 881	-3 651	-3.8%
China	3 903	2 778	1 530	668	-3 235	-6.1%
India	840	848	794	797	-43	-0.2%
Indonesia	682	565	421	322	-360	-2.6%
Oceania	261	199	148	116	-145	-2.8%
Australia	260	198	148	116	-144	-2.8%

Table 4-11 | Coking coal production [Advanced Technologies Scenario]

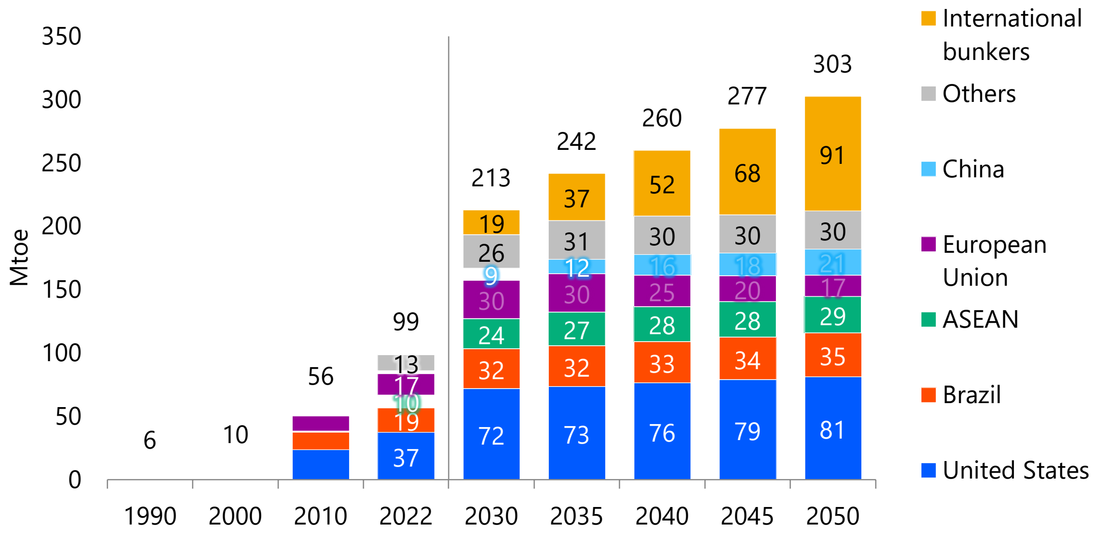
(Mt)

	2022	2030	2040	2050	2022-2050	
					Changes	CAGR
World	1 022	935	830	754	268	1.1%
North America	77	64	62	61	-17	-0.9%
United States	53	46	44	43	-10	-0.8%
Latin America	10	12	12	13	3	0.9%
Colombia	9	11	12	13	4	1.4%
OECD Europe	14	14	15	15	1	0.2%
Non-OECD Europe/Eurasia	109	107	94	86	-23	-0.8%
Russia	105	100	88	80	-25	-1.0%
Middle East	2	2	2	2	0	-0.1%
Africa	8	15	18	21	14	3.7%
Mozambique	5	11	14	17	13	4.9%
Asia	641	547	441	358	-283	-2.1%
China	554	451	330	228	-326	-3.1%
India	57	66	83	104	47	2.2%
Mongolia	24	24	22	19	-5	-0.8%
Oceania	161	175	185	198	37	0.7%
Australia	160	174	184	197	37	0.7%

Biofuels for transport

In the Advanced Technologies Scenario, although electrification of the road sector will progress, demand for biofuels will increase beyond the Reference Scenario due to expanded production of next-generation biofuels and the spread of flexible-fuel vehicles (FFVs) that can run on high biofuel blends (Figure 4-27). In 2050, the share of biofuels in total road sector energy demand will be approximately 12%. In the aviation sector, the use of bio-based sustainable aviation fuels (SAF) will increase significantly, reaching 25% of global aviation fuel in 2050.

Figure 4-28 | Biofuel consumption for transportation [Advanced Technologies Scenario]



5. Carbon dioxide emissions

5.1 Recent trends: Accelerated trading of advanced carbon removal credits

IEEJ Outlook 2025 newly reflects the introduction of negative emission technologies (NETs) in the Advanced Technologies Scenario. Therefore, we will focus here on the latest developments in voluntary credits derived from carbon dioxide removal (CDR), such as direct air capture (DAC) with carbon capture and storage (CCS) (DACCS) and bioenergy with CCS (BECCS)[25].

According to CDR[26, 27], which provides information on the CDR credit market, purchases of advanced CDR credits (including DACCS, BECCS and biochar, excluding traditional CDRs such as afforestation and forest management), reached 4.52 Mt in 2023, a 7.3-fold increase from 0.62 Mt in 2022. By the second quarter of 2024, purchases had already reached 5.33 Mt, exceeding the total for 2023. More recently, on 9 July 2024, 1PointFive announced the signing of an offtake agreement for DAC credits with Microsoft[28]. The trading volume was 500 kt over six years, the largest ever for DAC credits. According to CDR, the weighted average credit price for advanced CDR is $488/t and $715/t for DAC (both for 2023), which are extremely high compared to the overall average price for voluntary credits (less than $10/t[29]). Nevertheless, purchase agreements have been made before the actual issuance of credits, which indicates the high level of interest.

The market environment has also seen developments. On 27 June 2024, Verra, the world's largest voluntary credit issuer, announced a new methodology for CCS[30]. This methodology was developed in collaboration with the CCS+ Initiative, which aims to establish an international framework for calculating CO_2 reductions achieved through CCS. It encompasses multiple methodologies for each module of capture, transport and storage, and by combining these methodologies, CO_2 removal through DACCS and BECCS can also be represented[31]. Additionally, on 10 April 2024, the European Parliament adopted a 'regulation establishing a Union certification framework for permanent carbon removals, carbon farming and carbon storage in products'[32, 33]. Certification schemes that comply with the quality standards set by the European Union and are approved by third-party verification bodies will be able to issue European Union-certified carbon

[25] In this report, the terms 'negative emission technologies' (NETs) and 'CDRs' are synonymous, since the focus is on carbon dioxide. These are covered in detail in IEEJ Outlook 2024, "7. Growing importance of negative emissions technologies".
[26] CDR.fyi, "Trending on Track? - CDR.fyi 2023 Year in Review", 7 February 2024. https://www.cdr.fyi/blog/2023-year-in-review.
[27] CDR.fyi, "2024 Q2 Durable CDR Market Update - Microsoft: Market-Maker", 31 July 2024. https://www.cdr.fyi/blog/2024-q2-durable-cdr-market-update-microsoft-market-maker.
[28] 1PointFive, "1PointFive Announces Agreement to Sell 500,000 Metric Tons of Direct Air Capture Carbon Removal Credits to Microsoft", 9 July 2024. https://www.1pointfive.com/news/1pointfive-and-microsoft-announce-agreement-for-direct-air-capture-cdr-credits.
[29] World Bank (2024), "State and Trends of Carbon Pricing 2024". http://hdl.handle.net/10986/41544.
[30] Verra, "Verra Releases New Carbon Capture and Storage Methodology", 27 June 2024. https://verra.org/verra-releases-new-carbon-capture-and-storage-methodology/.
[31] The methodology for each module is under development at the time of writing.
[32] European Commission, "Carbon Removals and Carbon Farming". https://climate.ec.europa.eu/eu-action/carbon-removals-and-carbon-farming_en#eu-carbon-removals-and-carbon-farming-certification-crcf-regulation. Accessed 16 August 2024.
[33] Formal adoption by the Council of the European Union has yet to be completed at the time of writing.

removal credits. These are all initiatives within a voluntary framework, but they could have an impact on the creation of international rules for CDR.

On the other hand, the long-term CDR required to achieve net zero is estimated to be on the order of 1 Gt. Sustained incentives for CO_2 removal will be key to the future growth of the advanced CDR industry, but so far, support sources based on voluntary credits have been localised. Advanced CDR credits are supported by a few companies, including major tech companies such as Microsoft, which aims to procure more than 5 Mt of CDR credits (including conventional credits)[34] per year with the aim of becoming carbon negative by 2030, and airlines that will face mandatory compliance with the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) from 2027. Additionally, projects have been concentrated in North America and Europe[35].

The Corporate Net-Zero Standard[36] of the Science-Based Targeting Initiative (SBTi), the primary framework for voluntary corporate climate targets, permits the use of removal credits only to neutralise residual emissions (less than 10% of base year emissions) after reduction targets have been achieved. However, it does not approve credit use during the process of achieving reduction targets, which hampers short to medium-term investment incentives for the advanced CDR industry. The SBTi is currently considering whether to allow reductions in Scope 3 emission reductions, with a draft proposal expected to be released at the end of 2024[37].

While the supply of advanced CDR credits has been dominated by emerging companies, which are growing in number, a shakeout has already begun, as evidenced by the acquisition by Zero Carbon Systems of Global Thermostat[38], which developed the DAC project, and the closure of Running Tide[39], which developed the ocean carbon removal project. It is hoped that an environment can be created in which advanced CDR can overcome the ‘valley of death’ of innovation, reduce high removal costs and lead to further expansion. Although government subsidies and regulatory measures (such as carbon pricing schemes) will be important in the future, private sector support will continue to play a crucial role in establishing the initial market.

5.2 Outlook for emissions

As shown in Figure 5-1, global CO_2 emissions[40] in the Reference Scenario will peak by 2025. After peaking, emissions will decline gradually until around 2030, then remain relatively stable until

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[34] Microsoft, “Carbon dioxide removal”. https://www.microsoft.com/en-us/corporate-responsibility/sustainability/carbon-removal-program. Accessed 16 August 2024.

[35] Smith et al. (2024). “The State of Carbon Dioxide Removal 2024 – 2nd Edition”. https://socdr-portal.apps.ece.iiasa.ac.at/.

[36] SBTi (2024). “SBTi CORPORATE NET-ZERO STANDARD Version 1.2 March 2024”. https://sciencebasedtargets.org/resources/files/Net-Zero-Standard.pdf.

[37] SBTi, “SBTi releases technical publications in an early step in the Corporate Net-Zero Standard review”, 30 July 2024. https://sciencebasedtargets.org/news/sbti-releases-technical-publications-in-an-early-step-in-the-corporate-net-zero-standard-review.

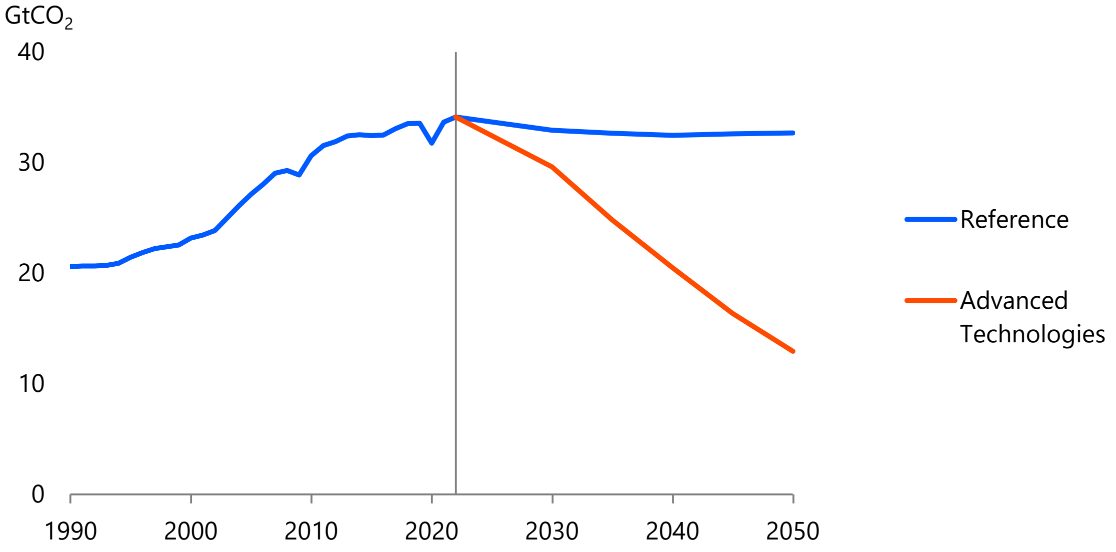
[38] Global Thermostat, “Zero Carbon Systems acquires Global Thermostat and its best-in-class technology to capture carbon dioxide from the air”, 22 May 2024. https://www.globalthermostat.com/news-and-updates/zero-carbon-systems-acquires-global-thermostat-and-its-best-in-class-technology-to-capture-carbon-dioxide-from-the-air.

[39] Portland Press Herald, “Portland startup that became global leader in capturing carbon shuts down, lays off all staff”, 15 June 2024. https://www.pressherald.com/2024/06/15/portland-startup-that-became-global-leader-in-capturing-carbon-shuts-down-lays-off-all-staff/.

[40] Energy-related CO_2 emissions minus removals by DACCS. The same applies throughout this chapter.

2050. In contrast, the Advanced Technologies Scenario projects significant emissions reductions: 12% below 2019 levels by 2030, 26% by 2035 and 61% by 2050. However, these reductions fall substantially short of the greenhouse gas emission reduction targets consistent with the 1.5°C pathway outlined in the global stocktake at COP28, which calls for a 60% reduction below 2019 levels by 2035 and carbon neutrality by 2050.

Figure 5-1 | Global CO_2 emissions

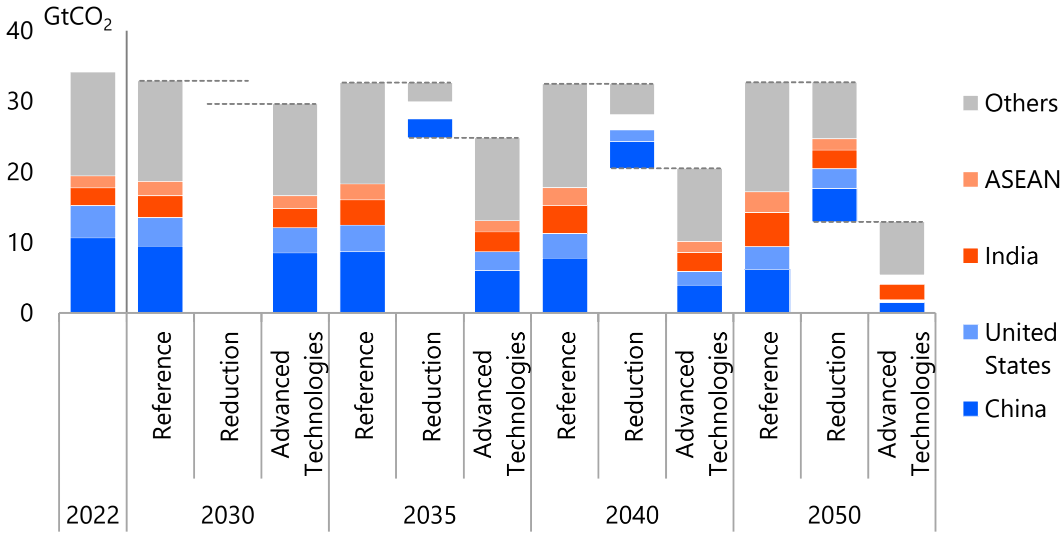


The share of emissions by country or region will change significantly (Figure 5-2, top). In 2022, China and the United States collectively accounted for 45% of global CO_2 emissions. In the Reference Scenario, while the total volume remains broadly unchanged from 2030, the combined share of China and the United States gradually decreases to 38% in 2035 and 29% in 2050. The difference between the Reference Scenario and the Advanced Technologies Scenario indicates that after 2030, China and the United States together will contribute 40%–50% of the total emission reductions. Consequently, the shift in emission shares will be more pronounced in the Advanced Technologies Scenario, with China and the United States accounting for just 14% of global emissions by 2050, while the combined share of India and the Association of Southeast Asian Nations (ASEAN) increases to 27%.

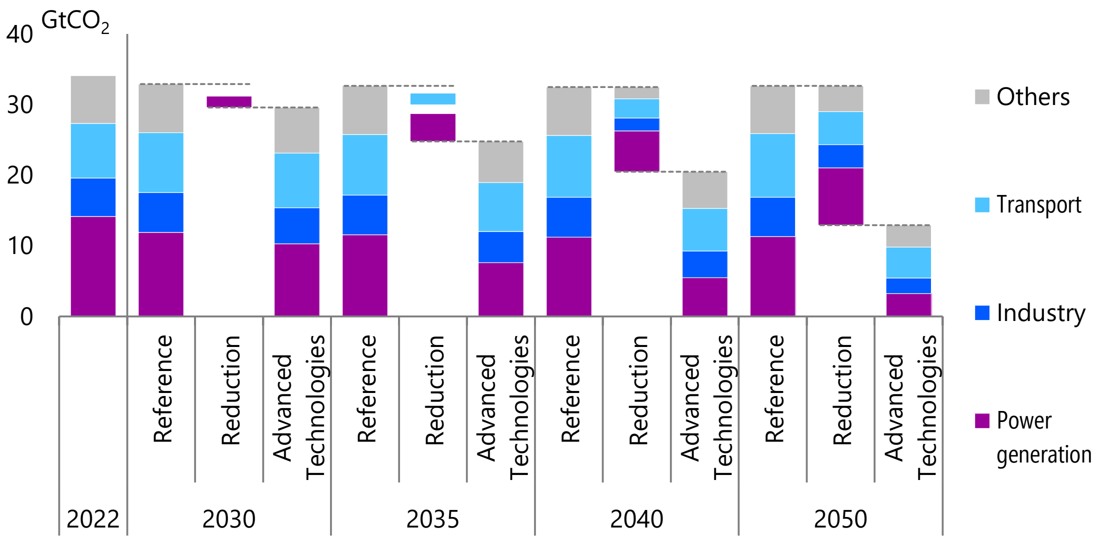
By sector (Figure 5-2, bottom) in the Reference Scenario, the emissions share of the power generation sector will decline from 42% in 2022 to 36% in 2030, with minimal change thereafter. In the Advanced Technologies Scenario, the power generation sector undergoes significant decarbonisation (contributing 40%–50% of reduction after 2030), resulting in a continuous decrease in the sector's emissions share to 25% by 2050. Meanwhile, the transport sector's relative share will increase.

Figure 5-2 | Global CO_2 emissions and reduction

By country/region



By sector



Note: In the figure by sector, removals by BECCS and DACCS are excluded from power generation and others, respectively.

In summary, the Advanced Technologies Scenario identifies China and the United States as the key countries and the power generation sector as the primary contributor to emission reductions compared to the Reference Scenario. Additionally, negative emission technologies (NETs), specifically DACCS and BECCS, have been newly incorporated into the Advanced Technologies Scenario and play a significant role. By 2050, these technologies are projected to capture and store nearly 1 Gt (964 Mt) of carbon, representing 4.9% of the 20 Gt emission reduction from the Reference Scenario[41].

[41] For details on assumptions regarding CCS, please refer to 'Carbon capture and storage' in 4.1 Major measures.

To reduce CO_2 emissions while enjoying economic growth, the rate of reduction in CO_2 emissions per gross domestic product (GDP) must exceed the GDP growth rate (decoupling). Reduction in CO_2 emissions per GDP can be decomposed into a reduction in primary energy supply per GDP and a reduction in CO_2 emissions per primary energy supply. Figure 5-3 shows the changes in each intensity since 1990 for China, India and ASEAN[42].

In China, a significant reduction in primary energy supply per unit of GDP from 1990 to 2000 (roughly halving in a decade) contributed to a reduction in CO_2 emissions per GDP, but little improvement has occurred since 2016. The Reference Scenario projects improvements consistent with long-term trends, while in the Advanced Technologies Scenario, additional reductions are modest. The most substantial difference between the two scenarios is in CO_2 emissions per primary energy supply, with the reduction rate from 2022 to 2050 being 35% in the Reference Scenario and 79% in the Advanced Technologies Scenario—more than double.

India's primary energy supply per GDP has been improving since 1990; however, CO_2 emissions per primary energy supply increased and then stagnated, without beginning the downward trend seen in China. Moreover, since 2020, primary energy supply per GDP has remained almost flat, while CO_2 emissions per primary energy supply have increased, resulting in an overall increase in CO_2 emissions per GDP. In the Reference Scenario, CO_2 emissions per primary energy supply remain roughly constant, meaning that any reduction in CO_2 emissions per GDP depends entirely on reducing primary energy supply per GDP.

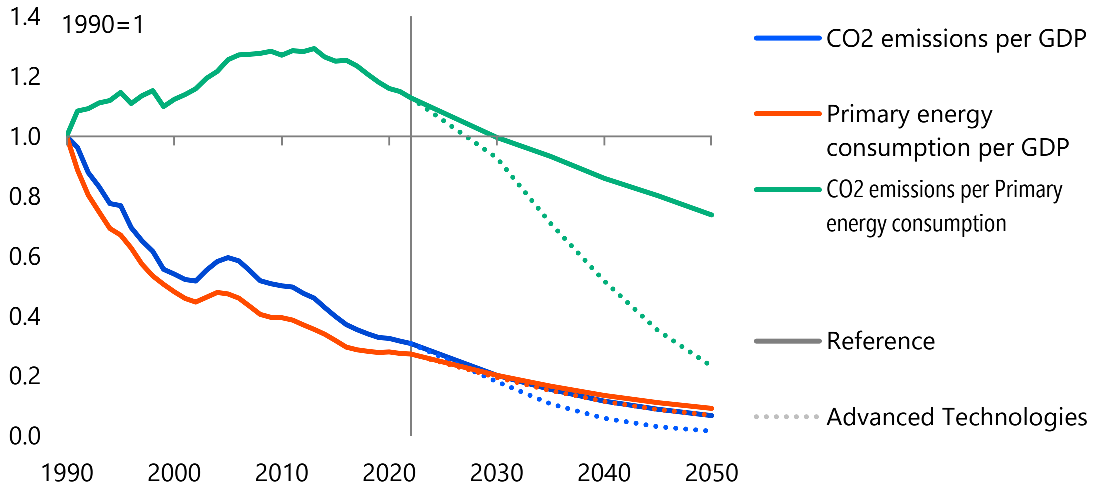
A similar situation can be observed in ASEAN as in India. For ASEAN, primary energy supply per GDP has been stagnant for a longer period than in India, and CO_2 emissions per primary energy supply are expected to reach their highest level since 1990 in 2022, creating even greater challenges for emission reduction.

In summary, in the Reference Scenario, primary energy supply per GDP is projected to improve generally in line with long-term trends. However, recent years have shown stagnation in China, India and ASEAN, suggesting that achieving the improvements projected in the Reference Scenario will require deliberate effort. CO_2 emissions per primary energy supply have peaked in China, whereas those in India and ASEAN have yet to begin declining. These results reflect the economic advantages of fossil fuels such as coal, highlighting the challenges of reducing CO_2 emissions per primary energy supply in Emerging and Developing Economies. This creates a significant divergence between the Reference Scenario and the Advanced Technologies Scenario. For Emerging and Developing Economies, the Advanced Technologies Scenario envisions a two-stage approach: first redirecting primary energy supply per GDP towards a downward trend in the short to medium-term, then achieving substantial improvement in CO_2 emissions per primary energy supply in the medium to long-term.

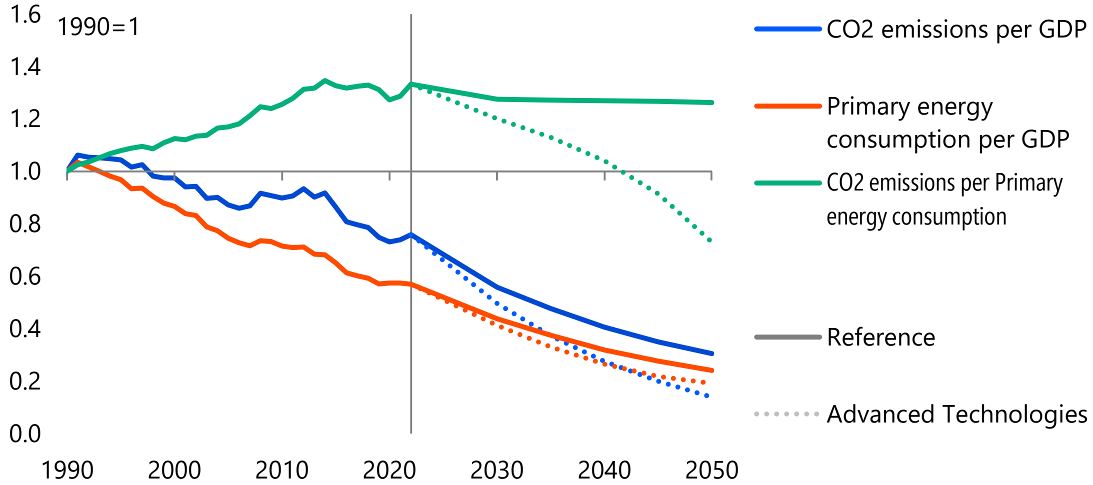
[42] Refer also to Box 4-2 for primary energy supply per GDP. As pointed out in Box 4-2, this indicator reflects not only so-called energy efficiency, but also factors such as changes in the industrial structure and the increase in household appliances due to improved living standards.

Figure 5-3 | Changes in CO_2 emissions per GDP, etc.

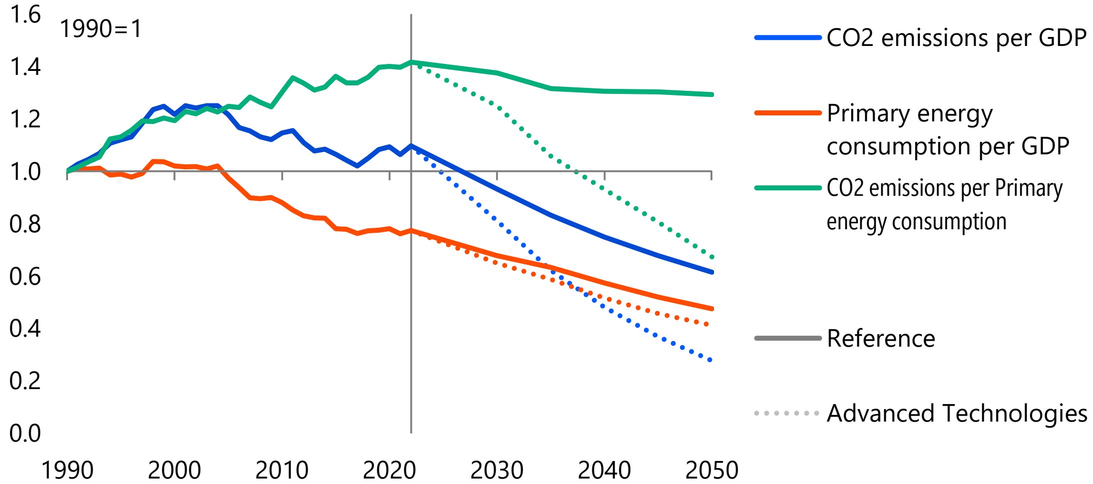
China



India



ASEAN



Box 5-1 | Achievability of 1.5°C target and progress towards NDC

The world is, on average, seeing a temperature rise of 1.5°C. According to observations by the European Union's Copernicus Climate Change Service, the global average temperature rose by more than 1.5°C above pre-industrial levels for 12 consecutive months from July 2023 to June 2024[43]. The El Niño phenomenon also contributed to the high temperatures in 2023, and while a temporary exceedance does not mean that the long-term 1.5°C target under the Paris Agreement will not be achieved, it is clear that stabilising global warming to 1.5°C is becoming increasingly difficult.

Furthermore, as noted in IEEJ Outlook 2024, the 1.5°C target is becoming more stringent, which is also evident from the decrease in the remaining carbon budget. A carbon budget represents the maximum amount of cumulative net anthropogenic CO_2 emissions that would limit global warming to a specific level with a certain probability, and the amount remaining after subtracting past emissions is called the remaining carbon budget. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) Working Group I (WG1) assessed the remaining carbon budget after 2020 to limit the temperature increase to 1.5°C with a 50% probability to be 500 $GtCO_2$.

Meanwhile, the latest research estimates of the remaining carbon budget from 2024 towards 1.5°C to be 200 $GtCO_2$ (Indicators of Global Climate Change [IGCC] 2023)[44] or 275 $GtCO_2$ (Global Carbon Budget [GCB] 2023)[45], which is roughly half the amount from IPCC AR6. The difference from the assessment at the time of IPCC AR6 comes from factors such as approximately 164 $GtCO_2$ emitted over the three-year period from 2020 to 2023 (estimated value for 2023), as well as an upward revision of the net greenhouse effect from non-CO_2 sources (updating a simplified climate model following updates to actual aerosol emissions[46]).

While there is significant uncertainty in estimating the remaining carbon budget[47], the 200 $GtCO_2$ figure represents only about five years' worth of CO_2 emissions at 2023 levels. As shown in Figure 5-4, if emissions are reduced linearly from 2024, the deadline for reaching net zero will be 2034, with an annual reduction of 9.4%. Even in 2020, a year hit by the COVID-19 pandemic, the reduction rate of energy-related CO_2 emissions was 5.7%.

Figure 5-4 also shows a group of CO_2 emission scenarios that are consistent with the 1.5°C target listed in the IPCC AR6 Working Group 3 (WG3) report. However, the scenario group with no or limited overshoot (C1)[48] corresponds to a remaining carbon budget of 500 $GtCO_2$, while the scenario group with high overshoot (C2)[49] is also depicted. Compared to C1, C2 is

[43] Copernicus Climate Change Service, "June 2024 marks 12th month of global temperatures at 1.5°C above pre-industrial levels", 10 July 2024. https://climate.copernicus.eu/june-2024-marks-12th-month-global-temperatures-15degc-above-pre-industrial-levels.

[44] Forster et al., "Indicators of Global Climate Change 2023: annual update of key indicators of the state of the climate system and human influence", ESSD, 16, 2625–2658, 2024. https://essd.copernicus.org/articles/16/2625/2024/.

[45] Friedlingstein et al., "Global Carbon Budget 2023", ESSD, 15, 5301–5369, 2023. https://essd.copernicus.org/articles/15/5301/2023/.

[46] Lamboll et al., "Assessing the size and uncertainty of remaining carbon budgets", Nature Climate Change, 13, 1360–1367, 2023. https://www.nature.com/articles/s41558-023-01848-5.

[47] IPCC AR6 assessed the carbon budget to be ±220 $GtCO_2$ with uncertainty alone for non-CO_2 emission scenarios.

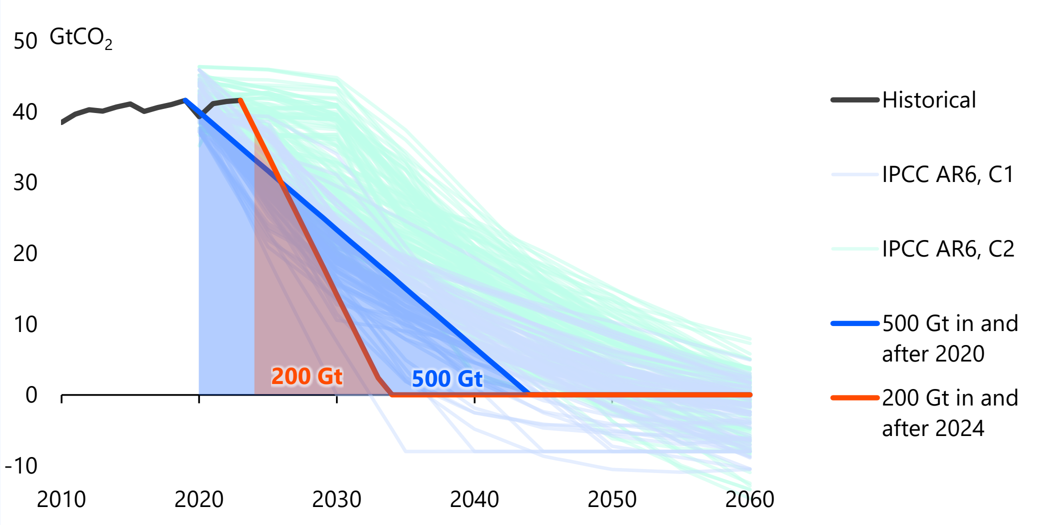
[48] Limited overshoot: 1.5°C exceeded by up to 0.1°C for up to several decades

[49] High overshoot: 1.5°C exceeded by 0.1°C–0.3°C for up to several decades

characterised by a slower pace of emission reductions in the short to medium-term, while CCS and CDR play a greater role in achieving significant reductions in the long-term.

Given the reduction in the remaining carbon budget, it may be difficult for the IPCC to present a scenario equivalent to C1 in the next assessment cycle (AR7), in which case the remaining path to 1.5°C would be a scenario equivalent to C2. At the recent COP28, a global stocktake was implemented for the first time to assess the world's overall progress towards the achievement of the goals of the Paris Agreement. The adopted decision document recognised the necessity of reducing GHG emissions by 43% by 2030 and 60% by 2035 relative to 2019 levels, and CO_2 emissions to net zero by 2050, in order to achieve the 1.5°C target. However, since these reduction targets are based on the C1 assessment at the time of IPCC AR6, under current circumstances, it is considered difficult to achieve 1.5°C with no or limited overshoot, even if these emission reductions are achieved.

Figure 5-4 | CO_2 emission path consistent with the 1.5°C target



Notes: 'Historical' was obtained from Global Carbon Budget 2023[50]. Including emissions from cement production processes, flaring, land use, land use change and forestry sector. 'IPCC AR6, C1' includes 97 scenarios that fall under 'C1: limiting warming to 1.5°C (>50%) with no or limited overshoot', while 'IPCC AR6 C2' includes 131 scenarios that fall under 'C2: returning to 1.5°C (>50%) after a high overshoot'[51].

Progress towards each country's 2030 targets (Nationally Determined Contributions: NDCs) has not been fully on track. Looking at advanced economies that have adopted absolute GHG emission targets, Japan's emissions result is roughly consistent with the target achievement path, while the United States and the European Union are above the target achievement path (Figure 5-5, left). Looking at the decomposition of energy-related CO_2 (the first item on the right of Figure 5-5), energy efficiency (including factors affecting changes in economic structure) has contributed the most to emission reductions since the base year in Japan, the United States and the European Union. It should also be noted that Japan's slower economic growth since the base year compared to the United States and the European Union (average annual GDP growth rate from the base year to 2022 was 1.7% for the United States and 1.6%

[50] Global Carbon Budget, "GCB 2023". https://globalcarbonbudget.org/carbonbudget2023/.
[51] Byers et al., "AR6 Scenarios Database hosted by IIASA", International Institute for Applied Systems Analysis, 2022. https://data.ene.iiasa.ac.at/ar6/#/login?redirect=%2Fworkspaces.

for the European Union, compared to 0.4% for Japan) has contributed significantly to emissions reductions.

For China and India, which have adopted targets for CO_2 or GHG emissions intensity per GDP, their performance changes are both on track to achieve their targets. However, the emissions figures on the left in Figure 5-5 are based on national inventories, and the latest years are somewhat outdated: 2018 for China and 2019 for India. Recently, both China and India have shown a slowdown in the improvement of primary energy and energy-related CO_2 emissions intensity per GDP[52]. In addition, the absolute value of emissions has increased significantly since the base year. Looking at energy-related CO_2 emissions, China has offset about half of the increase in emissions accompanying its economic growth through energy efficiency and new energy sources (renewables, hydrogen, synthetic fuels, etc.), but India saw limited contribution of emission reduction factors, including energy efficiency.

The achievement results of the 2030 target may also be divided (Figure 5-5, items 2 and 3 on the right). Compared with the scenarios in this outlook, China achieves its target even in the Reference Scenario, while the United States falls short of its target even in the Advanced Technologies Scenario. It should be noted, however, that the level of 'ambition' in each country's goals may differ. If the ambition level of the NDC goals is low, it will be easier to achieve the goals. In this regard, it is also necessary to evaluate each country's progress in achieving its goals relative to the ambition level.

Japan, the European Union and India will not reach their targets in the Reference Scenario but achieve or come close to the goals in the Advanced Technologies Scenario. In all countries and regions, new energy sources will play a greater role in the future, but unless energy efficiency contributes at least as much as in the past, achievement of the 2030 goals will be in jeopardy. Furthermore, Japan would not be able to achieve its goal without the contribution of nuclear power.

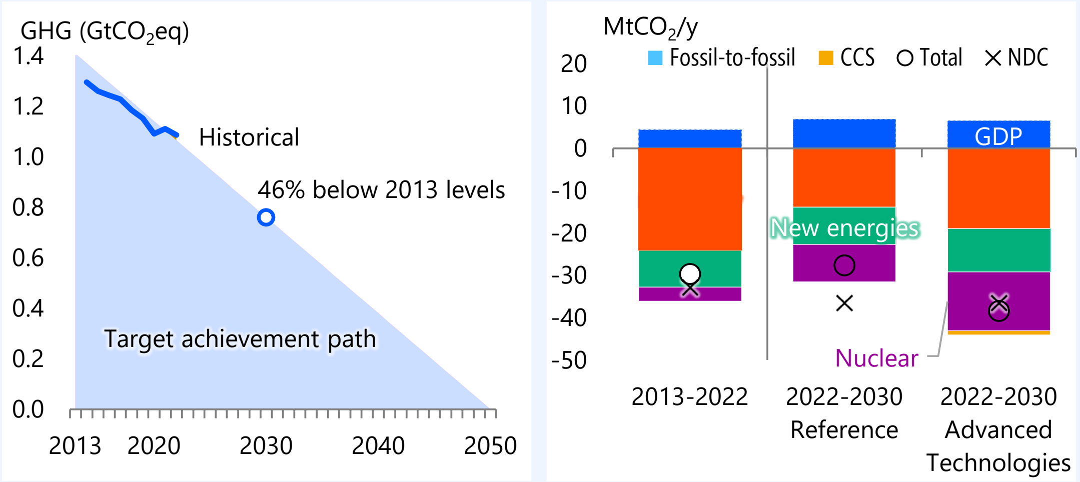
Governments' own projections assess that current policies are insufficient to achieve their medium- to long-term goals. The European Union's latest compilation of GHG emissions projections for its member states[53] assesses that current policies fall 15 percentage points short of the 2030 goal (55% below 1990 levels), and even if additional policies are taken into account, they will still fall 5% points short. These projections fall far short of net zero by 2050. The projections highlight challenges across the European Union, pointing out deep cuts still needed in the buildings and transport sectors, stagnation in emissions reductions in the agriculture sector, and backtracking against targets and declining removals in the land use, land-use change and the forestry (LULUCF) sector.

[52] China is not on track to achieve the intensity targets of its 14th Five-Year Plan (reducing energy consumption and CO_2 emissions per GDP by 13.5% and 18.0%, respectively, by 2025 compared to 2020). (According to the National Bureau of Statistics of China, the actual reduction in CO_2 intensity targets at the end of 2023 was approximately 4.6% below the 2020 level). Meanwhile, India's energy-related CO_2 emissions per GDP increased in 2021 and 2022 year on year.

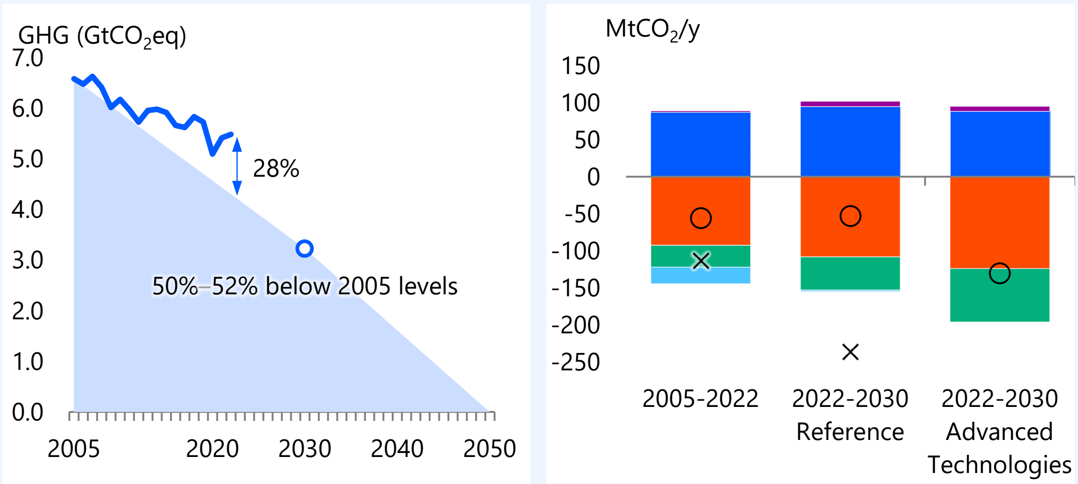
[53] European Commission (2023), "Progress Report 2023 Climate Action", https://climate.ec.europa.eu/document/download/60a04592-cf1f-4e31-865b-2b5b51b9d09f_en.

Figure 5-5 | Progress towards NDCs of major advanced economies and decomposition of reduction factors of energy-related CO_2 emissions

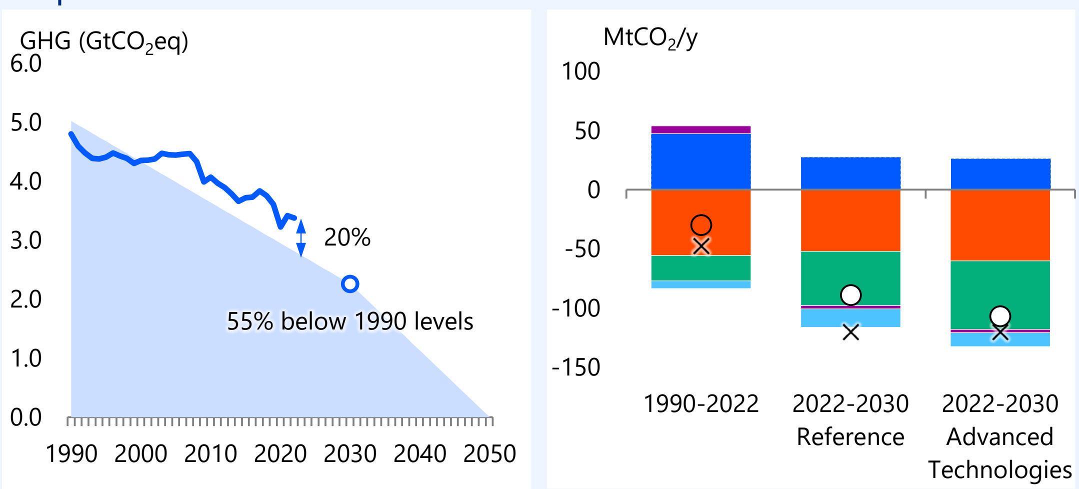
Japan



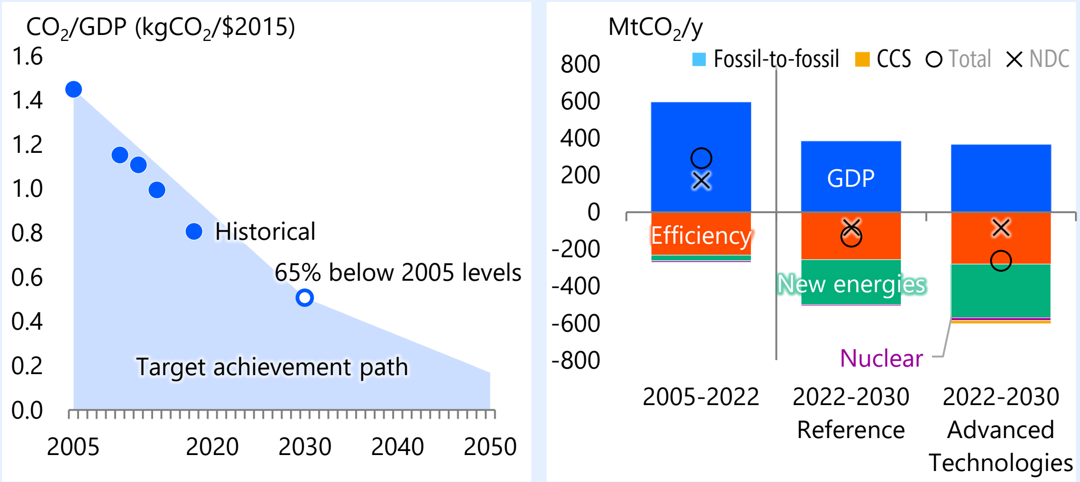
United States



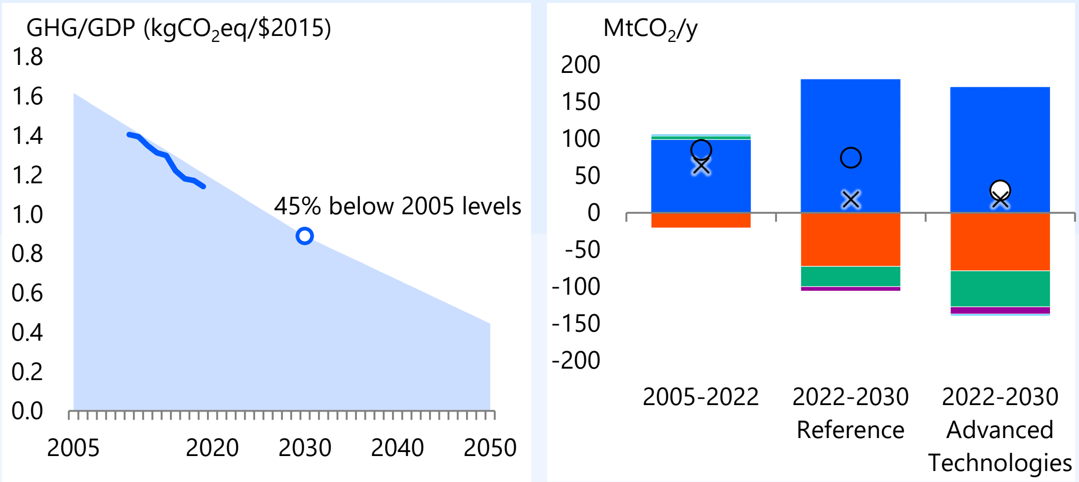
European Union



China



India



Notes: The figure on the left is based on national inventories (emissions) and the World Bank (GDP). The latest year for emissions is 2018 for China, 2019 for India and 2022 for the rest countries. The base year emissions on which the targets in Japan and the European Union are based do not include LULUCF in accordance with the NDC. The United States' NDC is plotted at a position 51% lower than 2005. Emissions from China and India, which are not specified in their NDCs, do not include LULUCF emissions here. In the legend on the right, 'new energies' refers to renewable energy, hydrogen and synthetic fuels, etc., and 'Fossil-to-fossil' refers to substitution between fossil fuels. 'Efficiency' includes factors that affect changes in the economic structure. Decomposition covers energy-related CO_2 based on IEA (historical) and this outlook (projection), and NDCs are based on GHG or CO_2 reduction rates directly read as reduction rates for energy-related CO_2, except for Japan. China and India have emissions targets per GDP, but these were converted to absolute values based on the GDP assumptions in this outlook.

On 6 February 2024, the European Commission recommended a 90% reduction in GHG emissions in 2040 compared to 1990 levels, but the focus will be on ensuring the implementation of the Fit For 55 policy package aimed at achieving the 2030 target. The United States government has also announced its outlook[54] for GHG emissions under the

[54] United States of America (2023), "2023 Voluntary Supplement to the U.S. Fifth Biennial Report", https://unfccc.int/sites/default/files/resource/23-11-21%20BR_Supplemental_FINAL_clean%20OCEII_2_UST%20edits_clean.pdf.

Inflation Reduction Act and the Infrastructure Investment and Jobs Act in a document submitted to the United Nations. The analysis shows that under current policies, including these two laws, GHG emission reductions in 2030 will be 33%–41% below 2005 levels, showing the significant impact of current policies. However, to achieve the NDC (50%–52% below 2005 greenhouse gas emissions), additional policies by the federal government, state governments and the private sector are essential.

As we have seen, the latest scientific findings suggest that achieving the 1.5°C target with no or limited overshoot is becoming virtually impossible. Furthermore, while progress towards NDC is being made in major countries, advanced economies in particular are expected to find it difficult to achieve their NDCs unless they take additional policies. Under these circumstances, there is concern that NDCs after 2035 will sooner or later reach a dead end if the target is simply linearly connected to the 2050 net zero target, as shown on the left side of Figure 5-5. More ambitious reduction goals alone will not solve the problem. In addition to accelerating adaptation to climate change, mitigation needs to be based on a convex emission path that enables steady emission reductions in the medium-term through measures that each country can take, while at the same time accelerating emission reductions in the second half of the century through sufficient investments in technological innovation, including CDRs.

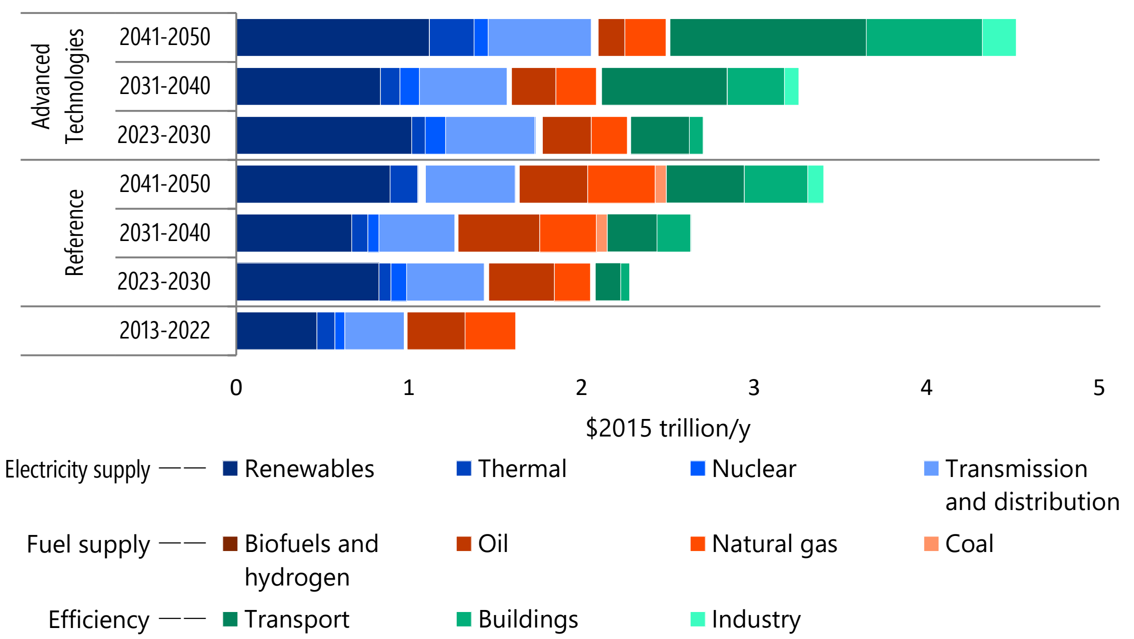
6. Energy-related investments

6.1 Recent trends and outlook

Most energy-related investments are made to oil production, natural gas production and renewables. In the last decade (2013–2022, same hereafter), investments have targeted primarily electric infrastructure such as renewables and transmission and distribution facilities, followed by facilities related to oil and natural gas production. From the 2020s (2023–2030, same hereafter), accelerated moves towards carbon neutrality will lead to significantly lower capital costs for renewable energy facilities, encouraging investments in renewables. Investments in energy-saving facilities will also increase to break away from dependence on fossil fuels. Nevertheless, fossil fuel investment will continue, supported by increased demand and other factors in Emerging and Developing Economies, and will continue until 2050 even in the Advanced Technologies Scenario.

In the Reference Scenario, energy-related investments[55] will double from an annual average of $1.7 trillion (in 2015 dollars, same hereafter) in the last 10 years to an annual average of $3.4 trillion in the 2040s (Figure 6-1). In the Advanced Technologies Scenario, investments in fossil fuels will be less than in the Reference Scenario. On the other hand, further investments in renewables and energy efficiency will be required, with annual average investments needed in the 2040s being $4.5 trillion, up $2.9 trillion from the last ten years. As a result, cumulative global energy investments required by 2050 will reach $99.7 trillion.

Figure 6-1 | Global energy-related investments

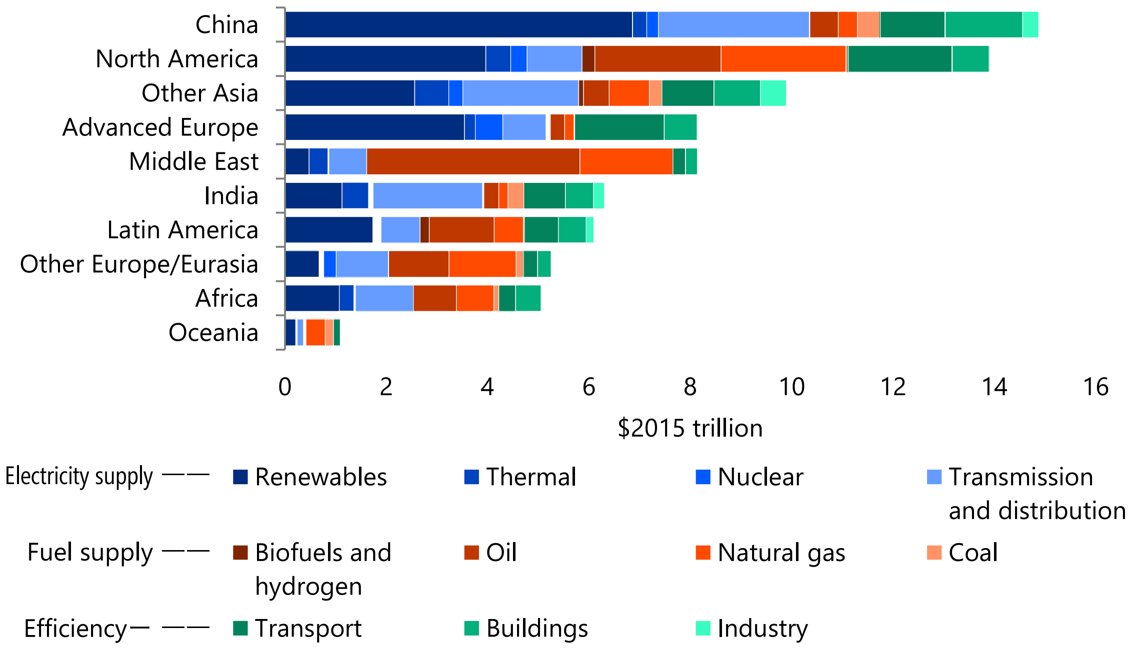


Note: Values of 2013–2022 are estimates.

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

The amount of energy-related investment varies by region (Figure 6-2). In Advanced Europe, which is moving away from dependence on fossil fuels, investments in renewables and energy efficiency will account for more than 70% of the total investments. On the other hand, in Oceania, which is also a fossil fuel supply region among other Advanced Economies, investments in oil and natural gas account for about half of the total investments, with renewable energy investments remaining at less than 20%.

Figure 6-2 | Energy-related investments [Reference Scenario, cumulative total for 2023–2050]



In the Middle East, another fossil fuel supply region, investments in oil and natural gas production exceed 70%, while investments in renewables and energy efficiency account for around 10%. In North America, investments in renewables will account for 30% of total investments, while those in the production of fossil fuels, such as the development of shale oil and gas, will account for a similar proportion.

In China, investment in renewable energy facilities is accelerating, accounting for nearly half of the total, aiming to achieve the '3060 Target', a national strategy to reach peak carbon dioxide (CO_2) emissions by 2030 and achieve carbon neutrality by 2060. In addition, China is investing heavily in power transmission and distribution, making its cumulative investment the largest of any country or region.

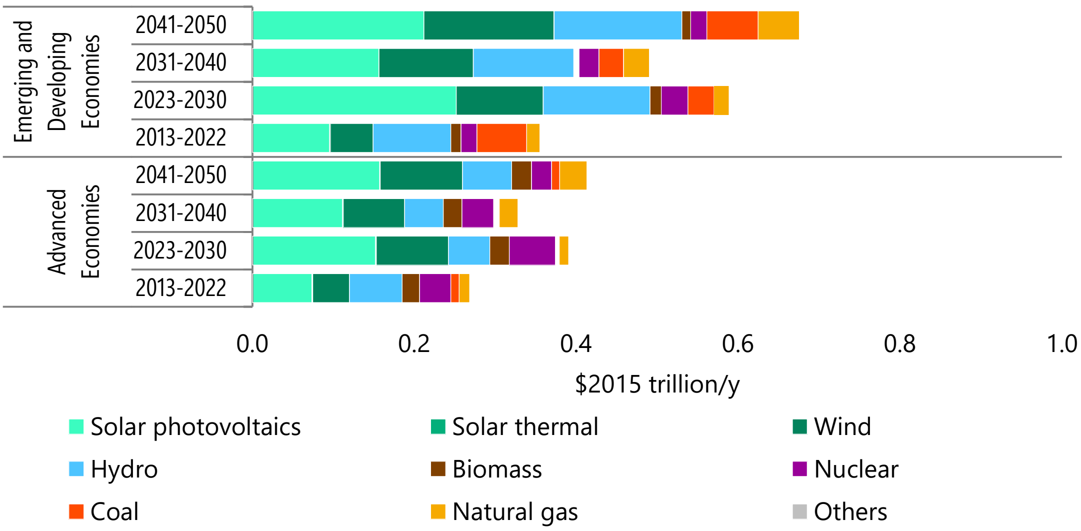
India, a fast-growing country, will have the largest share of investment in power transmission and distribution due to the installation of new power transmission and distribution networks to meet the growing demand for electricity, while investment in energy efficiency will be under 30% and renewables will be under 20%.

6.2 Electricity investments

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

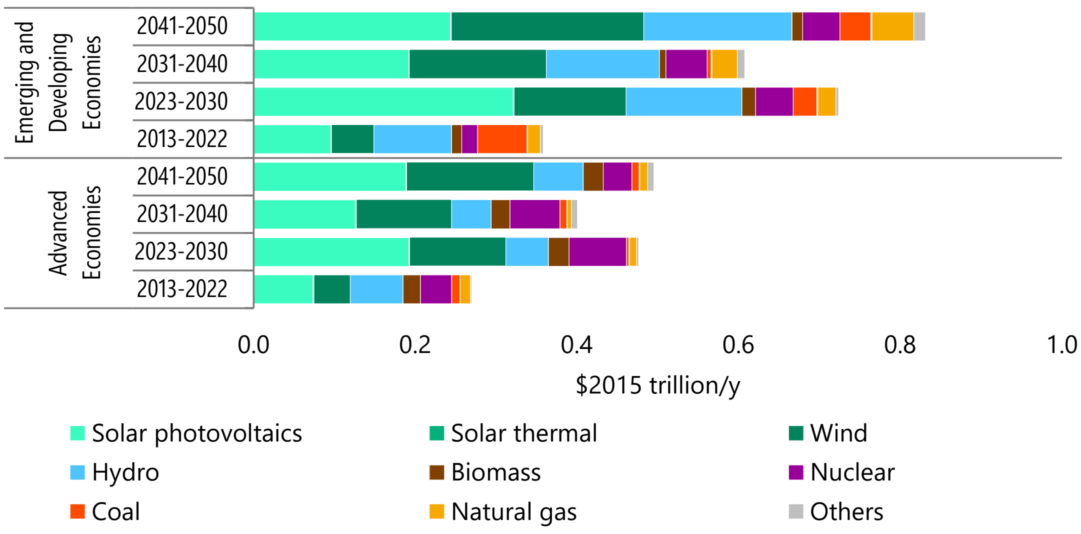
Of the investments in power generation equipment, those in renewable energy facilities account for the largest share (Figure 6-3 and Figure 6-4). In the last decade, feed-in tariffs and net metering systems contributed to active investments in renewable energy facilities in many regions. From the 2020s onward, investments in Emerging and Developing Economies will increase significantly both in the Reference and the Advanced Technologies Scenarios.

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



Note: Values of 2013–2022 are estimates.

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



Note: Values of 2013–2022 are estimates.

In the Reference Scenario, investments after the 2020s will be higher than in the last 10 years both in Advanced Economies and Emerging and Developing Economies. In the 2020s, countries will continue to expand investment, particularly in renewables such as solar photovoltaics and wind, to achieve their Nationally Determined Contributions (NDCs). As a result, the average annual investment will increase significantly compared to the last 10 years, approximately 1.5 times in Advanced Economies and 1.7 times in Emerging and Developing Economies.

In the 2030s, the average annual investment will decline in both Advanced Economies and Emerging and Developing Economies due to lower capital costs, such as cheaper solar panels and larger wind turbines, but will begin to increase again in the 2040s as more installed capacity is enhanced. Advanced Economies will mainly invest in solar photovoltaics, wind and nuclear. Among fossil fuel power sources, the average annual investment in natural gas-fired power generation will continue to expand through the 2040s. Emerging and Developing Economies will continue to invest in hydro in addition to solar photovoltaics and wind. Among fossil fuel power sources, investment in coal-fired power generation is notable and will exceed investment in natural gas-fired power generation in terms of average annual investment in the 2040s.

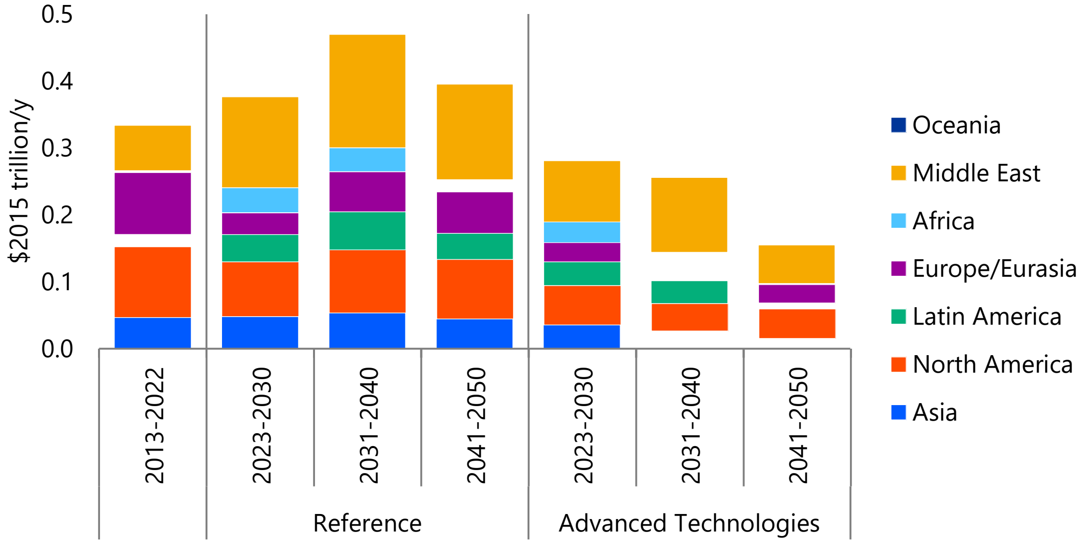
In the Advanced Technologies Scenario, solar photovoltaics and wind will be more actively introduced compared with the Reference Scenario. In addition, there is a marked increase in nuclear in Advanced Economies, while nuclear and natural gas are being actively introduced in Emerging and Developing Economies.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

6.3 Investments in oil and natural gas

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

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

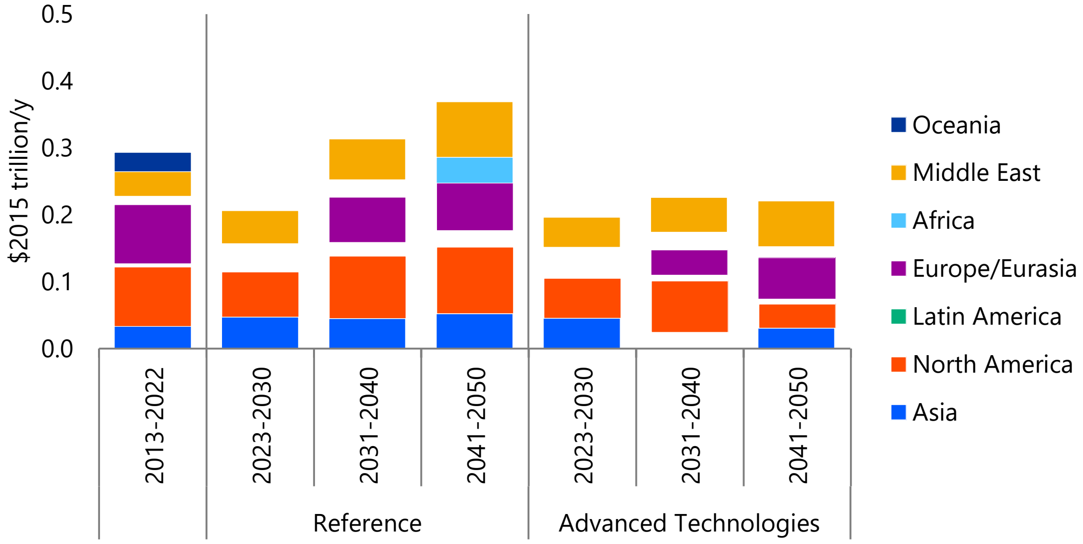
Figure 6-5 | Investment in the oil sector



Note: Values of 2013–2022 are estimates.

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

Figure 6-6 | Investment in the natural gas sector

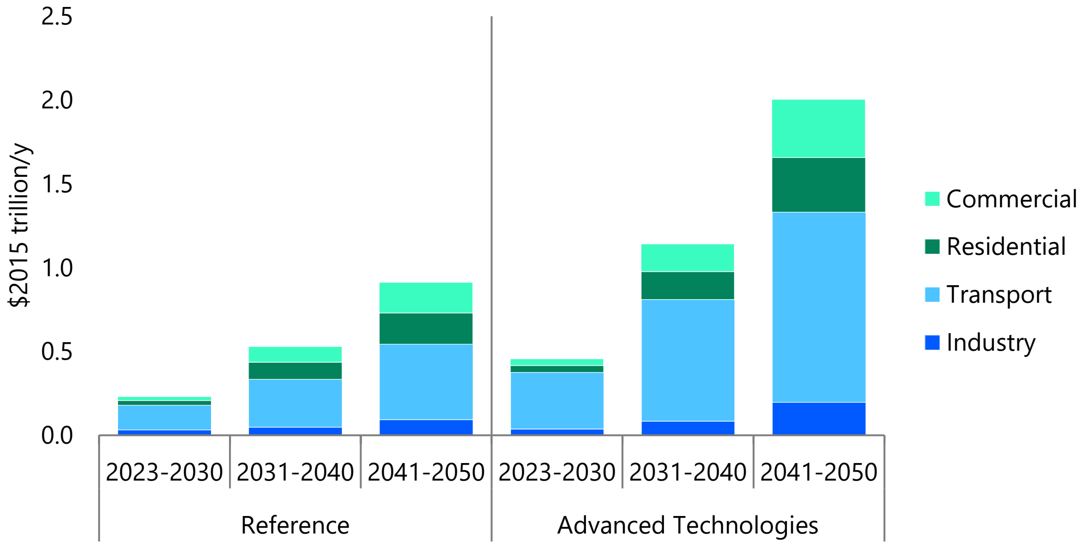


Note: Values of 2013–2022 are estimates.

6.4 Energy efficiency investments

In terms of average annual investment for introducing energy-efficient[56] equipment on the demand side, the transport sector will account for more than half, followed by the buildings sector with about 30% (Figure 6-7).

Figure 6-7 | Global energy efficiency investments



In the Reference Scenario, the transport sector will see increased average annual investment due to the shift from conventional internal combustion engine vehicles such as gasoline- and diesel-fuelled vehicles to zero-emission vehicles such as electric vehicles. In the Advanced Technologies Scenario, average annual investments will increase due to accelerated electrification caused by the expanded use of electric vehicles and the introduction of fuel cell vehicles that use hydrogen.

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

[56] Energy efficiency levels in 2022 are considered as the baseline.

Part II

How to address the uncertainties surrounding the energy transition

7. For LNG and natural gas to fulfil their roles

Among fossil fuels, liquefied natural gas (LNG) and natural gas are expected to continue to play a role in the energy transition. This chapter summarises the issues in fulfilling these roles, as well as the countermeasures.

7.1 New investments required to ensure a stable supply of LNG and natural gas

Clarifying LNG's evolving roles in response to changing needs

LNG and natural gas are expected to play a vital role as realistic solutions to resolving uncertainties in the energy transition. LNG's role has grown with the needs of the times, and it will serve as a key energy source also in the energy transition, contributing to energy security. It will underpin economic growth in emerging markets and provide a stable energy supply in mature markets, while contributing to the world's energy transition in combination with new energy sources. Making LNG and natural gas themselves cleaner 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, 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 coastal regions and islands.

In the Southeast Asian market, natural gas will play a crucial role in reducing emissions from the industrial sector and in balancing electricity supply and demand. It may serve as an economically rational fuel for reducing emissions during the transition period. Ensuring a stable natural gas market and expanding supply capability will help reduce energy transition costs.

Recent LNG market trends underline the importance of LNG's role and the need for long-term stability and security in the market. LNG provides the flexibility necessary for responding to energy crises, and the recent destabilisation of the supply-demand balance and prices has affirmed the importance of taking long-term measures to stabilise the market.

Table 7-1 | History and evolution of the role of LNG (natural gas)

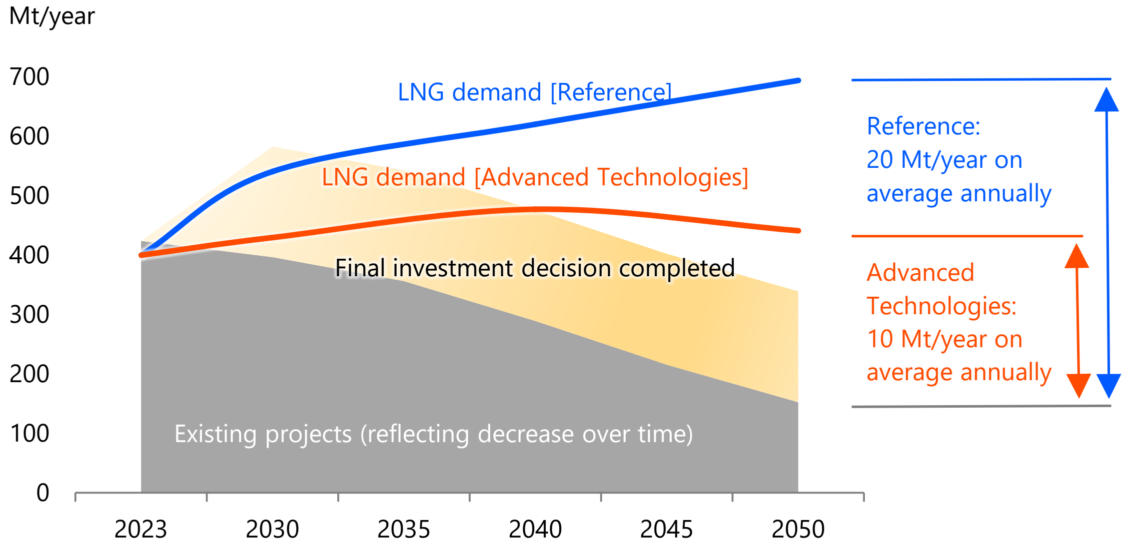
Timeline and events	LNG: Roles played and expectations
Late 20th century Oil crises Air pollution	Expanded as an alternative and clean energy source (Japan and Korea) Alternative source of supply for pipeline gas (Europe) Expanded its share among primary energy sources and helped ease the impact of the oil crises
2010s Covered the drop in nuclear power generation due to plant shutdowns Increasing energy demand	Demonstrated flexibility to respond quickly to baseload power supply shortages Liquefaction, marine transport and gasification ceased to be a logistics burden as more companies entered various parts of the value chain, giving LNG outstanding flexibility in crisis situations
2021–2022 Post-pandemic increase in energy demand Russia's war and gas shortages	LNG imports offset the supply cuts in Russian pipeline gas to Europe from before the invasion of Ukraine The drop in Russian pipeline gas imports due to the invasion of Ukraine and the sabotage of the Nord Stream pipeline was offset by LNG imports mainly from the United States.
For 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 Contributes to the energy transition in combination with new energy sources Could be utilised permanently if LNG becomes cleaner

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

The LNG production sector needs additional annual capacity ranging from 10 Mt/year to 20 Mt/year during the period up to 2050. These figures are based on the difference between estimated LNG demand and production capacity from existing LNG plants and new ones where investment decisions have already been made, incorporating expected capacity reductions due to ageing. The required capacity additions should come in the form of: 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 and other facilities.

The total capacity of new construction decisions (projects in final investment decision [FID] status) in the past three years exceeds this requirement until the early 2030s. However, even the implementation of FID projects is not completely certain, and attention should be paid to the possibility of delays or cancellations. Causes of delay that have emerged include uncertainty surrounding Russian projects, continued suspension of construction in Africa due to political unrest, difficulties 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 US environmental litigation.

Figure 7-1 | Estimated investment required for the LNG production sector



7.3 Development obstacles for LNG production projects

Cost increases occur simultaneously with technological innovations and evolution of models for development

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

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

The start of LNG exports from the West Coast of North America, 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 transportation routes, resolving bottlenecks in marine LNG transport to the Asian market.

The export capacity of the United States will grow steadily in the next few years, but long-term development is becoming unpredictable due to regulatory uncertainties. No US LNG projects have reached FID so far in 2024. Litigation and completion risks are also emerging for projects under construction.

The long-term commitment of buyers has been key for the steady stream of projects reaching FIDs in the past few years. A greater percentage of these commitments are now made by portfolio players and those made by Japanese LNG buyers (city gas utilities, electric power utilities, etc.) represent a relatively small portion.

Table 7-2 | Development trends for LNG production projects

	Characteristics of each time period	Initiatives to reduce costs and promote development
2010–2014	Costs increased with the soaring LNG demand in Northeast Asia, the LNG development boom in Australia and the concentration of construction projects.	The high costs in Australia triggered the start of LNG development in other regions.
2015–2020	The centre of LNG production facility development moved to the United States. Cost increases eased in both the upstream sector that handles LNG feedstock and in the liquefaction sector. The feedstock gas for US LNG does not cost less in absolute terms but there were high expectations for long-term stability.	US LNG import terminals were repurposed and developed into LNG export facilities. The US gas production sector and feedstock gas transport sector were unbundled. Floating liquefaction (FLNG) emerged as a new option, including in other regions.
2021–	Logistics disruptions caused by the pandemic led to construction delays and higher costs. Costs increased due to constraints caused by the impact of war. Construction was delayed due to political unrest in host countries. Increased costs could not be absorbed in some cases. Uncertainty related to export and construction licensing procedures rose in the United States.	Technological innovation took place in small- and medium-sized liquefaction facilities. Modular system (repeated application of the same design) spread with the expansion of the ecosystem and overall scale of LNG production projects. With the phase-out of Russian gas, the development of LNG production projects in other regions apparently gain momentum.
	Cost of raw materials, such as steel and concrete, increased. Financing costs increased. Costs of CCS and electrification (renewable energies)	Production projects competing for LNG market opportunities in the second half of the 2020s will continue to work to reduce costs.

While steady growth in production capacity is expected in the medium-term, construction delays are becoming the norm. Some consider that LNG supply capacity will be in excess around 2030, but forecasts of excess would also spur additional demand. Due to reasons on both the supply and demand sides, 'oversupply' is unlikely.

Major LNG exporting regions have issues as well as resource potential. Australia's LNG export development has matured, and hereafter, maintaining stable production through brownfield projects will be a challenge. Qatar is factoring clean measures into its mega expansion plan and will focus on additional marketing hereafter. East Africa has high resource potential, but full-scale expansion is stalled. Russia's supply is currently strong, but the country has problems, and new development projects are growing even more uncertain.

Table 7-3 | Current status and challenges of major LNG producer countries

	Current status and characteristics of LNG development	Key points and future challenges
Australia	A major resource exporter exporting three-fourths of its natural gas output Among the world's three top LNG exporter countries LNG exports started in western Australia in 1989 and in eastern Australia in 2014. LNG is exported almost entirely to Asian countries. Development of quasi-brownfield projects such as Scarborough and Barossa are under way.	Australia's 'Future Gas Strategy' released in 2024 states that the country's natural gas will play a key role in the energy transition to reach net zero emissions by 2050. The Safeguard Mechanism released in 2015 and revised in 2023 includes regulations imposing an annual baseline emission reduction of 4.9% to meet the country's target of a 43% reduction by 2030. LNG projects will be required to incorporate CCUS and other GHG measures in their plans.
Qatar	Exports 80 Mt/year of LNG based on the North Field, the world's largest gas field QatarEnergy leads LNG project development, with up to around 30% participation by international companies. Developing and marketing 64 Mt/year worth of output from mega LNG expansion plans	The sales policy for the ongoing expansion projects is receiving attention. For the NFE project, offtake commitments for periods beyond 2050 have been secured from partner companies, as well as from China. Ensuring sustainability in development by utilising renewable energy to power LNG production facilities and incorporating a large-scale CCS plan
Mozambique	The Rovuma Basin has massive production potential. In Area 4, FLNG projects began operations in 2022. The onshore project has also entered the FEED stage. For Area 1, the onshore LNG production project reached FID in 2019, but construction has been suspended since April 2021.	The Area 1 onshore project aims to resume construction soon. Conducting stable project development by restoring public safety is a challenge. The country is located at a geographically strategic place whose distance from Europe and Asia allows the sale of LNG to both regions. There are also no bottlenecks on the transportation route to Japan or other Asian countries.

	Current status and characteristics of LNG development	Key points and future challenges
Tanzania	Its offshore gas fields have high potential. In 2023, three international companies entered into a framework agreement on LNG project development with the government.	
Russia	LNG shipments from Sakhalin and the Arctic continue but with a constant risk of disruption. The outlook for ongoing and new construction projects is uncertain, and marketing success is not expected. Japanese companies continue to invest in and purchase LNG from Sakhalin 2. Arctic LNG 2 is attempting to ship LNG despite the sanctions.	There is a constant need to prepare for disruptions of LNG exports from existing projects. Ending the war and resolving conflicts are essential for starting new development projects.

7.4 LNG transportation bottlenecks and troubles in production facilities affect the market balance

Challenges with long-term impact on LNG transportation and production playing out

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

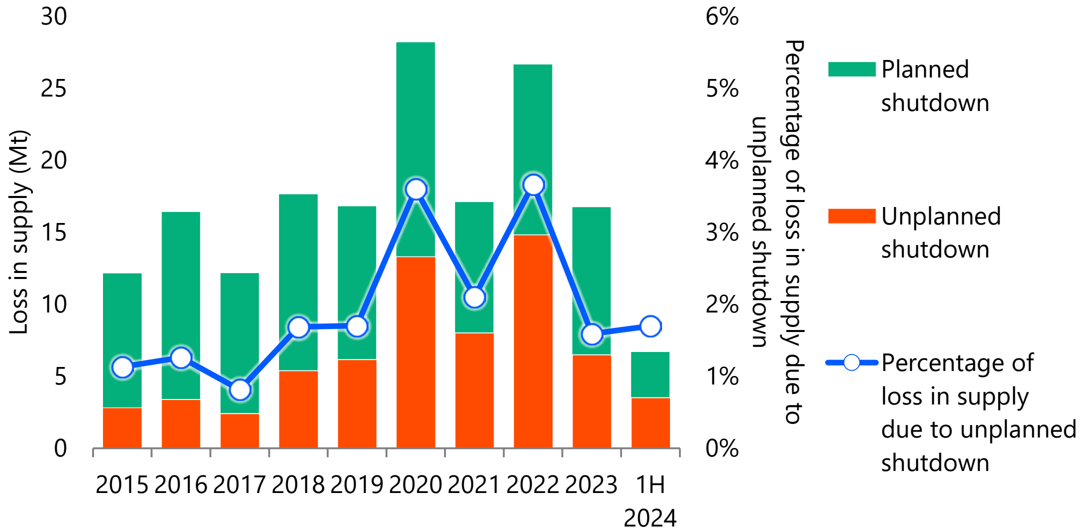
With the diversification of LNG supply sources, transportation routes and distances now vary depending on the source and consumption areas. The completion of the Panama Canal expansion in 2016 made it possible for LNG carriers to pass through, improving the convenience of transporting US LNG to Asia. After the shale revolution, the Canal has contributed to increasing the transportation of liquefied petroleum gas (LPG) to Asia, production of which has increased, as well as natural gas. The increase in traffic is causing long waiting times and detours. While passage and reservation systems are being rationalised, drops in water levels caused by droughts have led to restrictions on the number of large vessels that can pass through. In 2024, it is becoming the norm for US LNG bound for Northeast Asia to go around the Cape of Good Hope.

Going around the Cape of Good Hope has also become the norm for Middle Eastern LNG bound for Europe due to the effective closure of the Red Sea and Suez Canal routes. 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, which are likely to cause serious problems when the supply-demand balance is tight. As an example, in 2022, a large US LNG export facility shut down for extended periods after a fire, and there were relatively long unplanned shutdowns in other producer countries. Because this occurred when the market balance was tight, it pushed up the already high prices of spot LNG and natural gas. In 2023, the market balance improved, and supply loss due to unplanned shutdowns also decreased year-on-year.

Figure 7-2 | Estimated loss in supply caused by LNG production facility shutdowns



Source: Estimated based on the number of days facilities were in shutdown and the capacity of those facilities

7.5 Long-term challenges to stabilising the LNG market

Importance of international collaboration and setting clear roles for LNG

As a realistic solution to address the uncertainties of the energy transition, it is necessary to set clear roles for LNG as well as clear LNG standards to fulfil those roles. At the company level, the key will be strengthening countermeasures and setting targets for methane and GHG emissions, as well as disclosing information on them in an accurate and timely fashion. It is also necessary to widely demonstrate the economic advantages and environmental superiority of LNG as an investment target. International forums such as the Group of Seven (G7) have recognised the importance of natural gas and LNG, but it is important to establish standards for 'abated' LNG that can be allowed in the energy transition. The importance of strengthening methane and GHG emission measurement and international standardisation, as well as international cooperation in emission reduction measures, are being more widely recognised.

It will also be important for consumer countries to call on the United States, Australia, Canada Mexico to stabilise and promote regulations that help maintain and expand their LNG production, and to participate in and provide support for development in those countries.

Aggregating the medium- to long-term demand involving the emerging Southeast Asian market and helping exporters develop markets will contribute to the expansion of the global LNG market and production development.

8. Risk scenarios for energy security

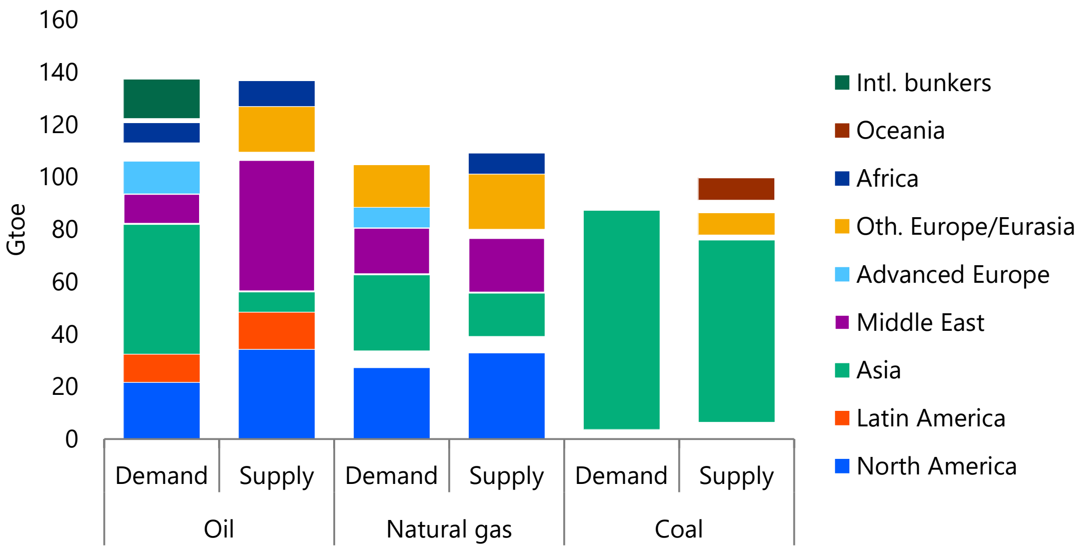
Securing necessary amounts of energy at affordable prices is vital for society and the economy. History has proven that the stable supply of energy can be threatened by various factors. This is why we need to correctly identify risks, estimate their impact should they materialise and take necessary measures. This section discusses five risks we consider having the greatest importance and attempts to understand them.

8.1 Risk of underinvestment in fossil fuels

Importance of fossil fuels

As of 2022, fossil fuels accounted for 81% of the world's primary energy consumption. Among fossil fuels, demand for coal may have already peaked. According to the Reference Scenario, coal demand will decrease at 1.2% per year towards 2050. On the other hand, demand for oil and natural gas is expected to continue growing until 2050 according to the Reference Scenario. As a result, even in 2050, the share of fossil fuels will remain very large at 73% (55% for oil and natural gas combined). By region, Asia will drive demand for all types of fossil fuels. As for supply, the Middle East and North America will drive oil and natural gas production, while Asia will maintain a strong presence in coal supply.

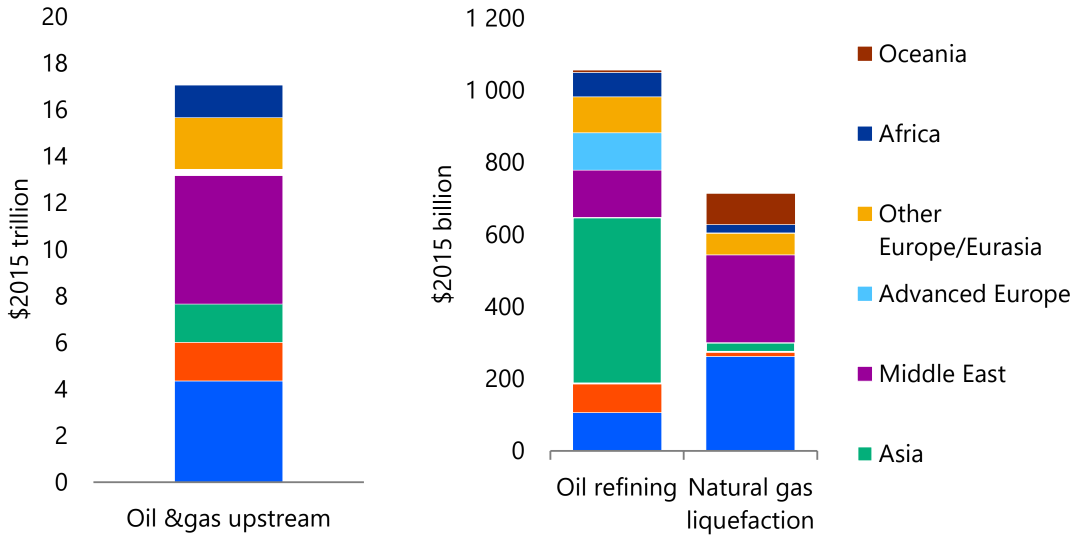
Figure 8-1 | Global supply and demand for fossil fuels [Reference Scenario, cumulative total for 2022–2050]



Risk of underinvestment

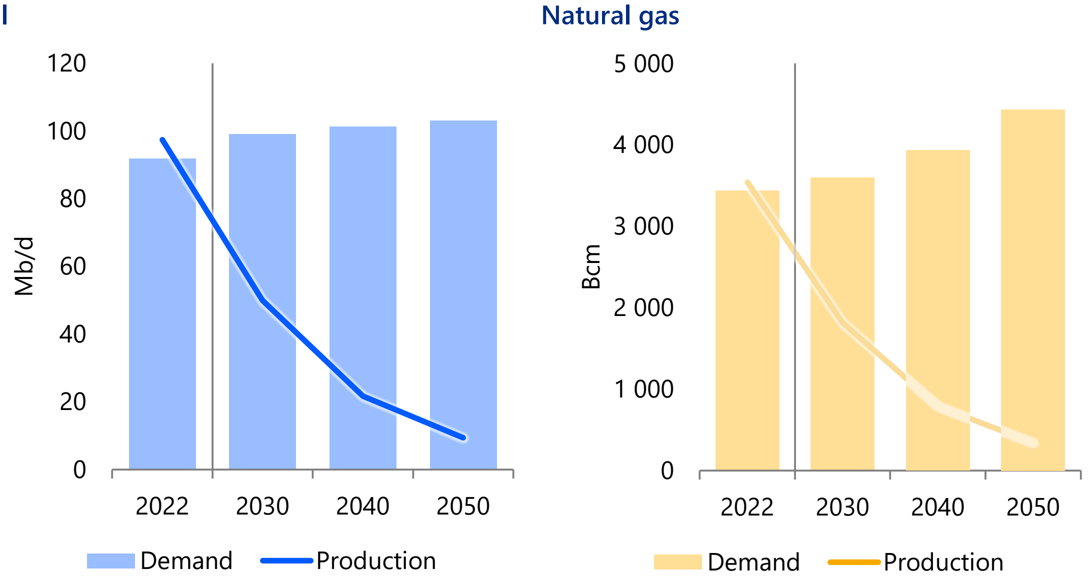
Stable investment in the entire value chain from upstream to downstream is essential for the stable supply of fossil fuels. To meet the demand estimated in the Reference Scenario, investment of about $22 trillion (real price in 2015) in the fossil fuel sector is required. In particular, it will be critically important to secure stable investments in oil and natural gas upstream (exploration, development and production), which require 80%–90% of the total investment in oil and natural gas, especially in major supply regions like the Middle East and North America (MENA). With the downscaling of refineries in advanced economies and delays in investment in refinery projects in emerging economies, securing investments in the oil refining sector is a challenge for many countries. Furthermore, for liquefied natural gas (LNG), for which strong demand growth is expected, it will be crucial to secure stable investment in liquefaction facilities, especially in MENA, where the potential for production increase is large.

Figure 8-2 | Major investment in oil and natural gas [Reference Scenario, cumulative total for 2022–2050]



However, amid increasing public pressure for climate measures, investments in fossil fuel projects are facing stronger headwinds. Though improving energy efficiency as part of climate measures helps reduce fossil fuel demand, the supply-demand balance of fossil fuels is likely to tighten if investment slows down due to divestments and tougher environmental regulations. If we assume that oil and natural gas production will decline at a rate of 8% unless there is additional investment in the upstream business, production will drop to about one-tenth of 2022 levels by 2050, resulting in an enormous supply-demand gap.

Figure 8-3 | Oil and natural gas production without additional investment compared with demand in the Reference Scenario

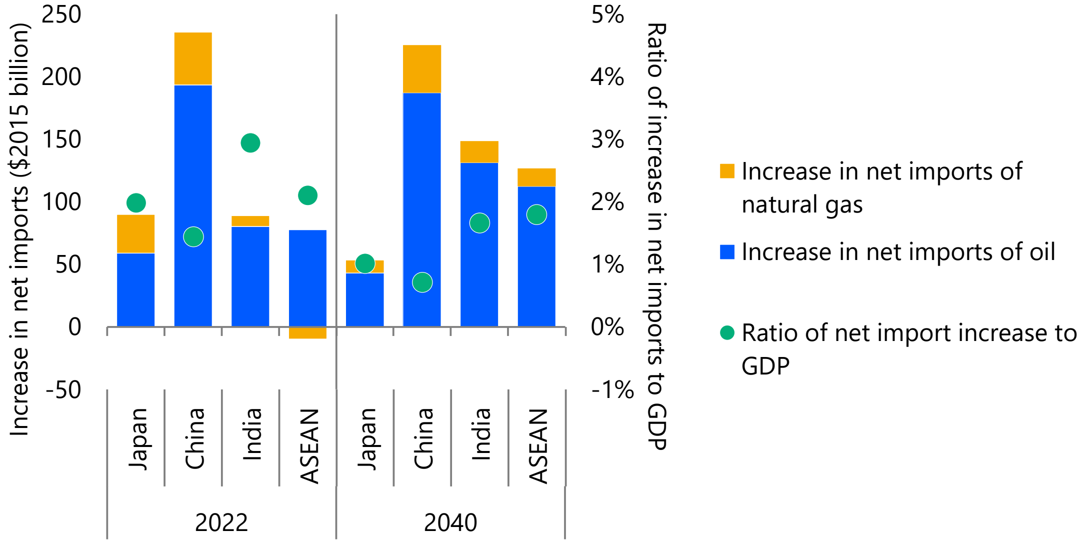


Macroeconomic impact

Figure 8-3 presents a hypothetical analysis comparing the demand in the Reference Scenario and estimated output without additional investment; in reality, such extreme supply-demand gaps are inconceivable. However, underinvestment could cause the oil and natural gas supply-demand balance to tighten and their prices to rise. The average Brent price for 2021 was 70% higher than the previous year, and the rise was probably caused not only by demand recovery after the pandemic but also by underinvestment in the upstream sector during the pandemic.

Generally speaking, higher resource prices have a negative impact on the macroeconomy through inflation in importing countries. If oil and natural gas import prices were to rise by 50% from the actual and estimated prices for 2022 and 2040, it would push up the share of their imports in the gross domestic product (GDP) of major Asian importer countries by 1 to 3 percentage points. The share is relatively small for Japan, whose net imports will decline, and China, whose GDP will expand significantly. Nevertheless, the impact could be relatively large for India and the Association of Southeast Asian Nations (ASEAN) countries, whose oil and natural gas imports are growing rapidly.

Figure 8-4 | Impact of a 50% increase in oil and natural gas prices on major Asian importing countries and regions

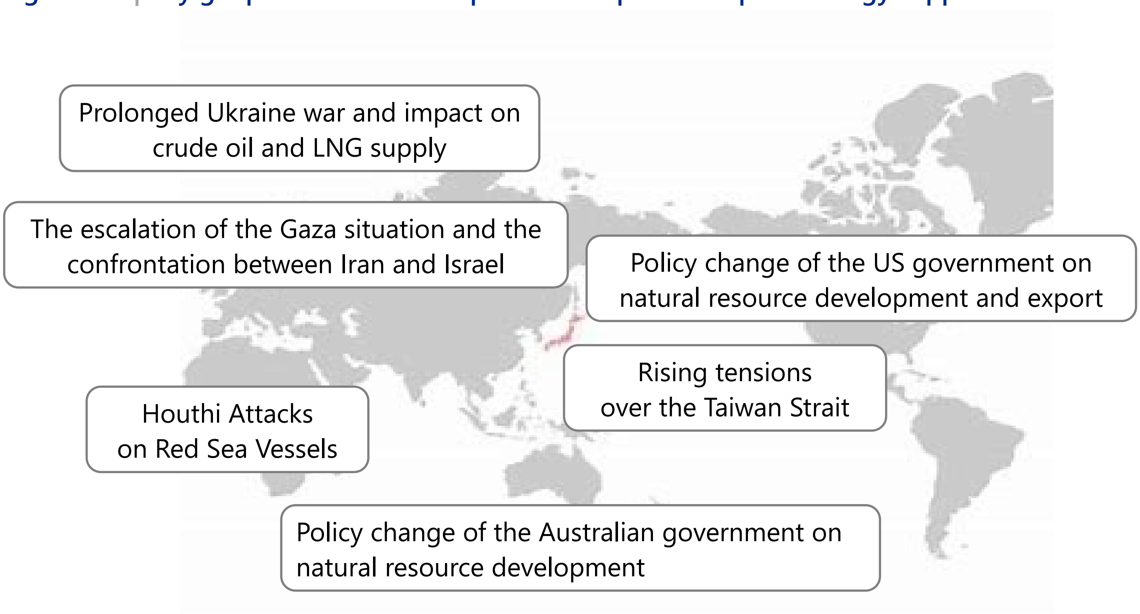


Note: 2040 figures are based on the Reference Scenario.

8.2 Materialisation of geopolitical risks

The international energy market has seen geopolitical events with devastating potential impacts on existing oil and natural gas supplies, such as the Russia-Ukraine war and the situation in the Gaza Strip in the Middle East, which has deteriorated in recent years (Figure 8-5). Meanwhile, as a new form of geopolitical risk, government policies to restrict fossil fuel development and export can be found in advanced economies. This section presents a summary of geopolitical risks, which are growing in both seriousness and variety.

Figure 8-5 | Key geopolitical risks with potential impact on Japan's energy supplies

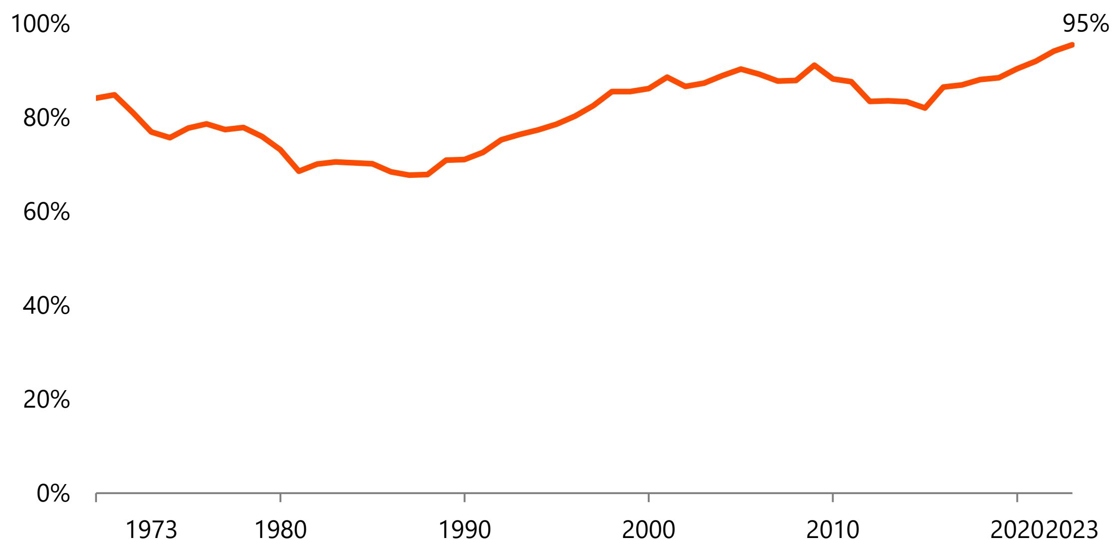


Geopolitical risks in the Middle East becoming increasingly serious

Geopolitical risks in the Middle East are both an old and new problem for Japan. Since the oil crises in the 1970s, reducing the dependency on Middle Eastern energy has been a long-standing objective for Japan's energy security. The dependency on the Middle East is currently at unprecedentedly high levels, reaching 95% for oil in 2023 (Figure 8-6). It has risen even higher since FY2022 as Japan stopped importing Russian crude oil in line with other Group of Seven (G7) countries after Russia launched a full-fledged invasion of Ukraine and turned to the Middle East for alternative oil supplies. This means that the political situation in the Middle East has a greater impact on Japan's oil supply than ever before.

The geopolitical risks in the Middle East have always been high, but they have grown even higher in the past year. In October 2023, the Islamic armed forces of Hamas, headquartered in the Gaza Strip, Palestine, launched a major surprise attack on Israel, in response to which Israel declared war on Hamas and took military actions in the Gaza Strip. As of August 2024, an estimated 40 000 lives have been lost to this armed conflict[57]. Western countries and neighbouring Middle Eastern countries have attempted to mediate peace but without major progress, and the situation surrounding Gaza remains dire.

Figure 8-6 | Japan's dependency on the Middle East for crude oil imports



Source: The Institute of Energy Economics, Japan (IEEJ) EDMC Databank

Despite the increasingly serious situation in Palestine, its impact on international energy prices has so far been minor. The Brent crude price, an international oil price indicator, was in the $90/bbl range as of October 2023 but began to fall the next month as the situation in Gaza worsened and dropped to as low as the $70/bbl range by the end of the year. Since then, there has been no significant rise in prices related to the Middle East situation in the international oil markets at the time of writing. At present, we can say that there is a gap between the seriousness of the Palestine situation and the international oil markets.

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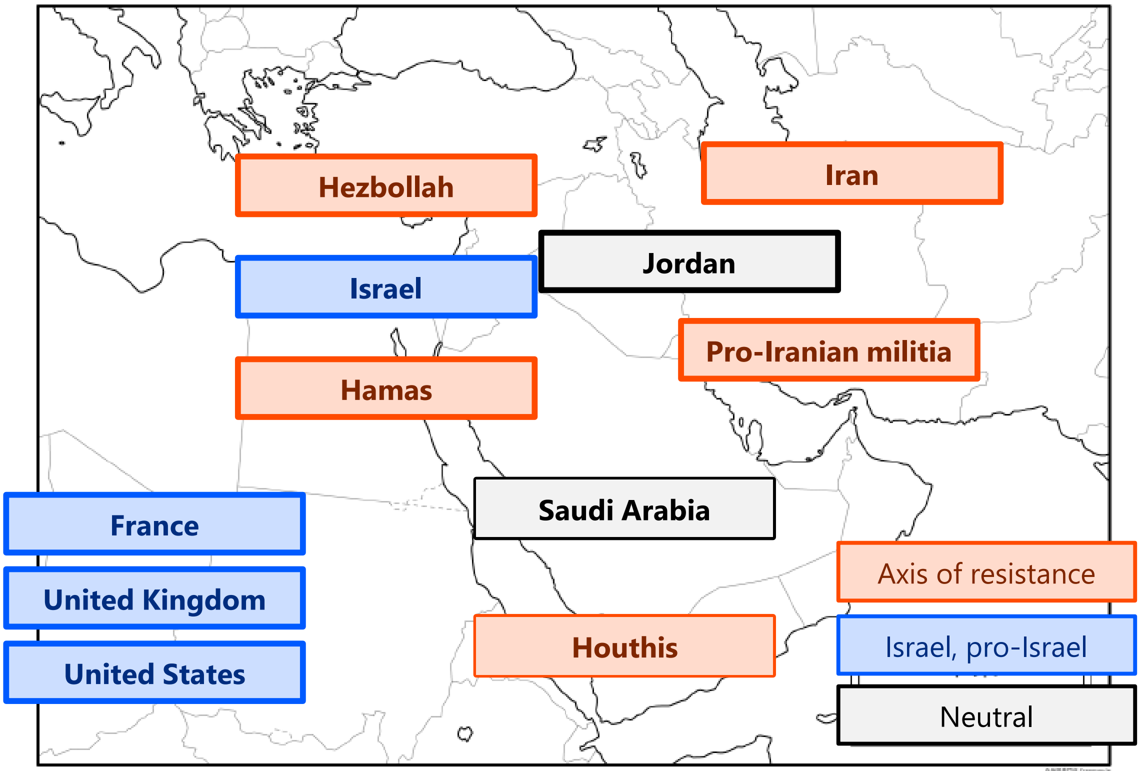
57 Julia Frankel. (2024). "With Gaza's death toll over 40,000, here's the conflict by numbers", *AP News*. https://apnews.com/article/israel-hamas-gaza-war-palestinians-statistics-40000-7ebec13101f6d08fe10cedbf5e172dde. (Accessed 20 September 2024).

-The real fear is if the Middle East situation worsens and has a direct physical impact on the oil and LNG exports from the region, narrowing the gap that we are now seeing. The Middle East is suffering various conflicts, and there are several possible scenarios that could result in the disruption of physical supplies to the international oil markets and LNG markets. Among them, the most likely one at this point with a serious impact is a full-fledged armed conflict between Iran and Israel. Iran and Israel have long been in a fierce political confrontation, but their relationship hit a new low in July 2024 when Ismail Haniyeh, chairman of Hamas, was killed during a visit to Iran by an attack said to be launched by Israel. Iran has declared they will retaliate against Israel in some way, and the hostility is deeper than ever. This confrontation is not simply between Iran and Israel but could escalate into a major regional conflict involving the 'Axis of Resistance' that consists of various armed forces with close ties with Iran, and Western countries supporting Israel (Figure 8-7). If this scenario materialises, oil prices could soar because the ongoing geopolitical antagonism in the Middle East would spill over to the Gulf countries. This would have a major psychological impact on the participants of the international oil markets, even though Iran's oil exports are small, accounting for only 1.3 Mb/d[58] of the world's total oil trade (68 Mb/d) as of 2023[59].

Figure 8-7 | The Axis of Resistance centred around Iran and Israel



Source: Compiled based on "Background and impact of Iran's attack on Israel", Sachi Sakanashi (2024), material for urgent situation analysis and reporting meeting by the JIME Center

[58] *Nikkei Asia* (31 January 2024) "Iran's oil exports reach 5-year high, with China as top buyer" https://asia.nikkei.com/Business/Markets/Commodities/Iran-s-oil-exports-reach-5-year-high-with-China-as-top-buyer (Accessed 20 September 2024)

[59] Energy Institute (2024) *Statistical Review of World Energy*. https://www.energyinst.org/statistical-review (Accessed 20 September 2024)

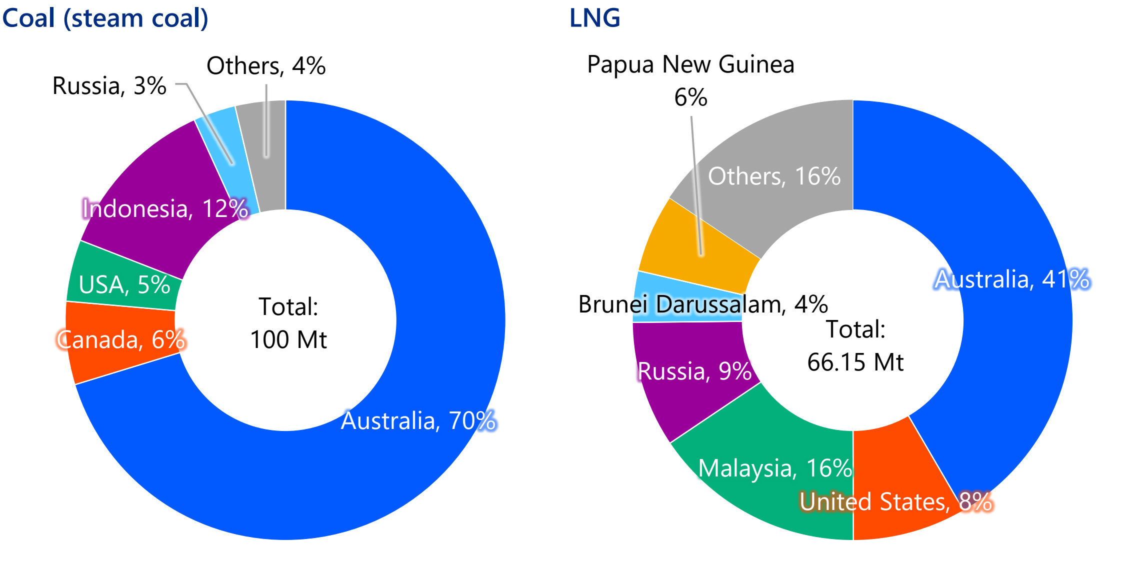
The Middle East has always involved a high geopolitical risk, but energy supplies have remained stable. However, the past does not guarantee that energy supplies from the Middle East will continue to be stable. While interest in decarbonisation is rising, Japan remains highly dependent on fossil fuels and the Middle East. Developments in the region must continue to be closely monitored.

Risk of policy change in advanced economies

If we define geopolitical risk in energy security as 'the risk for political factors to have significant impacts on real-life energy supplies and their prices', such risk events could occur not only in emerging economies and developing economies but also in advanced economies. However, the geopolitical risk seen in advanced economies is less likely to take the form of armed conflicts that occur in emerging economies and developing economies but could affect energy resource production and export due to changes in government policy, in particular, aggressive decarbonisation measures.

It is generally considered that Japan imports energy resources mainly from emerging economies and developing economies, but for example, in 2023, 70% of Japan's coal imports came from Australia, 6% from Canada and 5% from the United States. Likewise, Japan imported 42% of its LNG from Australia and 8% from the United States in 2023, making advanced economies critical energy suppliers for Japan (Figure 8-8). These advanced economies have had a few major policy changes regarding domestic resource development and export. However, as interest in climate action and energy security grows in those countries and as more people become critical of resource development, some governments have made policy changes that could increase the uncertainty of future production and exports of those countries.

Figure 8-8 | Sources of steam coal and LNG imports to Japan [2023]



Source: The Institute of Energy Economics, Japan (IEEJ) EDMC Databank

One example is the suspension of screening and approval of new LNG export applications to non-free trade agreement (FTA) countries announced by the U.S. Biden administration in January

2024[60]. This decision came as part of the countermeasures for global climate change aimed at highlighting the president's focus on climate change issues heading towards the presidential election in November, 2024[61]. The administration said that the decision to suspend the processes would not affect LNG supplies to the nation's allies, including Japan and Europe[62]. However, if decarbonisation does not proceed in Japan and Europe as currently planned, it is very likely that additional demand for LNG as an alternative energy source will arise. The suspension of screening of new export licence applications by the United States, now the world's largest exporter, may threaten the stability of the LNG market going forward.

In addition, in Australia, the federal government revised the Australian Domestic Gas Security Mechanism, or ADGSM, the mechanism for keeping domestic supply and demand of natural gas stable, in October 2022[63]. First introduced in 2017, the mechanism allows the Australian government to limit the export of gas that is free of any client commitment when a domestic gas shortage is foreseen. With the revision, the frequency of the government's supply-demand shortage monitoring was raised from once a year to once every quarter. No gas export has been restricted in the past based on this mechanism; however, Australia is Japan's largest LNG supplier, so Japan must keep a close watch on the status of Australia's energy policies. In July 2023, the Australian government also revised the Safeguard Mechanism, the government's policy for reducing emissions. With the revision, the upper limit for emissions, called the baseline, was lowered so that carbon neutrality can be achieved in 2050. The Safeguard Mechanism required that designated large-scale emitters including LNG liquefaction and coal production plants reduce their annual greenhouse gas (GHG) emissions by 4.9% starting from that very month. Furthermore, new LNG liquefaction plants were required to produce LNG with net zero emissions from the start of their operations[64]. This new mechanism may also impose additional burden on resource producers and could drive up procurement costs for Japan.

Also, many Japanese companies are considering producing low-carbon hydrogen and ammonia in the United States and Australia and importing them to Japan, though no commercial projects have started. If policies are implemented to limit projects on so-called blue hydrogen derived from natural gas to tighten climate measures, Japan's efforts to decarbonise using low-carbon hydrogen may be affected. Moreover, even if Japan manages to launch the project to collect carbon dioxide (CO_2) generated in Japan and send it to these countries for underground storage,

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[60] The White House (2024) "Statement from President Joe Biden on Decision to Pause Pending Approvals of Liquefied Natural Gas Exports". https://www.whitehouse.gov/briefing-room/statements-releases/2024/01/26/statement-from-president-joe-biden-on-decision-to-pause-pending-approvals-of-liquefied-natural-gas-exports/ (Accessed 20 September 2024)

[61] Later, in July 2024, President Biden announced that he would not run in the November presidential election that year, and the Democratic nominee for president became current Vice President Kamala Harris.

[62] The White House (2024) "FACT SHEET: Biden-Harris Administration Announces Temporary Pause on Pending Approvals of Liquefied Natural Gas Exports" https://www.whitehouse.gov/briefing-room/statements-releases/2024/01/26/fact-sheet-biden-harris-administration-announces-temporary-pause-on-pending-approvals-of-liquefied-natural-gas-exports/ (Accessed 20 September 2024)

[63] The Hon Madeleine King MP Minister for Resources and Minister for Northern Australia (2022) "Improving energy security, reliability and affordability" https://www.minister.industry.gov.au/ministers/king/media-releases/improving-energy-security-reliability-and-affordability (Accessed 25 September 2024)

[64] Australian Government Department of Climate Change, Energy, the Environment and Water (2024) "Safeguard Mechanism" https://www.dcceew.gov.au/sites/default/files/documents/safeguard-mechanism-reforms-factsheet-2023.pdf (Accessed 26 September 2024)

if the host countries change their policies on the acceptance of CO_2 from these countries after the project is launched, it could be a major roadblock for Japan's CCS business.

Policy changes like these in the United States and Australia have been implemented in their respective countries out of policy necessity. However, since LNG and other energy production projects and hydrogen, CCS and other decarbonisation projects involve enormous investments as well as long-term commitments, the possibility of government policy changing from one administration to the next will negatively impact final investment decisions. Climate change policies are likely to be treated as a top political agenda in advanced economies, raising the risk of domestic energy and climate change policies changing with every change of government. Going forward, policy changes in advanced economies like the ones above should also be recognised as an uncertainty in resource procurement.

8.3 Risk of electricity supply instability

Importance of a stable electricity supply

A stable electricity supply is vital for our daily lives and business activities today. In particular, with the rapid progress in electrification of demand and digitisation, society's dependency on electricity is increasing dramatically. With the progress in electrification including the spread of electric vehicles (EVs) and expansion of data centres, a lack of stable electricity supply would be highly disruptive in many areas including telecommunications, transportation and manufacturing.

Figure 8-9 | Supply and demand of electricity in Japan [Reference Scenario]

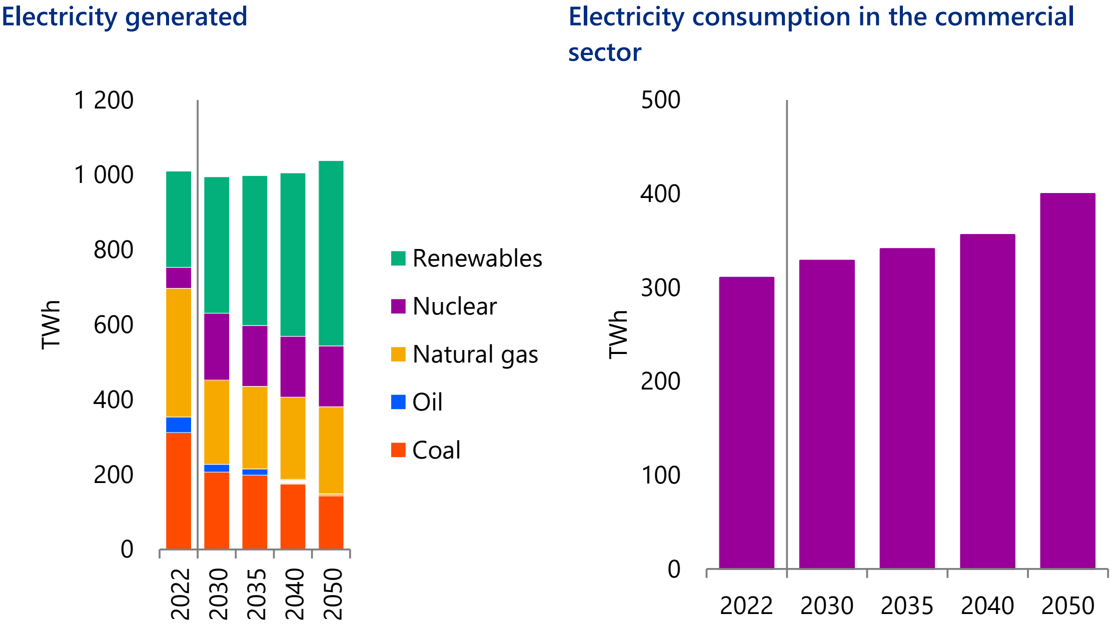
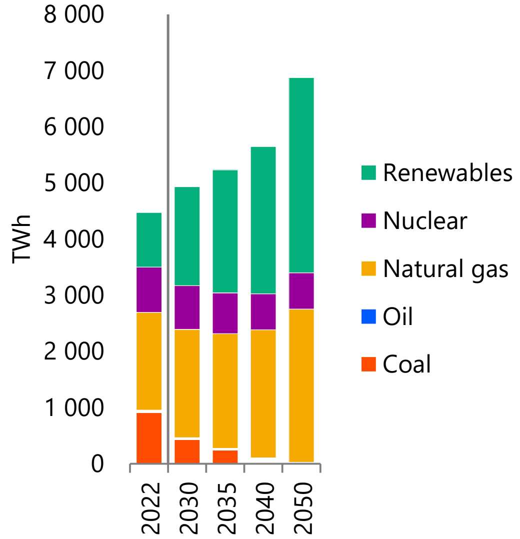
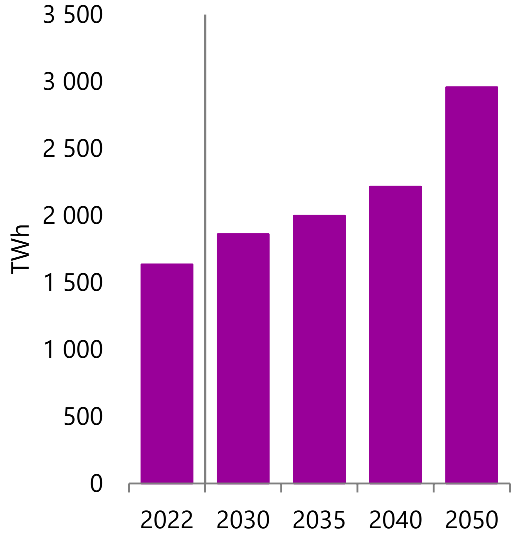


Figure 8-10 | Supply and demand of electricity in the United States [Reference Scenario]





Though more and more renewable power generation sources are being introduced for the energy transition to carbon neutrality, the output of variable renewable energies such as solar photovoltaics and wind fluctuates with the weather and season. As such, with the increase in renewable power sources, the importance of power sources with grid-balancing capabilities that can sustain a stable electricity supply, such as thermal, nuclear and storage batteries, is growing. To make the electricity supply more reliable, it is necessary to secure diverse power sources and to keep the supply and demand in balance, both in the short term and the long-term.

Risks related to a stable electricity supply

There are various risks in maintaining a stable supply of electricity. Among these risks are 'black swan' incidents that are hard to predict. Examples include the 'space weather' risk, the risk of unprecedented natural disasters, and the risk of an electromagnetic pulse disturbance. Space weather risk refers to disturbances in the Earth's magnetic field caused by strong solar flares and magnetic storms, which seriously affect the power grid. The risk of unprecedented natural disasters refers to the risk of an unexpectedly large natural disaster that damages multiple power sources and distribution and transmission systems at the same time. The risk of an electromagnetic pulse disturbance refers to the risk of electronic devices and electricity infrastructure becoming dysfunctional across a wide area as a result of a nuclear explosion or electromagnetic pulse attack. These 'black swan' events are not taken into consideration in this discussion. In this section, we will focus on risks that are reasonably foreseeable and have a strong impact.

First, main possible risks related to electricity supply include the risk of a decline in fossil fuel supply, the risk of fluctuations in fossil fuel prices, geopolitical risk, and the risk of output fluctuations of renewable power sources. While fossil fuels are a major energy source for power generation, they are prone to the risk of a supply crunch triggered by a drop in output in supplier countries and an increase in international demand, which in turn cause prices to soar. For fossil fuel importers including Japan, which relies on other countries for most of its energy resources, political and policy instability and conflicts in supplier countries and disruption of transportation routes are likely to affect their electricity supply directly. Unstable output of solar photovoltaics and wind power generation caused by climatic and seasonal fluctuations is also a risk. These fluctuations occur irrespective of demand and therefore may affect the entire electricity supply.

Next, the main possible risks related to electricity demand include the risk of an increase in electricity demand and the geographical concentration of electricity demand facilities. As the electrification of society makes progress, electricity demand is likely to rise with the increase in electric vehicles and data centres, among other factors. This increase may cause demand to exceed the supply capacity, and the supply and demand to go out of balance, triggering a power shortage. A rapid increase in demand in urban areas and industrial agglomerations in particular imposes a heavy burden on the electricity infrastructure. Furthermore, a concentration of demand in certain regions or a certain period may trigger a concentration of electricity demand facilities. For example, the concentrated use of air-conditioners and heaters in summer and winter can cause extremely high peak demand levels in certain areas. There is a risk for such concentration to cause the electricity supply to tighten in certain areas or periods, affecting the electricity supply as a whole.

Addressing risks related to a stable electricity supply

To address the risks related to a stable electricity supply, it is essential to purchase thermal power generation fuels and secure baseload power sources. Dependence on natural gas-fired power generation may rise in the short term, and so it is necessary to purchase the fuels accordingly in a stable manner. However, having limited natural resources, Japan depends on imports for most of its natural gas supply and is therefore susceptible to geopolitical risks, political circumstances in supplier countries, price fluctuations caused by the condition of transportation infrastructure and supply disruptions. One possible approach is for demand facilities to incorporate clauses on long-term fuel procurement in the long-term power purchase agreement (PPA) for thermal power generation when they sign one with a power producer. Also, to mitigate risks in fuel procurement and achieve carbon neutrality, it is also important, in the long-term, to promote the development of renewable energies that can serve as baseload power sources such as hydro, geothermal and biomass, and to consider introducing nuclear power plants including small modular reactors (SMRs) which are currently attracting attention. It is also necessary to mitigate the risk of output fluctuations of renewable power sources by introducing storage batteries, pumped-storage hydro power generation and other energy storage technologies.

To address the risk of an increase in electricity demand, it is important to secure supply capacities to respond to a rapid increase in electricity demand. The capacity market can be relied on to a certain extent, but that alone is not sufficient. It is necessary to introduce a system like Japan's Long-term Decarbonisation Power Resource Auction, which promotes the installation of new power sources, and to establish a system to maintain suspended power sources as reserves for securing additional emergency supplies in an emergency. Also, it is important to encourage demand facilities to have their own backup power sources and voluntarily use them as demand response (DR) resources by sharing best practices and expanding their use, as preparations for emergencies and electricity supply-demand crunches. Another solution may be to establish a stable electricity supply system by permitting demand facilities that have a long-term power purchase agreement with power producers to connect to the grid with priority.

To address the risk of concentration of electricity demand facilities, it is necessary to optimise the power grid. Transmission and distribution operators need to coordinate with demand facilities so that those facilities can be located close to power sources or in regions with sufficient transmission capacity. For example, the concentration of demand can be prevented by having transmission operators publish data on transmission capacity as appropriate, thereby clearly indicating 'welcome zones' for installing new demand facilities. Also, when connecting a demand facility to the grid in a region with insufficient transmission capacity, it is possible to consider giving priority to facilities that are ready to bear the cost of improving the grid. It is also important to avoid grid improvements by promoting the use of co-located load, in which electricity is supplied directly from the source, and by utilising dynamic line rating, in which the transmission capacity is optimised dynamically according to weather and other conditions.

As described above, a stable electricity supply is vital for modern society and its importance is growing with the progress in digitisation and electrification. While electricity demand is growing with the increase in electric vehicles and data centres, new renewable power generation capacities are also increasing. However, variable renewable energies are unstable in output. As such, power sources with grid-balancing capabilities such as thermal power generation, nuclear power generation and storage batteries are required to keep the electricity supply stable. Risks in electricity supply include drops in the supply of fossil fuels, dependence on fossil fuel imports, and output fluctuations of renewable power sources. To address these risks, it is important to secure stable fuel procurement and introduce geothermal and nuclear power sources. Also, to address the risk of surges and concentration of electricity demand, it is necessary to install new power sources, utilise reserve power sources, and optimise the grid. These measures will allow a stable supply of electricity to be maintained while keeping the supply and demand in balance.

Table 8-1 | Risks related to a stable electricity supply: challenges and solutions

Risk	Challenge	Solution
Decrease in fossil fuel supply Fluctuation of fossil fuel prices Geopolitical risks Renewable power source output fluctuations	Procuring thermal power generation fuels and securing baseload power sources	Incorporating clauses on long-term fuel procurement when the consumer signs a PPA with the power producer Purchasing stable power sources such as nuclear and geothermal by demand facilities
Increase in electricity demand	Securing supply capacity	Introducing a system to support the introduction of new power sources Demand facilities to have their own backup power generation facilities
Geographical concentration of electricity demand facilities	Optimising the power grid	Locating demand facilities in the vicinity of power sources Publishing information on zones where demand facilities are welcomed Dynamic line rating for transmission lines

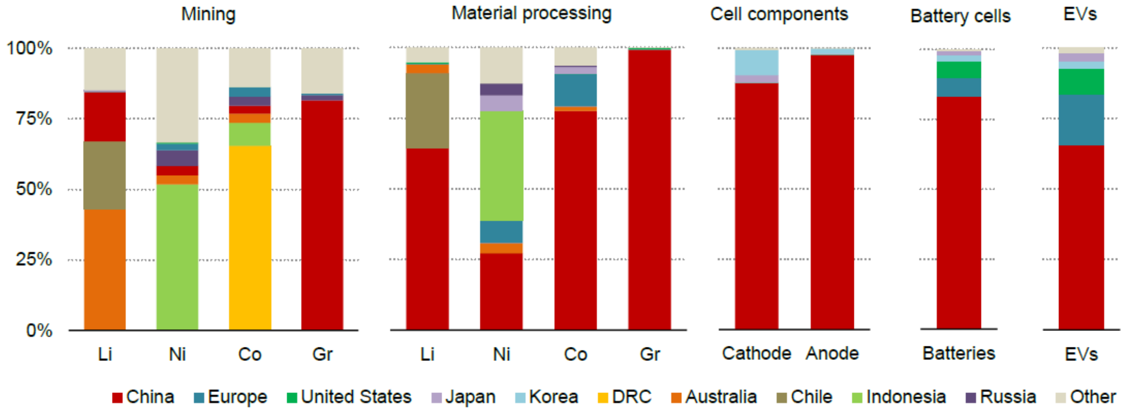
8.4 Risks in the supply of critical minerals

Risks for clean energy

The basic strategy for decarbonisation is to meet demand as much as possible with electricity (electrification) while thoroughly pursuing energy efficiency, and generating that electricity with renewables, nuclear and other carbon-free energies. These changes also help improve Japan's energy self-sufficiency rate. Since the oil crises, energy security has formed the core of Japan's energy policy. Reducing its dependence on imported fossil fuels has been Japan's long-cherished wish and decarbonisation is a golden opportunity for strengthening energy security.

Meanwhile, a new security issue has emerged in recent years. It is geopolitical risks associated with clean technologies and the minerals necessary for their manufacture (critical minerals). As an example, Figure 8-11 shows the share of each country in the supply chains for electric vehicle storage batteries. For manufacturing lithium-ion batteries, in addition to lithium, materials such as cobalt and nickel are often used as cathode materials and graphite as an anode material. The charts for the 'Mining' phase show that Australia, Indonesia, the Democratic Republic of Congo (DRC) and China all account for roughly half of the total or more. Note that for crude oil production, the United States, the world's largest producer, accounts for just 20%, followed by Saudi Arabia and Russia with just 10% each. In comparison, we can see that there is a significant geographical concentration of the critical minerals necessary for producing storage batteries. The concentration of producer countries is even greater for the 'Material processing' phase in which minerals are refined and semi-finished products are made. For lithium, cobalt and graphite in particular, China's shares are even greater. The concentration is even greater for the production of cathodes, anodes and battery cells using refined minerals, around 90% of whose global manufacturing capacity is located in China.

Figure 8-11 | Share of each country in the supply chains for electric vehicle storage batteries



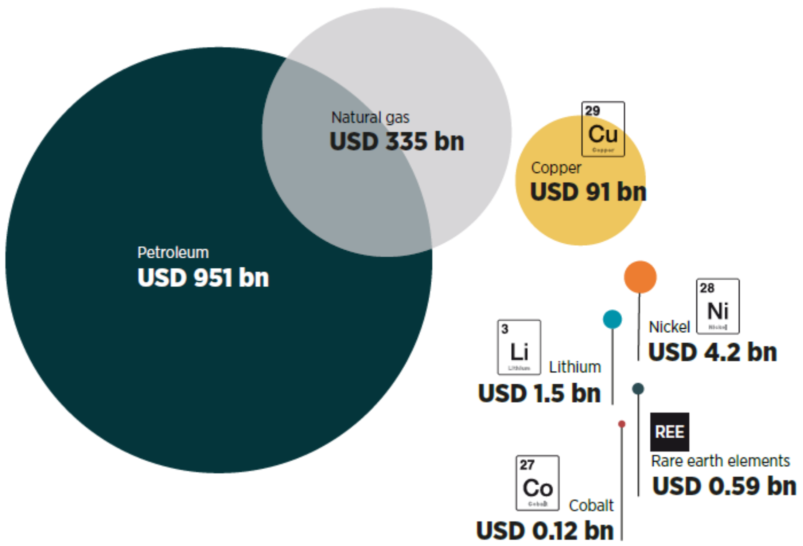
Note: Li = lithium, Ni = nickel, Co = cobalt, Gr = graphite, DRC = Democratic Republic of the Congo
Source: IEA (2024) "Global Critical Minerals Outlook 2024"

Alongside storage batteries, China also has a large share of manufacturing capabilities related to solar photovoltaic panels and wind turbines backed by its enormous domestic market and high price competitiveness, accounting for 80% and 60%, respectively (IEA, 2023). As shown by these facts, decarbonisation that relies on solar photovoltaic, wind, storage batteries and electric vehicles means higher dependence on certain countries. History has demonstrated that the concentration of import sources is a risk. For critical minerals, for example, Japan has had a bitter experience with China. In 2011, China stopped exporting rare earths to Japan after an incident over the Senkaku Islands. As Japan then relied on China for 80% of its rare earth supplies, this caused great disturbances in the industries that needed these minerals. Also, in recent years, resource-rich countries have become aware of the importance of mineral resources and are strengthening state control over them. Not only the oil crises but the Russia-Ukraine war is testimony to the fact that resource-rich countries may weaponise their resources when a dispute arises. Although a supply disruption situation has fortunately not occurred so far, we must recognise that the risk exists and that it could have a serious impact.

Challenges in the stable supply of critical minerals

Recognising the existence of these risks, Japan and other countries are working to diversify their critical mineral supply chains. The effort involves producing and refining minerals and manufacturing products in the home country, and when that becomes difficult, building a new supplier different from the current one. Diversifying supply chains, however, is not easy. The first factor behind the difficulty is the immaturity of the markets. The sizes of critical mineral markets are extremely small compared to those for energy commodities (Figure 8-12). The transaction opportunities themselves are limited due to the small number of participants and trade volume, and in addition, the environment is prone to supply-demand mismatches and associated price fluctuations.

Figure 8-12 | Typical export value of major resources [2021]



Source: (UN COMTRADE database).
Note: Numbers represent trade in raw, unprocessed fuels and ores only.

Source: IRENA (2023) "Geopolitics of energy transition, Critical Minerals"

Second, the motivation for development spiked simultaneously in advanced economies, increasing the risk of 'fights' over resources. This would lead to instability in the supply-demand balance and prices.

The third factor is the intensive energy consumption and the high environmental stress in the refining process. Refining is a process in which mineral ores are melted and decomposed with heat, acid, and through electrolysis to extract necessary minerals that consumes much energy. Furthermore, the residues arising from this process contain toxic substances which, if mishandled, could damage the environment and people's health. The energy-intensive nature of mineral refining and the need for advanced environmental protection set high economic hurdles for conducting refining in advanced economies.

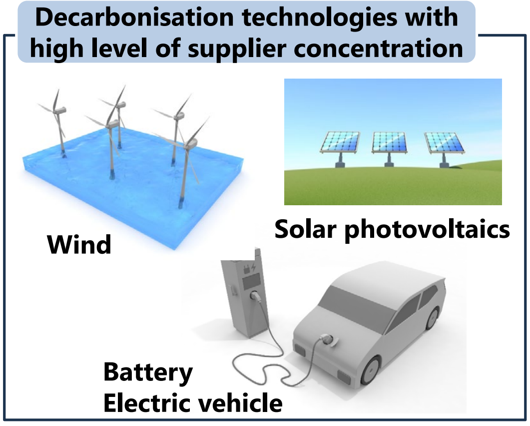
The fourth factor is the uncertain future of clean technologies and the long lead-time required for resource development. One example is cathode materials for storage batteries, which have changed significantly in just the past five years or so and products with less or without cobalt or nickel are also being widely used. Given the variety of technologies being developed, the definition of critical minerals themselves may change in a decade or so. On the other hand, the lead-time for developing mineral resources can sometimes be 10 years or more, creating a high hurdle for private companies to make investment decisions.

To overcome these issues and achieve a stable and secure supply, it is essential to have in place a consistent long-term policy, and for the supply and demand sides to coordinate the progress of development. The aim is to mitigate investment risk by having buyers and sellers make a mutual commitment under a long-term strategy.

Mixing technologies to mitigate risks

Risks for clean energy can be mitigated through the technology mix as well. While Japan is highly dependent on certain countries for solar photovoltaics, wind, storage batteries and electric vehicles, its suppliers of boilers and gas turbines, internal combustion engines (ICEs) and nuclear technologies are relatively diverse, with Japanese companies being highly competitive in many areas. The use of boilers, gas turbines and internal combustion engines can be decarbonised by switching fuels to hydrogen, ammonia, various synthetic fuels and gas and biomass. Also, thermal power plants and large industrial combustion facilities can be used cleanly by installing carbon capture and storage (CCS) systems in them. By appropriately combining clean technologies that have a low level of concentration in certain supplier countries, for the energy system as a whole, it is possible to mitigate the risk of a few countries dominating the supply of technology (Figure 8-13).

Figure 8-13 | Concentration of supplier countries that vary by technology



Decarbonisation technologies with low level of supplier concentration

- **Thermal power generation with CCS**
- **Hydrogen-/ammonia-fired power generation**
- **Nuclear**
- **Use of synthetic methane as city gas**
- **ICEV that uses zero-emission fuels (biofuels, synthetic fuels), HEV, PHEV**

Note: ICEV = internal combustion engine vehicle, HEV = hybrid vehicle, PHEV = plug-in hybrid vehicle

8.5 Mounting risk of cyber attacks with the energy transition

Cyber attacks on energy supply-related facilities are also emerging as a new risk for energy security. Such attacks have already occurred in energy-related facilities, resulting in energy supply disruption incidents in some cases. The importance of cyber attacks as a potential risk factor is expected to grow as electrification and digitalisation proceed, driven by the energy transition. Furthermore, the relationship between cyber attacks and geopolitical risks cannot be ignored; the weaponisation of cyber attacks poses a threat to energy supply. This section describes the relationships between the energy transition and cyber attacks, and the patterns of cyber attacks expected going forward.

What is a cyber attack?

A cyber attack generally refers to an incident in which the confidentiality and availability of digital information and information systems are breached by external access, while cyber security refers to the ability to avoid and guard against cyber attacks by securing the availability and confidentiality of information networks and infrastructure[65]. One of the characteristics of a cyber attack is that the perpetrator, aim, or scope of the attack is not immediately apparent. Even if one's own assets are found to be a target of a cyber attack, in many cases, the victim does not know who is attacking and for what purpose. In the case of a breach of a company's computer network, the company often does not realise the attack and the damage can continue to spread unnoticed in some cases. In particular, it is extremely difficult to know in advance how or when a cyber attack is going to occur, which is why cyber attacks are said to be almost impossible to guard against completely.

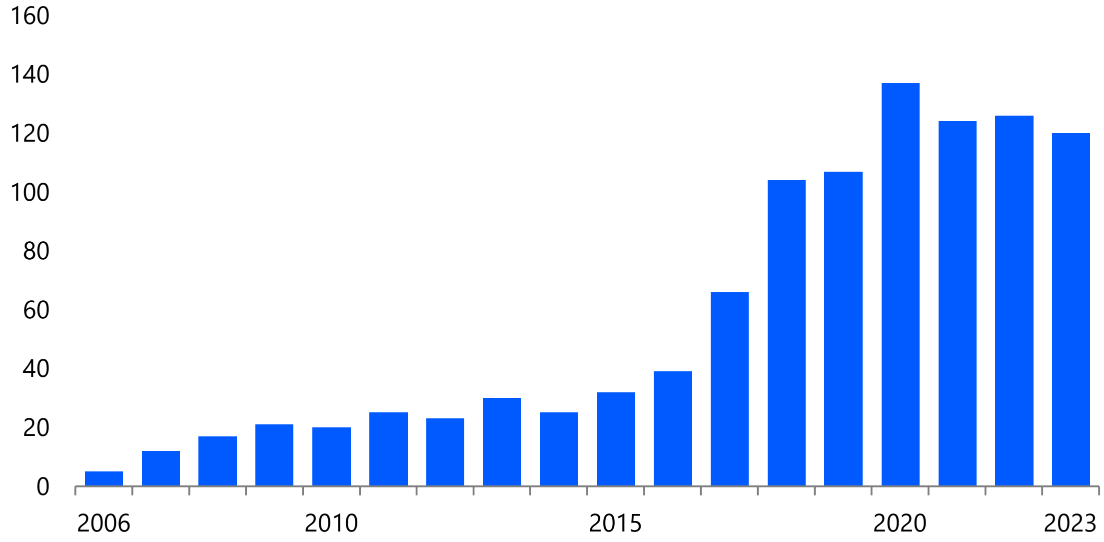
Cyber attacks can be divided roughly as follows: an attack to extort 'ransom money' by using ransomware and other software to obtain the target's personal information or other data or stop the target computer system from operating; and an attack aimed at damaging or disrupting the target's economic activity itself. The former mainly targets companies; an attack on a major media company recently made the news in Japan. From the perspective of energy security, the latter type, which disrupts the target's economic activity itself, may appear more harmful than cyber attacks for ransom. However, as discussed later, considering that a ransomware attack may cause the target to shut down their energy security infrastructure preventively, both types of attacks are potential threats to energy security.

Cyber attacks on energy supply facilities

The risk of cyber attacks on energy-related assets itself is not necessarily a new risk, as mentioned earlier. However, the number of major cyber attack incidents has soared since the late 2010s (Figure 8-14) and many cases have been reported. One example is the cyber attack on several German wind power generators in April 2022, resulting in the loss of the ability to operate the power generation facilities remotely. In August 2022, Italy's state-owned energy services firm GSE was hit by a cyber attack, resulting in blocked access to its information systems and a week-long shutdown of their websites. In March 2024, the Indian government and energy companies were attacked by malware disguised as an email from the Indian Air Force. Attacks on energy supply facilities could have an extensive impact if they succeed, which makes those facilities an extremely 'effective' and 'valuable' target for the attackers.

[65] International Energy Agency. (2021). Enhancing Cyber Resilience in Electricity Systems. p. 8.

Figure 8-14 | Number of major cyber attack incidents worldwide



Note: A major cyber attack incident is one which targets government organisations or the defence or the high-tech sector or results in damage exceeding $1 million
Source: Created based on: International Energy Agency (2021) "Cyber Resilience", Center for Strategic and International Studies (2024) "Significant Cyber Incidents"

The most well-known recent cyber attack on energy supply facilities is the attack on U.S. pipeline company Colonial Pipeline in 2021. The company operates pipelines to transport petroleum products from the U.S. Gulf Coast to the Northeast region and has an extremely large transportation capacity of 2.5 Mb/d, accounting for 45% of the region's demand. The cyber attack occurred on 7 May 2021 when a ransomware called Darkside breached the company's network and encrypted nearly 100 GB of the company's data. In response, the company voluntarily stopped the pipelines to locate the damage and prevent it from spreading[66]. The attack also forced some refineries on the Gulf Coast to shut down because the sales routes for their petroleum products were cut off. The pipelines eventually went back up between 12 May and 15 May but there were petrol shortages at many petrol stations in some regions, for example in the U.S. capital of Washington D.C. where 70% of petrol stations ran short of fuel (the impact on end product prices was limited because the attack occurred in the off-peak season for petrol, the main product, and the pipelines resumed operations relatively quickly[67]).

Another well-known case is the cyber attack on Ukraine's power grid in 2015. On 23 December 2015, three electricity distribution companies in western Ukraine were hit almost simultaneously by mass access attempts, resulting in substations being switched off. As a result, power was cut off for 225 000 people in Ukraine for up to six hours. The attacks occurred in the cold year-end season and immediately before the Christmas holidays and had an enormous impact on the lives of Ukrainian citizens. In addition to these attacks, Ukraine has been hit on and off by various types of cyber attacks allegedly by Russia since Russia's annexation of Crimea in 2014 and the

[66] Although the actual attack was on the company's billing system, not the pipeline's operations system, the company proactively shut down the pipeline to identify the target of the attack.
[67] Kevin Schaul, Tim Meko and Dylan Moriarty (2021) "Map of dry gas stations impacted by cyberattack" *The Washington Post*. https://www.washingtonpost.com/business/interactive/2021/map-gas-shortages/?itid=lb_colonial-pipeline-hack-what-you-need-to-know_8 (Accessed 21 September 2024)

situation still continues[68]. In June 2017, the Chornobyl Nuclear Power Station was hit by malware called NotPetya, which destroyed files in 13 000 computers of the station and other public organisations and rendered them irrecoverable[69]. Cyber attacks are also starting to be carried out in tandem with physical military operations, such as the cyber attacks on Ukraine's satellite network one hour before Russia began to invade Ukraine on 24 February 2022[70].

The risk of being hit by cyber attacks will rise in the energy supply, storage and utilisation sectors with the progress of the energy transition[71]. First, with the energy transition, the energy supply sector is expected to shift away from the conventional, centralised energy supply system run by dominant energy suppliers to one consisting of more diverse players from various fields. This means that the number of possible cyber attack targets will increase, making it more difficult to safeguard the energy supply business from such attacks.

The increased use of information and communication technologies (ICT) for managing facility operations in the energy supply sector will also heighten the risk of cyber attacks. Renewable energy and other power generation facilities introduced going forward will likely be installed with the surveillance control and data aggregation (SCADA) system, which aggregates large volumes of data via the internet to manage overall operations. The purpose is to ensure a stable supply of renewable electricity, whose output tends to fluctuate, by collecting and using weather forecast data and demand information to optimise plant operation. Integrating conventional operational technologies (OT) with ICT helps optimise operations and improve efficiency further. On the other hand, these systems inherently make the energy system more vulnerable to cyber attacks as they are connected to large numbers of personal computers and instrumentation devices via a computer network. Especially since plant operation is expected to be gradually automated under the SCADA system, it may become increasingly difficult to control the impact on operations in the event of a cyber attack. Furthermore, if an online cloud service is used to manage the bulk operations data collected from these systems, the connection to the cloud could also be targeted by an attack.

In the energy storage sector, the forecasted greater use of storage batteries driven by electrification and new renewable energy capacities will increase the risk of cyber attacks. Like the SCADA system in the energy supply sector, a battery management system (BMS), which remotely

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68 Stéphane Duguin and Pavlina Pavlova (2023) "The role of cyber in the Russian war against Ukraine: Its impact and the consequences for the future of armed conflict" European Parliament's Subcommittee on Security and Defence (SEDE)
https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/702594/EXPO_BRI(2023)702594_EN.pdf (Accessed 26 September 2024)

69 European Parliamentary Research Services (2022) "Briefing: Russia's war on Ukraine: Timeline of cyber-attacks"
https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/733549/EPRS_BRI(2022)733549_EN.pdf#:~:text=Ukraine%20has%20been%20a%20permanent%20target%20of%20Russian%20cyber-attacks%20since (Accessed 21 September 2024)

70 Council of the European Union (2022) "Russian cyber operations against Ukraine: Declaration by the High Representative on behalf of the European Union." https://www.consilium.europa.eu/en/press/press-releases/2022/05/10/russian-cyber-operations-against-ukraine-declaration-by-the-high-representative-on-behalf-of-the-european-union/#:~:text=The%20EU%20issued%20a%20declaration%20strongly%20condemning%20the%20malicious%20cyber (Accessed 21 September 2024)

71 The information of this section refers to the following report: Sneha Dawda, Chamin Herath and Jamie MacColl (2022) "Securing a Net-Zero Future: Cyber Risks to the Energy Transition"
https://static.rusi.org/305-EI-Cyber-Risks.pdf (Accessed 21 September 2024)

manages the charging and discharging operations of storage batteries, is expected to be installed in this sector. If these management systems are breached from the outside, it will be possible to control charging and discharging with malicious intent, disrupting the stable supply of electricity.

Similar risks apply to the energy usage sector as well. In the transportation sector, where battery electric vehicles (EVs) are set to increase, the increase itself could mean more attacking points for cyber attacks. Going forward, many EVs on the roads are expected to be mutually connected via the network to provide various services to drivers while onboard. While transforming how people travel and improving user convenience, these services are implemented via external internet connections and therefore heighten the risk of cyber attacks. Also, once the system on an EV is breached, the impact of the attack can spread to appliances at home if the EV is connected to the home power supply system.

In the energy use sector, smart houses and the Internet of Things (IoT) in buildings can also increase attacking points for cyber attackers. For the efficient use of energy, more and more buildings are expected to be fitted with systems that gather electricity consumption and temperature control data in the house, or that control energy-using devices. Energy management for such buildings will use network connections, like the various systems described earlier, and may thus provide new entry points for cyber attacks. Smart metres, which are widely used in the residential and commercial sectors in many countries, may also be a target as they are connected via external networks[72].

Expected patterns of cyber attacks

There are many types of cyber attacks and it is not easy to determine which scenarios to expect. However, past cyber attacks show that there are representative patterns in the path, method and format of the attacks. This section introduces typical patterns of cyber attack scenarios that we anticipate.

Pattern 1: Remote manipulation via malware

The first pattern is remote manipulation via malware. 'Malware' is short for malicious software and refers to software created to damage computers and networks. With this pattern of attack, the attacker first somehow establishes access to the target from the outside. Common ways to do this are sending a phishing email to employees of the target disguised as someone related to the workplace, and when the recipient clicks on the file attached to the email, the attacker enters the network via the recipient's computer. Other patterns include the attacker inserting a virus into the target's network via a universal serial bus (USB) memory stick or other device by physically entering the target's premises. Yet another method is to plant a device or a virus that causes network malfunctions in a device delivered to the target, and to activate the device or virus after a certain amount of time. Once access is established through these methods, the attacker remotely operates the network to execute attacks such as causing malfunctions in power plant instrumentation and shutting down operations of the target's assets. Examples include attacks on a Ukrainian power generation utility in 2015 and on a German wind power generator in 2022, both described earlier. It should be noted that while these attacks are carried out by a variety of parties, based on their nature, these attacks may involve state entities.

[72] *The Blackout* (2012, Kadokawa Shoten) by Marc Elsberg (translated by Inomata Kazuo and Takenouchi Etsuko) is a purely fictional novel that depicts the enormous damage that could result from simultaneous attacks on both upstream (power generation) and downstream (metres) in an electricity supply network.

Pattern 2: Causing system malfunctions through a malware

Another pattern of attack is causing the target's systems to malfunction using malware. This pattern is the same as remote manipulation up to the injection of the malware into the target's computer systems, but thereafter, the malware is simply used to shut down the system. An example of this type of attack is the one on Italy's energy agency in 2022. In this example, access to the agency's in-house computer systems was blocked and its website was inaccessible for a week. As with Pattern 1, there are a variety of possible attackers for this type but these attacks may involve state entities.

Pattern 3: Data encryption using ransomware

The third pattern is the so-called cyber attack for ransom, in which the attacker breaches the target's system and encrypts the data, and later demands that the target pay ransom money in exchange for decrypting the data. The attack mainly aims to extort ransom payments and not necessarily to damage energy facility operations directly, but if the target chooses to shut down the system to prevent data leaks, this disrupts the supply of energy by the target. As an example, the attacks on the U.S. petroleum product pipeline company Colonial Pipeline in 2020 fall under this category. These attacks are carried out mostly by for-profit, private cyber attack groups.

Pattern 4: Taking down the system by DDoS attacks

Last, while the above three patterns involve breaching the target's systems, there are other possible types of cyber attacks. One way is to cause the company's systems to malfunction with superfluous simultaneous accesses to the target. Superfluous accesses are also used to stop a company's computer system from operating. This type of attack is called a distributed denial-of-service (DDoS) attack and was carried out on a Lithuanian energy company in 2022. This type of attack can be perpetrated by a variety of parties, but sometimes with the involvement of a state entity, as in patterns 1 and 2.

The four patterns of cyber attacks have actually been carried out on energy supply-related assets in the past and new patterns of attack may emerge going forward. Also, the situation in Ukraine and other countries shows that we must not ignore the relationship between cyber attacks and geopolitical risks; cyber attacks may be weaponised in more and more state conflicts going forward. Cyber attacks on energy-related assets are almost certain to increase, so the latest status including in other countries must be monitored.

Countermeasures against cyber attacks

It is difficult to guard completely against cyber attacks, as there are numerous types and their aim or scope may not be identified immediately. Nevertheless, it is necessary to take the following countermeasures to prepare for cyber attacks to minimise the damage and restore the system as soon as possible[73].

Countermeasures against cyber attacks require coordination between the government and companies while they both prepare their own countermeasures. First, the countermeasure that should be taken by the government is to develop an institutional system. The government must define the scope of responsibility of government ministries and agencies, public organisations

[73] The information of this section refers to the following report: Ecofys. (2018). *Study on the Evaluation of Risks of Cyber-Incidents and on Costs of Preventing Cyber-Incidents in the Energy Sector*; IEA. (2021). *Enhancing Cyber Resilience in Electricity Systems*; World Energy Council (2022). *Cyber Challenges to the Energy Transition*; METI's Information-technology Promotion Agency (IPA) (2022). *Guide to establishing a cybersecurity system and securing human resources, 2nd edition*

and private sector corporations, and if any entities are slow to act, put in place policies and systems to urge their action. Another role of the government is to provide frameworks and 'forums' in which the parties involved can collaborate and share information across organisational boundaries. From the risk management perspective, in addition to identifying and managing risks in their own information systems, which goes without saying, it is the government's important role to urge private sector companies to identify risks including the locations of vulnerabilities in their own supply chains and what actual cyber attack risks there are, and to constantly monitor those risks. Other countermeasures that only governments can take include collaborating with national intelligence departments to gather information on cyber attacks and take measures against them. It is also necessary to anticipate specific types of cyber attacks, prepare clear recovery plans and procedures to minimise the risk, and regularly conduct drills.

As for corporations, they must first identify the risks in their businesses and supply chains and evaluate their seriousness, determine which of their assets are susceptible to cyber attacks, and evaluate the impact in case they are hit, as needed. Once a risk or asset is identified, the company must set procedures for managing the risk to minimise its impact and prepare to respond in case an attack occurs, including setting priorities for various countermeasures to take. Furthermore, any risks and highly vulnerable assets identified in the process must be monitored routinely, and it is important to prepare recovery plans to ensure quick recovery if an attack occurs, and to regularly conduct drills based on those plans.

There are also countermeasures that should be implemented under public-private collaboration. The first is raising awareness of cyber security. As already described, many cyber attacks on energy-related assets are carried out by sending malware to persons related to the target. The method of sending malware is becoming increasingly sophisticated each year; for example, for an attack on a government organisation, an email may be disguised as one from another government organisation. Raising awareness of cyber security and constantly being on alert is particularly important for energy supply-related organisations that play an essential role in society. Another important factor in preventing cyber attacks is sharing information. Information sharing is currently insufficient because, presumably, not all companies hit by an attack are disclosing their information. This is often because some of the information cannot be shared with third parties but sharing incident information to the extent possible between public and private sectors does strengthen preparedness against attacks. Public-private collaboration will also enable more effective development of measures for ensuring resilience against cyber attacks. Furthermore, skilled cyber security staff could be trained more effectively if carried out jointly between the public and private sectors, rather than by each organisation. As part of this initiative, as with information sharing mentioned earlier, an important countermeasure that calls for joint public-private efforts is widely sharing past cyber attack incidents and considering training and responses based on the lessons learned from them.

Annex

The EDMC Energy Databank provides even more data to its members.

Table A1 | Regional groupings

Asia	People's Republic of China	
	Hong Kong (China)	
	India	
	Japan	
	Korea	
	Chinese Taipei	
	ASEAN	Brunei Darussalam
		Cambodia
		Indonesia
		Lao People's Democratic Republic
		Malaysia
		Myanmar
		Philippines
		Singapore
		Thailand
		Viet Nam
	Other Asia	Bangladesh, Democratic People's Republic of Korea, Mongolia, Nepal, Pakistan, Sri Lanka, and Other non-Asia in IEA statistics
North America	Canada	
	United States	
Latin America	Brazil	
	Chile	
	Mexico	
	Other Latin America	Argentina, Plurinational State of Bolivia, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Bolivarian Republic of Venezuela, and Other non–OECD Americas in IEA statistics
Europe	Advanced Europe	France
		Germany
		Italy

		United Kingdom	
		Others	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Iceland, Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, and Republic of Türkiye
	Other Europe/Eurasia	Russian Federation	
		Other Former Soviet Union	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan
		Other Emerging and Developing Europe	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Gibraltar, Kosovo, Malta, Montenegro, Republic of North Macedonia, Romania, and Serbia
Africa	South Africa (Republic of)		
	North Africa	Algeria, Egypt, Libya, Morocco, and Tunisia	
	Other Africa	Angola, Benin, Botswana, Cameroon, Republic of the Congo, Democratic Republic of Congo, Côte d'Ivoire, Eritrea, Kingdom of Eswatini, Ethiopia, Gabon, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, South Sudan, Sudan, Togo, United Republic of Tanzania, Uganda, Zambia, Zimbabwe, and Other Africa in IEA statistics	
Middle East	Islamic Republic of Iran		
	Iraq		
	Kuwait		
	Oman		
	Qatar		
	Saudi Arabia		
	United Arab Emirates		

	Other Middle East	Bahrain, Israel, Jordan, Lebanon, Syrian Arab Republic, and Yemen
Oceania	Australia	
	New Zealand	
International bunkers		
European Union	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, and Sweden	
Advanced Economies	Advanced Europe, Hong Kong, Japan, Korea, North America, Oceania, Singapore, and Chinese Taipei	
Emerging and Developing Economies	Africa, Brunei Darussalam, Cambodia, People's Republic of China, India, Indonesia, Lao People's Democratic Republic, Latin America, Malaysia, Middle East, Myanmar, Other Europe/Eurasia, Other Asia, Philippines, Thailand, and Viet Nam	
Group of Seven	Canada, France, Germany, Italy, Japan, United Kingdom, and United States	
Organization of the Petroleum Exporting Countries (OPEC)	Algeria, Republic of the Congo, Equatorial Guinea, Gabon, Islamic Republic of Iran, Iraq, Kuwait, Libya, Nigeria, Saudi Arabia, United Arab Emirates, and Bolivarian Republic of Venezuela	

Notes: (1) Other Former Soviet Union includes Estonia, Latvia and Lithuania before 1990, and (2) Advanced Economies, and Emerging and Developing Economies include regions.

Table A2 | International energy prices

Real prices			Reference			Advanced Technologies		
		2023	2030	2040	2050	2030	2040	2050
Oil	$2023/bbl	82	85	90	95	80	75	70
Natural gas								
Japan	$2023/MBtu	13.7	9.3	8.8	8.5	9.0	8.1	7.6
Europe (Netherlands)	$2023/MBtu	13.1	9.8	9.7	9.5	9.7	9.2	8.8
United States	$2023/MBtu	2.5	3.0	4.0	4.0	3.4	4.1	4.0
Steam coal	$2023/t	243	105	110	110	100	95	90

Nominal prices			Reference			Advanced Technologies		
		2023	2030	2040	2050	2030	2040	2050
Oil	$/bbl	82	105	153	225	98	125	160
Natural gas								
Japan	$/MBtu	13.7	11.5	14.8	20.1	11.0	13.4	17.3
Europe (Netherlands)	$/MBtu	13.1	12.0	16.4	22.4	12.0	15.2	20.0
United States	$/MBtu	2.5	3.7	6.8	9.5	4.2	6.8	9.1
Steam coal	$/t	243	130	186	260	123	158	206

Table A3 | Population

	(Million)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	5 286	6 135	6 960	7 940	8 476	8 784	9 069	9 324	9 541
Asia	2 955	3 454	3 874	4 308	4 479	4 567	4 634	4 677	4 694
China	1 135	1 263	1 338	1 412	1 385	1 361	1 331	1 294	1 249
India	870	1 060	1 241	1 417	1 516	1 570	1 613	1 646	1 670
Japan	123	127	128	125	120	116	112	109	105
Korea	43	47	50	52	51	50	49	47	45
Chinese Taipei	20	22	23	23	22	22	21	20	19
ASEAN	440	524	599	679	716	735	751	762	768
Indonesia	182	214	244	276	292	301	308	314	317
Malaysia	18	23	29	34	37	39	41	42	43
Myanmar	40	46	49	54	57	58	59	59	59
Philippines	62	78	95	116	123	128	131	134	136
Singapore	3.0	4.0	5.1	5.6	6.0	6.1	6.2	6.1	6.1
Thailand	55	63	68	72	71	71	69	68	66
Viet Nam	67	79	87	98	103	105	107	108	108
North America	277	313	343	372	389	398	405	412	417
United States	250	282	309	333	347	355	361	367	372
Latin America	438	518	586	657	690	707	720	729	734
Brazil	151	176	196	215	221	223	224	224	223
Advanced Europe	505	528	557	583	585	584	582	578	572
Other Europe/Eurasia	337	335	332	338	339	340	340	341	342
Russia	148	147	143	144	141	139	137	136	135
Africa	620	794	1 021	1 377	1 643	1 816	1 993	2 170	2 344
Middle East	133	171	220	274	316	338	359	379	398
Oceania	20	23	26	31	33	35	36	37	38
International Bunkers	-	-	-	-	-	-	-	-	-
Advanced Economies	998	1 070	1 140	1 199	1 214	1 217	1 218	1 215	1 209
Group of Seven	652	699	740	775	787	792	795	796	796
Emerging and Developing Economies	4 288	5 065	5 820	6 741	7 262	7 567	7 851	8 108	8 331
Emerging and Developing Asia	2 759	3 247	3 661	4 095	4 272	4 366	4 438	4 489	4 513
Non-Asia	2 331	2 681	3 086	3 632	3 997	4 218	4 435	4 646	4 847
European Union	420	429	442	447	445	442	438	433	426

Source: United Nations "World Population Prospects 2024", World Bank "World Development Indicators"
Note: Same value for Reference Scenario and Advanced Technologies Scenario

CAGR (%)				
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
1.3	0.8	0.7	0.5	0.7
1.2	0.5	0.3	0.1	0.3
0.7	-0.2	-0.4	-0.6	-0.4
1.5	0.8	0.6	0.3	0.6
0.0	-0.6	-0.6	-0.6	-0.6
0.6	-0.1	-0.4	-0.8	-0.5
0.4	-0.5	-0.6	-0.9	-0.7
1.4	0.7	0.5	0.2	0.4
1.3	0.7	0.5	0.3	0.5
2.1	1.1	0.9	0.7	0.9
0.9	0.6	0.3	0.1	0.3
2.0	0.8	0.7	0.4	0.6
1.9	0.8	0.3	-0.2	0.3
0.8	-0.1	-0.2	-0.5	-0.3
1.2	0.6	0.4	0.1	0.4
0.9	0.5	0.4	0.3	0.4
0.9	0.5	0.4	0.3	0.4
1.3	0.6	0.4	0.2	0.4
1.1	0.3	0.1	-0.1	0.1
0.4	0.1	-0.1	-0.2	-0.1
0.0	0.1	0.0	0.1	0.1
-0.1	-0.3	-0.3	-0.2	-0.2
2.5	2.2	1.9	1.6	1.9
2.3	1.8	1.3	1.0	1.3
1.3	0.9	0.7	0.6	0.7
n.a.	n.a.	n.a.	n.a.	n.a.
0.6	0.2	0.0	-0.1	0.0
0.5	0.2	0.1	0.0	0.1
1.4	0.9	0.8	0.6	0.8
1.2	0.5	0.4	0.2	0.3
1.4	1.2	1.0	0.9	1.0
0.2	-0.1	-0.2	-0.3	-0.2

Table A4 | GDP

	($2015 billion)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	35 896	48 285	64 834	89 488	110 594	126 311	143 985	163 414	184 098
Asia	6 705	10 415	17 921	30 825	41 436	49 564	59 046	69 748	81 326
China	1 027	2 770	7 554	16 325	22 246	26 574	31 544	37 066	42 922
India	475	817	1 567	3 022	5 067	6 791	8 941	11 512	14 440
Japan	3 510	3 987	4 219	4 530	4 846	5 048	5 254	5 458	5 659
Korea	402	799	1 261	1 741	2 049	2 248	2 439	2 616	2 769
Chinese Taipei	161	307	463	676	812	900	990	1 076	1 157
ASEAN	736	1 178	1 971	3 230	4 609	5 736	7 055	8 536	10 127
Indonesia	270	395	658	1 122	1 663	2 117	2 666	3 312	4 045
Malaysia	75	148	233	387	533	635	749	874	1 007
Myanmar	7.1	14	44	66	79	99	125	156	194
Philippines	107	143	229	408	657	851	1 066	1 282	1 471
Singapore	71	141	248	380	453	502	546	583	615
Thailand	144	221	347	450	562	666	785	916	1 055
Viet Nam	45	94	177	359	580	763	990	1 256	1 551
North America	10 626	14 918	17 783	22 688	26 897	29 641	32 542	35 547	38 605
United States	9 811	13 754	16 383	20 927	24 890	27 442	30 149	32 957	35 815
Latin America	2 638	3 596	4 888	5 619	6 805	7 859	9 018	10 255	11 545
Brazil	917	1 186	1 703	1 901	2 268	2 648	3 077	3 542	4 033
Advanced Europe	11 640	14 619	16 890	20 529	22 972	24 734	26 523	28 324	30 060
Other Europe/Eurasia	1 789	1 230	2 045	2 571	3 193	3 534	3 909	4 325	4 771
Russia	1 161	780	1 251	1 472	1 707	1 842	1 989	2 153	2 327
Africa	925	1 216	2 010	2 762	3 731	4 680	5 838	7 220	8 832
Middle East	916	1 385	2 076	2 844	3 617	4 139	4 718	5 357	6 057
Oceania	656	907	1 220	1 650	1 943	2 160	2 391	2 639	2 901
International Bunkers	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Advanced Economies	27 187	35 856	42 352	52 512	60 366	65 672	71 165	76 755	82 292
Group of Seven	21 466	27 920	31 963	38 661	44 147	47 999	52 051	56 218	60 402
Emerging and Developing Economies	8 709	12 429	22 482	36 976	50 228	60 639	72 820	86 659	101 806
Emerging and Developing Asia	2 441	5 002	11 463	23 180	32 882	40 427	49 337	59 502	70 601
Non-Asia	29 191	37 870	46 913	58 663	69 158	76 746	84 939	93 667	102 771
European Union	9 067	11 227	12 852	15 226	17 029	18 314	19 624	20 940	22 204

Source: World Bank "World Development Indicators", etc. (historical)
The Institute of Energy Economics, Japan (assumption)
Note: Same value for Reference Scenario and Advanced Technologies Scenario

CAGR (%)				
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
2.9	2.7	2.7	2.5	2.6
4.9	3.8	3.6	3.3	3.5
9.0	3.9	3.6	3.1	3.5
6.0	6.7	5.8	4.9	5.7
0.8	0.8	0.8	0.7	0.8
4.7	2.1	1.8	1.3	1.7
4.6	2.3	2.0	1.6	1.9
4.7	4.5	4.3	3.7	4.2
4.5	5.0	4.8	4.3	4.7
5.3	4.1	3.5	3.0	3.5
7.2	2.1	4.7	4.5	3.9
4.3	6.1	5.0	3.3	4.7
5.4	2.2	1.9	1.2	1.7
3.6	2.8	3.4	3.0	3.1
6.7	6.2	5.5	4.6	5.4
2.4	2.1	1.9	1.7	1.9
2.4	2.2	1.9	1.7	1.9
2.4	2.4	2.9	2.5	2.6
2.3	2.2	3.1	2.7	2.7
1.8	1.4	1.4	1.3	1.4
1.1	2.7	2.0	2.0	2.2
0.7	1.9	1.5	1.6	1.6
3.5	3.8	4.6	4.2	4.2
3.6	3.1	2.7	2.5	2.7
2.9	2.1	2.1	2.0	2.0
n.a.	n.a.	n.a.	n.a.	n.a.
2.1	1.8	1.7	1.5	1.6
1.9	1.7	1.7	1.5	1.6
4.6	3.9	3.8	3.4	3.7
7.3	4.5	4.1	3.6	4.1
2.2	2.1	2.1	1.9	2.0
1.6	1.4	1.4	1.2	1.4

Table A5 | GDP per capita

	($2015 thousand/person)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	6.8	7.9	9.3	11	13	14	16	18	19
Asia	2.3	3.0	4.6	7.2	9.3	11	13	15	17
China	0.9	2.2	5.6	12	16	20	24	29	34
India	0.5	0.8	1.3	2.1	3.3	4.3	5.5	7.0	8.6
Japan	28	31	33	36	40	44	47	50	54
Korea	9.4	17	25	34	40	45	50	56	62
Chinese Taipei	7.9	14	20	29	36	41	47	53	60
ASEAN	1.7	2.2	3.3	4.8	6.4	7.8	9.4	11	13
Indonesia	1.5	1.8	2.7	4.1	5.7	7.0	8.7	11	13
Malaysia	4.3	6.5	8.1	11	14	16	18	21	23
Myanmar	0.2	0.3	0.9	1.2	1.4	1.7	2.1	2.6	3.3
Philippines	1.7	1.8	2.4	3.5	5.3	6.7	8.1	9.5	11
Singapore	23	35	49	67	75	82	88	95	101
Thailand	2.6	3.5	5.1	6.3	7.9	9.5	11	13	16
Viet Nam	0.7	1.2	2.0	3.7	5.6	7.3	9.3	12	14
North America	38	48	52	61	69	75	80	86	92
United States	39	49	53	63	72	77	83	90	96
Latin America	6.0	6.9	8.3	8.6	9.9	11	13	14	16
Brazil	6.1	6.7	8.7	8.8	10	12	14	16	18
Advanced Europe	23	28	30	35	39	42	46	49	53
Other Europe/Eurasia	5.3	3.7	6.2	7.6	9.4	10	11	13	14
Russia	7.8	5.3	8.8	10	12	13	15	16	17
Africa	1.5	1.5	2.0	2.0	2.3	2.6	2.9	3.3	3.8
Middle East	6.9	8.1	9.4	10	11	12	13	14	15
Oceania	32	40	46	53	58	62	67	72	76
International Bunkers	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Advanced Economies	27	33	37	44	50	54	58	63	68
Group of Seven	33	40	43	50	56	61	66	71	76
Emerging and Developing Economies	2.0	2.5	3.9	5.5	6.9	8.0	9.3	11	12
Emerging and Developing Asia	0.9	1.5	3.1	5.7	7.7	9.3	11	13	16
Non-Asia	13	14	15	16	17	18	19	20	21
European Union	22	26	29	34	38	41	45	48	52

Source: World Bank "World Development Indicators", International Energy Agency "World Energy Balances", etc. (historical)
The Institute of Energy Economics, Japan (assumption)
Note: Same value for Reference Scenario and Advanced Technologies Scenario

CAGR (%)				
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
1.6	1.8	2.0	2.0	1.9
3.7	3.3	3.3	3.1	3.2
8.3	4.2	4.0	3.8	4.0
4.4	5.8	5.2	4.5	5.1
0.8	1.4	1.5	1.4	1.4
4.1	2.2	2.2	2.1	2.2
4.1	2.8	2.6	2.5	2.6
3.3	3.9	3.9	3.4	3.7
3.2	4.3	4.3	4.0	4.2
3.1	2.9	2.5	2.3	2.6
6.2	1.5	4.4	4.4	3.6
2.2	5.3	4.3	2.9	4.1
3.4	1.4	1.6	1.4	1.5
2.8	2.9	3.6	3.5	3.4
5.4	5.6	5.1	4.4	5.0
1.5	1.6	1.5	1.4	1.5
1.5	1.7	1.5	1.4	1.5
1.1	1.8	2.4	2.3	2.2
1.2	1.9	2.9	2.8	2.6
1.3	1.4	1.5	1.4	1.4
1.1	2.7	2.0	1.9	2.2
0.8	2.2	1.8	1.7	1.9
0.9	1.6	2.6	2.5	2.3
1.3	1.2	1.4	1.5	1.4
1.6	1.2	1.4	1.3	1.3
n.a.	n.a.	n.a.	n.a.	n.a.
1.5	1.6	1.6	1.5	1.6
1.3	1.5	1.6	1.5	1.5
3.2	2.9	3.0	2.8	2.9
6.0	3.9	3.7	3.5	3.7
0.8	0.9	1.0	1.0	1.0
1.4	1.5	1.6	1.5	1.5

Table A6 | Primary energy consumption

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	8 699	9 936	12 732	14 860	15 565	15 956	16 281	16 628	16 984
Asia	2 071	2 837	4 758	6 582	7 096	7 374	7 586	7 793	7 978
China	874	1 133	2 536	3 800	3 842	3 762	3 648	3 527	3 387
India	280	418	661	1 015	1 309	1 501	1 685	1 875	2 058
Japan	437	516	500	392	367	352	339	327	317
Korea	90	186	244	280	274	272	263	252	242
Chinese Taipei	51	90	117	117	111	110	107	104	101
ASEAN	217	354	511	736	921	1 069	1 192	1 308	1 419
Indonesia	85	127	172	261	344	431	491	548	606
Malaysia	21	48	72	99	120	130	140	149	156
Myanmar	11	13	14	21	21	22	25	28	32
Philippines	27	39	42	63	80	94	107	117	126
Singapore	12	19	24	37	40	40	41	41	41
Thailand	42	73	118	133	142	151	160	168	175
Viet Nam	18	29	59	102	151	175	199	224	247
North America	2 126	2 525	2 476	2 470	2 399	2 346	2 297	2 275	2 281
United States	1 914	2 273	2 216	2 173	2 101	2 046	1 995	1 974	1 980
Latin America	467	611	790	845	908	955	997	1 037	1 076
Brazil	141	188	268	301	320	342	364	384	404
Advanced Europe	1 644	1 759	1 834	1 608	1 440	1 385	1 341	1 291	1 249
Other Europe/Eurasia	1 514	988	1 112	1 189	1 195	1 189	1 182	1 177	1 173
Russia	879	619	693	808	774	764	756	744	733
Africa	352	435	608	796	885	956	1 025	1 101	1 183
Middle East	223	380	648	860	990	1 049	1 101	1 153	1 199
Oceania	99	125	145	146	150	147	145	143	142
International Bunkers	203	275	362	363	502	553	606	657	704
Advanced Economies	4 467	5 233	5 354	5 062	4 792	4 663	4 542	4 442	4 381
Group of Seven	3 490	4 024	3 945	3 640	3 455	3 350	3 254	3 184	3 154
Emerging and Developing Economies	4 029	4 427	7 016	9 434	10 271	10 740	11 133	11 529	11 900
Emerging and Developing Asia	1 473	2 013	3 859	5 744	6 293	6 590	6 827	7 060	7 269
Non-Asia	6 425	6 823	7 612	7 915	7 968	8 028	8 089	8 178	8 303
European Union	1 441	1 471	1 528	1 307	1 189	1 140	1 098	1 054	1 018

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario					Advanced Technologies Scenario								
CAGR (%)					(Mtoe)					CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
1.7	0.6	0.5	0.4	0.5	14 967	14 645	14 209	13 948	13 894	0.1	-0.5	-0.2	-0.2
3.7	0.9	0.7	0.5	0.7	6 827	6 719	6 531	6 397	6 383	0.5	-0.4	-0.2	-0.1
4.7	0.1	-0.5	-0.7	-0.4	3 708	3 417	3 088	2 794	2 547	-0.3	-1.8	-1.9	-1.4
4.1	3.2	2.6	2.0	2.6	1 236	1 322	1 398	1 483	1 631	2.5	1.2	1.5	1.7
-0.3	-0.8	-0.8	-0.7	-0.8	361	338	313	298	286	-1.0	-1.4	-0.9	-1.1
3.6	-0.3	-0.4	-0.8	-0.5	273	264	254	241	225	-0.3	-0.7	-1.2	-0.8
2.7	-0.6	-0.3	-0.6	-0.5	108	103	97	91	86	-1.0	-1.1	-1.2	-1.1
3.9	2.8	2.6	1.8	2.4	881	993	1 074	1 150	1 230	2.3	2.0	1.4	1.8
3.6	3.5	3.6	2.1	3.1	335	412	466	515	566	3.2	3.4	2.0	2.8
4.9	2.4	1.6	1.1	1.6	114	119	123	125	128	1.7	0.8	0.4	0.9
2.2	-0.5	1.9	2.6	1.4	18	18	19	21	24	-2.1	0.6	2.2	0.4
2.7	3.1	2.9	1.7	2.5	77	90	98	104	109	2.5	2.5	1.0	2.0
3.7	0.7	0.4	0.1	0.4	39	40	40	39	38	0.7	0.1	-0.5	0.0
3.6	0.8	1.1	0.9	1.0	140	144	146	149	154	0.6	0.4	0.5	0.5
5.6	5.0	2.8	2.2	3.2	137	149	159	172	187	3.8	1.5	1.6	2.2
0.5	-0.4	-0.4	-0.1	-0.3	2 298	2 138	1 976	1 846	1 738	-0.9	-1.5	-1.3	-1.2
0.4	-0.4	-0.5	-0.1	-0.3	2 009	1 863	1 716	1 602	1 506	-1.0	-1.6	-1.3	-1.3
1.9	0.9	0.9	0.8	0.9	869	882	881	889	909	0.4	0.1	0.3	0.3
2.4	0.8	1.3	1.0	1.1	309	316	319	323	329	0.3	0.3	0.3	0.3
-0.1	-1.4	-0.7	-0.7	-0.9	1 389	1 307	1 224	1 169	1 149	-1.8	-1.3	-0.6	-1.2
-0.8	0.1	-0.1	-0.1	-0.1	1 174	1 128	1 076	1 046	1 021	-0.2	-0.9	-0.5	-0.5
-0.3	-0.5	-0.2	-0.3	-0.3	760	721	683	657	635	-0.8	-1.1	-0.7	-0.9
2.6	1.3	1.5	1.4	1.4	824	840	861	899	948	0.4	0.4	1.0	0.6
4.3	1.8	1.1	0.9	1.2	960	990	1 003	1 026	1 053	1.4	0.4	0.5	0.7
1.2	0.3	-0.3	-0.2	-0.1	146	138	131	133	136	0.0	-1.1	0.4	-0.3
1.8	4.1	1.9	1.5	2.4	479	503	526	544	556	3.5	0.9	0.6	1.5
0.4	-0.7	-0.5	-0.4	-0.5	4 625	4 339	4 042	3 822	3 663	-1.1	-1.3	-1.0	-1.1
0.1	-0.7	-0.6	-0.3	-0.5	3 320	3 078	2 842	2 661	2 537	-1.1	-1.5	-1.1	-1.3
2.7	1.1	0.8	0.7	0.8	9 863	9 803	9 642	9 582	9 675	0.6	-0.2	0.0	0.1
4.3	1.1	0.8	0.6	0.8	6 035	5 964	5 820	5 723	5 743	0.6	-0.4	-0.1	0.0
0.7	0.1	0.2	0.3	0.2	7 660	7 423	7 152	7 007	6 954	-0.4	-0.7	-0.3	-0.5
-0.3	-1.2	-0.8	-0.8	-0.9	1 157	1 085	1 011	955	931	-1.5	-1.3	-0.8	-1.2

Table A7 | Primary energy consumption, coal

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	2 219	2 316	3 652	4 106	3 607	3 430	3 225	3 093	2 956
Asia	785	1 036	2 406	3 253	3 020	2 910	2 748	2 629	2 493
China	531	668	1 790	2 317	1 972	1 779	1 547	1 360	1 176
India	93	146	274	466	563	629	684	737	781
Japan	77	97	115	109	82	78	71	66	61
Korea	22	39	68	68	66	60	56	51	45
Chinese Taipei	11	30	42	41	38	36	34	32	29
ASEAN	12	31	85	207	248	269	289	304	311
Indonesia	3.5	12	32	95	113	124	136	145	150
Malaysia	1.4	2.3	15	24	24	23	21	19	15
Myanmar	0.1	0.3	0.4	0.3	2.1	3.0	4.0	5.5	7.2
Philippines	1.3	4.6	7.0	19	21	24	26	26	25
Singapore	0.0	-	0.0	0.4	0.4	0.4	0.4	0.4	0.3
Thailand	3.8	7.7	16	18	17	17	17	16	16
Viet Nam	2.2	4.4	15	46	63	70	77	83	87
North America	484	565	525	247	124	81	42	25	24
United States	460	533	501	239	123	80	40	24	23
Latin America	21	28	40	38	38	37	36	34	33
Brazil	9.7	13	14	14	12	12	13	13	14
Advanced Europe	450	331	301	204	92	76	74	75	70
Other Europe/Eurasia	365	209	211	213	195	186	184	180	179
Russia	191	120	106	133	117	112	109	106	106
Africa	74	90	109	105	100	105	111	122	130
Middle East	3.0	8.1	9.8	7.2	8.4	7.7	7.0	6.5	6.8
Oceania	36	49	52	38	29	26	24	22	20
International Bunkers	-	-	-	-	-	-	-	-	-
Advanced Economies	1 087	1 115	1 109	711	435	361	302	271	250
Group of Seven	787	811	776	431	235	185	137	117	108
Emerging and Developing Economies	1 133	1 201	2 543	3 395	3 172	3 069	2 923	2 822	2 706
Emerging and Developing Asia	669	866	2 174	3 031	2 830	2 733	2 585	2 479	2 357
Non-Asia	1 434	1 280	1 246	853	587	520	477	464	463
European Union	393	285	252	167	77	66	63	64	59

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (Mtoe)					Advanced Technologies Scenario CAGR (%)			
1990/2022	2022/2030	2030/2040	2040/2050	2022/2050	2030	2035	2040	2045	2050	2022/2030	2030/2040	2040/2050	2022/2050
1.9	-1.6	-1.1	-0.9	-1.2	3 216	2 699	2 236	1 911	1 657	-3.0	-3.6	-3.0	-3.2
4.5	-0.9	-0.9	-1.0	-0.9	2 728	2 312	1 886	1 583	1 348	-2.2	-3.6	-3.3	-3.1
4.7	-2.0	-2.4	-2.7	-2.4	1 819	1 446	1 069	787	544	-3.0	-5.2	-6.5	-5.0
5.2	2.4	2.0	1.3	1.9	494	492	478	479	513	0.8	-0.3	0.7	0.3
1.1	-3.4	-1.4	-1.5	-2.0	70	59	49	42	36	-5.4	-3.5	-3.1	-3.9
3.6	-0.4	-1.6	-2.3	-1.5	57	46	34	26	20	-2.3	-4.9	-5.4	-4.3
4.0	-0.7	-1.1	-1.5	-1.1	33	27	22	17	14	-2.5	-4.1	-4.3	-3.7
9.2	2.3	1.5	0.7	1.5	213	198	186	175	157	0.3	-1.3	-1.7	-1.0
10.8	2.2	1.8	1.0	1.7	101	99	97	90	77	0.8	-0.5	-2.3	-0.8
9.3	0.4	-1.3	-3.5	-1.6	23	21	18	14	10	-0.5	-2.2	-5.6	-2.9
5.2	25.8	6.5	6.0	11.5	1.8	2.4	3.0	3.9	4.8	22.8	5.3	5.0	9.9
8.9	1.4	1.9	-0.2	1.0	17	17	17	17	15	-1.1	-0.2	-1.2	-0.8
9.7	0.3	-0.8	-1.9	-0.9	0.4	0.4	0.3	0.3	0.2	-0.6	-2.1	-4.8	-2.6
4.9	-0.4	0.0	-0.7	-0.4	16	14	13	12	11	-1.3	-1.9	-1.2	-1.5
9.9	4.0	2.1	1.2	2.3	47	39	33	32	32	0.4	-3.5	-0.4	-1.3
-2.1	-8.2	-10.4	-5.4	-8.0	82	24	21	20	19	-12.8	-12.6	-1.2	-8.8
-2.0	-8.0	-10.5	-5.5	-8.0	81	23	20	19	18	-12.7	-12.8	-1.1	-8.8
1.8	-0.2	-0.5	-0.8	-0.5	31	28	25	24	24	-2.7	-2.1	-0.2	-1.6
1.2	-2.2	0.9	0.7	-0.1	11	10	10	10	11	-3.4	-0.3	0.3	-1.0
-2.4	-9.5	-2.2	-0.5	-3.8	73	68	65	63	62	-12.0	-1.2	-0.4	-4.1
-1.7	-1.1	-0.6	-0.3	-0.6	179	154	137	126	118	-2.2	-2.6	-1.5	-2.1
-1.1	-1.7	-0.7	-0.3	-0.8	109	96	84	77	71	-2.5	-2.6	-1.7	-2.2
1.1	-0.6	1.0	1.6	0.8	87	78	71	67	61	-2.3	-1.9	-1.6	-1.9
2.8	1.8	-1.8	-0.3	-0.2	7.1	5.9	5.0	5.2	5.3	-0.2	-3.5	0.6	-1.1
0.2	-3.3	-2.2	-1.4	-2.2	28	27	25	24	19	-3.7	-1.3	-2.7	-2.5
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
-1.3	-5.9	-3.6	-1.9	-3.7	346	254	217	193	170	-8.6	-4.5	-2.4	-5.0
-1.9	-7.3	-5.2	-2.3	-4.8	177	106	93	84	77	-10.6	-6.3	-1.8	-6.0
3.5	-0.8	-0.8	-0.8	-0.8	2 870	2 445	2 018	1 718	1 487	-2.1	-3.5	-3.0	-2.9
4.8	-0.9	-0.9	-0.9	-0.9	2 566	2 179	1 781	1 496	1 279	-2.1	-3.6	-3.3	-3.0
-1.6	-4.6	-2.1	-0.3	-2.2	487	386	349	328	308	-6.8	-3.3	-1.2	-3.6
-2.6	-9.2	-2.1	-0.7	-3.7	63	56	53	51	51	-11.5	-1.7	-0.4	-4.2

Table A8 | Primary energy consumption, oil

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	3 237	3 683	4 152	4 488	4 655	4 712	4 791	4 850	4 878
Asia	618	918	1 170	1 518	1 635	1 684	1 758	1 832	1 894
China	119	221	428	680	721	694	681	664	637
India	61	112	162	243	301	353	413	480	550
Japan	249	253	201	151	132	123	115	108	100
Korea	50	99	95	102	98	94	90	85	80
Chinese Taipei	28	42	48	40	37	36	35	33	31
ASEAN	88	154	191	239	278	304	332	358	379
Indonesia	33	58	67	73	83	92	101	109	116
Malaysia	11	19	25	25	30	31	31	31	31
Myanmar	0.7	2.0	1.3	5.9	3.9	4.7	5.6	6.7	7.7
Philippines	9.7	16	14	20	29	36	42	48	52
Singapore	11	17	17	27	28	28	29	29	29
Thailand	18	32	45	55	55	57	60	62	63
Viet Nam	2.7	7.8	18	27	41	46	53	60	66
North America	833	958	901	856	795	760	719	669	618
United States	757	871	807	758	706	674	638	593	546
Latin America	241	313	365	352	355	367	377	385	389
Brazil	59	88	105	111	106	113	120	127	132
Advanced Europe	617	654	605	529	460	427	399	373	347
Other Europe/Eurasia	459	199	217	252	247	243	239	235	230
Russia	264	126	139	166	157	154	152	149	146
Africa	85	100	161	211	234	254	280	307	333
Middle East	146	225	323	359	388	402	412	417	417
Oceania	35	40	48	50	56	54	52	50	47
International Bunkers	203	275	362	362	484	519	554	582	604
Advanced Economies	1 827	2 070	1 918	1 756	1 608	1 525	1 441	1 348	1 253
Group of Seven	1 447	1 578	1 413	1 263	1 140	1 076	1 011	939	865
Emerging and Developing Economies	1 208	1 337	1 872	2 369	2 563	2 668	2 797	2 921	3 022
Emerging and Developing Asia	277	500	805	1 196	1 339	1 401	1 487	1 576	1 653
Non-Asia	2 416	2 489	2 620	2 608	2 536	2 509	2 480	2 436	2 380
European Union	531	550	506	437	379	352	329	306	284

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (Mtoe)					CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
1.0	0.5	0.3	0.2	0.3	4 277	3 901	3 490	3 048	2 654	-0.6	-2.0	-2.7	-1.9
2.8	0.9	0.7	0.8	0.8	1 509	1 421	1 326	1 218	1 108	-0.1	-1.3	-1.8	-1.1
5.6	0.7	-0.6	-0.7	-0.2	671	592	512	440	375	-0.2	-2.7	-3.1	-2.1
4.4	2.7	3.2	2.9	3.0	274	292	306	309	304	1.5	1.1	0.0	0.8
-1.6	-1.7	-1.3	-1.4	-1.5	122	103	86	71	60	-2.6	-3.4	-3.6	-3.3
2.3	-0.6	-0.8	-1.1	-0.9	94	84	75	65	57	-1.1	-2.2	-2.7	-2.1
1.1	-1.1	-0.6	-1.1	-0.9	35	32	29	25	22	-1.6	-2.0	-2.5	-2.0
3.2	1.9	1.8	1.3	1.7	249	248	245	233	215	0.5	-0.2	-1.3	-0.4
2.5	1.6	1.9	1.4	1.7	70	70	67	62	54	-0.6	-0.4	-2.2	-1.1
2.5	2.3	0.3	-0.1	0.7	27	25	21	17	13	0.8	-2.2	-4.6	-2.2
6.8	-5.3	3.9	3.2	0.9	3.6	4.0	4.3	4.5	4.6	-6.2	1.8	0.6	-0.9
2.3	5.0	3.7	2.2	3.5	27	31	33	33	31	4.0	1.9	-0.7	1.6
2.7	0.4	0.3	0.1	0.3	25	21	21	20	20	-1.0	-1.6	-0.3	-1.0
3.5	0.0	0.8	0.6	0.5	51	49	48	45	42	-0.9	-0.7	-1.3	-1.0
7.5	5.1	2.7	2.2	3.2	38	41	43	43	42	4.3	1.1	-0.2	1.5
0.1	-0.9	-1.0	-1.5	-1.2	722	600	460	322	220	-2.1	-4.4	-7.1	-4.7
0.0	-0.9	-1.0	-1.5	-1.2	642	533	408	282	189	-2.1	-4.4	-7.4	-4.8
1.2	0.1	0.6	0.3	0.4	332	316	290	260	230	-0.7	-1.4	-2.3	-1.5
2.0	-0.6	1.3	0.9	0.6	99	96	92	87	82	-1.5	-0.7	-1.2	-1.1
-0.5	-1.7	-1.4	-1.4	-1.5	403	317	247	181	131	-3.3	-4.8	-6.2	-4.9
-1.9	-0.2	-0.3	-0.4	-0.3	236	214	187	160	135	-0.8	-2.3	-3.2	-2.2
-1.4	-0.7	-0.4	-0.4	-0.5	150	137	121	104	90	-1.2	-2.2	-2.9	-2.2
2.9	1.3	1.8	1.7	1.6	223	230	236	233	228	0.7	0.6	-0.4	0.3
2.8	1.0	0.6	0.1	0.5	357	338	312	280	258	-0.1	-1.4	-1.9	-1.2
1.1	1.6	-0.7	-1.1	-0.2	52	44	36	27	21	0.6	-3.8	-5.3	-3.1
1.8	3.7	1.3	0.9	1.8	443	421	397	367	324	2.5	-1.1	-2.0	-0.4
-0.1	-1.1	-1.1	-1.4	-1.2	1 454	1 204	955	712	531	-2.3	-4.1	-5.7	-4.2
-0.4	-1.3	-1.2	-1.6	-1.3	1 024	839	646	462	326	-2.6	-4.5	-6.6	-4.7
2.1	1.0	0.9	0.8	0.9	2 380	2 276	2 138	1 968	1 799	0.1	-1.1	-1.7	-1.0
4.7	1.4	1.1	1.1	1.2	1 232	1 178	1 114	1 036	948	0.4	-1.0	-1.6	-0.8
0.2	-0.3	-0.2	-0.4	-0.3	2 325	2 059	1 768	1 463	1 222	-1.4	-2.7	-3.6	-2.7
-0.6	-1.8	-1.4	-1.4	-1.5	332	262	205	151	110	-3.4	-4.7	-6.0	-4.8

Table A9 | Primary energy consumption, natural gas

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	1 662	2 068	2 736	3 437	3 650	3 801	4 017	4 261	4 533
Asia	116	234	454	709	880	982	1 085	1 196	1 307
China	13	21	89	297	375	396	406	408	400
India	11	23	54	52	89	119	149	181	212
Japan	44	66	86	83	61	58	55	54	53
Korea	2.7	18	38	53	59	61	65	68	69
Chinese Taipei	1.6	6.2	15	27	28	28	28	28	28
ASEAN	30	74	125	139	197	234	279	332	394
Indonesia	16	27	39	33	56	73	98	128	164
Malaysia	6.8	25	31	47	60	68	77	88	100
Myanmar	0.8	1.2	1.3	3.4	4.6	6.1	7.6	9.7	12
Philippines	-	0.0	3.1	2.6	5.4	7.6	11	15	19
Singapore	-	1.1	6.5	9.5	10	11	11	11	11
Thailand	5.0	17	33	33	40	42	43	43	42
Viet Nam	0.0	1.1	8.1	7.6	18	23	28	35	43
North America	493	622	635	894	928	931	949	958	981
United States	438	548	556	771	794	790	798	800	816
Latin America	71	118	178	201	197	213	231	252	271
Brazil	3.4	8.4	24	28	21	24	27	30	34
Advanced Europe	267	396	473	390	292	247	227	219	206
Other Europe/Eurasia	596	481	566	583	560	548	550	546	547
Russia	367	319	384	423	393	381	377	371	369
Africa	30	47	89	142	180	214	255	308	375
Middle East	72	145	311	480	565	607	646	689	733
Oceania	19	24	32	38	37	38	38	38	39
International Bunkers	-	-	-	0.3	11	22	36	54	74
Advanced Economies	827	1 136	1 287	1 498	1 419	1 377	1 377	1 380	1 390
Group of Seven	704	941	992	1 193	1 154	1 125	1 124	1 128	1 142
Emerging and Developing Economies	835	933	1 449	1 939	2 220	2 402	2 603	2 827	3 069
Emerging and Developing Asia	67	141	306	533	718	820	923	1 032	1 143
Non-Asia	1 547	1 834	2 283	2 727	2 759	2 798	2 895	3 011	3 152
European Union	250	309	363	294	224	191	178	172	161

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (Mtoe)					Advanced Technologies Scenario CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
2.3	0.8	1.0	1.2	1.0	3 514	3 484	3 357	3 285	3 194	0.3	-0.5	-0.5	-0.3
5.8	2.7	2.1	1.9	2.2	842	866	850	829	832	2.2	0.1	-0.2	0.6
10.3	2.9	0.8	-0.1	1.1	363	338	279	195	107	2.5	-2.6	-9.2	-3.6
5.1	7.0	5.3	3.6	5.2	90	110	121	133	158	7.2	3.0	2.7	4.1
2.0	-3.8	-0.9	-0.5	-1.6	55	48	41	34	24	-4.9	-3.0	-5.3	-4.4
9.8	1.3	0.9	0.7	0.9	53	52	47	44	44	0.0	-1.3	-0.5	-0.7
9.3	0.6	0.0	-0.2	0.1	26	24	21	17	13	-0.3	-2.2	-4.4	-2.4
4.9	4.4	3.5	3.5	3.8	188	216	251	294	350	3.8	2.9	3.4	3.4
2.3	6.7	5.8	5.3	5.9	54	71	95	127	167	6.4	5.8	5.7	5.9
6.2	3.1	2.6	2.5	2.7	55	63	69	74	80	2.1	2.3	1.5	1.9
4.8	3.8	5.1	4.6	4.6	4.4	5.7	6.9	8.9	11	3.2	4.7	4.6	4.2
n.a.	9.3	7.4	5.5	7.3	4.3	5.6	8.1	12	17	6.2	6.6	7.9	7.0
n.a.	0.9	0.5	-0.1	0.4	9.9	9.6	8.9	7.3	5.7	0.5	-1.1	-4.4	-1.8
6.1	2.4	0.6	-0.1	0.9	42	42	41	43	45	2.8	-0.1	0.8	1.0
28.2	11.3	4.7	4.2	6.3	15	16	17	18	20	9.1	1.1	1.8	3.6
1.9	0.5	0.2	0.3	0.3	892	836	730	642	519	0.0	-2.0	-3.4	-1.9
1.8	0.4	0.0	0.2	0.2	762	710	610	533	423	-0.2	-2.2	-3.6	-2.1
3.3	-0.2	1.6	1.6	1.1	179	183	189	201	214	-1.4	0.5	1.2	0.2
6.8	-3.8	2.6	2.5	0.7	19	18	17	16	15	-4.7	-1.0	-1.5	-2.3
1.2	-3.6	-2.5	-1.0	-2.3	257	200	154	114	75	-5.1	-5.0	-7.0	-5.7
-0.1	-0.5	-0.2	-0.1	-0.2	553	520	490	472	460	-0.6	-1.2	-0.6	-0.8
0.4	-0.9	-0.4	-0.2	-0.5	389	363	335	321	312	-1.1	-1.5	-0.7	-1.1
5.0	3.0	3.6	3.9	3.5	177	209	237	269	303	2.8	3.0	2.5	2.7
6.1	2.0	1.3	1.3	1.5	560	599	615	640	650	1.9	1.0	0.6	1.1
2.2	-0.1	0.2	0.4	0.2	38	36	34	32	29	0.2	-1.3	-1.4	-0.9
n.a.	54.3	13.0	7.3	21.3	17	36	60	85	111	63.2	13.5	6.5	23.1
1.9	-0.7	-0.3	0.1	-0.3	1 336	1 210	1 039	895	713	-1.4	-2.5	-3.7	-2.6
1.7	-0.4	-0.3	0.2	-0.2	1 101	996	853	737	580	-1.0	-2.5	-3.8	-2.5
2.7	1.7	1.6	1.7	1.7	2 162	2 238	2 259	2 305	2 369	1.4	0.4	0.5	0.7
6.7	3.8	2.5	2.2	2.8	693	728	728	723	742	3.3	0.5	0.2	1.2
1.8	0.1	0.5	0.9	0.5	2 656	2 582	2 448	2 370	2 250	-0.3	-0.8	-0.8	-0.7
0.5	-3.4	-2.3	-1.0	-2.1	201	159	122	92	60	-4.7	-4.9	-6.9	-5.5

Table A10 | Primary energy consumption, nuclear

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	526	675	719	700	837	884	882	879	902
Asia	77	132	152	194	280	313	344	370	403
China	-	4.4	19	109	148	170	192	213	235
India	1.6	4.4	6.8	12	36	41	46	53	61
Japan	53	84	75	15	47	42	42	42	42
Korea	14	28	39	46	37	42	35	29	28
Chinese Taipei	8.6	10	11	6.2	-	-	-	-	-
ASEAN	-	-	-	-	-	4.0	9.7	14	18
Indonesia	-	-	-	-	-	-	-	-	-
Malaysia	-	-	-	-	-	1.8	3.7	3.7	3.7
Myanmar	-	-	-	-	-	-	-	-	-
Philippines	-	-	-	-	-	-	-	-	-
Singapore	-	-	-	-	-	-	-	-	-
Thailand	-	-	-	-	-	-	1.8	3.7	6.2
Viet Nam	-	-	-	-	-	2.2	4.2	6.4	8.6
North America	179	227	242	232	225	208	182	178	175
United States	159	208	219	209	204	188	168	167	167
Latin America	3.2	5.3	7.2	8.7	14	17	17	16	18
Brazil	0.6	1.6	3.8	3.8	6.9	6.9	6.9	5.6	5.6
Advanced Europe	210	247	239	170	184	196	194	172	169
Other Europe/Eurasia	55	61	76	85	114	127	121	121	115
Russia	31	34	45	59	70	77	77	72	63
Africa	2.2	3.4	3.2	2.6	5.6	7.8	10.0	8.8	8.8
Middle East	-	-	-	7.5	13	13	13	13	13
Oceania	-	-	-	-	-	-	-	-	-
International Bunkers	-	-	-	-	-	-	-	-	-
Advanced Economies	463	596	606	469	493	489	453	422	413
Group of Seven	370	485	482	345	386	371	342	313	308
Emerging and Developing Economies	62	79	113	231	344	395	428	457	488
Emerging and Developing Asia	1.7	9.3	27	128	197	229	267	298	333
Non-Asia	449	544	567	506	556	570	538	509	499
European Union	190	224	223	159	178	187	177	151	148

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (Mtoe)					Advanced Technologies Scenario CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
0.9	2.3	0.5	0.2	0.9	966	1 121	1 267	1 356	1 474	4.1	2.7	1.5	2.7
2.9	4.7	2.1	1.6	2.6	372	452	543	596	658	8.4	3.9	1.9	4.4
n.a.	3.9	2.6	2.0	2.8	170	202	236	268	300	5.7	3.3	2.5	3.7
6.5	14.8	2.5	2.7	6.0	48	62	90	96	118	19.1	6.4	2.7	8.5
-3.9	15.6	-0.9	0.0	3.9	64	66	65	65	65	20.4	0.1	0.0	5.5
3.8	-2.7	-0.6	-2.3	-1.8	53	58	67	65	55	1.7	2.4	-2.0	0.6
-1.0	-100	n.a.	n.a.	-100	4.3	6.8	6.8	6.8	6.8	-4.5	4.7	0.0	0.3
n.a.	n.a.	n.a.	6.6	n.a.	12	32	46	60	76	n.a.	14.8	5.0	n.a.
n.a.	n.a.	n.a.	n.a.	n.a.	3.7	7.3	7.3	7.3	7.3	n.a.	7.2	0.0	n.a.
n.a.	n.a.	n.a.	0.0	n.a.	1.8	2.1	3.8	6.3	8.9	n.a.	7.5	8.9	n.a.
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	n.a.	2.2	4.4	6.6	6.6	8.8	n.a.	11.6	2.9	n.a.
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	13.0	n.a.	-	1.8	3.9	6.4	9.0	n.a.	n.a.	8.8	n.a.
n.a.	n.a.	n.a.	7.4	n.a.	4.0	16	25	33	42	n.a.	19.9	5.4	n.a.
0.8	-0.4	-2.1	-0.4	-1.0	228	228	229	219	217	-0.2	0.0	-0.5	-0.2
0.9	-0.3	-1.9	0.0	-0.8	206	204	205	196	194	-0.2	0.0	-0.6	-0.3
3.1	6.6	1.6	0.7	2.7	16	24	31	37	43	8.1	6.6	3.5	5.9
6.0	7.7	0.0	-2.1	1.4	6.9	11	15	18	22	7.7	7.8	4.3	6.5
-0.6	1.0	0.5	-1.4	0.0	205	230	247	250	273	2.3	1.9	1.0	1.7
1.4	3.8	0.6	-0.5	1.1	121	144	154	174	188	4.6	2.4	2.0	2.9
2.0	2.2	1.0	-2.0	0.2	70	77	87	96	99	2.2	2.3	1.3	1.9
0.5	10.2	6.0	-1.3	4.5	5.6	14	22	32	45	10.2	14.7	7.4	10.8
n.a.	7.6	0.0	0.0	2.1	19	28	41	49	51	12.3	8.0	2.3	7.1
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
0.0	0.6	-0.8	-0.9	-0.5	554	588	614	606	616	2.1	1.0	0.0	1.0
-0.2	1.4	-1.2	-1.0	-0.4	407	419	426	404	417	2.1	0.5	-0.2	0.7
4.2	5.1	2.2	1.3	2.7	412	532	652	750	858	7.5	4.7	2.8	4.8
14.5	5.6	3.1	2.2	3.5	250	322	405	459	531	8.8	4.9	2.8	5.2
0.4	1.2	-0.3	-0.7	0.0	595	668	723	760	816	2.0	2.0	1.2	1.7
-0.6	1.4	-0.1	-1.7	-0.2	200	224	230	223	237	2.9	1.5	0.3	1.4

Table A11 | Primary energy consumption, hydro

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	184	225	297	374	413	436	457	477	497
Asia	32	41	92	162	181	194	205	215	224
China	11	19	61	113	119	125	130	134	137
India	6.2	6.4	11	15	20	23	27	30	34
Japan	7.6	7.2	7.2	6.6	7.4	7.7	7.9	8.0	8.1
Korea	0.5	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Chinese Taipei	0.5	0.4	0.3	0.5	0.7	0.7	0.7	0.7	0.7
ASEAN	2.3	4.4	6.8	19	25	27	29	30	32
Indonesia	0.5	0.9	1.5	2.3	3.1	3.4	3.8	4.1	4.4
Malaysia	0.3	0.6	0.6	2.7	2.9	3.2	3.4	3.5	3.6
Myanmar	0.1	0.2	0.5	0.8	1.2	1.3	1.5	1.7	1.8
Philippines	0.5	0.7	0.7	0.9	1.3	1.4	1.5	1.7	1.9
Singapore	-	-	-	-	-	-	-	-	-
Thailand	0.4	0.5	0.5	0.6	1.3	1.4	1.5	1.6	1.7
Viet Nam	0.5	1.3	2.4	8.2	11	12	12	13	13
North America	49	53	53	56	63	63	64	65	65
United States	23	22	23	22	27	27	27	28	28
Latin America	34	51	64	67	75	78	81	84	87
Brazil	18	26	35	37	39	41	44	46	49
Advanced Europe	39	47	48	43	43	44	45	45	46
Other Europe/Eurasia	22	23	26	27	28	29	30	31	32
Russia	14	14	14	17	18	19	20	20	21
Africa	4.8	6.4	9.4	14	17	20	25	30	36
Middle East	1.0	0.7	1.5	1.4	2.4	2.5	2.6	2.7	2.8
Oceania	3.2	3.5	3.3	3.7	4.1	4.1	4.1	4.2	4.2
International Bunkers	-	-	-	-	-	-	-	-	-
Advanced Economies	100	111	112	110	119	120	122	123	124
Group of Seven	66	72	72	71	79	80	81	81	82
Emerging and Developing Economies	85	114	185	264	295	315	335	354	373
Emerging and Developing Asia	23	33	84	154	172	185	196	206	215
Non-Asia	153	184	205	212	232	242	251	262	273
European Union	24	30	32	24	24	24	25	25	25

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario					Advanced Technologies Scenario								
CAGR (%)					(Mtoe)					CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
2.2	1.3	1.0	0.8	1.0	428	460	494	530	569	1.7	1.4	1.4	1.5
5.2	1.4	1.3	0.9	1.2	194	217	240	265	292	2.3	2.1	2.0	2.1
7.6	0.7	0.9	0.5	0.7	127	137	148	158	169	1.5	1.5	1.4	1.5
2.8	3.8	2.9	2.3	3.0	24	31	39	48	59	6.0	5.0	4.3	5.0
-0.4	1.4	0.6	0.2	0.7	7.5	7.9	8.1	8.3	8.5	1.5	0.8	0.5	0.9
-1.8	1.9	0.0	0.0	0.5	0.4	0.4	0.4	0.4	0.4	1.9	0.0	0.0	0.5
-0.4	5.5	0.1	0.1	1.6	0.7	0.7	0.7	0.7	0.7	5.5	0.1	0.1	1.6
6.8	3.1	1.6	1.0	1.8	26	30	33	36	38	4.0	2.2	1.5	2.5
5.0	3.6	1.9	1.6	2.3	3.3	3.7	4.1	4.5	4.9	4.3	2.3	1.9	2.7
6.6	1.2	1.4	0.5	1.0	3.2	3.6	3.8	4.0	4.1	2.3	1.8	0.6	1.5
6.5	5.3	2.4	1.9	3.1	1.3	1.6	1.8	2.1	2.3	6.9	3.3	2.5	4.0
1.6	5.3	1.6	2.2	2.9	1.3	1.5	1.6	1.8	2.1	5.6	2.0	2.6	3.2
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
1.0	10.5	1.6	0.9	3.8	1.4	1.6	1.7	1.8	1.9	11.4	2.0	1.0	4.2
9.4	3.5	1.3	0.7	1.7	12	14	15	16	17	4.8	2.2	1.5	2.7
0.4	1.4	0.2	0.1	0.5	63	64	65	66	66	1.5	0.3	0.2	0.6
-0.2	2.5	0.2	0.1	0.8	27	27	27	28	28	2.5	0.2	0.1	0.8
2.2	1.4	0.8	0.7	0.9	75	79	82	86	90	1.4	0.9	0.9	1.0
2.3	0.8	1.1	1.1	1.0	39	42	45	48	52	0.9	1.3	1.4	1.2
0.3	0.2	0.3	0.3	0.2	43	44	45	45	46	0.2	0.3	0.3	0.2
0.6	0.4	0.9	0.5	0.6	28	29	30	31	32	0.4	0.9	0.5	0.6
0.5	0.4	1.2	0.6	0.8	18	19	20	20	21	0.4	1.2	0.6	0.8
3.4	2.5	3.8	3.9	3.5	17	20	25	30	36	2.5	3.8	3.9	3.5
1.1	6.8	0.8	0.7	2.4	2.4	2.5	2.6	2.7	2.8	6.7	0.8	0.7	2.4
0.4	1.3	0.2	0.2	0.5	4.1	4.1	4.1	4.2	4.2	1.3	0.2	0.2	0.5
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
0.3	0.9	0.3	0.2	0.4	119	121	123	125	126	1.0	0.3	0.2	0.5
0.3	1.2	0.2	0.1	0.5	79	81	82	83	83	1.3	0.3	0.2	0.6
3.6	1.4	1.3	1.1	1.2	308	338	371	405	443	2.0	1.9	1.8	1.9
6.1	1.4	1.3	0.9	1.2	186	208	231	256	283	2.3	2.2	2.0	2.2
1.0	1.1	0.8	0.8	0.9	233	243	254	265	277	1.2	0.8	0.9	1.0
-0.1	0.1	0.3	0.3	0.2	24	24	25	25	25	0.1	0.3	0.3	0.2

Table A12 | Primary energy consumption, solar, wind, etc.

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	2.5	8.2	48	339	841	1 050	1 250	1 413	1 574
Asia	1.3	2.1	16	166	460	585	709	797	886
China	0.0	1.0	12	130	348	432	516	566	616
India	0.0	0.2	2.0	18	67	98	127	155	184
Japan	1.2	0.9	1.1	8.9	16	18	20	22	23
Korea	0.0	0.0	0.2	3.2	5.4	6.6	7.8	9.2	11
Chinese Taipei	0.0	0.1	0.2	1.3	5.7	6.8	7.9	9.2	10
ASEAN	-	0.0	0.0	4.7	14	18	23	27	31
Indonesia	-	-	0.0	0.2	1.8	3.0	4.3	5.6	6.9
Malaysia	-	-	-	0.2	0.4	0.6	0.9	1.1	1.4
Myanmar	-	-	-	0.0	0.0	0.1	0.1	0.1	0.2
Philippines	-	-	0.0	0.2	2.0	2.5	2.9	3.4	3.8
Singapore	-	-	0.0	0.1	0.2	0.3	0.3	0.3	0.4
Thailand	-	-	0.0	0.7	1.8	2.6	3.5	4.3	5.2
Viet Nam	-	-	0.0	3.2	7.4	9.0	11	12	13
North America	0.3	2.1	11	61	126	163	200	237	273
United States	0.3	2.1	11	57	119	155	191	227	263
Latin America	0.0	0.2	0.9	21	44	55	66	76	85
Brazil	0.0	0.1	0.5	11	24	31	36	42	47
Advanced Europe	0.4	2.9	18	73	162	184	199	216	231
Other Europe/Eurasia	-	0.0	0.2	3.5	7.8	9.5	11	12	14
Russia	-	0.0	0.0	0.7	1.1	1.4	1.7	2.1	2.4
Africa	0.0	0.0	0.3	4.3	17	23	29	35	41
Middle East	0.4	0.7	1.3	3.2	12	16	19	22	25
Oceania	0.1	0.1	0.9	6.3	11	14	16	18	20
International Bunkers	-	-	-	-	-	-	-	-	-
Advanced Economies	2.1	6.1	31	154	327	393	451	511	569
Group of Seven	1.6	4.1	20	104	223	274	322	371	421
Emerging and Developing Economies	0.5	2.1	17	185	514	657	799	902	1 005
Emerging and Developing Asia	0.0	1.2	14	153	433	553	673	757	841
Non-Asia	1.3	6.0	33	172	381	465	541	616	688
European Union	0.3	2.5	16	58	130	147	161	173	183

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario					Advanced Technologies Scenario								
CAGR (%)					(Mtoe)					CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
16.5	12.0	4.0	2.3	5.6	991	1 361	1 748	2 186	2 668	14.4	5.8	4.3	7.7
16.4	13.6	4.4	2.2	6.2	528	726	925	1 105	1 289	15.5	5.8	3.4	7.6
29.5	13.2	4.0	1.8	5.7	382	510	635	722	812	14.5	5.2	2.5	6.8
26.1	18.3	6.6	3.8	8.8	88	135	183	242	297	22.3	7.6	5.0	10.6
6.4	7.6	2.3	1.6	3.5	18	21	25	29	33	9.1	3.3	3.0	4.8
19.7	6.8	3.8	3.2	4.4	6.6	9.1	12	15	20	9.5	6.0	5.2	6.7
14.0	20.1	3.3	2.7	7.7	6.9	9.0	11	13	16	22.9	4.8	3.9	9.3
n.a.	14.3	5.3	3.2	7.0	21	33	48	67	92	20.2	8.7	6.8	11.2
n.a.	31.2	9.0	4.9	13.3	4.2	8.7	14	21	31	45.9	12.7	8.2	19.6
n.a.	9.8	8.4	4.4	7.4	0.6	1.7	3.3	6.2	10	15.3	18.7	12.0	15.3
n.a.	16.1	9.6	5.0	9.8	0.1	0.5	1.0	1.9	3.2	33.0	21.9	12.7	21.5
n.a.	30.3	3.7	2.7	10.3	3.5	4.7	6.1	7.7	9.4	39.3	5.8	4.4	13.9
n.a.	13.5	3.3	1.4	5.4	0.3	0.4	0.4	0.5	0.5	16.5	4.5	1.5	6.6
n.a.	12.1	7.1	4.0	7.3	2.2	3.9	6.1	9.0	12	15.4	10.6	7.4	10.8
n.a.	10.9	3.7	2.0	5.1	9.6	13	16	20	25	14.7	5.4	4.2	7.5
17.8	9.5	4.7	3.2	5.5	155	232	309	407	510	12.4	7.1	5.2	7.9
17.6	9.6	4.8	3.2	5.6	147	219	291	381	475	12.5	7.1	5.0	7.8
22.3	9.6	4.1	2.5	5.0	56	77	105	143	196	12.8	6.5	6.4	8.3
22.5	10.9	4.2	2.5	5.4	31	39	46	53	63	14.5	3.9	3.2	6.6
18.1	10.5	2.1	1.5	4.2	182	215	245	286	326	12.2	3.0	2.9	5.5
n.a.	10.6	3.6	2.0	5.0	12	16	20	25	31	16.5	5.5	4.5	8.2
n.a.	5.6	4.9	3.4	4.5	4.0	4.7	5.4	6.1	6.8	24.4	3.0	2.3	8.5
32.7	18.7	5.7	3.4	8.4	28	44	65	94	130	26.2	9.0	7.2	13.0
6.6	18.1	4.6	2.5	7.5	17	30	47	74	107	23.3	10.5	8.5	13.3
13.0	7.6	3.5	2.3	4.2	13	21	31	52	78	9.6	9.0	9.7	9.4
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
14.4	9.9	3.3	2.4	4.8	383	507	632	803	983	12.1	5.2	4.5	6.9
13.9	9.9	3.7	2.7	5.1	265	366	461	591	722	12.3	5.7	4.6	7.1
20.3	13.6	4.5	2.3	6.2	609	854	1 115	1 384	1 684	16.0	6.2	4.2	8.2
29.1	13.9	4.5	2.3	6.3	496	686	878	1 047	1 220	15.9	5.9	3.3	7.7
16.6	10.4	3.6	2.4	5.1	464	635	822	1 082	1 379	13.2	5.9	5.3	7.7
17.8	10.5	2.1	1.3	4.2	146	171	197	231	263	12.1	3.0	3.0	5.5

Table A13 | Primary energy consumption, biomass and waste

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	833	906	1 065	1 301	1 394	1 404	1 398	1 379	1 354
Asia	433	451	436	510	533	552	566	577	587
China	200	198	133	128	129	136	145	150	155
India	108	126	151	210	233	239	239	239	237
Japan	4.2	5.0	11	17	18	20	21	22	22
Korea	0.7	1.4	3.5	6.6	8.2	8.5	8.8	9.1	9.3
Chinese Taipei	0.0	0.9	1.8	1.7	1.8	1.8	1.8	1.8	1.8
ASEAN	78	72	79	89	91	96	101	106	111
Indonesia	30	21	17	28	28	30	32	34	36
Malaysia	1.2	1.2	0.8	1.2	2.5	2.5	2.6	2.7	2.7
Myanmar	9.0	9.2	10	11	9.6	8.5	7.5	6.8	6.2
Philippines	10	7.6	8.7	11	10	10	9.8	9.5	9.3
Singapore	0.1	0.2	0.6	0.7	1.1	1.1	1.1	1.1	1.1
Thailand	15	15	23	23	24	27	30	33	36
Viet Nam	12	14	15	9.4	11	12	13	14	15
North America	73	86	101	115	127	128	129	131	132
United States	62	73	89	103	115	115	116	119	120
Latin America	93	90	128	151	177	177	177	177	178
Brazil	48	47	82	95	111	114	117	120	123
Advanced Europe	56	72	137	176	193	188	183	176	171
Other Europe/Eurasia	17	15	19	29	32	31	31	30	29
Russia	12	6.9	6.9	10	11	12	12	13	13
Africa	156	186	235	313	318	309	289	258	222
Middle East	0.5	0.4	1.0	1.2	1.6	1.6	1.7	1.7	1.8
Oceania	4.8	6.1	6.1	5.9	6.1	6.2	6.2	6.3	6.3
International Bunkers	-	-	-	0.6	6.5	12	16	21	26
Advanced Economies	139	172	261	323	356	354	350	347	344
Group of Seven	95	114	174	213	234	233	231	230	229
Emerging and Developing Economies	694	734	803	978	1 032	1 039	1 031	1 010	984
Emerging and Developing Asia	428	443	419	484	504	520	534	543	552
Non-Asia	400	455	628	790	855	841	815	780	741
European Union	47	65	129	159	173	168	162	156	150

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario					Advanced Technologies Scenario								
CAGR (%)					(Mtoe)					CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
1.4	0.9	0.0	-0.3	0.1	1 407	1 358	1 318	1 300	1 315	1.0	-0.6	0.0	0.0
0.5	0.5	0.6	0.4	0.5	544	541	543	551	574	0.8	0.0	0.6	0.4
-1.4	0.1	1.2	0.6	0.7	147	159	177	192	208	1.8	1.8	1.6	1.7
2.1	1.3	0.3	-0.1	0.4	218	202	185	175	174	0.4	-1.6	-0.6	-0.7
4.4	1.0	1.2	0.9	1.0	21	24	28	29	34	2.5	3.0	2.0	2.5
7.1	2.8	0.7	0.5	1.2	9.1	9.8	11	12	14	4.1	1.9	2.3	2.7
11.7	0.5	0.2	0.1	0.3	1.8	2.1	2.4	2.8	3.3	1.0	2.6	3.2	2.4
0.4	0.2	1.1	1.0	0.8	101	104	106	109	113	1.6	0.4	0.7	0.9
-0.1	0.1	1.3	1.1	0.9	39	42	44	46	49	4.2	1.1	1.1	2.0
0.0	9.1	0.6	0.5	2.9	3.8	4.1	4.4	4.9	5.5	15.0	1.7	2.2	5.5
0.6	-1.7	-2.4	-1.9	-2.0	7.7	5.2	4.0	3.2	2.5	-4.4	-6.4	-4.4	-5.1
0.2	-1.2	-0.3	-0.5	-0.6	10	9.7	9.3	8.9	8.5	-1.3	-0.7	-0.9	-1.0
7.4	6.0	0.1	0.2	1.8	1.3	1.4	1.5	1.7	1.9	8.2	1.4	2.6	3.7
1.4	0.7	2.1	1.8	1.6	25	28	29	30	31	1.2	1.4	0.7	1.1
-0.9	1.5	2.2	1.5	1.7	9.9	10	10	11	11	0.6	0.3	1.0	0.7
1.4	1.2	0.1	0.2	0.5	148	149	152	155	158	3.2	0.3	0.4	1.1
1.6	1.3	0.2	0.3	0.5	133	135	138	141	145	3.3	0.4	0.5	1.2
1.5	2.0	0.0	0.1	0.6	172	165	156	149	144	1.7	-0.9	-0.8	-0.2
2.2	2.0	0.5	0.5	0.9	107	104	100	96	93	1.5	-0.7	-0.6	0.0
3.7	1.2	-0.6	-0.6	-0.1	210	202	190	178	170	2.2	-1.0	-1.1	-0.1
1.7	1.4	-0.5	-0.5	0.0	32	31	30	29	29	1.4	-0.8	-0.1	0.1
-0.5	1.2	0.7	0.9	0.9	12	13	13	15	16	2.0	1.0	1.9	1.6
2.2	0.2	-1.0	-2.6	-1.2	274	225	187	162	140	-1.6	-3.7	-2.8	-2.8
3.0	3.7	0.7	0.9	1.6	1.6	1.7	1.9	2.3	2.9	4.0	2.0	4.1	3.3
0.6	0.3	0.2	0.1	0.2	6.0	5.9	5.8	5.7	5.7	0.1	-0.4	-0.2	-0.2
n.a.	34.7	9.7	4.9	14.5	19	37	52	68	91	54.5	10.3	5.7	19.6
2.7	1.2	-0.2	-0.2	0.2	397	395	391	385	387	2.6	-0.2	-0.1	0.6
2.6	1.2	-0.1	-0.1	0.3	267	265	267	267	272	2.9	0.0	0.2	0.9
1.1	0.7	0.0	-0.5	0.0	991	926	876	847	838	0.2	-1.2	-0.4	-0.5
0.4	0.5	0.6	0.3	0.5	511	504	500	504	521	0.7	-0.2	0.4	0.3
2.2	1.0	-0.5	-1.0	-0.2	844	779	723	681	651	0.8	-1.5	-1.0	-0.7
3.9	1.1	-0.7	-0.7	-0.2	188	180	168	157	149	2.1	-1.1	-1.2	-0.2

Table A14 | Final energy consumption

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	6 178	6 918	8 719	10 076	10 898	11 192	11 490	11 769	12 044
Asia	1 511	1 946	3 132	4 138	4 660	4 855	5 058	5 244	5 420
China	658	781	1 645	2 290	2 487	2 464	2 447	2 405	2 355
India	215	291	440	672	887	1 024	1 157	1 295	1 434
Japan	289	334	312	259	239	230	220	212	204
Korea	65	127	161	181	182	179	176	171	165
Chinese Taipei	32	54	74	73	74	74	73	72	71
ASEAN	149	244	352	478	585	655	727	799	866
Indonesia	57	91	117	162	197	226	256	287	317
Malaysia	13	29	42	59	72	78	84	90	94
Myanmar	9.4	11	13	19	16	16	17	18	19
Philippines	19	23	25	36	48	57	66	75	81
Singapore	5.0	8.3	15	18	20	21	22	22	22
Thailand	29	51	84	98	106	113	119	126	131
Viet Nam	16	25	48	73	109	125	142	158	173
North America	1 452	1 728	1 699	1 776	1 763	1 741	1 722	1 706	1 701
United States	1 294	1 546	1 513	1 579	1 567	1 548	1 532	1 520	1 518
Latin America	344	442	570	608	665	698	730	759	785
Brazil	112	154	212	244	265	283	301	318	333
Advanced Europe	1 142	1 234	1 289	1 190	1 115	1 068	1 025	986	951
Other Europe/Eurasia	1 057	647	709	780	804	801	797	795	795
Russia	625	418	447	531	530	523	516	510	506
Africa	246	305	418	544	604	646	684	718	754
Middle East	157	259	450	585	687	732	770	804	836
Oceania	66	82	90	92	98	99	99	99	98
International Bunkers	203	275	362	363	502	553	606	657	704
Advanced Economies	3 057	3 576	3 647	3 597	3 498	3 418	3 342	3 273	3 217
Group of Seven	2 377	2 735	2 674	2 613	2 524	2 463	2 408	2 360	2 325
Emerging and Developing Economies	2 918	3 067	4 710	6 116	6 898	7 221	7 541	7 838	8 123
Emerging and Developing Asia	1 114	1 413	2 563	3 600	4 138	4 344	4 561	4 762	4 953
Non-Asia	4 464	4 697	5 225	5 575	5 736	5 784	5 825	5 867	5 920
European Union	995	1 026	1 071	966	904	866	830	797	768

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (Mtoe)					CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
1.5	1.0	0.5	0.5	0.6	10 412	10 082	9 722	9 438	9 312	0.4	-0.7	-0.4	-0.3
3.2	1.5	0.8	0.7	1.0	4 445	4 367	4 283	4 213	4 219	0.9	-0.4	-0.2	0.1
4.0	1.0	-0.2	-0.4	0.1	2 383	2 240	2 105	1 974	1 880	0.5	-1.2	-1.1	-0.7
3.6	3.5	2.7	2.2	2.7	831	887	934	988	1 074	2.7	1.2	1.4	1.7
-0.3	-1.0	-0.8	-0.8	-0.8	229	208	187	173	162	-1.5	-2.0	-1.4	-1.6
3.2	0.0	-0.3	-0.6	-0.3	177	168	158	148	139	-0.3	-1.1	-1.2	-0.9
2.6	0.1	-0.1	-0.4	-0.1	72	68	65	61	59	-0.3	-1.0	-1.0	-0.8
3.7	2.5	2.2	1.8	2.1	560	592	617	637	654	2.0	1.0	0.6	1.1
3.3	2.5	2.6	2.2	2.4	190	205	218	228	238	2.0	1.4	0.9	1.4
4.8	2.5	1.5	1.2	1.7	70	71	71	69	68	2.0	0.1	-0.3	0.5
2.2	-2.3	0.6	1.3	0.0	14	13	12	13	13	-3.9	-1.1	0.5	-1.3
2.0	3.8	3.2	2.1	3.0	46	52	57	60	62	3.2	2.1	0.8	2.0
4.1	1.2	0.6	0.1	0.6	20	20	19	19	19	0.9	-0.2	-0.3	0.1
3.9	1.0	1.2	0.9	1.0	103	105	106	106	106	0.6	0.2	0.0	0.3
4.9	5.2	2.7	2.0	3.2	103	111	118	124	131	4.4	1.4	1.1	2.1
0.6	-0.1	-0.2	-0.1	-0.2	1 695	1 572	1 439	1 334	1 267	-0.6	-1.6	-1.3	-1.2
0.6	-0.1	-0.2	-0.1	-0.1	1 508	1 399	1 280	1 188	1 130	-0.6	-1.6	-1.2	-1.2
1.8	1.1	0.9	0.7	0.9	640	637	626	613	606	0.6	-0.2	-0.3	0.0
2.5	1.1	1.3	1.0	1.1	255	257	257	257	258	0.6	0.1	0.0	0.2
0.1	-0.8	-0.8	-0.7	-0.8	1 063	958	863	791	741	-1.4	-2.1	-1.5	-1.7
-0.9	0.4	-0.1	0.0	0.1	775	734	690	649	617	-0.1	-1.2	-1.1	-0.8
-0.5	0.0	-0.3	-0.2	-0.2	511	480	448	420	399	-0.5	-1.3	-1.2	-1.0
2.5	1.3	1.2	1.0	1.2	555	544	541	547	561	0.3	-0.3	0.4	0.1
4.2	2.0	1.2	0.8	1.3	666	677	673	667	666	1.6	0.1	-0.1	0.5
1.0	0.8	0.1	-0.1	0.2	94	89	83	80	79	0.3	-1.3	-0.4	-0.5
1.8	4.1	1.9	1.5	2.4	479	503	526	544	556	3.5	0.9	0.6	1.5
0.5	-0.3	-0.5	-0.4	-0.4	3 355	3 089	2 818	2 610	2 470	-0.9	-1.7	-1.3	-1.3
0.3	-0.4	-0.5	-0.3	-0.4	2 417	2 214	2 010	1 856	1 756	-1.0	-1.8	-1.3	-1.4
2.3	1.5	0.9	0.7	1.0	6 577	6 489	6 378	6 284	6 286	0.9	-0.3	-0.1	0.1
3.7	1.8	1.0	0.8	1.1	3 942	3 897	3 849	3 808	3 836	1.1	-0.2	0.0	0.2
0.7	0.4	0.2	0.2	0.2	5 488	5 212	4 913	4 681	4 537	-0.2	-1.1	-0.8	-0.7
-0.1	-0.8	-0.9	-0.8	-0.8	863	778	699	637	591	-1.4	-2.1	-1.7	-1.7

Table A15 | Final energy consumption, industry

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	1 796	1 863	2 637	3 064	3 435	3 559	3 649	3 695	3 720
Asia	508	648	1 399	1 778	2 029	2 102	2 155	2 172	2 174
China	234	297	917	1 129	1 163	1 108	1 050	968	886
India	59	85	157	272	420	501	563	616	657
Japan	107	102	91	75	69	66	63	61	58
Korea	20	38	48	48	50	50	50	49	47
Chinese Taipei	13	21	25	25	27	28	28	28	28
ASEAN	41	75	122	177	232	266	299	330	357
Indonesia	17	30	49	68	88	103	119	134	148
Malaysia	5.5	12	15	19	26	29	33	36	39
Myanmar	0.4	1.2	1.3	1.6	2.1	2.4	2.8	3.1	3.4
Philippines	4.1	4.6	5.9	7.1	9.9	12	14	15	16
Singapore	0.6	2.2	5.1	7.0	7.9	8.1	8.1	8.0	7.8
Thailand	8.7	17	26	32	36	40	43	46	48
Viet Nam	4.5	7.9	17	38	56	64	71	78	84
North America	331	386	312	327	340	345	346	345	343
United States	284	332	270	281	291	295	297	296	294
Latin America	114	143	180	178	201	217	232	245	256
Brazil	40	57	80	83	90	99	107	114	121
Advanced Europe	330	324	296	284	283	279	272	265	257
Other Europe/Eurasia	391	205	205	208	236	242	245	249	252
Russia	209	128	126	151	160	161	161	160	161
Africa	53	58	84	91	108	122	137	151	165
Middle East	47	71	134	172	210	223	232	238	242
Oceania	23	28	26	26	28	30	30	31	31
International Bunkers	-	-	-	-	-	-	-	-	-
Advanced Economies	826	903	804	793	805	805	798	786	772
Group of Seven	602	645	544	529	526	525	520	512	503
Emerging and Developing Economies	970	959	1 833	2 271	2 630	2 754	2 852	2 909	2 948
Emerging and Developing Asia	365	483	1 230	1 622	1 875	1 950	2 006	2 027	2 033
Non-Asia	1 288	1 215	1 238	1 287	1 406	1 457	1 494	1 523	1 546
European Union	313	273	247	228	229	226	222	216	210

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (Mtoe)					CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
1.7	1.4	0.6	0.2	0.7	3 245	3 118	2 958	2 808	2 754	0.7	-0.9	-0.7	-0.4
4.0	1.7	0.6	0.1	0.7	1 906	1 821	1 726	1 638	1 618	0.9	-1.0	-0.6	-0.3
5.0	0.4	-1.0	-1.7	-0.9	1 095	969	854	741	660	-0.4	-2.5	-2.5	-1.9
4.9	5.6	3.0	1.5	3.2	387	412	422	437	482	4.5	0.9	1.3	2.1
-1.1	-1.2	-0.8	-0.9	-0.9	65	59	53	49	46	-1.8	-1.9	-1.5	-1.7
2.7	0.7	-0.1	-0.5	0.0	48	45	42	39	36	0.1	-1.3	-1.5	-1.0
2.1	0.9	0.3	-0.1	0.3	26	25	23	22	21	0.3	-1.0	-1.1	-0.7
4.6	3.4	2.6	1.8	2.5	221	236	246	252	261	2.8	1.1	0.6	1.4
4.4	3.2	3.1	2.2	2.8	86	95	102	107	113	2.8	1.7	1.0	1.8
4.0	3.5	2.5	1.8	2.5	24	25	25	25	24	2.9	0.3	-0.4	0.8
4.5	3.3	2.9	2.1	2.7	1.9	2.0	2.2	2.3	2.5	2.0	1.6	1.4	1.6
1.7	4.3	3.3	1.6	3.0	9.6	11	12	12	12	3.9	1.9	0.5	1.9
8.0	1.4	0.4	-0.5	0.3	7.5	7.3	6.9	6.4	6.0	0.8	-0.9	-1.3	-0.5
4.1	1.8	1.7	1.1	1.5	35	36	36	36	36	1.3	0.4	0.0	0.5
6.9	4.8	2.5	1.6	2.8	52	54	56	57	61	3.9	0.7	0.9	1.7
0.0	0.5	0.2	-0.1	0.2	324	305	281	260	246	-0.1	-1.4	-1.3	-1.0
0.0	0.5	0.2	-0.1	0.2	278	261	240	222	210	-0.1	-1.4	-1.4	-1.0
1.4	1.5	1.5	1.0	1.3	192	195	194	192	192	0.9	0.1	-0.1	0.3
2.3	1.1	1.7	1.3	1.4	86	88	88	88	89	0.5	0.3	0.1	0.3
-0.5	0.0	-0.4	-0.6	-0.4	270	251	230	213	201	-0.6	-1.6	-1.4	-1.2
-2.0	1.6	0.4	0.3	0.7	225	216	204	193	186	1.0	-1.0	-0.9	-0.4
-1.0	0.7	0.1	0.0	0.2	152	143	131	121	115	0.1	-1.4	-1.3	-1.0
1.7	2.1	2.4	1.9	2.1	102	108	112	115	121	1.4	0.9	0.7	1.0
4.1	2.6	1.0	0.4	1.2	200	196	186	174	168	1.9	-0.7	-1.0	-0.1
0.5	0.9	0.6	0.2	0.6	27	26	24	23	22	0.3	-1.1	-1.0	-0.7
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
-0.1	0.2	-0.1	-0.3	-0.1	767	719	662	612	578	-0.4	-1.5	-1.3	-1.1
-0.4	-0.1	-0.1	-0.3	-0.2	501	467	427	394	370	-0.7	-1.6	-1.4	-1.3
2.7	1.8	0.8	0.3	0.9	2 478	2 399	2 296	2 196	2 176	1.1	-0.8	-0.5	-0.2
4.8	1.8	0.7	0.1	0.8	1 759	1 684	1 601	1 522	1 509	1.0	-0.9	-0.6	-0.3
0.0	1.1	0.6	0.3	0.7	1 340	1 297	1 231	1 169	1 135	0.5	-0.8	-0.8	-0.4
-1.0	0.0	-0.3	-0.5	-0.3	218	203	186	172	162	-0.6	-1.6	-1.4	-1.2

Table A16 | Final energy consumption, transport

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	1 578	1 966	2 431	2 802	3 072	3 140	3 231	3 330	3 424
Asia	189	323	493	722	871	911	967	1 032	1 098
China	30	83	195	318	410	407	408	407	401
India	21	32	65	113	151	180	216	262	316
Japan	72	89	79	64	60	56	52	48	45
Korea	15	26	30	37	34	32	29	27	24
Chinese Taipei	7.3	12	13	13	12	11	10	9.2	8.2
ASEAN	33	62	88	140	162	178	197	215	232
Indonesia	11	21	30	56	64	70	77	84	90
Malaysia	4.9	11	15	19	22	22	22	22	22
Myanmar	0.4	1.2	0.8	4.3	2.3	2.9	3.6	4.5	5.4
Philippines	4.5	8.3	8.0	12	18	23	27	31	34
Singapore	1.4	1.8	2.4	2.2	2.5	2.4	2.3	2.2	2.0
Thailand	9.2	15	19	28	28	29	30	31	32
Viet Nam	1.4	3.5	10	15	19	23	27	31	35
North America	531	640	655	678	644	615	587	557	526
United States	488	588	596	619	588	563	537	510	482
Latin America	104	140	197	225	245	254	264	272	280
Brazil	33	47	70	90	97	102	107	113	118
Advanced Europe	269	318	335	345	307	283	263	245	229
Other Europe/Eurasia	170	110	145	155	149	145	142	140	137
Russia	116	74	96	103	97	95	94	93	92
Africa	38	54	87	129	146	162	180	198	217
Middle East	51	75	121	150	171	178	186	192	198
Oceania	24	30	35	35	38	37	36	35	34
International Bunkers	203	275	362	363	502	553	606	657	704
Advanced Economies	921	1 121	1 150	1 176	1 099	1 038	982	926	870
Group of Seven	768	915	909	912	848	803	761	717	674
Emerging and Developing Economies	455	569	918	1 263	1 471	1 549	1 643	1 747	1 849
Emerging and Developing Asia	92	189	366	604	761	809	872	944	1 018
Non-Asia	1 186	1 368	1 576	1 717	1 699	1 675	1 658	1 640	1 621
European Union	220	262	279	280	247	228	211	196	183

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (Mtoe)					CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
1.8	1.2	0.5	0.6	0.7	2 910	2 761	2 601	2 463	2 377	0.5	-1.1	-0.9	-0.6
4.3	2.4	1.1	1.3	1.5	820	794	763	735	717	1.6	-0.7	-0.6	0.0
7.6	3.2	-0.1	-0.2	0.8	389	357	324	297	280	2.5	-1.8	-1.5	-0.5
5.4	3.7	3.6	3.9	3.7	141	155	167	178	187	2.8	1.8	1.1	1.8
-0.4	-0.9	-1.4	-1.5	-1.3	55	46	37	31	27	-2.0	-3.8	-3.0	-3.0
2.9	-0.9	-1.4	-1.9	-1.4	32	28	23	19	16	-1.5	-3.4	-3.3	-2.8
1.8	-1.5	-1.3	-2.1	-1.7	11	9.0	7.2	5.7	4.9	-2.5	-4.0	-3.8	-3.5
4.7	1.8	1.9	1.7	1.8	153	156	158	155	150	1.1	0.3	-0.5	0.2
5.3	1.7	1.8	1.6	1.7	60	61	60	59	57	0.8	0.0	-0.5	0.1
4.3	1.8	0.1	-0.2	0.5	21	19	18	16	14	1.2	-1.6	-2.3	-1.1
7.4	-7.7	4.8	3.9	0.8	2.2	2.6	3.0	3.4	3.7	-8.3	3.3	2.2	-0.5
3.2	5.0	4.0	2.4	3.7	17	20	23	24	24	4.3	2.7	0.4	2.3
1.6	1.2	-0.8	-1.2	-0.4	2.3	2.0	1.7	1.5	1.3	0.3	-3.0	-2.3	-1.8
3.5	0.3	0.5	0.5	0.5	27	26	24	23	21	-0.3	-1.0	-1.5	-1.0
7.7	3.3	3.4	2.9	3.2	18	20	21	22	21	2.3	1.8	0.2	1.4
0.8	-0.6	-0.9	-1.1	-0.9	611	531	448	379	338	-1.3	-3.0	-2.8	-2.5
0.7	-0.6	-0.9	-1.1	-0.9	559	488	412	349	310	-1.3	-3.0	-2.8	-2.4
2.5	1.0	0.7	0.6	0.8	234	227	217	207	199	0.5	-0.7	-0.9	-0.4
3.2	0.9	1.0	1.0	1.0	92	91	89	89	89	0.3	-0.3	-0.1	-0.1
0.8	-1.5	-1.5	-1.4	-1.5	281	231	190	161	146	-2.5	-3.8	-2.6	-3.0
-0.3	-0.5	-0.5	-0.3	-0.4	142	129	114	102	91	-1.1	-2.2	-2.2	-1.9
-0.4	-0.7	-0.4	-0.2	-0.4	92	83	74	67	61	-1.4	-2.1	-2.0	-1.9
3.9	1.6	2.1	1.9	1.9	142	151	158	162	167	1.2	1.1	0.6	0.9
3.4	1.6	0.9	0.6	1.0	165	163	156	148	141	1.2	-0.5	-1.1	-0.2
1.2	0.9	-0.5	-0.6	-0.1	36	33	29	25	23	0.3	-2.3	-2.1	-1.5
1.8	4.1	1.9	1.5	2.4	479	503	526	544	556	3.5	0.9	0.6	1.5
0.8	-0.9	-1.1	-1.2	-1.1	1 031	880	738	624	558	-1.6	-3.3	-2.7	-2.6
0.5	-0.9	-1.1	-1.2	-1.1	793	676	566	477	427	-1.7	-3.3	-2.8	-2.7
3.2	1.9	1.1	1.2	1.4	1 400	1 377	1 338	1 295	1 263	1.3	-0.5	-0.6	0.0
6.0	2.9	1.4	1.6	1.9	718	708	693	677	666	2.2	-0.4	-0.4	0.3
1.2	-0.1	-0.2	-0.2	-0.2	1 611	1 464	1 313	1 184	1 105	-0.8	-2.0	-1.7	-1.6
0.8	-1.5	-1.6	-1.4	-1.5	228	187	153	128	114	-2.6	-3.9	-2.9	-3.2

Table A17 | Final energy consumption, buildings, etc.

	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	2 327	2 471	2 857	3 238	3 321	3 379	3 449	3 539	3 655
Asia	699	789	944	1 187	1 243	1 302	1 374	1 456	1 545
China	351	339	414	599	642	677	715	756	797
India	122	147	184	238	250	265	286	312	342
Japan	78	108	108	92	86	83	80	78	77
Korea	24	38	44	45	44	43	42	41	40
Chinese Taipei	6.9	11	12	13	13	13	13	13	12
ASEAN	64	86	102	109	121	133	146	161	176
Indonesia	22	30	27	31	36	42	48	55	63
Malaysia	2.1	4.3	8.2	9.9	12	13	14	15	16
Myanmar	8.5	9.1	10	13	11	10	9.9	9.8	9.8
Philippines	10.0	9.9	11	15	18	20	22	25	27
Singapore	1.1	1.7	2.3	2.9	3.1	3.2	3.3	3.4	3.5
Thailand	11	14	20	16	16	17	17	18	18
Viet Nam	10	13	18	17	20	23	27	30	34
North America	456	528	572	599	602	599	602	615	640
United States	403	473	511	531	534	533	537	550	574
Latin America	100	122	148	170	182	186	190	195	200
Brazil	29	36	44	55	62	66	69	71	74
Advanced Europe	442	477	545	472	438	419	403	390	379
Other Europe/Eurasia	431	285	279	320	316	309	302	297	294
Russia	260	179	157	191	183	175	168	162	157
Africa	144	178	228	300	324	332	334	333	333
Middle East	40	74	119	165	191	205	216	226	236
Oceania	15	19	23	25	26	26	27	27	28
International Bunkers	-	-	-	-	-	-	-	-	-
Advanced Economies	1 024	1 185	1 311	1 253	1 215	1 191	1 174	1 170	1 182
Group of Seven	783	904	972	932	910	893	882	884	900
Emerging and Developing Economies	1 302	1 286	1 546	1 984	2 106	2 189	2 275	2 369	2 473
Emerging and Developing Asia	587	628	773	1 029	1 093	1 157	1 232	1 318	1 410
Non-Asia	1 628	1 683	1 913	2 051	2 078	2 077	2 075	2 083	2 109
European Union	374	391	447	380	352	336	321	310	301

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (Mtoe)					Advanced Technologies Scenario CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
1.0	0.3	0.4	0.6	0.4	3 187	3 091	3 004	2 963	2 936	-0.2	-0.6	-0.2	-0.3
1.7	0.6	1.0	1.2	0.9	1 202	1 214	1 232	1 257	1 282	0.2	0.2	0.4	0.3
1.7	0.9	1.1	1.1	1.0	628	642	654	663	669	0.6	0.4	0.2	0.4
2.1	0.6	1.4	1.8	1.3	238	242	253	268	287	0.0	0.6	1.3	0.7
0.5	-0.9	-0.7	-0.4	-0.7	83	78	71	67	64	-1.2	-1.6	-1.0	-1.3
2.0	-0.3	-0.4	-0.7	-0.5	43	41	38	36	33	-0.6	-1.1	-1.5	-1.1
2.0	-0.1	-0.2	-0.2	-0.2	13	12	11	11	10	-0.4	-1.0	-1.1	-0.9
1.7	1.3	1.9	1.9	1.7	116	122	129	136	143	0.7	1.1	1.1	1.0
1.2	2.0	2.9	2.7	2.6	36	40	44	48	53	1.7	2.1	1.8	1.9
4.9	2.1	1.8	1.5	1.8	11	12	12	13	13	1.7	0.9	0.4	0.9
1.3	-1.7	-1.1	-0.1	-0.9	9.4	7.6	6.8	6.5	6.2	-3.7	-3.2	-0.8	-2.5
1.3	2.3	2.1	1.8	2.1	17	19	20	21	22	1.8	1.3	0.9	1.3
3.0	0.7	0.6	0.5	0.6	3.0	3.0	2.9	2.8	2.7	0.3	-0.3	-0.7	-0.3
1.3	0.1	0.5	0.5	0.4	16	16	16	15	15	-0.3	-0.2	-0.3	-0.3
1.6	2.5	2.9	2.4	2.6	20	22	24	26	29	2.1	2.1	1.7	2.0
0.9	0.1	0.0	0.6	0.2	583	554	523	505	491	-0.3	-1.1	-0.6	-0.7
0.9	0.1	0.1	0.7	0.3	517	493	466	453	443	-0.3	-1.0	-0.5	-0.7
1.7	0.9	0.4	0.5	0.6	177	174	171	168	165	0.5	-0.3	-0.4	-0.1
2.0	1.4	1.0	0.7	1.0	60	61	61	61	60	1.0	0.2	-0.2	0.3
0.2	-0.9	-0.8	-0.6	-0.8	425	390	356	331	308	-1.3	-1.8	-1.4	-1.5
-0.9	-0.2	-0.4	-0.3	-0.3	305	286	265	246	229	-0.6	-1.4	-1.5	-1.2
-1.0	-0.6	-0.8	-0.7	-0.7	177	163	149	137	126	-1.0	-1.7	-1.7	-1.5
2.3	0.9	0.3	0.0	0.4	284	255	238	233	234	-0.7	-1.8	-0.2	-0.9
4.5	1.9	1.2	0.9	1.3	186	192	195	197	198	1.5	0.4	0.2	0.7
1.6	0.5	0.3	0.3	0.4	25	24	24	26	28	0.2	-0.6	1.8	0.5
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
0.6	-0.4	-0.3	0.1	-0.2	1 178	1 106	1 030	982	941	-0.8	-1.3	-0.9	-1.0
0.5	-0.3	-0.3	0.2	-0.1	883	829	772	738	711	-0.7	-1.3	-0.8	-1.0
1.3	0.7	0.8	0.8	0.8	2 008	1 985	1 974	1 981	1 995	0.2	-0.2	0.1	0.0
1.8	0.8	1.2	1.4	1.1	1 056	1 077	1 105	1 137	1 170	0.3	0.5	0.6	0.5
0.7	0.2	0.0	0.2	0.1	1 985	1 876	1 771	1 706	1 653	-0.4	-1.1	-0.7	-0.8
0.0	-1.0	-0.9	-0.7	-0.8	341	312	285	262	242	-1.3	-1.8	-1.6	-1.6

Table A18 | Final energy consumption, electricity

	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	9 699	12 637	17 881	24 572	29 233	32 057	34 949	38 008	41 413
Asia	1 823	3 249	6 677	12 146	15 231	16 984	18 558	20 028	21 562
China	454	1 036	3 450	7 551	9 233	9 998	10 527	10 856	11 175
India	212	368	718	1 398	2 184	2 725	3 277	3 867	4 482
Japan	765	973	1 035	907	893	897	904	916	935
Korea	94	263	449	542	592	615	631	642	650
Chinese Taipei	77	160	218	260	281	290	299	307	314
ASEAN	130	321	606	1 154	1 613	1 926	2 269	2 642	3 039
Indonesia	28	79	147	355	504	625	769	936	1 127
Malaysia	20	61	111	164	219	255	292	331	371
Myanmar	1.7	3.3	6.3	21	26	32	39	47	56
Philippines	21	37	55	91	142	176	212	248	283
Singapore	13	27	42	55	62	65	67	69	70
Thailand	38	88	149	197	236	261	286	312	338
Viet Nam	6.2	22	87	241	383	461	543	629	716
North America	3 051	3 930	4 265	4 542	5 004	5 306	5 717	6 249	6 911
United States	2 633	3 499	3 788	4 005	4 414	4 684	5 058	5 549	6 167
Latin America	516	796	1 126	1 396	1 689	1 887	2 085	2 286	2 493
Brazil	211	321	438	551	664	753	839	923	1 008
Advanced Europe	2 248	2 717	3 106	3 061	3 136	3 177	3 255	3 365	3 493
Other Europe/Eurasia	1 448	1 001	1 193	1 323	1 530	1 640	1 761	1 891	2 031
Russia	826	608	727	823	885	937	994	1 054	1 119
Africa	256	361	544	728	965	1 189	1 484	1 865	2 344
Middle East	199	376	718	1 118	1 385	1 561	1 755	1 970	2 200
Oceania	158	207	252	259	294	313	333	354	377
International Bunkers	-	-	-	-	-	-	-	-	-
Advanced Economies	6 429	8 313	9 410	9 670	10 305	10 706	11 246	11 940	12 787
Group of Seven	5 062	6 373	6 904	6 902	7 352	7 673	8 122	8 712	9 449
Emerging and Developing Economies	3 270	4 324	8 471	14 902	18 928	21 351	23 703	26 068	28 626
Emerging and Developing Asia	851	1 789	4 890	10 338	13 359	15 075	16 618	18 056	19 557
Non-Asia	7 876	9 388	11 204	12 427	14 002	15 073	16 390	17 980	19 850
European Union	1 887	2 198	2 510	2 410	2 470	2 508	2 574	2 663	2 768

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario					Advanced Technologies Scenario								
CAGR (%)					(TWh)					CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
2.9	2.2	1.8	1.7	1.9	29 955	32 993	36 100	39 396	42 934	2.5	1.9	1.7	2.0
6.1	2.9	2.0	1.5	2.1	15 585	17 222	18 798	20 307	22 195	3.2	1.9	1.7	2.2
9.2	2.5	1.3	0.6	1.4	9 379	9 946	10 382	10 564	10 766	2.7	1.0	0.4	1.3
6.1	5.7	4.1	3.2	4.2	2 332	2 945	3 604	4 390	5 474	6.6	4.4	4.3	5.0
0.5	-0.2	0.1	0.3	0.1	904	910	910	928	936	0.0	0.1	0.3	0.1
5.6	1.1	0.6	0.3	0.7	591	612	624	627	623	1.1	0.5	0.0	0.5
3.9	0.9	0.6	0.5	0.7	283	291	295	296	295	1.0	0.4	0.0	0.4
7.1	4.3	3.5	3.0	3.5	1 644	1 951	2 271	2 611	2 991	4.5	3.3	2.8	3.5
8.2	4.5	4.3	3.9	4.2	531	668	819	982	1 159	5.2	4.4	3.5	4.3
6.8	3.7	2.9	2.4	3.0	222	253	280	307	337	3.9	2.4	1.8	2.6
8.2	2.3	4.2	3.7	3.5	28	35	43	51	60	3.3	4.4	3.4	3.8
4.7	5.7	4.1	2.9	4.1	143	178	215	256	301	5.8	4.1	3.4	4.3
4.6	1.5	0.9	0.4	0.9	62	64	65	63	62	1.5	0.4	-0.5	0.4
5.3	2.2	1.9	1.7	1.9	240	268	295	324	357	2.5	2.1	1.9	2.1
12.1	6.0	3.6	2.8	4.0	377	437	498	564	645	5.7	2.8	2.6	3.6
1.3	1.2	1.3	1.9	1.5	5 061	5 434	5 867	6 387	6 765	1.4	1.5	1.4	1.4
1.3	1.2	1.4	2.0	1.6	4 463	4 795	5 186	5 673	6 027	1.4	1.5	1.5	1.5
3.2	2.4	2.1	1.8	2.1	1 721	1 950	2 188	2 432	2 675	2.6	2.4	2.0	2.3
3.0	2.4	2.4	1.9	2.2	683	777	866	952	1 045	2.7	2.4	1.9	2.3
1.0	0.3	0.4	0.7	0.5	3 260	3 414	3 566	3 754	3 873	0.8	0.9	0.8	0.8
-0.3	1.8	1.4	1.4	1.5	1 595	1 752	1 916	2 079	2 250	2.4	1.9	1.6	1.9
0.0	0.9	1.2	1.2	1.1	933	1 015	1 095	1 171	1 251	1.6	1.6	1.3	1.5
3.3	3.6	4.4	4.7	4.3	1 005	1 260	1 552	1 891	2 296	4.1	4.4	4.0	4.2
5.5	2.7	2.4	2.3	2.4	1 431	1 643	1 872	2 144	2 425	3.1	2.7	2.6	2.8
1.6	1.6	1.3	1.3	1.3	298	319	342	401	455	1.7	1.4	2.9	2.0
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
1.3	0.8	0.9	1.3	1.0	10 501	11 085	11 707	12 494	13 043	1.0	1.1	1.1	1.1
1.0	0.8	1.0	1.5	1.1	7 498	7 954	8 450	9 087	9 530	1.0	1.2	1.2	1.2
4.9	3.0	2.3	1.9	2.4	19 454	21 908	24 393	26 903	29 891	3.4	2.3	2.1	2.5
8.1	3.3	2.2	1.6	2.3	13 702	15 303	16 865	18 356	20 245	3.6	2.1	1.8	2.4
1.4	1.5	1.6	1.9	1.7	14 370	15 772	17 303	19 089	20 738	1.8	1.9	1.8	1.8
0.8	0.3	0.4	0.7	0.5	2 563	2 681	2 797	2 918	2 989	0.8	0.9	0.7	0.8

Table A19 | Electricity generated

	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	11 849	15 425	21 515	29 143	34 528	37 744	40 956	44 290	47 956
Asia	2 243	3 969	7 967	14 310	17 929	19 939	21 694	23 283	24 913
China	621	1 356	4 197	8 911	10 847	11 702	12 271	12 599	12 909
India	289	561	972	1 814	2 807	3 458	4 089	4 739	5 394
Japan	862	1 055	1 164	1 010	995	998	1 005	1 018	1 038
Korea	109	288	472	610	667	692	709	721	728
Chinese Taipei	90	181	244	285	307	317	326	335	342
ASEAN	154	374	685	1 284	1 802	2 146	2 522	2 931	3 366
Indonesia	33	93	170	377	542	678	838	1 024	1 236
Malaysia	23	69	125	187	249	289	330	373	418
Myanmar	2.5	5.1	8.6	21	37	48	61	79	99
Philippines	26	45	68	112	170	208	248	285	320
Singapore	16	32	46	57	65	68	70	72	73
Thailand	44	96	159	186	230	253	275	294	312
Viet Nam	8.7	27	95	276	429	513	601	692	782
North America	3 685	4 632	4 957	5 124	5 639	5 975	6 430	7 019	7 752
United States	3 203	4 026	4 354	4 473	4 932	5 232	5 647	6 191	6 875
Latin America	623	1 009	1 406	1 716	2 052	2 280	2 503	2 722	2 941
Brazil	223	349	516	677	828	932	1 028	1 119	1 208
Advanced Europe	2 695	3 236	3 623	3 543	3 782	3 859	3 976	4 155	4 353
Other Europe/Eurasia	1 856	1 415	1 689	1 816	1 860	1 938	2 021	2 072	2 133
Russia	1 082	876	1 036	1 149	1 084	1 131	1 179	1 191	1 206
Africa	315	442	687	901	1 196	1 464	1 811	2 251	2 797
Middle East	244	472	888	1 418	1 714	1 910	2 124	2 366	2 622
Oceania	187	249	298	316	356	377	399	422	445
International Bunkers	-	-	-	-	-	-	-	-	-
Advanced Economies	7 673	9 704	10 842	10 981	11 844	12 320	12 946	13 770	14 760
Group of Seven	6 041	7 437	7 989	7 782	8 515	8 890	9 405	10 098	10 966
Emerging and Developing Economies	4 177	5 722	10 672	18 162	22 684	25 423	28 009	30 521	33 197
Emerging and Developing Asia	1 138	2 383	6 003	12 312	15 861	17 830	19 552	21 109	22 704
Non-Asia	9 606	11 456	13 547	14 833	16 599	17 805	19 262	21 007	23 044
European Union	2 256	2 630	2 955	2 793	3 072	3 154	3 299	3 380	3 503

Source: International Energy Agency "World Energy Balances" (historical)
The Institute of Energy Economics, Japan (projection)
Note: Excluding generation by pumped storage hydro

Reference Scenario CAGR (%)					Advanced Technologies Scenario (TWh)					CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
2.9	2.1	1.7	1.6	1.8	35 544	39 903	44 369	50 289	57 091	2.5	2.2	2.6	2.4
6.0	2.9	1.9	1.4	2.0	18 411	20 584	22 527	24 662	27 350	3.2	2.0	2.0	2.3
8.7	2.5	1.2	0.5	1.3	11 056	11 887	12 421	12 703	13 082	2.7	1.2	0.5	1.4
5.9	5.6	3.8	2.8	4.0	2 996	3 725	4 459	5 444	6 742	6.5	4.1	4.2	4.8
0.5	-0.2	0.1	0.3	0.1	1 009	1 029	1 043	1 088	1 120	0.0	0.3	0.7	0.4
5.5	1.1	0.6	0.3	0.6	668	708	734	764	794	1.1	0.9	0.8	0.9
3.7	0.9	0.6	0.5	0.7	309	324	332	344	359	1.0	0.7	0.8	0.8
6.8	4.3	3.4	2.9	3.5	1 846	2 242	2 685	3 236	3 893	4.6	3.8	3.8	4.0
7.9	4.6	4.5	4.0	4.3	576	748	951	1 199	1 491	5.4	5.1	4.6	5.0
6.8	3.6	2.8	2.4	2.9	255	302	353	414	490	3.9	3.3	3.4	3.5
6.9	7.2	5.2	5.0	5.7	39	56	74	103	138	8.1	6.5	6.5	7.0
4.6	5.4	3.9	2.6	3.8	172	216	264	322	386	5.6	4.4	3.9	4.5
4.1	1.5	0.9	0.4	0.9	65	69	70	63	53	1.6	0.8	-2.7	-0.3
4.6	2.7	1.8	1.3	1.9	237	269	307	362	429	3.1	2.6	3.4	3.0
11.4	5.7	3.4	2.7	3.8	425	496	572	665	783	5.5	3.0	3.2	3.8
1.0	1.2	1.3	1.9	1.5	5 723	6 273	6 876	7 735	8 464	1.4	1.9	2.1	1.8
1.0	1.2	1.4	2.0	1.5	5 004	5 479	6 000	6 732	7 328	1.4	1.8	2.0	1.8
3.2	2.3	2.0	1.6	1.9	2 110	2 496	2 974	3 637	4 490	2.6	3.5	4.2	3.5
3.5	2.5	2.2	1.6	2.1	914	1 045	1 183	1 323	1 501	3.8	2.6	2.4	2.9
0.9	0.8	0.5	0.9	0.7	3 966	4 352	4 765	5 345	5 903	1.4	1.9	2.2	1.8
-0.1	0.3	0.8	0.5	0.6	1 925	1 994	2 061	2 234	2 419	0.7	0.7	1.6	1.0
0.2	-0.7	0.8	0.2	0.2	1 140	1 164	1 174	1 233	1 295	-0.1	0.3	1.0	0.4
3.3	3.6	4.2	4.4	4.1	1 259	1 646	2 122	2 775	3 597	4.3	5.4	5.4	5.1
5.6	2.4	2.2	2.1	2.2	1 782	2 109	2 490	3 095	3 764	2.9	3.4	4.2	3.5
1.6	1.5	1.1	1.1	1.2	368	448	556	806	1 103	1.9	4.2	7.1	4.6
n.a.	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
1.1	1.0	0.9	1.3	1.1	12 142	13 235	14 405	16 172	17 820	1.3	1.7	2.2	1.7
0.8	1.1	1.0	1.5	1.2	8 738	9 491	10 279	11 527	12 608	1.5	1.6	2.1	1.7
4.7	2.8	2.1	1.7	2.2	23 402	26 668	29 964	34 116	39 271	3.2	2.5	2.7	2.8
7.7	3.2	2.1	1.5	2.2	16 326	18 423	20 319	22 376	25 000	3.6	2.2	2.1	2.6
1.4	1.4	1.5	1.8	1.6	17 133	19 319	21 842	25 626	29 741	1.8	2.5	3.1	2.5
0.7	1.2	0.7	0.6	0.8	3 304	3 673	4 031	4 254	4 480	2.1	2.0	1.1	1.7

Table A20 | Primary energy consumption per capita

	Reference Scenario (Tonne of oil equivalent [toe]/person)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	1.6	1.6	1.8	1.9	1.8	1.8	1.8	1.8	1.8
Asia	0.7	0.8	1.2	1.5	1.6	1.6	1.6	1.7	1.7
China	0.8	0.9	1.9	2.7	2.8	2.8	2.7	2.7	2.7
India	0.3	0.4	0.5	0.7	0.9	1.0	1.0	1.1	1.2
Japan	3.5	4.1	3.9	3.1	3.1	3.0	3.0	3.0	3.0
Korea	2.1	4.0	4.9	5.4	5.4	5.4	5.4	5.4	5.4
Chinese Taipei	2.5	4.0	5.1	5.0	4.9	5.0	5.1	5.1	5.2
ASEAN	0.5	0.7	0.9	1.1	1.3	1.5	1.6	1.7	1.8
Indonesia	0.5	0.6	0.7	0.9	1.2	1.4	1.6	1.7	1.9
Malaysia	1.2	2.1	2.5	2.9	3.2	3.3	3.5	3.5	3.6
Myanmar	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5
Philippines	0.4	0.5	0.4	0.5	0.7	0.7	0.8	0.9	0.9
Singapore	3.8	4.6	4.8	6.6	6.6	6.6	6.6	6.7	6.8
Thailand	0.8	1.2	1.7	1.9	2.0	2.1	2.3	2.5	2.6
Viet Nam	0.3	0.4	0.7	1.0	1.5	1.7	1.9	2.1	2.3
North America	7.7	8.1	7.2	6.6	6.2	5.9	5.7	5.5	5.5
United States	7.7	8.1	7.2	6.5	6.1	5.8	5.5	5.4	5.3
Latin America	1.1	1.2	1.3	1.3	1.3	1.4	1.4	1.4	1.5
Brazil	0.9	1.1	1.4	1.4	1.4	1.5	1.6	1.7	1.8
Advanced Europe	3.3	3.3	3.3	2.8	2.5	2.4	2.3	2.2	2.2
Other Europe/Eurasia	4.5	3.0	3.4	3.5	3.5	3.5	3.5	3.4	3.4
Russia	5.9	4.2	4.9	5.6	5.5	5.5	5.5	5.5	5.4
Africa	0.6	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.5
Middle East	1.7	2.2	2.9	3.1	3.1	3.1	3.1	3.0	3.0
Oceania	4.9	5.5	5.5	4.7	4.5	4.3	4.1	3.9	3.7
International Bunkers	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Advanced Economies	4.5	4.9	4.7	4.2	3.9	3.8	3.7	3.7	3.6
Group of Seven	5.4	5.8	5.3	4.7	4.4	4.2	4.1	4.0	4.0
Emerging and Developing Economies	0.9	0.9	1.2	1.4	1.4	1.4	1.4	1.4	1.4
Emerging and Developing Asia	0.5	0.6	1.1	1.4	1.5	1.5	1.5	1.6	1.6
Non-Asia	2.8	2.5	2.5	2.2	2.0	1.9	1.8	1.8	1.7
European Union	3.4	3.4	3.5	2.9	2.7	2.6	2.5	2.4	2.4

Source: World Bank "World Development Indicators", International Energy Agency "World Energy Balances", etc. (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (toe/person)					Advanced Technologies Scenario CAGR (%)			
1990/2022	2022/2030	2030/2040	2040/2050	2022/2050	2030	2035	2040	2045	2050	2022/2030	2030/2040	2040/2050	2022/2050
0.4	-0.2	-0.2	-0.1	-0.2	1.8	1.7	1.6	1.5	1.5	-0.7	-1.2	-0.7	-0.9
2.5	0.5	0.3	0.4	0.4	1.5	1.5	1.4	1.4	1.4	0.0	-0.8	-0.4	-0.4
4.0	0.4	-0.1	-0.1	0.0	2.7	2.5	2.3	2.2	2.0	-0.1	-1.4	-1.3	-1.0
2.5	2.4	1.9	1.7	2.0	0.8	0.8	0.9	0.9	1.0	1.6	0.6	1.2	1.1
-0.4	-0.3	-0.2	0.0	-0.1	3.0	2.9	2.8	2.7	2.7	-0.5	-0.8	-0.3	-0.5
3.0	-0.1	0.0	0.0	0.0	5.4	5.3	5.2	5.1	5.0	-0.1	-0.3	-0.4	-0.3
2.2	-0.2	0.3	0.3	0.1	4.8	4.7	4.6	4.5	4.4	-0.5	-0.5	-0.3	-0.4
2.5	2.2	2.1	1.5	1.9	1.2	1.4	1.4	1.5	1.6	1.6	1.5	1.1	1.4
2.2	2.8	3.1	1.8	2.5	1.1	1.4	1.5	1.6	1.8	2.4	2.8	1.7	2.3
2.8	1.2	0.7	0.4	0.7	3.1	3.1	3.0	3.0	2.9	0.6	-0.1	-0.3	0.0
1.3	-1.1	1.6	2.5	1.1	0.3	0.3	0.3	0.4	0.4	-2.7	0.2	2.1	0.0
0.7	2.3	2.2	1.3	1.9	0.6	0.7	0.7	0.8	0.8	1.7	1.8	0.7	1.4
1.8	-0.1	0.1	0.3	0.1	6.5	6.5	6.4	6.3	6.2	-0.2	-0.2	-0.3	-0.2
2.8	0.9	1.4	1.4	1.3	2.0	2.0	2.1	2.2	2.3	0.7	0.6	1.0	0.8
4.3	4.4	2.4	2.0	2.8	1.3	1.4	1.5	1.6	1.7	3.2	1.1	1.5	1.8
-0.4	-0.9	-0.8	-0.4	-0.7	5.9	5.4	4.9	4.5	4.2	-1.4	-1.9	-1.6	-1.7
-0.5	-0.9	-0.9	-0.4	-0.7	5.8	5.3	4.8	4.4	4.1	-1.5	-2.0	-1.6	-1.7
0.6	0.3	0.5	0.6	0.5	1.3	1.2	1.2	1.2	1.2	-0.3	-0.3	0.1	-0.1
1.3	0.4	1.2	1.1	0.9	1.4	1.4	1.4	1.4	1.5	0.0	0.2	0.4	0.2
-0.5	-1.4	-0.7	-0.5	-0.8	2.4	2.2	2.1	2.0	2.0	-1.9	-1.2	-0.5	-1.1
-0.8	0.0	-0.1	-0.1	-0.1	3.5	3.3	3.2	3.1	3.0	-0.2	-0.9	-0.6	-0.6
-0.2	-0.2	0.0	-0.2	-0.1	5.4	5.2	5.0	4.8	4.7	-0.4	-0.8	-0.6	-0.6
0.1	-0.9	-0.5	-0.2	-0.5	0.5	0.5	0.4	0.4	0.4	-1.8	-1.5	-0.7	-1.3
2.0	0.0	-0.2	-0.2	-0.1	3.0	2.9	2.8	2.7	2.6	-0.4	-0.8	-0.6	-0.6
-0.1	-0.6	-1.0	-0.8	-0.8	4.4	4.0	3.7	3.6	3.6	-0.9	-1.8	-0.2	-1.0
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
-0.2	-0.8	-0.6	-0.3	-0.5	3.8	3.6	3.3	3.1	3.0	-1.3	-1.4	-0.9	-1.2
-0.4	-0.8	-0.7	-0.3	-0.6	4.2	3.9	3.6	3.3	3.2	-1.3	-1.6	-1.1	-1.4
1.3	0.1	0.0	0.1	0.1	1.4	1.3	1.2	1.2	1.2	-0.4	-1.0	-0.6	-0.7
3.1	0.6	0.4	0.5	0.5	1.4	1.4	1.3	1.3	1.3	0.1	-0.7	-0.3	-0.3
-0.7	-1.1	-0.9	-0.6	-0.9	1.9	1.8	1.6	1.5	1.4	-1.6	-1.7	-1.2	-1.5
-0.5	-1.1	-0.6	-0.5	-0.7	2.6	2.5	2.3	2.2	2.2	-1.4	-1.2	-0.6	-1.0

Table A21 | Primary energy consumption per GDP

	Reference Scenario (Tonne of oil equivalent [toe]/$2015 million)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	242	206	196	166	141	126	113	102	92
Asia	309	272	265	214	171	149	128	112	98
China	850	409	336	233	173	142	116	95	79
India	590	511	422	336	258	221	189	163	143
Japan	124	129	118	87	76	70	65	60	56
Korea	223	233	193	161	134	121	108	96	87
Chinese Taipei	315	292	254	173	137	122	109	97	87
ASEAN	295	300	260	228	200	186	169	153	140
Indonesia	313	320	262	232	207	203	184	166	150
Malaysia	284	326	312	257	225	205	187	170	155
Myanmar	1 499	903	310	324	262	227	199	181	165
Philippines	249	272	182	154	122	110	100	91	85
Singapore	163	133	98	98	87	81	75	71	67
Thailand	294	328	340	296	253	226	203	183	166
Viet Nam	397	307	330	284	260	229	201	178	159
North America	200	169	139	109	89	79	71	64	59
United States	195	165	135	104	84	75	66	60	55
Latin America	177	170	162	150	133	122	111	101	93
Brazil	153	159	157	158	141	129	118	109	100
Advanced Europe	141	120	109	78	63	56	51	46	42
Other Europe/Eurasia	846	803	544	463	374	337	302	272	246
Russia	757	794	554	549	453	415	380	346	315
Africa	380	358	302	288	237	204	176	153	134
Middle East	243	274	312	302	274	254	233	215	198
Oceania	151	138	119	89	77	68	61	54	49
International Bunkers	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Advanced Economies	164	146	126	96	79	71	64	58	53
Group of Seven	163	144	123	94	78	70	63	57	52
Emerging and Developing Economies	463	356	312	255	204	177	153	133	117
Emerging and Developing Asia	604	402	337	248	191	163	138	119	103
Non-Asia	220	180	162	135	115	105	95	87	81
European Union	159	131	119	86	70	62	56	50	46

Source: World Bank "World Development Indicators", International Energy Agency "World Energy Balances", etc. (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (toe/$2015 million)					Advanced Technologies Scenario CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
-1.2	-2.0	-2.2	-2.0	-2.1	135	116	99	85	75	-2.5	-3.1	-2.6	-2.8
-1.1	-2.7	-2.8	-2.7	-2.7	165	136	111	92	78	-3.2	-3.9	-3.4	-3.5
-4.0	-3.7	-3.9	-3.8	-3.8	167	129	98	75	59	-4.1	-5.2	-4.9	-4.8
-1.7	-3.2	-3.1	-2.8	-3.0	244	195	156	129	113	-3.9	-4.3	-3.2	-3.8
-1.1	-1.7	-1.6	-1.4	-1.5	75	67	60	55	51	-1.9	-2.2	-1.6	-1.9
-1.0	-2.3	-2.1	-2.1	-2.2	133	118	104	92	81	-2.3	-2.5	-2.4	-2.4
-1.9	-2.9	-2.3	-2.2	-2.4	133	115	98	84	74	-3.2	-3.1	-2.7	-3.0
-0.8	-1.6	-1.7	-1.9	-1.7	191	173	152	135	121	-2.2	-2.3	-2.2	-2.2
-0.9	-1.4	-1.2	-2.0	-1.6	201	195	175	156	140	-1.8	-1.4	-2.2	-1.8
-0.3	-1.7	-1.8	-1.9	-1.8	214	187	164	143	127	-2.3	-2.6	-2.5	-2.5
-4.7	-2.6	-2.7	-1.8	-2.4	230	183	154	137	122	-4.2	-4.0	-2.2	-3.4
-1.5	-2.9	-2.0	-1.5	-2.1	117	106	92	81	74	-3.4	-2.3	-2.2	-2.6
-1.6	-1.5	-1.5	-1.1	-1.4	87	80	73	66	61	-1.5	-1.8	-1.7	-1.7
0.0	-1.9	-2.2	-2.0	-2.0	250	215	186	163	146	-2.1	-2.9	-2.4	-2.5
-1.0	-1.1	-2.5	-2.3	-2.1	236	195	161	137	120	-2.3	-3.8	-2.9	-3.0
-1.9	-2.5	-2.3	-1.8	-2.2	85	72	61	52	45	-3.0	-3.4	-2.9	-3.1
-2.0	-2.6	-2.4	-1.8	-2.2	81	68	57	49	42	-3.1	-3.4	-3.0	-3.2
-0.5	-1.5	-1.9	-1.7	-1.7	128	112	98	87	79	-2.0	-2.6	-2.1	-2.3
0.1	-1.4	-1.7	-1.7	-1.6	136	119	104	91	82	-1.8	-2.7	-2.4	-2.3
-1.8	-2.7	-2.1	-1.9	-2.2	60	53	46	41	38	-3.2	-2.7	-1.9	-2.5
-1.9	-2.6	-2.1	-2.1	-2.2	368	319	275	242	214	-2.8	-2.9	-2.5	-2.7
-1.0	-2.4	-1.7	-1.9	-2.0	445	392	343	305	273	-2.6	-2.6	-2.3	-2.5
-0.9	-2.4	-3.0	-2.7	-2.7	221	180	148	124	107	-3.3	-4.0	-3.1	-3.5
0.7	-1.2	-1.6	-1.6	-1.5	266	239	213	192	174	-1.6	-2.2	-2.0	-2.0
-1.7	-1.8	-2.3	-2.1	-2.1	75	64	55	50	47	-2.0	-3.1	-1.5	-2.3
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
-1.7	-2.4	-2.2	-1.8	-2.1	77	66	57	50	45	-2.8	-2.9	-2.4	-2.7
-1.7	-2.3	-2.2	-1.8	-2.1	75	64	55	47	42	-2.8	-3.2	-2.6	-2.8
-1.8	-2.7	-2.9	-2.6	-2.7	196	162	132	111	95	-3.2	-3.9	-3.3	-3.5
-2.7	-3.2	-3.2	-2.9	-3.1	184	148	118	96	81	-3.7	-4.3	-3.6	-3.9
-1.5	-2.0	-1.9	-1.6	-1.8	111	97	84	75	68	-2.4	-2.7	-2.2	-2.4
-1.9	-2.5	-2.2	-2.0	-2.2	68	59	52	46	42	-2.9	-2.7	-2.0	-2.5

Table A22 | Energy-related carbon dioxide emissions

	Reference Scenario (Mt)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
World	20 583	23 158	30 612	34 116	32 912	32 635	32 463	32 583	32 662
Asia	4 659	6 742	12 883	17 077	16 717	16 616	16 388	16 345	16 210
China	2 162	3 151	7 975	10 613	9 469	8 687	7 767	6 996	6 188
India	521	875	1 546	2 517	3 106	3 553	3 981	4 423	4 836
Japan	1 046	1 151	1 131	974	768	721	664	616	576
Korea	214	407	558	549	539	505	488	463	428
Chinese Taipei	116	220	260	264	247	237	224	209	194
ASEAN	350	682	1 074	1 683	2 042	2 269	2 510	2 751	2 958
Indonesia	130	255	396	652	801	907	1 034	1 162	1 281
Malaysia	53	112	188	241	281	292	302	312	316
Myanmar	4.0	9.6	8.1	26	30	39	50	64	79
Philippines	35	65	75	138	179	214	245	270	288
Singapore	26	40	48	47	49	50	50	49	49
Thailand	81	151	222	250	257	262	264	263	258
Viet Nam	17	42	123	287	389	443	497	552	600
North America	5 151	6 098	5 715	5 131	4 540	4 261	4 018	3 819	3 714
United States	4 760	5 621	5 217	4 608	4 043	3 761	3 510	3 313	3 206
Latin America	861	1 192	1 522	1 472	1 465	1 526	1 586	1 644	1 689
Brazil	199	305	381	414	370	397	425	452	476
Advanced Europe	3 964	3 927	3 834	3 153	2 279	2 016	1 879	1 789	1 662
Other Europe/Eurasia	3 872	2 328	2 490	2 510	2 369	2 295	2 274	2 235	2 216
Russia	2 144	1 400	1 462	1 623	1 465	1 412	1 383	1 350	1 332
Africa	571	689	1 017	1 262	1 391	1 543	1 728	1 962	2 214
Middle East	588	967	1 605	1 997	2 247	2 356	2 442	2 526	2 593
Oceania	285	356	416	383	370	352	335	321	309
International Bunkers	632	858	1 130	1 131	1 535	1 670	1 812	1 941	2 056
Advanced Economies	10 835	12 238	12 003	10 532	8 817	8 165	7 680	7 286	6 946
Group of Seven	8 423	9 386	8 825	7 619	6 391	5 933	5 547	5 263	5 039
Emerging and Developing Economies	9 117	10 062	17 480	22 453	22 560	22 800	22 971	23 356	23 660
Emerging and Developing Asia	3 224	4 886	10 846	15 212	15 088	15 080	14 940	14 989	14 948
Non-Asia	15 292	15 558	16 599	15 908	14 659	14 349	14 263	14 297	14 396
European Union	3 462	3 263	3 133	2 517	1 915	1 712	1 602	1 532	1 422

Source: International Energy Agency "World Energy Balances", etc. (historical)
The Institute of Energy Economics, Japan (projection)

Reference Scenario CAGR (%)					Advanced Technologies Scenario (Mt)					Advanced Technologies Scenario CAGR (%)			
1990/ 2022	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2040	2040/ 2050	2022/ 2050
1.6	-0.4	-0.1	0.1	-0.2	29 605	24 805	20 487	16 358	12 924	-1.8	-3.6	-4.5	-3.4
4.1	-0.3	-0.2	-0.1	-0.2	14 897	12 042	9 577	7 497	5 841	-1.7	-4.3	-4.8	-3.8
5.1	-1.4	-2.0	-2.2	-1.9	8 518	6 001	3 953	2 434	1 465	-2.7	-7.4	-9.5	-6.8
5.0	2.7	2.5	2.0	2.4	2 761	2 780	2 708	2 525	2 216	1.2	-0.2	-2.0	-0.5
-0.2	-2.9	-1.4	-1.4	-1.9	667	518	372	212	71	-4.6	-5.7	-15.3	-8.9
3.0	-0.2	-1.0	-1.3	-0.9	468	358	253	165	99	-2.0	-6.0	-9.0	-5.9
2.6	-0.9	-1.0	-1.5	-1.1	217	175	134	89	52	-2.4	-4.7	-9.0	-5.6
5.0	2.4	2.1	1.7	2.0	1 776	1 695	1 612	1 494	1 336	0.7	-1.0	-1.9	-0.8
5.2	2.6	2.6	2.2	2.4	710	720	714	684	619	1.1	0.1	-1.4	-0.2
4.8	1.9	0.7	0.4	1.0	250	234	211	180	151	0.5	-1.7	-3.3	-1.6
6.0	1.8	5.2	4.7	4.1	27	34	40	49	58	0.5	4.0	3.7	2.9
4.3	3.4	3.2	1.6	2.7	152	155	154	149	133	1.3	0.1	-1.5	-0.1
1.8	0.6	0.2	-0.3	0.1	39	23	16	7.2	0.9	-2.1	-8.9	-24.7	-13.1
3.6	0.3	0.3	-0.2	0.1	240	216	192	162	132	-0.5	-2.2	-3.7	-2.3
9.3	3.9	2.5	1.9	2.7	309	265	237	211	188	0.9	-2.6	-2.3	-1.5
0.0	-1.5	-1.2	-0.8	-1.1	4 029	3 061	2 214	1 290	551	-3.0	-5.8	-13.0	-7.7
-0.1	-1.6	-1.4	-0.9	-1.3	3 570	2 673	1 902	1 063	397	-3.1	-6.1	-14.5	-8.4
1.7	-0.1	0.8	0.6	0.5	1 324	1 234	1 106	968	827	-1.3	-1.8	-2.9	-2.0
2.3	-1.4	1.4	1.1	0.5	340	323	298	262	227	-2.4	-1.3	-2.7	-2.1
-0.7	-4.0	-1.9	-1.2	-2.3	1 950	1 527	1 139	678	285	-5.8	-5.2	-12.9	-8.2
-1.3	-0.7	-0.4	-0.3	-0.4	2 243	1 961	1 711	1 507	1 332	-1.4	-2.7	-2.5	-2.2
-0.9	-1.3	-0.6	-0.4	-0.7	1 395	1 209	1 026	888	773	-1.9	-3.0	-2.8	-2.6
2.5	1.2	2.2	2.5	2.0	1 291	1 312	1 324	1 326	1 324	0.3	0.3	0.0	0.2
3.9	1.5	0.8	0.6	0.9	2 106	2 003	1 841	1 640	1 464	0.7	-1.3	-2.3	-1.1
0.9	-0.5	-1.0	-0.8	-0.8	345	268	198	110	29	-1.3	-5.4	-17.4	-8.8
1.8	3.9	1.7	1.3	2.2	1 420	1 398	1 376	1 343	1 271	2.9	-0.3	-0.8	0.4
-0.1	-2.2	-1.4	-1.0	-1.5	7 740	5 948	4 341	2 561	1 097	-3.8	-5.6	-12.8	-7.8
-0.3	-2.2	-1.4	-1.0	-1.5	5 642	4 284	3 078	1 750	655	-3.7	-5.9	-14.3	-8.4
2.9	0.1	0.2	0.3	0.2	20 445	17 458	14 770	12 454	10 556	-1.2	-3.2	-3.3	-2.7
5.0	-0.1	-0.1	0.0	-0.1	13 481	10 949	8 787	7 013	5 609	-1.5	-4.2	-4.4	-3.5
0.1	-1.0	-0.3	0.1	-0.4	13 288	11 365	9 534	7 518	5 812	-2.2	-3.3	-4.8	-3.5
-1.0	-3.4	-1.8	-1.2	-2.0	1 664	1 318	974	588	251	-5.0	-5.2	-12.7	-7.9

Table A23 | World

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	8 699	9 936	12 732	14 860	15 565	15 956	16 281	16 628	16 984
Coal	2 219	2 316	3 652	4 106	3 607	3 430	3 225	3 093	2 956
Oil	3 237	3 683	4 152	4 488	4 655	4 712	4 791	4 850	4 878
Natural gas	1 662	2 068	2 736	3 437	3 650	3 801	4 017	4 261	4 533
Nuclear	526	675	719	700	837	884	882	879	902
Hydro	184	225	297	374	413	436	457	477	497
Geothermal	34	52	62	116	166	240	261	276	290
Solar, wind, etc.	2.5	8.2	48	339	841	1 050	1 250	1 413	1 574
Biomass and waste	833	906	1 065	1 301	1 394	1 404	1 398	1 379	1 354
Hydrogen	-	-	-	-	0.1	0.1	0.1	0.2	0.2

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	6 178	6 918	8 719	10 076	10 898	11 192	11 490	11 769	12 044
Coal	751	540	1 058	890	913	877	848	822	799
Oil	2 607	3 127	3 620	4 014	4 236	4 309	4 401	4 474	4 520
Natural gas	945	1 121	1 346	1 690	1 818	1 850	1 877	1 895	1 910
Electricity	834	1 087	1 538	2 113	2 514	2 757	3 006	3 269	3 561
Heat	336	248	275	360	405	401	391	376	360
Hydrogen	-	-	-	-	0.6	0.8	0.9	0.9	0.9
Renewables and waste	705	796	882	1 008	1 011	997	967	933	891
Industry	1 796	1 863	2 637	3 064	3 435	3 559	3 649	3 695	3 720
Transport	1 578	1 966	2 431	2 802	3 072	3 140	3 231	3 330	3 424
Buildings, etc.	2 327	2 471	2 857	3 238	3 321	3 379	3 449	3 539	3 655
Non-energy use	477	618	794	972	1 070	1 114	1 160	1 205	1 246

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	11 849	15 425	21 515	29 143	34 528	37 744	40 956	44 290	47 956
Coal	4 436	5 993	8 675	10 450	8 511	8 071	7 456	7 189	6 963
Oil	1 322	1 187	968	801	607	546	488	433	364
Natural gas	1 743	2 765	4 820	6 522	6 883	7 596	8 815	10 275	11 960
Nuclear	2 013	2 591	2 756	2 685	3 212	3 391	3 384	3 374	3 461
Hydro	2 143	2 619	3 455	4 350	4 809	5 068	5 312	5 548	5 781
Geothermal	36	52	68	97	136	197	215	229	242
Solar photovoltaics	0.1	0.8	32	1 295	5 110	6 586	8 026	9 076	10 109
Wind	3.9	31	342	2 120	4 115	5 048	5 924	6 760	7 595
Concentrated solar power and marine	1.2	1.1	2.2	15	20	20	21	23	25
Biomass and waste	130	163	363	760	1 076	1 170	1 264	1 336	1 408
Hydrogen	-	-	-	-	-	-	-	-	-
Others	20	22	34	49	49	49	49	49	49

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	20 583	23 158	30 612	34 116	32 912	32 635	32 463	32 583	32 662
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	35 896	48 285	64 834	89 488	110 594	126 311	143 985	163 414	184 098
Population (million)	5 286	6 135	6 960	7 940	8 476	8 784	9 069	9 324	9 541
GDP per capita ($2015 thousand)	6.8	7.9	9.3	11	13	14	16	18	19
Primary energy consumption per capita (toe/person)	1.6	1.6	1.8	1.9	1.8	1.8	1.8	1.8	1.8
Primary energy consumption per GDP (toe/$2015 million)	242	206	196	166	141	126	113	102	92
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	573	480	472	381	298	258	225	199	177
Energy-related CO_2 per primary energy consumption*2 (t/toe)	2.4	2.3	2.4	2.3	2.1	2.0	2.0	2.0	1.9

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
1.7	0.6	0.4	0.5	100	100	100	100	14 967	14 645	14 209	13 948	13 894	0.1	-0.4	-0.2	100	100
1.9	-1.6	-1.0	-1.2	26	28	23	17	3 216	2 699	2 236	1 911	1 657	-3.0	-3.3	-3.2	21	12
1.0	0.5	0.2	0.3	37	30	30	29	4 277	3 901	3 490	3 048	2 654	-0.6	-2.4	-1.9	29	19
2.3	0.8	1.1	1.0	19	23	23	27	3 514	3 484	3 357	3 285	3 194	0.3	-0.5	-0.3	23	23
0.9	2.3	0.4	0.9	6.0	4.7	5.4	5.3	966	1 121	1 267	1 356	1 474	4.1	2.1	2.7	6.5	11
2.2	1.3	0.9	1.0	2.1	2.5	2.7	2.9	428	460	494	530	569	1.7	1.4	1.5	2.9	4.1
3.9	4.6	2.8	3.3	0.4	0.8	1.1	1.7	167	262	300	333	364	4.7	4.0	4.2	1.1	2.6
16.5	12.0	3.2	5.6	0.0	2.3	5.4	9.3	991	1 361	1 748	2 186	2 668	14.4	5.1	7.7	6.6	19
1.4	0.9	-0.1	0.1	9.6	8.8	9.0	8.0	1 407	1 358	1 318	1 300	1 315	1.0	-0.3	0.0	9.4	9.5
n.a.	n.a.	0.8	n.a.	-	-	0.0	0.0	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	(Mtoe) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
1.5	1.0	0.5	0.6	100	100	100	100	10 412	10 082	9 722	9 438	9 312	0.4	-0.6	-0.3	100	100
0.5	0.3	-0.7	-0.4	12	8.8	8.4	6.6	829	718	629	566	521	-0.9	-2.3	-1.9	8.0	5.6
1.4	0.7	0.3	0.4	42	40	39	38	3 932	3 645	3 312	2 972	2 645	-0.3	-2.0	-1.5	38	28
1.8	0.9	0.2	0.4	15	17	17	16	1 705	1 574	1 419	1 256	1 109	0.1	-2.1	-1.5	16	12
2.9	2.2	1.8	1.9	14	21	23	30	2 576	2 837	3 105	3 388	3 692	2.5	1.8	2.0	25	40
0.2	1.5	-0.6	0.0	5.4	3.6	3.7	3.0	377	361	339	321	304	0.6	-1.1	-0.6	3.6	3.3
n.a.	n.a.	1.8	n.a.	-	-	0.0	0.0	0.8	31	74	132	247	n.a.	33.1	n.a.	0.0	2.7
1.1	0.0	-0.6	-0.4	11	10	9.3	7.4	992	914	844	804	793	-0.2	-1.1	-0.9	9.5	8.5
1.7	1.4	0.4	0.7	29	30	32	31	3 245	3 118	2 958	2 808	2 754	0.7	-0.8	-0.4	31	30
1.8	1.2	0.5	0.7	26	28	28	28	2 910	2 761	2 601	2 463	2 377	0.5	-1.0	-0.6	28	26
1.0	0.3	0.5	0.4	38	32	30	30	3 187	3 091	3 004	2 963	2 936	-0.2	-0.4	-0.3	31	32
2.2	1.2	0.8	0.9	7.7	9.6	9.8	10	1 070	1 113	1 159	1 204	1 245	1.2	0.8	0.9	10	13

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	(TWh) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
2.9	2.1	1.7	1.8	100	100	100	100	35 544	39 903	44 369	50 289	57 091	2.5	2.4	2.4	100	100
2.7	-2.5	-1.0	-1.4	37	36	25	15	7 297	5 683	4 223	3 243	2 524	-4.4	-5.2	-4.9	21	4.4
-1.6	-3.4	-2.5	-2.8	11	2.7	1.8	0.8	485	364	271	208	190	-6.1	-4.6	-5.0	1.4	0.3
4.2	0.7	2.8	2.2	15	22	20	25	6 740	7 211	7 450	8 169	8 797	0.4	1.3	1.1	19	15
0.9	2.3	0.4	0.9	17	9.2	9.3	7.2	3 709	4 302	4 861	5 204	5 657	4.1	2.1	2.7	10	9.9
2.2	1.3	0.9	1.0	18	15	14	12	4 974	5 347	5 741	6 162	6 619	1.7	1.4	1.5	14	12
3.1	4.3	2.9	3.3	0.3	0.3	0.4	0.5	137	221	250	275	299	4.3	4.0	4.1	0.4	0.5
34.9	18.7	3.5	7.6	0.0	4.4	15	21	6 017	8 451	11 021	13 693	16 636	21.2	5.2	9.5	17	29
21.8	8.6	3.1	4.7	0.0	7.3	12	16	4 931	6 762	8 678	11 069	13 695	11.1	5.2	6.9	14	24
8.1	3.7	1.2	1.9	0.0	0.1	0.1	0.1	21	25	30	39	51	4.5	4.5	4.5	0.1	0.1
5.7	4.4	1.4	2.2	1.1	2.6	3.1	2.9	1 187	1 314	1 444	1 548	1 668	5.7	1.7	2.8	3.3	2.9
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	176	352	630	907	n.a.	n.a.	n.a.	-	1.6
2.8	0.0	0.0	0.0	0.2	0.2	0.1	0.1	49	49	49	49	49	0.0	0.0	0.0	0.1	0.1

n.a.	n.a.	n.a.	n.a.					-	-	159	509	925	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
2.9	2.7	2.6	2.6	110 594	126 311	143 985	163 414	184 098	2.7	2.6	2.6
1.3	0.8	0.6	0.7	8 476	8 784	9 069	9 324	9 541	0.8	0.6	0.7
1.6	1.8	2.0	1.9	13	14	16	18	19	1.8	2.0	1.9
0.4	-0.2	-0.2	-0.2	1.8	1.7	1.6	1.5	1.5	-0.7	-1.0	-0.9
-1.2	-2.0	-2.1	-2.1	135	116	99	85	75	-2.5	-2.9	-2.8
-1.3	-3.0	-2.6	-2.7	268	196	142	100	70	-4.3	-6.5	-5.9
-0.1	-1.0	-0.5	-0.6	2.0	1.7	1.4	1.2	0.9	-1.8	-3.7	-3.2

Table A24 | Asia

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	2 071	2 837	4 758	6 582	7 096	7 374	7 586	7 793	7 978
Coal	785	1 036	2 406	3 253	3 020	2 910	2 748	2 629	2 493
Oil	618	918	1 170	1 518	1 635	1 684	1 758	1 832	1 894
Natural gas	116	234	454	709	880	982	1 085	1 196	1 307
Nuclear	77	132	152	194	280	313	344	370	403
Hydro	32	41	92	162	181	194	205	215	224
Geothermal	8.2	23	31	67	103	153	167	175	182
Solar, wind, etc.	1.3	2.1	16	166	460	585	709	797	886
Biomass and waste	433	451	436	510	533	552	566	577	587
Hydrogen	-	-	-	-	0.5	0.6	0.7	0.7	0.6

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	1 511	1 946	3 132	4 138	4 660	4 855	5 058	5 244	5 420
Coal	423	372	897	752	772	741	718	698	680
Oil	464	741	990	1 336	1 467	1 515	1 586	1 657	1 718
Natural gas	46	90	201	396	485	513	542	561	576
Electricity	157	279	574	1 045	1 310	1 461	1 596	1 722	1 854
Heat	14	30	69	181	226	226	220	211	201
Hydrogen	-	-	-	-	0.6	0.8	0.9	0.9	0.9
Renewables and waste	407	433	401	429	399	398	396	394	391
Industry	508	648	1 399	1 778	2 029	2 102	2 155	2 172	2 174
Transport	189	323	493	722	871	911	967	1 032	1 098
Buildings, etc.	699	789	944	1 187	1 243	1 302	1 374	1 456	1 545
Non-energy use	115	186	296	452	517	539	562	584	602

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	2 243	3 969	7 967	14 310	17 929	19 939	21 694	23 283	24 913
Coal	875	1 982	4 781	8 108	7 230	7 023	6 576	6 331	6 054
Oil	433	381	260	155	117	120	122	126	128
Natural gas	237	566	1 071	1 423	1 816	2 213	2 655	3 199	3 798
Nuclear	294	505	582	746	1 076	1 203	1 321	1 420	1 546
Hydro	368	478	1 072	1 882	2 105	2 257	2 389	2 505	2 609
Geothermal	8.4	20	22	31	50	81	89	93	98
Solar photovoltaics	0.1	0.4	5.2	707	2 985	3 849	4 713	5 229	5 745
Wind	0.0	2.4	70	881	1 988	2 568	3 137	3 636	4 139
Concentrated solar power and marine	0.0	0.0	0.0	2.5	5.4	6.1	6.8	8.5	10
Biomass and waste	9.0	15	82	355	535	600	665	716	767
Hydrogen	-	-	-	-	-	-	-	-	-
Others	20	20	21	20	20	20	20	20	20

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	4 659	6 742	12 883	17 077	16 717	16 616	16 388	16 345	16 210
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	6 705	10 415	17 921	30 825	41 436	49 564	59 046	69 748	81 326
Population (million)	2 955	3 454	3 874	4 308	4 479	4 567	4 634	4 677	4 694
GDP per capita ($2015 thousand)	2.3	3.0	4.6	7.2	9.3	11	13	15	17
Primary energy consumption per capita (toe/person)	0.7	0.8	1.2	1.5	1.6	1.6	1.6	1.7	1.7
Primary energy consumption per GDP (toe/$2015 million)	309	272	265	214	171	149	128	112	98
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	695	647	719	554	403	335	278	234	199
Energy-related CO_2 per primary energy consumption*2 (t/toe)	2.3	2.4	2.7	2.6	2.4	2.3	2.2	2.1	2.0

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario CAGR (%) 1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	Advanced Technologies Scenario (Mtoe) 2030	2035	2040	2045	2050	CAGR (%) 2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
3.7	0.9	0.6	0.7	100	100	100	100	6 827	6 719	6 531	6 397	6 383	0.5	-0.3	-0.1	100	100
4.5	-0.9	-1.0	-0.9	38	49	43	31	2 728	2 312	1 886	1 583	1 348	-2.2	-3.5	-3.1	40	21
2.8	0.9	0.7	0.8	30	23	23	24	1 509	1 421	1 326	1 218	1 108	-0.1	-1.5	-1.1	22	17
5.8	2.7	2.0	2.2	5.6	11	12	16	842	866	850	829	832	2.2	-0.1	0.6	12	13
2.9	4.7	1.8	2.6	3.7	3.0	4.0	5.0	372	452	543	596	658	8.4	2.9	4.4	5.4	10
5.2	1.4	1.1	1.2	1.5	2.5	2.6	2.8	194	217	240	265	292	2.3	2.1	2.1	2.8	4.6
6.8	5.5	2.9	3.6	0.4	1.0	1.5	2.3	105	168	197	222	245	5.6	4.4	4.7	1.5	3.8
16.4	13.6	3.3	6.2	0.1	2.5	6.5	11	528	726	925	1 105	1 289	15.5	4.6	7.6	7.7	20
0.5	0.5	0.5	0.5	21	7.8	7.5	7.4	544	541	543	551	574	0.8	0.3	0.4	8.0	9.0
n.a.	n.a.	1.4	n.a.	-	-	0.0	0.0	4.9	15	19	28	35	n.a.	10.4	n.a.	0.1	0.6

Reference Scenario 1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	Advanced Technologies Scenario (Mtoe) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
3.2	1.5	0.8	1.0	100	100	100	100	4 445	4 367	4 283	4 213	4 219	0.9	-0.3	0.1	100	100
1.8	0.3	-0.6	-0.4	28	18	17	13	705	614	539	488	452	-0.8	-2.2	-1.8	16	11
3.4	1.2	0.8	0.9	31	32	31	32	1 360	1 290	1 209	1 118	1 023	0.2	-1.4	-1.0	31	24
6.9	2.6	0.9	1.4	3.1	9.6	10	11	447	420	385	341	304	1.5	-1.9	-0.9	10	7.2
6.1	2.9	1.8	2.1	10	25	28	34	1 340	1 481	1 617	1 746	1 909	3.2	1.8	2.2	30	45
8.3	2.8	-0.6	0.4	0.9	4.4	4.9	3.7	203	194	180	169	157	1.5	-1.3	-0.5	4.6	3.7
n.a.	n.a.	1.9	n.a.	-	-	0.0	0.0	0.6	6.0	14	25	49	n.a.	24.5	n.a.	0.0	1.2
0.2	-0.9	-0.1	-0.3	27	10	8.6	7.2	388	362	339	326	325	-1.2	-0.9	-1.0	8.7	7.7
4.0	1.7	0.3	0.7	34	43	44	40	1 906	1 821	1 726	1 638	1 618	0.9	-0.8	-0.3	43	38
4.3	2.4	1.2	1.5	13	17	19	20	820	794	763	735	717	1.6	-0.7	0.0	18	17
1.7	0.6	1.1	0.9	46	29	27	29	1 202	1 214	1 232	1 257	1 282	0.2	0.3	0.3	27	30
4.4	1.7	0.8	1.0	7.6	11	11	11	517	538	561	583	601	1.7	0.8	1.0	12	14

Reference Scenario 1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	Advanced Technologies Scenario (TWh) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
6.0	2.9	1.7	2.0	100	100	100	100	18 411	20 584	22 527	24 662	27 350	3.2	2.0	2.3	100	100
7.2	-1.4	-0.9	-1.0	39	57	40	24	6 370	5 120	3 726	2 753	2 075	-3.0	-5.5	-4.8	35	7.6
-3.2	-3.4	0.4	-0.7	19	1.1	0.7	0.5	97	93	90	93	96	-5.6	-0.1	-1.7	0.5	0.3
5.8	3.1	3.8	3.6	11	9.9	10	15	1 842	2 198	2 401	2 676	3 072	3.3	2.6	2.8	10	11
2.9	4.7	1.8	2.6	13	5.2	6.0	6.2	1 426	1 736	2 086	2 286	2 524	8.4	2.9	4.4	7.7	9.2
5.2	1.4	1.1	1.2	16	13	12	10	2 261	2 519	2 792	3 084	3 398	2.3	2.1	2.1	12	12
4.1	6.4	3.4	4.2	0.4	0.2	0.3	0.4	51	93	111	126	140	6.5	5.2	5.6	0.3	0.5
33.4	19.7	3.3	7.8	0.0	4.9	17	23	3 475	4 839	6 227	7 303	8 422	22.0	4.5	9.2	19	31
37.4	10.7	3.7	5.7	0.0	6.2	11	17	2 259	3 185	4 119	5 117	6 135	12.5	5.1	7.2	12	22
20.2	10.0	3.2	5.1	0.0	0.0	0.0	0.0	6.1	7.3	8.5	11	14	11.7	4.4	6.4	0.0	0.1
12.2	5.3	1.8	2.8	0.4	2.5	3.0	3.1	602	691	783	862	956	6.8	2.3	3.6	3.3	3.5
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	82	164	331	498	n.a.	n.a.	n.a.	-	1.8
0.1	0.0	0.0	0.0	0.9	0.1	0.1	0.1	20	20	20	20	20	0.0	0.0	0.0	0.1	0.1

n.a.	n.a.	n.a.	n.a.	-	-	81	190	322	n.a.	n.a.	n.a.

Reference Scenario 1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Advanced Technologies Scenario 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
4.9	3.8	3.4	3.5	41 436	49 564	59 046	69 748	81 326	3.8	3.4	3.5
1.2	0.5	0.2	0.3	4 479	4 567	4 634	4 677	4 694	0.5	0.2	0.3
3.7	3.3	3.2	3.2	9.3	11	13	15	17	3.3	3.2	3.2
2.5	0.5	0.4	0.4	1.5	1.5	1.4	1.4	1.4	0.0	-0.6	-0.4
-1.1	-2.7	-2.7	-2.7	165	136	111	92	78	-3.2	-3.6	-3.5
-0.7	-3.9	-3.5	-3.6	360	243	162	107	72	-5.3	-7.7	-7.0
0.4	-1.2	-0.7	-0.9	2.2	1.8	1.5	1.2	0.9	-2.1	-4.3	-3.7

Table A25 | China

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	874	1 133	2 536	3 800	3 842	3 762	3 648	3 527	3 387
Coal	531	668	1 790	2 317	1 972	1 779	1 547	1 360	1 176
Oil	119	221	428	680	721	694	681	664	637
Natural gas	13	21	89	297	375	396	406	408	400
Nuclear	-	4.4	19	109	148	170	192	213	235
Hydro	11	19	61	113	119	125	130	134	137
Geothermal	-	1.7	3.6	26	30	31	32	33	33
Solar, wind, etc.	0.0	1.0	12	130	348	432	516	566	616
Biomass and waste	200	198	133	128	129	136	145	150	155
Hydrogen	-	-	-	-	-0.0	-0.0	-	-	-

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	658	781	1 645	2 290	2 487	2 464	2 447	2 405	2 355
Coal	311	274	712	525	484	422	374	335	301
Oil	85	180	369	607	644	622	612	598	575
Natural gas	8.9	12	73	223	269	267	267	259	248
Electricity	39	89	297	649	794	860	905	934	961
Heat	13	26	62	171	216	216	210	201	191
Hydrogen	-	-	-	-	0.0	0.0	0.0	0.0	0.0
Renewables and waste	200	199	132	114	80	78	78	78	79
Industry	234	297	917	1 129	1 163	1 108	1 050	968	886
Transport	30	83	195	318	410	407	408	407	401
Buildings, etc.	351	339	414	599	642	677	715	756	797
Non-energy use	43	62	120	244	272	273	274	274	272

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	621	1 356	4 197	8 911	10 847	11 702	12 271	12 599	12 909
Coal	441	1 060	3 240	5 524	4 477	4 069	3 441	3 003	2 578
Oil	50	47	15	8.7	5.9	4.7	3.4	2.4	1.6
Natural gas	2.8	5.8	78	267	387	486	532	576	597
Nuclear	-	17	74	418	568	651	737	818	902
Hydro	127	222	711	1 313	1 386	1 459	1 517	1 562	1 595
Geothermal	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Solar photovoltaics	0.0	0.0	0.7	427	2 022	2 524	3 026	3 211	3 395
Wind	0.0	0.6	45	763	1 682	2 151	2 620	3 010	3 401
Concentrated solar power and marine	0.0	0.0	0.0	2.1	1.9	1.9	1.9	1.9	2.0
Biomass and waste	-	2.4	34	189	319	355	392	414	437
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions[*2]	2 162	3 151	7 975	10 613	9 469	8 687	7 767	6 996	6 188
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	1 027	2 770	7 554	16 325	22 246	26 574	31 544	37 066	42 922
Population (million)	1 135	1 263	1 338	1 412	1 385	1 361	1 331	1 294	1 249
GDP per capita ($2015 thousand)	0.9	2.2	5.6	12	16	20	24	29	34
Primary energy consumption per capita (toe/person)	0.8	0.9	1.9	2.7	2.8	2.8	2.7	2.7	2.7
Primary energy consumption per GDP (toe/$2015 million)	850	409	336	233	173	142	116	95	79
Energy-related CO_2 emissions per GDP[*2] (t/$2015 million)	2 105	1 138	1 056	650	426	327	246	189	144
Energy-related CO_2 per primary energy consumption[*2] (t/toe)	2.5	2.8	3.1	2.8	2.5	2.3	2.1	2.0	1.8

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario								
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
4.7	0.1	-0.6	-0.4	100	100	100	100	3 708	3 417	3 088	2 794	2 547	-0.3	-1.9	-1.4	100	100
4.7	-2.0	-2.6	-2.4	61	61	51	35	1 819	1 446	1 069	787	544	-3.0	-5.9	-5.0	49	21
5.6	0.7	-0.6	-0.2	14	18	19	19	671	592	512	440	375	-0.2	-2.9	-2.1	18	15
10.3	2.9	0.3	1.1	1.5	7.8	9.8	12	363	338	279	195	107	2.5	-5.9	-3.6	9.8	4.2
n.a.	3.9	2.3	2.8	-	2.9	3.8	6.9	170	202	236	268	300	5.7	2.9	3.7	4.6	12
7.6	0.7	0.7	0.7	1.2	3.0	3.1	4.0	127	137	148	158	169	1.5	1.5	1.5	3.4	6.6
n.a.	1.7	0.4	0.8	-	0.7	0.8	1.0	31	34	33	33	32	2.0	0.2	0.7	0.8	1.3
29.5	13.2	2.9	5.7	0.0	3.4	9.1	18	382	510	635	722	812	14.5	3.8	6.8	10	32
-1.4	0.1	0.9	0.7	23	3.4	3.4	4.6	147	159	177	192	208	1.8	1.7	1.7	4.0	8.1
n.a.	n.a.	-100	n.a.	-	-	-0.0	-	0.0	0.3	0.7	1.3	2.1	n.a.	20.9	n.a.	0.0	0.1

Reference Scenario								Advanced Technologies Scenario								
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(Mtoe)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
4.0	1.0	-0.3	0.1	100	100	100	100	2 383	2 240	2 105	1 974	1 880	0.5	-1.2	-0.7	100	100
1.6	-1.0	-2.3	-2.0	47	23	19	13	447	362	298	256	225	-2.0	-3.4	-3.0	19	12
6.4	0.7	-0.6	-0.2	13	27	26	24	601	532	464	402	346	-0.1	-2.7	-2.0	25	18
10.6	2.4	-0.4	0.4	1.3	9.7	11	11	246	213	177	135	101	1.2	-4.3	-2.8	10	5.4
9.2	2.5	1.0	1.4	5.9	28	32	41	807	855	893	909	926	2.7	0.7	1.3	34	49
8.3	3.0	-0.6	0.4	2.0	7.5	8.7	8.1	193	184	169	158	145	1.5	-1.4	-0.6	8.1	7.7
n.a.	n.a.	1.1	n.a.	-	-	0.0	0.0	0.0	3.5	8.4	15	32	n.a.	41.9	n.a.	0.0	1.7
-1.7	-4.4	-0.1	-1.3	30	5.0	3.2	3.3	88	90	95	100	104	-3.2	0.8	-0.3	3.7	5.5
5.0	0.4	-1.4	-0.9	36	49	47	38	1 095	969	854	741	660	-0.4	-2.5	-1.9	46	35
7.6	3.2	-0.1	0.8	4.6	14	16	17	389	357	324	297	280	2.5	-1.6	-0.5	16	15
1.7	0.9	1.1	1.0	53	26	26	34	628	642	654	663	669	0.6	0.3	0.4	26	36
5.6	1.4	0.0	0.4	6.5	11	11	12	272	272	273	273	271	1.4	0.0	0.4	11	14

Reference Scenario								Advanced Technologies Scenario								
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(TWh)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
8.7	2.5	0.9	1.3	100	100	100	100	11 056	11 887	12 421	12 703	13 082	2.7	0.8	1.4	100	100
8.2	-2.6	-2.7	-2.7	71	62	41	20	4 039	2 989	1 803	898	90	-3.8	-17.3	-13.7	37	0.7
-5.3	-4.7	-6.3	-5.9	8.1	0.1	0.1	0.0	5.4	3.5	1.8	0.7	0.1	-5.7	-20.1	-16.2	0.0	0.0
15.3	4.8	2.2	2.9	0.4	3.0	3.6	4.6	450	515	431	264	36	6.8	-11.8	-6.9	4.1	0.3
n.a.	3.9	2.3	2.8	-	4.7	5.2	7.0	651	777	905	1 027	1 153	5.7	2.9	3.7	5.9	8.8
7.6	0.7	0.7	0.7	20	15	13	12	1 474	1 594	1 716	1 841	1 968	1.5	1.5	1.5	13	15
3.9	-5.4	0.0	-1.6	0.0	0.0	0.0	0.0	0.1	2.5	2.6	2.6	2.7	-5.4	16.5	9.8	0.0	0.0
46.7	21.4	2.6	7.7	0.0	4.8	19	26	2 228	2 972	3 708	3 989	4 292	22.9	3.3	8.6	20	33
49.4	10.4	3.6	5.5	0.0	8.6	16	26	1 851	2 593	3 328	4 055	4 814	11.7	4.9	6.8	17	37
19.5	-1.1	0.1	-0.2	0.0	0.0	0.0	0.0	1.9	2.0	2.0	2.1	2.2	-0.9	0.6	0.2	0.0	0.0
n.a.	6.8	1.6	3.0	-	2.1	2.9	3.4	356	398	440	482	523	8.3	1.9	3.7	3.2	4.0
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	42	84	142	200	n.a.	n.a.	n.a.	-	1.5
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

n.a.	n.a.	n.a.	n.a.	-	-	51	109	175	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
9.0	3.9	3.3	3.5	22 246	26 574	31 544	37 066	42 922	3.9	3.3	3.5
0.7	-0.2	-0.5	-0.4	1 385	1 361	1 331	1 294	1 249	-0.2	-0.5	-0.4
8.3	4.2	3.9	4.0	16	20	24	29	34	4.2	3.9	4.0
4.0	0.4	-0.1	0.0	2.7	2.5	2.3	2.2	2.0	-0.1	-1.3	-1.0
-4.0	-3.7	-3.8	-3.8	167	129	98	75	59	-4.1	-5.0	-4.8
-3.6	-5.2	-5.3	-5.2	383	226	125	66	34	-6.4	-11.4	-10.0
0.4	-1.5	-1.5	-1.5	2.3	1.8	1.3	0.9	0.6	-2.4	-6.7	-5.5

Table A26 | India

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	280	418	661	1 015	1 309	1 501	1 685	1 875	2 058
Coal	93	146	274	466	563	629	684	737	781
Oil	61	112	162	243	301	353	413	480	550
Natural gas	11	23	54	52	89	119	149	181	212
Nuclear	1.6	4.4	6.8	12	36	41	46	53	61
Hydro	6.2	6.4	11	15	20	23	27	30	34
Geothermal	-	-	-	-	-	-	0.0	0.0	0.0
Solar, wind, etc.	0.0	0.2	2.0	18	67	98	127	155	184
Biomass and waste	108	126	151	210	233	239	239	239	237
Hydrogen	-	-	-	-	-0.0	-0.0	-	-	-

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	215	291	440	672	887	1 024	1 157	1 295	1 434
Coal	38	33	83	112	158	180	197	212	225
Oil	50	94	138	211	279	329	387	450	517
Natural gas	6.1	12	19	42	65	82	98	112	125
Electricity	18	32	62	120	188	234	282	333	385
Heat	-	-	-	-	-	-	0.0	0.0	0.0
Hydrogen	-	-	-	-	-	-	0.0	0.0	0.0
Renewables and waste	102	119	138	186	197	199	194	189	182
Industry	59	85	157	272	420	501	563	616	657
Transport	21	32	65	113	151	180	216	262	316
Buildings, etc.	122	147	184	238	250	265	286	312	342
Non-energy use	13	27	34	48	66	78	92	105	119

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	289	561	972	1 814	2 807	3 458	4 089	4 739	5 394
Coal	189	387	658	1 307	1 479	1 639	1 771	1 913	2 034
Oil	13	25	19	4.7	2.6	0.8	-	-	-
Natural gas	10.0	56	107	55	133	207	294	398	516
Nuclear	6.1	17	26	46	138	156	178	202	233
Hydro	72	74	125	174	234	272	312	352	393
Geothermal	-	-	-	-	-	-	-	-	-
Solar photovoltaics	-	0.0	0.1	105	615	899	1 183	1 440	1 697
Wind	0.0	1.7	20	81	138	205	262	333	408
Concentrated solar power and marine	-	-	-	-	0.3	0.3	0.3	0.3	0.3
Biomass and waste	-	0.2	17	43	67	78	89	101	113
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	521	875	1 546	2 517	3 106	3 553	3 981	4 423	4 836
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	475	817	1 567	3 022	5 067	6 791	8 941	11 512	14 440
Population (million)	870	1 060	1 241	1 417	1 516	1 570	1 613	1 646	1 670
GDP per capita ($2015 thousand)	0.5	0.8	1.3	2.1	3.3	4.3	5.5	7.0	8.6
Primary energy consumption per capita (toe/person)	0.3	0.4	0.5	0.7	0.9	1.0	1.0	1.1	1.2
Primary energy consumption per GDP (toe/$2015 million)	590	511	422	336	258	221	189	163	143
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	1 098	1 071	986	833	613	523	445	384	335
Energy-related CO_2 per primary energy consumption*2 (t/toe)	1.9	2.1	2.3	2.5	2.4	2.4	2.4	2.4	2.3

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario										
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
5.2	2.4	1.6	1.9	33	46	43	38	494	492	478	479	513	0.8	0.2	0.3	40	31
4.4	2.7	3.1	3.0	22	24	23	27	274	292	306	309	304	1.5	0.5	0.8	22	19
5.1	7.0	4.4	5.2	3.8	5.1	6.8	10	90	110	121	133	158	7.2	2.8	4.1	7.3	9.7
6.5	14.8	2.6	6.0	0.6	1.2	2.8	2.9	48	62	90	96	118	19.1	4.6	8.5	3.9	7.2
2.8	3.8	2.6	3.0	2.2	1.5	1.5	1.6	24	31	39	48	59	6.0	4.7	5.0	1.9	3.6
n.a.	n.a.	n.a.	n.a.	-	-	-	0.0	-	-	-	0.0	0.0	n.a.	n.a.	n.a.	-	0.0
26.3	18.3	5.2	8.8	0.0	1.7	5.1	9.0	88	135	183	242	297	22.3	6.3	10.6	7.1	18
2.1	1.3	0.1	0.4	39	21	18	11	218	202	185	175	174	0.4	-1.1	-0.7	18	11
n.a.	n.a.	-100	n.a.	-	-	-0.0	-	-0.1	-0.9	-2.2	-0.2	6.6	n.a.	n.a.	n.a.	-0.0	0.4

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(Mtoe)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
3.4	4.3	1.8	2.5	18	17	18	16	138	136	131	126	123	2.6	-0.6	0.3	17	11
4.6	3.5	3.1	3.2	23	31	31	36	254	272	286	290	286	2.3	0.6	1.1	31	27
6.2	5.8	3.3	4.0	2.8	6.2	7.4	8.8	60	67	71	73	74	4.7	1.1	2.1	7.3	6.9
6.1	5.7	3.7	4.2	8.5	18	21	27	201	253	310	378	471	6.6	4.4	5.0	24	44
n.a.	n.a.	n.a.	n.a.	-	-	-	0.0	-	-	-	0.0	0.0	n.a.	n.a.	n.a.	-	0.0
n.a.	n.a.	n.a.	n.a.	-	-	-	0.0	-	0.8	2.2	4.3	7.5	n.a.	n.a.	n.a.	-	0.7
1.9	0.7	-0.4	-0.1	48	28	22	13	179	158	135	119	113	-0.5	-2.3	-1.8	22	10
4.9	5.6	2.3	3.2	27	41	47	46	387	412	422	437	482	4.5	1.1	2.1	47	45
5.4	3.7	3.8	3.7	9.6	17	17	22	141	155	167	178	187	2.8	1.4	1.8	17	17
2.1	0.6	1.6	1.3	57	35	28	24	238	242	253	268	287	0.0	0.9	0.7	29	27
4.1	4.0	3.0	3.2	6.2	7.2	7.5	8.3	66	78	92	105	119	4.0	3.0	3.2	8.0	11

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(TWh)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
6.2	1.6	1.6	1.6	65	72	53	38	1 296	1 247	1 157	1 166	1 381	-0.1	0.3	0.2	43	20
-3.0	-7.2	-100	-100	4.3	0.3	0.1	-	2.4	0.7	-	-	-	-8.3	-100	-100	0.1	-
5.5	11.7	7.0	8.3	3.4	3.0	4.7	9.6	172	270	326	410	583	15.4	6.3	8.8	5.8	8.7
6.5	14.8	2.6	6.0	2.1	2.5	4.9	4.3	186	237	346	370	453	19.1	4.6	8.5	6.2	6.7
2.8	3.8	2.6	3.0	25	9.6	8.3	7.3	277	357	451	561	689	6.0	4.7	5.0	9.2	10
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	24.8	5.2	10.5	-	5.8	22	31	804	1 246	1 693	2 220	2 720	29.0	6.3	12.3	27	40
27.7	7.0	5.5	6.0	0.0	4.4	4.9	7.6	184	278	382	544	674	10.8	6.7	7.9	6.1	10.0
n.a.	n.a.	0.0	n.a.	-	-	0.0	0.0	0.3	0.4	0.4	0.4	0.4	n.a.	0.5	n.a.	0.0	0.0
n.a.	5.9	2.6	3.5	-	2.3	2.4	2.1	75	89	104	120	136	7.3	3.0	4.2	2.5	2.0
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	53	106	n.a.	n.a.	n.a.	-	1.6
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
6.0	6.7	5.4	5.7	5 067	6 791	8 941	11 512	14 440	6.7	5.4	5.7
1.5	0.8	0.5	0.6	1 516	1 570	1 613	1 646	1 670	0.8	0.5	0.6
4.4	5.8	4.9	5.1	3.3	4.3	5.5	7.0	8.6	5.8	4.9	5.1
2.5	2.4	1.8	2.0	0.8	0.8	0.9	0.9	1.0	1.6	0.9	1.1
-1.7	-3.2	-2.9	-3.0	244	195	156	129	113	-3.9	-3.8	-3.8
-0.9	-3.8	-3.0	-3.2	545	409	303	219	153	-5.2	-6.1	-5.9
0.9	-0.5	-0.1	-0.2	2.2	2.1	1.9	1.7	1.4	-1.3	-2.5	-2.1

Table A27 | Japan

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	437	516	500	392	367	352	339	327	317
Coal	77	97	115	109	82	78	71	66	61
Oil	249	253	201	151	132	123	115	108	100
Natural gas	44	66	86	83	61	58	55	54	53
Nuclear	53	84	75	15	47	42	42	42	42
Hydro	7.6	7.2	7.2	6.6	7.4	7.7	7.9	8.0	8.1
Geothermal	1.6	3.1	2.4	2.7	3.4	4.8	5.5	5.9	6.3
Solar, wind, etc.	1.2	0.9	1.1	8.9	16	18	20	22	23
Biomass and waste	4.2	5.0	11	17	18	20	21	22	22
Hydrogen	-	-	-	-	0.4	0.5	0.5	0.5	0.5

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	289	334	312	259	239	230	220	212	204
Coal	27	21	23	18	16	15	13	12	12
Oil	179	204	165	128	115	107	100	93	87
Natural gas	14	21	29	28	25	24	22	21	19
Electricity	66	84	89	78	77	77	78	79	80
Heat	0.2	0.5	0.6	0.7	0.6	0.5	0.5	0.4	0.3
Hydrogen	-	-	-	-	0.4	0.5	0.6	0.6	0.6
Renewables and waste	3.8	4.1	6.1	6.7	6.1	5.9	5.7	5.4	5.2
Industry	107	102	91	75	69	66	63	61	58
Transport	72	89	79	64	60	56	52	48	45
Buildings, etc.	78	108	108	92	86	83	80	78	77
Non-energy use	32	35	35	27	25	25	25	25	25

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	862	1 055	1 164	1 010	995	998	1 005	1 018	1 038
Coal	125	228	317	312	206	198	175	157	143
Oil	250	133	91	41	21	17	12	8.9	5.7
Natural gas	168	255	332	343	225	220	220	224	232
Nuclear	202	322	288	56	179	162	163	162	162
Hydro	88	84	84	77	87	90	92	93	94
Geothermal	1.7	3.3	2.6	3.0	3.8	5.4	6.2	6.7	7.2
Solar photovoltaics	0.1	0.4	3.5	93	147	160	172	185	197
Wind	-	0.1	4.0	9.3	38	49	60	67	74
Concentrated solar power and marine	-	-	-	-	-	-	-	-	-
Biomass and waste	8.1	9.2	21	59	72	81	90	98	106
Hydrogen	-	-	-	-	-	-	-	-	-
Others	20	20	21	16	16	16	16	16	16

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions *2	1 046	1 151	1 131	974	768	721	664	616	576
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	3 510	3 987	4 219	4 530	4 846	5 048	5 254	5 458	5 659
Population (million)	123	127	128	125	120	116	112	109	105
GDP per capita ($2015 thousand)	28	31	33	36	40	44	47	50	54
Primary energy consumption per capita (toe/person)	3.5	4.1	3.9	3.1	3.1	3.0	3.0	3.0	3.0
Primary energy consumption per GDP (toe/$2015 million)	124	129	118	87	76	70	65	60	56
Energy-related CO_2 emissions per GDP *2 (t/$2015 million)	298	289	268	215	158	143	126	113	102
Energy-related CO_2 per primary energy consumption *2 (t/toe)	2.4	2.2	2.3	2.5	2.1	2.0	2.0	1.9	1.8

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
1.1	-3.4	-1.5	-2.0	18	28	22	19	70	59	49	42	36	-5.4	-3.3	-3.9	19	12
-1.6	-1.7	-1.4	-1.5	57	38	36	32	122	103	86	71	60	-2.6	-3.5	-3.3	34	21
2.0	-3.8	-0.7	-1.6	10	21	17	17	55	48	41	34	24	-4.9	-4.2	-4.4	15	8.3
-3.9	15.6	-0.5	3.9	12	3.7	13	13	64	66	65	65	65	20.4	0.0	5.5	18	23
-0.4	1.4	0.4	0.7	1.7	1.7	2.0	2.5	7.5	7.9	8.1	8.3	8.5	1.5	0.6	0.9	2.1	3.0
1.7	2.8	3.2	3.1	0.4	0.7	0.9	2.0	3.4	5.2	6.0	6.4	6.8	2.8	3.6	3.4	0.9	2.4
6.4	7.6	1.9	3.5	0.3	2.3	4.4	7.4	18	21	25	29	33	9.1	3.1	4.8	4.9	12
4.4	1.0	1.0	1.0	1.0	4.3	5.0	7.1	21	24	28	29	34	2.5	2.5	2.5	5.7	12
n.a.	n.a.	1.4	n.a.	-	-	0.1	0.2	0.8	3.6	6.0	13	20	n.a.	17.2	n.a.	0.2	7.0

Reference Scenario								Advanced Technologies Scenario									
				Shares (%)				(Mtoe)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
-1.3	-1.7	-1.5	-1.5	9.4	6.9	6.5	5.7	14	11	9.5	8.2	7.3	-3.2	-3.1	-3.1	6.0	4.5
-1.0	-1.3	-1.4	-1.4	62	49	48	42	106	90	74	62	52	-2.3	-3.5	-3.1	47	32
2.3	-1.3	-1.2	-1.3	4.7	11	10	9.5	24	21	17	14	11	-2.0	-3.9	-3.3	10	6.6
0.5	-0.2	0.2	0.1	23	30	32	39	78	78	78	80	80	0.0	0.2	0.1	34	50
3.8	-2.0	-2.4	-2.3	0.1	0.3	0.2	0.2	0.5	0.5	0.4	0.4	0.3	-2.3	-2.2	-2.3	0.2	0.2
n.a.	n.a.	2.0	n.a.	-	-	0.2	0.3	0.5	1.2	2.0	3.1	5.4	n.a.	12.5	n.a.	0.2	3.4
1.8	-1.2	-0.7	-0.9	1.3	2.6	2.5	2.6	6.0	5.8	5.7	5.7	6.0	-1.3	0.0	-0.4	2.6	3.7
-1.1	-1.2	-0.8	-0.9	37	29	29	28	65	59	53	49	46	-1.8	-1.7	-1.7	28	28
-0.4	-0.9	-1.5	-1.3	25	25	25	22	55	46	37	31	27	-2.0	-3.4	-3.0	24	17
0.5	-0.9	-0.5	-0.7	27	36	36	38	83	78	71	67	64	-1.2	-1.3	-1.3	36	40
-0.6	-0.7	-0.1	-0.3	11	10	11	12	25	25	25	25	25	-0.7	-0.1	-0.3	11	15

Reference Scenario								Advanced Technologies Scenario									
				Shares (%)				(TWh)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
2.9	-5.0	-1.8	-2.7	14	31	21	14	155	118	81	55	26	-8.4	-8.5	-8.5	15	2.3
-5.5	-8.1	-6.3	-6.8	29	4.1	2.1	0.5	15	12	7.3	4.4	1.8	-11.6	-10.1	-10.5	1.5	0.2
2.3	-5.2	0.2	-1.4	19	34	23	22	201	183	164	150	106	-6.5	-3.2	-4.1	20	9.4
-3.9	15.6	-0.5	3.9	23	5.6	18	16	247	252	250	249	249	20.4	0.0	5.5	25	22
-0.4	1.4	0.4	0.7	10	7.6	8.7	9.0	87	91	95	97	99	1.5	0.6	0.9	8.6	8.8
1.7	3.0	3.3	3.2	0.2	0.3	0.4	0.7	3.8	6.0	6.9	7.4	7.9	3.0	3.7	3.5	0.4	0.7
25.4	5.9	1.5	2.7	0.0	9.2	15	19	161	181	204	232	261	7.2	2.4	3.8	16	23
n.a.	19.4	3.3	7.7	-	0.9	3.9	7.2	45	62	81	100	121	21.7	5.1	9.6	4.4	11
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
6.4	2.5	2.0	2.1	0.9	5.8	7.2	10	78	98	122	132	158	3.5	3.6	3.6	7.7	14
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	8.7	17	45	73	n.a.	n.a.	n.a.	-	6.5
-0.6	0.0	0.0	0.0	2.3	1.6	1.6	1.6	16	16	16	16	16	0.0	0.0	0.0	1.6	1.4

n.a.	n.a.	n.a.	n.a.	-	-	20	59	113	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
0.8	0.8	0.8	0.8	4 846	5 048	5 254	5 458	5 659	0.8	0.8	0.8
0.0	-0.6	-0.6	-0.6	120	116	112	109	105	-0.6	-0.6	-0.6
0.8	1.4	1.4	1.4	40	44	47	50	54	1.4	1.4	1.4
-0.4	-0.3	-0.1	-0.1	3.0	2.9	2.8	2.7	2.7	-0.5	-0.5	-0.5
-1.1	-1.7	-1.5	-1.5	75	67	60	55	51	-1.9	-1.9	-1.9
-1.0	-3.7	-2.2	-2.6	138	103	71	39	12	-5.4	-11.3	-9.7
0.1	-2.1	-0.7	-1.1	1.8	1.5	1.2	0.7	0.2	-3.6	-9.6	-7.9

Table A28 | Korea

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	90	186	244	280	274	272	263	252	242
Coal	22	39	68	68	66	60	56	51	45
Oil	50	99	95	102	98	94	90	85	80
Natural gas	2.7	18	38	53	59	61	65	68	69
Nuclear	14	28	39	46	37	42	35	29	28
Hydro	0.5	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Geothermal	-	-	0.0	0.3	0.4	0.4	0.4	0.4	0.4
Solar, wind, etc.	0.0	0.0	0.2	3.2	5.4	6.6	7.8	9.2	11
Biomass and waste	0.7	1.4	3.5	6.6	8.2	8.5	8.8	9.1	9.3
Hydrogen	-	-	-	-	0.0	0.0	0.0	0.0	0.0

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	65	127	161	181	182	179	176	171	165
Coal	12	8.3	13	8.8	8.5	8.1	7.5	6.9	6.4
Oil	44	80	82	93	90	87	83	79	75
Natural gas	0.9	11	21	23	23	22	22	21	20
Electricity	8.1	23	39	47	51	53	54	55	56
Heat	-	3.3	4.3	5.7	5.5	5.3	5.1	4.8	4.5
Hydrogen	-	-	-	-	0.0	0.0	0.0	0.0	0.0
Renewables and waste	0.7	1.3	2.7	3.9	4.0	4.1	4.1	4.1	4.1
Industry	20	38	48	48	50	50	50	49	47
Transport	15	26	30	37	34	32	29	27	24
Buildings, etc.	24	38	44	45	44	43	42	41	40
Non-energy use	6.7	25	38	52	53	54	54	54	54

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	109	288	472	610	667	692	709	721	728
Coal	21	110	220	207	203	179	169	152	127
Oil	19	35	19	6.8	4.8	2.9	1.2	-	-
Natural gas	9.7	30	78	170	230	246	286	320	341
Nuclear	53	109	149	176	142	161	134	113	106
Hydro	6.4	4.0	3.7	3.5	4.1	4.1	4.1	4.1	4.1
Geothermal	-	-	-	-	-	-	-	-	-
Solar photovoltaics	0.0	0.0	0.8	29	43	52	62	72	83
Wind	-	0.0	0.8	3.4	16	20	24	28	33
Concentrated solar power and marine	-	-	-	0.4	3.1	3.8	4.6	6.2	7.8
Biomass and waste	-	0.1	1.1	10	17	19	21	22	23
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	0.3	3.8	3.8	3.8	3.8	3.8	3.8

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	214	407	558	549	539	505	488	463	428
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	402	799	1 261	1 741	2 049	2 248	2 439	2 616	2 769
Population (million)	43	47	50	52	51	50	49	47	45
GDP per capita ($2015 thousand)	9.4	17	25	34	40	45	50	56	62
Primary energy consumption per capita (toe/person)	2.1	4.0	4.9	5.4	5.4	5.4	5.4	5.4	5.4
Primary energy consumption per GDP (toe/$2015 million)	223	233	193	161	134	121	108	96	87
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	533	509	442	316	263	224	200	177	155
Energy-related CO_2 per primary energy consumption*2 (t/toe)	2.4	2.2	2.3	2.0	2.0	1.9	1.9	1.8	1.8

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
3.6	-0.4	-1.9	-1.5	25	24	24	18	57	46	34	26	20	-2.3	-5.1	-4.3	21	8.8
2.3	-0.6	-1.0	-0.9	56	36	36	33	94	84	75	65	57	-1.1	-2.5	-2.1	34	25
9.8	1.3	0.8	0.9	3.0	19	22	29	53	52	47	44	44	0.0	-0.9	-0.7	20	20
3.8	-2.7	-1.5	-1.8	15	16	13	11	53	58	67	65	55	1.7	0.2	0.6	19	24
-1.8	2.0	0.0	0.6	0.6	0.1	0.1	0.1	0.4	0.4	0.4	0.4	0.4	2.0	0.0	0.6	0.1	0.2
n.a.	3.7	0.0	1.0	-	0.1	0.1	0.2	0.4	0.4	0.4	0.4	0.4	4.3	0.3	1.4	0.1	0.2
19.7	6.8	3.5	4.4	0.0	1.1	2.0	4.4	6.6	9.1	12	15	20	9.5	5.6	6.7	2.4	8.7
7.1	2.8	0.6	1.2	0.8	2.4	3.0	3.8	9.1	9.8	11	12	14	4.1	2.1	2.7	3.3	6.1
n.a.	n.a.	-1.2	n.a.	-	-	0.0	0.0	0.8	4.6	8.0	12	15	n.a.	16.1	n.a.	0.3	6.8

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(Mtoe)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
-0.9	-0.3	-1.4	-1.1	18	4.8	4.7	3.9	7.6	6.3	5.1	4.2	3.5	-1.8	-3.8	-3.2	4.3	2.5
2.4	-0.4	-0.9	-0.8	67	51	50	45	87	80	72	65	58	-0.8	-2.0	-1.7	49	42
10.7	-0.2	-0.7	-0.6	1.4	13	12	12	21	18	15	12	8.9	-1.1	-4.2	-3.3	12	6.4
5.6	1.1	0.5	0.7	12	26	28	34	51	53	54	54	54	1.1	0.3	0.5	29	38
n.a.	-0.5	-1.0	-0.8	-	3.2	3.0	2.7	5.4	5.2	4.9	4.6	4.4	-0.8	-1.0	-1.0	3.0	3.1
n.a.	n.a.	-0.4	n.a.	-	-	0.0	0.0	0.1	0.5	1.0	1.8	3.4	n.a.	21.5	n.a.	0.0	2.4
5.3	0.5	0.1	0.2	1.1	2.1	2.2	2.5	4.4	4.7	5.3	6.2	7.3	1.4	2.6	2.3	2.5	5.3
2.7	0.7	-0.3	0.0	31	26	28	29	48	45	42	39	36	0.1	-1.4	-1.0	27	26
2.9	-0.9	-1.6	-1.4	22	20	19	15	32	28	23	19	16	-1.5	-3.4	-2.8	18	12
2.0	-0.3	-0.5	-0.5	36	25	24	24	43	41	38	36	33	-0.6	-1.3	-1.1	24	24
6.6	0.4	0.0	0.1	10	29	29	33	53	54	54	54	54	0.4	0.0	0.1	30	39

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(TWh)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
7.4	-0.2	-2.3	-1.7	20	34	31	17	161	121	74	43	17	-3.1	-10.8	-8.6	24	2.1
-3.1	-4.2	-100	-100	17	1.1	0.7	-	4.0	2.2	0.7	-	-	-6.4	-100	-100	0.6	-
9.4	3.8	2.0	2.5	8.9	28	34	47	199	214	205	216	249	2.0	1.1	1.4	30	31
3.8	-2.7	-1.5	-1.8	48	29	21	15	202	221	256	251	210	1.7	0.2	0.6	30	26
-1.8	1.9	0.0	0.6	5.8	0.6	0.6	0.6	4.1	4.1	4.1	4.1	4.1	1.9	0.0	0.6	0.6	0.5
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
37.9	5.1	3.3	3.8	0.0	4.7	6.4	11	50	67	87	112	140	7.0	5.3	5.8	7.4	18
n.a.	21.3	3.8	8.5	-	0.6	2.4	4.5	23	33	43	57	75	26.8	6.2	11.7	3.4	9.5
n.a.	28.3	4.7	11.0	-	0.1	0.5	1.1	3.7	4.8	5.9	8.3	11	31.1	5.5	12.3	0.6	1.4
n.a.	6.7	1.5	3.0	-	1.7	2.6	3.2	18	21	23	25	28	7.6	2.1	3.6	2.7	3.5
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	16	32	45	57	n.a.	n.a.	n.a.	-	7.2
n.a.	0.0	0.0	0.0	-	0.6	0.6	0.5	3.8	3.8	3.8	3.8	3.8	0.0	0.0	0.0	0.6	0.5

n.a.	n.a.	n.a.	n.a.	-	-	4.3	9.3	15	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
4.7	2.1	1.5	1.7	2 049	2 248	2 439	2 616	2 769	2.1	1.5	1.7
0.6	-0.1	-0.6	-0.5	51	50	49	47	45	-0.1	-0.6	-0.5
4.1	2.2	2.2	2.2	40	45	50	56	62	2.2	2.2	2.2
3.0	-0.1	0.0	0.0	5.4	5.3	5.2	5.1	5.0	-0.1	-0.3	-0.3
-1.0	-2.3	-2.1	-2.2	133	118	104	92	81	-2.3	-2.4	-2.4
-1.6	-2.3	-2.6	-2.5	229	159	104	63	36	-3.9	-8.9	-7.5
-0.6	0.0	-0.5	-0.4	1.7	1.4	1.0	0.7	0.4	-1.7	-6.6	-5.2

Table A29 | Chinese Taipei

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	51	90	117	117	111	110	107	104	101
Coal	11	30	42	41	38	36	34	32	29
Oil	28	42	48	40	37	36	35	33	31
Natural gas	1.6	6.2	15	27	28	28	28	28	28
Nuclear	8.6	10	11	6.2	-	-	-	-	-
Hydro	0.5	0.4	0.3	0.5	0.7	0.7	0.7	0.7	0.7
Geothermal	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0
Solar, wind, etc.	0.0	0.1	0.2	1.3	5.7	6.8	7.9	9.2	10
Biomass and waste	0.1	0.9	1.8	1.7	1.8	1.8	1.8	1.8	1.8
Hydrogen	-	-	-	-	-	-	-	-	-

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	32	54	74	73	74	74	73	72	71
Coal	3.5	5.4	6.5	4.9	5.0	4.9	4.6	4.3	4.0
Oil	21	32	44	38	37	36	35	33	32
Natural gas	1.0	1.8	2.4	5.3	5.4	5.4	5.4	5.4	5.4
Electricity	6.6	14	19	22	24	25	26	26	27
Heat	-	0.0	1.6	1.8	1.9	2.0	2.0	1.9	1.9
Hydrogen	-	-	-	-	-	-	-	-	-
Renewables and waste	0.0	0.4	0.7	0.6	0.7	0.7	0.8	0.8	0.8
Industry	13	21	25	25	27	28	28	28	28
Transport	7.3	12	13	13	12	11	10	9.2	8.2
Buildings, etc.	6.9	11	12	13	13	13	13	13	12
Non-energy use	4.9	9.4	23	22	22	22	23	23	23

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	90	181	244	285	307	317	326	335	342
Coal	27	87	122	121	107	100	93	85	77
Oil	22	31	11	4.4	3.2	2.6	1.9	1.2	0.6
Natural gas	1.2	18	60	112	118	123	128	130	132
Nuclear	33	39	42	24	-	-	-	-	-
Hydro	6.2	4.6	3.9	5.5	8.4	8.5	8.5	8.6	8.6
Geothermal	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0
Solar photovoltaics	-	-	0.0	11	23	26	30	35	40
Wind	-	0.0	1.0	3.5	42	52	62	71	80
Concentrated solar power and marine	-	-	-	-	-	-	-	-	-
Biomass and waste	0.2	1.8	3.4	3.8	3.7	3.7	3.7	3.7	3.7
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	116	220	260	264	247	237	224	209	194
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	161	307	463	676	812	900	990	1 076	1 157
Population (million)	20	22	23	23	22	22	21	20	19
GDP per capita ($2015 thousand)	7.9	14	20	29	36	41	47	53	60
Primary energy consumption per capita (toe/person)	2.5	4.0	5.1	5.0	4.9	5.0	5.1	5.1	5.2
Primary energy consumption per GDP (toe/$2015 million)	315	292	254	173	137	122	109	97	87
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	721	716	562	391	304	263	226	194	167
Energy-related CO_2 per primary energy consumption*2 (t/toe)	2.3	2.5	2.2	2.3	2.2	2.2	2.1	2.0	1.9

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
4.0	-0.7	-1.3	-1.1	23	35	34	29	33	27	22	17	14	-2.5	-4.2	-3.7	31	16
1.1	-1.1	-0.8	-0.9	56	34	33	31	35	32	29	25	22	-1.6	-2.2	-2.0	33	26
9.3	0.6	-0.1	0.1	3.1	23	25	27	26	24	21	17	13	-0.3	-3.3	-2.4	24	16
-1.0	-100	n.a.	-100	17	5.3	-	-	4.3	6.8	6.8	6.8	6.8	-4.5	2.3	0.3	4.0	7.9
-0.4	5.5	0.1	1.6	1.1	0.4	0.7	0.7	0.7	0.7	0.7	0.7	0.7	5.5	0.1	1.6	0.7	0.9
6.4	-11.9	0.0	-3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-11.9	0.0	-3.5	0.0	0.0
14.0	20.1	3.0	7.7	0.0	1.1	5.2	10	6.9	9.0	11	13	16	22.9	4.3	9.3	6.3	19
11.7	0.6	0.2	0.3	0.1	1.5	1.6	1.8	1.8	2.1	2.4	2.8	3.3	1.0	2.9	2.4	1.7	3.8
n.a.	n.a.	n.a.	n.a.	-	-	-	-	0.1	2.1	4.2	6.9	9.3	n.a.	25.1	n.a.	0.1	11

Reference Scenario								Advanced Technologies Scenario									
				Shares (%)				(Mtoe)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
1.1	0.2	-1.2	-0.8	11	6.8	6.8	5.6	4.5	3.9	3.3	2.8	2.5	-1.0	-3.0	-2.4	6.4	4.2
1.9	-0.5	-0.8	-0.7	65	52	50	45	35	33	30	27	24	-0.9	-1.9	-1.6	50	42
5.4	0.4	0.0	0.1	3.1	7.2	7.4	7.7	4.6	3.9	3.1	2.4	1.7	-1.7	-4.9	-4.0	6.5	2.9
3.9	0.9	0.6	0.7	21	31	33	38	24	25	25	25	25	1.0	0.2	0.4	34	43
n.a.	0.6	0.0	0.2	-	2.5	2.6	2.7	1.9	1.8	1.7	1.7	1.6	0.2	-0.6	-0.4	2.6	2.8
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	0.1	0.2	0.4	0.9	n.a.	n.a.	n.a.	-	1.6
11.0	2.5	0.8	1.3	0.1	0.8	0.9	1.1	0.8	1.0	1.3	1.7	2.1	3.9	5.3	4.9	1.1	3.7
2.1	0.9	0.1	0.3	40	35	37	39	26	25	23	22	21	0.3	-1.1	-0.7	36	36
1.8	-1.5	-1.7	-1.7	23	18	16	12	11	9.0	7.2	5.7	4.9	-2.5	-3.9	-3.5	15	8.3
2.0	-0.1	-0.2	-0.2	22	18	17	18	13	12	11	11	10	-0.4	-1.0	-0.9	18	17
4.8	0.3	0.1	0.1	15	30	30	32	22	22	23	23	23	0.3	0.1	0.1	31	38

Reference Scenario								Advanced Technologies Scenario									
				Shares (%)				(TWh)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
4.7	-1.5	-1.6	-1.6	30	43	35	23	87	61	41	24	12	-4.1	-9.5	-8.0	28	3.3
-4.9	-3.9	-8.3	-7.1	25	1.6	1.1	0.2	2.9	1.9	1.2	0.6	0.2	-5.4	-12.3	-10.4	0.9	0.1
15.2	0.7	0.6	0.6	1.3	39	39	39	113	106	99	86	67	0.1	-2.6	-1.8	36	19
-1.0	-100	n.a.	-100	36	8.3	-	-	16	26	26	26	26	-4.5	2.3	0.3	5.3	7.2
-0.4	5.5	0.1	1.6	6.8	1.9	2.8	2.5	8.4	8.5	8.5	8.6	8.6	5.5	0.1	1.6	2.7	2.4
6.9	-12.0	0.0	-3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-12.0	0.0	-3.6	0.0	0.0
n.a.	10.2	2.8	4.8	-	3.7	7.5	12	29	36	42	51	62	13.1	3.9	6.5	9.3	17
n.a.	36.4	3.3	11.8	-	1.2	14	23	50	68	84	103	123	39.3	4.6	13.5	16	34
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
9.5	-0.3	0.0	0.0	0.2	1.3	1.2	1.1	3.7	3.8	4.0	4.1	4.2	-0.3	0.6	0.4	1.2	1.2
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	13	25	41	56	n.a.	n.a.	n.a.	-	16
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

n.a.	n.a.	n.a.	n.a.	-	-	0.7	1.3	2.0	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
4.6	2.3	1.8	1.9	812	900	990	1 076	1 157	2.3	1.8	1.9
0.4	-0.5	-0.7	-0.7	22	22	21	20	19	-0.5	-0.7	-0.7
4.1	2.8	2.6	2.6	36	41	47	53	60	2.8	2.6	2.6
2.2	-0.2	0.3	0.1	4.8	4.7	4.6	4.5	4.4	-0.5	-0.4	-0.4
-1.9	-2.9	-2.2	-2.4	133	115	98	84	74	-3.2	-2.9	-3.0
-1.9	-3.1	-2.9	-3.0	268	195	136	82	45	-4.6	-8.5	-7.4
0.0	-0.2	-0.7	-0.6	2.0	1.7	1.4	1.0	0.6	-1.5	-5.8	-4.6

Table A30 | ASEAN

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	217	354	511	736	921	1 069	1 192	1 308	1 419
Coal	12	31	85	208	248	269	289	304	311
Oil	88	154	191	239	278	304	332	358	379
Natural gas	30	74	125	139	197	234	279	332	394
Nuclear	-	-	-	-	-	4.0	9.7	14	18
Hydro	2.3	4.4	6.8	19	25	27	29	30	32
Geothermal	6.6	18	25	38	69	117	129	136	142
Solar, wind, etc.	-	-	0.0	4.7	14	18	23	27	31
Biomass and waste	78	72	79	89	91	96	101	106	111
Hydrogen	-	-	-	-	0.1	0.1	0.1	0.1	0.1

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	149	244	352	478	585	655	727	799	866
Coal	5.4	14	40	61	75	82	88	92	94
Oil	67	124	165	213	249	274	301	326	347
Natural gas	7.5	17	29	45	61	69	77	85	92
Electricity	11	28	52	99	139	166	195	227	261
Heat	-	-	-	-	0.0	0.0	0.1	0.1	0.1
Hydrogen	-	-	-	-	0.1	0.2	0.2	0.2	0.2
Renewables and waste	58	62	66	61	61	63	66	69	71
Industry	41	75	122	177	232	266	299	330	357
Transport	33	62	88	140	162	178	197	215	232
Buildings, etc.	64	86	102	109	121	133	146	161	176
Non-energy use	11	21	40	52	70	77	85	93	100

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	154	374	685	1 284	1 802	2 146	2 522	2 931	3 366
Coal	28	79	185	568	684	746	813	874	909
Oil	66	72	60	24	17	16	16	13	8.9
Natural gas	26	154	336	336	556	707	906	1 163	1 474
Nuclear	-	-	-	-	-	15	37	53	71
Hydro	27	51	80	225	286	313	335	354	370
Geothermal	6.6	16	19	27	46	75	83	86	90
Solar photovoltaics	-	0.0	0.0	40	106	147	189	227	265
Wind	-	-	0.1	14	52	64	76	87	99
Concentrated solar power and marine	-	-	-	-	0.0	0.0	0.0	0.0	0.0
Biomass and waste	0.6	1.0	5.8	50	54	61	68	74	80
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	350	682	1 074	1 683	2 042	2 269	2 510	2 751	2 958
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	736	1 178	1 971	3 230	4 609	5 736	7 055	8 536	10 127
Population (million)	440	524	599	679	716	735	751	762	768
GDP per capita ($2015 thousand)	1.7	2.2	3.3	4.8	6.4	7.8	9.4	11	13
Primary energy consumption per capita (toe/person)	0.5	0.7	0.9	1.1	1.3	1.5	1.6	1.7	1.8
Primary energy consumption per GDP (toe/$2015 million)	295	300	260	228	200	186	169	153	140
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	475	579	545	521	443	396	356	322	292
Energy-related CO_2 per primary energy consumption*2 (t/toe)	1.6	1.9	2.1	2.3	2.2	2.1	2.1	2.1	2.1

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.

*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario										
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
9.2	2.3	1.1	1.5	5.7	28	27	22	213	198	186	175	157	0.3	-1.5	-1.0	24	13
3.2	1.9	1.6	1.7	40	32	30	27	249	248	245	233	215	0.5	-0.7	-0.4	28	17
4.9	4.4	3.5	3.8	14	19	21	28	188	216	251	294	350	3.8	3.2	3.4	21	28
n.a.	n.a.	n.a.	n.a.	-	-	-	1.3	12	32	46	60	76	n.a.	9.8	n.a.	1.3	6.2
6.8	3.1	1.3	1.8	1.1	2.6	2.7	2.2	26	30	33	36	38	4.0	1.9	2.5	3.0	3.1
5.6	7.9	3.7	4.8	3.1	5.1	7.5	10.0	69	127	157	181	205	7.9	5.6	6.2	7.8	17
n.a.	14.3	4.2	7.0	-	0.6	1.5	2.2	21	33	48	67	92	20.2	7.7	11.2	2.3	7.5
0.4	0.2	1.0	0.8	36	12	9.9	7.8	101	104	106	109	113	1.6	0.6	0.9	11	9.2
n.a.	n.a.	0.1	n.a.	-	-	0.0	0.0	2.8	5.1	1.9	-5.9	-17	n.a.	n.a.	n.a.	0.3	-1.4

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	(Mtoe) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
7.8	2.6	1.1	1.6	3.6	13	13	11	69	69	67	65	63	1.6	-0.4	0.1	12	9.7
3.7	2.0	1.7	1.8	45	44	43	40	226	229	228	219	203	0.7	-0.5	-0.2	40	31
5.7	3.9	2.1	2.6	5.1	9.3	10	11	57	61	62	63	63	3.1	0.5	1.3	10	9.7
7.1	4.3	3.2	3.5	7.5	21	24	30	141	168	195	225	257	4.5	3.0	3.5	25	39
n.a.	n.a.	9.3	n.a.	-	-	0.0	0.0	0.1	0.1	0.2	0.3	0.3	n.a.	7.9	n.a.	0.0	0.0
n.a.	n.a.	2.2	n.a.	-	-	0.0	0.0	0.0	0.0	0.1	0.2	0.3	n.a.	20.3	n.a.	0.0	0.0
0.1	0.0	0.8	0.6	39	13	10	8.3	66	66	65	65	67	1.0	0.1	0.3	12	10
4.6	3.4	2.2	2.5	28	37	40	41	221	236	246	252	261	2.8	0.8	1.4	40	40
4.7	1.8	1.8	1.8	22	29	28	27	153	156	158	155	150	1.1	-0.1	0.2	27	23
1.7	1.3	1.9	1.7	43	23	21	20	116	122	129	136	143	0.7	1.1	1.0	21	22
4.9	3.9	1.8	2.4	7.4	11	12	12	70	77	85	93	100	3.9	1.8	2.4	12	15

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	(TWh) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
9.9	2.4	1.4	1.7	18	44	38	27	577	524	493	461	403	0.2	-1.8	-1.2	31	10
-3.0	-4.8	-3.0	-3.5	43	1.9	0.9	0.3	15	13	12	8.7	5.2	-6.0	-5.1	-5.4	0.8	0.1
8.3	6.5	5.0	5.4	17	26	31	44	549	690	878	1 126	1 450	6.3	5.0	5.4	30	37
n.a.	n.a.	n.a.	n.a.	-	-	-	2.1	45	122	178	230	290	n.a.	9.8	n.a.	2.4	7.5
6.8	3.1	1.3	1.8	18	18	16	11	308	348	384	416	445	4.0	1.9	2.5	17	11
4.5	6.9	3.4	4.4	4.3	2.1	2.6	2.7	46	83	100	115	129	6.9	5.3	5.7	2.5	3.3
n.a.	13.0	4.7	7.0	-	3.1	5.9	7.9	161	273	408	593	821	19.1	8.5	11.4	8.7	21
n.a.	18.5	3.2	7.4	-	1.1	2.9	2.9	77	107	141	186	239	24.3	5.8	10.8	4.2	6.2
n.a.	n.a.	0.0	n.a.	-	-	0.0	0.0	0.1	0.2	0.3	0.6	0.9	n.a.	11.9	n.a.	0.0	0.0
14.8	1.1	2.0	1.7	0.4	3.9	3.0	2.4	68	77	86	95	103	4.1	2.1	2.6	3.7	2.6
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	2.6	5.2	5.2	5.2	n.a.	n.a.	n.a.	-	0.1
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

n.a.	n.a.	n.a.	n.a.	-	-	5.0	11	17	n.a.	n.a.	n.a.		

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
4.7	4.5	4.0	4.2	4 609	5 736	7 055	8 536	10 127	4.5	4.0	4.2
1.4	0.7	0.3	0.4	716	735	751	762	768	0.7	0.3	0.4
3.3	3.9	3.7	3.7	6.4	7.8	9.4	11	13	3.9	3.7	3.7
2.5	2.1	1.8	1.9	1.2	1.4	1.4	1.5	1.6	1.6	1.3	1.4
-0.8	-1.6	-1.8	-1.7	191	173	152	135	121	-2.2	-2.2	-2.2
0.3	-2.0	-2.1	-2.0	385	295	229	175	132	-3.7	-5.2	-4.8
1.1	-0.4	-0.3	-0.3	2.0	1.7	1.5	1.3	1.1	-1.6	-3.0	-2.6

Table A31 | Indonesia

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	85	127	172	261	344	431	491	548	606
Coal	3.5	12	32	95	113	124	136	145	150
Oil	33	58	67	73	83	92	101	109	116
Natural gas	16	27	39	33	56	73	98	128	164
Nuclear	-	-	-	-	-	-	-	-	-
Hydro	0.5	0.9	1.5	2.3	3.1	3.4	3.8	4.1	4.4
Geothermal	1.9	8.4	16	29	59	105	117	122	128
Solar, wind, etc.	-	-	-	0.2	1.8	3.0	4.3	5.6	6.9
Biomass and waste	30	21	17	28	28	30	32	34	36
Hydrogen	-	-	-	-	-0.0	-0.0	-0.0	-0.0	-0.0

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	57	91	117	162	197	226	256	287	317
Coal	1.5	4.6	17	29	37	41	45	49	51
Oil	27	48	55	70	79	88	96	105	112
Natural gas	6.0	12	16	15	19	23	27	30	34
Electricity	2.4	6.8	13	31	43	54	66	81	97
Heat	-	-	-	-	-	-	-	-	-
Hydrogen	-	-	-	-	-	-	-	-	0.0
Renewables and waste	20	20	16	19	19	20	21	22	24
Industry	17	30	49	68	88	103	119	134	148
Transport	11	21	30	56	64	70	77	84	90
Buildings, etc.	22	30	27	31	36	42	48	55	63
Non-energy use	7.4	9.8	10	6.5	8.5	9.9	12	13	15

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	33	93	170	377	542	678	838	1 024	1 236
Coal	9.8	34	68	249	290	315	352	385	405
Oil	15	18	34	8.3	8.1	7.3	5.9	3.4	-
Natural gas	0.7	26	40	51	128	193	290	422	592
Nuclear	-	-	-	-	-	-	-	-	-
Hydro	5.7	10	17	27	36	40	44	47	51
Geothermal	1.1	4.9	9.4	17	34	61	68	71	75
Solar photovoltaics	-	-	0.0	0.4	16	29	41	54	66
Wind	-	-	0.0	0.4	3.5	5.3	7.1	9.8	13
Concentrated solar power and marine	-	-	-	-	-	-	-	-	-
Biomass and waste	-	0.0	0.1	24	25	28	30	32	34
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	130	255	396	652	801	907	1 034	1 162	1 281
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	270	395	658	1 122	1 663	2 117	2 666	3 312	4 045
Population (million)	182	214	244	276	292	301	308	314	317
GDP per capita ($2015 thousand)	1.5	1.8	2.7	4.1	5.7	7.0	8.7	11	13
Primary energy consumption per capita (toe/person)	0.5	0.6	0.7	0.9	1.2	1.4	1.6	1.7	1.9
Primary energy consumption per GDP (toe/$2015 million)	313	320	262	232	207	203	184	166	150
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	480	645	602	581	482	428	388	351	317
Energy-related CO_2 per primary energy consumption*2 (t/toe)	1.5	2.0	2.3	2.5	2.3	2.1	2.1	2.1	2.1

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario										
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
10.8	2.2	1.4	1.7	4.2	36	33	25	101	99	97	90	77	0.8	-1.4	-0.8	30	14
2.5	1.6	1.7	1.7	39	28	24	19	70	70	67	62	54	-0.6	-1.3	-1.1	21	9.5
2.3	6.7	5.6	5.9	19	13	16	27	54	71	95	127	167	6.4	5.8	5.9	16	29
n.a.	n.a.	n.a.	n.a.	-	-	-	-	3.7	7.3	7.3	7.3	7.3	n.a.	3.5	n.a.	1.1	1.3
5.0	3.6	1.7	2.3	0.6	0.9	0.9	0.7	3.3	3.7	4.1	4.5	4.9	4.3	2.1	2.7	1.0	0.9
8.8	9.3	4.0	5.5	2.3	11	17	21	59	111	140	164	187	9.3	6.0	6.9	17	33
n.a.	31.1	6.9	13.3	-	0.1	0.5	1.1	4.2	8.7	14	21	31	45.9	10.4	19.6	1.3	5.4
-0.1	0.1	1.2	0.9	35	11	8.3	6.0	39	42	44	46	49	4.2	1.1	2.0	12	8.6
n.a.	n.a.	3.8	n.a.	-	-	-0.0	-0.0	-0.1	-1.0	-2.5	-5.6	-10	n.a.	26.4	n.a.	-0.0	-1.8

Reference Scenario								Advanced Technologies Scenario										
				Shares (%)				(Mtoe)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
9.7	3.0	1.6	2.0	2.6	18	19	16	34	34	34	33	32	2.0	-0.3	0.4	18	13
3.0	1.7	1.7	1.7	48	43	40	35	67	67	65	61	55	-0.4	-1.0	-0.9	36	23
2.8	3.4	2.8	3.0	11	9.0	9.7	11	18	20	22	22	23	2.7	1.2	1.6	9.6	9.7
8.2	4.5	4.1	4.2	4.3	19	22	31	46	57	70	84	100	5.2	4.0	4.3	24	42
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
-0.2	-0.1	1.2	0.8	35	12	9.5	7.5	25	26	26	27	28	3.5	0.7	1.5	13	12
4.4	3.2	2.7	2.8	31	42	45	47	86	95	102	107	113	2.8	1.4	1.8	45	47
5.3	1.7	1.7	1.7	19	35	33	28	60	61	60	59	57	0.8	-0.2	0.1	32	24
1.2	2.0	2.8	2.6	38	19	18	20	36	40	44	48	53	1.7	2.0	1.9	19	22
-0.4	3.3	3.0	3.1	13	4.0	4.3	4.8	8.5	9.9	12	13	15	3.3	3.0	3.1	4.5	6.4

Reference Scenario								Advanced Technologies Scenario										
				Shares (%)				(TWh)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
10.6	2.0	1.7	1.8	30	66	54	33	258	246	242	220	173	0.5	-2.0	-1.3	45	12
-1.9	-0.3	-100	-100	47	2.2	1.5	-	7.7	6.6	5.2	2.9	-	-1.0	-100	-100	1.3	-
14.2	12.1	7.9	9.1	2.2	14	24	48	138	218	338	500	712	13.1	8.5	9.8	24	48
n.a.	n.a.	n.a.	n.a.	-	-	-	-	14	28	28	28	28	n.a.	3.5	n.a.	2.4	1.9
5.0	3.6	1.7	2.3	17	7.2	6.7	4.1	38	43	48	53	57	4.3	2.1	2.7	6.6	3.8
8.8	9.3	4.0	5.5	3.4	4.4	6.3	6.0	34	65	81	95	109	9.3	6.0	6.9	5.9	7.3
n.a.	56.5	7.4	19.6	-	0.1	3.0	5.4	37	79	129	196	278	73.6	10.7	25.9	6.4	19
n.a.	32.8	6.7	13.6	-	0.1	0.6	1.0	11	21	32	52	77	53.7	10.2	21.2	1.9	5.1
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	0.8	1.5	1.3	-	6.3	4.7	2.7	38	43	48	52	57	6.0	2.1	3.2	6.5	3.8
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

n.a.	n.a.	n.a.	n.a.	-	-	4.9	10	17	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
4.5	5.0	4.5	4.7	1 663	2 117	2 666	3 312	4 045	5.0	4.5	4.7
1.3	0.7	0.4	0.5	292	301	308	314	317	0.7	0.4	0.5
3.2	4.3	4.1	4.2	5.7	7.0	8.7	11	13	4.3	4.1	4.2
2.2	2.8	2.5	2.5	1.1	1.4	1.5	1.6	1.8	2.4	2.2	2.3
-0.9	-1.4	-1.6	-1.6	201	195	175	156	140	-1.8	-1.8	-1.8
0.6	-2.3	-2.1	-2.1	427	340	268	207	153	-3.8	-5.0	-4.6
1.5	-0.9	-0.5	-0.6	2.1	1.7	1.5	1.3	1.1	-2.0	-3.3	-2.9

Table A32 | Malaysia

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	21	48	72	99	120	130	140	149	156
Coal	1.4	2.3	15	24	24	23	21	19	15
Oil	11	19	25	25	30	31	31	31	31
Natural gas	6.8	25	31	47	60	68	77	88	100
Nuclear	-	-	-	-	-	1.8	3.7	3.7	3.7
Hydro	0.3	0.6	0.6	2.7	2.9	3.2	3.4	3.5	3.6
Geothermal	-	-	-	-	-	-	-	-	-
Solar, wind, etc.	-	-	-	0.2	0.4	0.6	0.9	1.1	1.4
Biomass and waste	1.2	1.3	0.8	1.2	2.5	2.5	2.6	2.7	2.7
Hydrogen	-	-	-	-	-0.0	-0.0	-0.0	-0.0	-0.0

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	13	29	42	59	72	78	84	90	94
Coal	0.5	1.0	1.8	0.8	0.9	0.9	0.9	0.9	0.8
Oil	9.3	18	24	25	28	28	29	29	29
Natural gas	1.1	3.9	6.3	18	23	25	27	29	31
Electricity	1.7	5.3	9.5	14	19	22	25	28	32
Heat	-	-	-	-	-	-	-	-	-
Hydrogen	-	-	-	-	-	-	-	-	-
Renewables and waste	0.7	0.7	0.2	0.8	2.1	2.1	2.2	2.2	2.3
Industry	5.5	12	15	19	26	29	33	36	39
Transport	4.9	11	15	19	22	22	22	22	22
Buildings, etc.	2.1	4.3	8.2	9.9	12	13	14	15	16
Non-energy use	0.8	2.3	3.7	11	13	14	15	16	17

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	23	69	125	187	249	289	330	373	418
Coal	2.9	7.7	43	88	96	92	85	76	62
Oil	11	3.6	3.7	1.0	1.0	0.8	0.6	0.3	-
Natural gas	5.5	51	71	64	112	143	179	227	283
Nuclear	-	-	-	-	-	7.0	14	14	14
Hydro	4.0	7.0	6.5	31	34	37	39	41	41
Geothermal	-	-	-	-	-	-	-	-	-
Solar photovoltaics	-	-	-	2.2	4.6	7.5	10	13	16
Wind	-	-	-	-	-	-	-	-	-
Concentrated solar power and marine	-	-	-	-	-	-	-	-	-
Biomass and waste	-	-	1.0	1.2	1.2	1.3	1.5	1.6	1.6
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	53	112	188	241	281	292	302	312	316
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	75	148	233	387	533	635	749	874	1 007
Population (million)	18	23	29	34	37	39	41	42	43
GDP per capita ($2015 thousand)	4.3	6.5	8.1	11	14	16	18	21	23
Primary energy consumption per capita (toe/person)	1.2	2.1	2.5	2.9	3.2	3.3	3.5	3.5	3.6
Primary energy consumption per GDP (toe/$2015 million)	284	326	312	257	225	205	187	170	155
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	710	753	807	623	527	461	404	357	314
Energy-related CO_2 per primary energy consumption*2 (t/toe)	2.5	2.3	2.6	2.4	2.3	2.2	2.2	2.1	2.0

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.

*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario CAGR (%)				Reference Scenario Shares (%)				Advanced Technologies Scenario (Mtoe)					Advanced Technologies Scenario CAGR (%)			Advanced Technologies Scenario Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
9.3	0.4	-2.4	-1.6	6.4	24	20	9.6	23	21	18	14	10	-0.5	-3.9	-2.9	20	8.0
2.5	2.3	0.1	0.7	54	25	25	20	27	25	21	17	13	0.8	-3.4	-2.2	24	10
6.2	3.1	2.6	2.7	32	47	50	64	55	63	69	74	80	2.1	1.9	1.9	49	63
n.a.	n.a.	n.a.	n.a.	-	-	-	2.3	1.8	2.1	3.8	6.3	8.9	n.a.	8.2	n.a.	1.6	7.0
6.6	1.2	0.9	1.0	1.6	2.7	2.5	2.3	3.2	3.6	3.8	4.0	4.1	2.3	1.2	1.5	2.8	3.2
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	9.8	6.4	7.3	-	0.2	0.3	0.9	0.6	1.7	3.3	6.2	10	15.2	15.3	15.3	0.5	7.9
0.0	9.1	0.5	2.9	5.8	1.2	2.1	1.8	3.8	4.1	4.4	4.9	5.5	15.0	1.9	5.5	3.3	4.3
n.a.	n.a.	4.5	n.a.	-	-	-0.0	-0.0	-0.0	-0.5	-1.3	-3.0	-5.6	n.a.	34.9	n.a.	-0.0	-4.4

Reference Scenario				Reference Scenario Shares (%)				Advanced Technologies Scenario (Mtoe)					Advanced Technologies Scenario			Advanced Technologies Scenario Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
1.3	1.6	-0.2	0.3	3.8	1.3	1.2	0.9	0.8	0.7	0.6	0.6	0.5	0.4	-2.2	-1.5	1.2	0.8
3.2	1.1	0.1	0.4	70	43	39	30	25	23	20	17	14	-0.3	-2.9	-2.2	36	20
9.2	2.7	1.6	1.9	8.2	31	31	33	21	22	22	21	20	2.0	-0.2	0.4	31	30
6.8	3.7	2.7	3.0	13	24	26	34	19	22	24	26	29	3.9	2.1	2.6	27	42
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
0.3	12.2	0.4	3.6	5.6	1.4	2.9	2.4	3.4	3.6	3.8	4.2	4.7	19.2	1.7	6.4	4.8	6.9
4.0	3.5	2.2	2.5	41	33	36	42	24	25	25	25	24	2.9	0.0	0.8	35	36
4.3	1.8	0.0	0.5	36	32	30	23	21	19	18	16	14	1.2	-1.9	-1.1	30	21
4.9	2.1	1.7	1.8	16	17	16	17	11	12	12	13	13	1.7	0.7	0.9	16	19
8.4	2.0	1.4	1.5	6.3	19	18	18	13	14	15	16	17	2.0	1.4	1.5	19	25

Reference Scenario				Reference Scenario Shares (%)				Advanced Technologies Scenario (TWh)					Advanced Technologies Scenario			Advanced Technologies Scenario Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
11.2	1.2	-2.2	-1.2	13	47	39	15	89	81	72	57	41	0.2	-3.8	-2.6	35	8.4
-7.1	-0.3	-100	-100	46	0.5	0.4	-	0.9	0.8	0.6	0.3	-	-0.9	-100	-100	0.4	-
8.0	7.2	4.8	5.4	24	34	45	68	112	149	181	211	247	7.2	4.0	4.9	44	50
n.a.	n.a.	n.a.	n.a.	-	-	-	3.4	7.0	8.2	15	24	34	n.a.	8.2	n.a.	2.8	7.0
6.6	1.2	0.9	1.0	17	17	14	9.9	37	42	45	46	47	2.3	1.2	1.5	15	9.6
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	9.8	6.4	7.4	-	1.2	1.9	3.8	6.8	19	38	72	118	15.3	15.3	15.3	2.7	24
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	0.0	1.5	1.1	-	0.7	0.5	0.4	1.2	1.6	2.0	2.4	2.8	0.0	4.2	3.0	0.5	0.6
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

n.a.	n.a.	n.a.	n.a.	-	-	0.1	0.3	0.5	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
5.3	4.1	3.2	3.5	533	635	749	874	1 007	4.1	3.2	3.5
2.1	1.1	0.8	0.9	37	39	41	42	43	1.1	0.8	0.9
3.1	2.9	2.4	2.6	14	16	18	21	23	2.9	2.4	2.6
2.8	1.2	0.6	0.7	3.1	3.1	3.0	3.0	2.9	0.6	-0.2	0.0
-0.3	-1.7	-1.8	-1.8	214	187	164	143	127	-2.3	-2.6	-2.5
-0.4	-2.1	-2.6	-2.4	470	368	282	206	150	-3.5	-5.5	-5.0
-0.1	-0.4	-0.7	-0.7	2.2	2.0	1.7	1.4	1.2	-1.2	-3.0	-2.5

Table A33 | Myanmar

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	11	13	14	21	21	22	25	28	32
Coal	0.1	0.3	0.4	0.3	2.1	3.0	4.0	5.5	7.2
Oil	0.7	2.0	1.3	5.9	3.9	4.7	5.6	6.7	7.7
Natural gas	0.8	1.2	1.3	3.4	4.6	6.1	7.6	9.7	12
Nuclear	-	-	-	-	-	-	-	-	-
Hydro	0.1	0.2	0.5	0.8	1.2	1.3	1.5	1.7	1.8
Geothermal	-	-	-	-	0.0	0.0	0.0	0.0	0.1
Solar, wind, etc.	-	-	-	0.0	0.0	0.1	0.1	0.1	0.2
Biomass and waste	9.0	9.2	10	11	9.6	8.5	7.5	6.8	6.2
Hydrogen	-	-	-	-	-0.0	-0.0	-0.0	-0.0	-0.0

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	9.4	11	13	19	16	16	17	18	19
Coal	0.1	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Oil	0.6	1.5	1.0	5.6	3.5	4.3	5.2	6.2	7.2
Natural gas	0.2	0.3	0.6	0.4	0.3	0.3	0.4	0.4	0.5
Electricity	0.1	0.3	0.5	1.8	2.2	2.7	3.3	4.0	4.8
Heat	-	-	-	-	0.0	0.0	0.0	0.0	0.1
Hydrogen	-	-	-	-	0.0	0.0	0.0	0.0	0.1
Renewables and waste	8.4	9.0	10	11	9.4	8.3	7.4	6.7	6.1
Industry	0.4	1.2	1.3	1.6	2.1	2.4	2.8	3.1	3.4
Transport	0.4	1.2	0.8	4.3	2.3	2.9	3.6	4.5	5.4
Buildings, etc.	8.5	9.1	10	13	11	10	9.9	9.8	9.8
Non-energy use	0.1	0.1	0.1	0.3	0.3	0.3	0.4	0.4	0.4

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	2.5	5.1	8.6	21	37	48	61	79	99
Coal	0.0	-	0.6	0.1	5.2	7.9	11	16	22
Oil	0.3	0.7	0.0	0.1	0.2	0.3	0.4	0.4	0.5
Natural gas	1.0	2.5	1.8	11	17	24	31	42	54
Nuclear	-	-	-	-	-	-	-	-	-
Hydro	1.2	1.9	6.2	9.1	14	16	17	19	21
Geothermal	-	-	-	-	-	-	-	-	-
Solar photovoltaics	-	-	-	0.2	0.4	0.7	1.0	1.2	1.5
Wind	-	-	-	-	-	-	-	-	-
Concentrated solar power and marine	-	-	-	-	-	-	-	-	-
Biomass and waste	-	-	-	0.0	0.0	0.0	0.0	0.0	0.0
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	4.0	9.6	8.1	26	30	39	50	64	79
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	7.1	14	44	66	79	99	125	156	194
Population (million)	40	46	49	54	57	58	59	59	59
GDP per capita ($2015 thousand)	0.2	0.3	0.9	1.2	1.4	1.7	2.1	2.6	3.3
Primary energy consumption per capita (toe/person)	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5
Primary energy consumption per GDP (toe/$2015 million)	1 499	903	310	324	262	227	199	181	165
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	567	673	184	391	380	398	399	410	408
Energy-related CO_2 per primary energy consumption*2 (t/toe)	0.4	0.7	0.6	1.2	1.5	1.8	2.0	2.3	2.5

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario CAGR (%) 1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	Advanced Technologies Scenario (Mtoe) 2030	2035	2040	2045	2050	CAGR (%) 2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
5.2	25.8	6.2	11.5	0.6	1.6	10	23	1.8	2.4	3.0	3.9	4.8	22.8	5.1	9.9	9.8	20
6.8	-5.3	3.5	0.9	6.8	28	19	24	3.6	4.0	4.3	4.5	4.6	-6.2	1.2	-0.9	20	19
4.8	3.8	4.9	4.6	7.1	16	22	37	4.4	5.7	6.9	8.9	11	3.2	4.7	4.2	24	46
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
6.5	5.3	2.2	3.1	1.0	3.6	5.7	5.7	1.3	1.6	1.8	2.1	2.3	6.9	2.9	4.0	7.3	9.9
n.a.	n.a.	10.3	n.a.	-	-	0.0	0.2	0.1	0.1	0.2	0.2	0.3	n.a.	7.9	n.a.	0.3	1.1
n.a.	15.7	7.3	9.7	-	0.1	0.2	0.6	0.1	0.5	1.0	1.9	3.2	32.6	17.2	21.4	0.7	14
0.6	-1.7	-2.2	-2.0	84	51	47	19	7.7	5.2	4.0	3.2	2.5	-4.4	-5.4	-5.1	42	11
n.a.	n.a.	5.6	n.a.	-	-	-0.0	-0.0	-0.0	-0.2	-0.5	-1.2	-2.1	n.a.	25.2	n.a.	-0.1	-8.7

Reference Scenario 1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	Advanced Technologies Scenario (Mtoe) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
5.2	0.0	1.3	0.9	0.5	1.4	1.6	1.8	0.2	0.2	0.2	0.2	0.2	-1.0	-0.2	-0.4	1.7	1.8
7.3	-5.8	3.7	0.9	6.2	30	22	38	3.2	3.6	3.9	4.0	4.1	-6.8	1.3	-1.1	23	32
1.6	-2.5	2.1	0.8	2.4	2.0	1.9	2.4	0.3	0.3	0.3	0.3	0.3	-3.5	0.3	-0.8	2.0	2.3
8.2	2.3	4.0	3.5	1.6	9.7	14	25	2.4	3.0	3.7	4.4	5.2	3.3	3.9	3.8	17	40
n.a.	n.a.	10.3	n.a.	-	-	0.1	0.3	0.1	0.1	0.2	0.2	0.3	n.a.	7.9	n.a.	0.4	2.0
n.a.	n.a.	11.1	n.a.	-	-	0.0	0.3	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
0.8	-1.7	-2.2	-2.0	89	57	60	32	7.6	5.2	4.1	3.4	2.8	-4.3	-4.8	-4.7	55	22
4.5	3.3	2.5	2.7	4.2	8.5	13	18	1.9	2.0	2.2	2.3	2.5	2.0	1.5	1.6	14	19
7.4	-7.7	4.4	0.8	4.7	23	14	28	2.2	2.6	3.0	3.4	3.7	-8.3	2.7	-0.5	16	29
1.3	-1.7	-0.6	-0.9	90	67	71	52	9.4	7.6	6.8	6.5	6.2	-3.7	-2.0	-2.5	69	48
3.5	0.1	2.1	1.6	1.0	1.5	1.8	2.3	0.3	0.3	0.4	0.4	0.4	0.1	2.1	1.6	2.1	3.4

Reference Scenario 1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	Advanced Technologies Scenario (TWh) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
3.2	62.5	7.5	21.0	1.6	0.5	14	23	5.0	7.2	9.4	13	17	61.4	6.2	19.7	13	12
-2.8	9.2	4.1	5.6	11	0.5	0.6	0.5	0.2	0.3	0.4	0.4	0.5	9.5	4.0	5.5	0.6	0.4
8.0	5.0	5.9	5.7	39	55	46	54	18	25	33	46	59	5.5	6.2	6.0	45	43
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
6.5	5.3	2.2	3.1	48	43	37	21	15	18	21	24	27	6.9	2.9	4.0	39	20
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	13.4	6.4	8.3	-	0.8	1.2	1.5	0.9	4.3	9.3	20	34	24.3	19.9	21.2	2.3	25
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.

Reference Scenario 1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Advanced Technologies Scenario 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
7.2	2.1	4.6	3.9	79	99	125	156	194	2.1	4.6	3.9
0.9	0.6	0.2	0.3	57	58	59	59	59	0.6	0.2	0.3
6.2	1.5	4.4	3.6	1.4	1.7	2.1	2.6	3.3	1.5	4.4	3.6
1.3	-1.1	2.0	1.1	0.3	0.3	0.3	0.4	0.4	-2.7	1.2	0.1
-4.7	-2.6	-2.3	-2.4	230	183	154	137	122	-4.2	-3.1	-3.4
-1.2	-0.4	0.4	0.2	344	341	320	312	297	-1.6	-0.7	-1.0
3.7	2.3	2.7	2.6	1.5	1.9	2.1	2.3	2.4	2.7	2.5	2.5

Table A34 | Philippines

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	27	39	42	63	80	94	107	117	126
Coal	1.3	4.6	7.0	19	21	24	26	26	25
Oil	9.7	16	14	20	29	36	42	48	52
Natural gas	-	0.0	3.1	2.6	5.4	7.6	11	15	19
Nuclear	-	-	-	-	-	-	-	-	-
Hydro	0.5	0.7	0.7	0.9	1.3	1.4	1.5	1.7	1.9
Geothermal	4.7	10	8.5	9.0	10	12	13	13	13
Solar, wind, etc.	-	-	0.0	0.2	2.0	2.5	2.9	3.4	3.8
Biomass and waste	10	7.6	8.7	11	10	10	9.8	9.6	9.3
Hydrogen	-	-	-	-	-0.0	-0.0	-	-	-

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	19	23	25	36	48	57	66	75	81
Coal	0.7	0.8	1.9	1.9	2.4	2.6	2.7	2.8	2.7
Oil	8.1	13	11	18	27	33	39	45	49
Natural gas	-	-	0.1	-	0.0	0.1	0.1	0.1	0.2
Electricity	1.8	3.1	4.8	7.9	12	15	18	21	24
Heat	-	-	-	-	-	-	-	-	-
Hydrogen	-	-	-	-	-	-	-	-	-
Renewables and waste	8.4	6.4	6.9	7.7	6.5	6.3	6.0	5.7	5.4
Industry	4.1	4.6	5.9	7.1	9.9	12	14	15	16
Transport	4.5	8.3	8.0	12	18	23	27	31	34
Buildings, etc.	10.0	9.9	11	15	18	20	22	25	27
Non-energy use	0.4	0.4	0.2	1.3	1.9	2.4	3.0	3.7	4.3

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	26	45	68	112	170	208	248	285	320
Coal	1.9	17	23	66	75	89	97	100	98
Oil	12	9.2	7.1	2.5	4.3	4.6	4.7	4.5	3.9
Natural gas	-	0.0	20	18	37	53	76	103	133
Nuclear	-	-	-	-	-	-	-	-	-
Hydro	6.1	7.8	7.8	10	15	16	18	20	22
Geothermal	5.5	12	9.9	10	12	14	15	15	15
Solar photovoltaics	-	-	0.0	1.8	14	17	21	24	28
Wind	-	-	0.1	1.0	9.5	12	14	15	17
Concentrated solar power and marine	-	-	-	-	-	-	-	-	-
Biomass and waste	0.4	-	0.0	1.3	1.9	2.2	2.6	2.7	2.9
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	35	65	75	138	179	214	245	271	288
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	107	143	229	408	657	851	1 066	1 282	1 471
Population (million)	62	78	95	116	123	128	131	134	136
GDP per capita ($2015 thousand)	1.7	1.8	2.4	3.5	5.3	6.7	8.1	9.5	11
Primary energy consumption per capita (toe/person)	0.4	0.5	0.4	0.5	0.7	0.7	0.8	0.9	0.9
Primary energy consumption per GDP (toe/$2015 million)	249	272	182	154	122	110	100	91	85
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	329	452	327	337	272	251	230	211	196
Energy-related CO_2 per primary energy consumption*2 (t/toe)	1.3	1.7	1.8	2.2	2.2	2.3	2.3	2.3	2.3

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario										
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
8.9	1.4	0.8	1.0	4.7	30	27	20	17	17	17	17	15	-1.1	-0.7	-0.8	23	14
2.3	5.0	2.9	3.5	36	32	36	42	27	31	33	33	31	4.0	0.6	1.6	35	28
n.a.	9.3	6.5	7.3	-	4.2	6.7	15	4.3	5.6	8.1	12	17	6.2	7.3	7.0	5.6	16
n.a.	n.a.	n.a.	n.a.	-	-	-	-	2.2	4.4	6.6	6.6	8.8	n.a.	7.2	n.a.	2.9	8.1
1.6	5.3	1.9	2.9	2.0	1.4	1.6	1.5	1.3	1.5	1.6	1.8	2.1	5.6	2.3	3.2	1.8	1.9
2.0	1.9	1.2	1.4	18	14	13	11	10	16	16	17	17	1.9	2.6	2.4	14	16
n.a.	30.4	3.2	10.3	-	0.4	2.5	3.1	3.5	4.7	6.1	7.7	9.4	39.3	5.1	13.9	4.5	8.7
0.2	-1.2	-0.4	-0.6	39	18	13	7.4	10	9.7	9.3	8.9	8.5	-1.3	-0.8	-1.0	13	7.8
n.a.	n.a.	-100	n.a.	-	-	-0.0	-	0.0	-0.1	-0.3	-0.7	-1.4	n.a.	n.a.	n.a.	0.0	-1.3

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	(Mtoe) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
3.3	2.6	0.6	1.1	3.7	5.4	5.0	3.3	2.2	2.3	2.2	2.1	2.0	1.8	-0.6	0.1	4.8	3.2
2.6	5.0	3.0	3.6	43	51	56	60	25	29	31	31	29	4.1	0.7	1.7	55	48
n.a.	n.a.	9.5	n.a.	-	-	0.1	0.2	0.0	0.0	0.1	0.1	0.1	n.a.	6.4	n.a.	0.1	0.1
4.7	5.7	3.5	4.1	9.6	22	25	30	12	15	19	22	26	5.8	3.8	4.3	27	42
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
-0.3	-2.1	-1.0	-1.3	44	22	14	6.6	6.4	5.9	5.4	4.9	4.5	-2.4	-1.7	-1.9	14	7.3
1.7	4.3	2.5	3.0	22	20	21	20	9.6	11	12	12	12	3.9	1.2	1.9	21	20
3.2	5.0	3.2	3.7	24	35	38	42	17	20	23	24	24	4.3	1.6	2.3	38	38
1.3	2.3	2.0	2.1	52	42	38	33	17	19	20	21	22	1.8	1.1	1.3	38	35
3.7	5.2	4.1	4.4	2.1	3.6	4.0	5.3	1.9	2.4	3.0	3.7	4.3	5.2	4.1	4.4	4.2	7.0

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	(TWh) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
11.7	1.5	1.3	1.4	7.3	60	44	31	60	61	63	65	58	-1.3	-0.1	-0.5	35	15
-4.9	6.8	-0.4	1.6	47	2.3	2.5	1.2	3.4	3.3	3.3	3.4	3.1	3.8	-0.5	0.7	2.0	0.8
n.a.	9.6	6.6	7.4	-	16	22	41	30	41	61	96	134	6.8	7.7	7.5	18	35
n.a.	n.a.	n.a.	n.a.	-	-	-	-	8.4	17	25	25	34	n.a.	7.2	n.a.	4.9	8.7
1.6	5.3	1.9	2.9	23	9.0	9.0	7.0	16	17	19	21	24	5.6	2.3	3.2	9.1	6.3
2.0	1.9	1.2	1.4	21	9.3	7.2	4.8	12	19	19	20	20	1.9	2.6	2.4	7.1	5.2
n.a.	29.3	3.3	10.2	-	1.6	8.4	8.6	25	36	48	61	76	38.8	5.7	14.2	15	20
n.a.	32.0	3.0	10.6	-	0.9	5.6	5.4	15	19	23	28	34	40.1	4.0	13.3	8.9	8.7
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
3.6	4.8	2.1	2.9	1.6	1.2	1.1	0.9	2.1	2.5	2.9	3.0	3.1	5.7	2.1	3.1	1.2	0.8
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
4.3	6.1	4.1	4.7	657	851	1 066	1 282	1 471	6.1	4.1	4.7
2.0	0.8	0.5	0.6	123	128	131	134	136	0.8	0.5	0.6
2.2	5.3	3.6	4.1	5.3	6.7	8.1	9.5	11	5.3	3.6	4.1
0.7	2.3	1.8	1.9	0.6	0.7	0.7	0.8	0.8	1.7	1.2	1.4
-1.5	-2.9	-1.8	-2.1	117	106	92	81	74	-3.4	-2.3	-2.6
0.1	-2.6	-1.6	-1.9	231	182	144	116	90	-4.6	-4.6	-4.6
1.6	0.2	0.1	0.2	2.0	1.7	1.6	1.4	1.2	-1.2	-2.4	-2.1

Table A35 | Thailand

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	42	73	118	133	142	151	160	168	175
Coal	3.8	7.7	16	18	17	17	17	16	16
Oil	18	32	45	55	55	57	60	62	63
Natural gas	5.0	17	33	33	40	42	43	43	42
Nuclear	-	-	-	-	-	-	1.8	3.7	6.2
Hydro	0.4	0.5	0.5	0.6	1.3	1.4	1.5	1.6	1.7
Geothermal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar, wind, etc.	-	-	0.0	0.7	1.8	2.6	3.5	4.3	5.2
Biomass and waste	15	15	23	23	24	27	30	33	36
Hydrogen	-	-	-	-	-0.0	-0.0	-0.0	-0.0	-0.0

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	29	51	84	98	106	113	119	126	131
Coal	1.3	3.6	9.2	8.5	8.6	8.7	8.6	8.5	8.2
Oil	15	29	43	54	56	58	61	63	64
Natural gas	0.1	1.1	4.6	7.3	8.2	8.9	9.6	10	11
Electricity	3.3	7.6	13	17	20	22	25	27	29
Heat	-	-	-	-	-	-	-	-	-
Hydrogen	-	-	-	-	-	-	-	-	-
Renewables and waste	9.3	9.4	14	11	13	14	16	17	19
Industry	8.7	17	26	32	36	40	43	46	48
Transport	9.2	15	19	28	28	29	30	31	32
Buildings, etc.	11	14	20	16	16	17	17	18	18
Non-energy use	0.4	5.8	18	23	25	27	29	31	33

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	44	96	159	186	230	253	275	294	312
Coal	11	18	30	37	36	37	38	37	36
Oil	10	10.0	1.1	11	-	-	-	-	-
Natural gas	18	62	120	105	140	146	147	145	141
Nuclear	-	-	-	-	-	-	7.0	14	24
Hydro	5.0	6.0	5.6	6.8	15	17	18	19	19
Geothermal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar photovoltaics	-	-	0.0	5.1	15	25	34	43	52
Wind	-	-	-	3.0	5.1	5.7	6.3	6.9	7.4
Concentrated solar power and marine	-	-	-	-	0.0	0.0	0.0	0.0	0.0
Biomass and waste	-	0.5	3.4	19	19	22	25	29	32
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	81	151	222	250	257	262	264	263	258
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	144	221	347	450	562	666	785	916	1 055
Population (million)	55	63	68	72	71	71	69	68	66
GDP per capita ($2015 thousand)	2.6	3.5	5.1	6.3	7.9	9.5	11	13	16
Primary energy consumption per capita (toe/person)	0.8	1.2	1.7	1.9	2.0	2.1	2.3	2.5	2.6
Primary energy consumption per GDP (toe/$2015 million)	294	328	340	296	253	226	203	183	166
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	560	680	640	555	457	394	336	287	244
Energy-related CO_2 per primary energy consumption*2 (t/toe)	1.9	2.1	1.9	1.9	1.8	1.7	1.7	1.6	1.5

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
4.9	-0.4	-0.4	-0.4	9.0	13	12	9.0	16	14	13	12	11	-1.3	-1.6	-1.5	11	7.5
3.5	0.0	0.7	0.5	43	41	39	36	51	49	48	45	42	-0.9	-1.0	-1.0	37	27
6.1	2.4	0.2	0.9	12	25	28	24	42	42	41	43	45	2.8	0.4	1.0	30	29
n.a.	n.a.	n.a.	n.a.	-	-	-	3.5	-	1.8	3.9	6.4	9.0	n.a.	n.a.	n.a.	-	5.8
1.0	10.5	1.2	3.8	1.0	0.4	0.9	0.9	1.4	1.6	1.7	1.8	1.9	11.4	1.5	4.2	1.0	1.2
0.0	0.0	3.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	2.5	0.0	0.0
n.a.	12.1	5.5	7.3	-	0.5	1.2	2.9	2.2	3.9	6.1	9.0	12	15.4	9.0	10.8	1.6	8.1
1.4	0.7	1.9	1.6	35	17	17	20	25	28	29	30	31	1.2	1.1	1.1	18	20
n.a.	n.a.	3.5	n.a.	-	-	-0.0	-0.0	0.0	-0.1	-0.4	-1.3	-2.7	n.a.	n.a.	n.a.	0.0	-1.7

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(Mtoe)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
6.0	0.1	-0.2	-0.1	4.6	8.6	8.0	6.3	8.1	7.6	7.1	6.7	6.6	-0.7	-1.0	-0.9	7.8	6.2
4.0	0.5	0.7	0.6	52	55	53	49	53	51	50	47	44	-0.3	-0.8	-0.7	51	42
13.2	1.4	1.4	1.4	0.5	7.5	7.7	8.3	7.8	7.9	8.0	8.1	8.1	0.7	0.2	0.4	7.6	7.7
5.3	2.2	1.8	1.9	11	17	19	22	21	23	25	28	31	2.5	2.0	2.1	20	29
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
0.7	1.7	1.8	1.8	32	12	12	14	14	16	15	16	16	2.3	0.7	1.2	13	15
4.1	1.8	1.4	1.5	30	32	34	37	35	36	36	36	36	1.3	0.2	0.5	34	34
3.5	0.3	0.5	0.5	32	28	27	24	27	26	24	23	21	-0.3	-1.3	-1.0	26	20
1.3	0.1	0.5	0.4	37	17	15	14	16	16	16	15	15	-0.3	-0.2	-0.3	15	14
13.2	1.3	1.5	1.4	1.5	23	24	26	25	27	29	31	33	1.3	1.5	1.4	24	32

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(TWh)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
3.8	-0.2	0.0	-0.1	25	20	16	12	32	29	25	24	23	-1.5	-1.6	-1.6	14	5.4
0.0	-100	n.a.	-100	23	5.7	-	-	-	-	-	-	-	-100	n.a.	-100	-	-
5.7	3.7	0.1	1.1	40	56	61	45	143	147	152	162	177	4.0	1.1	1.9	60	41
n.a.	n.a.	n.a.	n.a.	-	-	-	7.6	-	7.0	15	25	34	n.a.	n.a.	n.a.	-	8.0
1.0	10.5	1.2	3.8	11	3.7	6.5	6.2	16	18	20	21	22	11.4	1.5	4.2	6.8	5.1
0.0	0.0	3.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	2.5	0.0	0.0
n.a.	14.7	6.4	8.7	-	2.7	6.6	17	20	38	60	90	127	18.6	9.7	12.2	8.4	29
n.a.	6.7	1.9	3.2	-	1.6	2.2	2.4	5.5	7.2	9.3	12	15	7.8	5.2	6.0	2.3	3.6
n.a.	n.a.	0.0	n.a.	-	-	0.0	0.0	0.1	0.2	0.3	0.6	0.9	n.a.	11.9	n.a.	0.0	0.2
n.a.	-0.1	2.6	1.9	-	10	8.3	10	20	23	25	28	30	0.4	2.1	1.6	8.4	7.0
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
3.6	2.8	3.2	3.1	562	666	785	916	1 055	2.8	3.2	3.1
0.8	-0.1	-0.4	-0.3	71	71	69	68	66	-0.1	-0.4	-0.3
2.8	2.9	3.6	3.4	7.9	9.5	11	13	16	2.9	3.6	3.4
2.8	0.9	1.4	1.3	2.0	2.0	2.1	2.2	2.3	0.7	0.8	0.8
0.0	-1.9	-2.1	-2.0	250	215	186	163	146	-2.1	-2.7	-2.5
0.0	-2.4	-3.1	-2.9	426	324	244	177	125	-3.3	-5.9	-5.2
0.0	-0.5	-1.0	-0.9	1.7	1.5	1.3	1.1	0.9	-1.2	-3.4	-2.8

Table A36 | Viet Nam

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	18	29	59	102	151	175	199	224	247
Coal	2.2	4.4	15	46	63	70	77	83	87
Oil	2.7	7.8	18	27	41	46	53	60	66
Natural gas	0.0	1.1	8.1	7.6	18	23	28	35	43
Nuclear	-	-	-	-	-	2.2	4.2	6.4	8.6
Hydro	0.5	1.3	2.4	8.2	11	12	12	13	13
Geothermal	-	-	-	-	-	-	-	-	-
Solar, wind, etc.	-	-	0.0	3.2	7.4	9.0	11	12	13
Biomass and waste	12	14	15	9.4	11	12	13	14	15
Hydrogen	-	-	-	-	-0.0	-0.0	-	-0.0	-0.0

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	16	25	48	73	109	125	142	158	173
Coal	1.3	3.2	9.8	20	25	27	29	30	30
Oil	2.3	6.5	17	23	35	41	47	53	58
Natural gas	-	0.0	0.5	2.1	7.8	9.1	10	12	13
Electricity	0.5	1.9	7.5	21	33	40	47	54	62
Heat	-	-	-	-	-	-	-	-	-
Hydrogen	-	-	-	-	-	-	-	-	-
Renewables and waste	12	13	14	7.1	7.5	8.5	9.4	10	11
Industry	4.5	7.9	17	38	56	64	71	78	84
Transport	1.4	3.5	10	15	19	23	27	31	35
Buildings, etc.	10	13	18	17	20	23	27	30	34
Non-energy use	0.0	0.1	2.3	3.0	14	15	17	19	20

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	8.7	27	95	276	429	513	601	692	782
Coal	2.0	3.1	20	111	154	176	198	220	238
Oil	1.3	4.5	3.4	0.2	0.0	-	-	-	-
Natural gas	0.0	4.4	44	29	60	84	116	155	201
Nuclear	-	-	-	-	-	8.4	16	25	33
Hydro	5.4	15	28	96	126	136	144	150	154
Geothermal	-	-	-	-	-	-	-	-	-
Solar photovoltaics	-	-	-	28	51	63	74	81	88
Wind	-	-	0.1	9.1	34	42	49	55	61
Concentrated solar power and marine	-	-	-	-	-	-	-	-	-
Biomass and waste	-	-	0.1	2.3	3.7	4.3	4.9	5.6	6.2
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	17	42	123	287	389	443	497	552	600
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	45	94	177	359	580	763	990	1 256	1 551
Population (million)	67	79	87	98	103	105	107	108	108
GDP per capita ($2015 thousand)	0.7	1.2	2.0	3.7	5.6	7.3	9.3	12	14
Primary energy consumption per capita (toe/person)	0.3	0.4	0.7	1.0	1.5	1.7	1.9	2.1	2.3
Primary energy consumption per GDP (toe/$2015 million)	397	307	330	284	260	229	201	178	159
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	368	448	693	799	672	580	502	439	386
Energy-related CO_2 per primary energy consumption*2 (t/toe)	0.9	1.5	2.1	2.8	2.6	2.5	2.5	2.5	2.4

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
9.9	4.0	1.6	2.3	12	45	42	35	47	39	33	32	32	0.4	-2.0	-1.3	35	17
7.5	5.1	2.4	3.2	15	27	27	27	38	41	43	43	42	4.3	0.4	1.5	28	22
27.8	11.3	4.4	6.3	0.0	7.5	12	17	15	16	17	18	20	9.1	1.4	3.6	11	11
n.a.	n.a.	n.a.	n.a.	-	-	-	3.5	4.0	16	25	33	42	n.a.	12.4	n.a.	2.9	22
9.4	3.5	1.0	1.7	2.6	8.1	7.2	5.4	12	14	15	16	17	4.8	1.9	2.7	8.7	9.3
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	10.9	2.8	5.1	-	3.2	4.9	5.2	9.6	13	16	20	25	14.7	4.8	7.5	7.0	13
-0.9	1.5	1.8	1.7	70	9.2	7.0	6.2	9.9	10	10	11	11	0.6	0.7	0.7	7.2	6.1
n.a.	n.a.	-3.4	n.a.	-	-	-0.0	-0.0	-0.0	-0.3	-0.9	-2.0	-3.7	n.a.	29.8	n.a.	-0.0	-2.0

Reference Scenario								Advanced Technologies Scenario									
				Shares (%)				(Mtoe)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
8.8	3.1	0.9	1.5	8.3	27	23	17	23	23	22	22	21	2.0	-0.4	0.3	22	16
7.5	5.4	2.5	3.3	15	32	33	34	33	36	37	38	37	4.6	0.5	1.7	32	28
n.a.	18.0	2.4	6.6	-	2.9	7.2	7.2	7.5	8.3	9.0	9.5	10.0	17.4	1.4	5.8	7.3	7.6
12.1	6.0	3.2	4.0	3.3	29	30	35	32	38	43	49	56	5.7	2.7	3.6	32	42
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
-1.6	0.7	1.9	1.6	74	9.7	6.9	6.3	6.6	6.5	6.5	6.6	7.2	-0.8	0.4	0.0	6.4	5.5
6.9	4.8	2.0	2.8	28	53	51	48	52	54	56	57	61	3.9	0.8	1.7	51	46
7.7	3.3	3.2	3.2	8.7	20	17	20	18	20	21	22	21	2.3	1.0	1.4	17	16
1.6	2.5	2.6	2.6	63	23	19	20	20	22	24	26	29	2.1	1.9	2.0	19	22
15.7	20.7	2.0	7.0	0.2	4.1	12	12	14	15	17	19	20	20.7	2.0	7.0	13	15

Reference Scenario								Advanced Technologies Scenario									
				Shares (%)				(TWh)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
13.4	4.1	2.2	2.8	23	40	36	30	108	76	58	54	58	-0.4	-3.0	-2.3	25	7.5
-6.0	-28.7	-100	-100	15	0.1	0.0	-	0.0	-	-	-	-	-32.2	-100	-100	0.0	-
30.4	9.3	6.2	7.1	0.1	11	14	26	46	47	51	56	71	5.8	2.2	3.2	11	9.1
n.a.	n.a.	n.a.	n.a.	-	-	-	4.2	15	62	95	127	160	n.a.	12.4	n.a.	3.6	20
9.4	3.5	1.0	1.7	62	35	29	20	139	157	174	189	202	4.8	1.9	2.7	33	26
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	7.7	2.8	4.1	-	10	12	11	67	88	112	140	172	11.3	4.8	6.6	16	22
n.a.	18.1	2.9	7.1	-	3.3	8.0	7.9	45	60	77	94	114	22.2	4.7	9.4	11	15
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	6.1	2.6	3.6	-	0.8	0.9	0.8	4.1	4.7	5.2	5.7	6.2	7.5	2.1	3.6	1.0	0.8
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-

n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
6.7	6.2	5.0	5.4	580	763	990	1 256	1 551	6.2	5.0	5.4
1.2	0.6	0.3	0.4	103	105	107	108	108	0.6	0.3	0.4
5.4	5.6	4.8	5.0	5.6	7.3	9.3	12	14	5.6	4.8	5.0
4.3	4.4	2.2	2.8	1.3	1.4	1.5	1.6	1.7	3.2	1.3	1.8
-1.0	-1.1	-2.4	-2.1	236	195	161	137	120	-2.3	-3.3	-3.0
2.5	-2.1	-2.7	-2.6	532	348	240	168	121	-4.9	-7.1	-6.5
3.5	-1.0	-0.3	-0.5	2.3	1.8	1.5	1.2	1.0	-2.7	-4.0	-3.6

Table A37 | North America

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	2 126	2 525	2 476	2 470	2 399	2 346	2 297	2 275	2 281
Coal	484	565	525	247	124	81	42	25	24
Oil	833	958	901	856	795	760	719	669	618
Natural gas	493	622	635	894	928	931	949	958	981
Nuclear	179	227	242	232	225	208	182	178	175
Hydro	49	53	53	56	63	63	64	65	65
Geothermal	14	13	8.4	9.5	11	12	13	13	14
Solar, wind, etc.	0.3	2.1	11	61	126	163	200	237	273
Biomass and waste	73	86	101	115	127	128	129	131	132
Hydrogen	-	-	-	-	-0.1	-0.1	-0.1	-0.1	-0.0

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	1 452	1 728	1 699	1 776	1 763	1 741	1 722	1 706	1 701
Coal	59	36	30	15	16	15	14	13	12
Oil	749	870	851	829	773	742	706	662	616
Natural gas	346	413	364	438	431	417	400	384	369
Electricity	262	338	367	391	430	456	492	537	594
Heat	2.8	6.1	7.1	6.0	5.9	5.9	5.7	5.5	5.4
Hydrogen	-	-	-	-	0.0	0.0	0.0	0.0	0.0
Renewables and waste	33	64	80	98	106	105	104	104	103
Industry	331	386	312	327	340	345	346	345	343
Transport	531	640	655	678	644	615	587	557	526
Buildings, etc.	456	528	572	599	602	599	602	615	640
Non-energy use	134	173	160	172	178	182	186	189	192

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	3 685	4 632	4 957	5 124	5 639	5 975	6 430	7 019	7 752
Coal	1 782	2 247	2 074	940	431	245	75	4.1	4.3
Oil	147	133	56	48	36	32	29	26	22
Natural gas	391	668	1 070	1 823	2 036	2 177	2 463	2 698	3 007
Nuclear	685	871	930	891	864	800	698	684	672
Hydro	570	612	614	654	729	738	745	751	755
Geothermal	16	15	18	19	21	25	27	28	29
Solar photovoltaics	0.0	0.2	3.3	190	688	972	1 256	1 548	1 840
Wind	3.1	5.9	104	476	735	877	1 019	1 153	1 287
Concentrated solar power and marine	0.7	0.6	0.9	3.3	3.0	3.0	3.0	3.0	3.0
Biomass and waste	91	80	82	76	91	101	111	119	128
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	6.8	4.9	4.9	4.9	4.9	4.9	4.9

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions[*2]	5 151	6 098	5 715	5 131	4 540	4 261	4 018	3 819	3 714
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	10 626	14 918	17 783	22 688	26 897	29 641	32 542	35 547	38 605
Population (million)	277	313	343	372	389	398	405	412	417
GDP per capita ($2015 thousand)	38	48	52	61	69	75	80	86	92
Primary energy consumption per capita (toe/person)	7.7	8.1	7.2	6.6	6.2	5.9	5.7	5.5	5.5
Primary energy consumption per GDP (toe/$2015 million)	200	169	139	109	89	79	71	64	59
Energy-related CO_2 emissions per GDP[*2] (t/$2015 million)	485	409	321	226	169	144	123	107	96
Energy-related CO_2 per primary energy consumption[*2] (t/toe)	2.4	2.4	2.3	2.1	1.9	1.8	1.8	1.7	1.6

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
-2.1	-8.2	-7.9	-8.0	23	10.0	5.2	1.1	82	24	21	20	19	-12.8	-7.1	-8.8	3.6	1.1
0.1	-0.9	-1.3	-1.2	39	35	33	27	722	600	460	322	220	-2.1	-5.8	-4.7	31	13
1.9	0.5	0.3	0.3	23	36	39	43	892	836	730	642	519	0.0	-2.7	-1.9	39	30
0.8	-0.4	-1.2	-1.0	8.4	9.4	9.4	7.7	228	228	229	219	217	-0.2	-0.2	-0.2	9.9	12
0.4	1.4	0.2	0.5	2.3	2.3	2.6	2.8	63	64	65	66	66	1.5	0.2	0.6	2.8	3.8
-1.2	1.3	1.4	1.4	0.7	0.4	0.4	0.6	11	13	14	14	15	1.3	1.8	1.7	0.5	0.9
17.8	9.5	3.9	5.5	0.0	2.5	5.3	12	155	232	309	407	510	12.4	6.1	7.9	6.8	29
1.4	1.2	0.2	0.5	3.5	4.7	5.3	5.8	148	149	152	155	158	3.2	0.3	1.1	6.4	9.1
n.a.	n.a.	-9.0	n.a.	-	-	-0.0	-0.0	-2.5	-7.0	-3.5	1.5	13	n.a.	n.a.	n.a.	-0.1	0.8

Reference Scenario								Advanced Technologies Scenario									
				Shares (%)				(Mtoe)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
-4.1	0.3	-1.2	-0.7	4.1	0.9	0.9	0.7	13	11	9.0	8.0	7.3	-1.9	-2.9	-2.6	0.8	0.6
0.3	-0.9	-1.1	-1.1	52	47	44	36	710	606	486	376	291	-1.9	-4.4	-3.7	42	23
0.7	-0.2	-0.8	-0.6	24	25	24	22	405	352	292	233	179	-1.0	-4.0	-3.2	24	14
1.3	1.2	1.6	1.5	18	22	24	35	435	467	505	549	582	1.4	1.5	1.4	26	46
2.4	-0.3	-0.5	-0.4	0.2	0.3	0.3	0.3	5.6	5.4	5.3	5.2	5.1	-1.0	-0.4	-0.6	0.3	0.4
n.a.	n.a.	-1.2	n.a.	-	-	0.0	0.0	0.1	7.6	19	38	77	n.a.	41.4	n.a.	0.0	6.1
3.5	1.0	-0.2	0.2	2.3	5.5	6.0	6.1	126	124	123	124	126	3.2	0.0	0.9	7.4	10.0
0.0	0.5	0.0	0.2	23	18	19	20	324	305	281	260	246	-0.1	-1.4	-1.0	19	19
0.8	-0.6	-1.0	-0.9	37	38	37	31	611	531	448	379	338	-1.3	-2.9	-2.5	36	27
0.9	0.1	0.3	0.2	31	34	34	38	583	554	523	505	491	-0.3	-0.9	-0.7	34	39
0.8	0.4	0.4	0.4	9.2	9.7	10	11	178	182	186	189	192	0.4	0.4	0.4	10	15

Reference Scenario								Advanced Technologies Scenario									
				Shares (%)				(TWh)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
-2.0	-9.3	-20.6	-17.5	48	18	7.6	0.1	258	11	9.3	9.7	8.8	-14.9	-15.5	-15.4	4.5	0.1
-3.4	-3.5	-2.3	-2.7	4.0	0.9	0.6	0.3	32	23	19	13	5.3	-4.9	-8.6	-7.6	0.6	0.1
4.9	1.4	2.0	1.8	11	36	36	39	1 939	1 764	1 385	1 115	627	0.8	-5.5	-3.7	34	7.4
0.8	-0.4	-1.2	-1.0	19	17	15	8.7	874	875	877	841	833	-0.2	-0.2	-0.2	15	9.8
0.4	1.4	0.2	0.5	15	13	13	9.7	735	747	756	764	769	1.5	0.2	0.6	13	9.1
0.6	1.4	1.4	1.4	0.4	0.4	0.4	0.4	21	27	29	30	31	1.4	1.9	1.8	0.4	0.4
41.3	17.5	5.0	8.5	0.0	3.7	12	24	747	1 172	1 601	2 229	2 888	18.7	7.0	10.2	13	34
17.1	5.6	2.8	3.6	0.1	9.3	13	17	1 014	1 473	1 937	2 449	2 992	9.9	5.6	6.8	18	35
5.0	-1.0	0.0	-0.3	0.0	0.1	0.1	0.0	3.0	3.1	3.1	3.2	3.3	-0.9	0.5	0.1	0.1	0.0
-0.6	2.4	1.7	1.9	2.5	1.5	1.6	1.7	95	111	128	138	147	2.8	2.2	2.4	1.7	1.7
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	63	125	140	154	n.a.	n.a.	n.a.	-	1.8
n.a.	0.0	0.0	0.0	-	0.1	0.1	0.1	4.9	4.9	4.9	4.9	4.9	0.0	0.0	0.0	0.1	0.1

n.a.	n.a.	n.a.	n.a.	-	-	25	131	262	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
2.4	2.1	1.8	1.9	26 897	29 641	32 542	35 547	38 605	2.1	1.8	1.9
0.9	0.5	0.4	0.4	389	398	405	412	417	0.5	0.4	0.4
1.5	1.6	1.5	1.5	69	75	80	86	92	1.6	1.5	1.5
-0.4	-0.9	-0.6	-0.7	5.9	5.4	4.9	4.5	4.2	-1.4	-1.7	-1.7
-1.9	-2.5	-2.0	-2.2	85	72	61	52	45	-3.0	-3.2	-3.1
-2.4	-3.6	-2.8	-3.0	150	103	68	36	14	-5.0	-11.1	-9.4
-0.5	-1.2	-0.7	-0.9	1.8	1.4	1.1	0.7	0.3	-2.1	-8.2	-6.5

Table A38 | United States

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	1 914	2 273	2 216	2 173	2 101	2 046	1 995	1 974	1 980
Coal	460	533	501	239	123	80	40	24	23
Oil	757	871	807	758	706	674	638	593	546
Natural gas	438	548	556	771	794	790	798	800	816
Nuclear	159	208	219	209	204	188	168	167	167
Hydro	23	22	23	22	27	27	27	28	28
Geothermal	14	13	8.4	9.5	11	12	13	13	14
Solar, wind, etc.	0.3	2.1	11	57	119	155	191	227	263
Biomass and waste	62	73	89	103	115	115	116	119	120
Hydrogen	-	-	-	-	-0.1	-0.1	-0.1	-0.0	-0.0

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	1 294	1 546	1 513	1 579	1 567	1 548	1 532	1 520	1 518
Coal	56	33	27	13	14	13	13	12	11
Oil	683	793	762	742	692	664	631	591	550
Natural gas	303	360	322	386	380	368	353	340	327
Electricity	226	301	326	344	380	403	435	477	530
Heat	2.2	5.3	6.6	5.5	5.3	5.3	5.2	5.0	4.9
Hydrogen	-	-	-	-	0.0	0.0	0.0	0.0	0.0
Renewables and waste	23	54	70	88	96	95	94	95	94
Industry	284	332	270	281	291	295	297	296	294
Transport	488	588	596	619	588	563	537	510	482
Buildings, etc.	403	473	511	531	534	533	537	550	574
Non-energy use	119	153	135	148	153	157	161	164	167

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	3 203	4 026	4 354	4 473	4 932	5 232	5 647	6 191	6 875
Coal	1 700	2 129	1 994	913	430	245	74	3.3	3.3
Oil	131	118	48	43	32	28	25	23	21
Natural gas	382	634	1 018	1 740	1 926	2 044	2 284	2 475	2 732
Nuclear	612	798	839	804	782	723	644	642	642
Hydro	273	253	262	257	312	315	318	321	323
Geothermal	16	15	18	19	21	25	27	28	29
Solar photovoltaics	0.0	0.2	3.1	184	672	953	1 233	1 522	1 812
Wind	3.1	5.7	95	439	668	802	937	1 065	1 192
Concentrated solar power and marine	0.7	0.5	0.9	3.3	3.0	3.0	3.0	3.0	3.0
Biomass and waste	86	72	73	66	81	90	98	106	114
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	3.7	4.5	4.5	4.5	4.5	4.5	4.5

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions[*2]	4 760	5 621	5 217	4 608	4 043	3 761	3 510	3 313	3 206
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	9 811	13 754	16 383	20 927	24 890	27 442	30 149	32 957	35 815
Population (million)	250	282	309	333	347	355	361	367	372
GDP per capita ($2015 thousand)	39	49	53	63	72	77	83	90	96
Primary energy consumption per capita (toe/person)	7.7	8.1	7.2	6.5	6.1	5.8	5.5	5.4	5.3
Primary energy consumption per GDP (toe/$2015 million)	195	165	135	104	84	75	66	60	55
Energy-related CO_2 emissions per GDP[*2] (t/$2015 million)	485	409	318	220	162	137	116	101	90
Energy-related CO_2 per primary energy consumption[*2] (t/toe)	2.5	2.5	2.4	2.1	1.9	1.8	1.8	1.7	1.6

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.

*2 After avoidance by carbon dioxide removal [CDR].

	Reference Scenario								Advanced Technologies Scenario									
	CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
	1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
	-2.0	-8.0	-8.1	-8.0	24	11	5.8	1.2	81	23	20	19	18	-12.7	-7.2	-8.8	4.0	1.2
	0.0	-0.9	-1.3	-1.2	40	35	34	28	642	533	408	282	189	-2.1	-5.9	-4.8	32	13
	1.8	0.4	0.1	0.2	23	35	38	41	762	710	611	533	423	-0.2	-2.9	-2.1	38	28
	0.9	-0.3	-1.0	-0.8	8.3	9.6	9.7	8.5	206	204	205	196	194	-0.2	-0.3	-0.3	10	13
	-0.2	2.5	0.2	0.8	1.2	1.0	1.3	1.4	27	27	27	28	28	2.5	0.2	0.8	1.3	1.8
	-1.2	1.3	1.4	1.4	0.7	0.4	0.5	0.7	11	13	14	14	15	1.3	1.8	1.7	0.5	1.0
	17.6	9.6	4.0	5.6	0.0	2.6	5.7	13	147	219	291	381	475	12.5	6.0	7.8	7.3	32
	1.6	1.3	0.2	0.5	3.3	4.7	5.5	6.0	133	135	138	141	145	3.3	0.4	1.2	6.6	9.6
	n.a.	n.a.	-13.3	n.a.	-	-	-0.0	-0.0	-2.0	-5.4	-1.7	4.1	16	n.a.	n.a.	n.a.	-0.1	1.1

	Reference Scenario								Advanced Technologies Scenario									
					Shares (%)				(Mtoe)								Shares (%)	
	1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
	-4.4	0.4	-1.1	-0.6	4.3	0.8	0.9	0.7	11	9.4	8.0	7.1	6.5	-1.8	-2.8	-2.5	0.8	0.6
	0.3	-0.9	-1.1	-1.1	53	47	44	36	636	543	434	333	255	-1.9	-4.5	-3.7	42	23
	0.8	-0.2	-0.7	-0.6	23	24	24	22	357	311	258	207	159	-1.0	-3.9	-3.1	24	14
	1.3	1.2	1.7	1.6	18	22	24	35	384	412	446	488	518	1.4	1.5	1.5	25	46
	3.0	-0.3	-0.5	-0.4	0.2	0.3	0.3	0.3	5.0	4.9	4.8	4.6	4.6	-1.0	-0.4	-0.6	0.3	0.4
	n.a.	n.a.	-1.0	n.a.	-	-	0.0	0.0	0.1	6.7	17	35	70	n.a.	41.1	n.a.	0.0	6.2
	4.3	1.1	-0.1	0.3	1.8	5.5	6.1	6.2	114	112	112	113	116	3.4	0.1	1.0	7.6	10
	0.0	0.5	0.1	0.2	22	18	19	19	278	261	240	222	210	-0.1	-1.4	-1.0	18	19
	0.7	-0.6	-1.0	-0.9	38	39	38	32	559	488	412	349	310	-1.3	-2.9	-2.4	37	27
	0.9	0.1	0.4	0.3	31	34	34	38	517	493	466	453	443	-0.3	-0.8	-0.7	34	39
	0.7	0.5	0.4	0.4	9.2	9.4	9.8	11	153	157	161	164	167	0.5	0.4	0.4	10	15

	Reference Scenario								Advanced Technologies Scenario									
					Shares (%)				(TWh)								Shares (%)	
	1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
	-1.9	-9.0	-21.6	-18.2	53	20	8.7	0.0	256	9.4	7.1	7.2	6.8	-14.7	-16.6	-16.1	5.1	0.1
	-3.4	-3.4	-2.1	-2.5	4.1	1.0	0.7	0.3	28	20	16	11	4.5	-4.9	-8.8	-7.7	0.6	0.1
	4.9	1.3	1.8	1.6	12	39	39	40	1 842	1 657	1 261	964	459	0.7	-6.7	-4.6	37	6.3
	0.9	-0.3	-1.0	-0.8	19	18	16	9.3	790	785	787	751	743	-0.2	-0.3	-0.3	16	10
	-0.2	2.5	0.2	0.8	8.5	5.7	6.3	4.7	312	315	318	321	323	2.5	0.2	0.8	6.2	4.4
	0.6	1.4	1.5	1.4	0.5	0.4	0.4	0.4	21	27	29	30	31	1.4	1.9	1.8	0.4	0.4
	41.1	17.6	5.1	8.5	0.0	4.1	14	26	730	1 145	1 563	2 171	2 807	18.8	7.0	10.2	15	38
	16.8	5.4	2.9	3.6	0.1	9.8	14	17	935	1 356	1 779	2 215	2 668	9.9	5.4	6.7	19	36
	5.1	-1.1	0.0	-0.3	0.0	0.1	0.1	0.0	3.0	3.1	3.1	3.2	3.3	-1.1	0.5	0.0	0.1	0.0
	-0.8	2.5	1.7	1.9	2.7	1.5	1.6	1.7	82	97	113	122	131	2.6	2.4	2.4	1.6	1.8
	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	60	119	133	147	n.a.	n.a.	n.a.	-	2.0
	n.a.	0.0	0.0	0.0	-	0.1	0.1	0.1	4.5	4.5	4.5	4.5	4.5	0.0	0.0	0.0	0.1	0.1

	n.a.	n.a.	n.a.	n.a.	-	-	22	126	254	n.a.	n.a.	n.a.

	Reference Scenario				Advanced Technologies Scenario							
	1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
	2.4	2.2	1.8	1.9	24 890	27 442	30 149	32 957	35 815	2.2	1.8	1.9
	0.9	0.5	0.3	0.4	347	355	361	367	372	0.5	0.3	0.4
	1.5	1.7	1.5	1.5	72	77	83	90	96	1.7	1.5	1.5
	-0.5	-0.9	-0.6	-0.7	5.8	5.3	4.8	4.4	4.1	-1.5	-1.8	-1.7
	-2.0	-2.6	-2.1	-2.2	81	68	57	49	42	-3.1	-3.2	-3.2
	-2.4	-3.7	-2.9	-3.2	143	97	63	32	11	-5.2	-12.0	-10.1
	-0.5	-1.2	-0.9	-1.0	1.8	1.4	1.1	0.7	0.3	-2.2	-9.1	-7.2

Table A39 | Latin America

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	467	611	790	845	908	955	997	1 037	1 076
Coal	21	28	40	38	38	37	36	34	33
Oil	241	313	365	352	355	367	377	385	389
Natural gas	71	118	178	201	197	213	231	252	271
Nuclear	3.2	5.3	7.2	8.7	14	17	17	16	18
Hydro	34	51	64	67	75	78	81	84	87
Geothermal	5.1	6.5	6.4	6.5	8.2	12	13	14	15
Solar, wind, etc.	0.0	0.2	0.9	21	44	55	66	76	85
Biomass and waste	93	90	128	151	177	177	177	177	178
Hydrogen	-	-	-	-	-0.0	-0.1	-0.1	-0.1	-0.2

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	344	442	570	608	665	698	730	759	785
Coal	8.3	11	15	13	14	14	14	13	13
Oil	178	235	284	292	304	318	330	339	344
Natural gas	38	54	74	70	76	79	83	86	90
Electricity	44	68	97	120	145	162	179	197	214
Heat	-	-	-	-	-	-	-	-	0.0
Hydrogen	-	-	-	-	-	-	-	-	-
Renewables and waste	75	74	99	112	126	125	124	123	123
Industry	114	143	180	178	201	217	232	245	256
Transport	104	140	197	225	245	254	264	272	280
Buildings, etc.	100	122	148	170	182	186	190	195	200
Non-energy use	26	38	45	34	38	41	44	47	50

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	623	1 009	1 406	1 716	2 052	2 280	2 503	2 722	2 941
Coal	24	44	75	77	75	71	68	61	53
Oil	130	197	188	111	70	60	45	33	29
Natural gas	54	134	317	397	353	414	493	582	661
Nuclear	12	20	28	33	56	65	65	60	70
Hydro	391	591	739	780	871	906	941	975	1 010
Geothermal	5.9	8.0	9.9	9.6	12	16	18	20	21
Solar photovoltaics	0.0	0.0	0.1	76	262	323	380	431	477
Wind	0.0	0.3	4.7	138	228	297	361	423	480
Concentrated solar power and marine	-	-	-	0.3	0.2	0.2	0.2	0.2	0.2
Biomass and waste	7.4	13	44	79	109	113	117	120	124
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	0.4	0.5	15	15	15	15	15	15

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	861	1 192	1 522	1 472	1 465	1 526	1 586	1 644	1 689
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	2 638	3 596	4 888	5 619	6 805	7 859	9 018	10 255	11 545
Population (million)	438	518	586	657	690	707	720	729	734
GDP per capita ($2015 thousand)	6.0	6.9	8.3	8.6	9.9	11	13	14	16
Primary energy consumption per capita (toe/person)	1.1	1.2	1.3	1.3	1.3	1.4	1.4	1.4	1.5
Primary energy consumption per GDP (toe/$2015 million)	177	170	162	150	133	122	111	101	93
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	326	332	311	262	215	194	176	160	146
Energy-related CO_2 per primary energy consumption*2 (t/toe)	1.8	2.0	1.9	1.7	1.6	1.6	1.6	1.6	1.6

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
1.8	-0.2	-0.7	-0.5	4.6	4.5	4.1	3.1	31	28	25	24	24	-2.7	-1.2	-1.6	3.5	2.7
1.2	0.1	0.5	0.4	51	42	39	36	332	316	290	260	230	-0.7	-1.8	-1.5	38	25
3.3	-0.2	1.6	1.1	15	24	22	25	179	183	189	201	214	-1.4	0.9	0.2	21	23
3.1	6.6	1.1	2.7	0.7	1.0	1.6	1.7	16	24	31	37	43	8.1	5.0	5.9	1.9	4.8
2.2	1.4	0.7	0.9	7.2	7.9	8.2	8.1	75	79	82	86	90	1.4	0.9	1.0	8.6	9.9
0.8	2.9	3.2	3.1	1.1	0.8	0.9	1.4	8.2	13	15	16	17	2.9	3.6	3.4	0.9	1.8
22.3	9.6	3.3	5.0	0.0	2.5	4.9	7.9	56	77	105	143	196	12.8	6.5	8.3	6.4	22
1.5	2.0	0.0	0.6	20	18	19	17	172	165	156	149	144	1.7	-0.9	-0.2	20	16
n.a.	n.a.	9.7	n.a.	-	-	-0.0	-0.0	0.0	-3.8	-11	-26	-48	n.a.	n.a.	n.a.	0.0	-5.3

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(Mtoe)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
1.4	0.5	-0.1	0.1	2.4	2.1	2.0	1.7	12	10	9.2	8.3	7.7	-1.4	-2.0	-1.8	1.8	1.3
1.6	0.5	0.6	0.6	52	48	46	44	287	275	255	231	205	-0.2	-1.7	-1.3	45	34
1.9	1.0	0.8	0.9	11	12	11	11	72	69	64	59	54	0.2	-1.4	-0.9	11	8.9
3.2	2.4	2.0	2.1	13	20	22	27	148	168	188	209	230	2.6	2.2	2.3	23	38
n.a.	n.a.	n.a.	n.a.	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	0.0	1.0	2.8	6.2	15	n.a.	39.2	n.a.	0.0	2.5
1.3	1.5	-0.1	0.3	22	18	19	16	122	115	106	99	94	1.1	-1.3	-0.6	19	15
1.4	1.5	1.2	1.3	33	29	30	33	192	195	194	192	192	0.9	0.0	0.3	30	32
2.5	1.0	0.7	0.8	30	37	37	36	234	227	217	207	199	0.5	-0.8	-0.4	37	33
1.7	0.9	0.5	0.6	29	28	27	25	177	174	171	168	165	0.5	-0.3	-0.1	28	27
0.9	1.1	1.4	1.3	7.6	5.7	5.7	6.3	38	41	44	47	50	1.1	1.4	1.3	5.9	8.2

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(TWh)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
3.7	-0.3	-1.7	-1.3	3.8	4.5	3.6	1.8	56	51	40	39	43	-3.9	-1.3	-2.1	2.6	1.0
-0.5	-5.5	-4.3	-4.7	21	6.4	3.4	1.0	56	52	34	32	29	-8.1	-3.3	-4.7	2.7	0.6
6.5	-1.5	3.2	1.8	8.6	23	17	22	295	365	473	622	781	-3.6	5.0	2.4	14	17
3.1	6.6	1.1	2.7	2.0	1.9	2.7	2.4	62	94	118	142	167	8.1	5.0	5.9	2.9	3.7
2.2	1.4	0.7	0.9	63	45	42	34	874	914	954	998	1 044	1.4	0.9	1.0	41	23
1.5	3.3	2.8	2.9	1.0	0.6	0.6	0.7	12	19	21	22	23	3.3	3.3	3.3	0.6	0.5
42.1	16.8	3.0	6.8	0.0	4.4	13	16	327	448	595	792	1 062	20.1	6.1	9.9	16	24
44.8	6.5	3.8	4.5	0.0	8.0	11	16	298	421	596	840	1 185	10.1	7.2	8.0	14	26
n.a.	-8.3	0.0	-2.4	-	0.0	0.0	0.0	0.2	0.2	0.2	0.3	0.4	-7.8	5.2	1.3	0.0	0.0
7.6	4.2	0.6	1.6	1.2	4.6	5.3	4.2	113	119	124	130	135	4.7	0.9	1.9	5.4	3.0
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	0.4	0.7	3.4	6.0	n.a.	n.a.	n.a.	-	0.1
n.a.	0.0	0.0	0.0	-	0.9	0.7	0.5	15	15	15	15	15	0.0	0.0	0.0	0.7	0.3

n.a.	n.a.	n.a.	n.a.	-	-	3.6	7.3	11	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
2.4	2.4	2.7	2.6	6 805	7 859	9 018	10 255	11 545	2.4	2.7	2.6
1.3	0.6	0.3	0.4	690	707	720	729	734	0.6	0.3	0.4
1.1	1.8	2.4	2.2	9.9	11	13	14	16	1.8	2.4	2.2
0.6	0.3	0.5	0.5	1.3	1.2	1.2	1.2	1.2	-0.3	-0.1	-0.1
-0.5	-1.5	-1.8	-1.7	128	112	98	87	79	-2.0	-2.4	-2.3
-0.7	-2.4	-1.9	-2.1	195	157	123	94	72	-3.6	-4.9	-4.5
-0.2	-1.0	-0.1	-0.4	1.5	1.4	1.3	1.1	0.9	-1.7	-2.6	-2.3

Table A40 | Advanced Europe

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	1 644	1 759	1 834	1 608	1 440	1 385	1 341	1 291	1 249
Coal	450	331	301	204	92	76	74	75	70
Oil	617	654	605	529	460	427	399	373	347
Natural gas	267	396	473	390	292	247	227	219	206
Nuclear	210	247	239	170	184	196	194	172	169
Hydro	39	47	48	43	43	44	45	45	46
Geothermal	4.9	7.1	11	22	25	35	36	36	36
Solar, wind, etc.	0.4	2.9	18	73	162	184	199	216	231
Biomass and waste	56	72	137	176	193	188	183	176	171
Hydrogen	-	-	-	-	-	-0.0	-0.0	-0.0	-0.0

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	1 142	1 234	1 289	1 190	1 115	1 068	1 025	986	951
Coal	123	61	54	37	35	31	28	25	23
Oil	528	573	538	485	429	399	373	347	322
Natural gas	205	269	285	255	236	226	215	203	192
Electricity	193	234	267	263	270	273	280	289	300
Heat	45	42	53	44	42	41	39	37	35
Hydrogen	-	-	-	-	0.0	0.0	0.0	0.0	0.0
Renewables and waste	48	56	92	106	104	98	90	84	79
Industry	330	324	296	284	283	279	272	265	257
Transport	269	318	335	345	307	283	263	245	229
Buildings, etc.	442	477	545	472	438	419	403	390	379
Non-energy use	101	114	113	89	87	87	87	86	86

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	2 695	3 236	3 623	3 543	3 782	3 859	3 976	4 155	4 353
Coal	1 030	968	873	568	105	64	38	54	70
Oil	209	180	81	53	9.6	3.3	2.1	3.6	2.3
Natural gas	176	514	857	726	286	79	33	71	71
Nuclear	804	948	916	654	707	753	745	659	647
Hydro	450	547	559	498	506	513	520	527	534
Geothermal	3.6	6.2	11	23	26	40	41	41	42
Solar photovoltaics	0.0	0.1	23	235	828	976	1 092	1 183	1 262
Wind	0.8	22	153	541	985	1 088	1 148	1 252	1 354
Concentrated solar power and marine	0.5	0.5	1.2	5.1	6.1	6.2	6.1	6.3	6.4
Biomass and waste	21	48	146	235	318	331	344	351	358
Hydrogen	-	-	-	-	-	-	-	-	-
Others	0.3	1.5	4.6	6.6	6.6	6.6	6.6	6.6	6.6

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions[*2]	3 964	3 927	3 834	3 153	2 279	2 016	1 879	1 789	1 662
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	11 640	14 619	16 890	20 529	22 972	24 734	26 523	28 324	30 060
Population (million)	505	528	557	583	585	584	582	578	572
GDP per capita ($2015 thousand)	23	28	30	35	39	42	46	49	53
Primary energy consumption per capita (toe/person)	3.3	3.3	3.3	2.8	2.5	2.4	2.3	2.2	2.2
Primary energy consumption per GDP (toe/$2015 million)	141	120	109	78	63	56	51	46	42
Energy-related CO_2 emissions per GDP[*2] (t/$2015 million)	341	269	227	154	99	82	71	63	55
Energy-related CO_2 per primary energy consumption[*2] (t/toe)	2.4	2.2	2.1	2.0	1.6	1.5	1.4	1.4	1.3

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
-2.4	-9.5	-1.4	-3.8	27	13	6.4	5.6	73	68	65	63	62	-12.0	-0.8	-4.1	5.3	5.4
-0.5	-1.7	-1.4	-1.5	38	33	32	28	403	317	247	181	131	-3.3	-5.5	-4.9	29	11
1.2	-3.6	-1.7	-2.3	16	24	20	16	257	200	154	114	75	-5.1	-6.0	-5.7	18	6.5
-0.6	1.0	-0.4	0.0	13	11	13	13	205	230	247	250	273	2.3	1.4	1.7	15	24
0.3	0.2	0.3	0.2	2.4	2.7	3.0	3.7	43	44	45	45	46	0.2	0.3	0.2	3.1	4.0
4.9	1.4	1.9	1.8	0.3	1.4	1.7	2.9	25	37	38	38	38	1.4	2.2	1.9	1.8	3.3
18.1	10.5	1.8	4.2	0.0	4.5	11	19	182	215	245	286	326	12.2	2.9	5.5	13	28
3.7	1.2	-0.6	-0.1	3.4	11	13	14	210	202	190	178	170	2.2	-1.1	-0.1	15	15
n.a.	n.a.	n.a.	n.a.	-	-	-	-0.0	2.8	13	22	44	61	n.a.	16.8	n.a.	0.2	5.3

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	(Mtoe) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
-3.7	-0.9	-2.1	-1.8	11	3.1	3.1	2.4	29	22	18	14	12	-3.1	-4.3	-3.9	2.7	1.6
-0.3	-1.5	-1.4	-1.4	46	41	38	34	379	306	246	199	163	-3.0	-4.1	-3.8	36	22
0.7	-0.9	-1.0	-1.0	18	21	21	20	221	187	151	115	82	-1.8	-4.9	-4.0	21	11
1.0	0.3	0.5	0.5	17	22	24	32	280	294	307	323	333	0.8	0.9	0.8	26	45
0.0	-0.6	-0.8	-0.8	3.9	3.7	3.8	3.7	42	41	39	38	37	-0.8	-0.6	-0.6	3.9	5.0
n.a.	n.a.	0.0	n.a.	-	-	0.0	0.0	0.1	5.0	12	22	44	n.a.	36.6	n.a.	0.0	5.9
2.5	-0.3	-1.4	-1.1	4.2	8.9	9.3	8.3	112	104	90	79	70	0.6	-2.3	-1.5	11	9.5
-0.5	0.0	-0.5	-0.4	29	24	25	27	270	251	230	213	201	-0.6	-1.5	-1.2	25	27
0.8	-1.5	-1.5	-1.5	24	29	28	24	281	231	190	161	146	-2.5	-3.2	-3.0	26	20
0.2	-0.9	-0.7	-0.8	39	40	39	40	425	390	356	331	308	-1.3	-1.6	-1.5	40	42
-0.4	-0.3	-0.1	-0.1	8.9	7.5	7.8	9.0	87	87	87	86	86	-0.3	-0.1	-0.1	8.2	12

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	(TWh) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
-1.8	-19.0	-2.0	-7.2	38	16	2.8	1.6	37	31	46	68	60	-28.9	2.5	-7.7	0.9	1.0
-4.2	-19.2	-6.9	-10.6	7.8	1.5	0.3	0.1	8.0	3.4	1.4	2.3	-	-21.0	-100	-100	0.2	-
4.5	-11.0	-6.7	-8.0	6.5	20	7.6	1.6	187	72	26	38	-	-15.6	-100	-100	4.7	-
-0.6	1.0	-0.4	0.0	30	18	19	15	786	884	949	959	1 046	2.3	1.4	1.7	20	18
0.3	0.2	0.3	0.2	17	14	13	12	506	513	520	527	534	0.2	0.3	0.2	13	9.0
6.0	1.5	2.3	2.1	0.1	0.7	0.7	1.0	26	43	44	44	44	1.5	2.6	2.3	0.7	0.7
35.0	17.1	2.1	6.2	0.0	6.6	22	29	975	1 171	1 365	1 533	1 691	19.5	2.8	7.3	25	29
22.7	7.8	1.6	3.3	0.0	15	26	31	1 077	1 254	1 411	1 716	2 014	9.0	3.2	4.8	27	34
7.5	2.3	0.2	0.8	0.0	0.1	0.2	0.1	6.0	6.2	7.0	9.1	12	2.1	3.4	3.0	0.2	0.2
7.9	3.9	0.6	1.5	0.8	6.6	8.4	8.2	351	364	377	386	394	5.2	0.6	1.9	8.9	6.7
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	5.1	10	56	101	n.a.	n.a.	n.a.	-	1.7
9.6	0.0	0.0	0.0	0.0	0.2	0.2	0.2	6.6	6.6	6.6	6.6	6.6	0.0	0.0	0.0	0.2	0.1

n.a.	n.a.	n.a.	n.a.	-	-	47	141	240	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
1.8	1.4	1.4	1.4	22 972	24 734	26 523	28 324	30 060	1.4	1.4	1.4
0.4	0.1	-0.1	-0.1	585	584	582	578	572	0.1	-0.1	-0.1
1.3	1.4	1.5	1.4	39	42	46	49	53	1.4	1.5	1.4
-0.5	-1.4	-0.6	-0.8	2.4	2.2	2.1	2.0	2.0	-1.9	-0.8	-1.1
-1.8	-2.7	-2.0	-2.2	60	53	46	41	38	-3.2	-2.3	-2.5
-2.5	-5.3	-2.9	-3.6	85	62	43	24	9.5	-7.1	-10.4	-9.5
-0.6	-2.6	-0.9	-1.4	1.4	1.2	0.9	0.6	0.2	-4.1	-8.3	-7.1

Table A41 | Other Europe/Eurasia

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	1 514	988	1 112	1 189	1 195	1 189	1 182	1 177	1 173
Coal	365	209	211	213	195	186	184	180	179
Oil	459	199	217	252	247	243	239	235	230
Natural gas	596	481	566	583	560	548	550	546	547
Nuclear	55	61	76	85	114	127	121	121	115
Hydro	22	23	26	27	28	29	30	31	32
Geothermal	0.0	0.1	0.6	0.2	0.3	0.3	0.3	0.3	0.3
Solar, wind, etc.	-	0.0	0.2	3.5	7.8	9.5	11	12	14
Biomass and waste	17	15	19	29	32	31	31	30	29
Hydrogen	-	-	-	-	-0.0	-0.0	-0.0	-0.0	-0.0

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	1 057	647	709	780	804	801	797	795	795
Coal	113	36	39	47	51	49	47	45	43
Oil	275	144	174	216	217	214	211	207	203
Natural gas	258	200	233	254	251	246	243	240	237
Electricity	125	86	103	114	132	141	151	163	175
Heat	274	170	147	129	131	129	125	122	119
Hydrogen	-	-	-	-	-	-	-	-	-
Renewables and waste	13	11	14	20	22	21	20	19	18
Industry	391	205	205	208	236	242	245	249	252
Transport	170	110	145	155	149	145	142	140	137
Buildings, etc.	431	285	279	320	316	309	302	297	294
Non-energy use	65	47	80	97	103	105	107	109	111

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	1 856	1 415	1 689	1 816	1 860	1 938	2 021	2 072	2 133
Coal	429	338	396	370	311	302	319	321	335
Oil	252	69	22	20	15	13	13	11	11
Natural gas	707	504	671	739	671	670	727	751	798
Nuclear	209	234	289	323	436	489	465	465	442
Hydro	259	267	306	316	325	342	355	365	373
Geothermal	0.0	0.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Solar photovoltaics	-	-	0.0	16	48	59	70	76	82
Wind	-	0.0	1.2	23	40	49	57	65	73
Concentrated solar power and marine	-	-	-	-	0.0	0.0	0.1	0.1	0.2
Biomass and waste	0.0	2.6	3.3	9.6	13	14	16	17	18
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	0.0	0.1	0.1	0.1	0.1	0.1	0.1

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions[*2]	3 872	2 328	2 490	2 510	2 369	2 295	2 274	2 235	2 216
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	1 789	1 230	2 045	2 571	3 193	3 534	3 909	4 325	4 771
Population (million)	337	335	332	338	339	340	340	341	342
GDP per capita ($2015 thousand)	5.3	3.7	6.2	7.6	9.4	10	11	13	14
Primary energy consumption per capita (toe/person)	4.5	3.0	3.4	3.5	3.5	3.5	3.5	3.4	3.4
Primary energy consumption per GDP (toe/$2015 million)	846	803	544	463	374	337	302	272	246
Energy-related CO_2 emissions per GDP[*2] (t/$2015 million)	2 164	1 893	1 217	976	742	650	582	517	464
Energy-related CO_2 per primary energy consumption[*2] (t/toe)	2.6	2.4	2.2	2.1	2.0	1.9	1.9	1.9	1.9

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
-1.7	-1.1	-0.4	-0.6	24	18	16	15	179	154	137	126	118	-2.2	-2.1	-2.1	15	12
-1.9	-0.2	-0.4	-0.3	30	21	21	20	236	214	187	160	135	-0.8	-2.7	-2.2	20	13
-0.1	-0.5	-0.1	-0.2	39	49	47	47	553	520	490	472	460	-0.6	-0.9	-0.8	47	45
1.4	3.8	0.1	1.1	3.6	7.1	9.5	9.8	121	144	154	174	188	4.6	2.2	2.9	10	18
0.6	0.4	0.7	0.6	1.5	2.3	2.3	2.7	28	29	30	31	32	0.4	0.7	0.6	2.4	3.1
7.4	1.4	0.5	0.8	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3	1.2	0.4	0.6	0.0	0.0
n.a.	10.6	2.8	5.0	-	0.3	0.7	1.2	12	16	20	25	31	16.5	5.0	8.2	1.0	3.1
1.7	1.4	-0.5	0.0	1.1	2.4	2.7	2.5	32	31	30	29	29	1.4	-0.4	0.1	2.7	2.9
n.a.	n.a.	6.3	n.a.	-	-	-0.0	-0.0	0.1	-0.6	-1.7	-3.4	-6.0	n.a.	n.a.	n.a.	0.0	-0.6

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(Mtoe)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
-2.7	1.0	-0.8	-0.3	11	6.0	6.3	5.4	45	39	33	28	24	-0.4	-3.2	-2.4	5.9	3.8
-0.7	0.1	-0.3	-0.2	26	28	27	26	208	191	169	146	126	-0.5	-2.5	-1.9	27	20
-0.1	-0.1	-0.3	-0.2	24	33	31	30	236	213	190	170	151	-0.9	-2.2	-1.8	30	24
-0.3	1.8	1.4	1.5	12	15	16	22	137	151	165	179	194	2.4	1.7	1.9	18	31
-2.3	0.2	-0.5	-0.3	26	17	16	15	127	121	115	109	105	-0.2	-1.0	-0.7	16	17
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
1.4	1.4	-1.2	-0.4	1.2	2.6	2.8	2.2	21	20	18	17	17	0.9	-1.1	-0.5	2.8	2.8
-2.0	1.6	0.3	0.7	37	27	29	32	225	216	204	193	186	1.0	-1.0	-0.4	29	30
-0.3	-0.5	-0.4	-0.4	16	20	19	17	142	129	114	102	91	-1.1	-2.2	-1.9	18	15
-0.9	-0.2	-0.4	-0.3	41	41	39	37	305	286	265	246	229	-0.6	-1.4	-1.2	39	37
1.2	0.7	0.4	0.5	6.2	12	13	14	103	105	107	109	111	0.7	0.4	0.5	13	18

Reference Scenario								Advanced Technologies Scenario									
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(TWh)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
-0.5	-2.2	0.4	-0.4	23	20	17	16	268	204	168	152	139	-4.0	-3.2	-3.4	14	5.8
-7.6	-3.6	-1.7	-2.2	14	1.1	0.8	0.5	14	10	8.7	8.0	7.6	-4.5	-3.0	-3.4	0.7	0.3
0.1	-1.2	0.9	0.3	38	41	36	37	701	689	689	729	796	-0.7	0.6	0.3	36	33
1.4	3.8	0.1	1.1	11	18	23	21	466	551	590	667	720	4.7	2.2	2.9	24	30
0.6	0.4	0.7	0.6	14	17	17	18	325	342	355	365	373	0.4	0.7	0.6	17	15
9.6	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	-0.1	0.0	0.0	0.0	0.0
n.a.	15.2	2.7	6.1	-	0.9	2.6	3.9	63	87	114	145	182	19.0	5.5	9.2	3.3	7.5
n.a.	7.1	3.0	4.2	-	1.3	2.2	3.4	73	94	118	146	179	15.4	4.6	7.6	3.8	7.4
n.a.	n.a.	12.6	n.a.	-	-	0.0	0.0	0.1	0.3	0.5	0.7	0.9	n.a.	13.4	n.a.	0.0	0.0
18.0	3.5	1.8	2.3	0.0	0.5	0.7	0.8	14	16	18	19	21	5.3	1.9	2.8	0.8	0.9
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	0.0	0.0	0.0	-	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0

n.a.	n.a.	n.a.	n.a.	-	-	2.0	4.3	6.9	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
1.1	2.7	2.0	2.2	3 193	3 534	3 909	4 325	4 771	2.7	2.0	2.2
0.0	0.1	0.0	0.1	339	340	340	341	342	0.1	0.0	0.1
1.1	2.7	2.0	2.2	9.4	10	11	13	14	2.7	2.0	2.2
-0.8	0.0	-0.1	-0.1	3.5	3.3	3.2	3.1	3.0	-0.2	-0.7	-0.6
-1.9	-2.6	-2.1	-2.2	368	319	275	242	214	-2.8	-2.7	-2.7
-2.5	-3.4	-2.3	-2.6	702	555	438	348	279	-4.0	-4.5	-4.4
-0.6	-0.8	-0.2	-0.4	1.9	1.7	1.6	1.4	1.3	-1.2	-1.9	-1.7

Table A42 | European Union

Primary energy consumption	1990	2000	2010	2022	2030	2035	2040	2045	2050
Reference Scenario (Million tonnes of oil equivalent [Mtoe])									
	1 441	1 471	1 528	1 307	1 189	1 140	1 098	1 054	1 018
Coal	393	285	252	167	77	66	63	64	59
Oil	531	550	506	437	379	352	329	306	284
Natural gas	250	309	363	294	224	191	178	172	161
Nuclear	190	224	223	159	178	187	177	151	148
Hydro	24	30	32	24	24	24	25	25	25
Geothermal	3.2	4.6	5.5	6.7	7.5	7.9	7.9	7.9	7.9
Solar, wind, etc.	0.3	2.5	16	58	130	147	161	173	183
Biomass and waste	47	65	129	159	173	168	162	156	150
Hydrogen	-	-	-	-	-	-0.0	-0.0	-0.0	-0.0

Final energy consumption	1990	2000	2010	2022	2030	2035	2040	2045	2050
Reference Scenario (Mtoe)									
Total	995	1 026	1 071	966	904	866	830	797	768
Coal	109	46	37	25	23	21	18	17	15
Oil	445	479	448	398	351	326	305	283	263
Natural gas	185	220	231	195	182	174	166	157	148
Electricity	162	189	216	207	212	216	221	229	238
Heat	55	43	52	42	40	39	37	35	33
Hydrogen	-	-	-	-	0.0	0.0	0.0	0.0	0.0
Renewables and waste	39	50	87	99	96	90	83	76	71
Industry	313	273	247	228	229	226	222	216	210
Transport	220	262	279	280	247	228	211	196	183
Buildings, etc.	374	391	447	380	352	336	321	310	301
Non-energy use	88	100	98	78	76	76	76	75	74

Electricity generated	1990	2000	2010	2022	2030	2035	2040	2045	2050
Reference Scenario (TWh)									
Total	2 256	2 630	2 955	2 793	3 072	3 154	3 299	3 380	3 503
Coal	844	846	755	482	106	69	49	60	64
Oil	189	173	82	56	-	-	-	-	-
Natural gas	188	331	589	541	221	69	43	79	78
Nuclear	729	860	854	609	683	718	679	581	569
Hydro	284	350	372	276	279	283	286	290	294
Geothermal	3.2	4.8	5.6	6.4	8.8	13	14	14	14
Solar photovoltaics	0.0	0.1	22	206	704	833	961	1 018	1 074
Wind	0.8	21	140	421	805	893	982	1 049	1 115
Concentrated solar power and marine	0.5	0.5	1.2	5.0	6.1	6.1	6.2	6.3	6.4
Biomass and waste	19	42	129	186	255	265	274	279	284
Hydrogen	-	-	-	-	-	-	-	-	-
Others	0.2	1.4	4.4	4.6	4.6	4.6	4.6	4.6	4.6

Carbon dioxide [CO_2]	1990	2000	2010	2022	2030	2035	2040	2045	2050
Reference Scenario ($MtCO_2$)									
Energy-related CO_2 emissions*2	3 462	3 263	3 133	2 517	1 915	1 712	1 602	1 532	1 422
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	1990	2000	2010	2022	2030	2035	2040	2045	2050
Reference Scenario									
Gross domestic product [GDP] ($2015 billion)	9 067	11 227	12 852	15 226	17 029	18 314	19 624	20 940	22 204
Population (million)	420	429	442	447	445	442	438	433	426
GDP per capita ($2015 thousand)	22	26	29	34	38	41	45	48	52
Primary energy consumption per capita (toe/person)	3.4	3.4	3.5	2.9	2.7	2.6	2.5	2.4	2.4
Primary energy consumption per GDP (toe/$2015 million)	159	131	119	86	70	62	56	50	46
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	382	291	244	165	112	93	82	73	64
Energy-related CO_2 per primary energy consumption*2 (t/toe)	2.4	2.2	2.1	1.9	1.6	1.5	1.5	1.5	1.4

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

	Reference Scenario								Advanced Technologies Scenario									
	CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
	1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
	-2.6	-9.2	-1.4	-3.7	27	13	6.5	5.7	63	56	53	51	51	-11.5	-1.1	-4.2	5.4	5.4
	-0.6	-1.8	-1.4	-1.5	37	33	32	28	332	262	205	151	110	-3.4	-5.4	-4.8	29	12
	0.5	-3.4	-1.6	-2.1	17	23	19	16	201	159	122	92	60	-4.7	-5.9	-5.5	17	6.4
	-0.6	1.4	-0.9	-0.2	13	12	15	15	200	224	230	223	237	2.9	0.9	1.4	17	25
	-0.1	0.1	0.3	0.2	1.7	1.8	2.0	2.5	24	24	25	25	25	0.1	0.3	0.2	2.1	2.7
	2.4	1.4	0.2	0.6	0.2	0.5	0.6	0.8	7.5	8.1	8.2	8.2	8.3	1.4	0.5	0.7	0.7	0.9
	17.8	10.5	1.7	4.2	0.0	4.5	11	18	146	171	197	231	263	12.1	3.0	5.5	13	28
	3.9	1.1	-0.7	-0.2	3.3	12	15	15	188	180	168	157	149	2.1	-1.2	-0.2	16	16
	n.a.	n.a.	n.a.	n.a.	-	-	-	-0.0	2.0	9.3	15	29	39	n.a.	16.1	n.a.	0.2	4.2

	Reference Scenario								Advanced Technologies Scenario									
					Shares (%)				(Mtoe)								Shares (%)	
	1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
	-4.5	-0.9	-2.1	-1.7	11	2.6	2.6	2.0	19	15	12	9.8	8.3	-3.0	-4.2	-3.8	2.2	1.4
	-0.3	-1.6	-1.4	-1.5	45	41	39	34	311	252	203	164	134	-3.0	-4.1	-3.8	36	23
	0.2	-0.9	-1.0	-1.0	19	20	20	19	170	145	117	90	64	-1.7	-4.8	-3.9	20	11
	0.8	0.3	0.6	0.5	16	21	23	31	220	231	241	251	257	0.8	0.8	0.8	26	43
	-0.8	-0.7	-0.9	-0.8	5.5	4.3	4.4	4.3	39	38	37	36	35	-0.8	-0.6	-0.7	4.6	5.9
	n.a.	n.a.	-2.0	n.a.	-	-	0.0	0.0	0.1	3.7	9.0	17	32	n.a.	36.3	n.a.	0.0	5.4
	2.9	-0.4	-1.5	-1.2	4.0	10	11	9.3	103	94	81	70	61	0.4	-2.6	-1.7	12	10
	-1.0	0.0	-0.4	-0.3	31	24	25	27	218	203	186	172	162	-0.6	-1.5	-1.2	25	27
	0.8	-1.5	-1.5	-1.5	22	29	27	24	228	187	153	128	114	-2.6	-3.4	-3.2	26	19
	0.0	-1.0	-0.8	-0.8	38	39	39	39	341	312	285	262	242	-1.3	-1.7	-1.6	40	41
	-0.4	-0.3	-0.1	-0.2	8.9	8.1	8.4	9.7	76	76	75	75	74	-0.3	-0.2	-0.2	8.8	12

	Reference Scenario								Advanced Technologies Scenario									
					Shares (%)				(TWh)								Shares (%)	
	1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
	-1.7	-17.3	-2.5	-7.0	37	17	3.4	1.8	48	30	39	60	52	-25.0	0.3	-7.7	1.5	1.2
	-3.7	-100	n.a.	-100	8.4	2.0	-	-	-	-	-	-	-	-100	n.a.	-100	-	-
	3.4	-10.6	-5.1	-6.7	8.3	19	7.2	2.2	160	76	28	40	1.1	-14.1	-21.9	-19.7	4.8	0.0
	-0.6	1.4	-0.9	-0.2	32	22	22	16	766	860	885	855	910	2.9	0.9	1.4	23	20
	-0.1	0.1	0.3	0.2	13	9.9	9.1	8.4	279	283	286	290	294	0.1	0.3	0.2	8.4	6.6
	2.2	4.0	2.3	2.8	0.1	0.2	0.3	0.4	8.8	14	15	15	15	4.0	2.6	3.0	0.3	0.3
	34.7	16.6	2.1	6.1	0.0	7.4	23	31	849	1 044	1 239	1 300	1 361	19.4	2.4	7.0	26	30
	21.8	8.4	1.6	3.5	0.0	15	26	32	895	1 054	1 213	1 333	1 454	9.9	2.5	4.5	27	32
	7.5	2.3	0.2	0.8	0.0	0.2	0.2	0.2	6.2	6.4	6.5	6.7	6.9	2.6	0.5	1.1	0.2	0.2
	7.4	4.0	0.5	1.5	0.8	6.7	8.3	8.1	287	297	306	312	318	5.6	0.5	1.9	8.7	7.1
	n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	4.7	9.3	37	64	n.a.	n.a.	n.a.	-	1.4
	10.1	0.0	0.0	0.0	0.0	0.2	0.2	0.1	4.6	4.6	4.6	4.6	4.6	0.0	0.0	0.0	0.1	0.1

	n.a.	n.a.	n.a.	n.a.	-	-	65	159	259	n.a.	n.a.	n.a.

	Reference Scenario				Advanced Technologies Scenario							
	1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
	1.6	1.4	1.3	1.4	17 029	18 314	19 624	20 940	22 204	1.4	1.3	1.4
	0.2	-0.1	-0.2	-0.2	445	442	438	433	426	-0.1	-0.2	-0.2
	1.4	1.5	1.6	1.5	38	41	45	48	52	1.5	1.6	1.5
	-0.5	-1.1	-0.6	-0.7	2.6	2.5	2.3	2.2	2.2	-1.4	-0.9	-1.0
	-1.9	-2.5	-2.1	-2.2	68	59	52	46	42	-2.9	-2.4	-2.5
	-2.6	-4.7	-2.8	-3.3	98	72	50	28	11	-6.4	-10.2	-9.1
	-0.7	-2.2	-0.7	-1.1	1.4	1.2	1.0	0.6	0.3	-3.6	-8.0	-6.8

Table A43 | Africa

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	352	435	608	796	885	956	1 025	1 101	1 183
Coal	74	90	109	105	100	105	111	122	130
Oil	85	100	161	211	234	254	280	307	333
Natural gas	30	47	89	142	180	214	255	308	375
Nuclear	2.2	3.4	3.2	2.6	5.6	7.8	10.0	8.8	8.8
Hydro	4.8	6.4	9.4	14	17	20	25	30	36
Geothermal	0.3	0.4	0.9	4.7	14	22	27	32	37
Solar, wind, etc.	0.0	0.0	0.3	4.3	17	23	29	35	41
Biomass and waste	156	186	235	313	318	309	289	258	222
Hydrogen	-	-	-	-	-0.1	-0.1	-0.1	-0.1	-0.1

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	246	305	418	544	604	646	684	718	754
Coal	20	19	18	20	20	21	22	22	23
Oil	70	89	136	182	207	232	257	283	307
Natural gas	8.6	14	28	43	54	60	67	73	79
Electricity	22	31	47	63	83	102	128	160	202
Heat	-	-	-	-	-	-	0.0	0.0	0.0
Hydrogen	-	-	-	-	-	-	-	0.0	0.0
Renewables and waste	125	152	190	236	240	231	211	180	144
Industry	53	58	84	91	108	122	137	151	165
Transport	38	54	87	129	146	162	180	198	217
Buildings, etc.	144	178	228	300	324	332	334	333	333
Non-energy use	11	15	19	24	27	30	33	36	40

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	315	442	687	901	1 196	1 464	1 811	2 251	2 797
Coal	164	208	259	236	225	241	264	306	341
Oil	40	37	65	65	50	33	26	22	17
Natural gas	45	107	235	377	494	633	829	1 101	1 468
Nuclear	8.4	13	12	9.8	21	30	38	34	34
Hydro	56	75	110	161	197	236	285	345	419
Geothermal	0.3	0.4	1.1	5.5	16	25	31	37	44
Solar photovoltaics	-	0.0	0.3	15	120	176	232	285	337
Wind	-	0.2	2.4	25	64	80	97	112	128
Concentrated solar power and marine	-	-	-	2.3	2.6	2.6	2.6	2.6	2.6
Biomass and waste	0.5	1.5	2.4	2.5	4.0	4.4	4.9	5.3	5.8
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	0.1	0.6	1.6	1.6	1.6	1.6	1.6	1.6

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	571	689	1 017	1 262	1 391	1 543	1 728	1 962	2 214
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	925	1 216	2 010	2 762	3 731	4 680	5 838	7 220	8 832
Population (million)	620	794	1 021	1 377	1 643	1 816	1 993	2 170	2 344
GDP per capita ($2015 thousand)	1.5	1.5	2.0	2.0	2.3	2.6	2.9	3.3	3.8
Primary energy consumption per capita (toe/person)	0.6	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.5
Primary energy consumption per GDP (toe/$2015 million)	380	358	302	288	237	204	176	153	134
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	617	566	506	457	373	330	296	272	251
Energy-related CO_2 per primary energy consumption*2 (t/toe)	1.6	1.6	1.7	1.6	1.6	1.6	1.7	1.8	1.9

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
1.1	-0.6	1.3	0.8	21	13	11	11	87	78	71	67	61	-2.3	-1.8	-1.9	11	6.4
2.9	1.3	1.8	1.6	24	26	26	28	223	230	236	233	228	0.7	0.1	0.3	27	24
5.0	3.0	3.8	3.5	8.4	18	20	32	177	209	237	269	303	2.8	2.7	2.7	21	32
0.5	10.2	2.3	4.5	0.6	0.3	0.6	0.7	5.6	14	22	32	45	10.2	11.0	10.8	0.7	4.7
3.4	2.5	3.8	3.5	1.4	1.7	1.9	3.0	17	20	25	30	36	2.5	3.8	3.5	2.1	3.8
9.2	14.5	5.0	7.7	0.1	0.6	1.6	3.2	14	26	31	37	44	14.5	5.8	8.2	1.7	4.6
29.9	18.7	4.6	8.4	0.0	0.5	1.9	3.5	28	44	65	94	130	26.2	8.1	13.0	3.3	14
2.2	0.2	-1.8	-1.2	44	39	36	19	274	225	187	162	140	-1.6	-3.3	-2.8	33	15
n.a.	n.a.	4.1	n.a.	-	-	-0.0	-0.0	-1.0	-6.2	-12	-24	-37	n.a.	20.0	n.a.	-0.1	-3.9

Reference Scenario								Advanced Technologies Scenario									
				Shares (%)				(Mtoe)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
0.0	0.1	0.6	0.4	8.1	3.7	3.3	3.0	19	18	17	16	15	-0.9	-1.0	-1.0	3.3	2.7
3.0	1.6	2.0	1.9	29	34	34	41	202	217	225	227	225	1.3	0.5	0.7	36	40
5.2	2.8	1.9	2.2	3.5	8.0	8.9	10	51	54	55	56	56	2.2	0.4	0.9	9.3	9.9
3.3	3.6	4.5	4.3	9.0	12	14	27	86	108	133	163	197	4.1	4.2	4.2	16	35
n.a.	n.a.	n.a.	n.a.	-	-	-	0.0	-	0.0	0.0	0.0	0.0	n.a.	n.a.	n.a.	-	0.0
n.a.	n.a.	n.a.	n.a.	-	-	-	0.0	0.0	0.3	1.0	2.1	5.9	n.a.	46.1	n.a.	0.0	1.1
2.0	0.2	-2.5	-1.7	51	43	40	19	196	147	109	84	62	-2.2	-5.6	-4.7	35	11
1.7	2.1	2.2	2.1	22	17	18	22	102	108	112	115	121	1.4	0.8	1.0	18	22
3.9	1.6	2.0	1.9	16	24	24	29	142	151	158	162	167	1.2	0.8	0.9	26	30
2.3	0.9	0.1	0.4	58	55	54	44	284	255	238	233	234	-0.7	-1.0	-0.9	51	42
2.5	1.6	1.9	1.8	4.4	4.4	4.5	5.2	27	30	33	36	40	1.6	1.9	1.8	4.9	7.1

Reference Scenario								Advanced Technologies Scenario									
				Shares (%)				(TWh)								Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
1.1	-0.6	2.1	1.3	52	26	19	12	189	165	148	139	126	-2.8	-2.0	-2.2	15	3.5
1.5	-3.3	-5.4	-4.8	13	7.2	4.2	0.6	36	17	10	2.7	2.5	-7.1	-12.4	-10.9	2.9	0.1
6.9	3.5	5.6	5.0	14	42	41	52	483	633	806	1 042	1 323	3.2	5.2	4.6	38	37
0.5	10.2	2.3	4.5	2.7	1.1	1.8	1.2	21	55	84	121	171	10.2	11.0	10.8	1.7	4.8
3.4	2.5	3.8	3.5	18	18	16	15	197	236	285	345	419	2.5	3.8	3.5	16	12
9.2	14.5	5.0	7.7	0.1	0.6	1.4	1.6	16	30	36	43	51	14.5	5.8	8.2	1.3	1.4
n.a.	29.7	5.3	11.8	-	1.7	10	12	192	328	495	717	1 000	37.6	8.6	16.2	15	28
n.a.	12.8	3.5	6.1	-	2.7	5.4	4.6	115	173	246	351	491	21.4	7.5	11.3	9.2	14
n.a.	1.3	0.0	0.4	-	0.3	0.2	0.1	2.6	3.0	3.5	4.5	5.7	1.7	3.9	3.3	0.2	0.2
5.3	6.0	1.9	3.1	0.2	0.3	0.3	0.2	4.3	5.0	5.7	6.4	7.0	7.1	2.4	3.7	0.3	0.2
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	0.0	0.0	0.0	-	0.2	0.1	0.1	1.6	1.6	1.6	1.6	1.6	0.0	0.0	0.0	0.1	0.0

n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
3.5	3.8	4.4	4.2	3 731	4 680	5 838	7 220	8 832	3.8	4.4	4.2
2.5	2.2	1.8	1.9	1 643	1 816	1 993	2 170	2 344	2.2	1.8	1.9
0.9	1.6	2.6	2.3	2.3	2.6	2.9	3.3	3.8	1.6	2.6	2.3
0.1	-0.9	-0.3	-0.5	0.5	0.5	0.4	0.4	0.4	-1.8	-1.1	-1.3
-0.9	-2.4	-2.8	-2.7	221	180	148	124	107	-3.3	-3.5	-3.5
-0.9	-2.5	-2.0	-2.1	346	280	227	184	150	-3.4	-4.1	-3.9
-0.1	-0.1	0.9	0.6	1.6	1.6	1.5	1.5	1.4	-0.1	-0.6	-0.5

Table A44 | Middle East

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	223	380	648	860	990	1 049	1 101	1 153	1 199
Coal	3.0	8.1	9.8	7.2	8.4	7.7	7.0	6.5	6.8
Oil	146	225	323	359	388	402	412	417	417
Natural gas	72	145	311	480	565	607	646	689	733
Nuclear	-	-	-	7.5	13	13	13	13	13
Hydro	1.0	0.7	1.5	1.4	2.4	2.5	2.6	2.7	2.8
Geothermal	-	-	-	-	-	-	-	-	0.0
Solar, wind, etc.	0.4	0.7	1.3	3.2	12	16	19	22	25
Biomass and waste	0.5	0.4	1.0	1.2	1.6	1.6	1.7	1.7	1.8
Hydrogen	-	-	-	-	-0.1	-0.1	-0.1	-0.1	-0.1

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	157	259	450	585	687	732	770	804	836
Coal	0.2	0.5	1.2	2.5	2.7	2.6	2.5	2.3	2.2
Oil	108	160	238	264	304	323	338	352	363
Natural gas	31	65	147	220	259	270	276	279	279
Electricity	17	32	62	96	119	134	151	169	189
Heat	-	-	-	-	-	-	-	-	0.0
Hydrogen	-	-	-	-	0.0	0.0	0.0	0.0	0.0
Renewables and waste	0.7	1.0	2.2	1.7	1.8	1.8	1.9	1.9	2.0
Industry	47	71	134	172	210	223	232	238	242
Transport	51	75	121	150	171	178	186	192	198
Buildings, etc.	40	74	119	165	191	205	216	226	236
Non-energy use	20	39	75	98	115	125	136	148	160

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	244	472	888	1 418	1 714	1 910	2 124	2 366	2 622
Coal	11	30	35	18	22	19	16	15	17
Oil	108	189	290	345	305	282	250	208	153
Natural gas	114	246	545	982	1 175	1 356	1 562	1 816	2 092
Nuclear	-	-	-	29	51	51	52	51	51
Hydro	12	8.0	18	17	28	29	31	32	33
Geothermal	-	-	-	-	-	-	-	-	-
Solar photovoltaics	-	-	0.1	22	119	155	191	217	243
Wind	0.0	0.0	0.2	4.5	9.4	13	18	23	28
Concentrated solar power and marine	-	-	-	1.1	2.4	2.4	2.4	2.4	2.4
Biomass and waste	-	0.0	0.1	0.0	1.4	1.5	1.7	1.8	2.0
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	-	0.0	0.2	0.2	0.2	0.2	0.2	0.2

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	588	967	1 605	1 997	2 247	2 356	2 442	2 526	2 593
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	916	1 385	2 076	2 844	3 617	4 139	4 718	5 357	6 057
Population (million)	133	171	220	274	316	338	359	379	398
GDP per capita ($2015 thousand)	6.9	8.1	9.4	10	11	12	13	14	15
Primary energy consumption per capita (toe/person)	1.7	2.2	2.9	3.1	3.1	3.1	3.1	3.0	3.0
Primary energy consumption per GDP (toe/$2015 million)	243	274	312	302	274	254	233	215	198
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	642	698	773	702	621	569	518	471	428
Energy-related CO_2 per primary energy consumption*2 (t/toe)	2.6	2.5	2.5	2.3	2.3	2.2	2.2	2.2	2.2

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario									
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
2.8	1.8	-1.0	-0.2	1.3	0.8	0.8	0.6	7.1	5.9	5.0	5.2	5.3	-0.2	-1.5	-1.1	0.7	0.5
2.8	1.0	0.4	0.5	66	42	39	35	357	338	312	280	258	-0.1	-1.6	-1.2	37	24
6.1	2.0	1.3	1.5	32	56	57	61	560	599	615	640	650	1.9	0.8	1.1	58	62
n.a.	7.6	0.0	2.1	-	0.9	1.4	1.1	19	28	41	49	51	12.3	5.1	7.1	2.0	4.9
1.1	6.8	0.7	2.4	0.5	0.2	0.2	0.2	2.4	2.5	2.6	2.7	2.8	6.7	0.7	2.4	0.3	0.3
n.a.	n.a.	n.a.	n.a.	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
6.6	18.1	3.5	7.5	0.2	0.4	1.2	2.1	17	30	47	74	107	23.3	9.5	13.3	1.8	10
3.0	3.7	0.8	1.6	0.2	0.1	0.2	0.2	1.6	1.7	1.9	2.3	2.9	4.0	3.0	3.3	0.2	0.3
n.a.	n.a.	-3.9	n.a.	-	-	-0.0	-0.0	-3.3	-15	-20	-26	-24	n.a.	10.3	n.a.	-0.3	-2.3

Reference Scenario								Advanced Technologies Scenario									
1990/	2022/	2030/	2022/	Shares (%)				(Mtoe)					2022/	2030/	2022/	Shares (%)	
2022	2030	2050	2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2030	2050	2050	2030	2050
8.4	1.3	-1.0	-0.4	0.1	0.4	0.4	0.3	2.5	2.2	2.0	1.8	1.7	0.2	-1.8	-1.3	0.4	0.3
2.8	1.8	0.9	1.1	69	45	44	43	296	299	292	279	265	1.4	-0.5	0.0	44	40
6.3	2.0	0.4	0.9	20	38	38	33	243	231	210	187	166	1.2	-1.9	-1.0	36	25
5.5	2.7	2.3	2.4	11	16	17	23	123	141	161	184	209	3.1	2.7	2.8	18	31
n.a.	n.a.	n.a.	n.a.	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	3.5	n.a.	-	-	0.0	0.0	0.0	2.2	6.1	12	22	n.a.	59.3	n.a.	0.0	3.3
2.6	0.8	0.6	0.6	0.5	0.3	0.3	0.2	1.8	1.9	2.1	2.4	3.0	0.6	2.7	2.1	0.3	0.5
4.1	2.6	0.7	1.2	30	29	31	29	200	196	186	174	168	1.9	-0.9	-0.1	30	25
3.4	1.6	0.7	1.0	32	26	25	24	165	163	156	148	141	1.2	-0.8	-0.2	25	21
4.5	1.9	1.1	1.3	25	28	28	28	186	192	195	197	198	1.5	0.3	0.7	28	30
5.2	2.0	1.7	1.8	12	17	17	19	115	125	136	148	160	2.0	1.7	1.8	17	24

Reference Scenario								Advanced Technologies Scenario									
1990/	2022/	2030/	2022/	Shares (%)				(TWh)					2022/	2030/	2022/	Shares (%)	
2022	2030	2050	2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2030	2050	2050	2030	2050
1.6	2.6	-1.2	-0.1	4.3	1.2	1.3	0.7	17	13	9.8	12	13	-0.3	-1.6	-1.2	1.0	0.3
3.7	-1.5	-3.4	-2.9	44	24	18	5.8	237	163	107	57	50	-4.5	-7.5	-6.7	13	1.3
7.0	2.3	2.9	2.7	47	69	69	80	1 237	1 433	1 610	1 877	2 128	2.9	2.7	2.8	69	57
n.a.	7.6	0.0	2.1	-	2.0	3.0	2.0	72	107	157	187	197	12.3	5.1	7.1	4.1	5.2
1.1	6.8	0.7	2.4	4.9	1.2	1.6	1.2	28	29	30	32	33	6.7	0.7	2.4	1.6	0.9
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	23.8	3.6	9.0	-	1.5	6.9	9.3	168	295	457	700	984	29.2	9.2	14.6	9.4	26
30.1	9.6	5.6	6.7	0.0	0.3	0.5	1.1	18	38	63	127	207	18.6	13.1	14.6	1.0	5.5
n.a.	9.5	0.0	2.6	-	0.1	0.1	0.1	2.8	4.6	6.4	9.9	14	11.8	8.3	9.3	0.2	0.4
n.a.	66.8	1.8	17.2	-	0.0	0.1	0.1	1.6	1.8	2.1	2.2	2.3	70.0	1.9	18.0	0.1	0.1
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	23	47	92	137	n.a.	n.a.	n.a.	-	3.7
n.a.	0.0	0.0	0.0	-	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0

n.a.	n.a.	n.a.	n.a.	-	-	-	14	32	n.a.	n.a.	n.a.

Reference Scenario				Advanced Technologies Scenario							
1990/	2022/	2030/	2022/						2022/	2030/	2022/
2022	2030	2050	2050	2030	2035	2040	2045	2050	2030	2050	2050
3.6	3.1	2.6	2.7	3 617	4 139	4 718	5 357	6 057	3.1	2.6	2.7
2.3	1.8	1.2	1.3	316	338	359	379	398	1.8	1.2	1.3
1.3	1.2	1.4	1.4	11	12	13	14	15	1.2	1.4	1.4
2.0	0.0	-0.2	-0.1	3.0	2.9	2.8	2.7	2.6	-0.4	-0.7	-0.6
0.7	-1.2	-1.6	-1.5	266	239	213	192	174	-1.6	-2.1	-2.0
0.3	-1.5	-1.8	-1.8	582	484	390	306	242	-2.3	-4.3	-3.7
-0.4	-0.3	-0.2	-0.3	2.2	2.0	1.8	1.6	1.4	-0.7	-2.3	-1.8

Table A45 | Oceania

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	99	125	145	146	150	147	145	143	142
Coal	36	49	52	38	29	26	24	22	20
Oil	35	40	48	50	56	54	52	50	47
Natural gas	19	24	32	38	37	38	38	38	39
Nuclear	-	-	-	-	-	-	-	-	-
Hydro	3.2	3.5	3.3	3.7	4.1	4.1	4.1	4.2	4.2
Geothermal	1.5	2.0	3.3	4.9	5.0	5.0	5.0	5.0	5.0
Solar, wind, etc.	0.1	0.1	0.9	6.3	11	14	16	18	20
Biomass and waste	4.8	6.1	6.1	5.9	6.1	6.2	6.2	6.3	6.3
Hydrogen	-	-	-	-	-0.0	-0.1	-0.1	-0.1	-0.1

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	66	82	90	92	98	99	99	99	98
Coal	5.2	4.7	3.1	3.2	3.3	3.3	3.1	3.0	2.9
Oil	33	40	45	47	49	48	47	45	43
Natural gas	10	14	14	15	15	15	15	15	15
Electricity	14	18	22	22	25	27	29	30	32
Heat	-	-	-	-	-	-	-	-	-
Hydrogen	-	-	-	-	-	-	-	-	-
Renewables and waste	3.8	5.2	5.3	5.1	5.1	5.1	5.1	5.1	5.1
Industry	23	28	26	26	28	30	30	31	31
Transport	24	30	35	35	38	37	36	35	34
Buildings, etc.	15	19	23	25	26	26	27	27	28
Non-energy use	4.6	6.1	5.9	5.9	5.9	5.9	6.0	6.0	5.9

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	187	249	298	316	356	377	399	422	445
Coal	122	176	182	135	114	106	100	96	88
Oil	3.6	1.8	6.1	4.7	3.6	3.1	2.7	2.4	2.1
Natural gas	20	26	54	54	52	54	54	56	65
Nuclear	-	-	-	-	-	-	-	-	-
Hydro	37	41	38	43	47	48	48	48	49
Geothermal	2.1	2.9	5.9	8.5	8.7	8.7	8.7	8.7	8.7
Solar photovoltaics	-	0.0	0.4	35	60	76	92	107	122
Wind	-	0.2	6.7	32	65	77	88	97	106
Concentrated solar power and marine	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biomass and waste	1.6	2.0	3.5	3.9	4.6	4.9	5.1	5.2	5.4
Hydrogen	-	-	-	-	-	-	-	-	-
Others	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	285	356	416	383	370	352	335	321	309
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	656	907	1 220	1 650	1 943	2 160	2 391	2 639	2 901
Population (million)	20	23	26	31	33	35	36	37	38
GDP per capita ($2015 thousand)	32	40	46	53	58	62	67	72	76
Primary energy consumption per capita (toe/person)	4.9	5.5	5.5	4.7	4.5	4.3	4.1	3.9	3.7
Primary energy consumption per GDP (toe/$2015 million)	151	138	119	89	77	68	61	54	49
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	434	393	341	232	190	163	140	122	106
Energy-related CO_2 per primary energy consumption*2 (t/toe)	2.9	2.8	2.9	2.6	2.5	2.4	2.3	2.2	2.2

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario CAGR (%) 1990/2022	2022/2030	2030/2050	2022/2050	Shares (%) 1990	2022	2030	2050	Advanced Technologies Scenario (Mtoe) 2030	2035	2040	2045	2050	CAGR (%) 2022/2030	2030/2050	2022/2050	Shares (%) 2030	2050
0.2	-3.3	-1.8	-2.2	36	26	20	14	28	27	25	24	19	-3.7	-2.0	-2.5	19	14
1.1	1.6	-0.9	-0.2	35	34	38	33	52	44	36	27	21	0.6	-4.5	-3.1	36	15
2.2	-0.1	0.3	0.2	19	26	25	28	38	36	34	32	29	0.2	-1.3	-0.9	26	22
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
0.4	1.3	0.2	0.5	3.2	2.5	2.7	3.0	4.1	4.1	4.1	4.2	4.2	1.3	0.2	0.5	2.8	3.1
3.8	0.4	0.0	0.1	1.5	3.3	3.4	3.5	5.0	5.0	5.0	5.0	5.0	0.4	0.0	0.1	3.4	3.7
13.0	7.6	2.9	4.2	0.1	4.3	7.6	14	13	21	31	52	78	9.6	9.3	9.4	9.0	57
0.6	0.3	0.2	0.2	4.9	4.1	4.1	4.4	6.0	5.9	5.8	5.7	5.7	0.1	-0.3	-0.2	4.1	4.2
n.a.	n.a.	5.2	n.a.	-	-	-0.0	-0.1	-1.0	-5.2	-9.0	-17	-25	n.a.	17.4	n.a.	-0.7	-18

Reference Scenario 1990/2022	2022/2030	2030/2050	2022/2050	Shares (%) 1990	2022	2030	2050	Advanced Technologies Scenario (Mtoe) 2030	2035	2040	2045	2050	2022/2030	2030/2050	2022/2050	Shares (%) 2030	2050
-1.5	0.4	-0.7	-0.4	7.9	3.5	3.4	2.9	3.0	2.4	2.0	1.6	1.4	-0.9	-3.6	-2.8	3.2	1.8
1.1	0.6	-0.7	-0.3	50	51	50	43	46	41	35	28	23	-0.2	-3.4	-2.5	49	29
1.0	0.4	0.0	0.1	16	16	15	15	14	13	11	9.2	7.3	-0.4	-3.2	-2.4	15	9.3
1.6	1.6	1.3	1.3	21	24	26	33	26	27	29	34	39	1.7	2.1	2.0	27	49
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
n.a.	n.a.	n.a.	n.a.	-	-	-	-	0.0	0.3	0.8	1.6	3.6	n.a.	45.4	n.a.	0.0	4.5
0.9	0.0	0.0	0.0	5.8	5.5	5.2	5.2	5.1	4.9	4.7	4.5	4.5	-0.1	-0.6	-0.4	5.4	5.7
0.5	0.9	0.4	0.6	34	29	29	31	27	26	24	23	22	0.3	-1.0	-0.7	29	28
1.2	0.9	-0.5	-0.1	36	38	39	34	36	33	29	25	23	0.3	-2.2	-1.5	38	29
1.6	0.5	0.3	0.4	22	27	26	28	25	24	24	26	28	0.2	0.6	0.5	27	36
0.8	0.1	0.0	0.0	6.9	6.4	6.0	6.0	5.9	5.9	6.0	6.0	5.9	0.1	0.0	0.0	6.3	7.5

Reference Scenario 1990/2022	2022/2030	2030/2050	2022/2050	Shares (%) 1990	2022	2030	2050	Advanced Technologies Scenario (TWh) 2030	2035	2040	2045	2050	2022/2030	2030/2050	2022/2050	Shares (%) 2030	2050
0.3	-2.1	-1.3	-1.5	65	43	32	20	103	88	76	69	60	-3.4	-2.7	-2.9	28	5.4
0.9	-3.3	-2.7	-2.9	1.9	1.5	1.0	0.5	3.4	2.7	-	-	-	-3.9	-100	-100	0.9	-
3.1	-0.4	1.1	0.6	11	17	15	14	55	58	59	69	71	0.3	1.3	1.0	15	6.4
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	-	-
0.4	1.3	0.2	0.5	20	13	13	11	47	48	48	49	49	1.3	0.2	0.5	13	4.4
4.4	0.3	0.0	0.1	1.1	2.7	2.5	2.0	8.7	8.7	8.7	8.7	8.7	0.3	0.0	0.1	2.4	0.8
n.a.	7.1	3.6	4.6	-	11	17	27	70	111	166	275	406	9.0	9.2	9.2	19	37
n.a.	9.4	2.4	4.4	-	10	18	24	77	124	187	322	492	11.6	9.7	10.3	21	45
n.a.	4.3	0.0	1.2	-	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	34.3	11.9	17.9	0.0	0.0
2.9	2.1	0.7	1.1	0.9	1.2	1.3	1.2	4.6	4.9	5.2	5.5	5.7	2.1	1.0	1.3	1.3	0.5
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	2.7	5.3	7.7	10	n.a.	n.a.	n.a.	-	0.9
-1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

n.a.	n.a.	n.a.	n.a.	-	-	0.4	20	51	n.a.	n.a.	n.a.

Reference Scenario 1990/2022	2022/2030	2030/2050	2022/2050	Advanced Technologies Scenario 2030	2035	2040	2045	2050	2022/2030	2030/2050	2022/2050
2.9	2.1	2.0	2.0	1 943	2 160	2 391	2 639	2 901	2.1	2.0	2.0
1.3	0.9	0.7	0.7	33	35	36	37	38	0.9	0.7	0.7
1.6	1.2	1.4	1.3	58	62	67	72	76	1.2	1.4	1.3
-0.1	-0.6	-0.9	-0.8	4.4	4.0	3.7	3.6	3.6	-0.9	-1.0	-1.0
-1.7	-1.8	-2.2	-2.1	75	64	55	50	47	-2.0	-2.3	-2.3
-1.9	-2.5	-2.9	-2.7	178	124	83	42	10	-3.3	-13.4	-10.6
-0.3	-0.7	-0.6	-0.7	2.4	1.9	1.5	0.8	0.2	-1.3	-11.3	-8.5

Table A46 | Advanced Economies

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	4 467	5 233	5 354	5 062	4 792	4 663	4 542	4 442	4 381
Coal	1 087	1 115	1 109	711	435	361	302	271	250
Oil	1 827	2 070	1 918	1 756	1 608	1 525	1 441	1 348	1 253
Natural gas	827	1 136	1 287	1 498	1 419	1 377	1 377	1 380	1 390
Nuclear	463	596	606	469	493	489	453	422	413
Hydro	100	111	112	110	119	120	122	123	124
Geothermal	22	25	25	40	44	58	60	61	62
Solar, wind, etc.	2.1	6.1	31	154	327	393	451	511	569
Biomass and waste	139	172	261	323	356	354	350	347	344
Hydrogen	-	-	-	-	0.3	0.4	0.4	0.4	0.4

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	3 057	3 576	3 647	3 597	3 498	3 418	3 342	3 273	3 217
Coal	230	136	130	87	83	77	71	65	60
Oil	1 559	1 810	1 739	1 634	1 509	1 435	1 359	1 275	1 190
Natural gas	578	732	717	765	738	712	682	652	622
Electricity	553	715	809	832	886	921	967	1 027	1 100
Heat	48	52	66	58	56	55	53	50	48
Hydrogen	-	-	-	-	0.5	0.6	0.7	0.7	0.7
Renewables and waste	89	131	186	220	226	218	210	204	197
Industry	826	903	804	793	805	805	798	786	772
Transport	921	1 121	1 150	1 176	1 099	1 038	982	926	870
Buildings, etc.	1 024	1 185	1 311	1 253	1 215	1 191	1 174	1 170	1 182
Non-energy use	286	366	381	374	379	384	389	392	393

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	7 673	9 704	10 842	10 981	11 844	12 320	12 946	13 770	14 760
Coal	3 136	3 835	3 813	2 296	1 176	900	656	553	512
Oil	667	539	274	159	80	62	51	43	35
Natural gas	766	1 528	2 501	3 304	3 028	2 985	3 269	3 587	3 935
Nuclear	1 776	2 288	2 324	1 800	1 891	1 876	1 740	1 618	1 587
Hydro	1 158	1 293	1 302	1 281	1 381	1 400	1 417	1 432	1 444
Geothermal	23	27	37	54	60	80	83	85	86
Solar photovoltaics	0.1	0.7	31	593	1 792	2 266	2 708	3 134	3 548
Wind	3.8	29	269	1 065	1 882	2 163	2 400	2 668	2 935
Concentrated solar power and marine	1.2	1.1	2.1	8.7	12	13	14	15	17
Biomass and waste	121	142	257	389	510	543	577	603	629
Hydrogen	-	-	-	-	-	-	-	-	-
Others	20	22	33	31	31	31	31	31	31

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	10 835	12 238	12 003	10 532	8 817	8 165	7 680	7 286	6 946
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	27 187	35 856	42 352	52 512	60 366	65 672	71 165	76 755	82 292
Population (million)	998	1 070	1 140	1 199	1 214	1 217	1 218	1 215	1 209
GDP per capita ($2015 thousand)	27	33	37	44	50	54	58	63	68
Primary energy consumption per capita (toe/person)	4.5	4.9	4.7	4.2	3.9	3.8	3.7	3.7	3.6
Primary energy consumption per GDP (toe/$2015 million)	164	146	126	96	79	71	64	58	53
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	399	341	283	201	146	124	108	95	84
Energy-related CO_2 per primary energy consumption*2 (t/toe)	2.4	2.3	2.2	2.1	1.8	1.8	1.7	1.6	1.6

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario										
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
0.4	-0.7	-0.4	-0.5	100	100	100	100	4 625	4 339	4 042	3 822	3 663	-1.1	-1.2	-1.1	100	100
-1.3	-5.9	-2.7	-3.7	24	14	9.1	5.7	346	254	217	193	170	-8.6	-3.5	-5.0	7.5	4.6
-0.1	-1.1	-1.2	-1.2	41	35	34	29	1 454	1 204	955	712	531	-2.3	-4.9	-4.2	31	15
1.9	-0.7	-0.1	-0.3	19	30	30	32	1 336	1 210	1 039	895	713	-1.4	-3.1	-2.6	29	19
0.0	0.6	-0.9	-0.5	10	9.3	10	9.4	554	588	614	606	616	2.1	0.5	1.0	12	17
0.3	0.9	0.2	0.4	2.2	2.2	2.5	2.8	119	121	123	125	126	1.0	0.3	0.5	2.6	3.4
1.9	1.4	1.7	1.6	0.5	0.8	0.9	1.4	44	61	64	65	66	1.4	2.0	1.8	1.0	1.8
14.4	9.9	2.8	4.8	0.0	3.0	6.8	13	383	507	632	803	983	12.1	4.8	6.9	8.3	27
2.7	1.2	-0.2	0.2	3.1	6.4	7.4	7.9	397	395	391	385	387	2.6	-0.1	0.6	8.6	11
n.a.	n.a.	1.9	n.a.	-	-	0.0	0.0	4.3	19	35	69	103	n.a.	17.2	n.a.	0.1	2.8

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(Mtoe)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
0.5	-0.3	-0.4	-0.4	100	100	100	100	3 355	3 089	2 818	2 610	2 470	-0.9	-1.5	-1.3	100	100
-3.0	-0.6	-1.6	-1.3	7.5	2.4	2.4	1.9	71	57	47	39	34	-2.5	-3.6	-3.3	2.1	1.4
0.1	-1.0	-1.2	-1.1	51	45	43	37	1 380	1 170	956	770	624	-2.1	-3.9	-3.4	41	25
0.9	-0.5	-0.8	-0.7	19	21	21	19	691	596	491	387	289	-1.3	-4.3	-3.4	21	12
1.3	0.8	1.1	1.0	18	23	25	34	903	953	1 007	1 074	1 122	1.0	1.1	1.1	27	45
0.6	-0.6	-0.8	-0.7	1.6	1.6	1.6	1.5	55	54	52	50	49	-0.8	-0.6	-0.6	1.6	2.0
n.a.	n.a.	1.7	n.a.	-	-	0.0	0.0	0.7	15	35	68	134	n.a.	29.6	n.a.	0.0	5.4
2.9	0.3	-0.7	-0.4	2.9	6.1	6.5	6.1	254	244	230	221	217	1.8	-0.8	0.0	7.6	8.8
-0.1	0.2	-0.2	-0.1	27	22	23	24	767	719	662	612	578	-0.4	-1.4	-1.1	23	23
0.8	-0.9	-1.2	-1.1	30	33	31	27	1 031	880	738	624	558	-1.6	-3.0	-2.6	31	23
0.6	-0.4	-0.1	-0.2	34	35	35	37	1 178	1 106	1 030	982	941	-0.8	-1.1	-1.0	35	38
0.8	0.2	0.2	0.2	9.4	10	11	12	379	384	389	392	393	0.2	0.2	0.2	11	16

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(TWh)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
1.1	1.0	1.1	1.1	100	100	100	100	12 142	13 235	14 405	16 172	17 820	1.3	1.9	1.7	100	100
-1.0	-8.0	-4.1	-5.2	41	21	9.9	3.5	809	436	330	270	184	-12.2	-7.1	-8.6	6.7	1.0
-4.4	-8.3	-4.1	-5.3	8.7	1.5	0.7	0.2	67	46	31	21	8.3	-10.2	-9.9	-10.0	0.6	0.0
4.7	-1.1	1.3	0.6	10.0	30	26	27	2 775	2 478	2 019	1 746	1 180	-2.2	-4.2	-3.6	23	6.6
0.0	0.6	-0.9	-0.5	23	16	16	11	2 126	2 258	2 358	2 326	2 364	2.1	0.5	1.0	18	13
0.3	0.9	0.2	0.4	15	12	12	9.8	1 387	1 411	1 431	1 448	1 464	1.0	0.3	0.5	11	8.2
2.6	1.4	1.8	1.7	0.3	0.5	0.5	0.6	60	85	88	90	92	1.4	2.1	1.9	0.5	0.5
31.8	14.8	3.5	6.6	0.0	5.4	15	24	2 035	2 743	3 471	4 438	5 456	16.7	5.1	8.3	17	31
19.2	7.4	2.2	3.7	0.1	9.7	16	20	2 285	3 014	3 745	4 747	5 818	10.0	4.8	6.3	19	33
6.4	4.3	1.7	2.4	0.0	0.1	0.1	0.1	13	14	16	21	26	4.8	3.7	4.0	0.1	0.1
3.7	3.4	1.1	1.7	1.6	3.5	4.3	4.3	554	607	663	694	741	4.5	1.5	2.3	4.6	4.2
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	110	221	339	457	n.a.	n.a.	n.a.	-	2.6
1.4	0.0	0.0	0.0	0.3	0.3	0.3	0.2	31	31	31	31	31	0.0	0.0	0.0	0.3	0.2

n.a.	n.a.	n.a.	n.a.					-	-	98	363	683	n.a.	n.a.	n.a.		

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
2.1	1.8	1.6	1.6	60 366	65 672	71 165	76 755	82 292	1.8	1.6	1.6
0.6	0.2	0.0	0.0	1 214	1 217	1 218	1 215	1 209	0.2	0.0	0.0
1.5	1.6	1.6	1.6	50	54	58	63	68	1.6	1.6	1.6
-0.2	-0.8	-0.4	-0.5	3.8	3.6	3.3	3.1	3.0	-1.3	-1.1	-1.2
-1.7	-2.4	-2.0	-2.1	77	66	57	50	45	-2.8	-2.7	-2.7
-2.1	-3.9	-2.7	-3.0	128	91	61	33	13	-5.4	-10.7	-9.2
-0.5	-1.5	-0.7	-1.0	1.7	1.4	1.1	0.7	0.3	-2.7	-8.2	-6.7

Table A47 | Group of Seven

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	3 490	4 024	3 945	3 640	3 455	3 350	3 254	3 184	3 154
Coal	787	811	776	431	235	185	137	117	108
Oil	1 447	1 578	1 413	1 263	1 140	1 076	1 011	939	865
Natural gas	704	941	992	1 193	1 154	1 125	1 124	1 128	1 142
Nuclear	370	485	482	345	386	371	342	313	308
Hydro	66	72	72	71	79	80	81	81	82
Geothermal	19	21	16	18	21	24	25	26	27
Solar, wind, etc.	1.6	4.1	20	104	223	274	322	371	421
Biomass and waste	95	114	174	213	234	233	231	230	229
Hydrogen	-	-	-	-	0.3	0.4	0.4	0.5	0.5

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	2 377	2 735	2 674	2 613	2 524	2 463	2 408	2 360	2 325
Coal	146	76	68	44	41	39	36	33	31
Oil	1 237	1 393	1 292	1 193	1 086	1 030	972	906	840
Natural gas	495	613	568	611	588	564	538	512	488
Electricity	435	548	594	594	632	660	699	749	813
Heat	13	19	26	22	22	21	20	19	18
Hydrogen	-	-	-	-	0.4	0.6	0.6	0.6	0.6
Renewables and waste	51	85	126	149	155	149	143	140	135
Industry	602	645	544	529	526	525	520	512	503
Transport	768	915	909	912	848	803	761	717	674
Buildings, etc.	783	904	972	932	910	893	882	884	900
Non-energy use	224	270	248	240	240	243	245	247	248

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	6 041	7 437	7 989	7 782	8 515	8 890	9 405	10 098	10 966
Coal	2 506	2 963	2 844	1 478	673	463	268	194	168
Oil	553	373	189	115	67	52	43	38	30
Natural gas	647	1 236	1 845	2 565	2 458	2 477	2 715	2 993	3 310
Nuclear	1 419	1 862	1 849	1 324	1 483	1 422	1 311	1 202	1 181
Hydro	765	832	834	829	914	927	937	945	950
Geothermal	21	23	26	28	32	38	40	41	43
Solar photovoltaics	0.1	0.6	21	403	1 225	1 605	1 969	2 324	2 677
Wind	3.1	17	176	749	1 298	1 516	1 706	1 923	2 148
Concentrated solar power and marine	1.2	1.1	1.4	3.8	3.9	4.0	4.0	4.1	4.1
Biomass and waste	106	110	174	262	337	363	389	410	431
Hydrogen	-	-	-	-	-	-	-	-	-
Others	20	21	31	24	24	24	24	24	24

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions*2	8 423	9 386	8 825	7 619	6 391	5 933	5 547	5 263	5 039
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	21 466	27 920	31 963	38 661	44 147	47 999	52 051	56 218	60 402
Population (million)	652	699	740	775	787	792	795	796	796
GDP per capita ($2015 thousand)	33	40	43	50	56	61	66	71	76
Primary energy consumption per capita (toe/person)	5.4	5.8	5.3	4.7	4.4	4.2	4.1	4.0	4.0
Primary energy consumption per GDP (toe/$2015 million)	163	144	123	94	78	70	63	57	52
Energy-related CO_2 emissions per GDP*2 (t/$2015 million)	392	336	276	197	145	124	107	94	83
Energy-related CO_2 per primary energy consumption*2 (t/toe)	2.4	2.3	2.2	2.1	1.9	1.8	1.7	1.7	1.6

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.
*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario										
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
-1.9	-7.3	-3.8	-4.8	23	12	6.8	3.4	177	106	93	84	77	-10.6	-4.1	-6.0	5.3	3.0
-0.4	-1.3	-1.4	-1.3	41	35	33	27	1 024	839	646	462	326	-2.6	-5.6	-4.7	31	13
1.7	-0.4	-0.1	-0.2	20	33	33	36	1 101	996	853	737	580	-1.0	-3.2	-2.5	33	23
-0.2	1.4	-1.1	-0.4	11	9.5	11	9.8	407	419	426	404	417	2.1	0.1	0.7	12	16
0.3	1.2	0.2	0.5	1.9	2.0	2.3	2.6	79	81	82	83	83	1.3	0.3	0.6	2.4	3.3
-0.1	1.6	1.3	1.4	0.5	0.5	0.6	0.8	21	25	27	28	29	1.6	1.7	1.7	0.6	1.1
13.9	9.9	3.2	5.1	0.0	2.9	6.5	13	265	366	461	591	722	12.3	5.1	7.1	8.0	28
2.6	1.2	-0.1	0.3	2.7	5.8	6.8	7.3	267	265	267	267	272	2.9	0.1	0.9	8.0	11
n.a.	n.a.	2.6	n.a.	-	-	0.0	0.0	-1.1	0.7	9.8	31	57	n.a.	n.a.	n.a.	-0.0	2.2

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(Mtoe)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
-3.7	-0.9	-1.5	-1.3	6.1	1.7	1.6	1.3	35	29	24	21	19	-2.6	-3.2	-3.0	1.5	1.1
-0.1	-1.2	-1.3	-1.2	52	46	43	36	986	826	659	514	404	-2.4	-4.4	-3.8	41	23
0.7	-0.5	-0.9	-0.8	21	23	23	21	552	475	390	308	231	-1.3	-4.3	-3.4	23	13
1.0	0.8	1.3	1.1	18	23	25	35	645	684	727	781	820	1.0	1.2	1.2	27	47
1.8	-0.3	-0.8	-0.7	0.5	0.8	0.9	0.8	21	21	21	21	21	-0.5	-0.1	-0.2	0.9	1.2
n.a.	n.a.	1.9	n.a.	-	-	0.0	0.0	0.6	11	27	53	103	n.a.	29.1	n.a.	0.0	5.9
3.4	0.5	-0.7	-0.4	2.1	5.7	6.1	5.8	177	168	162	159	159	2.1	-0.5	0.2	7.3	9.0
-0.4	-0.1	-0.2	-0.2	25	20	21	22	501	467	427	394	370	-0.7	-1.5	-1.3	21	21
0.5	-0.9	-1.1	-1.1	32	35	34	29	793	676	566	477	427	-1.7	-3.1	-2.7	33	24
0.5	-0.3	-0.1	-0.1	33	36	36	39	883	829	772	738	711	-0.7	-1.1	-1.0	37	40
0.2	0.0	0.2	0.1	9.4	9.2	9.5	11	240	243	245	247	248	0.0	0.2	0.1	9.9	14

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)				(TWh)					2022/ 2030	2030/ 2050	2022/ 2050	Shares (%)	
				1990	2022	2030	2050	2030	2035	2040	2045	2050				2030	2050
-1.6	-9.4	-6.7	-7.5	41	19	7.9	1.5	430	138	112	107	68	-14.3	-8.8	-10.4	4.9	0.5
-4.8	-6.6	-3.9	-4.7	9.2	1.5	0.8	0.3	55	38	28	19	7.1	-8.8	-9.8	-9.5	0.6	0.1
4.4	-0.5	1.5	0.9	11	33	29	30	2 327	2 018	1 575	1 303	733	-1.2	-5.6	-4.4	27	5.8
-0.2	1.4	-1.1	-0.4	23	17	17	11	1 562	1 607	1 636	1 550	1 602	2.1	0.1	0.7	18	13
0.3	1.2	0.2	0.5	13	11	11	8.7	921	938	951	961	970	1.3	0.3	0.6	11	7.7
0.9	1.6	1.4	1.5	0.3	0.4	0.4	0.4	32	40	43	44	46	1.6	1.8	1.8	0.4	0.4
30.8	14.9	4.0	7.0	0.0	5.2	14	24	1 359	1 934	2 486	3 264	4 058	16.4	5.6	8.6	16	32
18.6	7.1	2.5	3.8	0.1	9.6	15	20	1 650	2 256	2 806	3 533	4 262	10.4	4.9	6.4	19	34
3.7	0.4	0.3	0.3	0.0	0.0	0.0	0.0	4.0	4.3	4.5	4.7	4.9	0.9	1.0	1.0	0.0	0.0
2.9	3.2	1.2	1.8	1.8	3.4	4.0	3.9	374	418	465	490	532	4.5	1.8	2.6	4.3	4.2
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	75	150	226	302	n.a.	n.a.	n.a.	-	2.4
0.6	0.0	0.0	0.0	0.3	0.3	0.3	0.2	24	24	24	24	24	0.0	0.0	0.0	0.3	0.2
n.a.	n.a.	n.a.	n.a.					-	-	77	297	560	n.a.	n.a.	n.a.		

Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
1.9	1.7	1.6	1.6	44 147	47 999	52 051	56 218	60 402	1.7	1.6	1.6
0.5	0.2	0.1	0.1	787	792	795	796	796	0.2	0.1	0.1
1.3	1.5	1.5	1.5	56	61	66	71	76	1.5	1.5	1.5
-0.4	-0.8	-0.5	-0.6	4.2	3.9	3.6	3.3	3.2	-1.3	-1.4	-1.4
-1.7	-2.3	-2.0	-2.1	75	64	55	47	42	-2.8	-2.9	-2.8
-2.1	-3.8	-2.7	-3.0	128	89	59	31	11	-5.3	-11.6	-9.8
-0.4	-1.5	-0.7	-1.0	1.7	1.4	1.1	0.7	0.3	-2.6	-9.0	-7.2

Table A48 | Emerging and Developing Economies

Primary energy consumption	Reference Scenario (Million tonnes of oil equivalent [Mtoe])								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
	4 029	4 427	7 016	9 434	10 271	10 740	11 133	11 529	11 900
Coal	1 133	1 201	2 543	3 395	3 172	3 069	2 923	2 822	2 706
Oil	1 208	1 337	1 872	2 369	2 563	2 668	2 797	2 921	3 022
Natural gas	835	933	1 449	1 939	2 220	2 402	2 603	2 827	3 069
Nuclear	62	79	113	231	344	395	428	457	488
Hydro	85	114	185	264	295	315	335	354	373
Geothermal	12	27	36	76	122	182	201	215	228
Solar, wind, etc.	0.5	2.1	17	185	514	657	799	902	1 005
Biomass and waste	694	734	803	978	1 032	1 039	1 031	1 010	984
Hydrogen	-	-	-	-	-0.2	-0.2	-0.2	-0.3	-0.3

Final energy consumption	Reference Scenario (Mtoe)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	2 918	3 067	4 710	6 116	6 898	7 221	7 541	7 838	8 123
Coal	521	404	928	803	830	800	777	757	739
Oil	844	1 041	1 519	2 018	2 243	2 355	2 488	2 616	2 727
Natural gas	367	388	629	925	1 069	1 116	1 158	1 190	1 214
Electricity	281	372	728	1 282	1 628	1 836	2 038	2 242	2 462
Heat	288	196	209	302	349	347	338	326	313
Hydrogen	-	-	-	-	0.2	0.2	0.2	0.2	0.2
Renewables and waste	616	665	696	787	778	767	741	708	668
Industry	970	959	1 833	2 271	2 630	2 754	2 852	2 909	2 948
Transport	455	569	918	1 263	1 471	1 549	1 643	1 747	1 849
Buildings, etc.	1 302	1 286	1 546	1 984	2 106	2 189	2 275	2 369	2 473
Non-energy use	191	252	413	598	691	730	771	813	853

Electricity generated	Reference Scenario (TWh)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Total	4 177	5 722	10 672	18 162	22 684	25 423	28 009	30 521	33 197
Coal	1 301	2 158	4 862	8 155	7 335	7 171	6 800	6 636	6 451
Oil	656	648	694	641	527	484	437	389	329
Natural gas	977	1 237	2 319	3 218	3 855	4 611	5 546	6 688	8 025
Nuclear	236	303	432	885	1 321	1 515	1 644	1 756	1 874
Hydro	985	1 326	2 154	3 069	3 428	3 668	3 895	4 116	4 337
Geothermal	13	25	31	43	76	118	133	144	156
Solar photovoltaics	0.0	0.1	1.4	702	3 318	4 320	5 317	5 941	6 560
Wind	0.0	2.8	73	1 055	2 233	2 885	3 524	4 092	4 660
Concentrated solar power and marine	0.0	0.0	0.0	5.8	7.4	7.4	7.4	7.5	7.6
Biomass and waste	8.5	21	105	371	566	627	687	733	780
Hydrogen	-	-	-	-	-	-	-	-	-
Others	-	0.5	1.1	17	17	17	17	17	17

Carbon dioxide [CO_2]	Reference Scenario ($MtCO_2$)								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Energy-related CO_2 emissions *2	9 117	10 062	17 480	22 453	22 560	22 800	22 971	23 356	23 660
Avoidance by carbon dioxide removal [CDR]	-	-	-	-	-	-	-	-	-

Energy and economic indicators	Reference Scenario								
	1990	2000	2010	2022	2030	2035	2040	2045	2050
Gross domestic product [GDP] ($2015 billion)	8 709	12 429	22 482	36 976	50 228	60 639	72 820	86 659	101 806
Population (million)	4 288	5 065	5 820	6 741	7 262	7 567	7 851	8 108	8 331
GDP per capita ($2015 thousand)	2.0	2.5	3.9	5.5	6.9	8.0	9.3	11	12
Primary energy consumption per capita (toe/person)	0.9	0.9	1.2	1.4	1.4	1.4	1.4	1.4	1.4
Primary energy consumption per GDP (toe/$2015 million)	463	356	312	255	204	177	153	133	117
Energy-related CO_2 emissions per GDP *2 (t/$2015 million)	1 047	810	777	607	449	376	315	270	232
Energy-related CO_2 per primary energy consumption *2 (t/toe)	2.3	2.3	2.5	2.4	2.2	2.1	2.1	2.0	2.0

*1 The total and breakdown do not necessarily match since international exports/imports of electricity and heat are not shown.

*2 After avoidance by carbon dioxide removal [CDR].

Reference Scenario								Advanced Technologies Scenario										
CAGR (%)				Shares (%)				(Mtoe)					CAGR (%)			Shares (%)	
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	1990	2022	2030	2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	2030	2050
2.7	1.1	0.7	0.8	100	100	100	100	9 863	9 803	9 642	9 582	9 675	0.6	-0.1	0.1	100	100
3.5	-0.8	-0.8	-0.8	28	36	31	23	2 870	2 445	2 018	1 718	1 487	-2.1	-3.2	-2.9	29	15
2.1	1.0	0.8	0.9	30	25	25	25	2 380	2 276	2 138	1 968	1 799	0.1	-1.4	-1.0	24	19
2.7	1.7	1.6	1.7	21	21	22	26	2 162	2 238	2 259	2 305	2 369	1.4	0.5	0.7	22	24
4.2	5.1	1.8	2.7	1.5	2.4	3.4	4.1	412	532	652	750	858	7.5	3.7	4.8	4.2	8.9
3.6	1.4	1.2	1.2	2.1	2.8	2.9	3.1	308	338	371	405	443	2.0	1.8	1.9	3.1	4.6
5.9	6.1	3.2	4.0	0.3	0.8	1.2	1.9	123	201	237	268	298	6.2	4.5	5.0	1.2	3.1
20.3	13.6	3.4	6.2	0.0	2.0	5.0	8.4	609	854	1 115	1 384	1 684	16.0	5.2	8.2	6.2	17
1.1	0.7	-0.2	0.0	17	10	10	8.3	991	926	876	847	838	0.2	-0.8	-0.5	10	8.7
n.a.	n.a.	2.5	n.a.	-	-	-0.0	-0.0	-4.3	-28	-53	-93	-133	n.a.	18.8	n.a.	-0.0	-1.4

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	(Mtoe) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
2.3	1.5	0.8	1.0	100	100	100	100	6 577	6 489	6 378	6 284	6 286	0.9	-0.2	0.1	100	100
1.4	0.4	-0.6	-0.3	18	13	12	9.1	757	661	582	526	487	-0.7	-2.2	-1.8	12	7.7
2.8	1.3	1.0	1.1	29	33	33	34	2 109	2 054	1 960	1 836	1 697	0.6	-1.1	-0.6	32	27
2.9	1.8	0.6	1.0	13	15	16	15	997	942	868	783	709	0.9	-1.7	-0.9	15	11
4.9	3.0	2.1	2.4	9.6	21	24	30	1 673	1 884	2 098	2 314	2 571	3.4	2.2	2.5	25	41
0.1	1.9	-0.6	0.1	9.9	4.9	5.1	3.9	322	307	288	271	255	0.8	-1.2	-0.6	4.9	4.1
n.a.	n.a.	2.1	n.a.	-	-	0.0	0.0	0.1	7.8	20	40	82	n.a.	43.3	n.a.	0.0	1.3
0.8	-0.1	-0.8	-0.6	21	13	11	8.2	719	633	562	514	485	-1.1	-1.9	-1.7	11	7.7
2.7	1.8	0.6	0.9	33	37	38	36	2 478	2 399	2 296	2 196	2 176	1.1	-0.6	-0.2	38	35
3.2	1.9	1.1	1.4	16	21	21	23	1 400	1 377	1 338	1 295	1 263	1.3	-0.5	0.0	21	20
1.3	0.7	0.8	0.8	45	32	31	30	2 008	1 985	1 974	1 981	1 995	0.2	0.0	0.0	31	32
3.6	1.8	1.1	1.3	6.5	9.8	10	10	691	729	771	812	852	1.8	1.1	1.3	11	14

Reference Scenario								Advanced Technologies Scenario										
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 1990	2022	2030	2050	(TWh) 2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050	Shares (%) 2030	2050
4.7	2.8	1.9	2.2	100	100	100	100	23 402	26 668	29 964	34 116	39 271	3.2	2.6	2.8	100	100
5.9	-1.3	-0.6	-0.8	31	45	32	19	6 488	5 247	3 893	2 973	2 340	-2.8	-5.0	-4.4	28	6.0
-0.1	-2.4	-2.3	-2.4	16	3.5	2.3	1.0	417	318	240	187	181	-5.2	-4.1	-4.4	1.8	0.5
3.8	2.3	3.7	3.3	23	18	17	24	3 965	4 732	5 431	6 423	7 618	2.6	3.3	3.1	17	19
4.2	5.1	1.8	2.7	5.7	4.9	5.8	5.6	1 583	2 044	2 504	2 878	3 293	7.5	3.7	4.8	6.8	8.4
3.6	1.4	1.2	1.2	24	17	15	13	3 586	3 936	4 310	4 714	5 155	2.0	1.8	1.9	15	13
3.8	7.2	3.7	4.7	0.3	0.2	0.3	0.5	76	136	162	184	207	7.3	5.1	5.8	0.3	0.5
47.2	21.4	3.5	8.3	0.0	3.9	15	20	3 982	5 708	7 550	9 256	11 180	24.2	5.3	10.4	17	28
37.9	9.8	3.7	5.4	0.0	5.8	9.8	14	2 645	3 748	4 933	6 322	7 877	12.2	5.6	7.4	11	20
23.4	2.9	0.1	0.9	0.0	0.0	0.0	0.0	8.0	11	13	18	24	4.1	5.7	5.2	0.0	0.1
12.5	5.4	1.6	2.7	0.2	2.0	2.5	2.3	633	707	781	854	927	6.9	1.9	3.3	2.7	2.4
n.a.	n.a.	n.a.	n.a.	-	-	-	-	-	66	131	291	450	n.a.	n.a.	n.a.	-	1.1
n.a.	0.0	0.0	0.0	-	0.1	0.1	0.1	17	17	17	17	17	0.0	0.0	0.0	0.1	0.0

n.a.	n.a.	n.a.	n.a.	-	-	62	146	242	n.a.	n.a.	n.a.

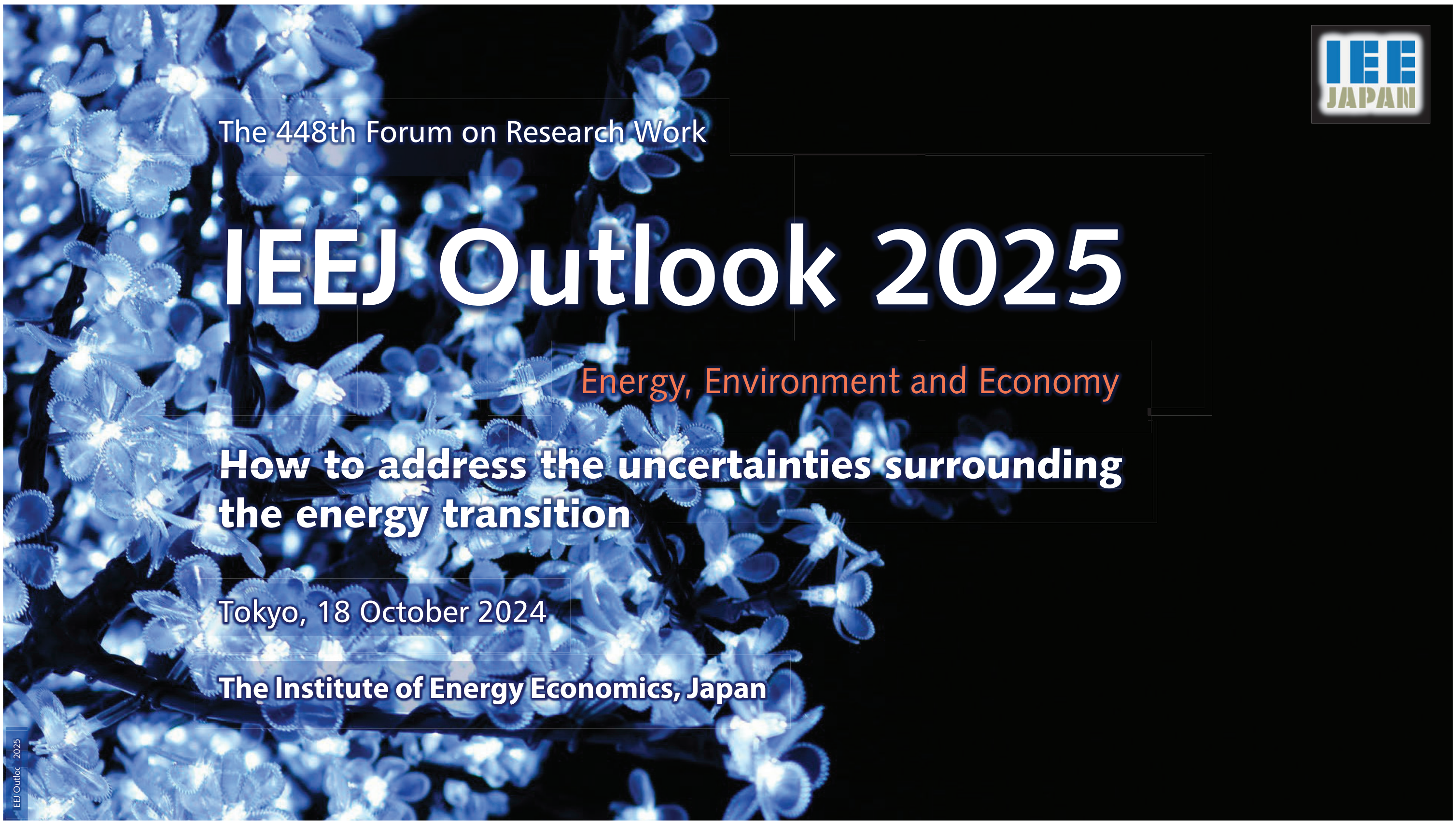
Reference Scenario				Advanced Technologies Scenario							
1990/ 2022	2022/ 2030	2030/ 2050	2022/ 2050	2030	2035	2040	2045	2050	2022/ 2030	2030/ 2050	2022/ 2050
4.6	3.9	3.6	3.7	50 228	60 639	72 820	86 659	101 806	3.9	3.6	3.7
1.4	0.9	0.7	0.8	7 262	7 567	7 851	8 108	8 331	0.9	0.7	0.8
3.2	2.9	2.9	2.9	6.9	8.0	9.3	11	12	2.9	2.9	2.9
1.3	0.1	0.0	0.1	1.4	1.3	1.2	1.2	1.2	-0.4	-0.8	-0.7
-1.8	-2.7	-2.8	-2.7	196	162	132	111	95	-3.2	-3.6	-3.5
-1.7	-3.7	-3.2	-3.4	407	288	203	144	104	-4.9	-6.6	-6.1
0.2	-1.0	-0.5	-0.6	2.1	1.8	1.5	1.3	1.1	-1.7	-3.2	-2.7

Table A49 | Conversion factors

To / From	Megajoule (MJ)	Kilowatt hour (kWh)	Kilocalorie (kcal)	Tonne of oil equivalent (toe)	British thermal unit (Btu)	Tonne of coal equivalent (tce)
MJ	1	2.77778×10^{-1}	2.38846×10^{2}	2.38846×10^{-5}	9.47817×10^{2}	3.41209×10^{-5}
kWh	3.60000	1	8.59845×10^{2}	8.59845×10^{-5}	3.41214×10^{3}	1.22835×10^{-4}
Kcal	4.18680×10^{-3}	1.16300×10^{-3}	1	1×10^{-7}	3.96832	1.42857×10^{-7}
Toe	4.18680×10^{4}	1.16300×10^{4}	1×10^{7}	1	3.96832×10^{7}	1.42857
Btu	1.05506×10^{-3}	2.93071×10^{-4}	2.51996×10^{-1}	2.51996×10^{-8}	1	3.59994×10^{-8}
Tce	2.93076×10^{4}	0.8141×10^{4}	0.7×10^{7}	0.7	2.77782×10^{7}	1

Crude oil is calculated as 1 million barrels per day (1 Mb/d) = 47.26 Mtoe, natural gas as 1 billion cubic metres (1 Bcm) = 0.8373 Mtoe, steam coal as 1 Mt = 0.5222 Mtoe, coking coal as 1 Mt = 0.6480 Mtoe, and liquid biofuels as 1 Mb/d = 35.34 Mtoe.

Slides



IEEJ Outlook 2025
Global Energy Supply and Demand Outlook to 2050

The Institute of Energy Economics, Japan

Seiya ENDO
Senior Economist, Energy Data and Modelling Center

Key Points

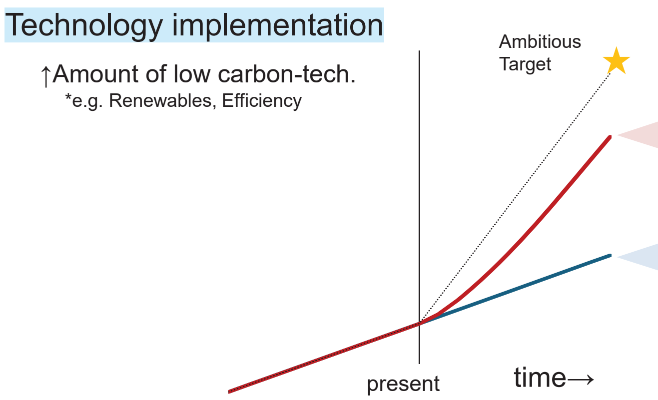
- ✓ Quantitative assessment of global energy supply and demand through 2050, using two scenarios:
  (**Reference**: Current Trends & **Adv.Tech.**: Maximum Climate Action)

- ✓ CO_2 reduction requires deployment of all available technologies across sectors.
  (1) energy efficiency, **(2) renewables** (especially solar and wind), and in the longer term, **(3) CCUS** will make particularly significant contributions. The outlook and implementation challenges for each are analyzed.

- ✓ Fossil fuel demand faces significant uncertainty. Stable supply remains essential over the coming decades.

Scenario Framework

- Created global energy supply and demand outlook through 2050.
  - Conducted model analysis incorporating the latest energy and socioeconomic data. Estimated energy demand by type and CO_2 emissions for 44 global regions plus international bunkers.
- Established two scenarios with different technology and policy progression assumptions.
  - Both are **forecast-type** scenarios examining "what if" scenarios, not **backcast-type** scenarios (which calculate backward from targets to determine "what should be done"). Target achievement is not necessarily incorporated.



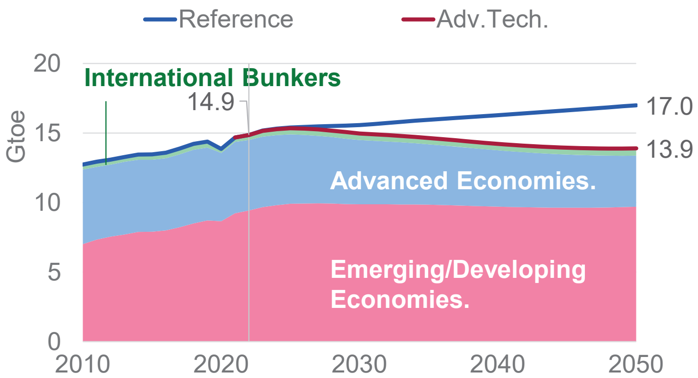
[Advanced Technologies] **(Adv.Tech.)**
Maximum implementation of policies for energy security and climate action, with technologies deployed to maximum extent.
(considering feasibility and acceptance)

[Reference]
Continuation of current trends in energy and environmental policies.
*Does not imply fixed current policies/technologies

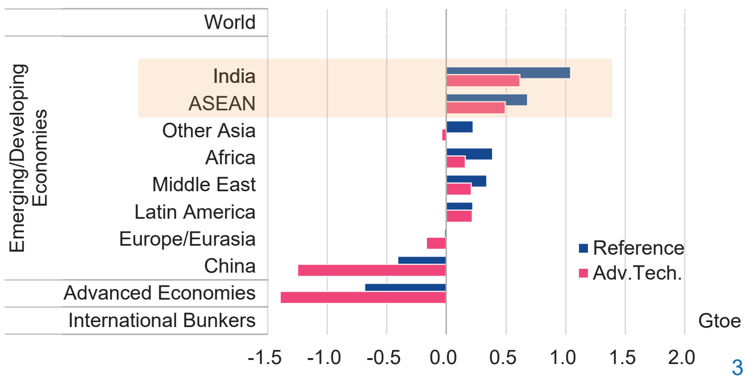
Primary Energy Demand: India and ASEAN at Center of Demand Growth

- **Reference:** Primary energy demand increases 14% from 2022 to 2050.
  - Real GDP doubles during this period. Efficiency improvements and industrial structure transformation suppress demand.
- **Adv.Tech:** Energy efficiency improvements accelerate, primary demand peaks before 2030.
- India and ASEAN drive demand growth in both scenarios, pushing up global demand.
  - Global emissions reduction requires engagement of these two regions plus other emerging/developing economies.

Primary Energy Demand (Global)

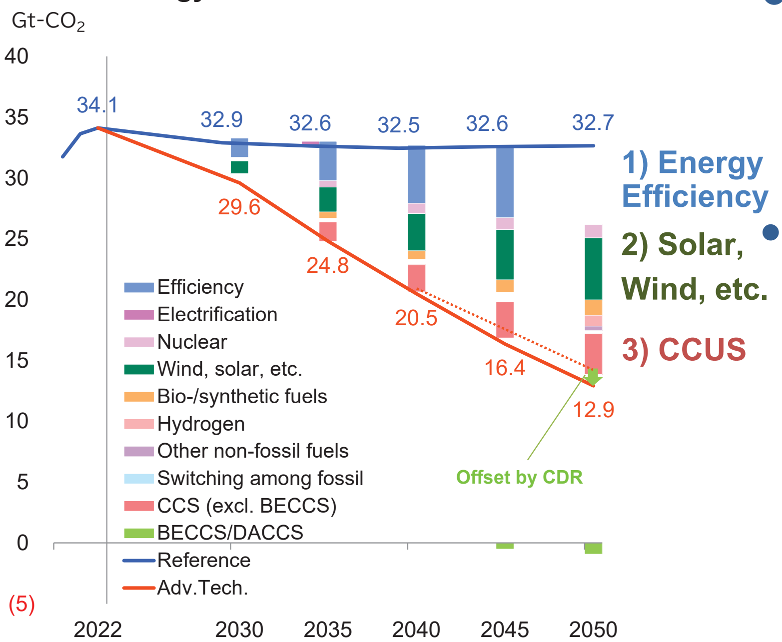


Primary Energy Demand Change(2022-2050)



CO2 Reduction: Energy Efficiency, Renewables and CCUS

Energy-Related CO2 Emission（World）



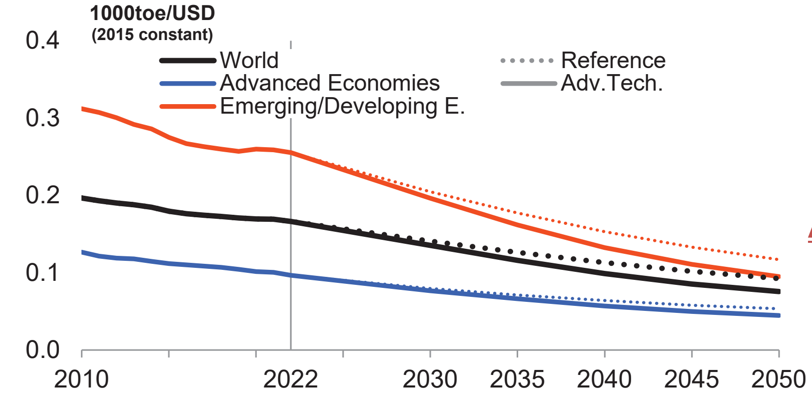
*Although not originally applicable to energy-related CO2, the offsetting effect is included for reference.

- **Reference**
  - While energy demand continues to grow, renewables expansion and electrification/natural gas switching in demand sectors suppress emissions.
- **Adv.Tech**
  - Major contributions to CO2 reduction primarily from (1) energy efficiency, (2) solar/wind, and (3) CCUS.
  - (1) and (2) contribute significantly from 2030, CCUS expands after 2040
  - Gap remains between the "2050 Net Zero" target, particularly challenging for emerging/developing nations and non-power sectors.

1)Energy Efficiency: Major Acceleration Post-2030, in Emerging Economies

Primary Energy Intensity:

※Primary demand/Real GDP[2015･MER]



Average annual improvement of primary energy intensity (world)

		2010-2022	2022-2030	2030-2040	2040-2050
TPES/GDP	Reference	-1.4% (history)	-2.0%	-2.2%	-2.0%
	Advanced		-2.5%	-3.1%	-2.7%

References

- **Primary energy intensity improves faster than recent history.**
  - Recent demand-side progress (e.g., hybrid vehicles) drives intensity improvement
  - *Efficiency improvements, renewable powers, and industrial structure shifts contribute to intensity improvement.

Adv.Tech.

- **Intensity halves from 2022 to 2050, with major acceleration 2030-2040.**
  - Time lag between policy implementation and equipment deployment means limited improvement rates until 2030.
- **Emerging economies show particularly significant improvement (-63% vs 2022)**
  - Cost-effective reductions possible, but requires regulatory framework and technology transfer from advanced economies.

1) Energy Efficiency: Different Priority Areas by Region/Economic Level

Sectors with particularly effective efficiency improvements vary by region.

- **Advanced economies show improvement in efficiency across sectors.**

  Transportation shows particularly large reductions due to next-generation vehicles (EVs, hybrids) with better efficiency.

- **Emerging economies (especially China, India, ASEAN) focus on industry.**

  Major industrial production in China and expected growth in India/ASEAN make industrial efficiency improvements effective.

- **Developing economies (Africa, Other Asia) show major reductions in residential.**

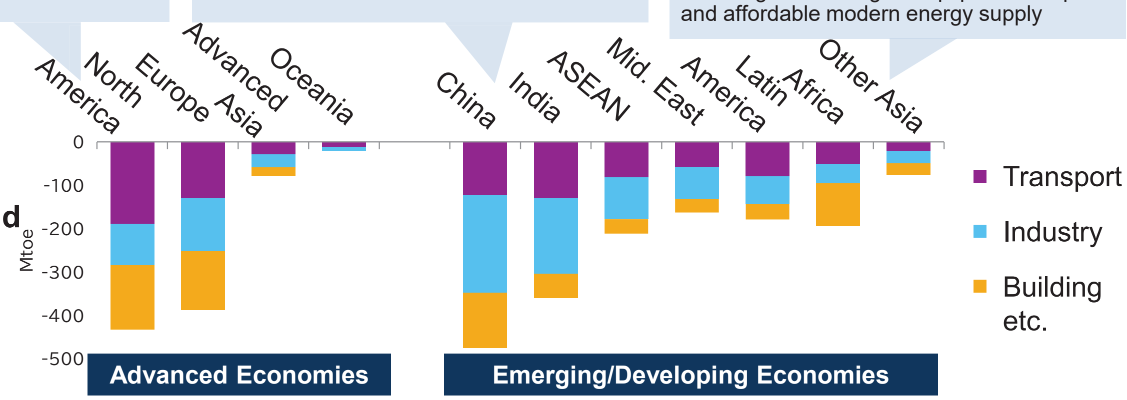
  Household transition from traditional biomass (wood) to LPG, city gas, and eventually electricity.

  Challenges: Funding for equipment adoption and affordable modern energy supply

Difference in Final Energy Demand

[Adv.Tech.-Reference]

(2050)



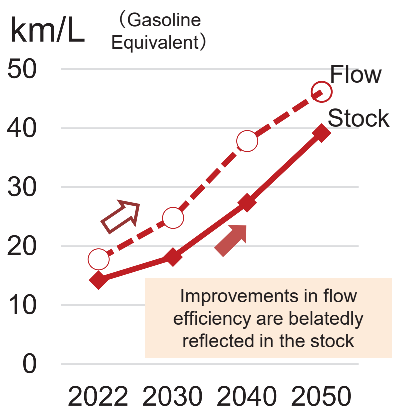
1) Energy Efficiency: Delayed Effect of Improvements

- Energy Efficiency: Delayed Effect of Improvements.
  - Intensity improvements in Adv.Tech become particularly evident after 2030.
- Flow efficiency (new equipment) reflects in stock efficiency (existing equipment) with delay.
  - Particularly pronounced in industrial sector with long equipment lifespans
  - Early action necessary for significant energy savings by 2050.

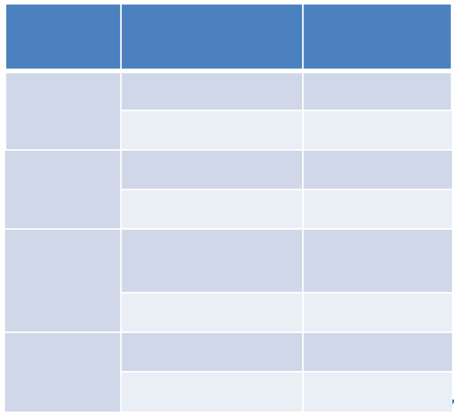
Average annual improvement of primary energy demand intensity (World)

		2010-2022	2022-2030	2030-2040	2040-2050
TPES/GDP	Reference	-1.4% (history)	-2.0%	-2.2%	-2.0%
	Advanced		-2.5%	-3.1%	-2.7%

Average fuel economy of passenger vehicles (Adv.Tech, World)

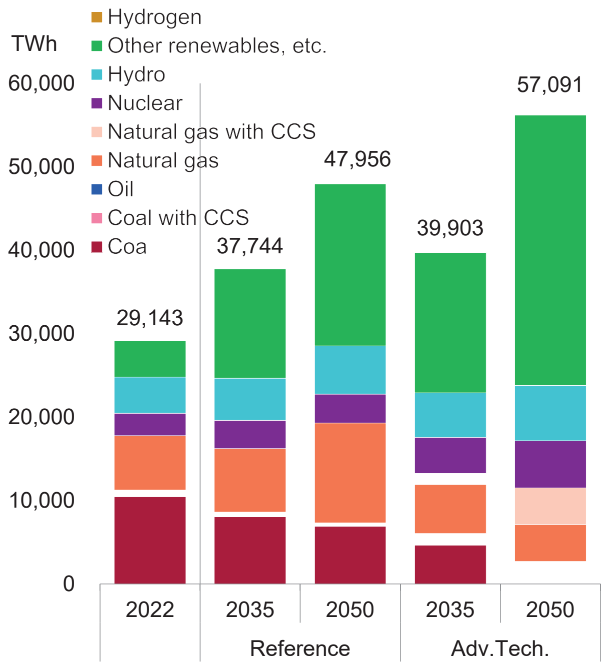


Average years of equipment use (example)



2) Renewables(excl. hydro): 60% in Advanced, with Total Generation Increasing Significantly

Power Generation (World)

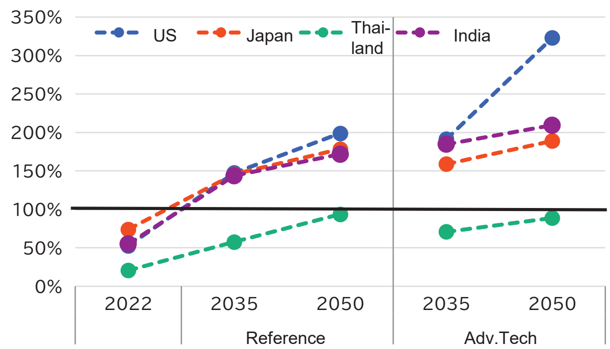


- **Power generation in 2050 requires 1.6x (Reference) and 2.0x (Adv.Tech.) vs 2022 levels.**
  - Substantial power demand increase is unavoidable in both scenarios.
  - Particularly in emerging/developing economies; urgent need for generation and transmission expansion.
- **Adv.Tech: "Renewables (excl. hydro)" increase dramatically to 60% of power.**
  - Mostly solar and wind; implementation at this scale requires fundamental intermittency countermeasures.
- **Nuclear expands particularly in emerging/developing economies.**

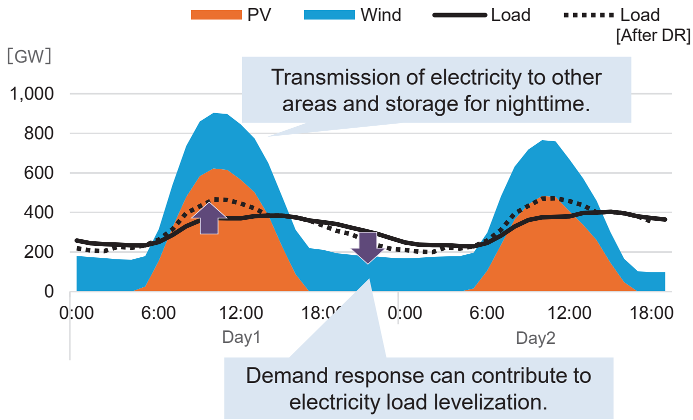
2) Renewables: Large Power Supply-Demand Gaps from Massive Deployment

- In **Adv.Tech**, major variable renewable (solar, wind) deployment, many regions see variable renewable capacity exceed twice the annual average load.
  - May require large-scale storage facilities, grid expansion, demand response utilization, and CO_2-mitigated thermal power beyond existing pumped storage and thermal capacity.

Ratio of VRE installations to annual average load

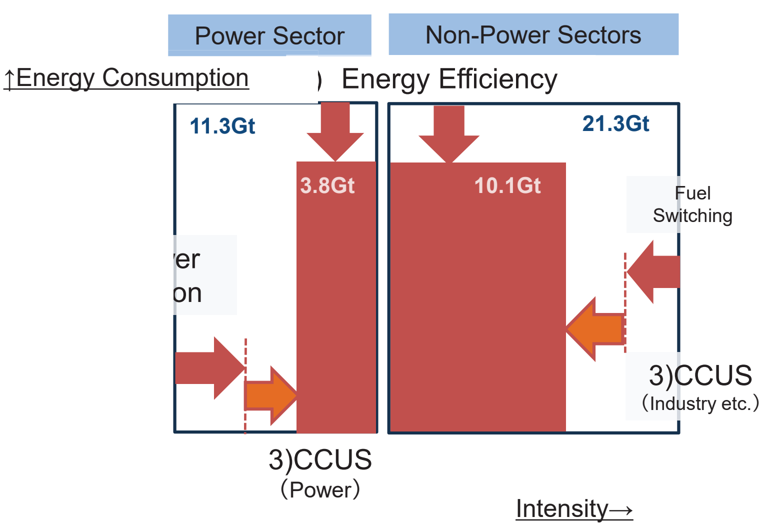


Gap between solar and wind output and demand [Adv.Tech・India・August 2050]



3) CCUS: Reducing Emissions from Hard-to-Abate Non-Power Sectors

CO_2 Reduction Framework



*Arrow and rectangle widths do not exactly match the emissions in each scenario.

CO_2 Emission 2050		
	Reference	32.7Gt
	Adv.Tech.	13.8Gt*

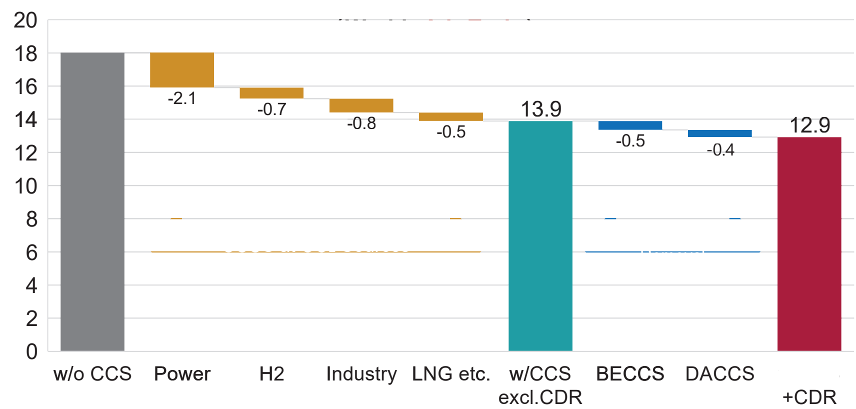
*Emissions excluding offsetting effects from CDRs. After offsetting, 12.9 Gt.

- Energy consumption (vertical axis) can be reduced through **1)energy efficiency** in both power and non-power consumption.
- intensity (horizontal axis) can be significantly reduced in power generation through **2) power transition**, but harder to reduce in non-power consumption.
- **3)CCUS** is effective for both power and non-power emission reduction.

3）CCUS: Major Deployment Potential in Industry and Power Generation

- **Adv.Tech.** projects total CCUS deployment of 5.1 Gt-CO2 by 2050.
  - Power sector shows the largest reduction potential for point-source CCUS.
  - In industry sector, becomes a key decarbonization method for sectors with limited electrification potential, like steel and cement.
  - Carbon removal (BECCS, DACCS* in this outlook) expected to be higher cost but valuable for offsetting residual emissions from sectors where capturing is difficult (Building/ Transport).

CO_2 emissions and reduction/removal by CCUS



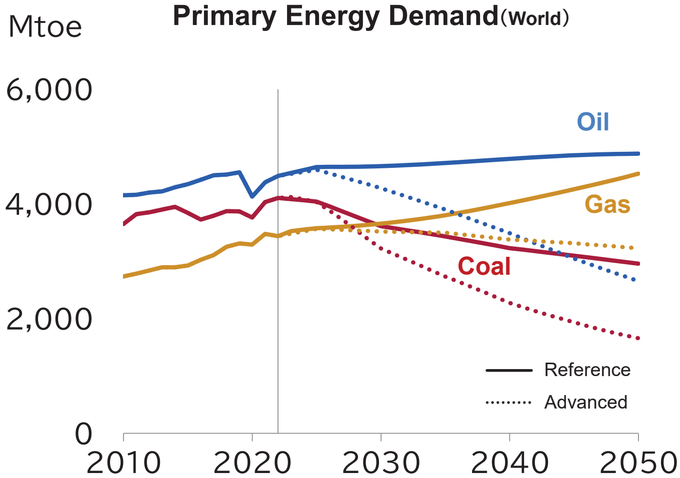
For Additional reduction…
- Addition of various CCUS/
- Nature-based Carbon Removal
(e.g.) Forests, Agricultural lands, and other land uses, Blue carbon, etc.

*BECCS: Bioenergy with CCS, DACCS: Direct Air Carbon Capture and Storage
Both qualify as negative emission technologies directly reducing atmospheric CO2

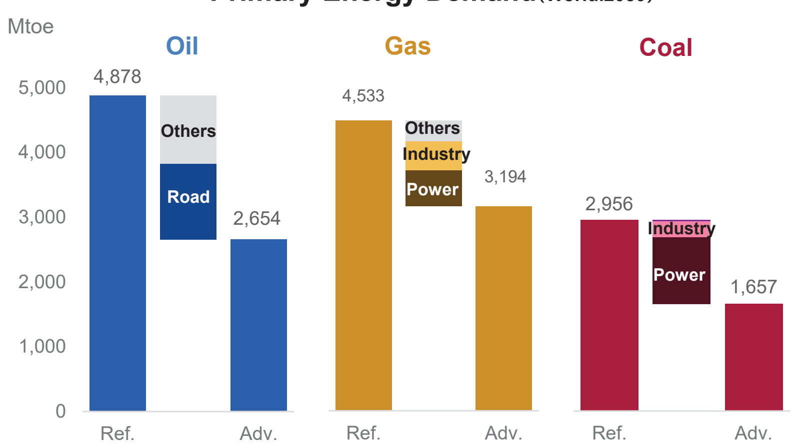
Fossil Fuel Demand Uncertainty: Wide Gap Between Scenarios

- Large divergence in fossil fuel demand between **Reference** and **Adv.Tech.** scenarios. While pursuing energy transition, a stable fossil fuel supply remains necessary.
  - Oil shows the largest demand difference, with road transport accounting for over half. Uncertainty in EV/HEV adoption, and ICE efficiency improvements.
  - Natural gas and coal demand differences are primarily driven by power generation and industry.

Primary Energy Demand (World)



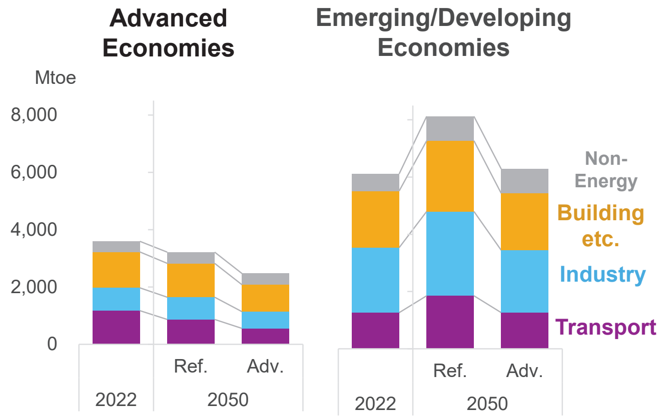
Primary Energy Demand (World.2050)



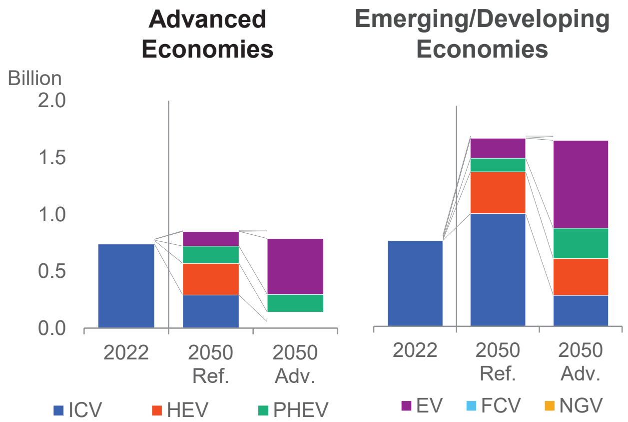
Final Energy Demand: Transport (Especially Road) Shows Major Divergence

- [**Reference**] Transport sector demand grows significantly in emerging economies.
  - Vehicle ownership in emerging/developing economies more than double by 2050 from 2022. Oil demand varies greatly depending on fuel efficiency improvements and powertrain choices.
- [**Adv.Tech.**] Efficiency improves particularly in road transport.
  - While EVs see mass adoption, ICEs and hybrids maintain presence, especially in emerging/developing economies. Vehicle choice is important based on power mix, range requirements, and usage frequency.

Final Energy Demand (Sectoral)

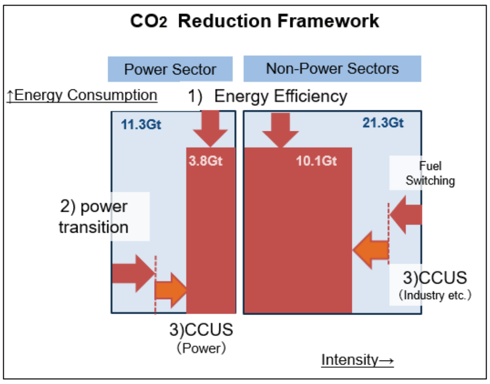


Vehicle Ownership (By Powertrain)



Summary

✓ CO_2 reduction relies primarily on (1) energy efficiency, (2) renewables, and long-term (3) CCUS. [**Adv.Tech.**]
- Energy efficiency enhancement provides 6.2 Gt-CO_2 reduction; early action is essential due to implementation lag.
- Renewables (excl. hydro) reach ~60% of total generation; variable renewable capacity exceeds twice the average load.
- CCUS promising for large emission sources in power and industry; 5.1 Gt-CO_2/year capture (including CDR).



✓ **Primary Demand and Power Generation Trends**
- **India, ASEAN show dramatic primary energy demand increase.** International climate action must include these regions.
- Global power generation in 2050: 1.6x (**Reference**), 2.0x (**Adv. Tech.**) vs 2022.

✓ **Significant Fossil Fuel Demand Uncertainty.**
- Under current trends, gas and oil demand may continue growing through 2050.
- Uncertainty drivers: road transport for oil; industry and power generation for gas/coal.
- Stable fuel supply remains critical through 2050. Sustained adequate investment essential.

IEEJ Outlook 2025
Risk scenarios of energy security

Ichiro Kutani

Senior Research Director
Director, Energy Security Unit
The Institute of Energy Economics, Japan

1. Risks of Fossil Fuel Underinvestment
2. More Serious and Diverse Geopolitical Risks
3. Risks of Electricity Supply Instability
4. Risks of Critical Mineral Supply
5. Increasing Risks of Cyberattacks

Co-Authors
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Summary

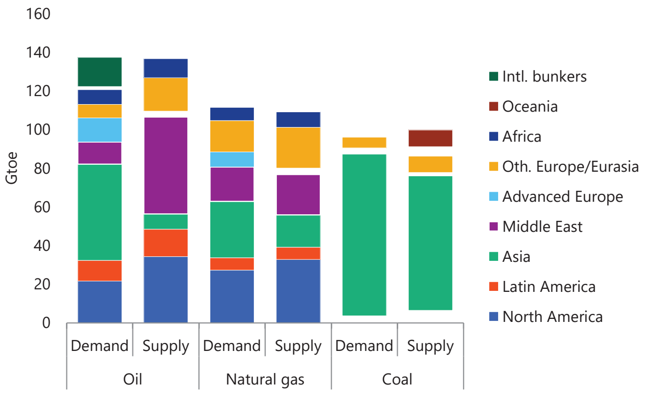
- Risks of Fossil Fuel Underinvestment
  - ✓ According to the IEEJ Outlook Reference Scenario, fossil fuels will still provide 73% of global energy demand in 2050. Without additional investment, oil and natural gas production in 2050 would plummet to about one-tenth of current levels. Underinvestment will result in a large gap from fossil fuel demand in the real world.
- More Serious and Diverse Geopolitical Risks
  - ✓ Geopolitical risks in the Middle East region are becoming more serious as Japan's dependence on the region for crude oil imports increases. In addition, policy changes in developed countries have also become a risk factor in recent years.
- Risks of Electricity Supply Instability
  - ✓ Electricity supply is subject to various risks on both supply and demand sides. In order to achieve stable supply, it is necessary to take measures in the fields such as ensuring fossil fuel, securing baseload power like nuclear power, securing supply capacity, and optimising the power system. It is also essential to pursue the best power mix for stable supply.
- Risks of Critical Mineral Supply
  - ✓ Some critical minerals that are essential raw materials for clean technologies have high market concentration and emerging as a risk to the energy transition. Risks can be mitigated by combining various technologies with different nature of risk.
- Increasing Risks of Cyberattacks
  - ✓ The number of critical cyber attack incidents has increased significantly around the world. Cyber-attacks against energy, a fundamental infrastructure, becoming a key issue in energy security.

Risks of Fossil Fuel Underinvestment

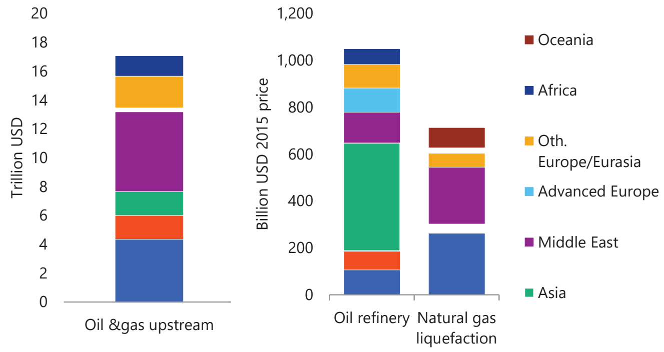
Supply demand and investment of fossil fuel

- In the Reference Scenario, fossil fuels will still provide 73% of global energy demand in 2050.
- Asia is the center of demand growth, while the Middle East and North America oil and natural gas) and Asia coal have the highest shares in the supply region.
- Stable investment, particularly in these regions, is vital for the stable supply of fossil fuels.

Fossil fuel demand



Selected oil and gas investment amount



Cumulative total of 2022-2050 in the Reference Scenario
Source: IEEJ

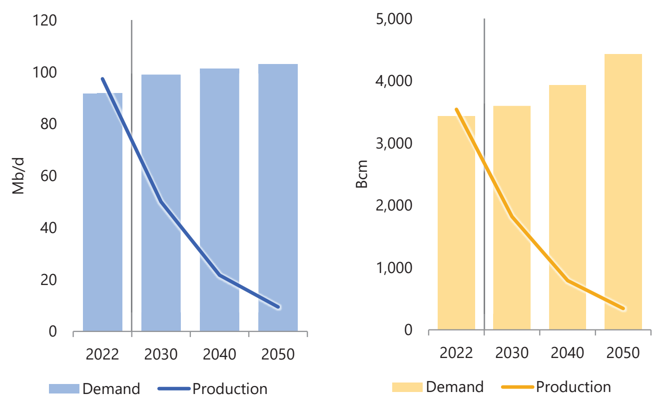
Increasing hurdles to investment

- Underinvestment is currently not serious, but the risk of underinvestment due to climate change concerns and decarbonisation policies has become apparent.
- Without additional investment, oil and natural gas production in 2050 will be about 1/10th of current levels.

Head wind against fossil fuel projects

Oil	Natural gas	Coal
Financial institutions and pension funds restrict investment in fossil fuel development and coal-fired projects		
Upstream asset sales by IOCs $290 billion over 2015-2023)		Thermal coal asset sale by coal majors
Europe: Refining capacity may decrease by 1-1.5 million b/d by 2030	Suspend LNG projects with high environmental impact. (e.g. Natuna field in Indonesia)	Ban of new coal-fired power in OECD countries

Prospect of oil and gas production without investment and demand in the Reference scenario



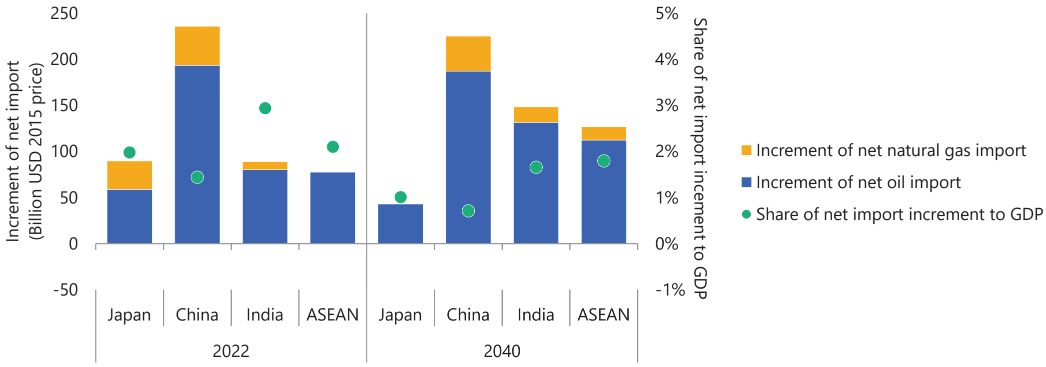
IOC = international oil companies
Source: IEEJ, IEA, Bloomberg

Source: IEEJ

Economic impact of price increases

- Tight supply and demand leads to higher prices: the average Brent price in 2021 was 70% higher than the previous year, partly due to lack of upstream investment during the pandemic period as well as a recovery in demand after the pandemic.
- For a 50% price increase, the share of oil and natural gas imports in the GDP of Asian importing countries rises by 1-3 percentage points. The rise in India and ASEAN is relatively large and the impact on the economy is more worrying.

Impact of crude oil and natural gas price increase on import bill

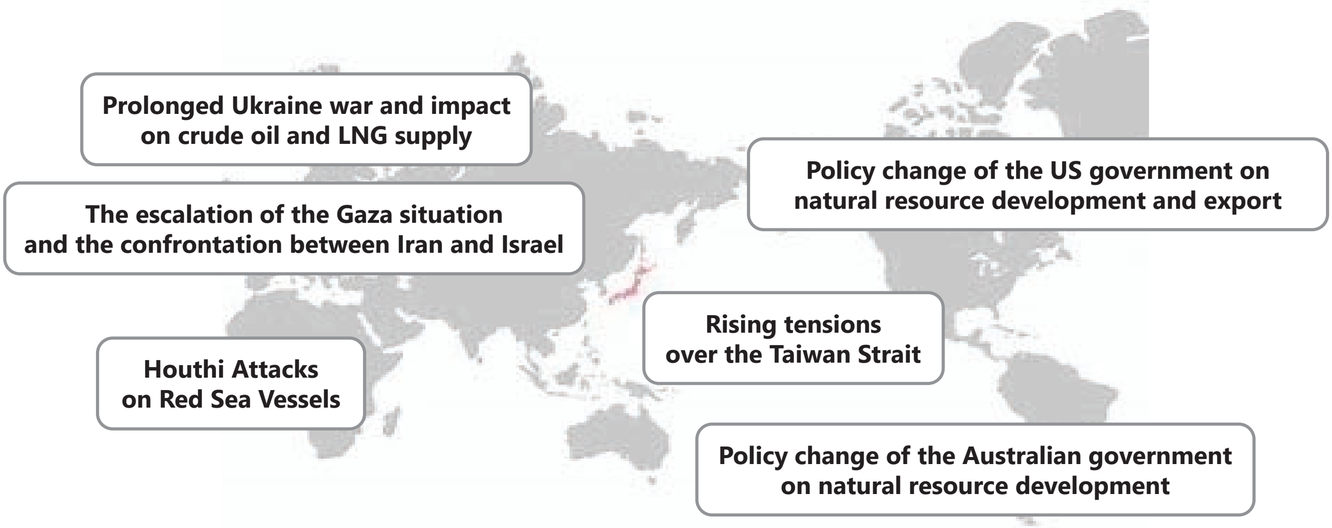


Assume that oil and natural gas import prices will be 50% higher than actual (2022) or preconditioned 2040) due to tight supply and demand caused by underinvestment. Source: IEEJ

More Serious and Diverse Geopolitical Risks

More diverse geopolitical risks

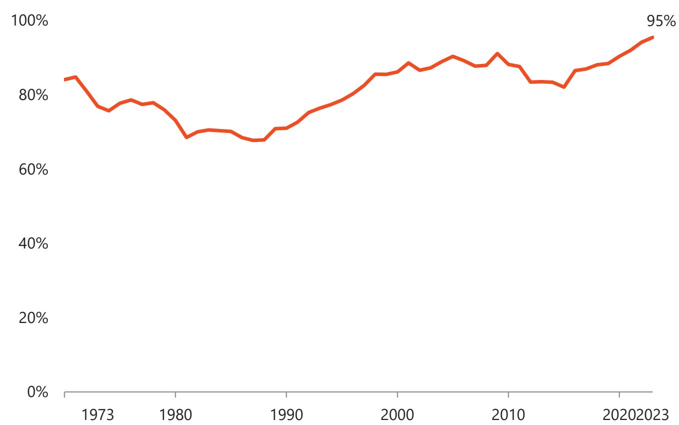
- Geopolitical risks remain a major concern in energy security.
- In addition to the risk of political instability in resource-exporting countries/regions, policy changes in developed countries have also been a risk factor in recent years.



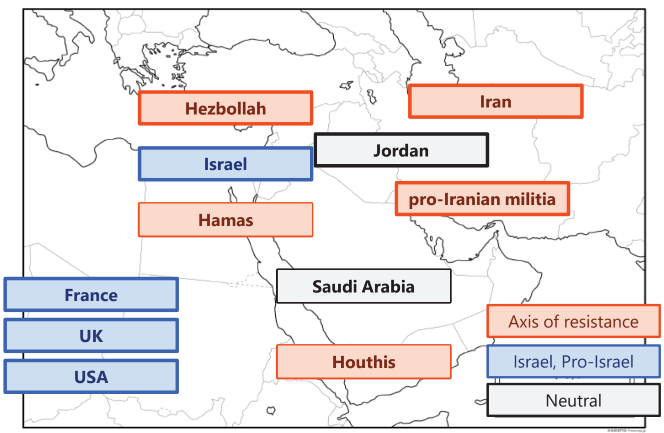
More serious geopolitical risks in the Middle East

- As Japan's dependence on the Middle East crude oil rises, the geopolitical risks in the region, escalation of conflicts surrounding Israel, are becoming even more serious for Japan.
  - In particular, the worsening of Iran-Israel relations could be a factor linking the situation in Palestine to energy supplies in the Persian Gulf, and the impact of these developments would be very significant.

Middle East dependency of Japan's crude oil import



Israel and the Axis of Resistance



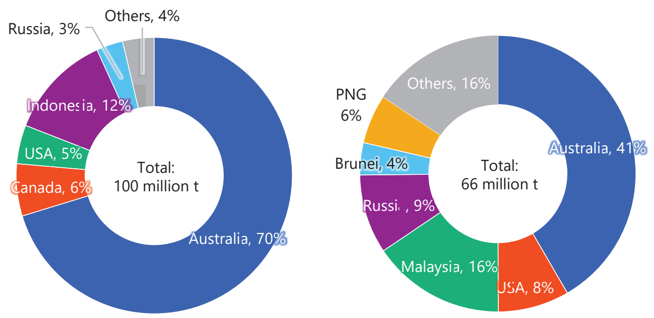
Source: Ministry of Finance, "Trade statistics"

Source: JIME, IEEJ

Policy change risks in developed countries

- Coal and LNG imports are highly dependent on developed countries 81% for coal and 50% for LNG: 2023).
- There are concerns that policies have been introduced in the US and Australia that place restrictions on the development and export of domestic fossil resources, reflecting domestic interest in climate change issues, which may pose a challenge to market stabilisation.

Import partners of Coal (left) and LNG (right) supply in Japan (2023)



Recent policy developments in the US and Australia that would affect their LNG export

US	• In January 2024, the Biden administration announced a pause on the review and approval of export licence applications for new LNG projects for non-FTA countries as part of its response to the global climate crisis.
Australia	• In October 2022, the ADGSM was amended to restrict gas exports in the event of a domestic gas supply crisis. • July 2023, requiring GHG emissions from designated large emission sources, including LNG liquefaction and coal mines, to be reduced by 4.9% annually. Requires new LNG facilities to have net-zero emissions from the start of operations.

PNG = Papua New Guinea
Source: Ministry of Finance, “Trade statistics”

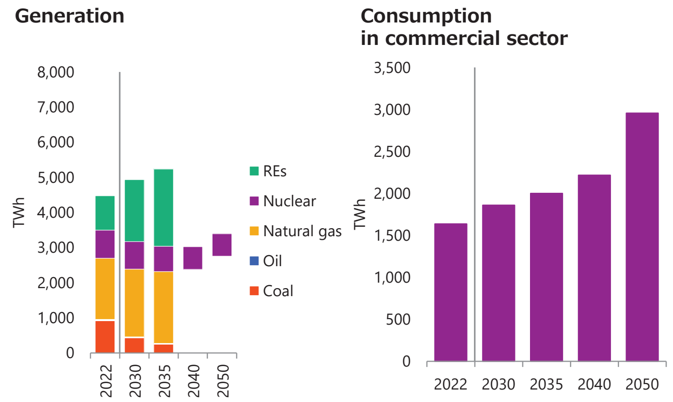
ADGSM = Australian domestic gas security mechanism
Source: Ministry of Finance, “Trade statistics”

Risks of Electricity Supply Instability

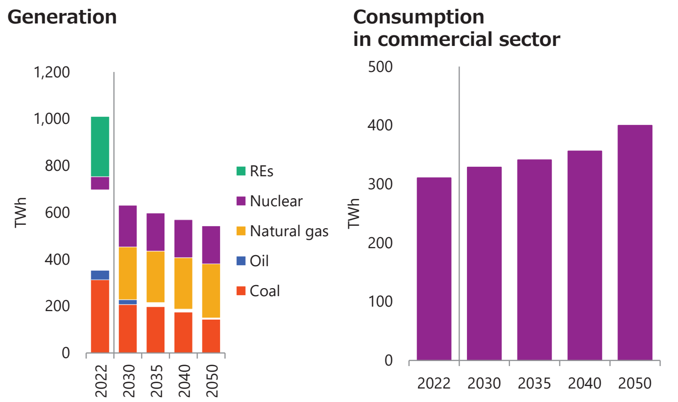
Increasing electricity demand and VREs

- Society is becoming increasingly reliant on electricity as the digitalisation of the economy and the electrification of demand continue. Electric vehicles and the expansion of data centres are the key drivers of demand growth.
- The energy transition is pushing solar photovoltaic and wind power, whose output fluctuates with the weather and the seasons, to become the mainstay of electricity supply.

Electricity demand and supply in the US



Electricity demand and supply in Japan



Reference Scenario
Source: IEEJ

Reference Scenario
Source: IEEJ

Risks, challenges, and measures of supply security

- On the supply side, risks of supply stability include supply shortage and price fluctuation of fossil fuels, geopolitical risks, and fluctuations in the output of renewable energy sources.
  While on the demand side, there is the risk of an increase in electricity demand and uneven distribution of electricity demand.
- To address these risks, it will be necessary to secure fossil fuel procurement and baseload power sources such as nuclear power, secure supply capacity, and optimise the power system.

Risks, challenges, and measures against risks of electricity supply instability

Risks	Challenges	Measures
• Shortage of fossil fuel supply • Fluctuation of fossil fuel price • Geopolitical risks • Fluctuation of RE power output	• Procurement of fossil furl • Securing baseload power	• Attach conditions for long-term fuel procurement to PPA contracts • Procurement of stable power sources such as nuclear and geothermal
• Increase of demand	• Secure supply capacity	• Introduction of support schemes for new power supply installations • Consumers own back-up power generation
• Uneven distribution of demand	• Optimise power system	• Locate demand proximity to power generator • Announce areas with surplus supply capacity • Introduce dynamic line rating to transmission line

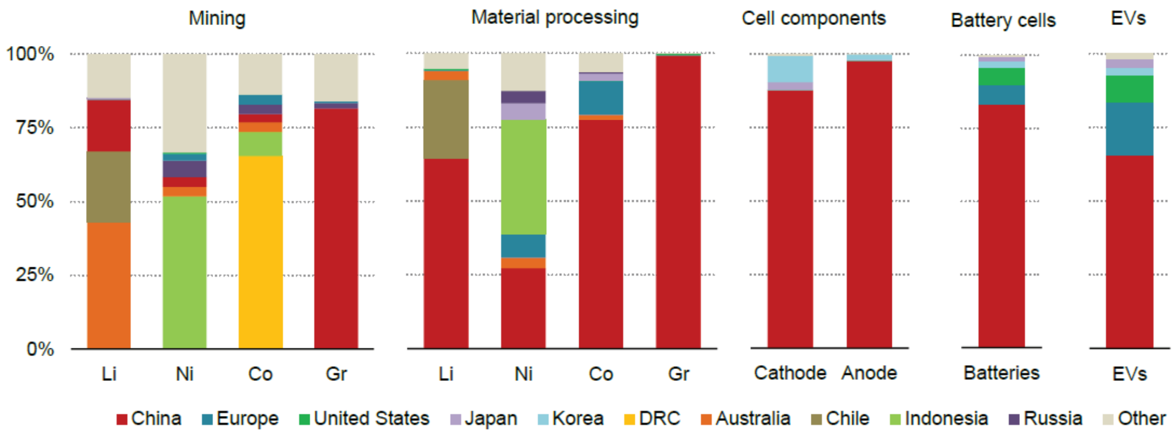
RE renewable energy
Source: IEEJ

Risks of Critical Mineral Supply

Risks of clean technologies

- High market concentration observed in some clean technology production and in the supply of critical minerals that are essential for clean technologies. This is increasingly recognised as an emerging risk to the energy transition.
- Demand for critical minerals is expected to increase in the future. Therefore, the impact of supply disruptions (risk of supply shortages and price spikes will also increase

Structure of on-board battery supply chain

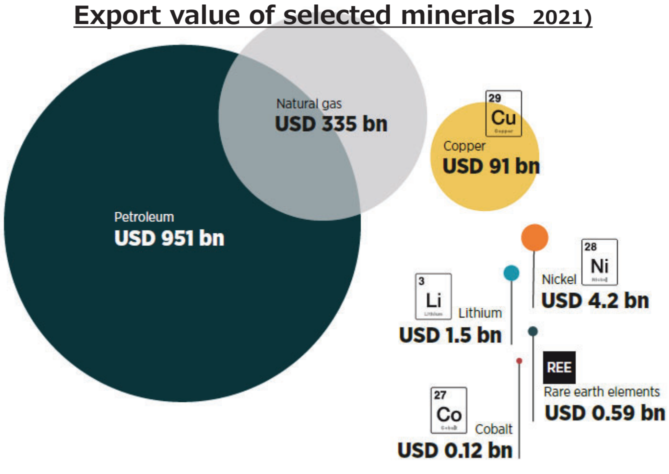


Li = lithium, Ni nickel, Co = cobalt, Gr graphite
Source: IEA (2024) "Global Critical Minerals Outlook 2024"

Challenges of stable supply of critical minerals

- The critical minerals market is small and immature, making it prone to the exercise of market power, cause supply-demand gaps and the resulting price volatility.
- As refining is energy-intensive and high environmental load, it is not easy for developed countries to make it competitive.
- Increasing international competition to secure key minerals and heightened resource nationalism should also be reminded.
- Uncertainty in future demand for critical minerals due to the potential for technological innovation.
- Long lead times for the development of new resources make it difficult to invest in supply source diversification.
- Overcoming these requires 1) consistent policy and 2) coherent development of supply and demand.

Export value of selected minerals 2021)



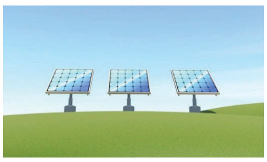
Source: (UN COMTRADE database).
Note: Numbers represent trade in raw, unprocessed fuels and ores only.

Source: IRENA (2023) "Geopolitics of energy transition, Critical Minerals"

Technology mix for risk control

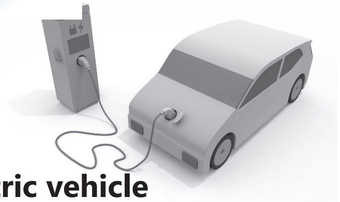
- Risks can be mitigated by combining different technologies with different risk characteristics.
- Development of those technologies and market creation is needed.

Technologies with higher market concentration



Solar PV

Wind power



Battery
Battery electric vehicle

Technologies with lower market concentration

- **Fossil power with CCS**
- **Hydrogen and ammonia power**
- **Nuclear power**
- **CN synthetic methane as city gas**
- **ICEV, HEV, and PHEV run by CN fuels (biofuel, synthetic fuel)**

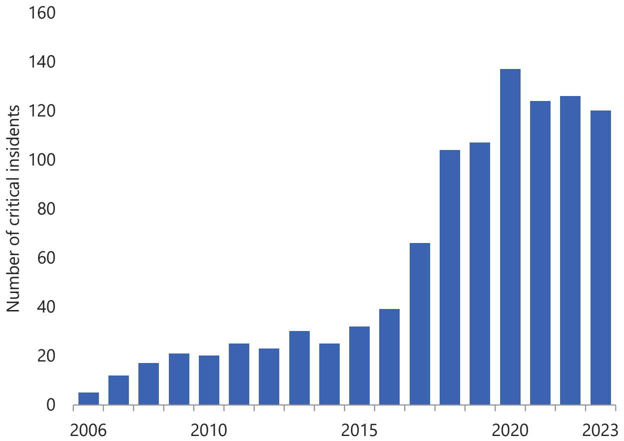
CN carbon neutral, ICEV internal combustion engine vehicle, HEV hybrid vehicle, PHEV = plug-in hybrid vehicle
Source: IEEJ

Increasing Risks of Cyberattacks

Growing cyber risks to energy supply

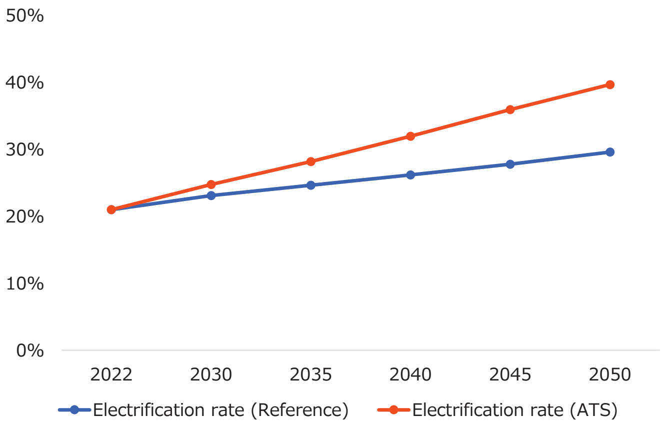
- Since mid-2010, the number of critical cyber-attack events has increased significantly worldwide.
- The energy transition, with its accompanying electrification, digitisation, and network connectivity, will result in an increase in the severity of cyber-attacks as a potential risk factor.

Number of critical cyber incidents



Attacks targeting the government, defense or hi-tech sectors or with a damage value exceeding $1 million. Source: IEA 2020), CSIS 2024)

Share of electricity in final consumption in the world



ATS Advanced Technologies Scenario
Source: IEEJ

Increased cyber vulnerability

- As the energy transition progresses, vulnerability to cyber-attacks increases in the energy supply, storage and demand sectors.

Increase of vulnerability against cyberattack due to energy transition

Energy supply	Energy storage	Energy demand
• Upgrading of operational management systems - Operations management systems are integrated with information systems and connected to the internet - Increased use of cloud services and automation increases the impact in the event of an attack. • Increase in the number and diversification of distribute power operators - Increased number of attack points along the entire power supply chain, making it more difficult to build defenses.	• Increased reliance on storage batteries - Potential impact of cyber-attacks on the operation of storage batteries storage and discharge) due to an internet-connected storage battery management system (BMS)	• Increase in the number of EVs - EVs connected to each other and to the internet for diverse services - Potential intrusion into systems controlling energy-using equipment in dwellings via charging points • Smart dwellings and IoT in buildings - Possible attack points for cyber-attacks due to the introduction of systems that collect data on electricity use and temperature control in dwellings and control energy equipment

BMS battery management system, EV electric vehicle, IoT internet of things
Source: Dawda, Herath, and Maccall2022)

Scenarios of cyber-attack

- There are diverse patterns of cyber-attacks, with different actors, objectives and targets of attack.
- Considering Ukraine war, geopolitical risks should not be underestimated, and the possibility of weaponisation in the form of threats to energy supply should also be taken into account.

Types of cyber-attacks on energy assets

Types	Methods	Incidents
Remote control and systemmalfunctioning by malware	Malware malicious software) is fed into the attack target's internal network to remotely control the attack target's energy supply facilities from the outside, affecting the actual energy supply or causing the attack target's PCs or network to malfunction. State actors may also adopt this method.	2022, Germany: Wind power company 2022, Italy: Energy agency 2015, Ukraine: Power sysem
Securing ransom through ransomware	The same as above until the malware is sent to the internal network of the attack target. It then encrypts the internal data of the attack target and affects the operation of the system by the attack target. The attacks are often carried out by private actors.	2021, US: Oil pipeline company (the company stopped the operation for a week as a precaution)
System down through mass access	Concentrating large amounts of access against an attack target aim to bring down the target's systems.	2022, Lithuania: Energy company

Source: IEEJ

countermeasures against cyber-attacks

- It is difficult to provide 100% protection against cyber-attacks with their diverse patterns.
- However, the following measures can be taken to limit the damage caused by attacks and ensure early recovery.

Major countermeasures against cyber-attacks

Measures	At the government	At both ends	At the private sector
Institutional arrangement	• Develop policies to clarify the responsibilities of actors and encourage them to respond • Develop a framework for cooperation between actors	• Raise awareness of cyber security	-
Identify the risks	• Encouraging operators to identify cyber vulnerabilities and analyse risks	• Information sharing	• Identify and assess the risks • Identify and classify the risks of assets
Manage and minimise the risk	• Develop risk management processes • Prioritise response measures	• Develop and share methods for ensuring resilience • Human capacity building	• Develop risk management method • Prioritise response measures
Monitor the risks	• Develop risk monitoring processes • Cooperation with the National Intelligence Unit	-	• Regular monitoring of identified risks and vulnerabilities
Recovery from an attack	• Develop recovery plans / procedures and regular drills.	• Learning and preparation through sharing of past attack cases and lessons learnt	• Develop recovery plans / procedures and regular drills.

Source: Ecofys 2018); IEA (2021), World Energy Council (2022); METI･IPA2022)

IEEJ Outlook 2025
The Critical Role of LNG

The Institute of Energy Economics, Japan - IEEJ

Hiroshi Hashimoto
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Abstract

✓ **LNG plays an important role - demand is expected to grow further**
- LNG is expected to play an important role as a realistic solution toward the energy transition - as a pragmatic and reliable energy source - enhancing energy security and contributing to decarbonization at the same time.
- Global LNG demand in 2050 is projected to increase by 74% from the present level in the Reference Scenario of the IEEJ Outlook 2025 - with Southeast Asia in focus

✓ **LNG supply stability requires sustaining investment**
- The LNG production sector requires additions of 10 - 20 million-tonne-per-year capacity addition each year
- Even with steady FIDs (final investment decisions) during the past three years, uncertainty should be noted over realisation and timely implementation of the projects

✓ **Long-term agenda toward the stable LNG market**
- Efforts of the LNG market and industry players are necessary to meet the expectations
- It is important for companies and governments in consuming countries to encourage stabilization of regulatory aspects and LNG production project development
- Demand aggregation and market development support lead to expansion of the market

[Issues surrounding LNG production project development with long-lasting implications]

✓ **Issues and challenges related to LNG production project development**
- In parallel of rising LNG production project development costs, progress has been made in FLNG and small and medium size LNG liquefaction
- Upcoming launch of LNG export from the West Coast of North America is expected to be a gamechanger of LNG marine transportation
- While LNG export capacity is expected to expand, long-term development activities face uncertainty caused by the "pause"

✓ **LNG transportation bottlenecks and unplanned outages of LNG production plants affect the market balance**
- Longer distances of LNG transportation and bottlenecks at canals and routes require a long-term strategy of transportation
- Unplanned outages at LNG production facilities are likely to exacerbate supply-demand imbalances

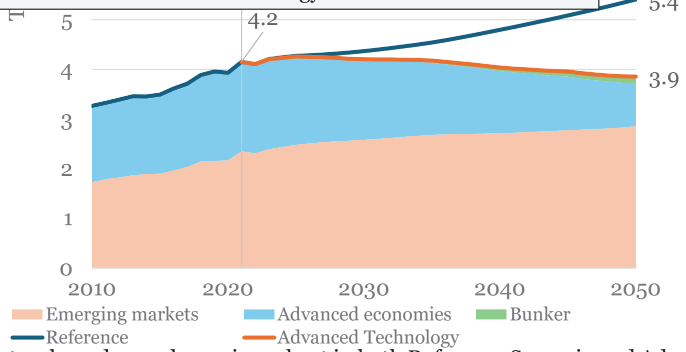
LNG Has A Role to Take Care of Uncertainty under the Energy Transition

- In its 60-year growth history, LNG has expanded and demonstrated its role in response to the demands of each era to enhance energy security
- A wide variety of reserves and backup mechanisms have been introduced to enhance resilience of LNG supply along with LNG's expanded role
- Progress has been made in supply source diversification and international partnerships to enhance LNG supply security

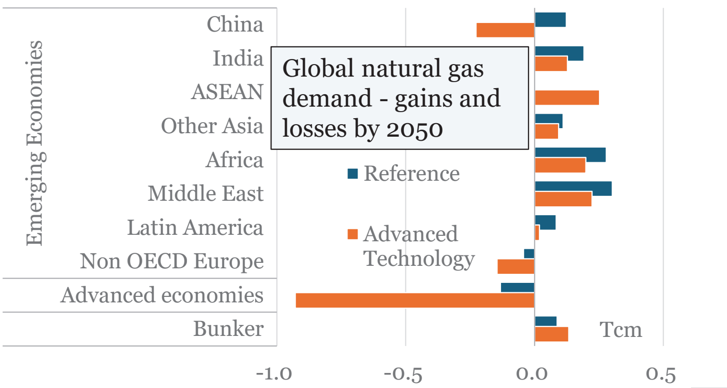
Era and issues	LNG's role of the era and expectation
Late 20th century ✓ Oil crisis ✓ Air Pollution	✓ The share of LNG expands as an alternative and clean energy source (Japan and Korea) ✓ LNG is a gas supply source alternative to pipeline gas (Europe) ✓ LNG mitigates impacts of the oil crisis with an increasing share in the primary energy mix
2010s ✓ Replacing lost nuclear power ✓ Meeting increasing energy demand	✓ LNG demonstrates flexibility to swiftly respond to shortages of baseload electricity supply ✓ A wider range of participants in each segment of the LNG value-chain have mitigated burdens at each segment of liquefaction, marine transportation and regasification, revealing LNG's flexibility more vividly in emergency cases
2021 - 2022 ✓ Energy demand surge after the pandemic ✓ Russian war and gas shortages	✓ Europe's increasing LNG import offsets decreasing pipeline gas supply from Russia even before Russia's invasion in Ukraine ✓ Increasing LNG supply mainly from the United States takes care of loss of Russian pipeline gas import after Russia's invasion in Ukraine and the sabotage against the pipeline into Germany
Into the future ✓ A realistic solution taking care of uncertainty of the energy transition	✓ LNG provides a realistic solution toward the energy transition enhancing energy security and contributing to decarbonization at the same time ➢ LNG supports economic growth in emerging markets and provides stable energy supply to matured markets ➢ LNG contributes to the energy transition, partnering with new energy sources ➢ Assuming efforts to make LNG cleaner, LNG can be utilized further longer

Natural Gas Demand Is Robust and Asia's Share in LNG Grows

Global natural gas demand – demand expands in emerging markets even in Advanced Technology Scenario

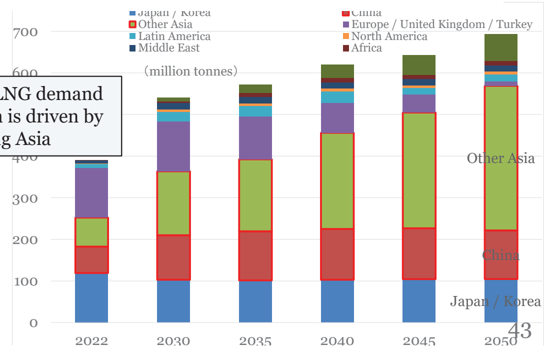


Global natural gas demand - gains and losses by 2050



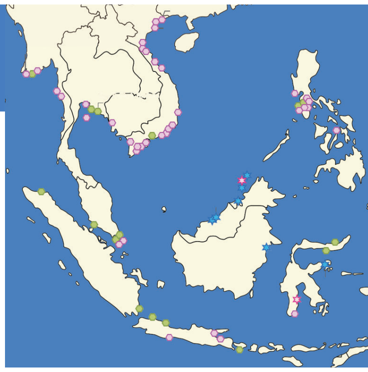
- ✓ Natural gas demand remains robust in both Reference Scenario and Advanced Technology Scenario
  - ➢ Global LNG demand in 2050 increases by 74% from the current level in the Reference Scenario
  - ➢ Global LNG demand increases until around 2040 and stays at the current level in 2050 in the Advanced Technology Scenario
  - ➢ If energy efficiency improvements do not materialize, LNG demand could be higher
- ✓ Demand increases center on Southeast Asia and Power Generation
  - ➢ Natural gas plays a role in emission reductions in the industrial sector and demand and supply balance management in power generation, being an economically viable energy source, reducing costs of the energy transition
- ✓ Instability of demand and supply balance and volatile prices indicate the importance of long-term measures for stability of the market

Global LNG demand - growth is driven by emerging Asia

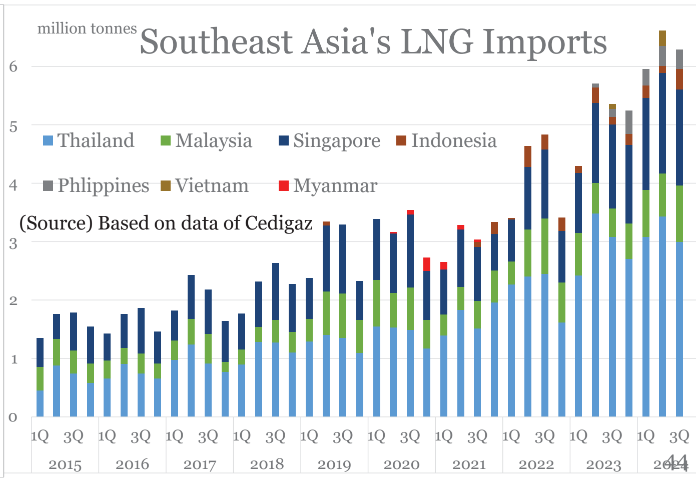


Southeast Asia Has A Potential to Expand Use of LNG

- ✓ Southeast Asia has expanded use of natural gas in tandem with LNG export project development after the 1970s
- ✓ Traditional gas producing countries anticipate larger consumption
- ✓ Seven countries have started LNG imports since 2011 – within and from outside of the region
- ✓ Share of LNG in natural gas consumption in Southeast Asia is projected to increase from current one-sixth to one-third
- ✓ Near-shore land areas and island areas have potential to expand LNG utilization infrastructure



LNG infrastructure in Southeast Asia Existing and planned LNG production plants (star, existing in blue and planned in red) and LNG receiving terminals (hexagon, existing in green and planned in pink) are spread around



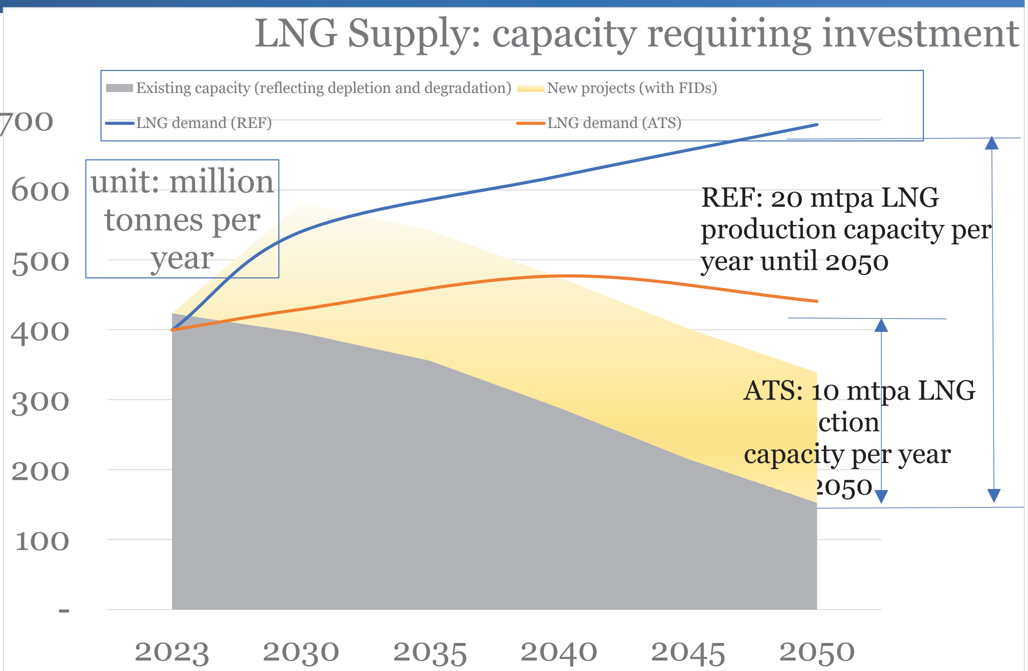
Investment - to Meet Demand, to Replace Existing Capacity - Is Required

The LNG production sector requires additions of 10 - 20 million-tonne-per-year capacity each year until 2050

- ✓ To meet incremental demand and to supplement reductions of productivity of existing gas fields and processing facilities

1. New projects
2. Backfill supply from other fields
3. Offsetting decreasing gas supply
4. Rejuvenating existing liquefaction facilities

- ✓ Uncertainty over timely realization of those projects under construction (yellow)
- ✓ As construction delays are now the norm and the increasing supply is likely to be absorbed by markets in Asia and elsewhere, widely touted "oversupply" around the end of the decade is unlikely



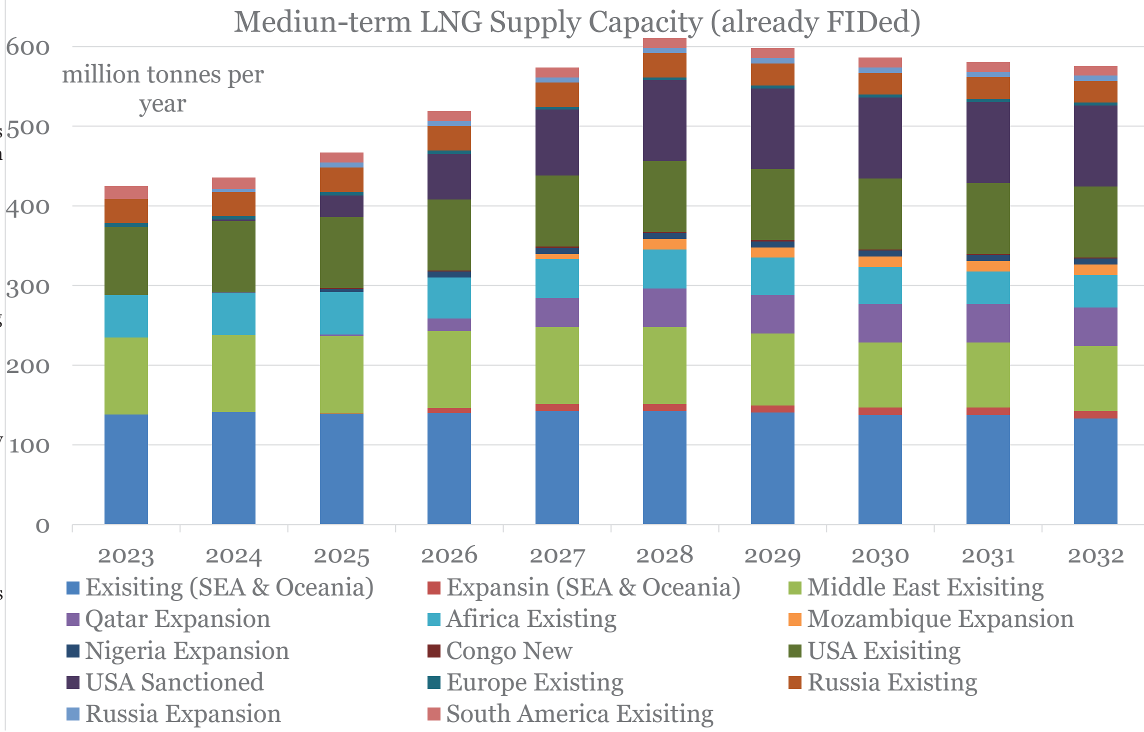
After Many FIDs 2021-2023, Uncertainty Thereafter and Uncertainty of Completion

- ✓ After the energy crisis in 2022, LNG development activities have been accelerated
- ✓ The capacity for which FIDs were made in 2021-2023 apparently exceeded the above-mentioned required capacity
- ✓ The pause of non-FTA export authorization and regulatory uncertainty have slowed down FIDs in the United States in 2024
- ✓ Uncertainty and delays should be noted over realization and timely implementation of those sanctioned projects

(Those with FIDs originally planned by 2024 and pushed back)

Medium-Term LNG Production Capacity Additions Entail Uncertainty

- ✓ If LNG production projects currently under construction are completed as scheduled, the total capacity is expected to exceed demand around 2030
- ✓ However, there are some uncertainties with those projects under construction
  - ✓ Uncertainty of new projects in Russia
  - ✓ Suspended construction due to political instability
  - ✓ Project delays caused by prolonged negotiations regarding additional cost allocations between project owners and contractors
  - ✓ Court decisions to suspend construction permits triggered by environmental claims
- ✓ Price sensitive LNG users are likely to commit more LNG offtakes based on prospective increases of LNG production
- ✓ "Glut" of LNG capacity around 2030 is illusive



(Source) compiled by the author

Issues Surrounding LNG to Function as A Realistic Solution

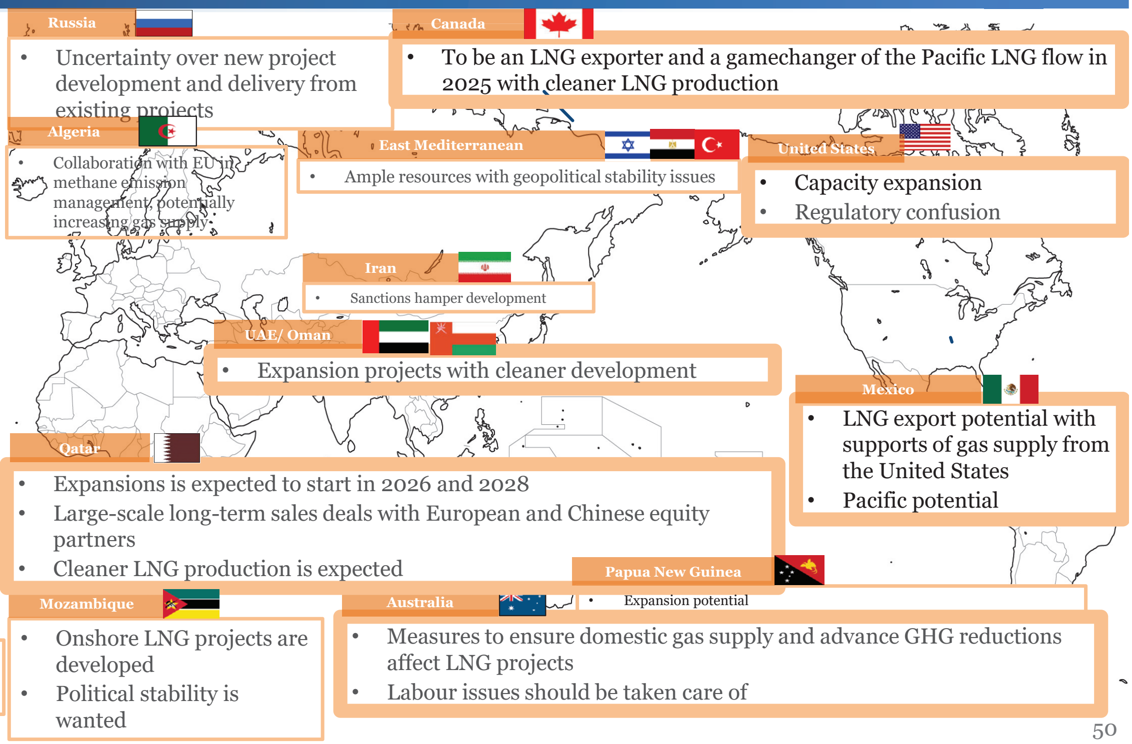
1. The role of LNG in the energy transition and energy supply security is important
   i. Efforts of the LNG market and industry players are necessary to meet these expectations toward stable supply and cleaner LNG
   ii. Clearer standards of LNG that could fit the goal are necessary
   iii. Companies should make efforts to better manage methane and GHG emissions, to set higher goals, and to disclose appropriate and timely information. It is important to make the entire LNG value chain even cleaner
   iv. It is also helpful if the industry can make LNG look more attractive as an investment and financing target
2. LNG consuming countries have roles in expanding and maintaining production
   i. it is important for companies and governments in consuming countries to encourage stabilization of regulatory aspects and project development in LNG producing countries,
   ii. as well as to participate in such development
3. Demand aggregation engaging emerging markets and market development supports help expand the global LNG market and support LNG production development
   i. Medium- to long-term demand aggregation and market development support, including those in emerging markets in Southeast Asia
   ii. The resulting expansion of the global LNG market will support LNG production development

Trends in LNG Production Projects in Recent Years

	Major trends	Factors promoting projects
2010-2014	• Northeast Asian LNG demand surge • Australian LNG project boom	• Development activities are stimulated elsewhere
2015-2020	• Activities shifted to the United States with moderated cost escalations in upstream and liquefaction sectors • Feedgas supply in the United States is not necessarily cheap but is expected to be stable on the long-term basis	• Conversion of receiving infrastructure into export facilities • Separated gas production and transportation sectors • FLNG (floating LNG production) as a competitive option
2021-	• Logistical constraints caused by the pandemic and the war have delayed construction activities • Instability in some countries has caused delays • Difficulties in absorbing cost escalations • Uncertainty in export authorisation and construction approvals in the United States	• Small and mid-scale liquefaction applications • Modular and design-one-and-build-many strategy • Phasing out from Russian gas - activities elsewhere
	• Prices of materials are on the rise • CCS and electrification add costs • Financial costs are on the rise	• Developers pursue cost reductions

LNG Supply Sources Have Advantages and Challenges

- ✓ Although the United States leads capacity expansion for several years to come, additional regulatory uncertainty has emerged including the pause of non-FTA LNG export authorization and the suspension of construction approvals
- ✓ New LNG supply sources have potential advantages of increasing supply, avoiding transportation bottlenecks, and shorter and diversified transportation
- ✓ Qatar is expected to further advance its LNG marketing activities beyond partners in expansion projects
- ✓ Australia needs measures to maintain stable supply and risk mitigation



The "Pause" and Court Decisions to Suspend Construction Approvals Cause Uncertainty

- January 2024 Pause of non-FTA authorization and economic and environmental impact study
- Certain LNG projects suffer delays and uncertainty - credibility in limbo
- After a court order to stop "pause" of 2 July, a non-FTA approval of a Mexican project on 31 August
- Another court vacated two FERC authorizations on 6 August
- FERC plans to conduct additional environmental reviews of two front-running projects
- **Uncertainty over LNG export authorization and over construction approval should be removed**

Issues to be considered on the "pause"	Points to be noted
Direct impact of the "pause"	30 mt out of 150 mt/y LT deals in 2022/2023
"48 bcf/d (365 mt/y) authorised; 26 bcf/d (200 mt/y) to be realised"	22 bcf/d without FIDs, no assurance
Disagreements between commercial and regulatory progress	Regulators do not directly take account of commercial arrangements, but something should be done
License extensions are said to be unaffected	Extension reviews are closely watched
Uncertain when the review process will resume	Exactly when new reviews will resume after the election
Public comment period	Parties should start preparation
Other LNG projects may benefit from the pause	Some projects within and outside of the United States
Possible outcomes of the studies	Upper and/or time (adjustable) limits of LNG exports Tougher (adjustable) standards for license extensions

The Shale Revolution in the United States and Its Global Impact

- The Shale Revolution evolves with interaction with the global LNG market
- The United States is now the largest exporter in the world, contributing to Europe's phasing out of Russian gas supply
- **Incremental LNG production project development should support LNG market development focusing on emerging markets**

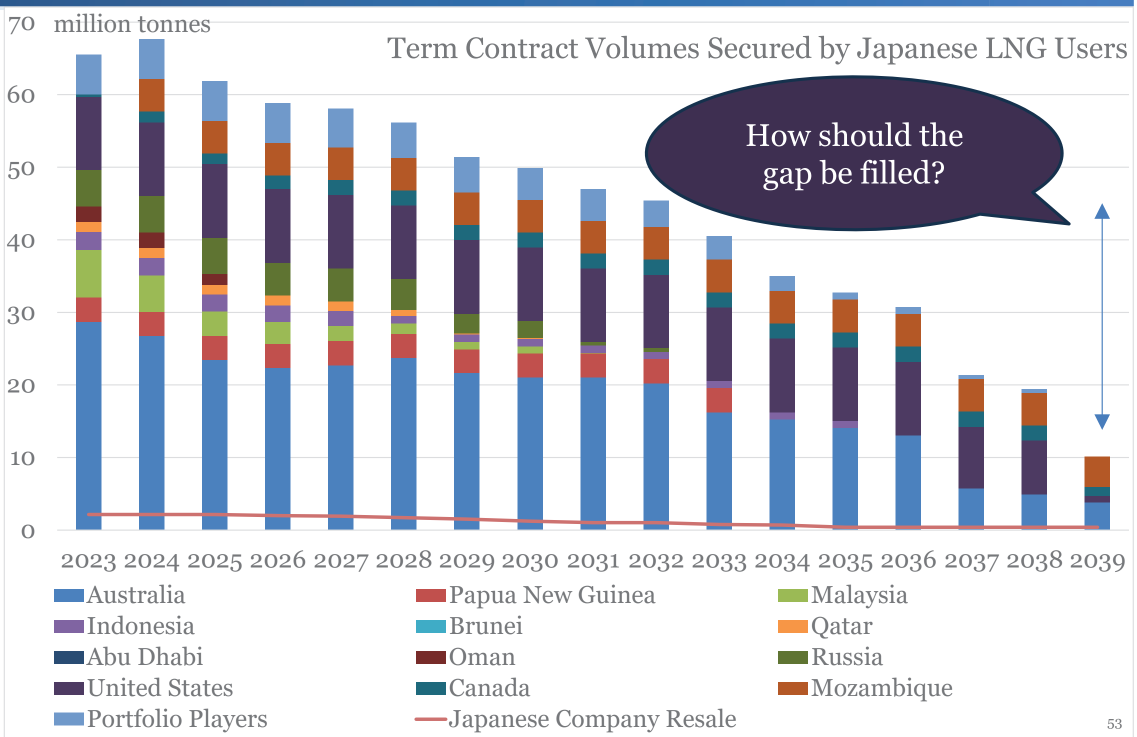
	Natural gas market in the United States	Global LNG market	Interaction
- 2007	Rising prices encourage more production	Gas and crude prices rise	LNG export projects target the United States
2008 -	Shale Revolution starts from natural gas Gap widens between gas and oil prices	Qatar and Russia increase LNG exports	LNG prices present Asian premiums (especially after nuclear shutdowns in Japan)
2014 -	LNG export projects commence and expand Increasing crude production increases gas	LNG exports increase mainly from Australia	LNG from the United States brings about flexibility in international LNG trades
2019	30 out of 70 million-tonne-per-year LNG export FIDs in the world come from the United States	Increasing supply lowers LNG and gas prices	A gap between domestic and international gas prices encourage projects in the United States
2020	Many LNG cargoes are cancelled in the Northern Hemisphere summer	Lowest ever LNG and gas prices with convergence between regions	Sluggish global gas prices lead to LNG cargo cancellations in the United States
2021	The United States dominates the incremental LNG supply in the global LNG market	Gas prices maintain high levels from the second half of 2021	LNG investment decisions are few despite higher LNG prices due to uncertainty
2022 -	**The United States becomes No 1 LNG exporter in 2023** **LNG project development entails uncertainty due to the pause of non-FTA export authorization and the court order to suspend construction approvals** A brief period of higher gas prices in the United States	**Significant reduction of Russian pipeline gas supply** **EU increases LNG imports supported by LNG from the United States** Natural gas prices become much volatile	LNG production development is accelerated around the world **The United States is expected to continue being a stable and enormous supply source to the global LNG market. Supports and encouragements from importing countries gain more importance**

LNG Procurement by Japanese Expects More Partnerships and Portfolio Players

- ✓ The task is how the gap between the already secured volume and projected future demand should be filled
- ✓ The Reference Scenario projects 45 million tonnes in 2050
  - ➢ It is increasingly difficult for an individual company to make a long-term procurement deal with large volume
  - ➢ Smaller volume requirement could lead to a weaker bargaining position

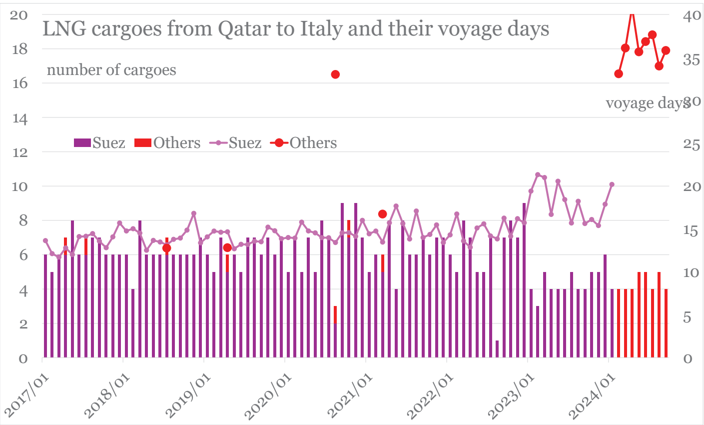
↓

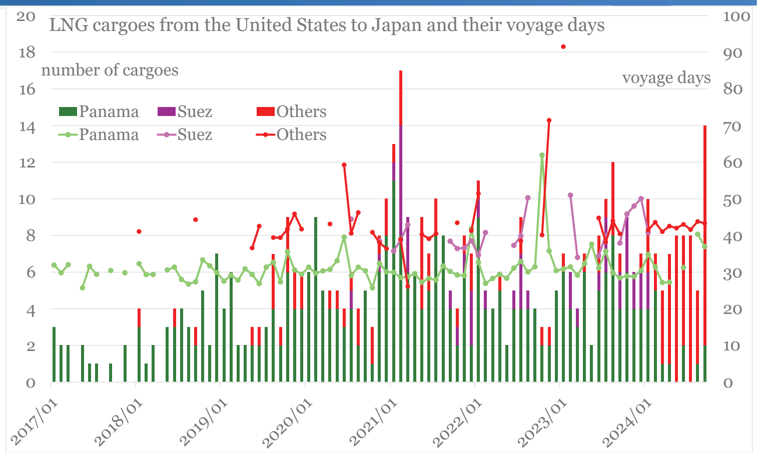
- ✓ Policy supports and company - government collaborations gain importance



The More LNG Is Transported, The More Evident Bottlenecks Are

- ✓ Bottlenecks on important shipping routes are likely to be a major obstacle in times of tight supply and demand
- ✓ After the Panama Canal was expanded in 2016, more LNG has been transported from the Atlantic to Asia
- ✓ In addition to the transit capacity limit, draughts restricts traffic, leading to alternative longer transportation routes
- ✓ The Red Sea - Suez Canal route has its own obstacles
- ✓ A long-term LNG transportation strategy is needed

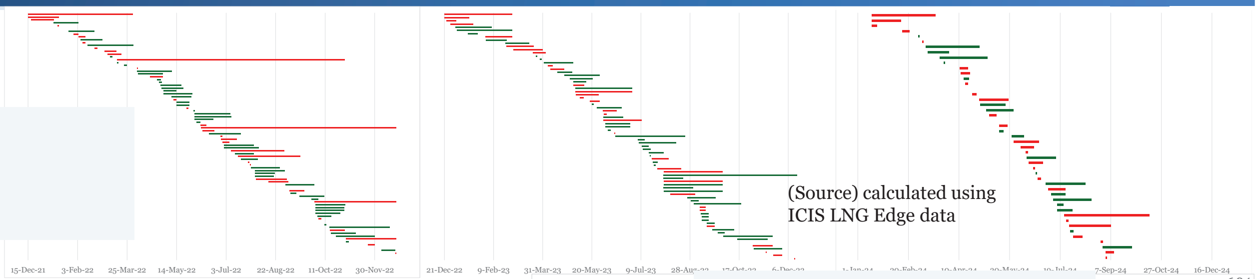




	Panama	Suez	Others	Total
2016				
2017	30			30
2018	30		43	31
2019	30		41	33
2020	31	41	43	33
2021	30	39	39	32
2022	32	40	50	34
2023	31	44	49	35
2024	32	41	42	39

(Source) calculated using ICIS LNG Edge data

Unplanned Outages of LNG Production Amplify Market Imbalances

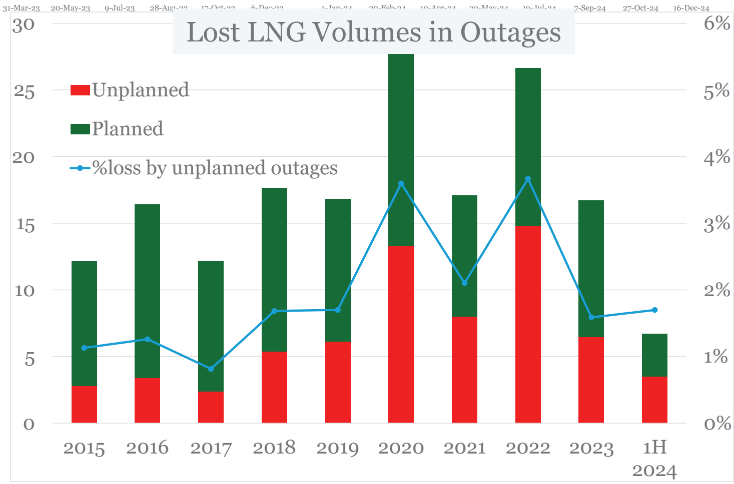


(Source) calculated using ICIS LNG Edge data

- ✓ There was a lengthy unplanned outage caused by a fire incident at a large-scale LNG export facility in the United States in 2022, as well as relatively long unplanned outages in other producing countries
- ✓ At the time of slim supply margins, spot prices were further pushed up by the loss caused by unplanned outages

Average day changes of spot gas and LNG prices

	2010	2011	2012	2013	2014	2015	2016
TTF	0.12	0.13	0.09	0.07	0.13	0.07	0.09
Spot LNG	0.09	0.12	0.12	0.11	0.15	0.11	0.12
2017	2018	2019	2020	2021	2022	2023	2024
0.08	0.13	0.13	0.09	0.85	2.42	0.61	0.26
0.10	0.16	0.11	0.19	1.01	2.37	0.52	0.25



Reference materials

Geographical coverage

- Countries/regions in the world are geographically aggregated into 44 regions.
- Especially the Asian energy supply/demand structure is considered in detail, aggregating the area into 17 regions. That of the Middle East is also aggregated into eight regions

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

Modelling framework

Major assumptions
GDP, population, energy prices, exchange rates, international trade, etc.

Macroeconomic model
Calculate GDP-related indices, price indices, activity indices including material production, etc. consistently.

Technology assessment model
Use a bottom-up approach to calculate future efficiencies of appliances, vehicles, etc.

Optimal power generation planning model
Calculate the cost-optimal power generation mix to meet the projected future electricity demand.

Energy supply-demand model
Econometric model to project future energy supply and demand by regression analysis of historical trends based on the energy balance tables data of the International Energy Agency.

This model calculates energy demand, supply and transformation as well as related indices including CO_2 emissions, CO_2 intensities and energy self-sufficiency ratios.

Experts' opinions

World trade model
Use the linear programming (LP) method to calculate the future international trade flows of crude oil, petroleum products, etc.

Computable general equilibrium model
Estimate economic impacts induced by changes in energy supply and demand, based on input-output table data.

Climate change model
Calculate future GHG concentration in the atmosphere, temperature rise, damage caused by climate change, etc.

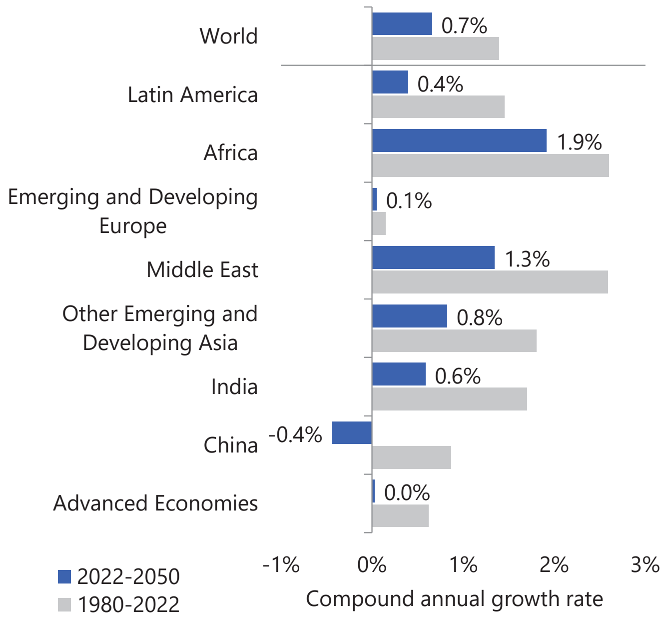
Basic scenarios in IEEJ Outlook

	Reference Scenario	Advanced Technologies Scenario
	Reflects past trends with technology progress and current energy policies, without any aggressive policies for low-carbon measures	Assumes introduction of powerful policies to address energy security and climate change issues with the utmost penetration of low-carbon technologies
Socio-economic structure	Stable growth led by developing economies despite slower population growth. Rapid penetration of energy consuming appliances and vehicles due to higher income.	
International energy prices	**Oil** supply cost increases along with demand growth. **Natural gas** prices converge among Europe, North America and Asia markets. **Coal** price decreases due to request for decarbonization.	All prices decrease along with decrease in demand due to progress in energy saving and request for decarbonization
		Further reinforcement of domestic policies along with international collaboration
Energy and environmental technologies	Improving efficiency and declining cost of existing technology with past pace	Further declining cost of existing and promising technology

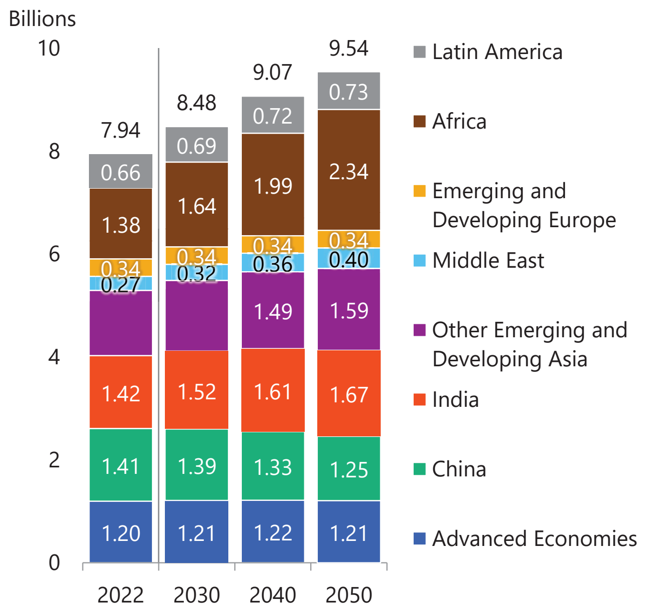
Assumptions

Population

CAGR



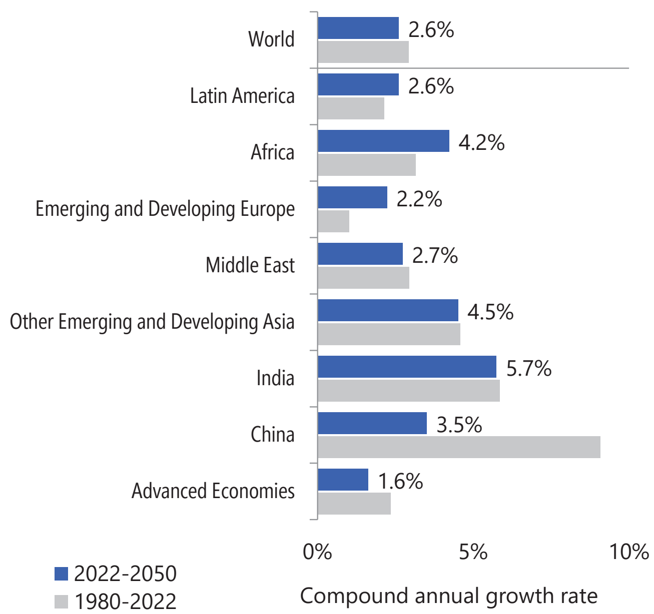
Composition



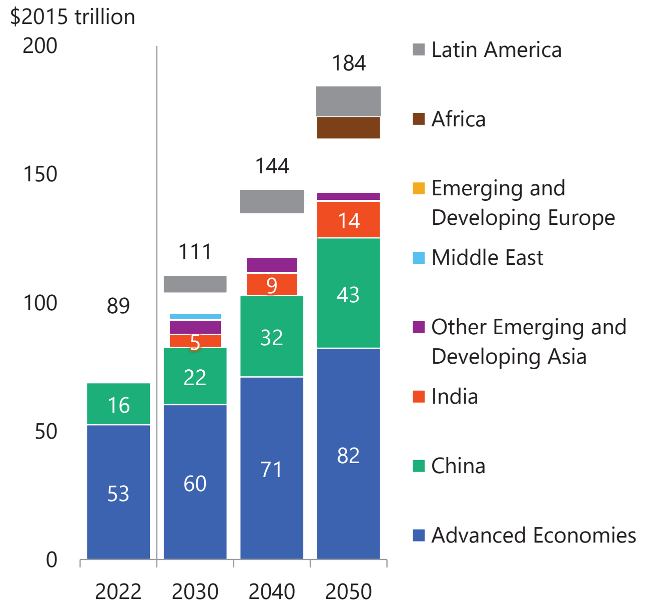
Assumptions

Real GDP

CAGR



Composition

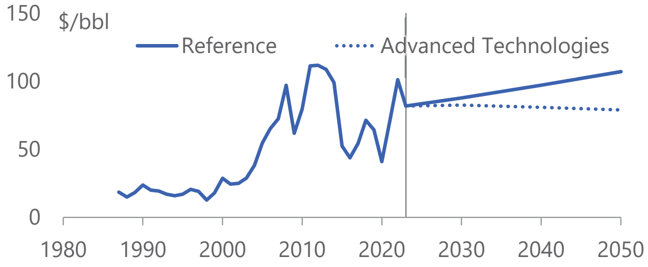


Assumptions

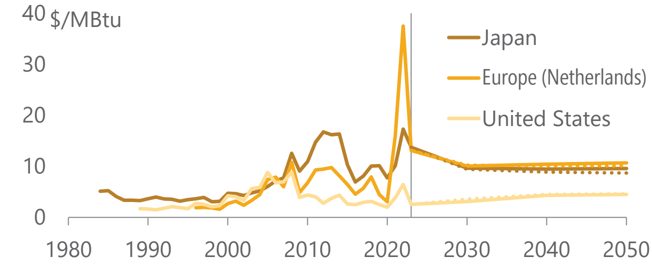
International energy prices

Reference : ———— Advanced Technologies : ··········

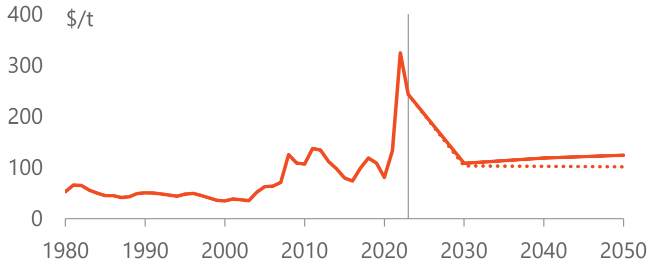
Crude oil



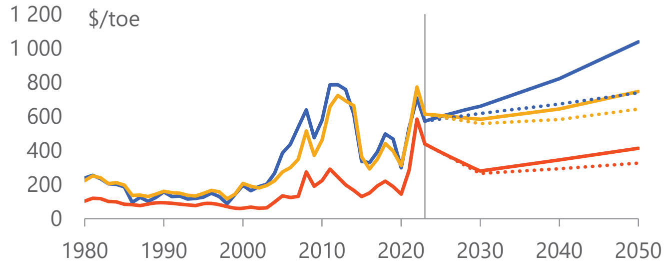
Natural gas



Coal



CIF import prices for Japan



Note: Historical prices are nominal. Assumed future prices are real in $2023.

Assumptions

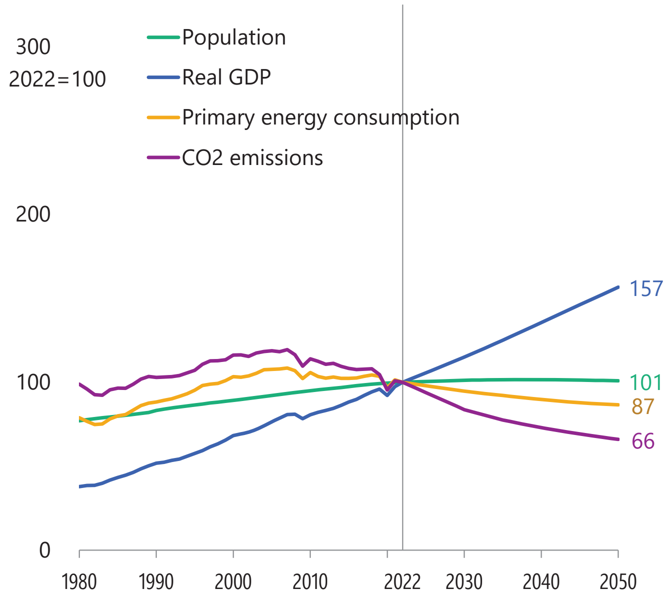
Energy and environmental technology

			2022	2050 Reference	2050 Advanced Technologies	Assumptions for Advanced Technologies Scenario
Improving energy efficiency	Industry	Intensity in steel industry (ktoe/kt)	0.270	0.260	0.201	100% penetration of Best Available Technology by 2050.
		Intensity in non-metallic minerals industry	0.095	0.074	0.065	
	Transport	Electrified vehicle share in passenger car sales	17%	60%	96%	Cost reduction of electrified vehicles. Promotion measures including fuel supply infrastructure. *electrified vehicle includes hybrid vehicle, plug-in hybrid vehicle, electric vehicle and fuel-cell vehicle
		Average fuel efficiency in new passenger car (km/L)	17.8	27.2	46.2	
	Buildings	Residential total efficiency (Y2022=100)	100	141	175	Efficiency improvement at 1.7 times the speed for installed appliance, equipment and insulation. Electrification in space heating, water heater and cooking (clean cooking in developing regions).
		Commercial total efficiency	100	131	172	
	Power generation	Thermal generation efficiency (Power transmission end)	37%	45%	48%	Financial scheme for initial investment in high-efficient thermal power plant.
Penetrating low-carbon technology	Biofuels for transport (Mtoe)		99	178	303	Development of next generation biofuel with cost reduction. Relating to agricultural policy in developing regions.
	Nuclear power generation capacity (GW)		387	498	814	Appropriate price in wholesale electricity market. Framework for financing initial investment in developing regions.
	Wind power generation capacity (GW)		962	3 548	5 156	Further reduction of generation cost. Cost reduction of grid stabilization technology. Efficient operation of power system.
	Solar PV power generation capacity		1 107	8 214	10 693	
	Thermal power generation capacity with CCS (GW)		0	0	1 137	Installing CCS after 2030 (regions which have storage potential except for aquifer).
	Zero-emission generation ratio (incl. CCS)		39%	60%	87%	Efficient operation of power system including international power grid.

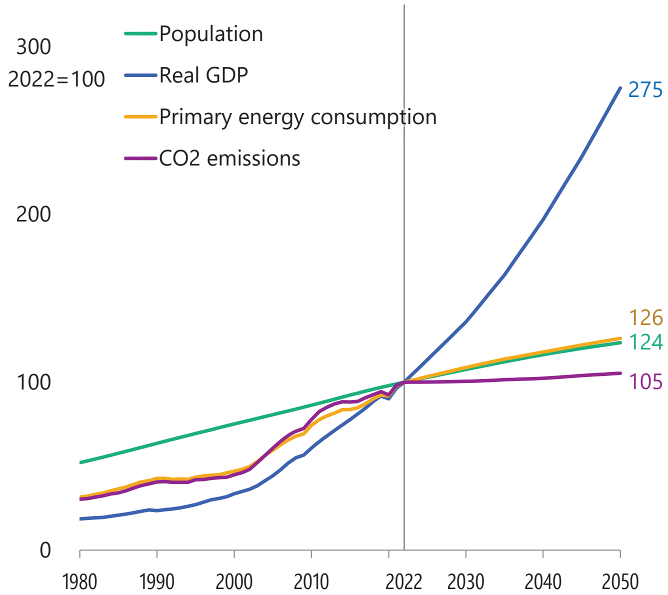
Reference Scenario

Population, GDP, energy and CO_2

Advanced Economies



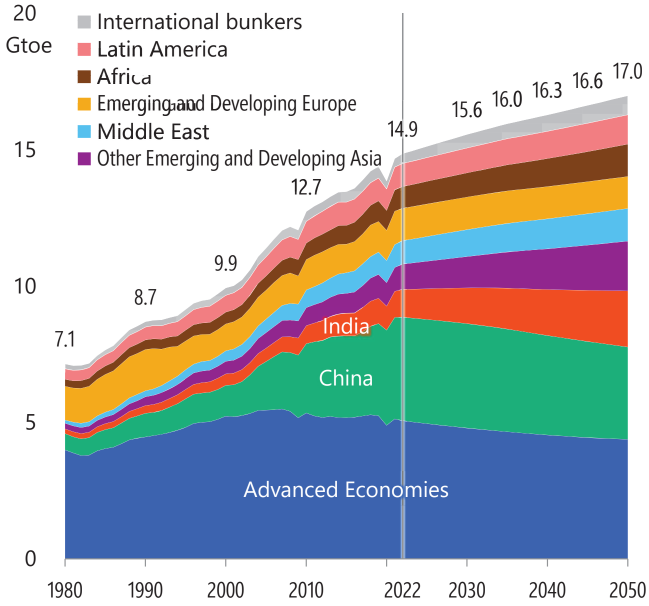
Emerging and Developing Economies



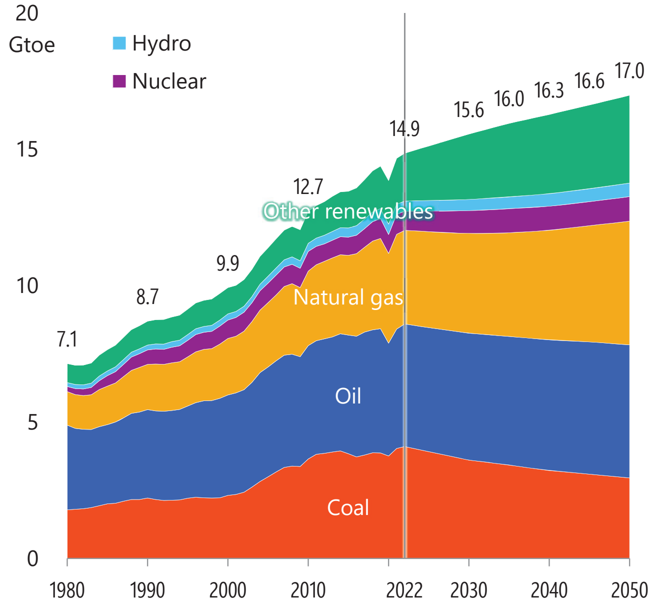
Reference Scenario

Primary energy consumption

By region

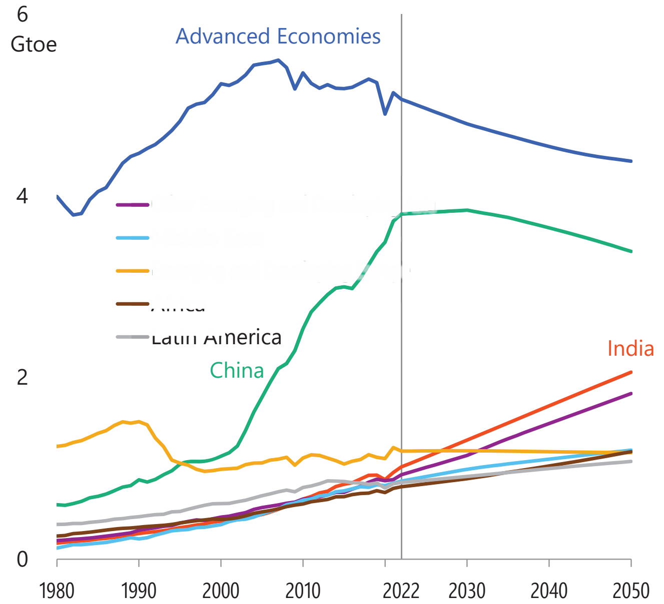


By energy source

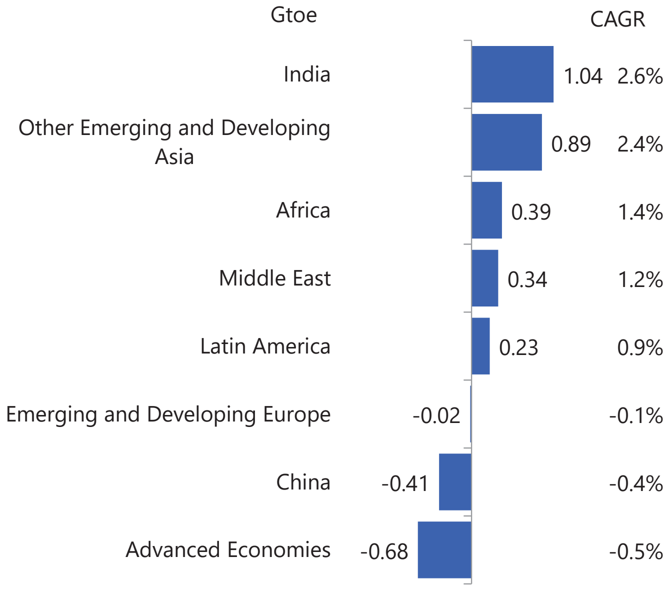


Primary energy consumption (by region)

Energy consumption

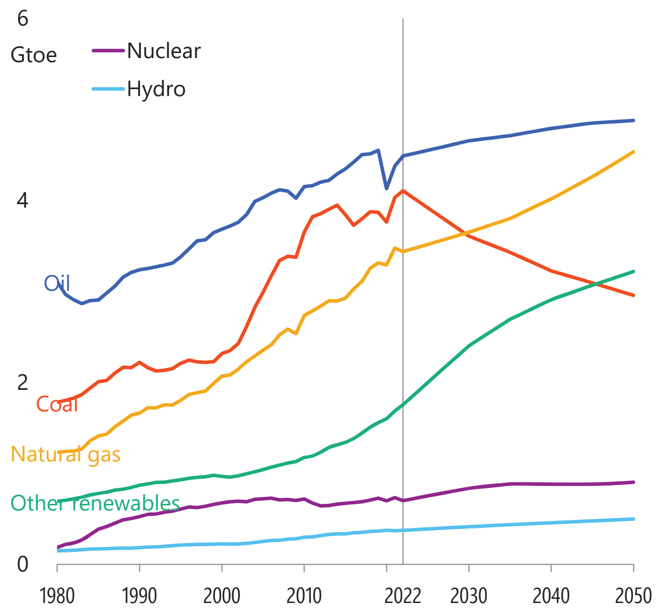


Changes (2022-2050)

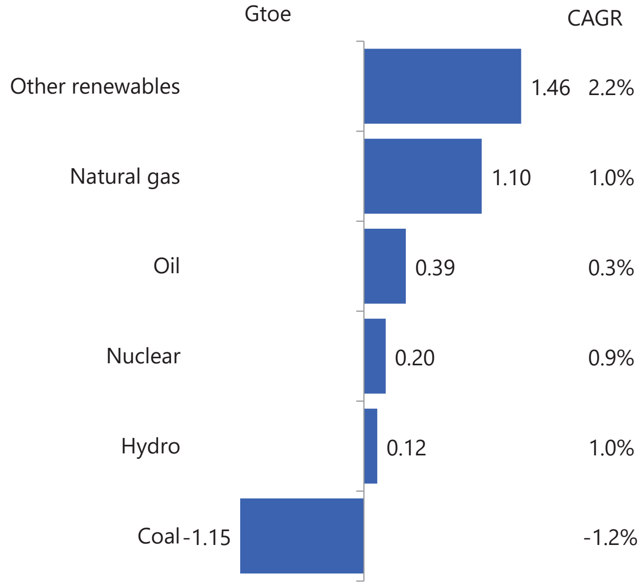


Primary energy consumption (by energy source)

Energy consumption

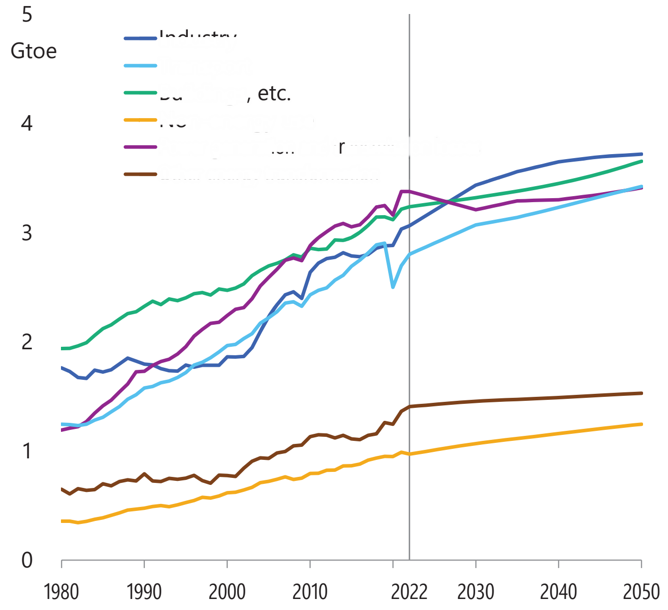


Changes (2022-2050)

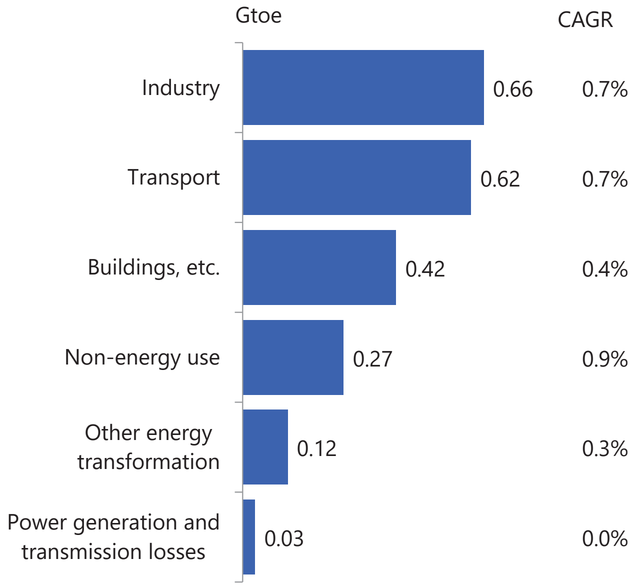


Primary energy consumption (by sector)

Energy consumption



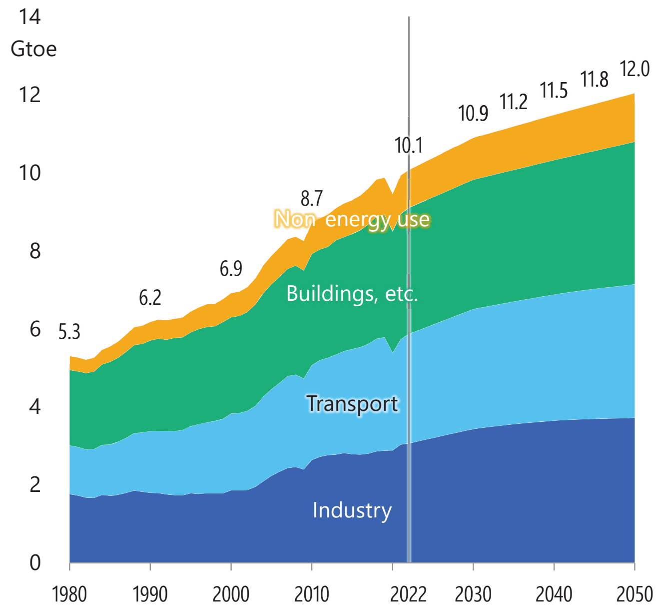
Changes (2022-2050)



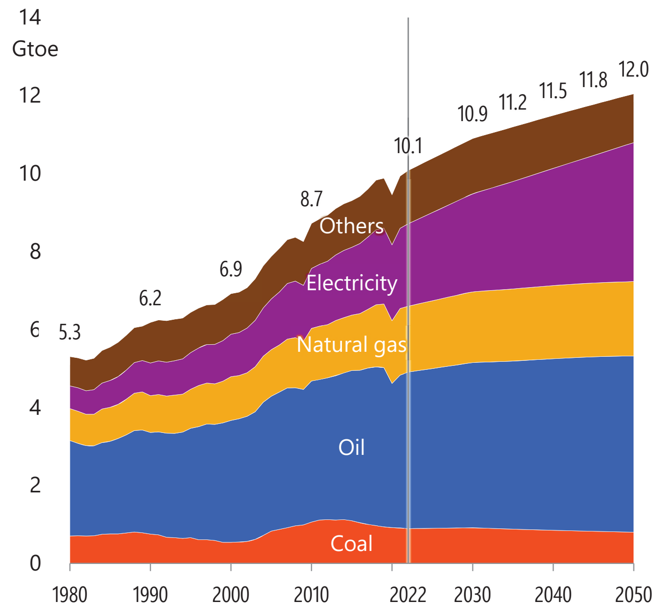
Reference Scenario

Final energy consumption

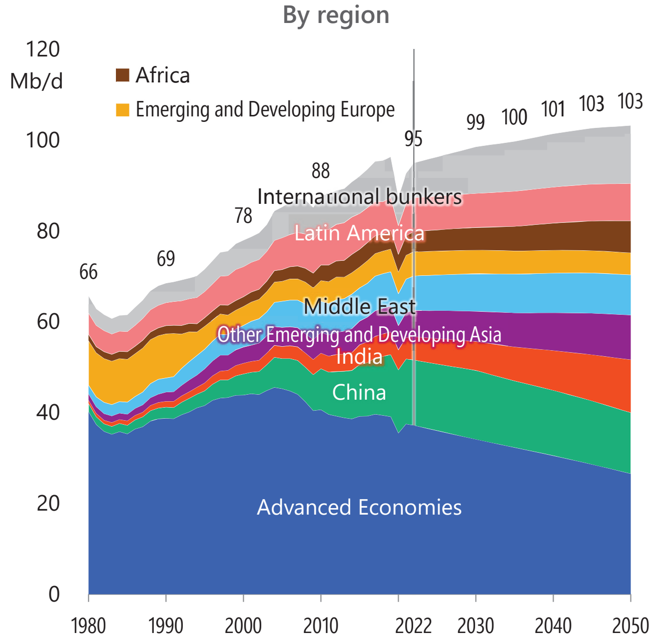
By sector

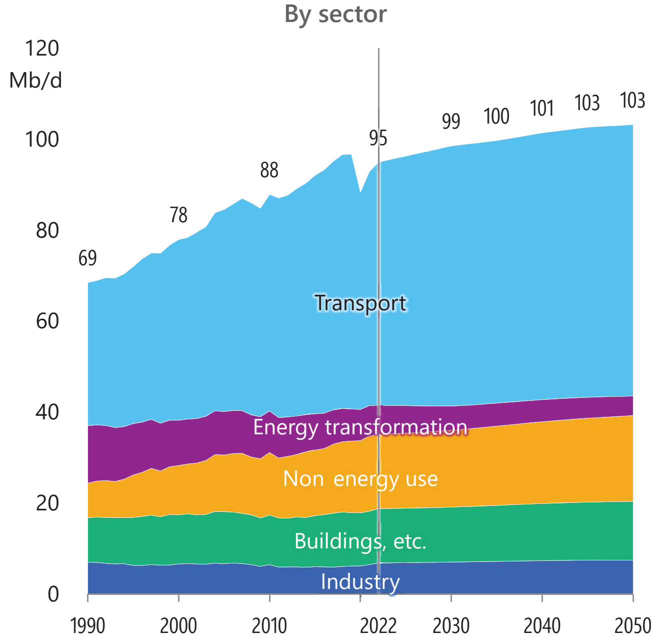


By energy source



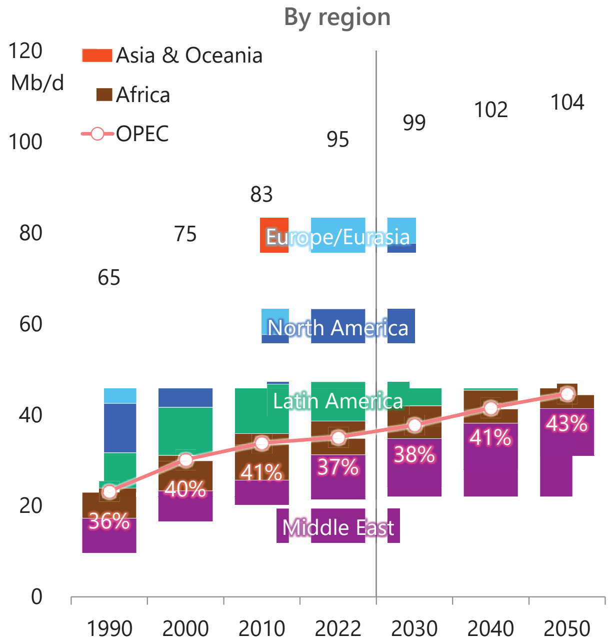
Oil consumption

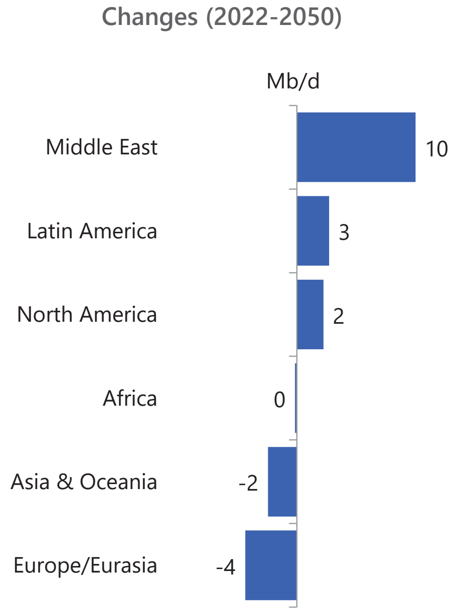




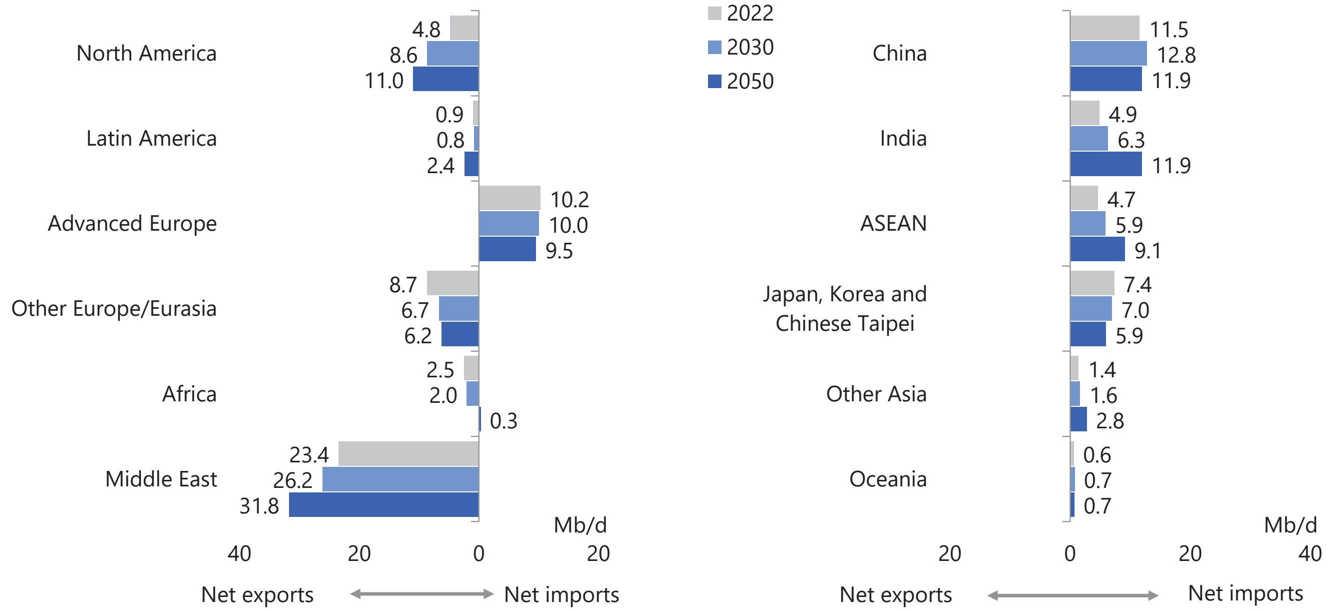
Reference Scenario

Crude oil production

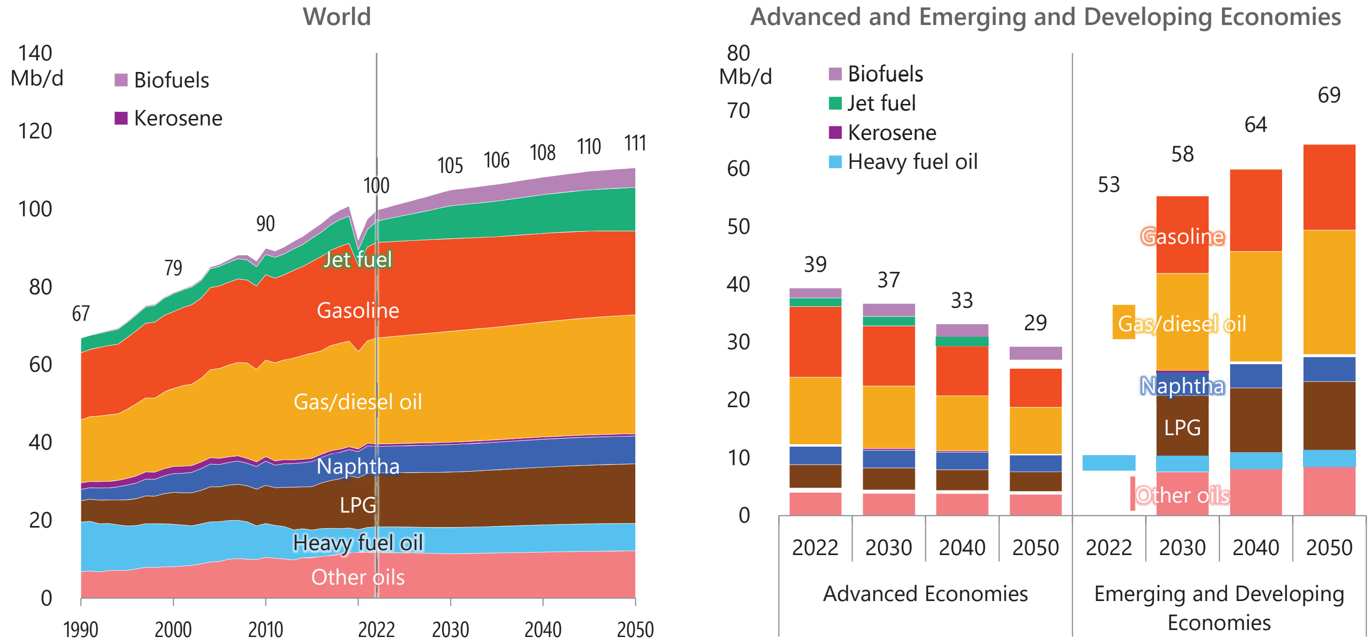




Net exports and imports of oil

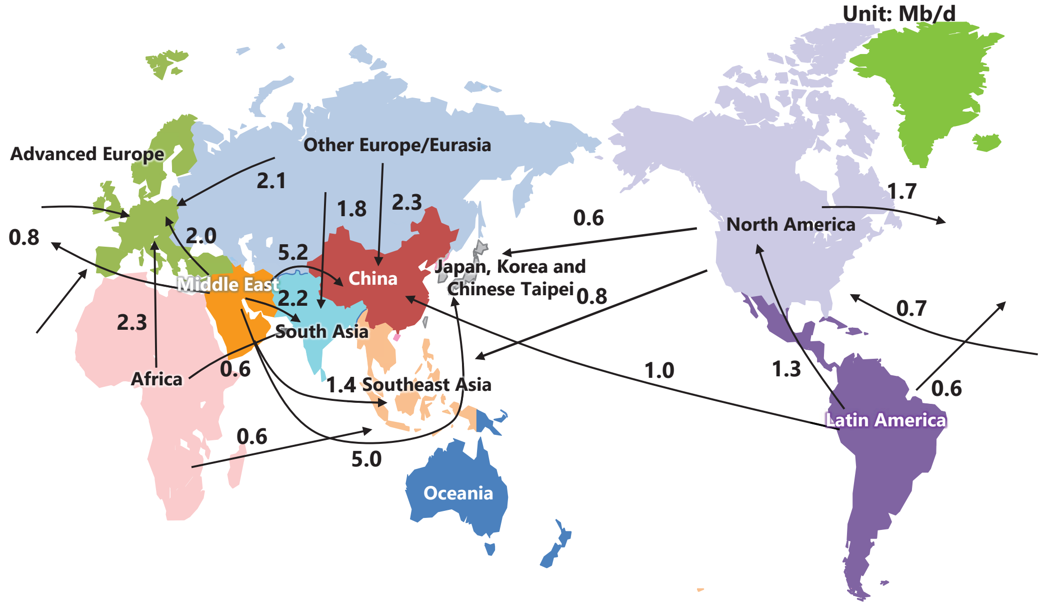


Petroleum product demand



Note: Other oils includes crude oil (direct consumption), asphalt, refinery gas, gas-liquefied oil [GTL], etc.

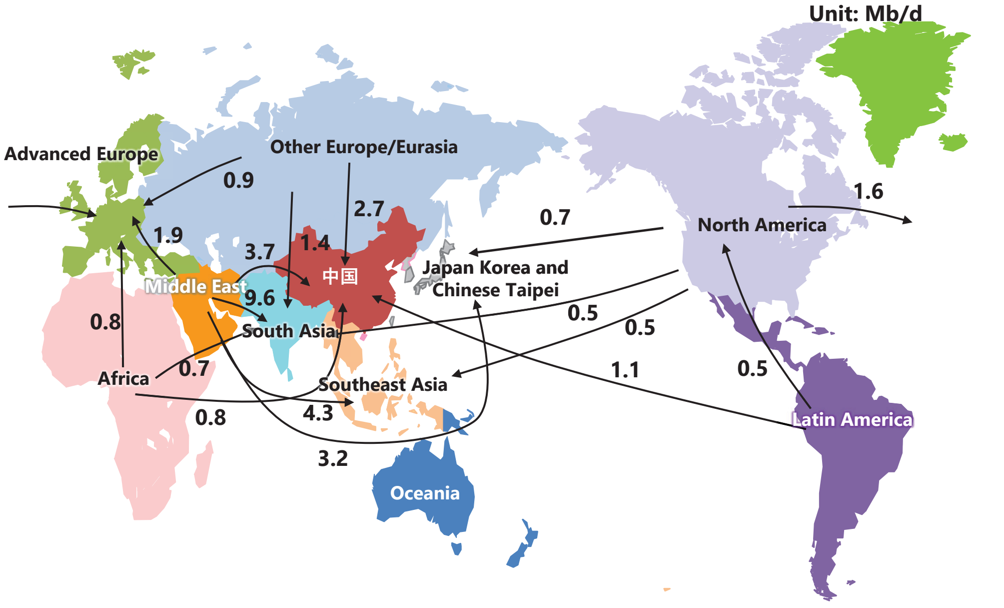
Major trade flows of crude oil (2023)



Note: 0.5 Mb/d or more are shown

Reference Scenario

Major trade flows of crude oil (2050)

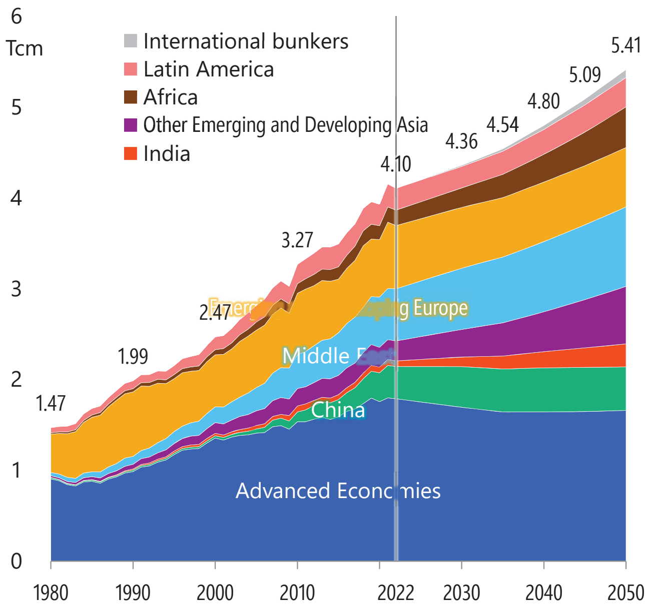


Note: 0.5 Mb/d or more are shown

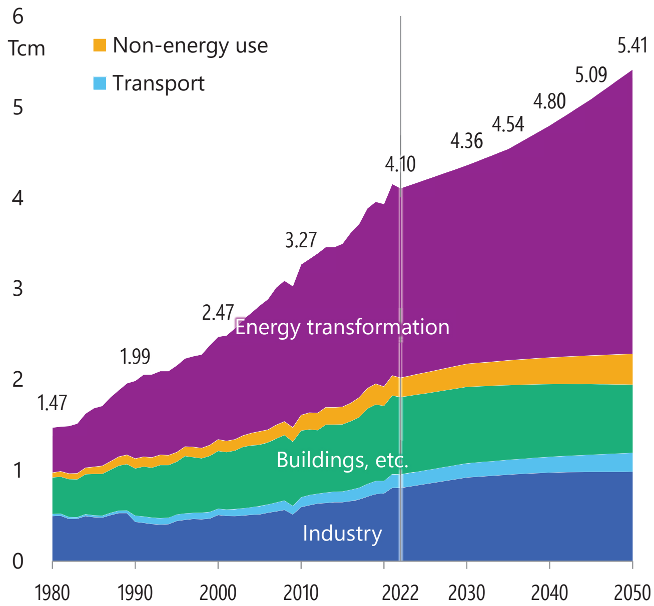
Reference Scenario

Natural gas consumption

By region



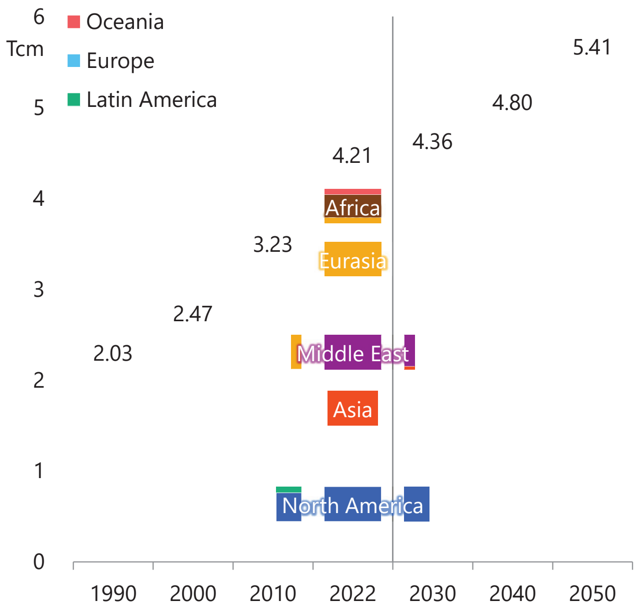
By sector



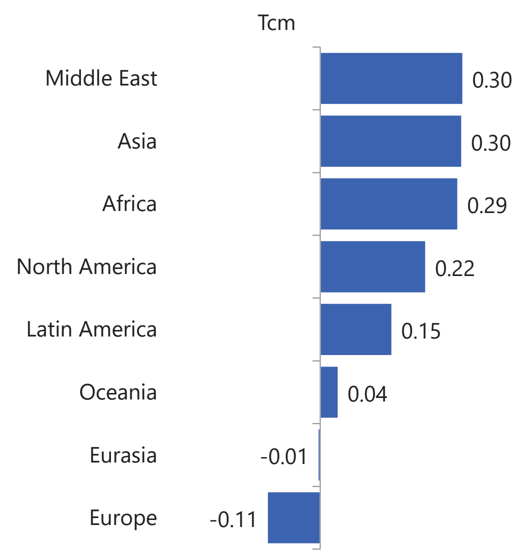
Reference Scenario

Natural gas production

By region

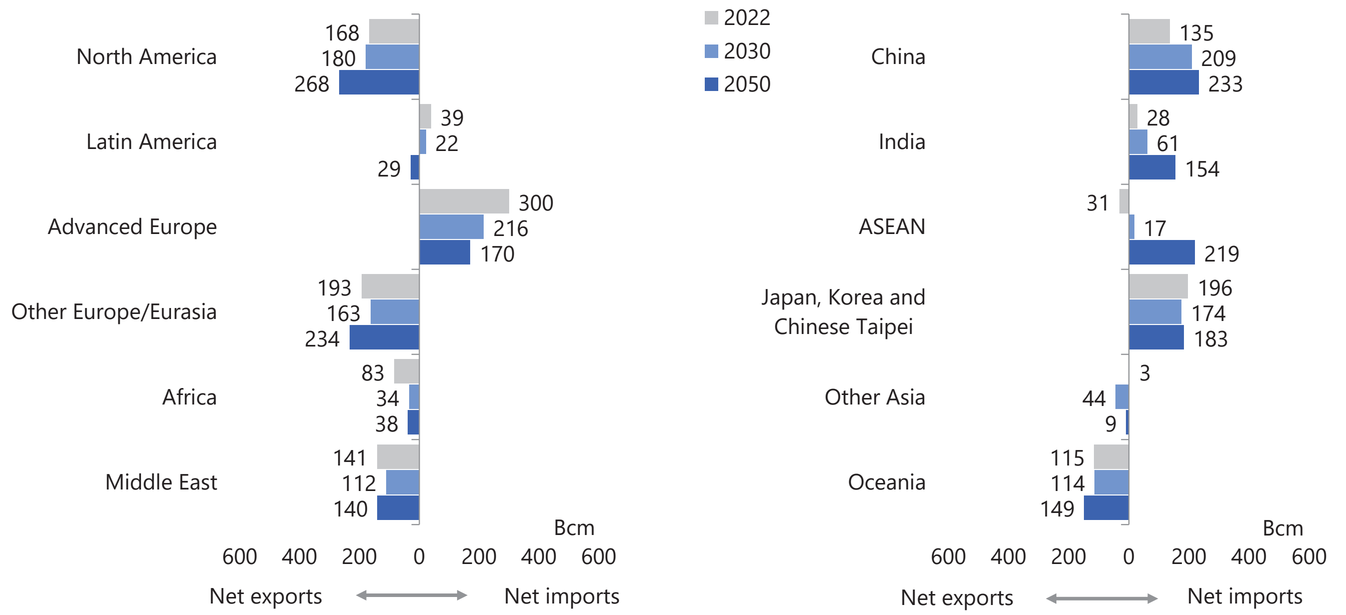


Changes (2022-2050)



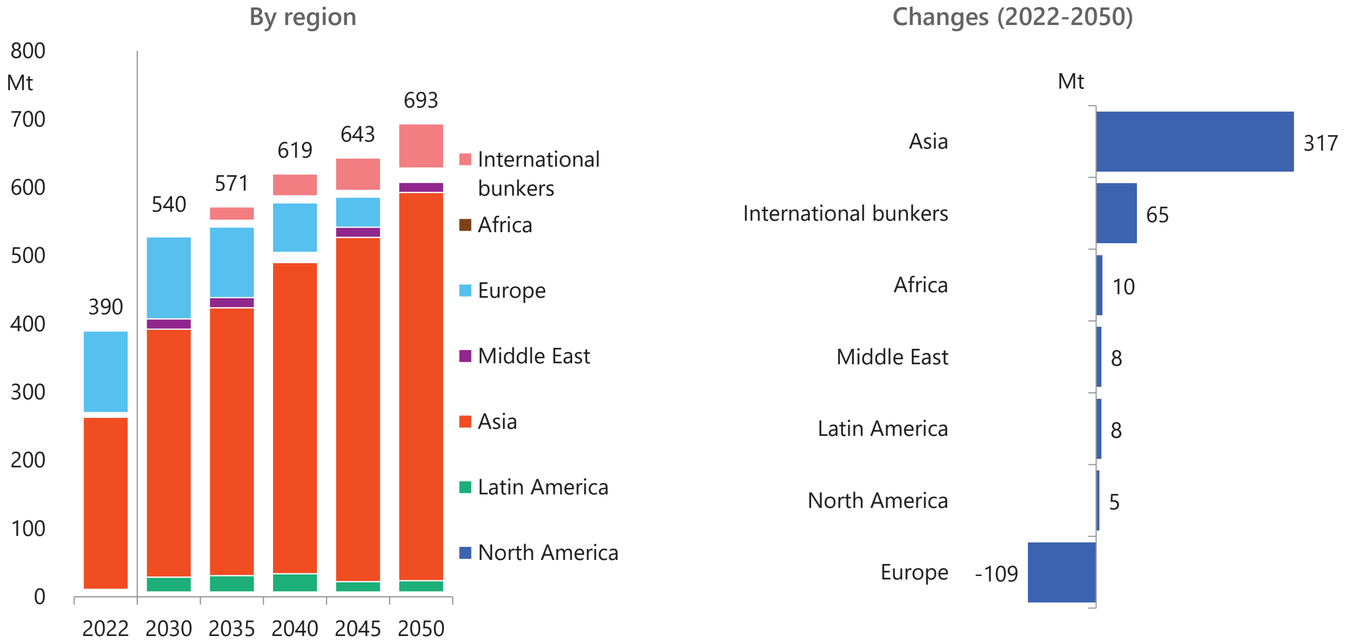
Reference Scenario

Net exports and imports of natural gas

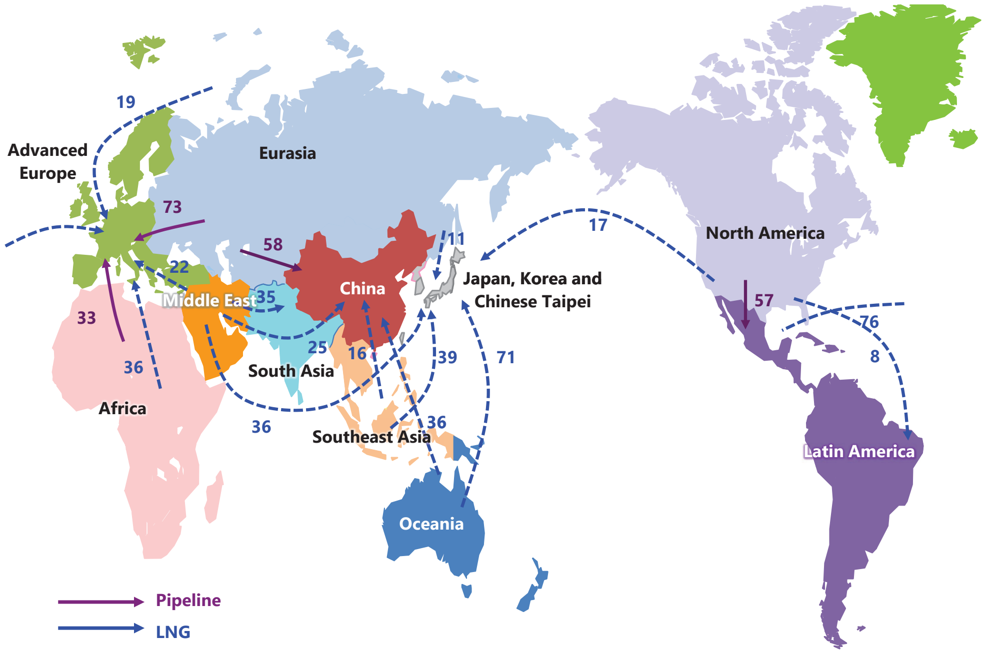


Reference Scenario

LNG demand



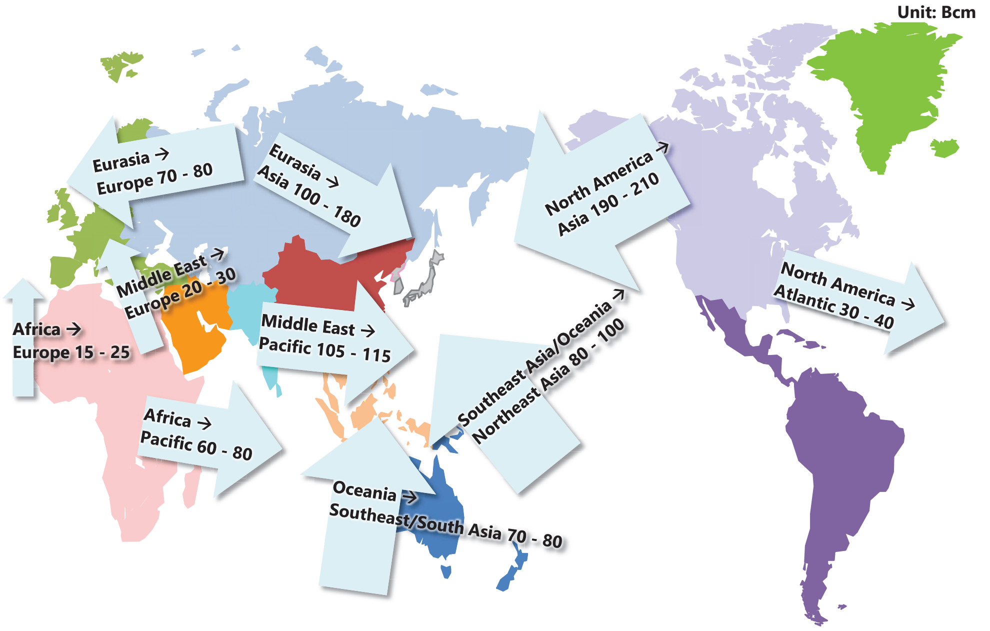
Major trade flows of natural gas (2023)



Note: This figure shows the main interregional trade and does not include the total trade volume.

Reference Scenario

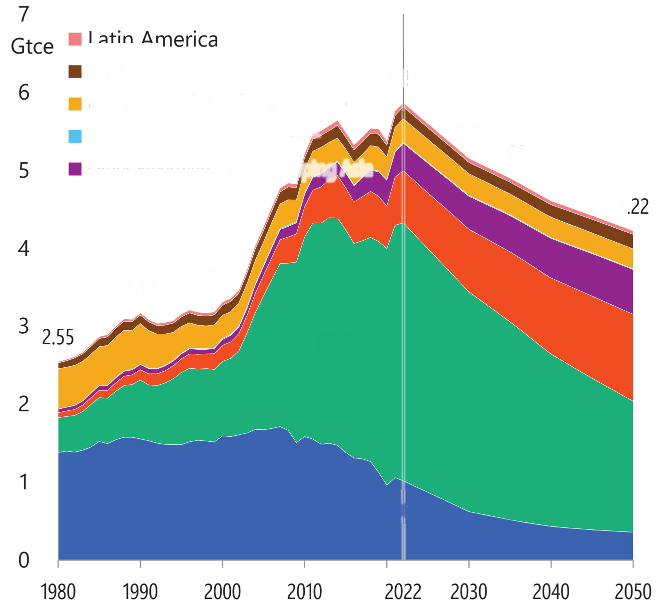
Major trade flows of natural gas (2050)



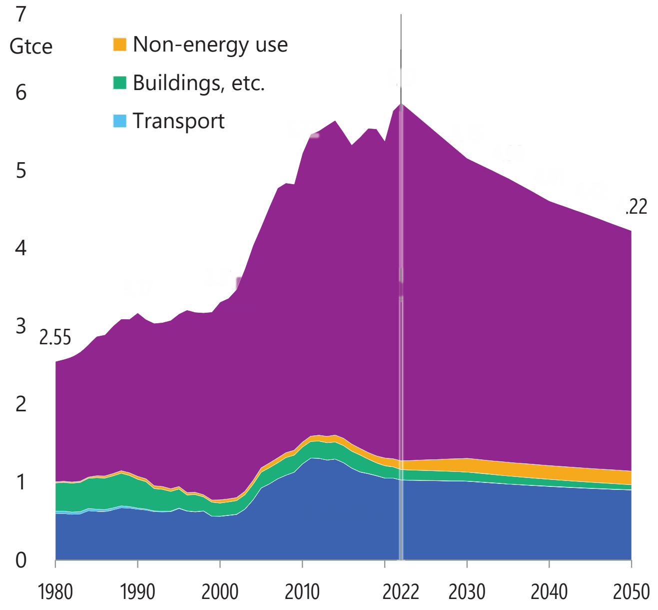
Note: This figure shows the main interregional trade and does not include the total trade volume.

Coal consumption

By region

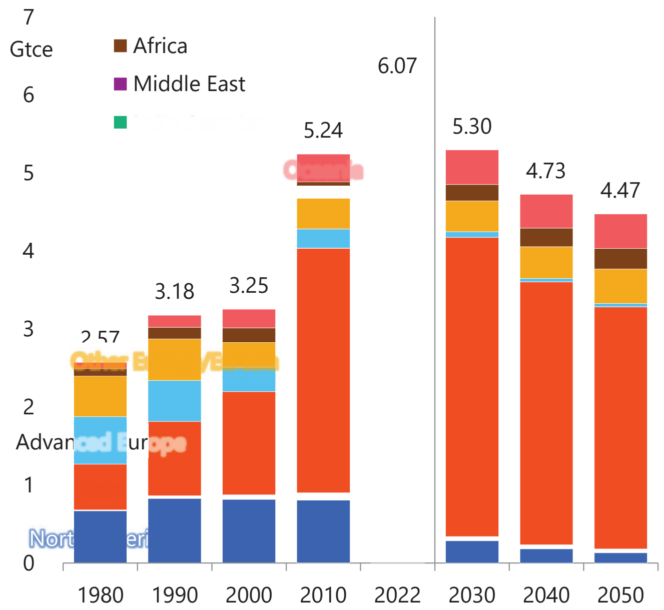


By sector

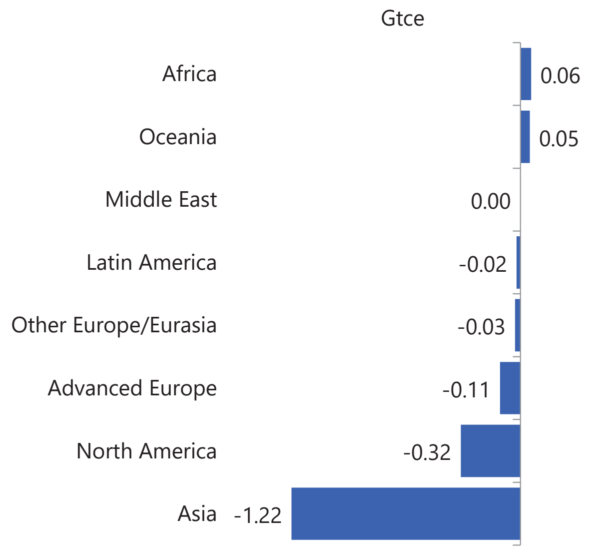


Coal production

By region

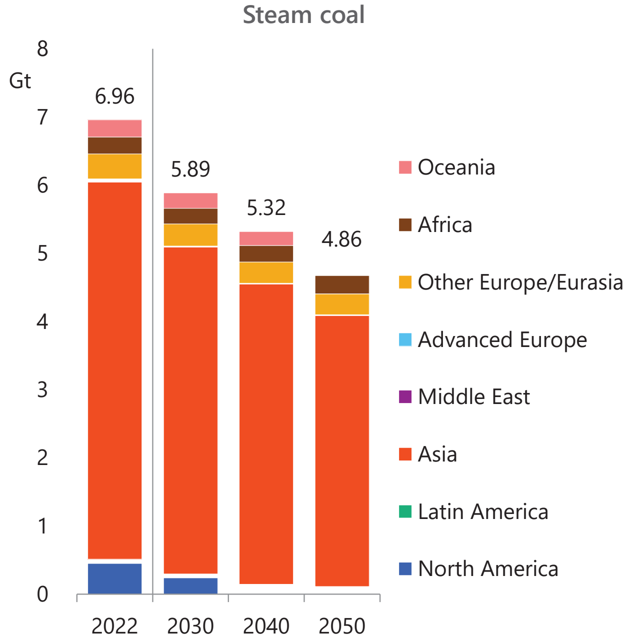


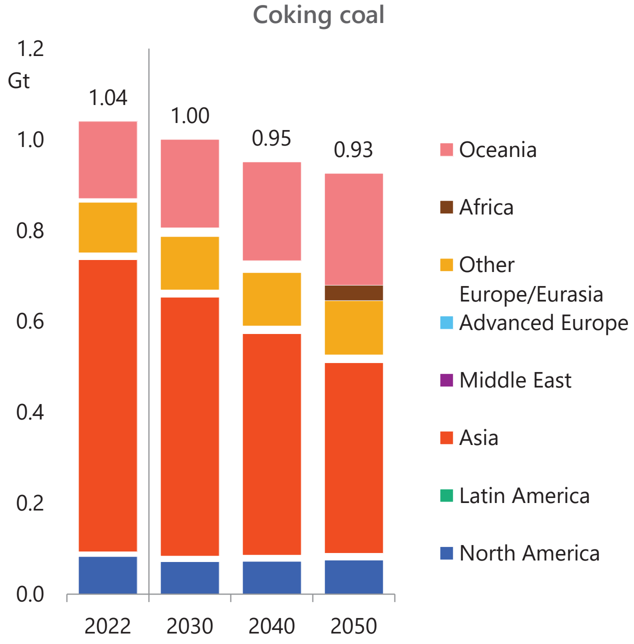
Changes (2022-2050)



Reference Scenario

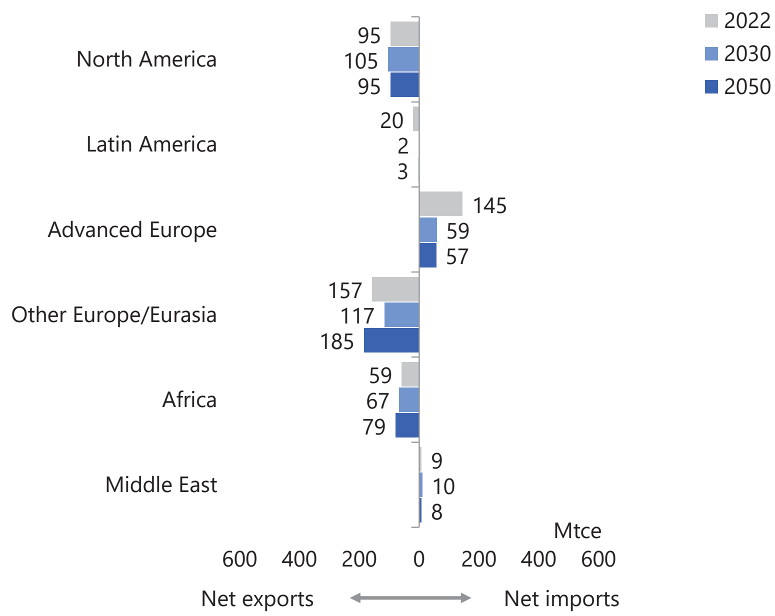
Coal production (steam and coking coal)

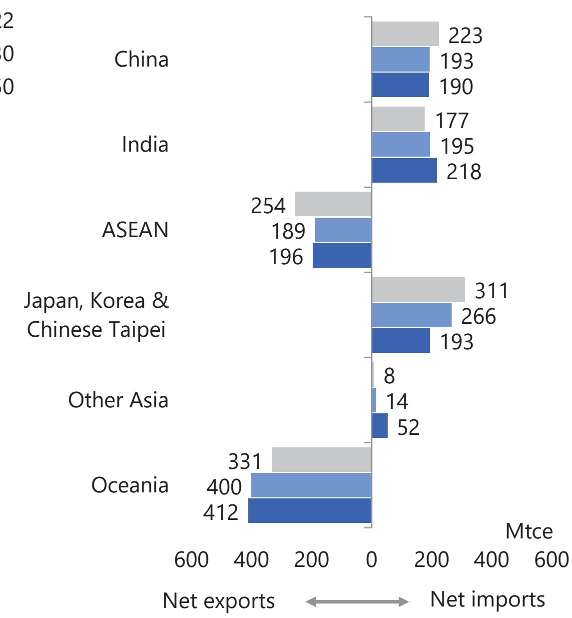




Reference Scenario

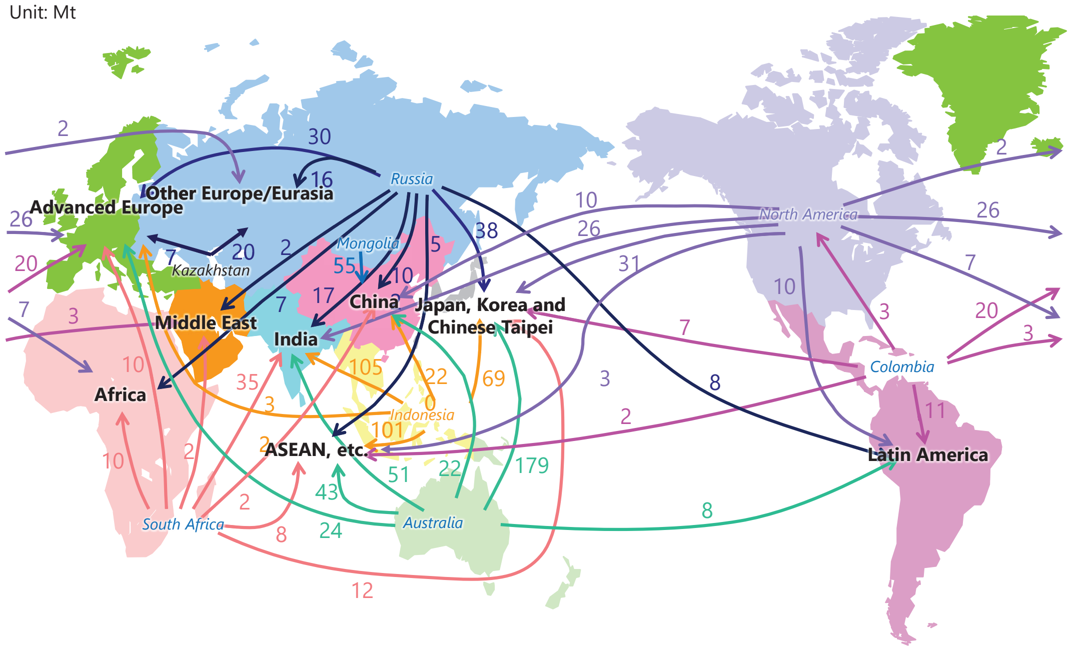
Net exports and imports of coal





Major trade flows of steam and coking coal (2023)

Unit: Mt

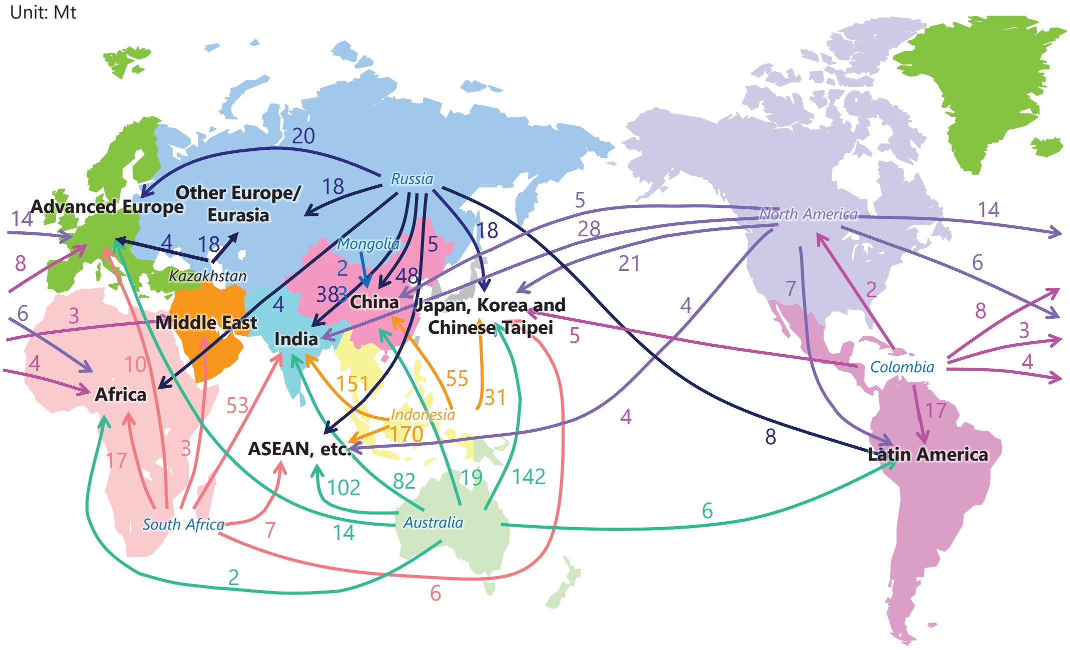


Notes: Total value of steam and coking coal. 2 Mt or more are shown. South Africa includes Mozambique. Source:E stimated from IEA "Coal Information 2024", "TEX Report", etc.

Reference Scenario

Major trade flows of steam and coking coal (2050)

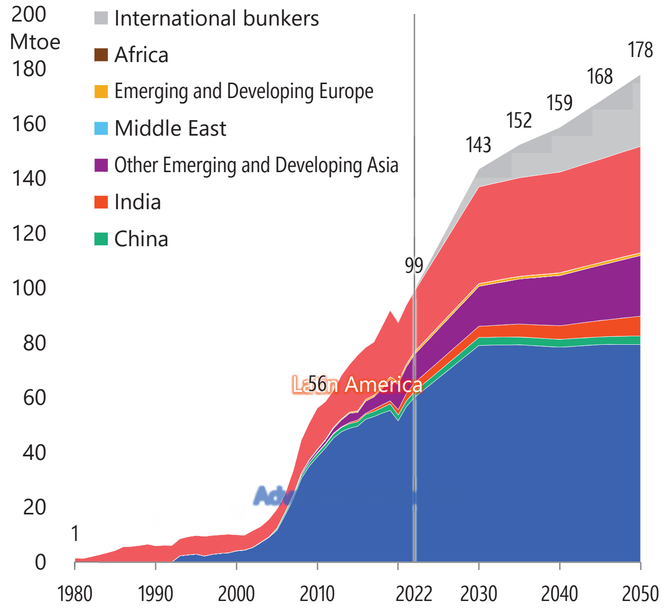
Unit: Mt



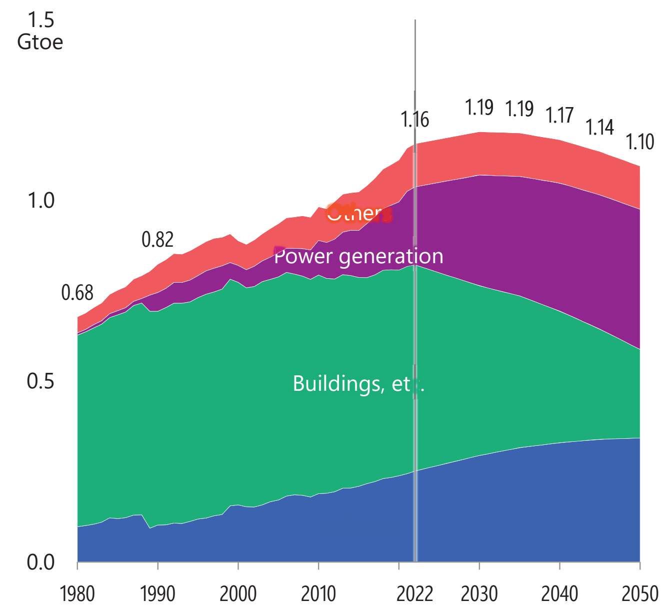
Notes: Total value of steam and coking coal. 2 Mt or more are shown. South Africa includes Mozambique.

Biomass consumption

Biofuels for transport

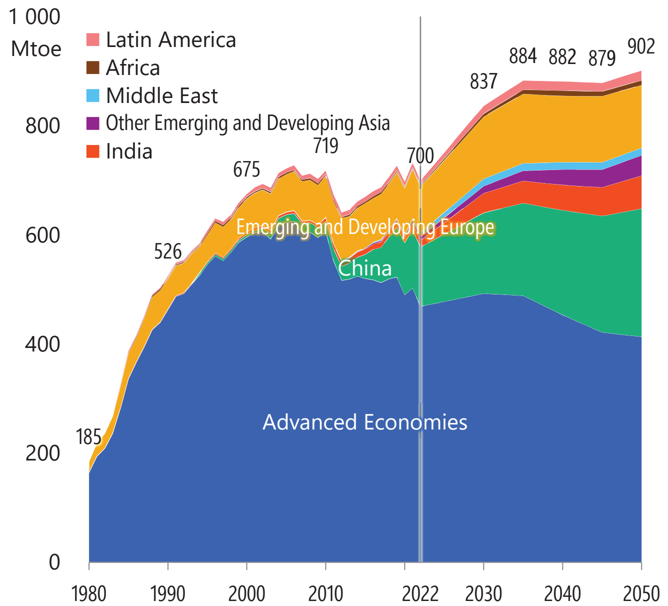


Solid biomass

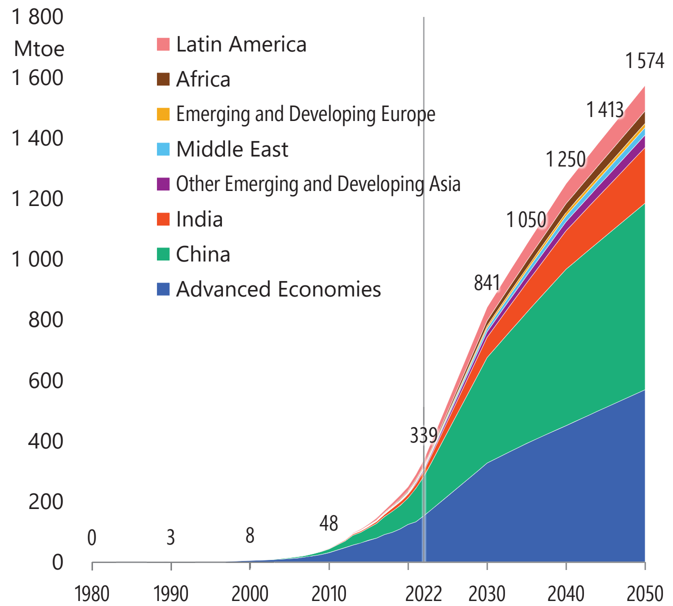


Consumption of nuclear and solar/wind/other

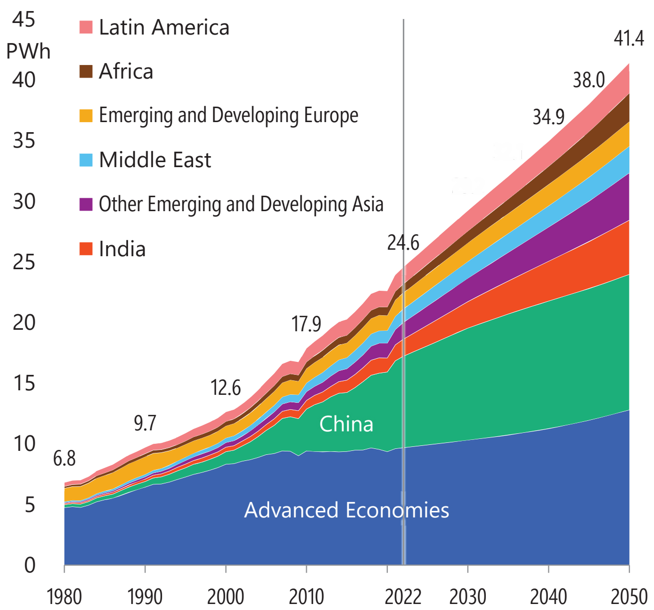
Nuclear

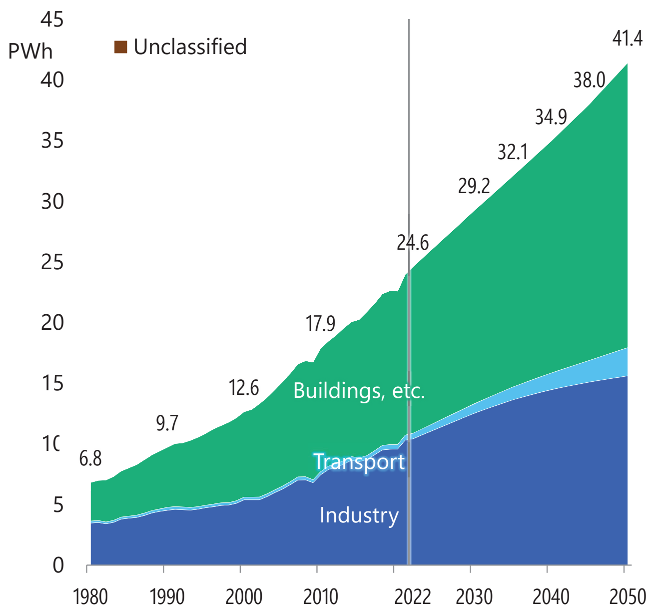


Solar/wind/other

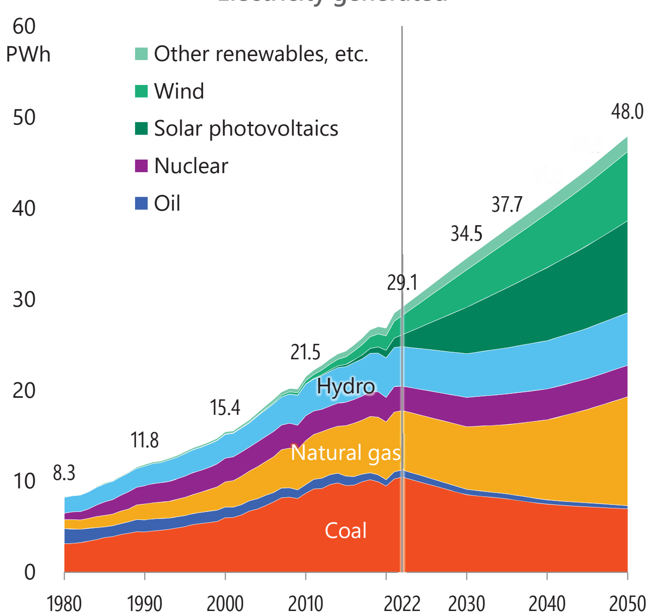


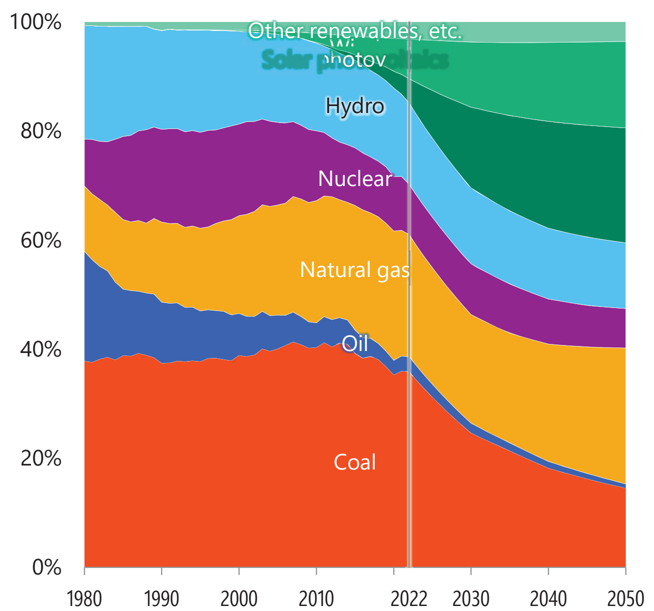
Final consumption of electricity





Power generation mix

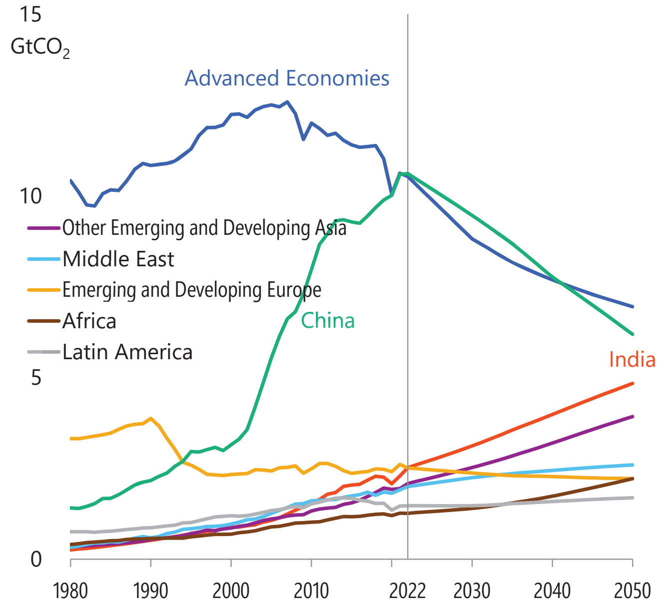




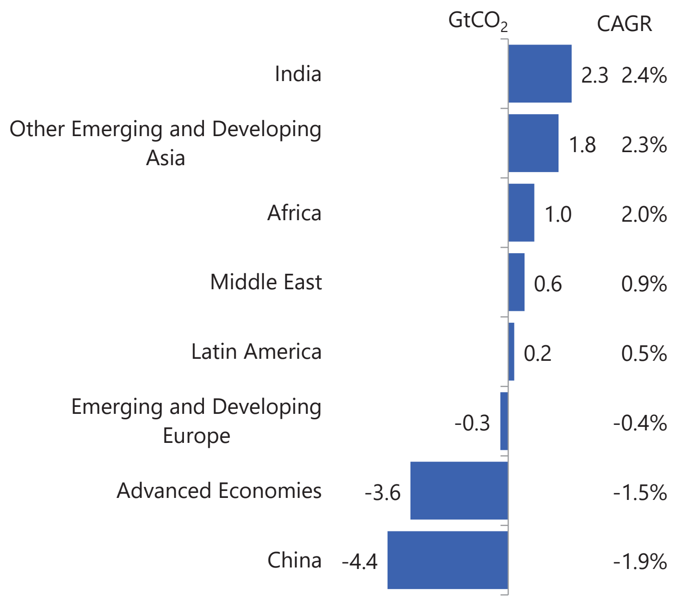
Reference Scenario

Energy-related CO_2 emissions

Emissions



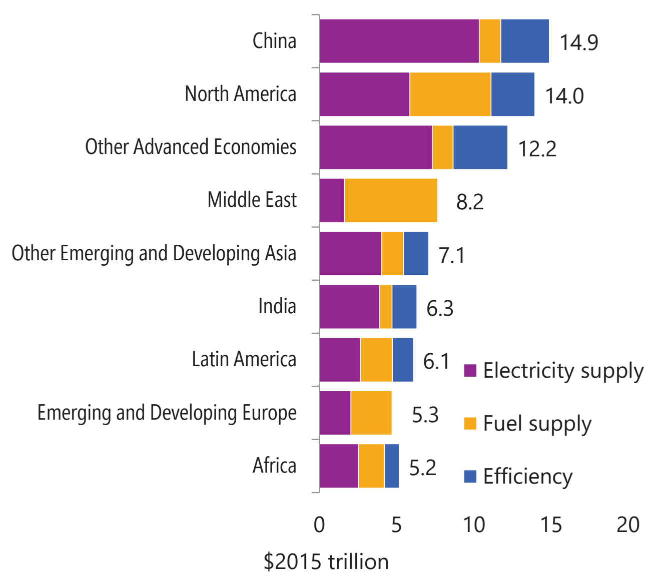
Changes (2022-2050)



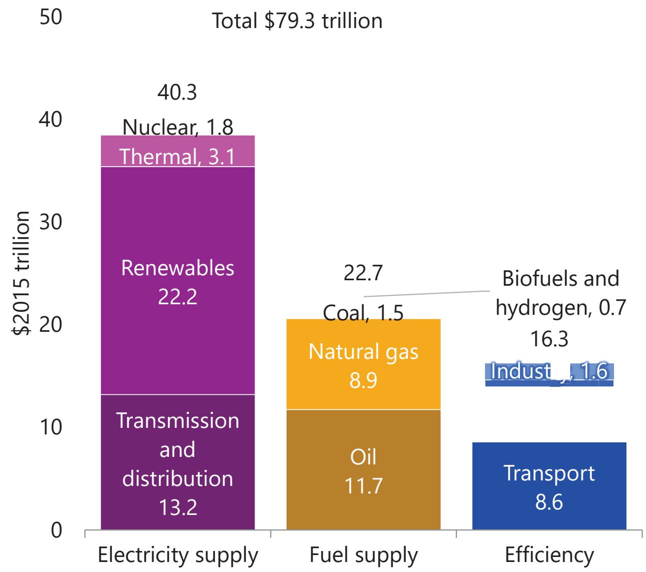
Reference Scenario

Energy-related investments (2023–2050)

By region

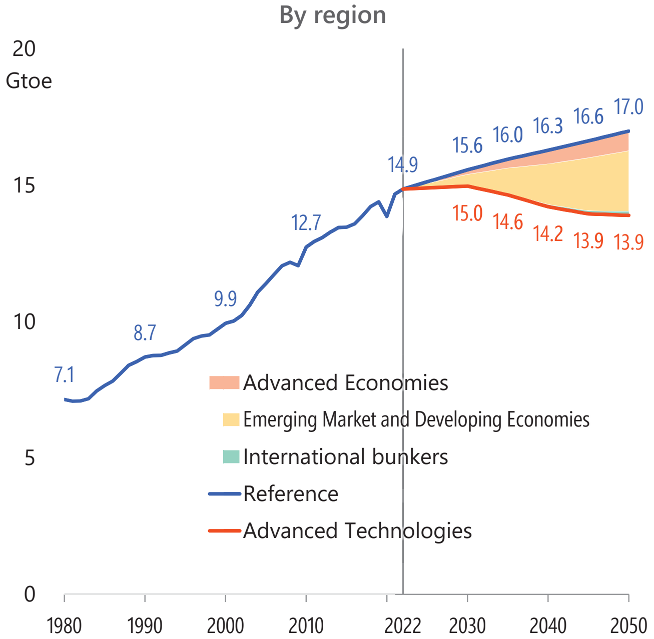


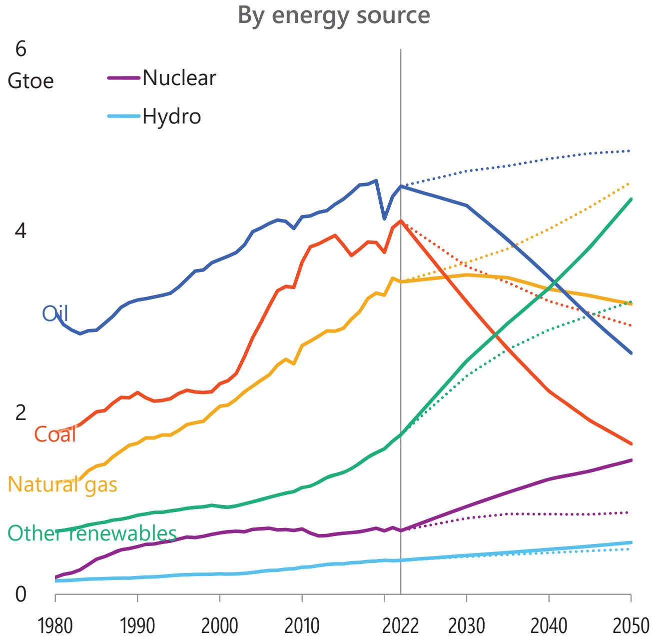
By sector



Advanced Technologies Scenario

Primary energy consumption

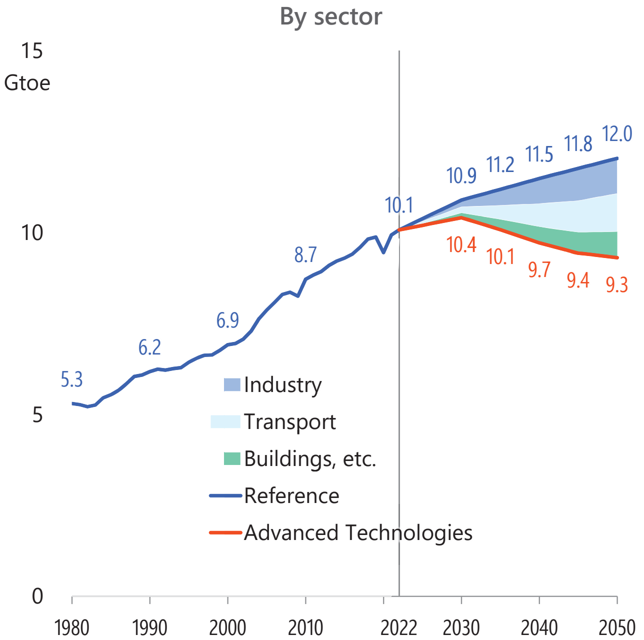


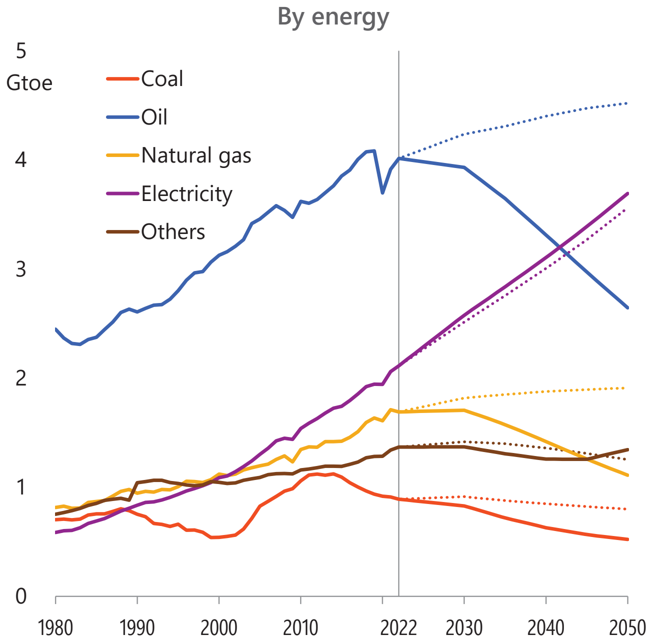


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

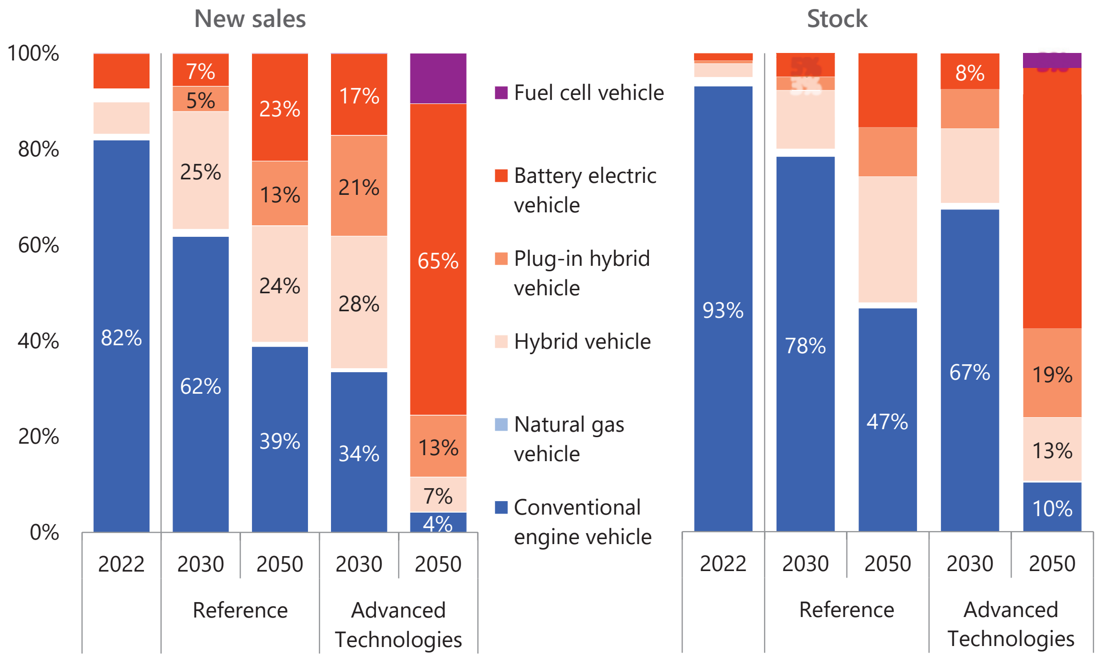
Advanced Technologies Scenario

Final energy consumption



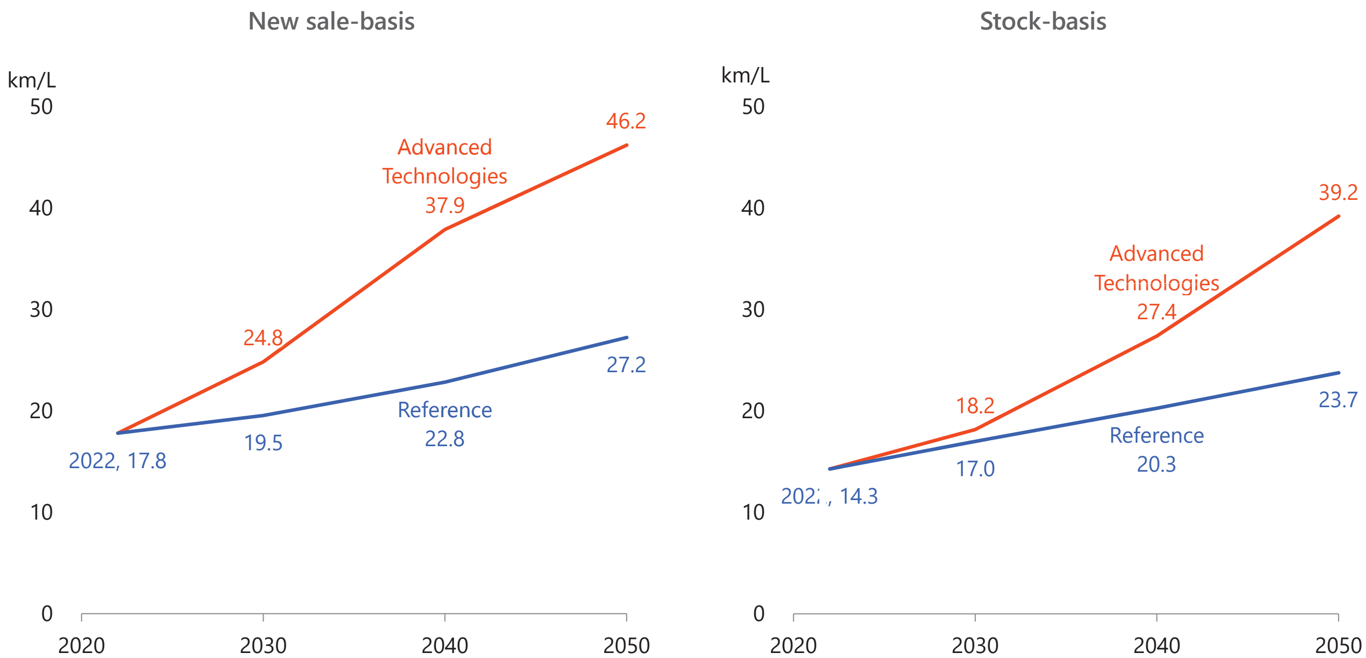


Share of passenger vehicle



Advanced Technologies Scenario

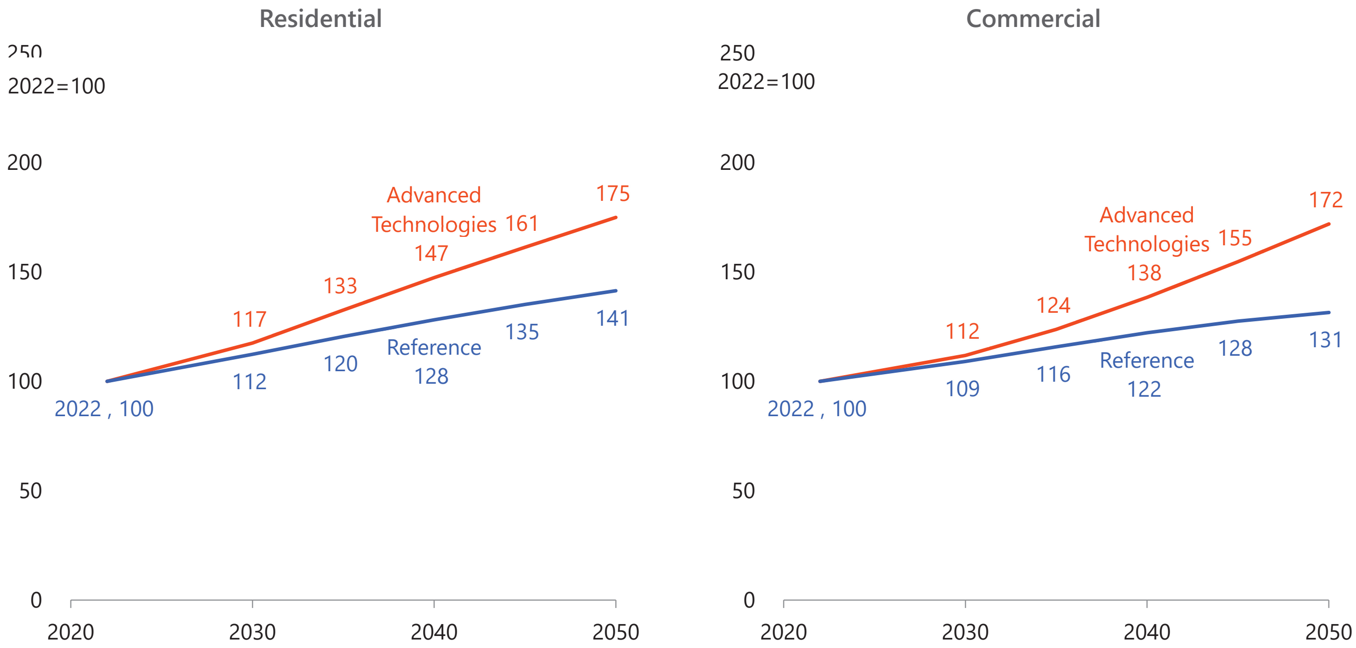
Fuel efficiency of passenger vehicle



Note: Litres of gasoline equivalent

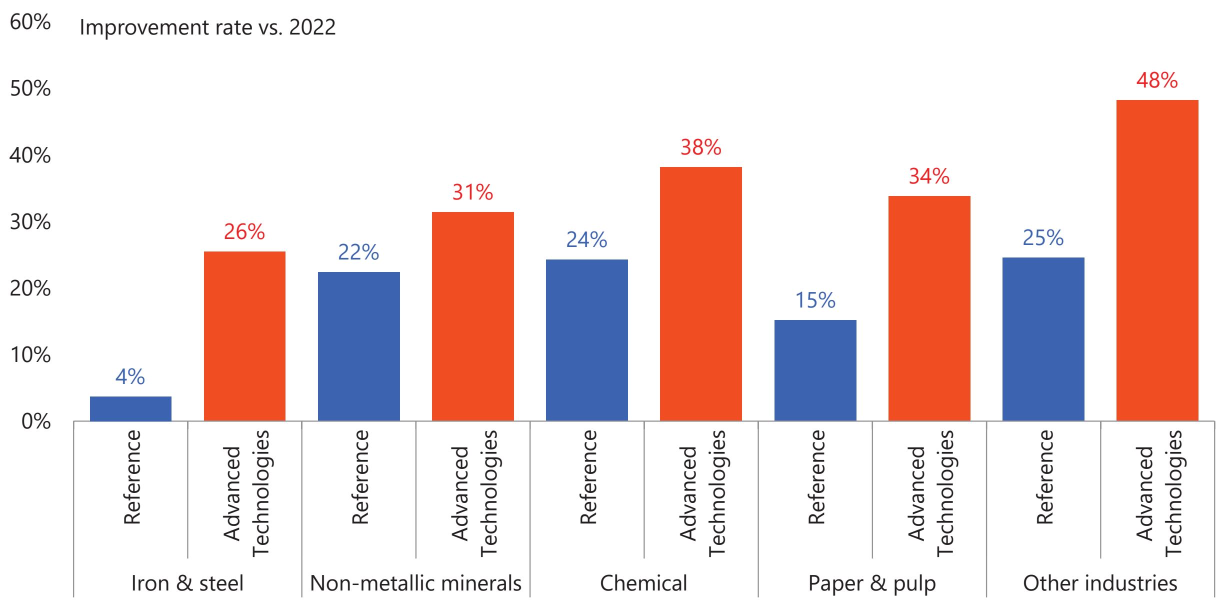
Advanced Technologies Scenario

Energy efficiency in buildings sector



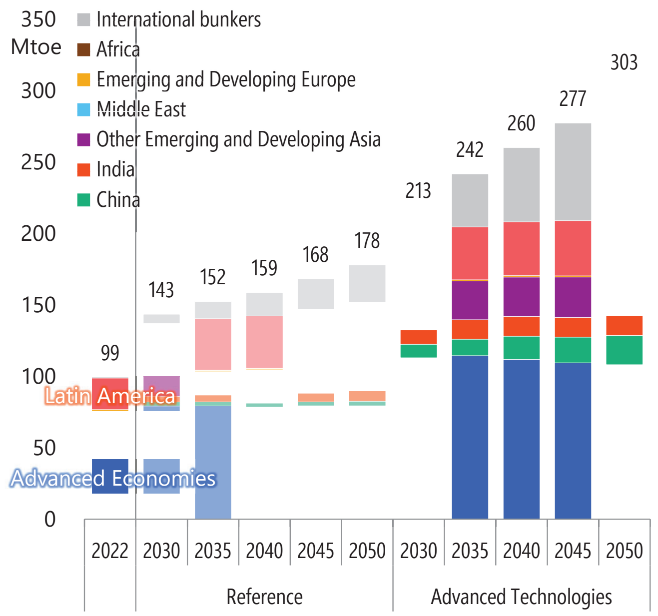
Advanced Technologies Scenario

Energy intensity improvement in industry sector

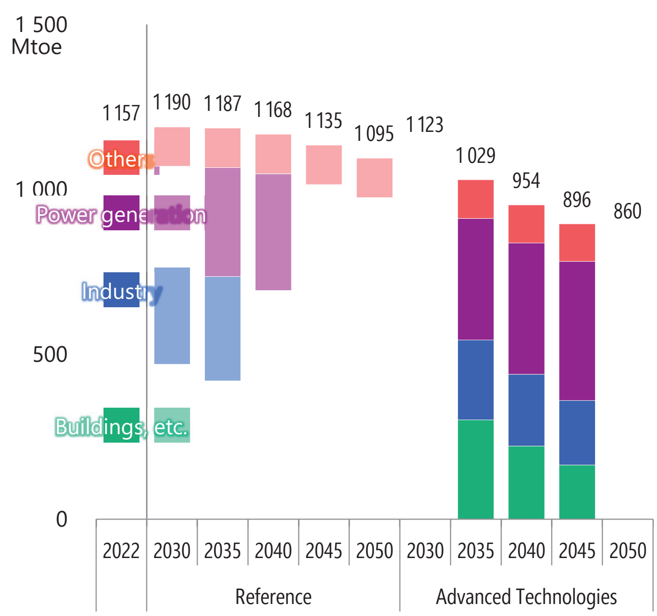


Biomass consumption

Biofuels for transport



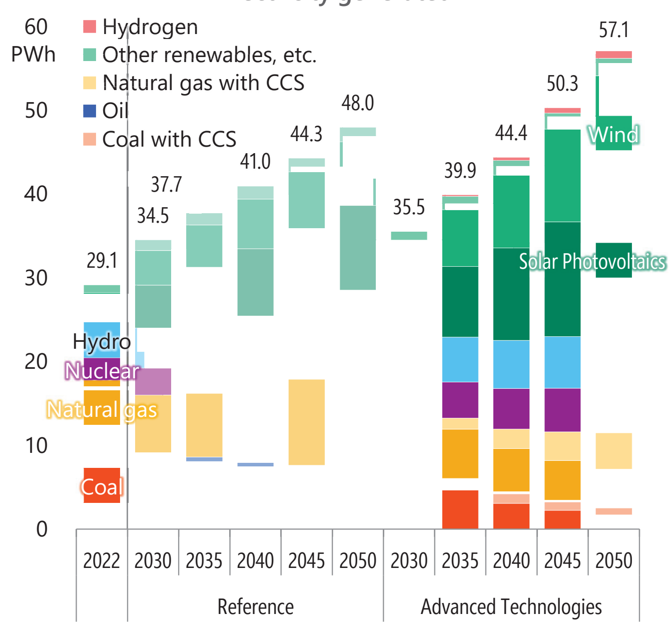
Solid biomass



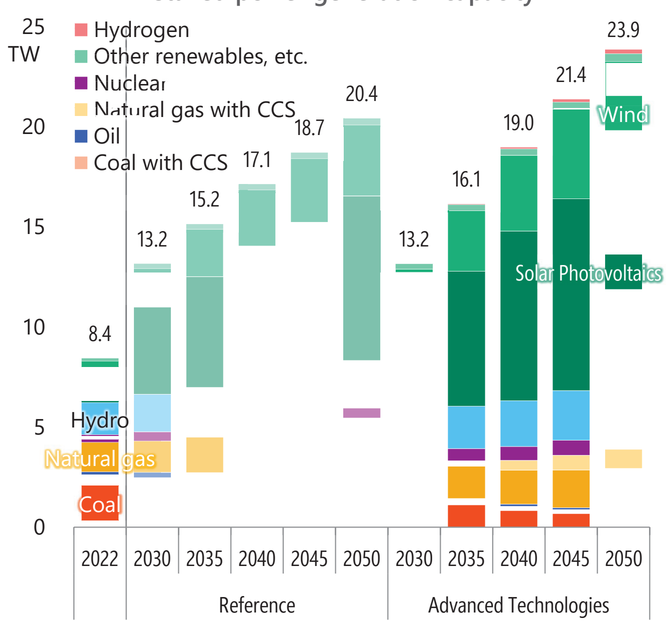
Advanced Technologies Scenario

Power generation mix

Electricity generated

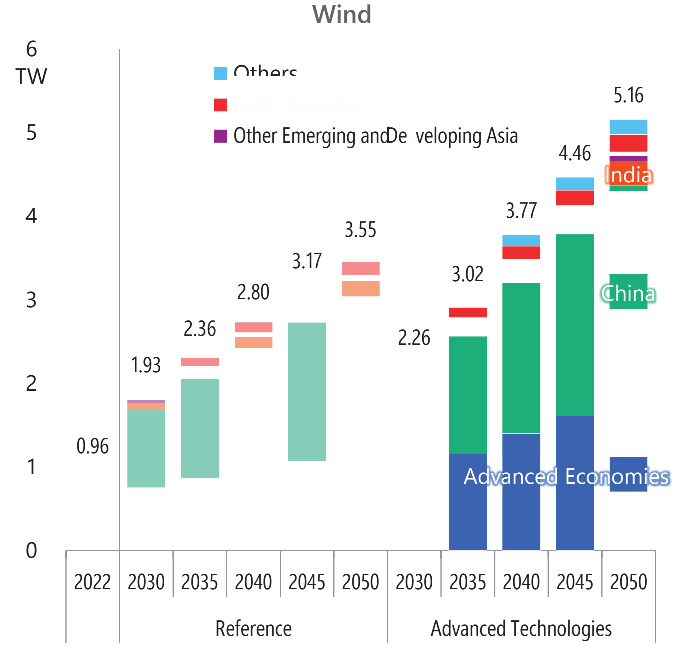


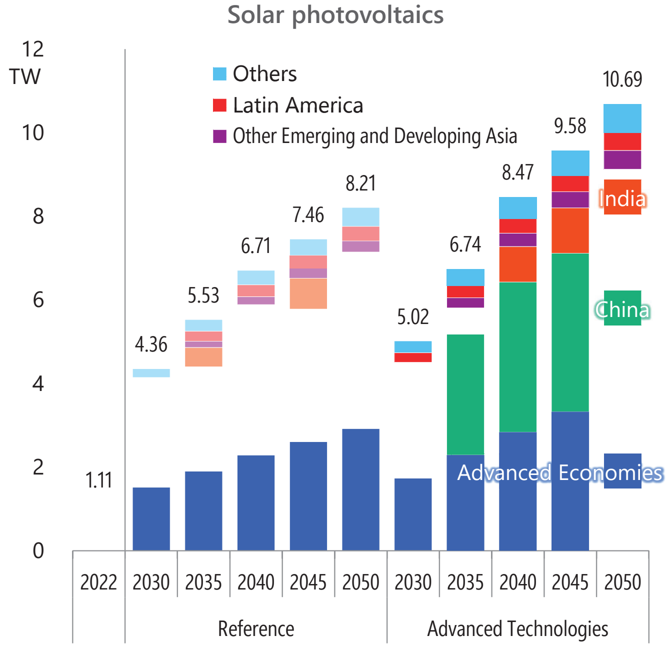
Installed power generation capacity



Advanced Technologies Scenario

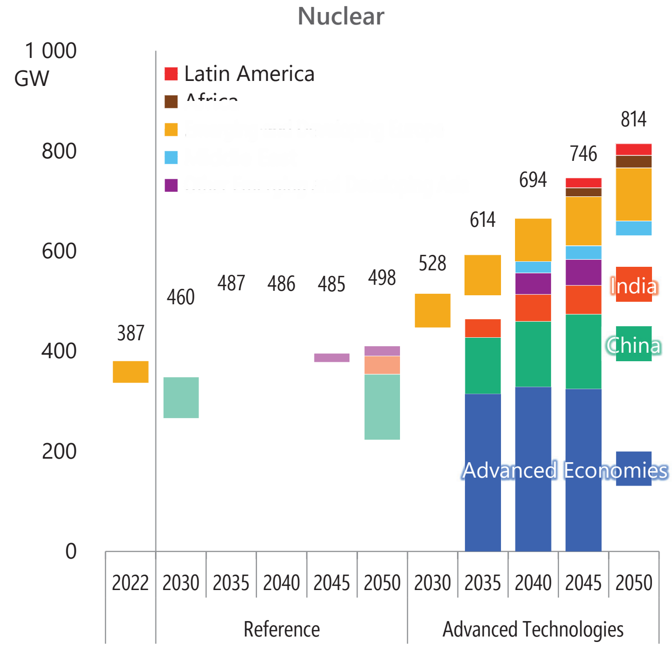
Installed wind and solar PV power generation capacity

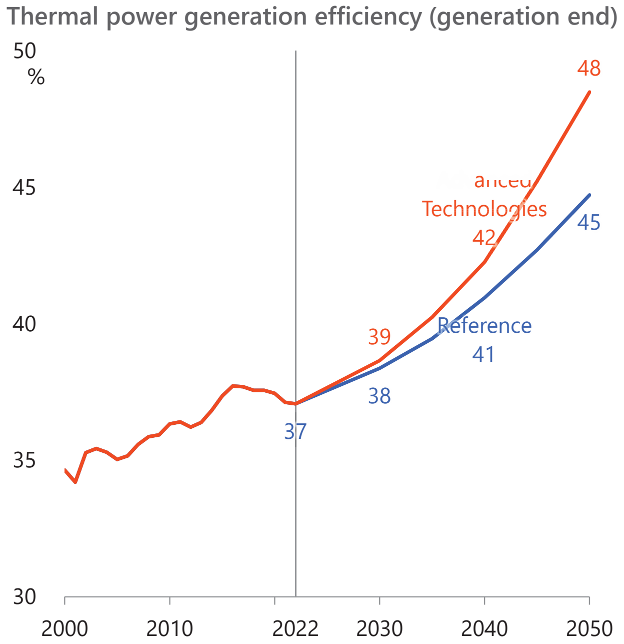




Advanced Technologies Scenario

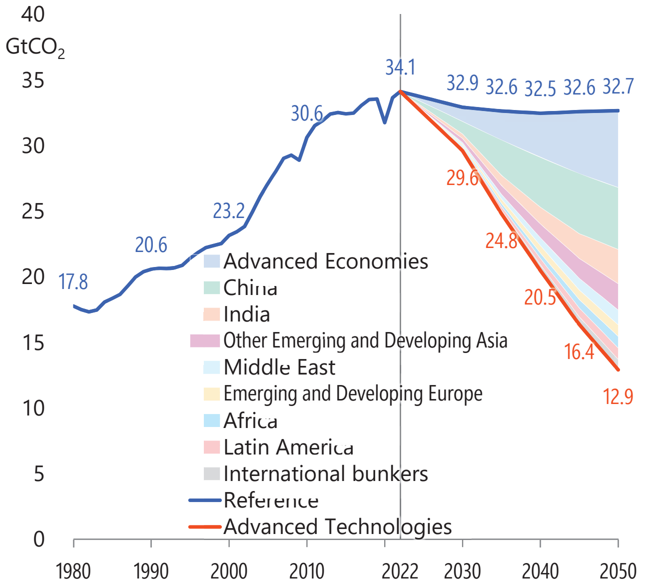
Installed nuclear power generation capacity and thermal power generation efficiency



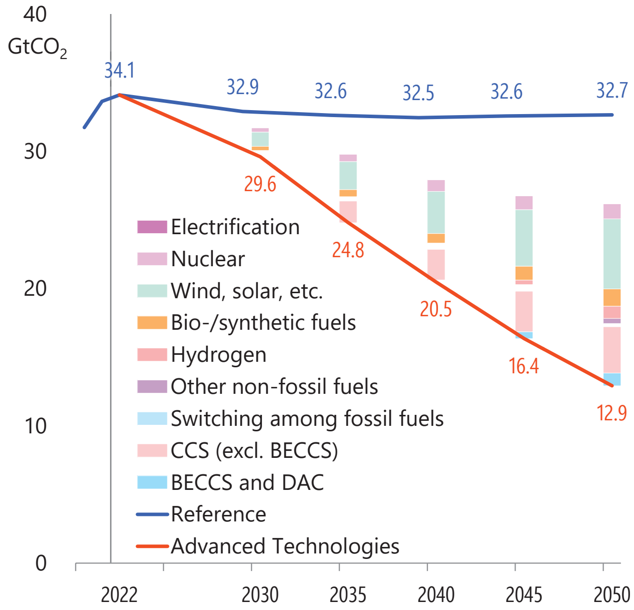


Energy-related CO_2 emissions

By region

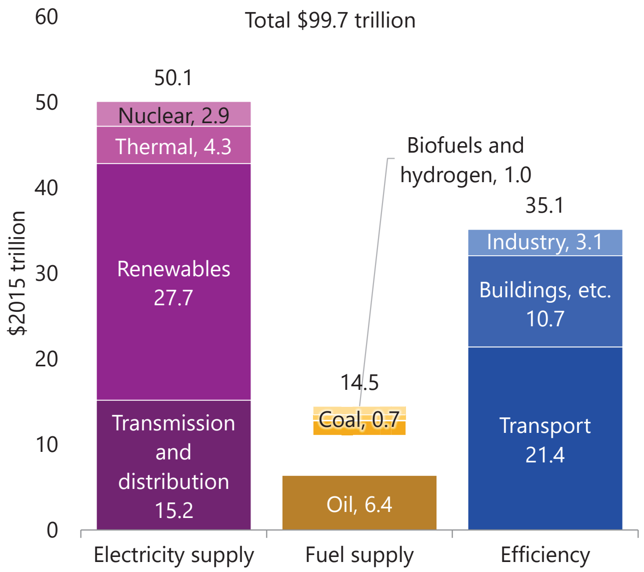


By technology

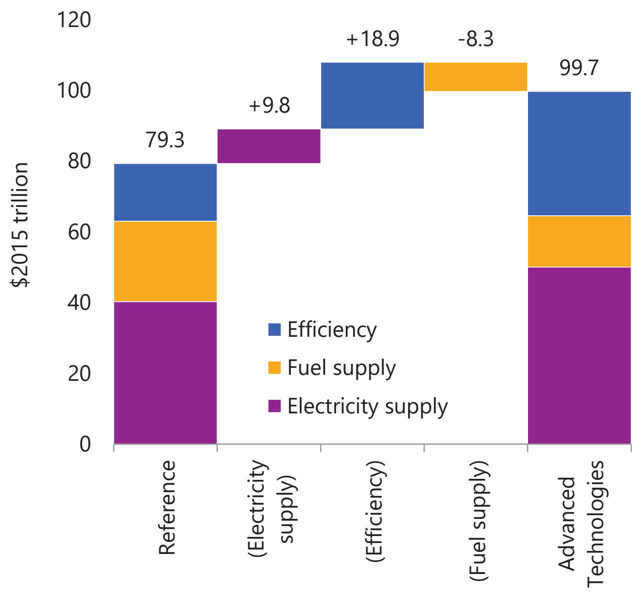


Energy-related investments (2023–2050)

By sector

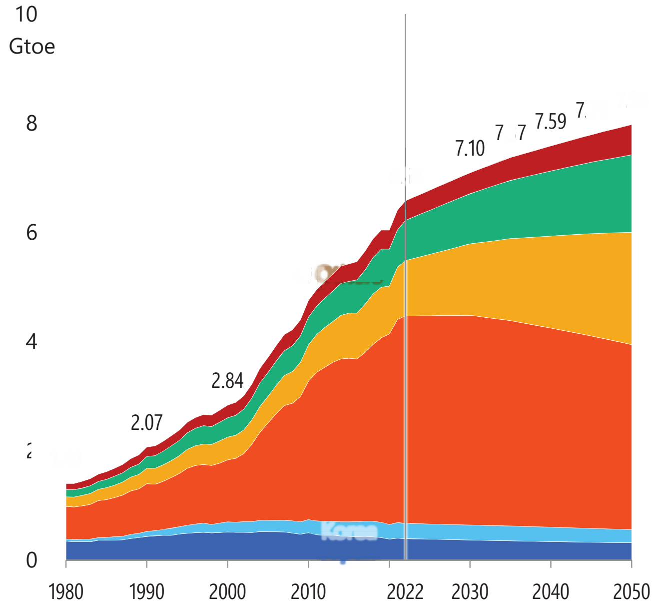


Changes from Reference Scenario

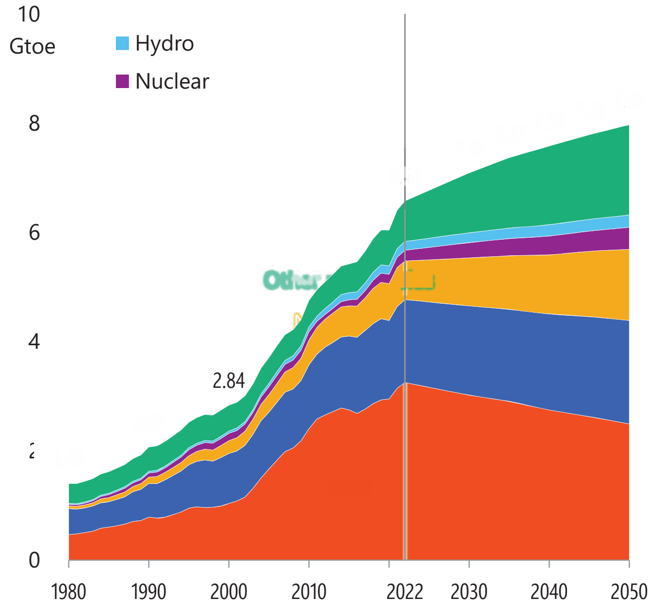


Primary energy consumption

By region

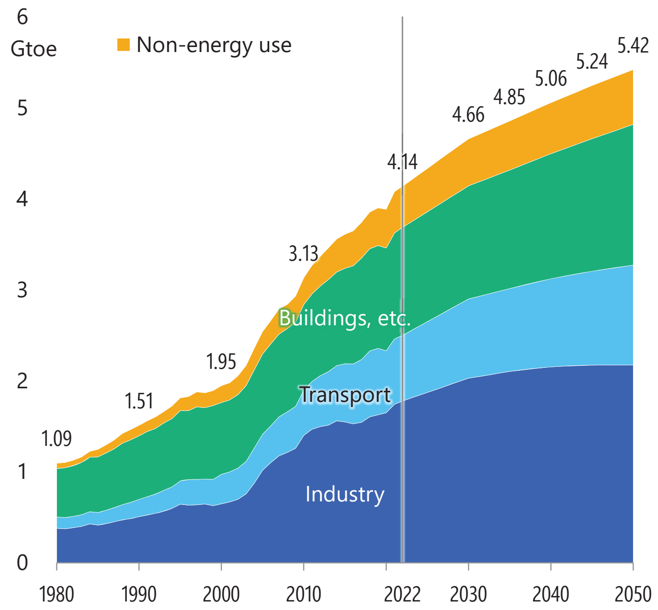


By energy source

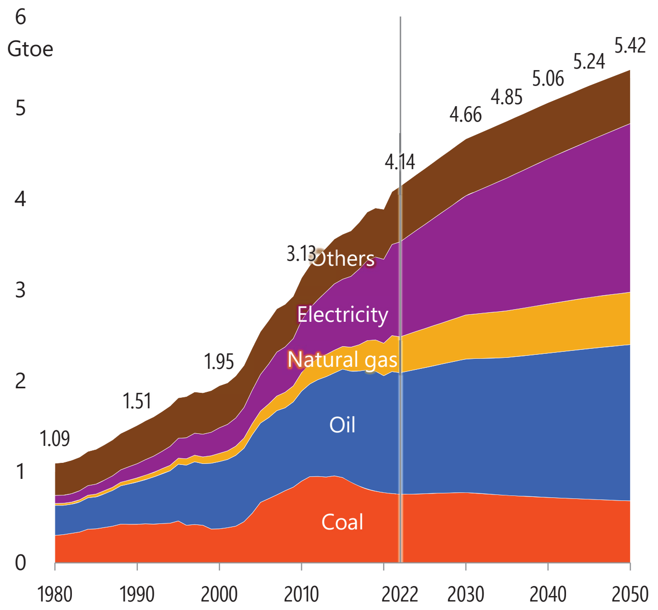


Final energy consumption

By sector



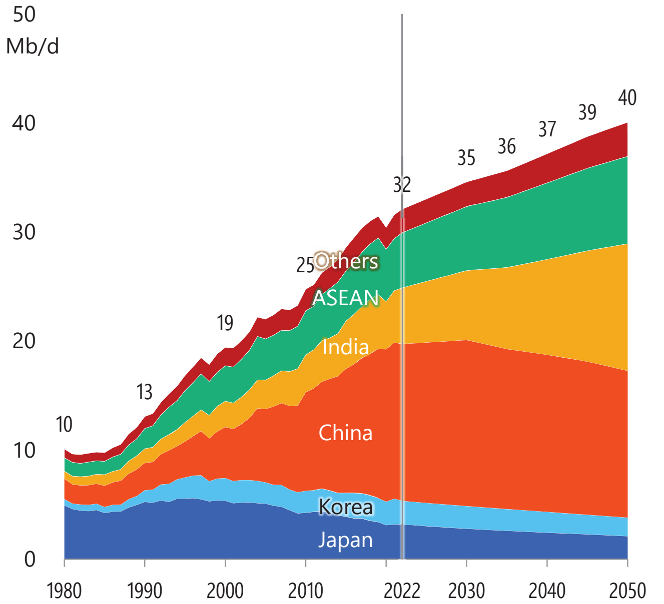
By energy source



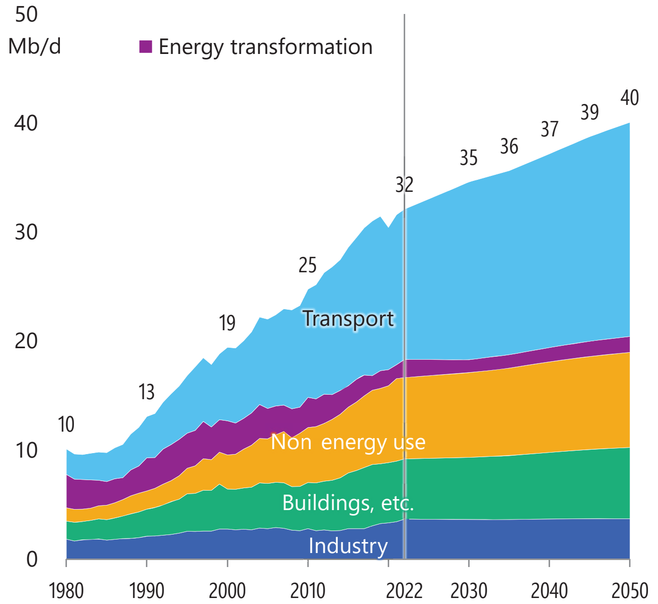
Asia Reference Scenario

Oil consumption

By region



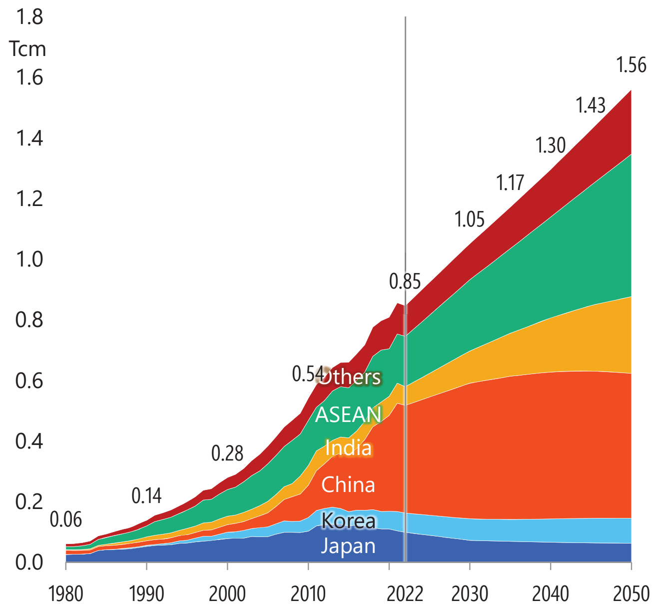
By sector



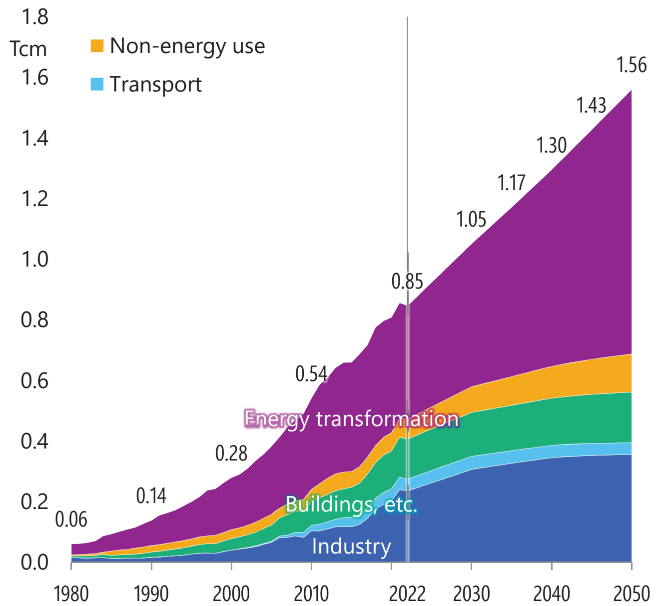
Asia Reference Scenario

Natural gas consumption

By region



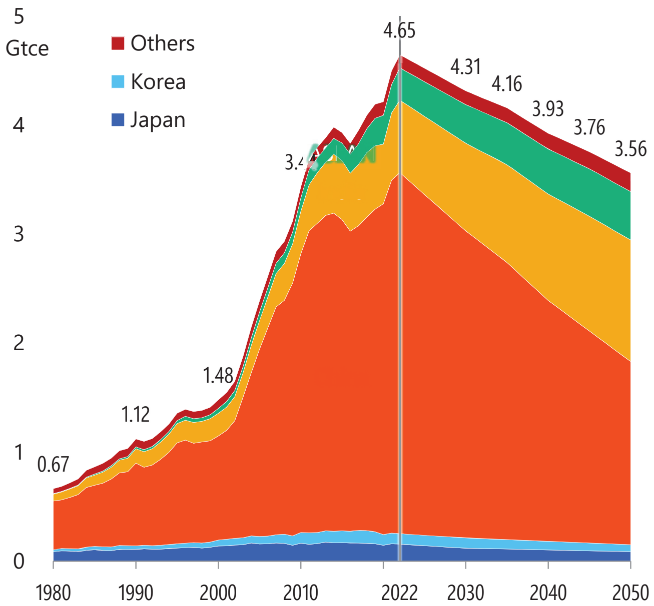
By sector



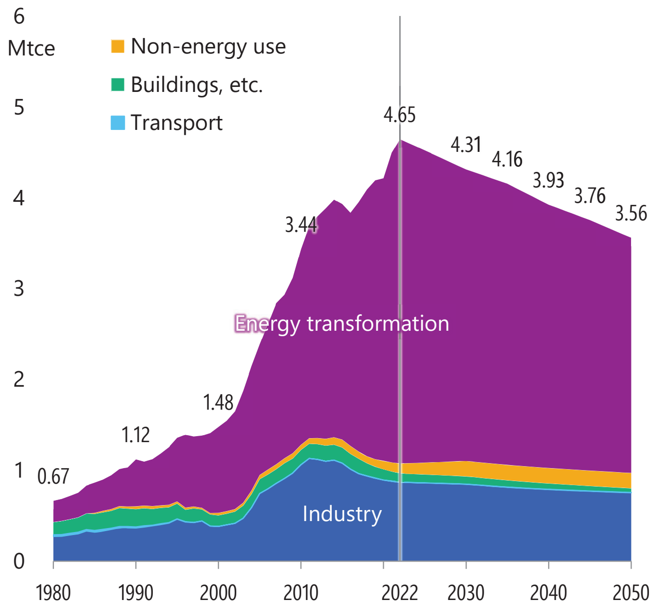
Asia | Reference Scenario

Coal consumption

By region



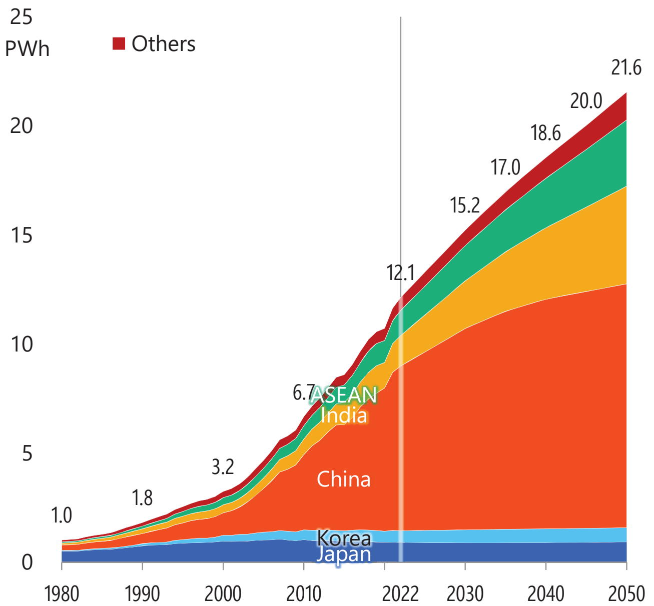
By sector



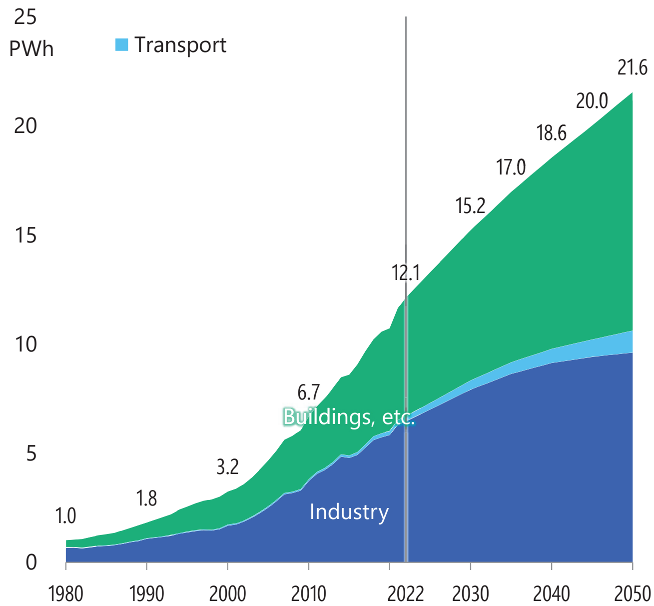
Asia | Reference Scenario

Final consumption of electricity

By region

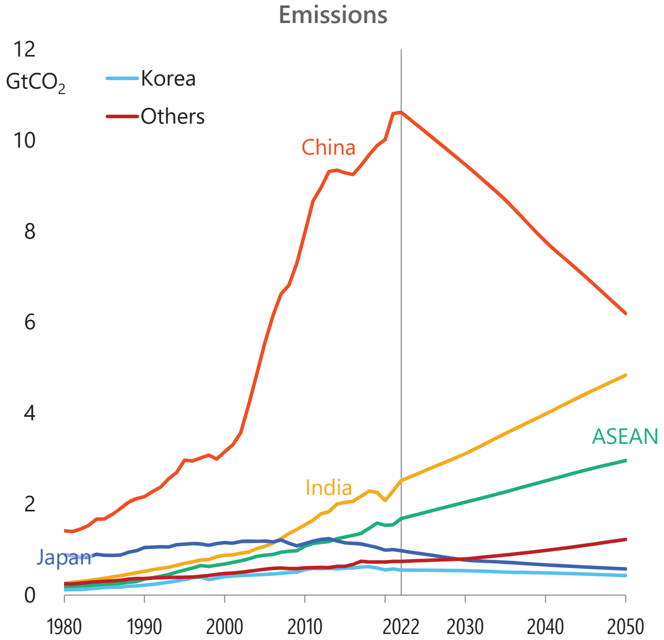


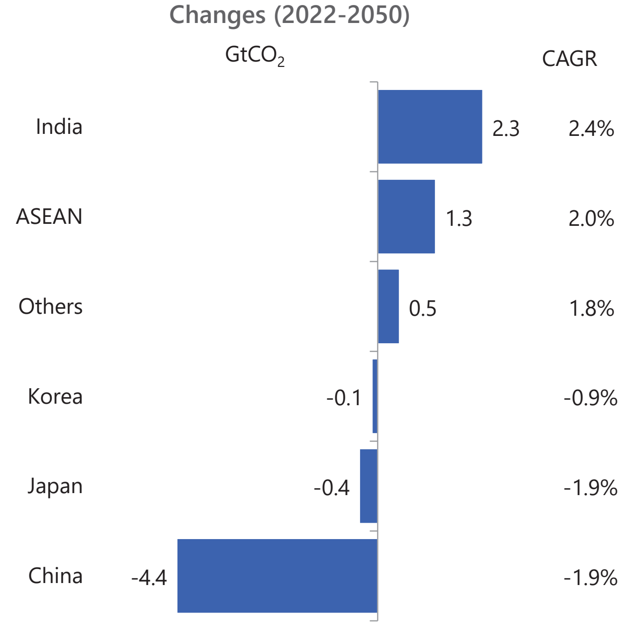
By sector



Asia | Reference Scenario

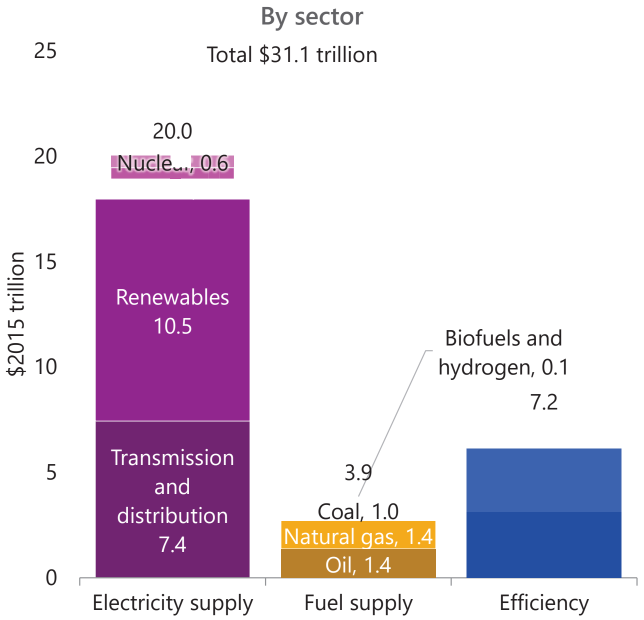
Energy-related CO_2 emissions

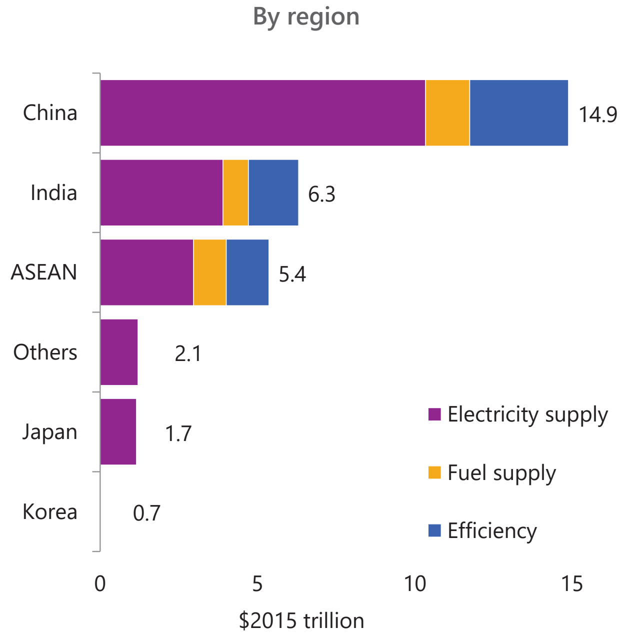




Asia | Reference Scenario

Energy-related investments (2023–2050)

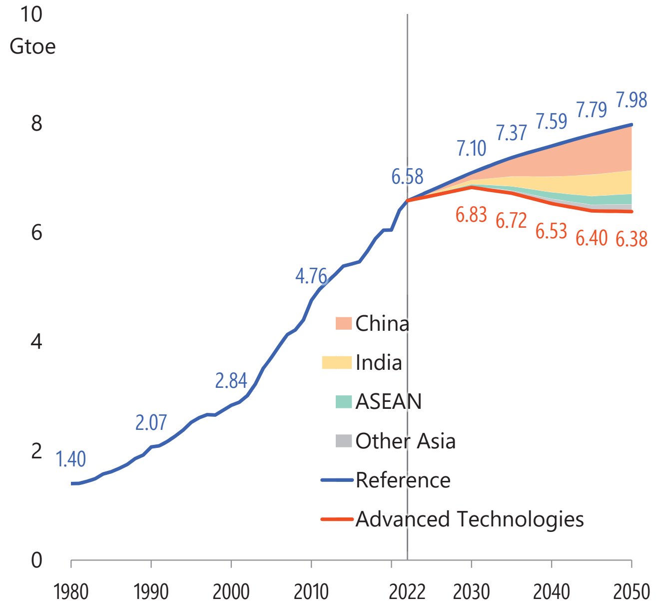




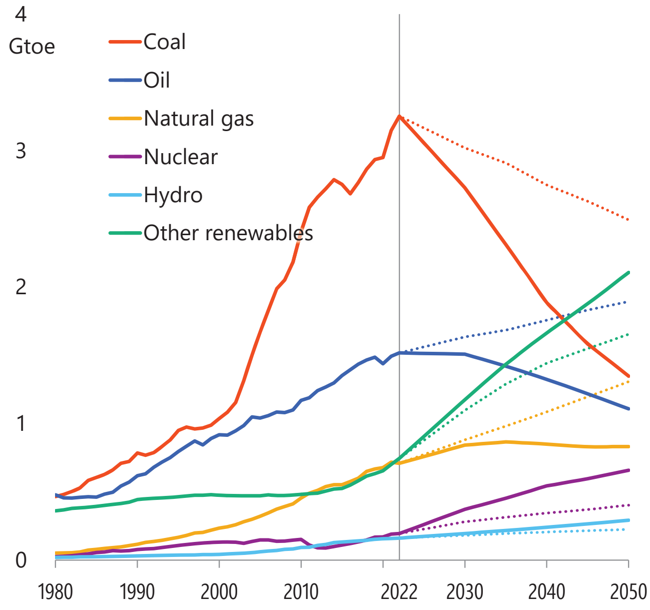
Asia | Advanced Technologies Scenario

Primary energy consumption

By region



By energy source

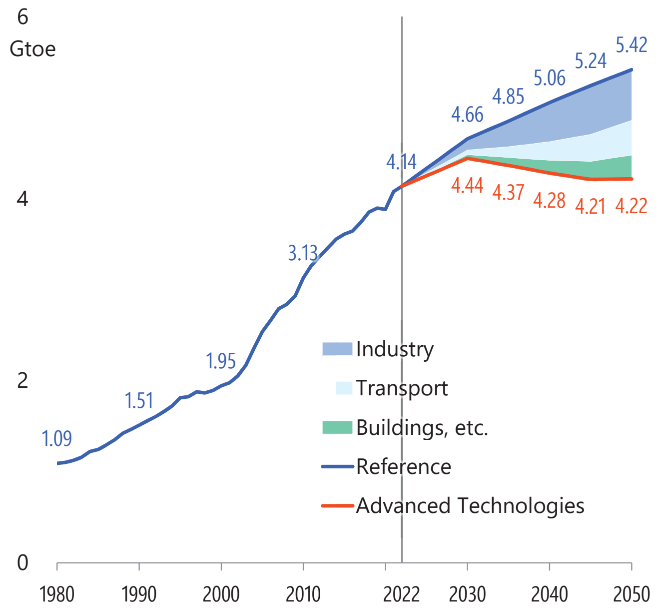


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

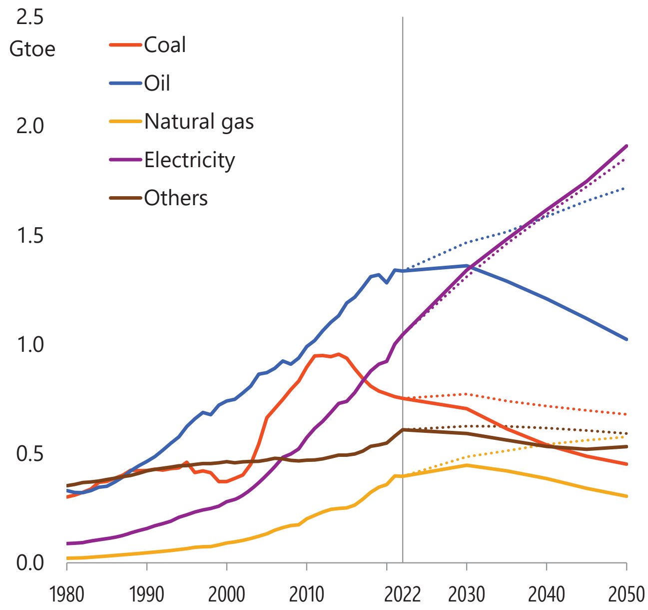
Asia | Advanced Technologies Scenario

Final energy consumption

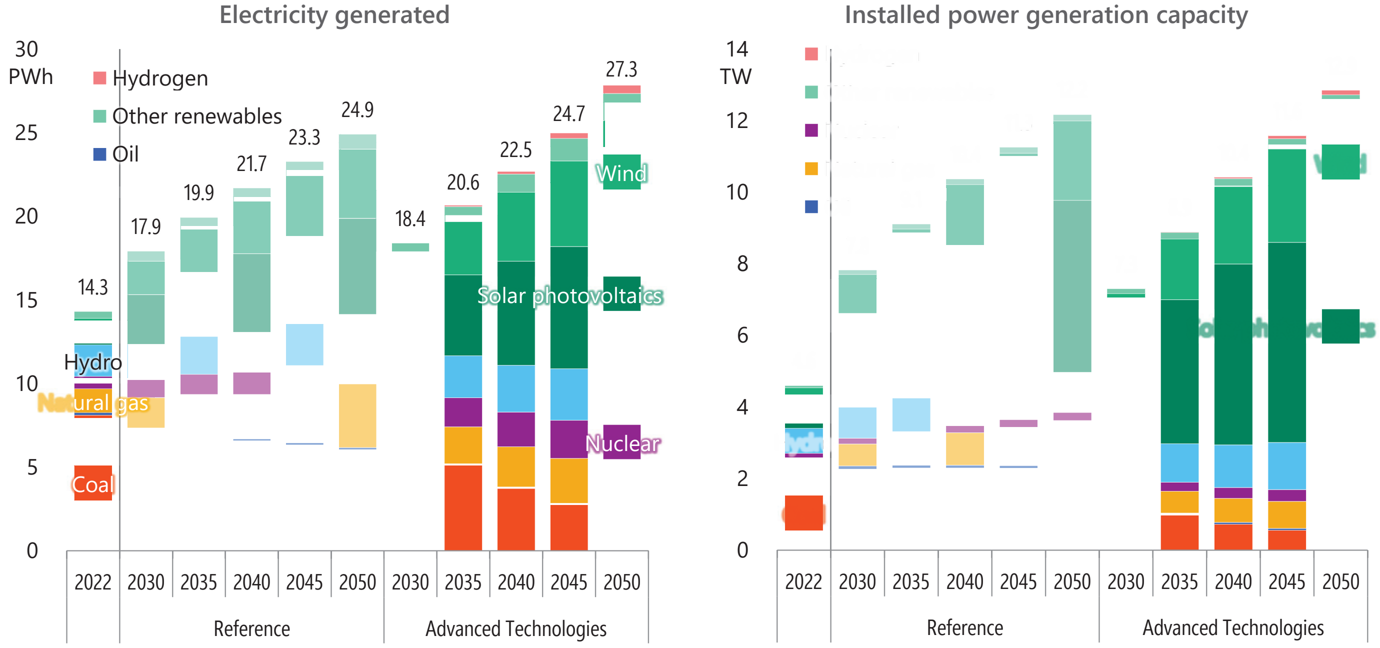
By sector



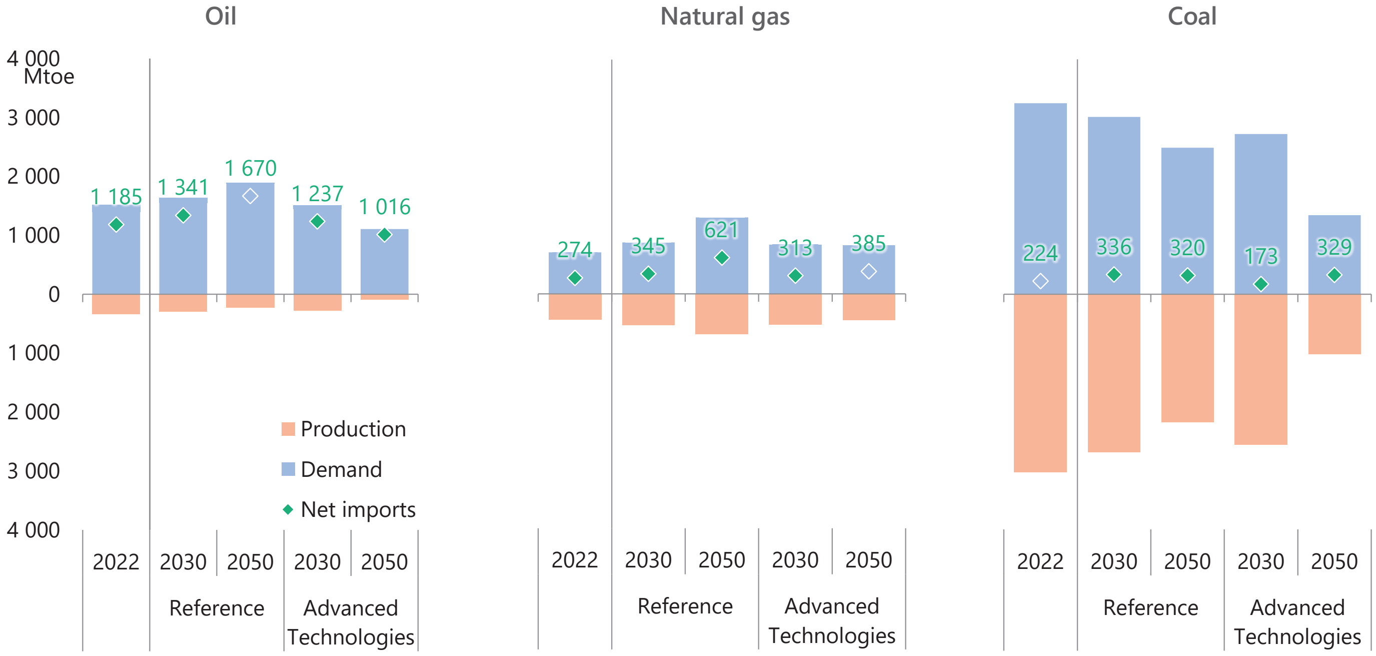
By energy source



Power generation mix



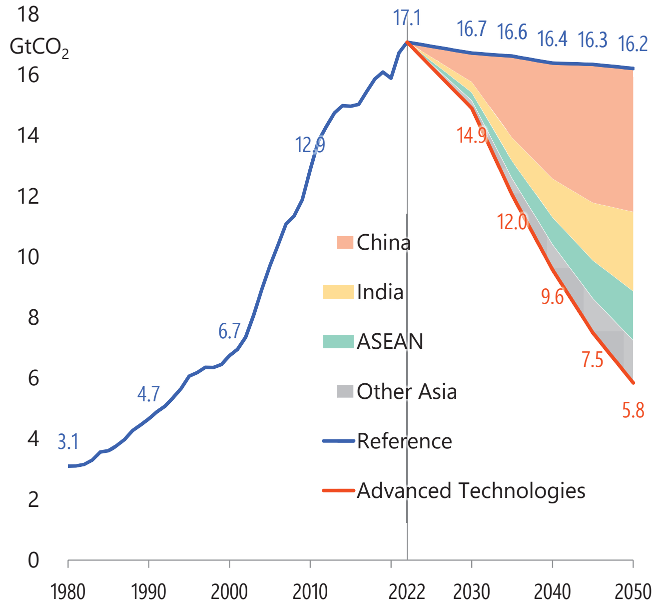
Supply and demand balance of fossil fuels



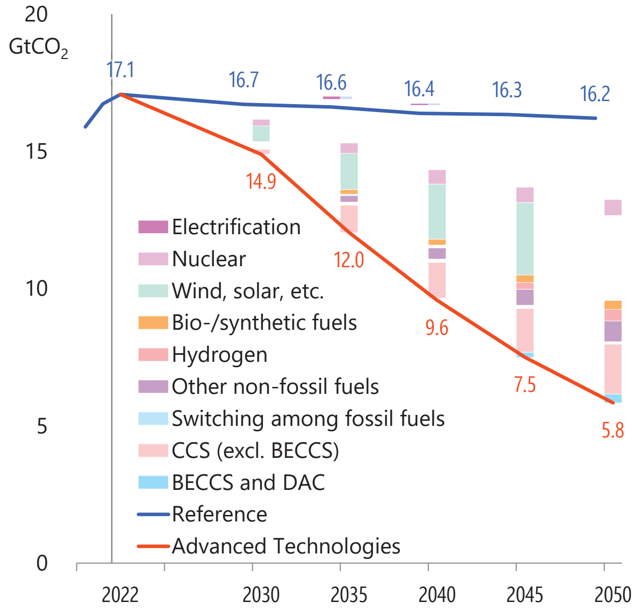
Asia | Advanced Technologies Scenario

Energy-related CO_2 emissions

By region



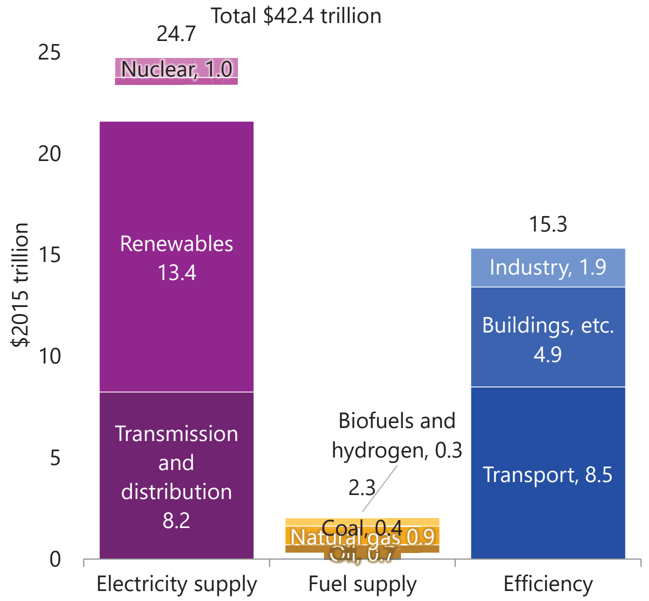
By technology



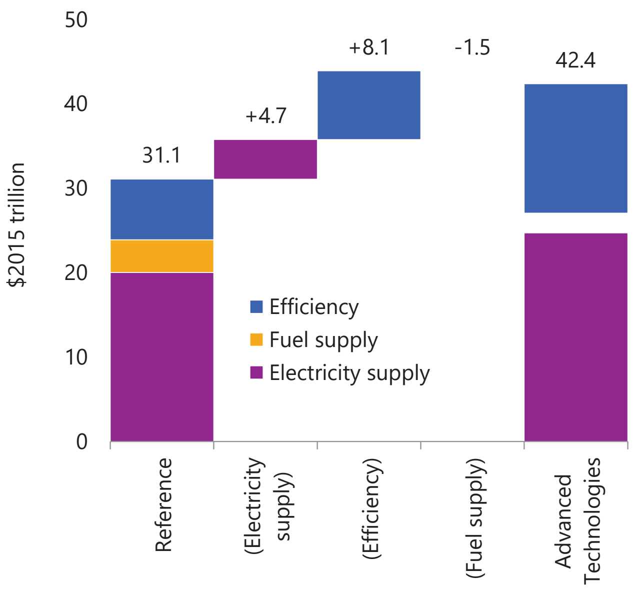
Asia | Advanced Technologies Scenario

Energy-related investments (2023–2050)

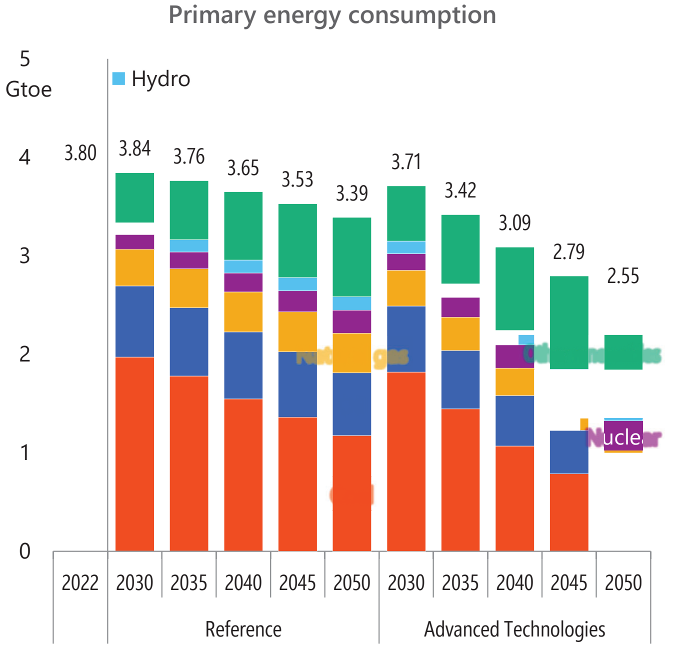
By sector

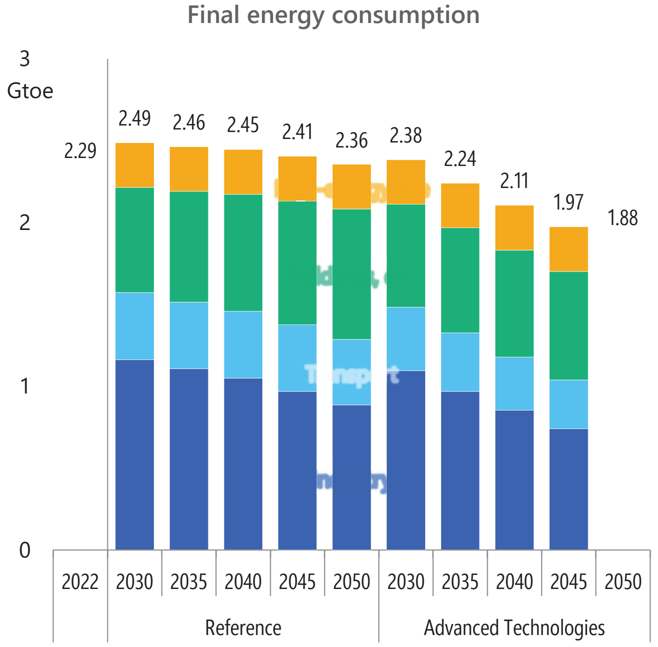


Changes from Reference Scenario

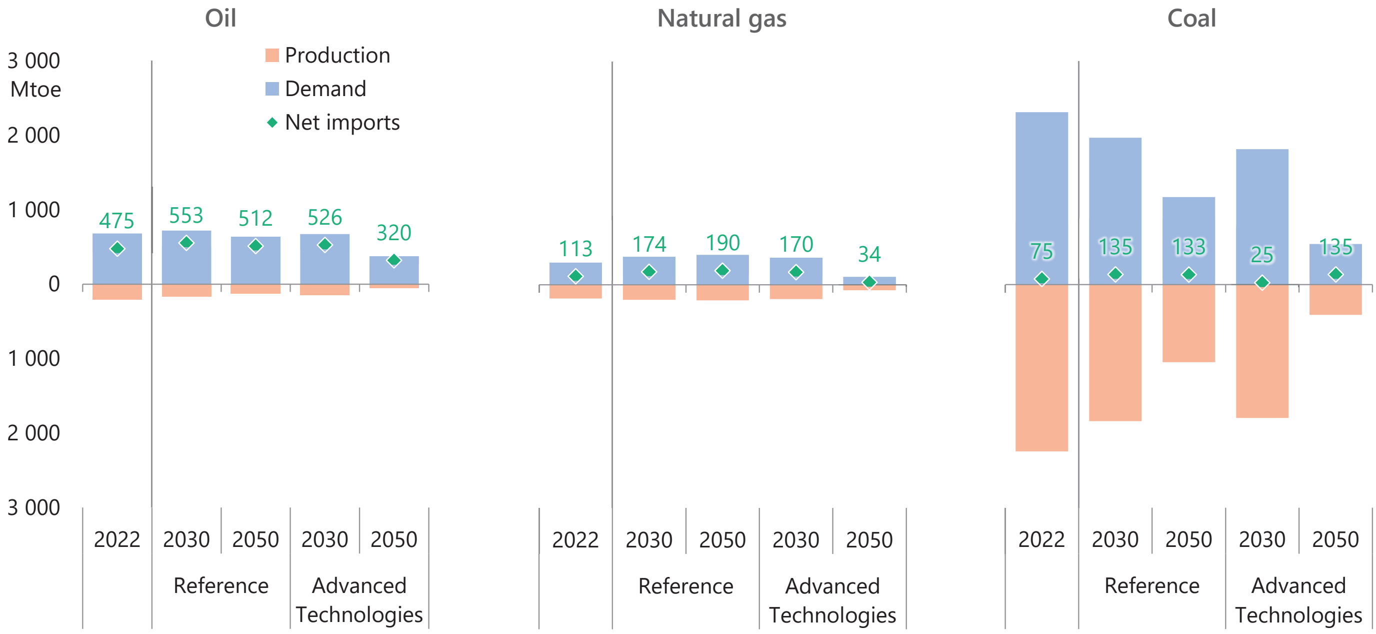


Energy consumption

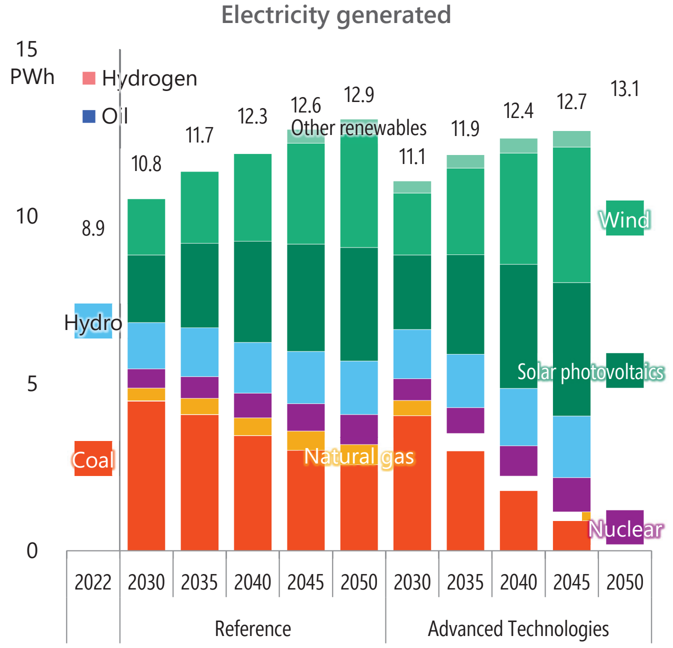


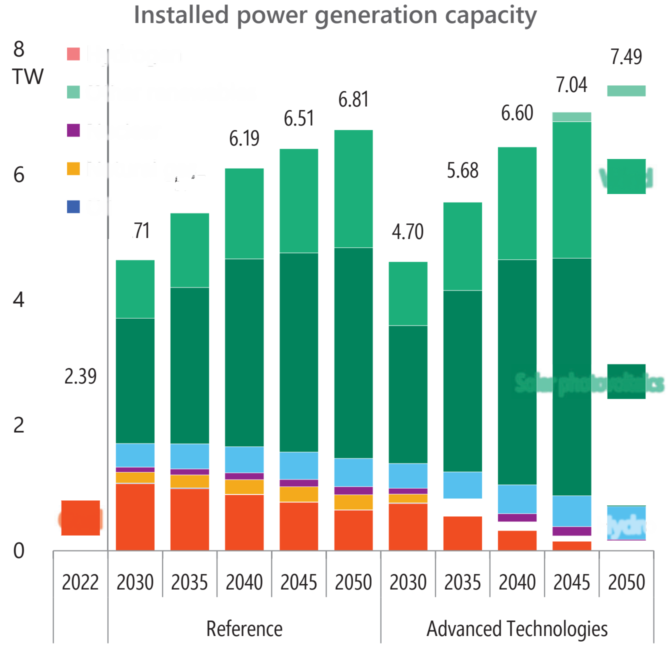


Supply and demand balance of fossil fuels

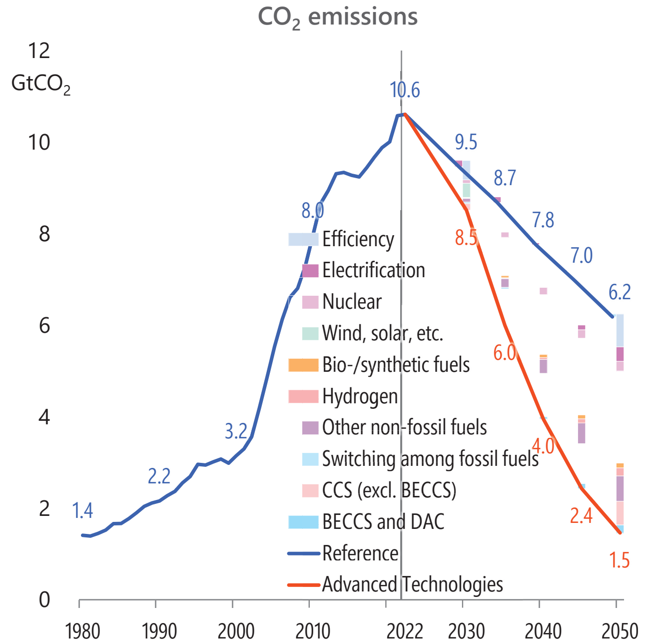


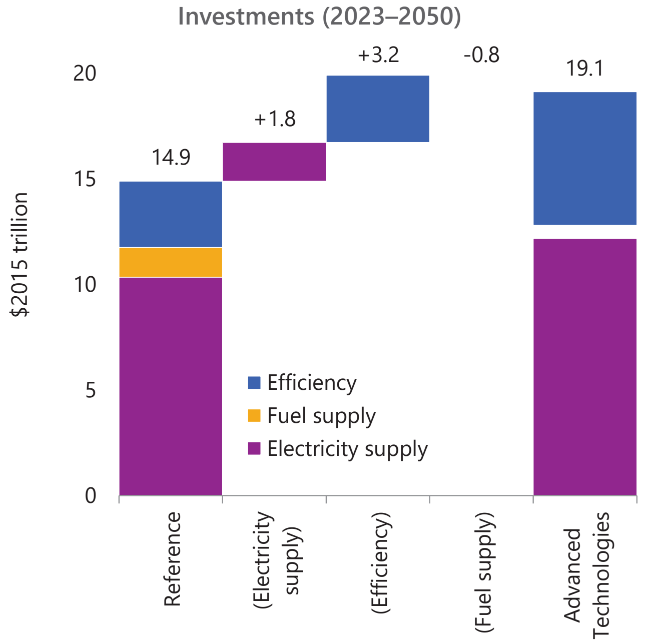
Power generation mix



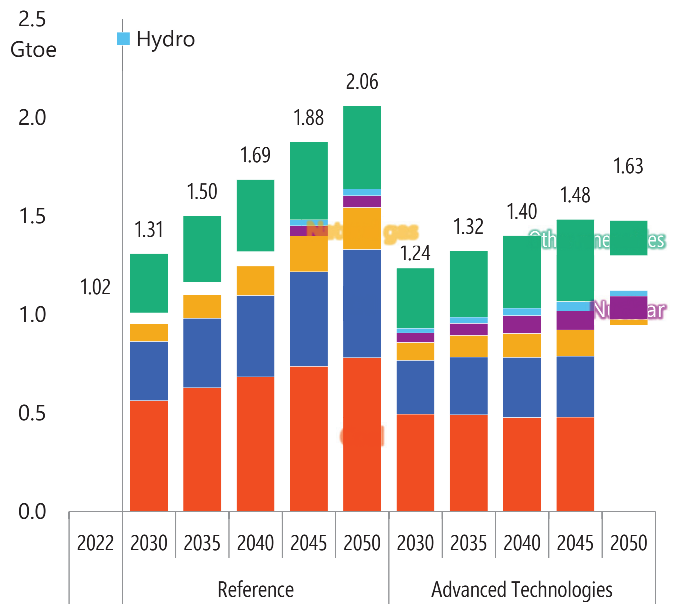


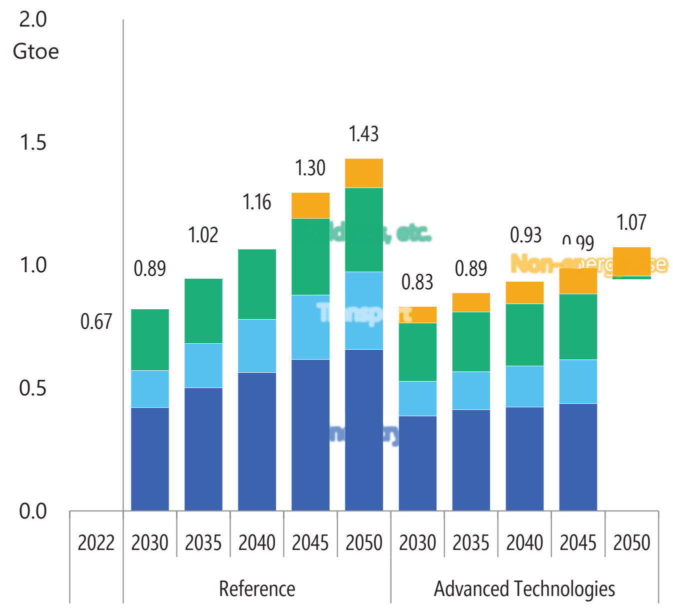
Energy-related CO_2 emissions and investments





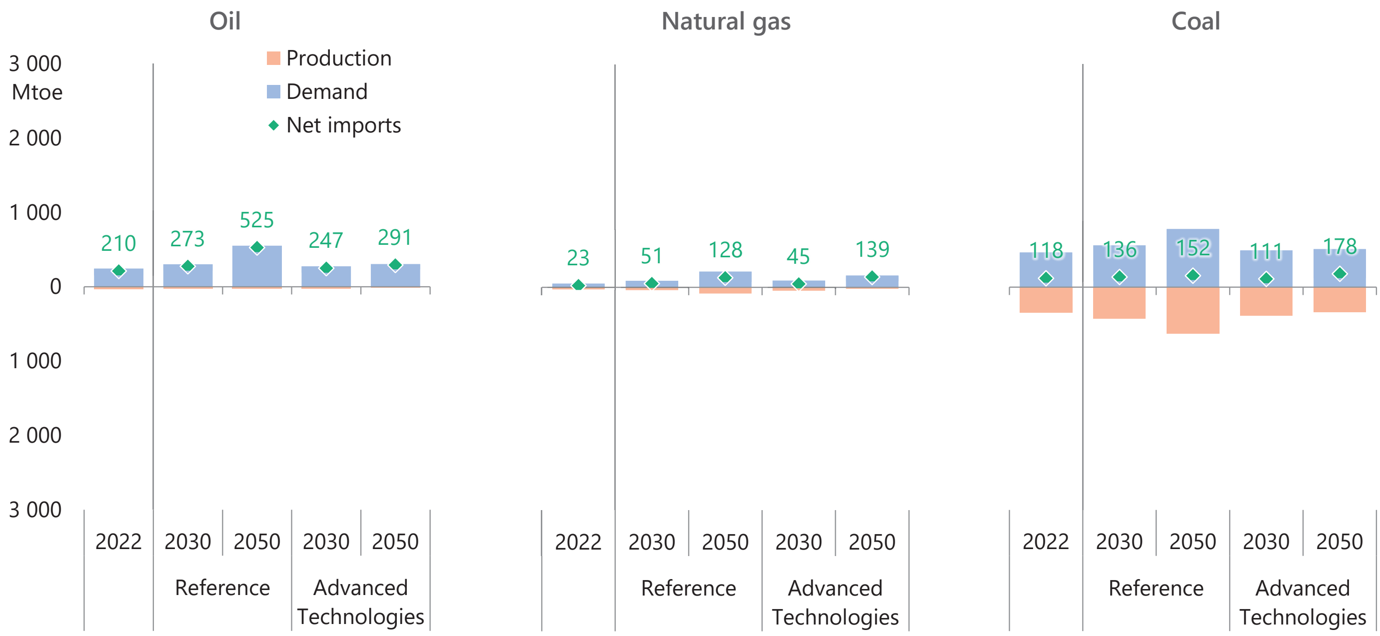
Energy consumption



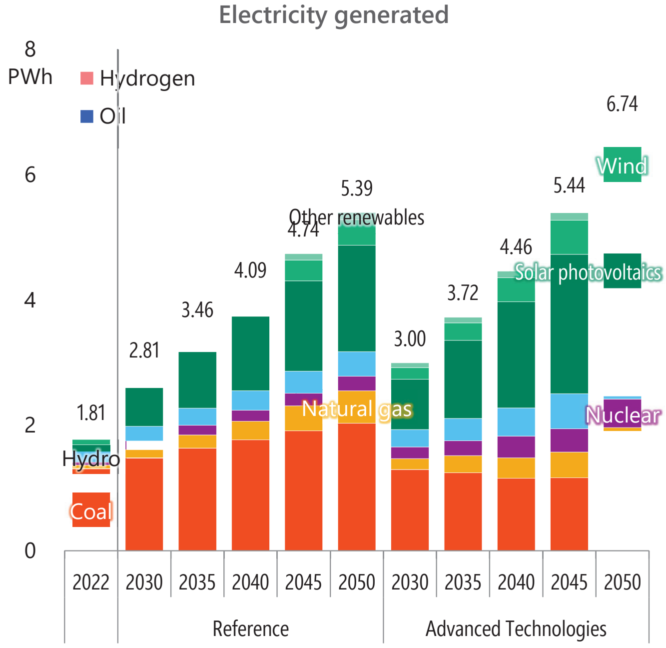


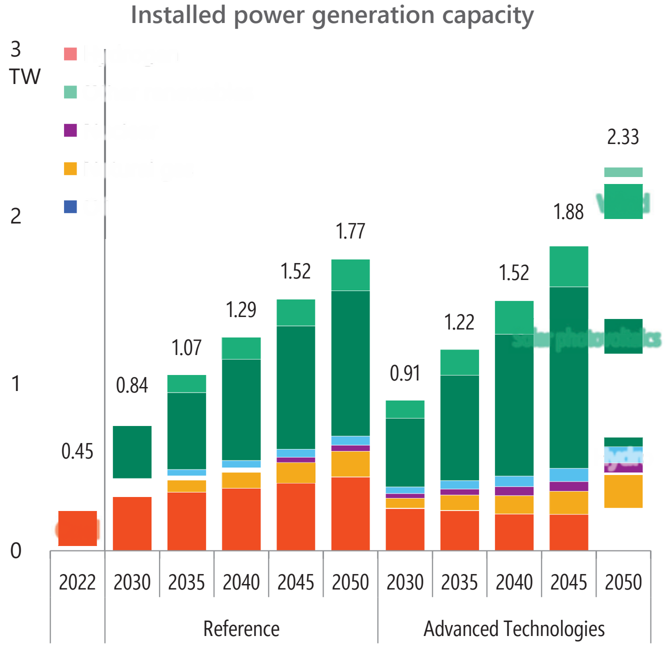
India

Supply and demand balance of fossil fuels

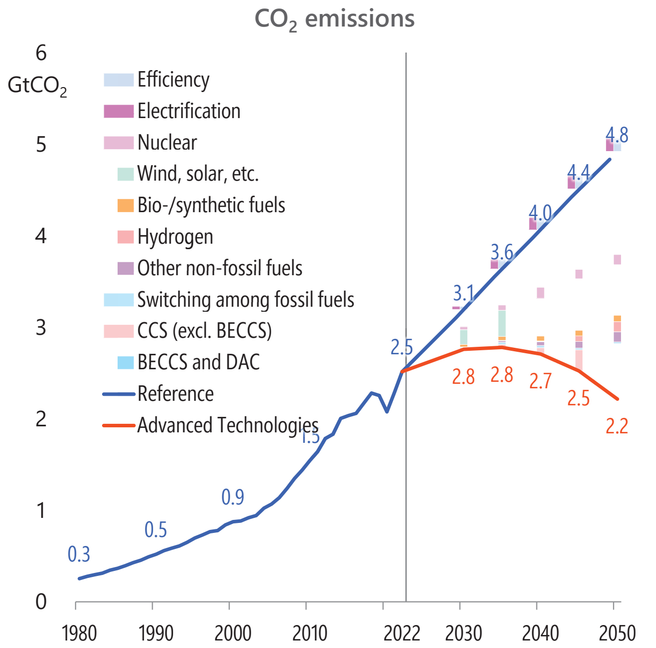


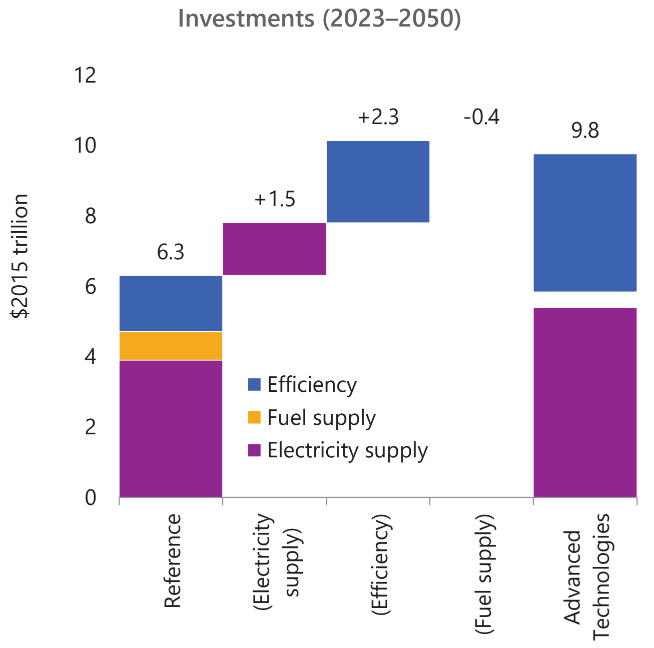
Power generation mix



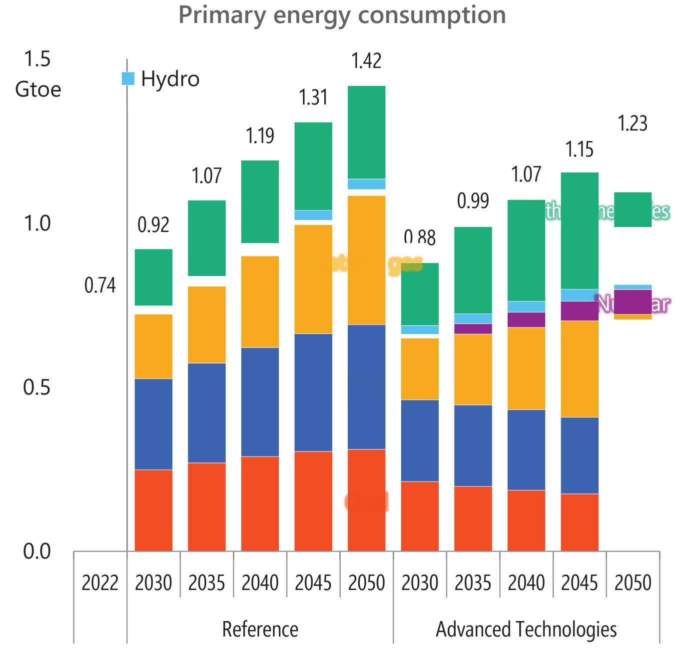


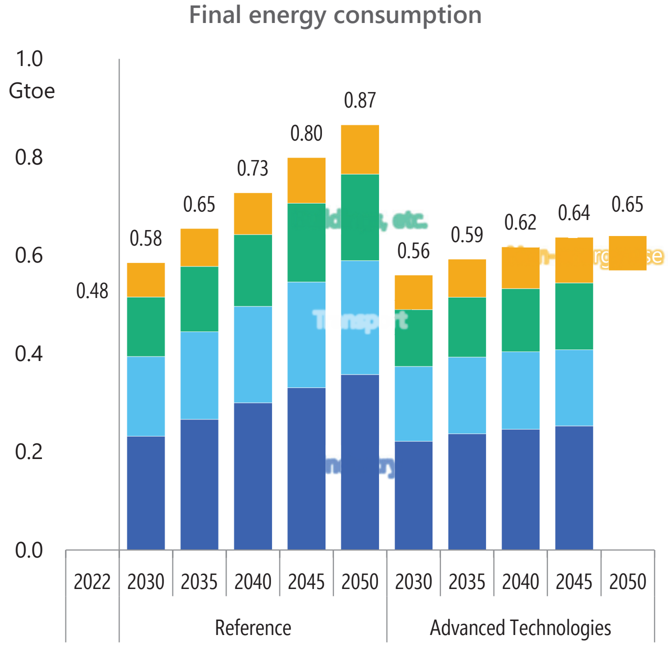
Energy-related CO_2 emissions and investments



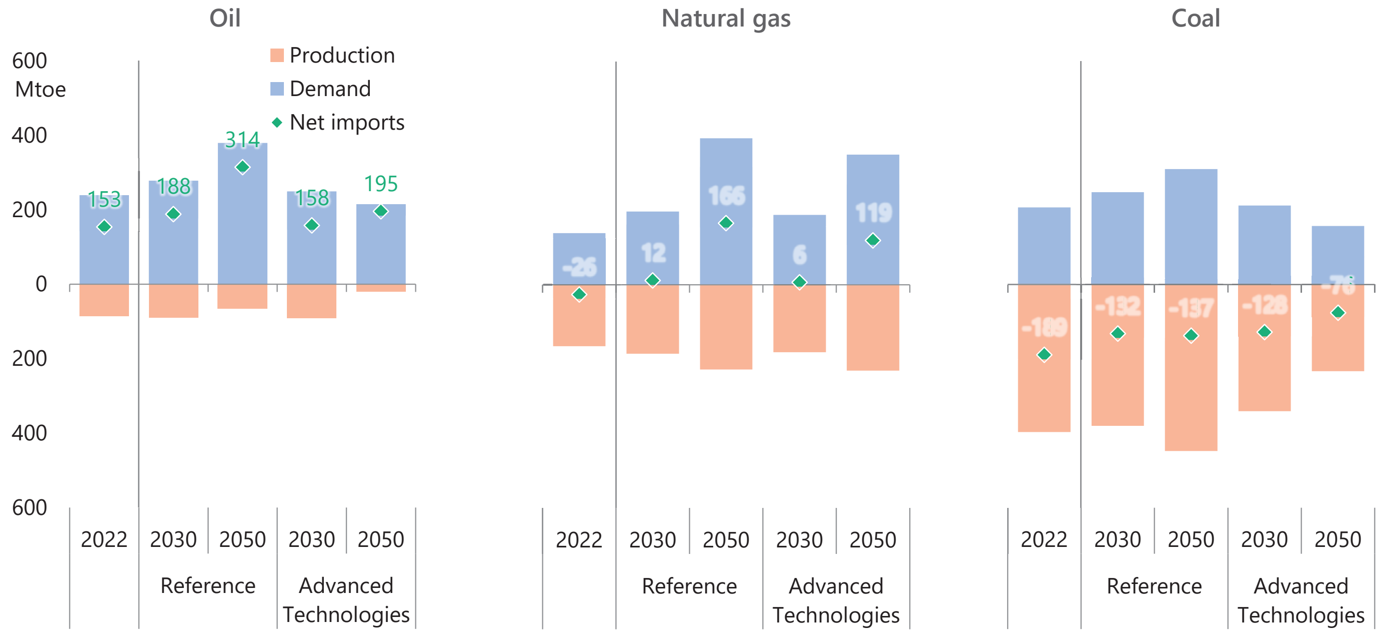


Energy consumption



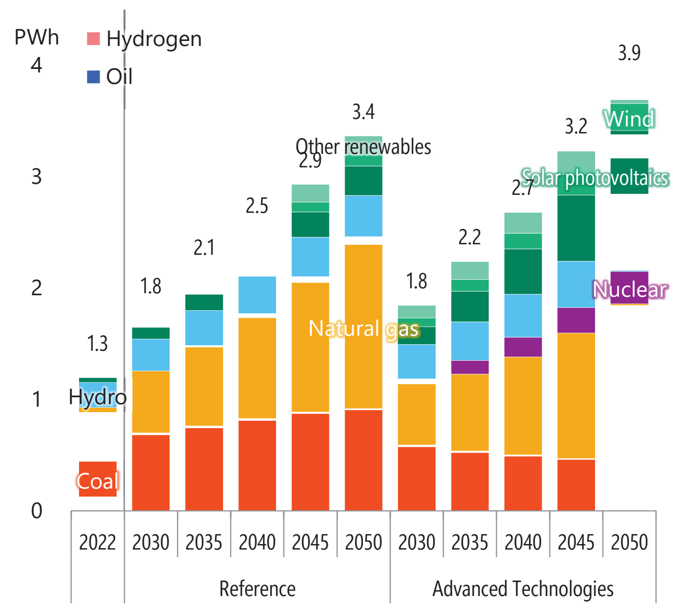


Supply and demand balance of fossil fuels

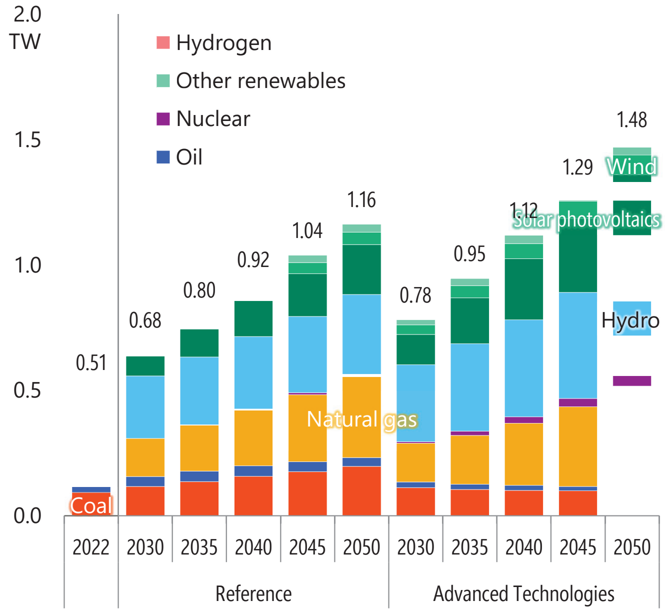


Power generation mix

Electricity generated

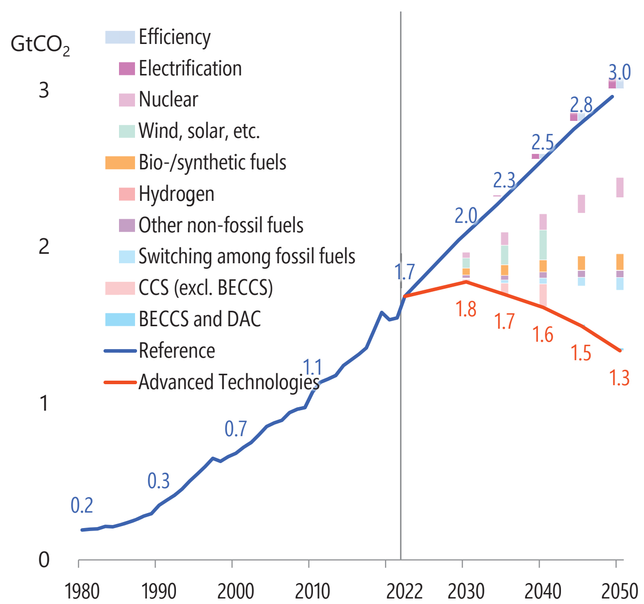


Installed power generation capacity

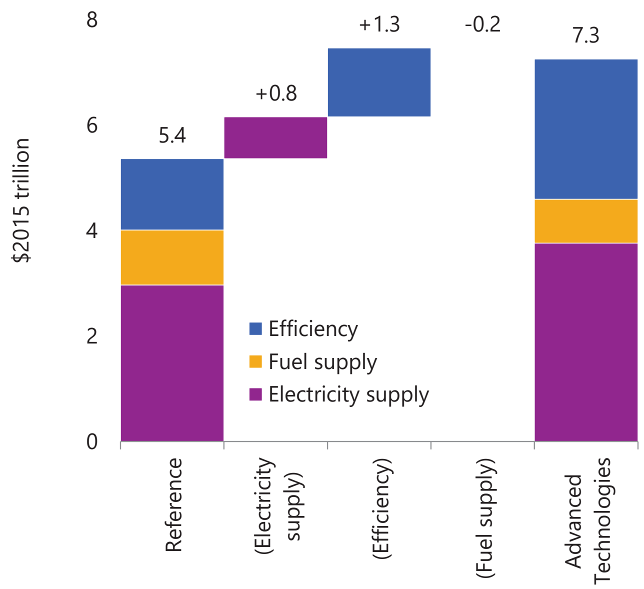


Energy-related CO_2 emissions and investments

CO_2 emissions



Investments (2023–2050)



IEEJ Outlook 2025

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The Institute of Energy Economics, Japan