IEEJ Outlook 2023

Energy, Environment and Economy

Challenges for achieving both energy security and carbon neutrality

The Institute of Energy Economics, Japan

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Executive summary

Global energy supply and demand outlook (Reference Scenario)

Energy consumption will continue to increase despite energy efficiency that will improve to address climate change and energy security

- Under the Reference Scenario, and from the perspective of climate change and energy security, the rate at which the world's energy intensity per unit of gross domestic product (GDP) will decline is faster than in the past. However, as the macroeconomy expands beyond the rate of decline, global energy consumption in 2050 will increase by 1.3 times from 2020 to 17 649 million tonnes of oil equivalent (Mtoe). The Reference Scenario incorporates past trends and the expected effects of the extension of energy and environmental policies and technologies to date.
- The lack of upstream investment and the Russian invasion of Ukraine have raised concerns about a stable and sufficient supply of fossil fuels to meet the overall consumption which will continue to increase at an annual rate of 0.8%. The use of natural gas will grow at an annual rate of 1.3%, mainly to supply the power generation sector and will approach oil which is the largest energy source. Oil will expand at an annual rate of 0.7%, increasing mainly in the aviation, shipping and petrochemical feedstocks sectors. Against the backdrop of air pollution and climate change, coal will peak around 2030 and begin to decline, falling below 2020 levels in 2050.
- Expectations for more non-fossil energy are growing as many countries aim to become carbon neutral. Solar photovoltaics, wind and others will see the largest growth, increasing 3.9 times in 2050 compared to 2020. However, the share of non-fossil energy in total primary energy consumption will increase only slightly, from 20% in 2020 to 23% in 2050.
- Consumption in China, which had until recently driven the global demand growth, will peak around 2030 before turning downward while demand in India, the Middle East and North Africa and the Association of Southeast Asian Nations (ASEAN) will continue to increase. India's consumption will surpass that of the United States and ASEAN's will surpass that of the European Union in the 2040s, making Emerging Market and Developing Economies in the energy and environmental fields all the more important.

Middle Eastern oil producers take advantage of their low production costs to lead crude oil supply. Russia is suffering from a severe shortage of upstream investment due to embargoes and sanctions, and its rate of decline is accelerating.

- In the medium-term, until 2030, the Organization of the Petroleum Exporting Countries (OPEC) and non-OPEC will both increase crude oil production. However, in Europe and Eurasia, where oil production was expected to decline over the medium to long term even before the Ukrainian war, the impact of Western countries' embargoes and sanctions will deepen Russia's lack of upstream investment and accelerate the pace of decline. Production in North America, led by the United States which increased output dramatically in the 2010s, will peak around 2030.

- From 2030, OPEC, especially the Middle East OPEC members with their abundant oil reserves and cheap production costs, will become increasingly prominent despite increases in production from Latin America. The share of OPEC crude oil in the global oil supply will rise from 34% in 2020 to 44% in 2050.

- Total world crude oil trade will increase as a result of rising oil demand. Imports will fall in Organisation for Economic Co-operation and Development (OECD) countries, where demand will decline, but imports from non-OECD countries will increase at a faster pace. Asia's dependence on imports will continue to rise, and while inflows from the Americas will increase, the Middle East will remain the largest supplier. Non-OECD Europe/Central Asia, especially Russia, will see an accelerated decline in exports to Europe and become more dependent on the Chinese market.

The LNG market is expanding due to abundant supply potential, but the outlook is uncertain

- The United States, the world's largest producer and consumer of natural gas, will continue to increase its production of natural gas, especially shale gas. Until about 2030, production will increase at an annual rate of about 1% and then stabilise.

- Australia, which slightly surpassed Qatar as the world's largest exporter of liquefied natural gas (LNG) in 2020, will experience steady growth in production. The increase is in part due to projects centring on supply of additional feedgas to existing LNG production facilities. The increase will moderate after 2030.

- In the Russian Arctic, a second major LNG export project is under construction based on the investment decision made a few years ago. However, the future of this project is uncertain due to the Russian invasion of Ukraine in February 2022.

Achieving decarbonisation is, realistically, a long-term commitment

- Decarbonisation has accelerated faster in Advanced Economies such as the United States and Europe. Emerging Market and Developing Economies have announced their intention to become carbon neutral, despite a long run coal demand that will expand in Asia, except in China, and Africa. Global coal production will increase until the early 2030s in response to demand but after that, it will start to decline; the downward trend will intensify in the 2040s.

- Steam coal production will increase from 5 950 Mt in 2020 to 6 537 Mt in 2040 mainly due to increased demand for power generation. It then begins to slowly decline, reaching 6 311 Mt in 2050. Production of coking coal, used mainly as a raw material for steel production, will gradually decline from 1 014 Mt in 2020 to 824 Mt in 2050.

Electricity generation is expanding rapidly in Asia. Natural gas-fired power generation is the biggest source of electricity

- Global electricity generation will grow at an annual rate of 1.8%, rising to 45 777 TWh in 2050, 1.7 times higher than in 2020. 95% of that increase comes from Emerging Market and Developing Economies. Continuing its rapid economic growth, electricity generation in Asia will increase at an annual rate of 2.1% to reach 23 313 TWh in 2050, roughly half of the world's requirements.
- Although coal has the largest current share of the global power generation mix, natural gas will be the largest source of electricity in 2050. With a continuing upward trend in electricity demand in both Advanced Economies and Emerging Market and Developing Economies, ensuring a stable supply of natural gas remains an urgent and a long-term issue.
- In Advanced Economies, renewable energy will overtake natural gas as the largest source of electricity in the first half of the 2020s due to its rapid adoption. Of these, solar photovoltaic and wind, which have output variability, will account for 25% of the electricity generated in 2050. Measures to deal with these output fluctuations and the expansion of the network connecting the sites suitable for power generation and the location of demand will be issues.
- In Emerging Market and Developing Economies, renewable energy, especially wind, will continue to increase and replace coal as the largest power source in 2050. However, the role of coal-fired power generation in supporting the robust demand for electricity is no small matter, and it is necessary to develop a highly predictable investment environment and address environmental issues, such as air pollution.
- The role of nuclear is being recognised anew in Japan, Europe and other countries from the perspectives of climate change countermeasures and ensuring energy security, especially after Russia invaded Ukraine. However, although new construction starts are underway, mainly in Asia, nuclear will not grow faster than the rate of increase in electricity demand through 2050, reducing its share of the power generation mix to 7%.

Advanced Technologies Scenario

Even under the Advanced Technologies Scenario, reaching global carbon neutrality by 2050 is far from being achieved. Further promotion of energy efficiency and climate change measures will require the full mobilisation of all means possible.

- The "Advanced Technologies Scenario" anticipates maximum carbon dioxide (CO_2) emission reduction measures based on the application opportunities and acceptability in society, including the full-scale introduction of newly factored hydrogen, and enhanced energy security measures. It should be noted that this Outlook is a forecast-type of exercise that projects in the future based on the premise of the introduction of technology, etc. It contrasts with a backcast-type analysis that defines a future "landing point" and charts a possible path to reach it. Global final energy consumption under the Advanced

Technologies Scenario will be reduced by 5.2% in 2030 and 23.5% in 2050 compared to the Reference Scenario.

- Primary energy consumption will decline by 4.4% relative to the Reference Scenario in 2030 but will increase relative to 2020. After 2030, the reduction will accelerate as energy efficiency continues to improve. The reduction from the Reference Scenario in 2050 will only reach 18.5%, which is less than that of final energy consumption of 23.5%. This is due to the increased use of electricity and hydrogen, which have energy transformation losses.
- Fuel switching will also advance, reducing fossil fuel primary energy consumption by 1.1 Gtoe relative to the Reference Scenario in 2030 and 5.1 Gtoe in 2050. Despite a substantial growth in non-fossil energy of 0.4 Gtoe in 2030 and 1.8 Gtoe in 2050, the world cannot continue to maintain and improve its economy, society and livelihoods without fossil fuels, even in the Advanced Technologies Scenario.
- Energy-related CO_2 emissions will be 31.2 Gt in 2030 (down 1.4% from 2020) and 16.9 Gt in 2050 (down 46.5%). In this scenario, CO_2 emissions would significantly reduce to levels equivalent to the *Announced Pledges Scenario* of the International Energy Agency (IEA) released in its "World Energy Outlook 2021". Consequently, such scenario is still far from a worldwide "Net Zero" emissions. The reduction from the Reference Scenario will amount to 20.1 Gt in 2050, of which China and India accounted for 38.1%.
- One of China's 2030 targets for Nationally Determined Contribution is to reduce CO_2 emissions intensity per GDP by more than 65% from 2005 levels, which is roughly equivalent to the Reference Scenario results. India's target of a 45% reduction in intensity, in its 2022 update, is roughly equivalent to results in the Advanced Technologies Scenario. On the other hand, the set targets to reduce emissions by the United States (50% to 52% reduction from 2005 levels), the European Union (55% reduction from 1990 levels) and Japan (45% reduction from 2013 levels), will fall short of the Advanced Technologies Scenario results.
- As expected, the Advanced Technologies Scenario requires less investment in fossil fuels than in the Reference Scenario, but further low-carbon investment in renewable energy and energy efficient equipment is required. The investment required in the 2040s, under the Advanced Technologies Scenario, is $35 trillion (at 2015 prices), $20 trillion more than in the 2010s, or an increase of $6 trillion from the Reference Scenario in the 2040s. The cumulative global energy investment requirement by 2050 will reach $88 trillion, or an average of $2.9 trillion per year.

Energy security strategy to address the Ukraine crisis and the energy transition

- A growing number of Asian countries are declaring themselves as also aiming at carbon neutrality. In addition to building a new energy infrastructure, free of carbon emissions, the world must focus on big problems that cannot be solved easily in the limited time we have (between 30 and 40 years). The problems include the mass disposal of existing equipment and job displacement, due to reworking the energy system. There is also a great deal of uncertainty surrounding the specific means of realisation.

- Asia faces a variety of challenges stemming from energy security. In emerging and developing Asia, where high economic growth is expected, it is essential to provide stably and inexpensively a large amount of energy. Considering the current trend toward a return to coal due to soaring energy prices, the amount of renewable energy available and their integrating costs, the transition from coal to natural gas is the realistic path forward. In doing so, the first phase of switching from coal to natural gas will involve increasing supply investments outside Russia while presenting a practical solution to the supply and cost problem. In the second phase, decarbonisation will be achieved by adding various measures, including the use of renewable energy and decarbonised natural gas.

- The so-called "4R technologies" is a tool to realise the decarbonisation of fossil fuels. Among them are the use of blue hydrogen produced by capturing CO_2 generated during manufacturing, the introduction of carbon capture and storage (CCS) technology in manufacturing plants and power plants, and carbon recycling technology that uses the captured CO_2 for other purposes.

Response to strengthening stable power supply and importance of nuclear power generation

- Under electricity deregulation, power generation facilities that are used infrequently in the market – with fewer generating opportunities – will be suspended and decommissioned. The introduction of renewables power generation has been expanded based on government support measures and in part caused the suspension and abolition of thermal power generation in many developed countries due to the decline in operating rates and the deterioration of profitability. As a result, the remaining power supply capacity of the entire electricity system declined. A sudden surge in demand for electricity triggered by extreme heat or severe winter, combined with output declines and outages of power generation facilities (also caused by heat and cold waves), create situations in which the balance between supply and demand becomes tight.

- Until now, the assessment of a stable supply of electricity has been to evaluate the possibility of a shortage of generating capacity (kW shortage) in response to increased demand. As decarbonisation policies proceed in the future, it is expected that dependence on a small number of power sources will increase. Another major issue is how to assess the risk of a shortfall in the amount of electricity generated (kWh shortage) when facing unforeseen events in a power source that the system heavily depends on.

- In a climate dominated by low-carbon arguments, the sharp rise in global fossil fuel prices since around 2021 and the Russian invasion of Ukraine in February 2022 put greater emphasis on securing a stable supply of energy. The role of nuclear in energy security is once more being recognised in Japan, Europe and elsewhere. The importance of its utilisation as a stable large-scale baseload power source under fossil fuel-fired power generation constraints has been highlighted anew.

- France and other countries announced ambitious nuclear targets while analysing the best mix with renewables. Plans to build new nuclear power plants are also underway in the United Kingdom and Eastern European countries. Expanding the operation of existing nuclear power plants and restarting them in Japan attract global interest. Attention is being paid to initiatives such as the introduction of a Regulated Asset Base (RAB) model, which is under consideration in the United Kingdom and can be considered as providing regulated returns to secure new investment in nuclear that will simultaneously achieve decarbonisation and stable supply.
- Nuclear is considered important from the standpoint of energy security, but it is also important for companies and countries in which nuclear is developed. A series of new projects by Western companies have faced delays in construction times and higher costs that far exceeded their original estimates. In one instance, it was pointed out that the company lost its construction know-how and was forced to change its design after construction began, due to regulatory requirements.

Critical mineral issues and energy, and economic security

- To achieve carbon neutrality, a massive adoption of renewable energy, electric vehicles, hydrogen and other low-carbon technologies is necessary. A new energy security challenge is emerging, caused by tight supply and demand for rare minerals (critical minerals), which are considered essential for these technologies. Like for fossil fuels, these resources are unevenly distributed around the globe.
- In the Advanced Technologies Scenario, the supply and demand for lithium, cobalt, neodymium and dysprosium will be tight by the mid-2030s, mainly due to the increased penetration of electric vehicles. For nickel and cobalt, there are concerns that the cumulative demand by 2050 will exceed the sum of the total recycled supply and the resource reserves to cover long-term demand.
- Resources are concentrated in Chile, Argentina, Australia and China for lithium, Indonesia and the Philippines for nickel, the Democratic Republic of Congo for cobalt, and China for the rare earth's neodymium and dysprosium.
- There are short-term and long-term perspectives on energy security. Unlike "flow-type" commodities such as oil and natural gas, which can face a significant impact in the event of a sudden supply disruption caused by some disturbance, "stock-type" materials are more resistant to short-term risks because even if a supply disruption occurs, the portion already imported can be incorporated into renewable energy facilities to provide energy. On the other hand, from a long-term perspective, it will be difficult to achieve carbon neutrality based on renewable energy, electric vehicles, hydrogen, etc., unless measures are prepared in advance to address the tightening of global supply and demand and uneven distribution of resources for critical minerals. While it will be essential to increase production at existing mines and promote the development of new mines for those types of ore that are feared to be in short supply, there are concerns that resource development

and export controls will be tightened in supplier countries in the future. Therefore, it goes without saying that demand countries are required to not only strengthen resource diplomacy aimed at securing interests, but they are also required to reduce import dependency and increase recycling rates to diversify sources of procurement, and to promote the development of technologies for non-use and reduced usage, as well as alternative technologies.

- On the other hand, supplier policies and the prospects for recycling, shifting and developing alternative technologies all involve uncertainty. Therefore, from the perspective of energy and economic security, consideration should also be given to balanced technology choices aimed at avoiding excessive reliance on specific carbon-neutral technologies[1].

Economic impact of green investment

- When investments in climate change measures create a virtuous cycle of emissions reductions and economic growth, it is called "Green growth". The results, however, may not be realised or they may appear differently in different economies and entities. It could create new disparities – (1) among developed economies and emerging/developing economies, (2) between developed and emerging/developing economies, (3) between economies that rely on fossil fuel exports and those that do not, and (4) within the population and citizens of the same economies.
- The cumulative additional green investment and consumption to realise the Advanced Technologies Scenario amounts to $14 trillion (at 2015 prices). If this green investment and consumption were carried out in a "No Financial Constrained" situation where the total amount of funds available could be increased at will, the GDP in 2050 would increase by $20 trillion (11.2%, an annual average of 0.4%). On the other hand, under a "Financial Constrained" situation in which the total amount of funds cannot be changed due to limited economic and financing capacity, GDP would be reduced by $6.2 trillion (3.5%, an annual average of 0.1%). "Financial constrained" means that incremental green investments will be offset by declines in investment and consumption in other areas.
- Under the No Financial Constrained Case, GDP and output would increase in many economies, but would decrease in economies such as those in the Middle East and the former Soviet Union that are highly dependent on mining (fossil fuels). In the Financial Constrained Case, GDP and output will decrease in many economies. However, in some developed countries and China, the decrease in the value of energy imports due to green investment and consumption is significant and GDP and output will increase, outweighing the decrease in investment in other sectors due to financial constraints.

[1] With the permission of the Japan Oil, Gas and Metals National Corporation (JOGMEC), this article presents a part of the results of its commissioned study, "Survey of Mineral Resource Supply and Demand to Achieve Carbon Neutrality" (FY2022), and details of the results will be reported at a seminar scheduled to be held by JOGMEC on 10 November 2022.

- Investment is a new demand and a source of growth. However, if other investments are reduced in proportion to new investments in a situation of financial constraints and budget constraints, no new demand is created as a total amount. In addition, green investment is unlikely to be a source of growth because it is not itself an investment to expand production capacity. Relaxing financial constraints and providing sufficient funds are the key to achieving green growth.
- For smooth financing, it is necessary to use not only government budgets but also green finance, which is mainly funded by the private sector. It is important to clarify the direction of the environmental policies to limit risks and encourage investment. How to limit negative economic impacts and how to even out the different impacts between economies and industries is important.

Part Ⅰ

Energy supply and demand outlook

1. Framework assumptions

1.1 Model and scenarios

We used a quantitative analysis model, with an econometric approach adopted as the core, to develop an energy outlook and assess energy supply and demand in the world through 2050. The model, based on the energy balance tables of the International Energy Agency (IEA), covers various economic indicators as well as population, vehicle ownership, basic materials production and other energy-related data collected for modelling. We divided the world into 42 regions[2] and international bunkers, as indicated in Figure 1-1, and built a detailed supply and demand analysis model for each.

Figure 1-1 | Geographical coverage

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

We assumed the following two main scenarios for the projection.

Reference Scenario

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

[2] See Table A1 for a detailed definition.

Advanced Technologies Scenario

In this scenario, all countries in the world are assumed to strongly implement energy and environmental policies contributing to securing stable energy supplies and enhancing countermeasures against climate change and air pollution. The effects of those policies are assumed to be successfully maximised. Specifically, our projection assumes that advanced technologies for the energy supply and demand sides, as given in Figure 1-2, will be introduced as much as possible, with their application opportunities and acceptability considered. The IEEJ Outlook 2023 also considers the efforts made by various countries and companies in developing hydrogen technologies to further reduce carbon dioxide (CO_2) emissions[3].

[3] The IEEJ Outlook 2022 also referred to hydrogen, however, the introduced amount of hydrogen in the Advanced Technologies Scenario was extremely limited.

Figure 1-2 | Technology introduction assumptions for the Advanced Technologies Scenario

Introduction and enhancement of environmental regulations and national targets

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

Promoting technology development and international technology cooperation

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

Demand-side technologies

Industry

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

Transport

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

Buildings

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

Supply-side technologies

Renewable energies

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

Enhanced introduction of nuclear power

Acceleration in nuclear power plant construction and improvement in capacity factor

Promotion of highly efficient fossil fuel-fired power generation technologies

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

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 subject to population, economic growth, other social and economic factors, energy prices, as well as the above-mentioned energy utilisation technologies and energy and environmental policies. The following assumptions for economic growth and population among these factors are common to the Reference and Advanced Technologies Scenarios. Considerations for the economic impacts of green investment for energy transformation, are covered in Chapter 9 “Economic impact of green investments”.

Economy

Recent situation

In 2021, despite the continuing COVID-19 pandemic, large-scale fiscal stimulus and monetary easing by many governments began to take effect, allowing major economies to achieve substantial growth and recover above their pre-COVID-19 levels of 2019. On the other hand, the current situation remains uncertain, the spread of COVID-19 is not expected to end soon due to the emergence of new mutant strains and, Russia’s invasion of Ukraine in February 2022 is increasingly affecting the global economy.

In the United States, due to active monetary easing by the Federal Reserve Board (FRB) and despite the peaking of COVID-19 new infections, the economy started to recover and experienced steady growth. As expected, however, inflation took off because of an enlarging supply-demand gap and higher energy prices. The large supply-demand gap followed a series of supply-side disruptions, resulting from COVID-19. To address the inflation, the FRB lifted its zero interest-rate policy in March 2022, began a tightening monetary policy, and raised interest rates by an unprecedented three consecutive hikes of 0.75% in June, July and September. These hikes were intended to curb high inflation, but there are fears that they could hurt the economy.

European economies are facing the impact of Russia’s invasion of Ukraine, while slowly recovering from the effects of COVID-19. As in the United States, inflation has been high due to soaring fuel and food prices resulting from the embargo on Russian fossil fuels imposed as part of sanctions against Russia. Although their economy seems to be supported by rising consumption of services, the impact of the invasion of Ukraine is a serious concern.

China, the world’s third largest economy, was initially relatively successful in containing the pandemic compared to other regions. Its economy has slowed down due to strict city lockdowns addressing the repeated spread of mutant strains. To mitigate the impact of the pandemic on economic growth, the Chinese government has eased some of its regulations on real estate and finance and has eased its fiscal and monetary policies. This tentatively boosted infrastructure investment, lessening the pace of decline in real estate investment. Demand has been slow to recover after the lifting of the city lockdowns imposed in Shanghai and other cities since April 2022.

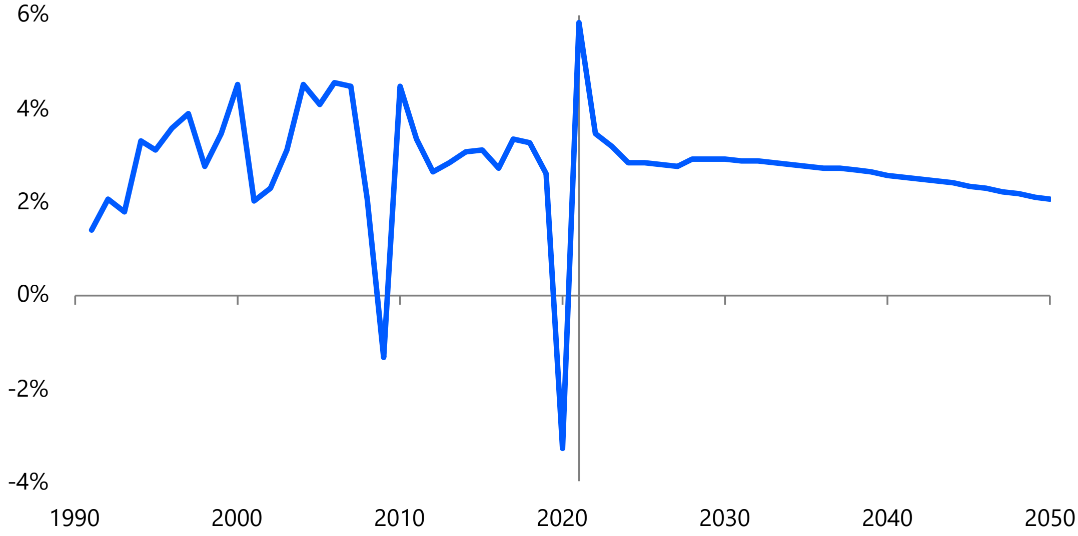
Oil demand is gradually recovering after a sharp drop due to the global economic slowdown and the decline in transportation demand, both caused by the pandemic. In February 2021, international oil prices returned to the $60/bbl range, which was almost the pre-pandemic level, and then continued to rise thereafter. However, when Russia invaded Ukraine, the price skyrocketed to the \$100/bbl - \$120/bbl range, fuelled by concerns over crude oil supply and other factors. The price soon slightly declined, the result of the global economic slowdown, but has remained high ever since.

Assumptions for the future

While referring to country-by-country economic development plans and economic outlooks prepared by think-tanks around the world, economic growth is assumed to be as follows:

After 2023, there will be no large-scale waves of COVID-19 infections or associated severe city lockdowns that could affect the global economy. Russia's invasion of Ukraine will continue to cause local and short-term effects, but is not expected to drastically affect the global economy, like the negative growth in 2020 that was caused by the pandemic. The economic growth of 2022 will continue in 2023 and is expected to reach 3.1%. The growth rate will gradually decline from 2023 onwards, from high 2% to low 2% (Figure 1-3).

Figure 1-3 | World economic growth assumption

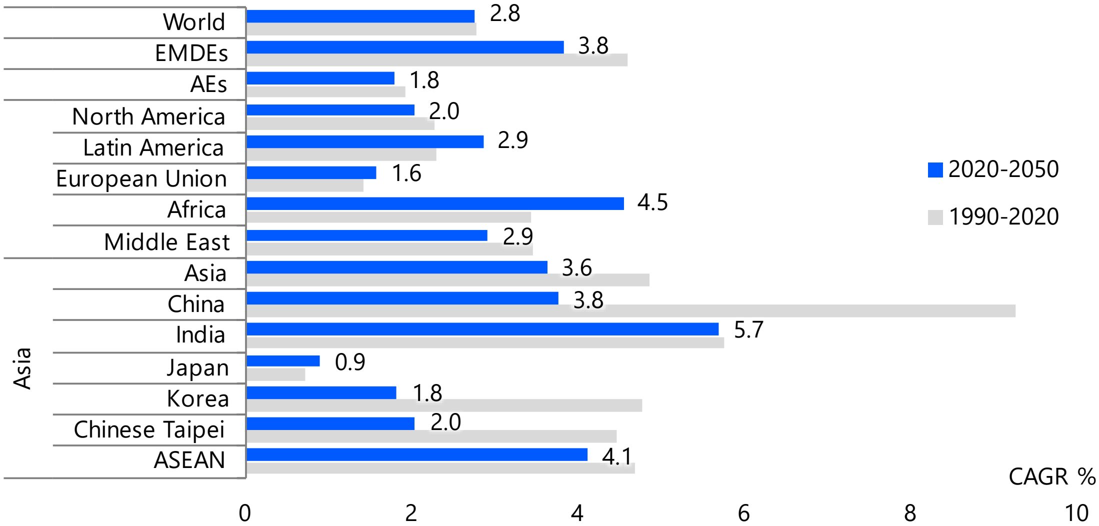


The impacts of COVID-19 and Russia's invasion of Ukraine on the world economy will be short-lived. Most economies will resume growth over the medium to long term. However, this will require that countries improve productivity, achieve technological innovation, implement proper fiscal, monetary and distribution policies, extend international cooperation and ensure security.

Advanced Economies will continue to grow at almost the same rate as before while the Emerging Market and Developing Economies of Asia and Africa will continue to grow rapidly. For example, India will grow the fastest in the world at an average annual rate of 5.7% over the projection period, comparable to 5.8% of the past 30 years. China will grow at an annual pace of 3.8%, though growth will continue to slow down, and Africa will grow at 4.5% per annum, the fastest by region.

In consideration of the above situation, we assume the world's annual economic growth rate at 2.8% over the projection period (Figure 1-4).

Figure 1-4 | Economic growth assumption in selected countries/regions



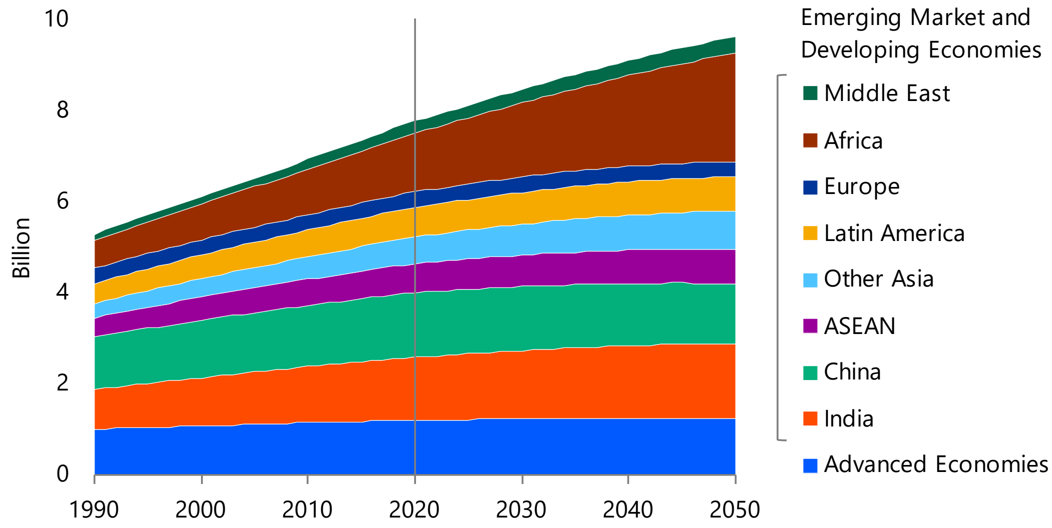
Notes: AEs stands for Advanced Economies. EMDEs stands for Emerging Market and Developing Economies.

Population

For assumptions on population changes, we referred to the United Nations' "World Population Prospects". In many Advanced Economies, the total fertility rate (TFR), or the average number of children born to a woman during her lifetime, has slipped below two. Currently, the spread of COVID-19 and subsequent economic stagnation around the world are increasing the downward pressure on population. In Emerging Market and Developing Economies, the TFR is also trending down, in line with income growth and women's increasing social participation. Nevertheless, the population of Emerging Market and Developing Economies will continue to increase, although at a slower pace, as mortality rates are declining due to improving medical technologies and food and sanitation conditions. The world's population will continue increasing at an average annual rate of approximately 0.7%, reaching 9.6 billion in 2050, up from 5.3 billion from 1990 and 7.8 billion from 2020 (Figure 1-5).

Among Advanced Economies, North American countries, particularly the United States, will post a relatively steady population increase due to a massive population influx from abroad and a high TFR. However, the increase will be moderate, with the United States' share of global population falling slightly. The population of the European Union will increase very moderately until the 2030s, before turning downward. In Asia, Japan's population started to shrink in 2011 and will decrease by some 20% from the current level to 104 million in 2050. The population of Korea also began to decline from 2021 and will fall below 46 million by 2050.

Figure 1-5 | Population assumption



The population of Emerging Market and Developing Economies will continue to increase substantially, driven by Africa and India. Africa will nearly double its population from its present level to 2.37 billion in 2050, as the lower mortality rate counters a gradual fall in the birth rate. The population of the Middle East will expand 1.4-fold, the result of governments' financial incentives to increase the population and a growing influx from other regions. In Asia, India's population will continue to grow fast and will soon surpass that of China. At 1.7 billion by 2050, India's population will be the world's largest. China's population which currently is the largest, peaked in 2021 and has begun to decline; it will drop to around 1.3 billion by 2050. The population of the Association of Southeast Asian Nations (ASEAN) will increase by 110 million to 760 million by 2050.

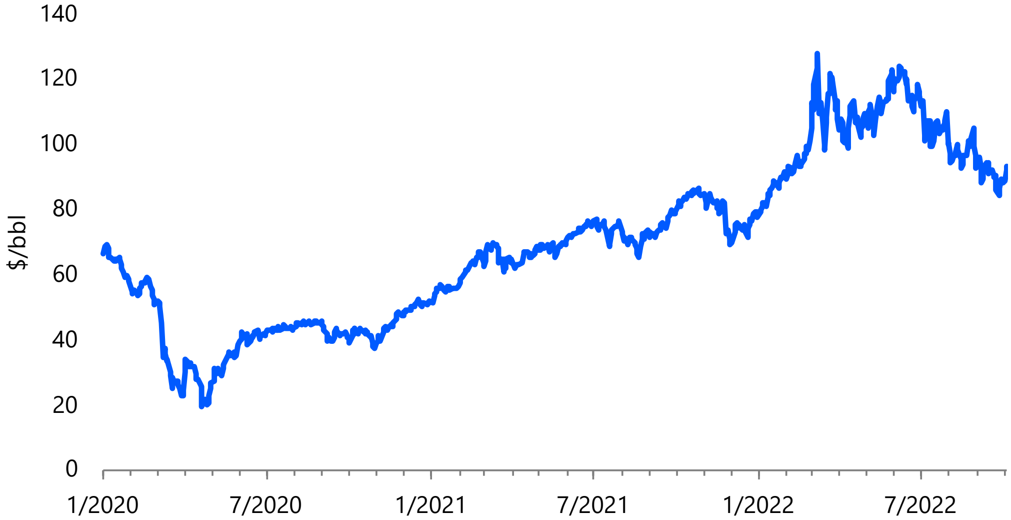
International energy prices

Recent situation

In 2021, global demand rose as the economies of many countries recovered from the pandemic, leading to a rapid increase in energy demand. However, supply and demand tightened as fossil fuel supply investments were curbed, amid the move toward decarbonisation, causing energy prices to well exceed their pre-COVID-19 levels. Furthermore, the impact of Russia's invasion of Ukraine in February 2022 caused concerns over continuously high energy prices in the future.

At first, oil prices plunged amid the collapse in global demand for crude oil due to the impact of COVID-19 (Figure 1-6). Subsequently, economic recovery from the pandemic and production adjustments by OPEC Plus, which consists of the Organization of Petroleum Exporting Countries (OPEC) and non-OPEC major oil-producing countries, contributed to the average Brent price in 2021 rising to about $70/bbl, a similar level to that of before COVID-19. The Russian invasion of Ukraine led to a sharp spike in oil prices in March 2022, with Brent price hitting $128/bbl on 8th March. Since then, prices have remained high despite some drop due to the release of oil stockpiles in consuming countries, the effects of lockdowns in some Chinese cities, and concerns about a global economic decline.

Figure 1-6 | Brent crude oil prices



Source: Intercontinental Exchange

As for natural gas, Japan's average import price of liquefied natural gas (LNG) has been on an upward trend lagging a few months behind changes in the oil price. The most recent bottom in prices was in September 2020. However, spot prices, which sensitively reflect supply and demand, have been more strongly affected by international interactions. Asian spot LNG prices (Japan Korea Marker [JKM]) have been volatile, hovering in the $20/MBtu range in January and February 2022, but temporarily surged above $80/MBtu in March due to concerns about the disruption of Russian pipeline gas supplies to Europe. The prices once fell to around $20/MBtu in April but have, since late June, remained high at around $40/MBtu on the back of renewed concerns about supply. European gas spot prices (Title Transfer Facility [TTF] in the Netherlands, National Balancing Point [NBP] in the UK, etc.), which had been less than $10/MBtu in early 2021, exceeded $40/MBtu in March 2022 due to the sharp recovery in demand (from the pandemic), a lower wind power generation (poor wind conditions), a severe winter and the Russian invasion of Ukraine. U.S. spot gas prices (Henry Hub [HH]) remained in the $3/MBtu to $5/MBtu range in 2021, but have been in the $6/MBtu to $8/MBtu range since April 2022. Factors contributing to the price rise include increased LNG exports to Europe in light of the Ukraine situation and supply disruptions due to troubles in production facilities.

The international coal market tightened because China increased coal imports to support its revived economic activity, amid supply disruptions caused by natural disasters and production equipment problems. As a result, prices have been soaring since 2021. While coking coal prices have been softening for some time now due to fears of a global economic recession, steam coal prices are more likely to rise and remain high due to the embargo on Russian coal by major countries. The coal market is becoming structurally unstable due to less flexibility in supply capacity and a trend to phase out coal.

Reference Scenario

Oil demand in the Reference Scenario will continue increasing, driven by emerging economies of Asia such as India and ASEAN. On the supply side, dependence on OPEC and other oil countries will increase over the medium to long term, while oil prices, which balance supply and demand, will rise during the same period due to divestment and Advanced Economies' tighter regulations on oil field development. However, as many countries, mainly the developed ones, enhance their decarbonisation initiatives to decelerate the growth in oil demand, oil price hikes will be limited. The real oil price (in 2021 dollars) is assumed to increase to $80/bbl in 2030 and $95/bbl in 2050 (Table 1-1). Under an assumed annual inflation rate of about 2%, the nominal price is projected to reach $96/bbl in 2030 and $148/bbl in 2050.

Table 1-1 | International energy price assumption

Real prices			Reference			Advanced Technologies		
		2021	2030	2040	2050	2030	2040	2050
Oil	$2021/bbl	71	80	90	95	60	55	45
Natural gas								
Japan	$2021/MBtu	10.8	7.6	7.2	7.1	6.5	5.8	4.6
Europe (UK)	$2021/MBtu	16.1	7.5	7.5	7.4	6.9	6.2	5.0
United States	$2021/MBtu	3.9	3.3	3.8	3.8	3.0	3.5	3.5
Steam coal	$2021/t	129	99	96	93	84	77	70

Nominal prices			Reference			Advanced Technologies		
		2021	2030	2040	2050	2030	2040	2050
Oil	$/bbl	71	96	125	148	72	77	70
Natural gas								
Japan	$/MBtu	10.8	9.1	10.0	11.1	7.7	8.1	7.2
Europe (UK)	$/MBtu	16.1	9.0	10.5	11.6	8.3	8.6	7.8
United States	$/MBtu	3.9	4.0	5.3	5.9	3.6	4.9	5.5
Steam coal	$/t	129	119	134	145	101	107	109

Note: The annual inflation rate is assumed at about 2%.

Natural gas prices have risen to a 14-year high in the United States, but will remain low compared to other regions due to abundant supply capacity. In line with the relative increase in development and production costs and expanded demand, including exports, prices will decline toward 2030, will rise again toward 2040 and level off thereafter. Japan's real import prices are now rising due to soaring oil prices and the Ukraine situation, but will tend to stabilise, factoring in a future recovery in LNG investment. Prices will remain mostly flat from 2040 onward. The increase and regularisation of LNG exports from the United States mainland is expected to lead to diversification of procurement sources and the elimination or relaxation of destination restrictions, which is expected to lead to a gradual shift away from oil prices. In fact, for Asia-bound LNG, the gap between spot prices which have been subject to increased volatility, and long-term contract prices which are often linked to oil prices, has widened in recent years. These factors have led to a move to reconsider the terms and conditions of long-term contracts. For LNG prices in Japan, supply sources other than from the United States would be higher due to limitations on cost cuts, despite progress in the optimisation of LNG maritime transportation. Meanwhile, prices would become more linked to European prices, narrowing bilateral gaps.

Coal prices (FOB steam coal from Newcastle, Australia) will reach a record high in 2022 due to the embargo on Russian coal imposed by major countries, but demand will decline thereafter, partly due to the global trend toward carbon neutrality, thus stabilising in the low $90/t range in 2050. While demand for coal for power generation will increase in Asian countries such as India and ASEAN nations, tougher environmental regulations and trends toward decarbonisation are likely to make it difficult to expand coal production capacity. Risks of short-term fluctuations due to seasonal factors and supply-demand imbalances will increase. Although prices per thermal unit for coal are lower than those for oil or natural gas, coal's economic advantage will decline amid a global relative downtrend of natural gas prices, especially in Europe and other regions that introduce carbon prices.

Advanced Technologies Scenario

In the Advanced Technologies Scenario, fossil fuel demand will decline as a result of improvements in energy efficiency and fuel switching to nuclear, renewables and hydrogen. As a result, the prices of fossil fuels of all kinds will fall compared to those in the Reference Scenario. However, prices may become volatile if a smooth transformation of the energy demand structure and the corresponding supply structure are not coordinated.

2. Energy demand

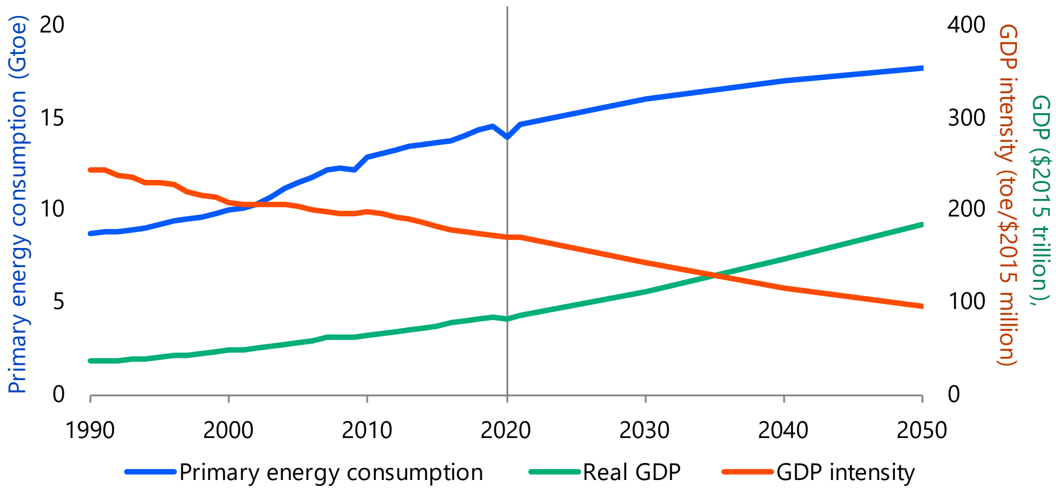
2.1 Primary energy consumption

Energy consumption continues to increase although GDP energy intensity is rapidly improving thanks to climate change countermeasures and energy security

The Working Group I report of the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that "it is unequivocal that human influence has warmed the atmosphere, ocean and land". As a countermeasure, many countries have announced carbon neutral policies that aim to achieve net-zero carbon dioxide (CO_2) emissions. Furthermore, Russia's invasion of Ukraine in February 2022 has highlighted the instability of fossil fuel supply and threatens energy security. Policies toward further energy conservation and decarbonisation have been identified, particularly in Europe, to address a stable energy supply.

Global gross domestic product (GDP) energy intensity from 2020 to 2050 will decline faster than from 1990 to 2020 as countries around the world promote higher energy efficiency and energy conservation in the context of climate change actions and energy security (Figure 2-1). However, as GDP grows faster than the intensity, global primary energy consumption will continue to increase. The growth of primary energy consumption, which was 1.6% annually from 1990 to 2020, will decline to 0.8% annually from 2020 to 2050 due to progress in energy conservation. Yet, global energy consumption in 2050 will rise to 17 649 million tonnes of oil equivalent (Mtoe), 1.3 times that of 2020. It is difficult to satisfy the new demand simply by increasing the supply of non-fossil fuels such as nuclear and renewable energies. Each country needs to improve efficiency even more in order to reduce fossil fuel consumption worldwide.

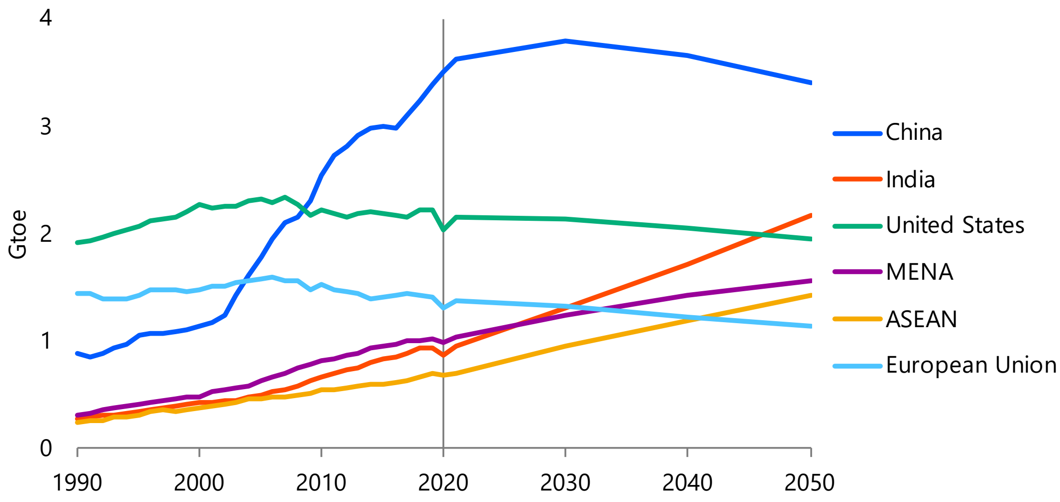
Figure 2-1 | Global primary energy consumption, real GDP and GDP energy intensity [Reference Scenario]



By region, China, which has led the increase in global primary energy consumption since 2000, will decrease its consumption after peaking around 2030. India, the Middle East and North

Africa (MENA) and the Association of Southeast Asian Nations (ASEAN) will steadily increase their consumption. The increase in these three countries and regions will account for 71% of the increase in the world's consumption from 2020 to 2050, pushing up global primary energy consumption, with their share growing from 18% in 2020 to 29% in 2050 (Figure 2-2). Therefore, in addition to accelerating the reduction in consumption in Advanced Economies and China, whether India, MENA and ASEAN can curb their energy consumption will determine the global trend of energy consumption and, ultimately, measures for climate change and energy security.

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



India, MENA and ASEAN, respectively, will increase their energy consumption by 3.1%, 1.5% and 2.5% per annum from 2020 to 2050 and account for 12%, 9% and 8% of global energy consumption in 2050. Their growth rates are 2.3, 0.8 and 1.7 percentage points higher than the global average, respectively, since their economies grow faster by 5.3%, 2.6% and 3.4% per annum, respectively through 2050. Decoupling energy consumption from economic growth in India, MENA and ASEAN will become a global challenge.

As a matter of course, it will be indispensable for energy-consuming economies such as the United States, the European Union (EU) and Japan, as well as China, to continue reducing their energy consumption in view of climate change and energy security concerns. The United States, Europe and Japan will account for 34% of global GDP and China for 16%, while the total primary energy consumption of these two groups will each account for 19%, a large share of the world total. To suppress global energy consumption, these economies should accelerate their reduction of energy consumption through climate change and energy security measures while playing a role in boosting the global economy stably through consumption and investment.

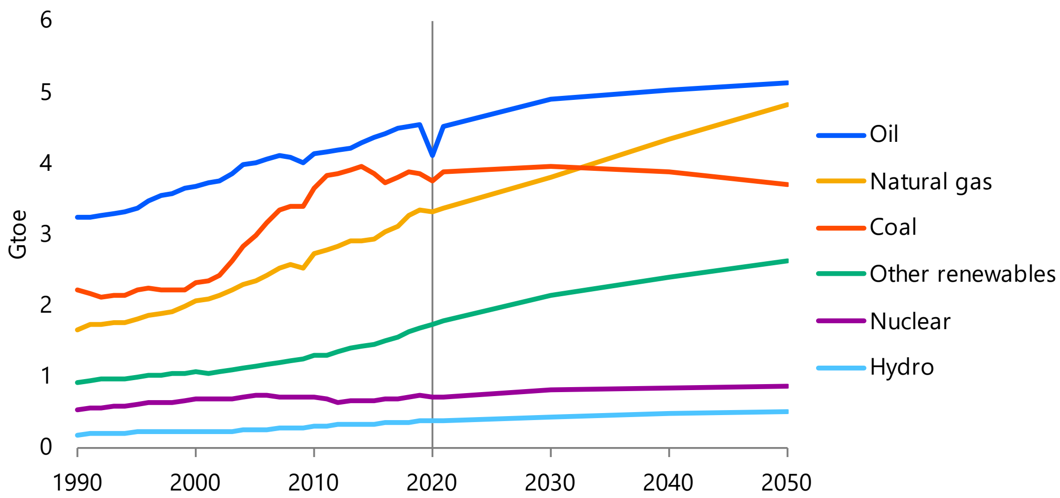
To further reduce global energy consumption, international cooperation between the Advanced Economies and the Emerging Market and Developing Economies and among the

Emerging Market and Developing Economies, as well as each economy's policies will have to be enhanced. Advanced Economies such as the United States, Europe and Japan will need to offer highly efficient technology transfer and support to the rest of the world so that it can achieve economic growth while curbing energy consumption by utilising Article 6 of the Paris Agreement, addressing energy security concerns, particularly the instability of fossil fuel supplies.

Fossil fuel consumption 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 raised concerns about the stable supply of fossil fuels, mainly in Europe. Fossil fuel consumption declined significantly in 2020, partly due to the economic downturn and voluntary staying indoors (or lockdowns) amid the COVID-19 pandemic. However, in line with the recovery from the pandemic, consumption is now increasing and will continue to grow at an annual rate of 0.8% (Figure 2-3). Natural gas has the lowest carbon emissions of all fossil fuels and thus will be most actively introduced to mitigate climate change. Natural gas consumption in 2050 will increase at an average annual rate of 1.3%, mainly in the power generation sector, to 1.5 times the 2020 level, approaching that of oil, which is the highest. Oil will post the second largest consumption growth, expanding at an annual rate of 0.7% mainly in the transport sector (automobiles, aircraft and ships). Coal consumption will peak around 2030 due to restrictions against the backdrop of mitigating air pollution and climate change and will decline below 2020 levels by 2050.

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



Non-fossil energy sources, such as nuclear and renewable energy, will continue to expand due to measures addressing climate change and energy security. Nuclear, and hydro and other renewables (excluding solid biomass) will boost their share from 20% in 2020 to 23% in 2050.

Non-fossil energy sources will increase their presence through 2050 but overall demand will grow even more; therefore, non-fossil energy sources face difficulties in fully meeting energy demand alone even 30 years from now. Through 2050, it will remain realistic for the world, including the Emerging Market and Developing Economies which are expanding their energy consumption, to use both fossil fuels and non-fossil energy (Figure 2-4).

Dependence on fossil fuels will decrease from 80% in 2020 to 77% in 2050 (Figure 2-5). The dependence will fall from 81% in 2020 to 73% in 2050 for the United States, from 68% to 60% for the European Union and from 89% to 73% for Japan. However, it will remain high in Emerging Market and Developing Economies, including China. The dependence on fossil fuels in India, MENA and ASEAN will remain large, at 81%, 93% and 77%, respectively, as their total energy consumption is increasing and fossil fuels will meet much of the increase.

Figure 2-4 | Primary energy consumption changes [Reference Scenario, 2020-2050]

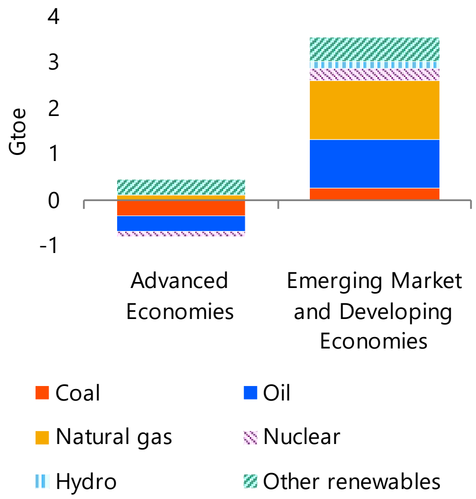
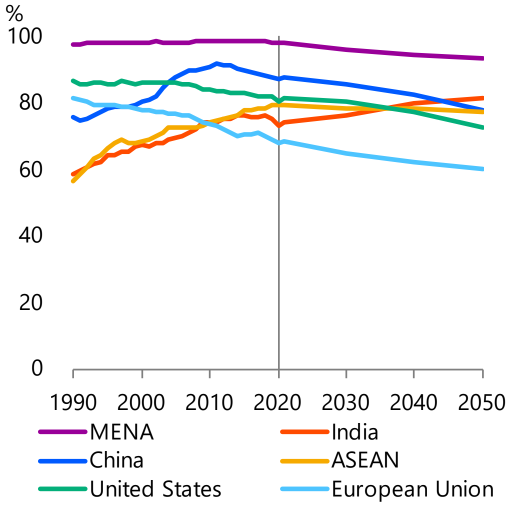


Figure 2-5 | Dependence on fossil fuels in selected countries/regions [Reference Scenario]



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

Among sectors, transport and power generation will post the largest consumption growth rates mainly in Emerging Market and Developing Economies (Figure 2-6). Supported by income growth in Emerging Market and Developing Economies, automobiles will account for most of the energy consumption increase in the transport sector. Energy consumption by aircraft and ships will also increase sharply due to the movement of people and increased trade. The power generation sector will boost its energy consumption as electricity is increasingly used for its convenience on the strength of rising incomes and infrastructure development in unelectrified regions. The energy consumption expansion in the transport and power generation sectors is premised on economic recovery from the COVID-19 pandemic and the development of transport and power generation infrastructure in the Emerging Market and Developing Economies.

Figure 2-6 | Contributions to global primary energy consumption growth [Reference Scenario, 2020-2050]

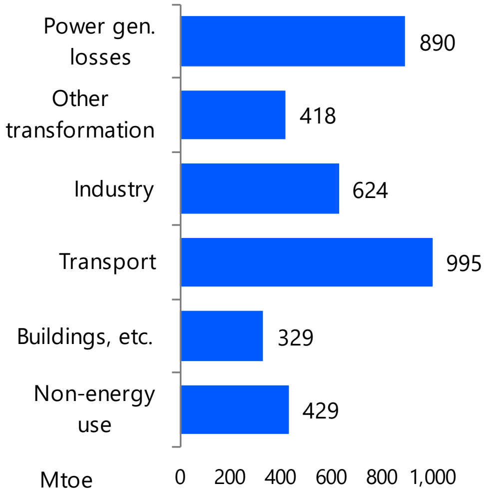
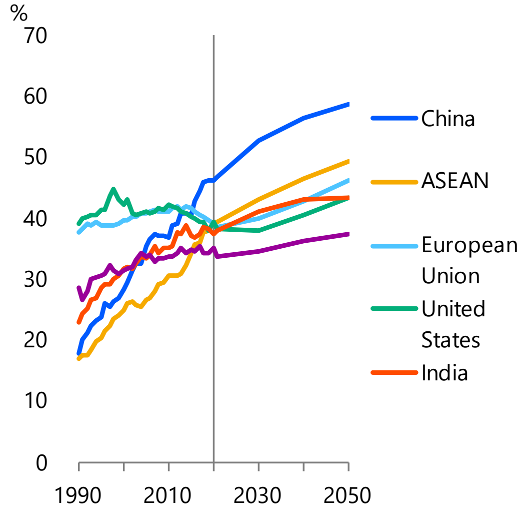


Figure 2-7 | Electrification rates on the supply side in selected countries/regions [Reference Scenario]



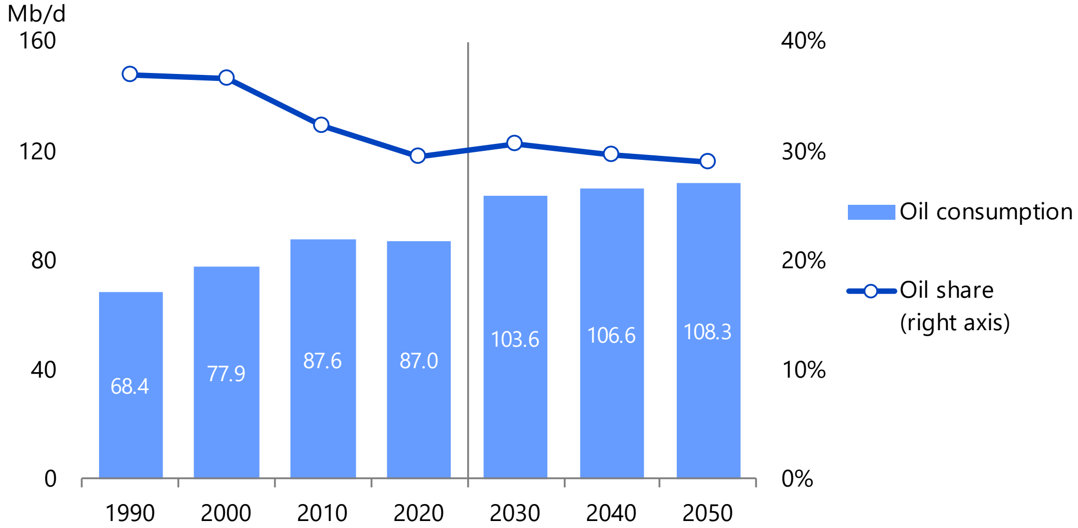
The electrification rate on the supply side will rise in almost all countries (Figure 2-7). It will make progress not only in the Emerging Market and Developing Economies but also in the Advanced Economies backed by the digitalisation of economies. Although non-fossil energy is expected to expand, it will most likely be unable to fully cover the growing electricity demand.

The industry and buildings sectors will also boost energy consumption. India, MENA and ASEAN plan to expand their heavy chemicals and other energy-intensive secondary industries and wish to further develop their tertiary industries, including call centres for the world. In these economies, a larger industry sector, with increased energy demand, will lead to improving living standards, thus contributing to growth in energy demand in the buildings sector. It will be difficult for those economies to reduce energy consumption while ensuring economic growth.

Oil consumption growth curbed but its share in primary energy unchanged

In 2020, oil consumption declined 9% from the previous year because of controlled human mobility due to the spread of COVID-19. With more mobility, it will start to increase again. After standing at 87.0 million barrels per day (Mb/d) in 2020, oil consumption will slowly increase, reaching 108.3 Mb/d in 2050 (Figure 2-8). The oil's share in primary energy consumption fell to 29% in 2020 due to the pandemic. It will rise to 31% in 2030 but will fall back to 29% toward 2050. Nevertheless, in the Reference Scenario, oil will remain the most widely used energy source in the world in 2050.

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



In the Advanced Economies, however, oil consumption has already peaked (Figure 2-9). After falling at an annual rate of 1.6% from the peak in 2004 to 2020, their oil consumption will continue to decrease by 7.3 Mb/d, or at an annual rate of 0.8%, from 2020 to 2050. A major factor behind the overall decline in oil consumption in the Advanced Economies is a fall in automobile fuel consumption due to fuel efficiency improvements and the diffusion of electrified vehicles, including hybrid cars. Meanwhile, oil consumption in India, MENA and ASEAN will increase greatly. Although COVID-19 caused an 8.6% year-to-year decline in 2020, oil consumption will increase by 15.7 Mb/d at an annual rate of 2.1% from 2020 to 2050. The oil consumption of these three economies will grow mainly in the transport, non-energy use and buildings sectors.

In the road sector, which accounts for the largest share by use, the decline due to improved fuel efficiency and spread of electrified vehicles outweighs the increase due to more vehicles owned. Consumption will increase compared to 2020 when COVID-19 struck but will peak early and then start to decline (Figure 2-10). Meanwhile, consumption by other transportation sectors, such as international bunkers, domestic aviation and internal navigation, will continue to grow due to the increase in international logistics and people's mobility.

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

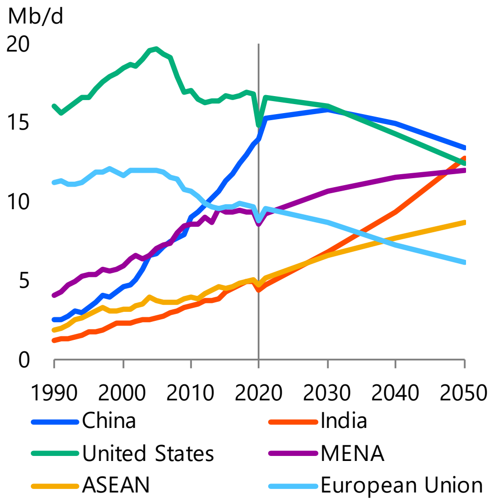
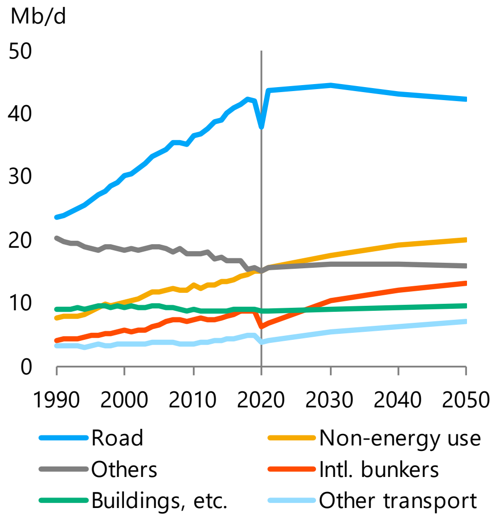


Figure 2-10 | Global oil consumption [Reference Scenario]



In the transport sector in India, MENA and ASEAN, oil consumption for automobiles will increase sharply from 7.4 Mb/d in 2020 to 15.3 Mb/d in 2050. Demand from these three economies accounts for 180% of the net increase in oil consumption in the global transportation sector. This means that outside of these three economies, consumption in the transportation sector will decrease significantly. In the three economies, vehicle ownership will soar 3.8-fold from the present level, thanks to income growth and improvements in transport infrastructure such as roads and bridges. To suppress oil consumption, they would have to actively promote a transition to electric vehicles. In the Emerging Market and Developing Economies, the initial cost of electric vehicles may remain high even in 2050, with sales limited to high-income earners, unless strong countermeasures to climate change are taken.

The non-energy use sector in India, MENA and ASEAN will increase oil consumption mainly for the petrochemical industry by 3.3 Mb/d from 2020 to 2050, accounting for 66% of global oil consumption growth in that sector. While global demand for plastics and other petrochemical products is strong, oil-producing countries hope to foster their petrochemical industries as part of their industrial diversification. Therefore, both the supply and demand sides will drive oil consumption in the three economies' non-energy use sector. To suppress consumption in the sector, regulations on plastics consumption will need to be toughened.

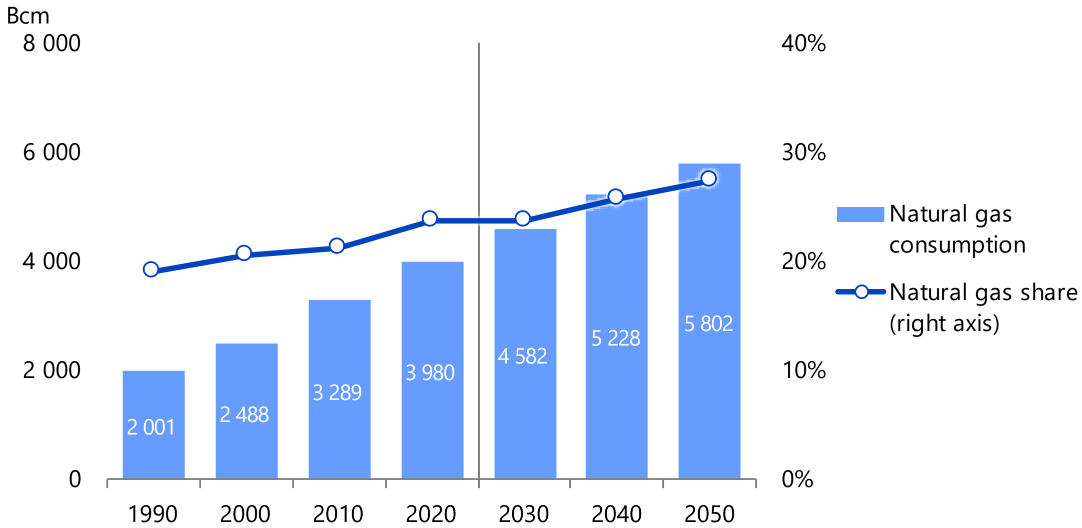
In the buildings sector in India, MENA and ASEAN, oil consumption will increase by 1.4 Mb/d from 2020 to 2050 mainly for water heating and cooking, accounting for 204% of the net global consumption increase. In line with income growth, consumers will switch from coal and solid biomass to oil which is relatively cleaner in terms of health impacts. It should also be noted that in Sub-Saharan countries other than South Africa, oil consumption by the buildings sector will increase by 0.5 Mb/d during the same period. In those countries, the initial investment for switching and operating on electricity or city gas for water heating and cooking is costly, leading consumers to choose liquefied petroleum gas for that purpose.

China's oil consumption will peak at 15.8 Mb/d around 2030 and fall to 13.5 Mb/d in 2050. The transport sector will reduce oil consumption due to the saturation of vehicle ownership, improvements in vehicle fuel efficiency and the diffusion of electrified vehicles. With the spread of electrification and city gas, the buildings sector will reduce its oil consumption. To drastically cut global oil consumption, it will also be necessary to accelerate the pace of reduction in oil consumption in China.

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

Like oil, natural gas posted a 1.2% decline in consumption between 2019 and 2020 due to COVID-19, but will show the largest increase among all energy sources toward 2050. It will post an annual increase of 1.5% from 3 980 billion cubic metres (Bcm) in 2020 to 5 802 Bcm in 2050 (Figure 2-11). Natural gas will increase its share of primary energy consumption from 24% in 2020 to 27% in 2050, becoming the second most consumed energy source after oil. As the European Union lessens its natural gas dependence on Russia and increases imports from other regions, particularly liquified natural gas (LNG), how to reduce this growth in demand is one of the challenges facing the world.

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



India, MENA and ASEAN will account for 47% of the growth of global natural gas consumption totalling 1 822 Bcm between 2022 and 2050 (Figure 2-12). Natural gas consumption in 2050 will reach 275 Bcm in India, 1 048 Bcm in MENA and 413 Bcm in ASEAN. The Middle East will promote domestic natural gas consumption to earn foreign currency with cost-competitive oil exports. India and ASEAN will boost natural gas consumption mainly for power generation in order to meet increasing electricity demand. In China, natural gas consumption mainly for the power generation sector will increase by 188 Bcm by 2050. The United States will expand natural gas consumption by 105 Bcm by around 2040 as shale gas production continues. The European Union, on the other hand, is moving away from natural gas for the sake of energy security, reducing consumption by 42 Bcm from 2020 to 2050.

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

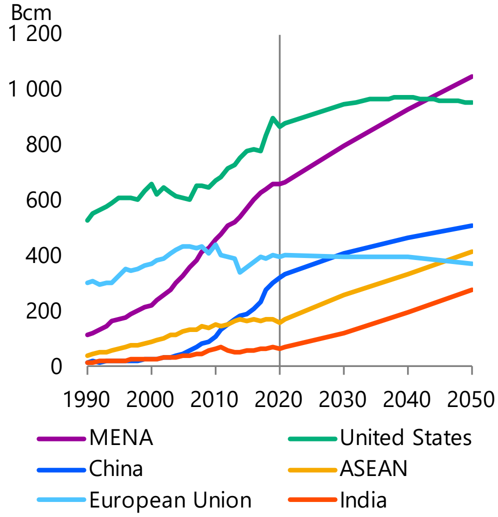
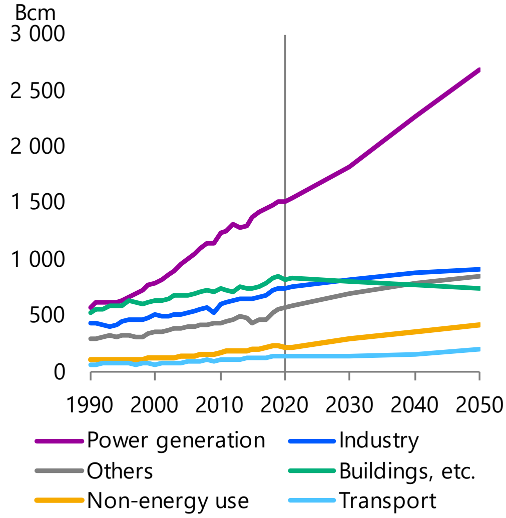


Figure 2-13 | Global natural gas consumption [Reference Scenario]



Natural gas consumption in the buildings sector will tend to decline as energy conservation and electrification progress. It will increase in Emerging Market and Developing Economies, including China, mainly in the power generation and industrial sectors (Figure 2-13). Natural gas consumption in those sectors will increase at an annual rate of 2.6% from 2020 to 2050, accounting for 81% of the growth of global natural gas consumption in the sectors. This is because natural gas emits the least amount of CO_2 per unit of energy of all fossil fuels and more easily allows large-scale power generation at lower integration costs than renewable energy.

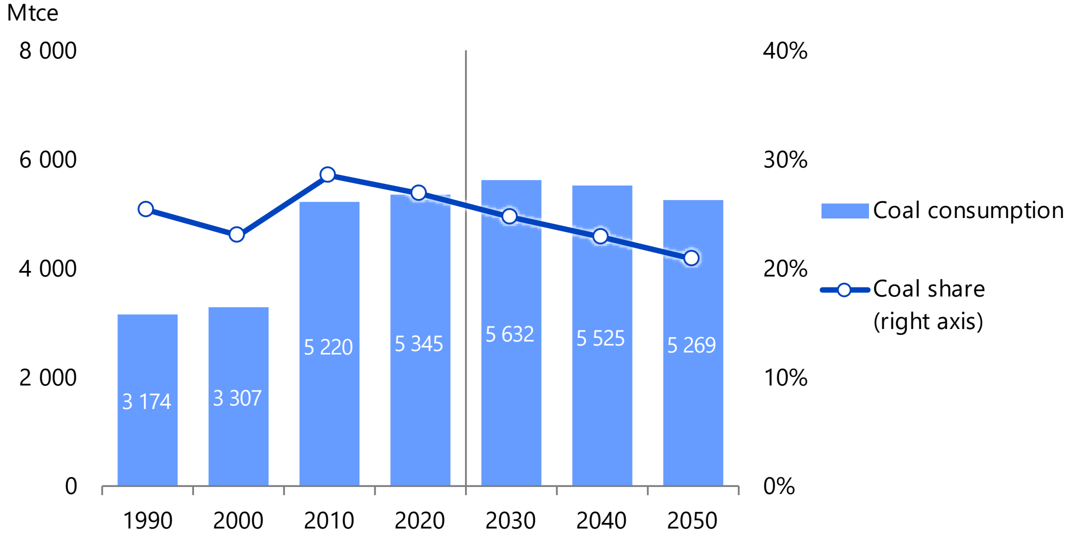
While natural gas consumption in the industrial sector in Advanced Economies will decline, consumption in the Emerging Market and Developing Economies will grow at an annual rate of 1.3%, amounting to 105% of the net global growth. In view of convenience and environmental considerations, the sector will switch from oil and coal to natural gas. Consumption growth in the buildings sector will mostly come from China as it rapidly switches to city gas from solid fuels such as coal and fuel wood that adversely affect health and cause air pollution. However, electrification and energy conservation in other countries and regions will lead to declining use.

As India, MENA, ASEAN and China drive the growth in natural gas consumption, they should introduce and widely diffuse highly efficient equipment through such measures as the power generation sector's adoption of natural gas combined cycle plants to reduce consumption. In addition, it is hoped that technologies will be developed and markets created where hydrogen can be procured at an affordable cost for Emerging Market and Developing Economies so that hydrogen, which does not emit CO_2, can be used for power generation as an alternative to natural gas.

Coal consumption will peak around 2030 and begin to decline due to environmental measures

Coal consumption, which stood at 5 345 million tonnes of coal equivalent (Mtce) in 2020, will peak around 2030 after a short-term rise in terms of stable supply, but will decrease thereafter at an annual rate of 0.3% (Figure 2-14). Coal will reduce its share of primary energy consumption from 27% in 2020 to 21% in 2050, being 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 2020, China accounted for 57% of global coal consumption, Europe, the United States and Japan combined for 13%, and India and ASEAN combined for 15%. China and the three Advanced Economies will reduce their respective coal consumption shares, while India and ASEAN will boost theirs (Figure 2-15).

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

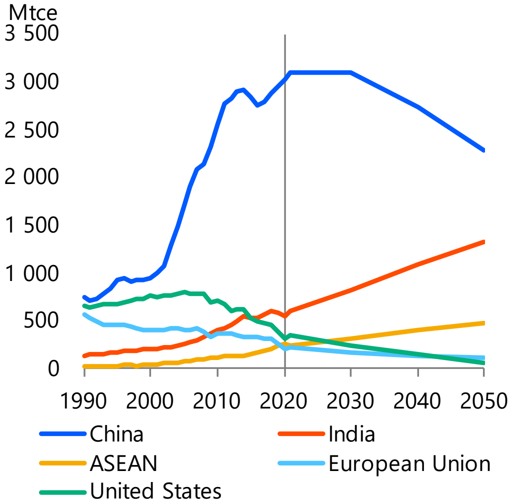
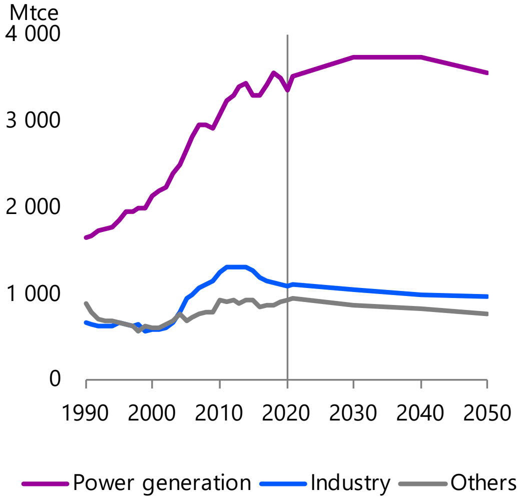


Figure 2-16 | Global coal consumption [Reference Scenario]



While coal consumption for power generation will increase through 2030 in China, industrial coal consumption will plunge by 55% by 2050, with steel and cement production peaking soon. China's coal consumption will thus peak in the first half of the 2020s. Coal consumption in Europe, the United States and Japan will continue falling both for power generation and industry sectors, posting a 59% drop by 2050. On the other hand, in India and ASEAN, coal use for power generation will increase by 2.4 and 2.0 times, respectively, by 2050, while industrial use will increase by 2.6 and 1.7 times. Note that MENA consumes limited coal due to the large number of oil- and gas-producing countries. Because of the need to address climate change, coal consumption has increasingly come under fire globally. By toughening the regulations on all coal consumption, Europe increased the economic burdens on coal-fired power plants and further restricted CO_2 and mercury emissions. Meanwhile, Asian Emerging Market and Developing Economies, such as China, India and ASEAN, still view coal as an affordable domestic energy source from the viewpoint of energy self-sufficiency and do not impose particularly severe restrictions on coal consumption. Although governments and financial institutions in the Advanced Economies promote coal divestment, financial institutions in China and India do not necessarily support such divestment. To curb coal consumption, Europe, the United States and Japan should reduce consumption further, while China, India and ASEAN should switch from coal to natural gas, hydrogen and ammonia for their power generation and industry sectors.

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

While many countries are pursuing carbon neutrality and place growing hopes on the expansion of non-fossil energy use, such energy sources' share of primary energy consumption is projected to rise only slightly from 20% in 2020 to 23% in 2050. Non-fossil energy consumption for power generation, mainly solar, wind, nuclear and hydro, will increase 1.9-fold from 1 576 Mtoe in 2020 to 3 015 Mtoe in 2050 (Figure 2-17). Solar photovoltaics, wind and others will grow the most, expanding 3.9-fold by 2050 compared to 2020. Nuclear and hydro use will be subject to slow growth due to nuclear policy reforms, as well as overall environmental and social considerations. Their share of non-fossil energy consumption for power generation will fall from 57% in 2020 to 46% in 2050.

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

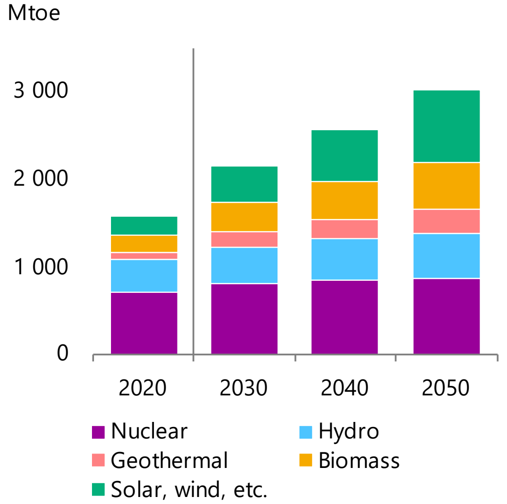
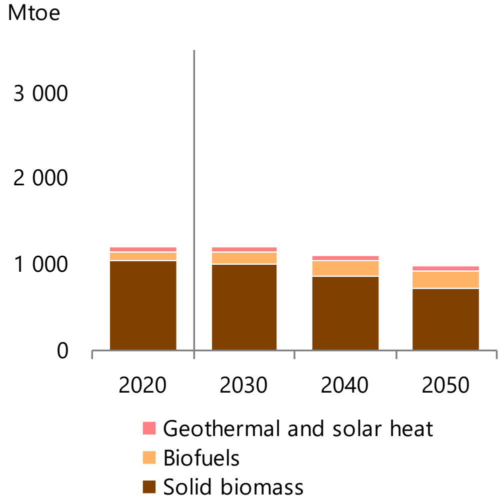


Figure 2-18 | Non-fossil energy consumption for heating [Reference Scenario]



On the other hand, consumption for heating will continue to concentrate on traditional solid biomass such as firewood and manure, which are widely used in rural areas in Emerging Market and Developing Economies. From 1 222 Mtoe in 2020, it will start decreasing in the 2030s, falling to 1 001 Mtoe in 2050 (Figure 2-18). Its consumption will decline as rural residents switch to modern energy sources in line with improvements in their income and living standards. Liquid biofuel for automobiles and buildings and biogas consumption will increase 1.9-fold through 2050, accounting for only 20% of the total non-fossil energy consumption for heating.

Non-fossil energy consumption will dramatically increase toward 2050. However, the growth of its share in primary energy consumption is not large, as overall primary energy consumption is also increasing significantly. Solar photovoltaics, wind and others are expected to expand in response to substantial cost reductions but will capture only 17% 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 53% of the global energy consumption growth as its share of the global economy increases from 34% in 2020 to 44% in 2050 in real terms (Figure 2-19). China, India and ASEAN, in particular, will drive the global macro economy and energy consumption growth. These economies have both similarities and differences. Energy consumption in China will peak around 2030, while consumption in India and ASEAN will continue to expand

(Figure 2-20). Factors behind the three economies' differences include changes in their respective economic growth as well as population growth.

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

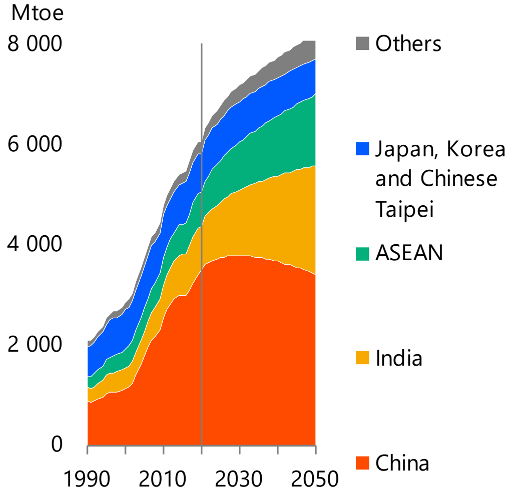
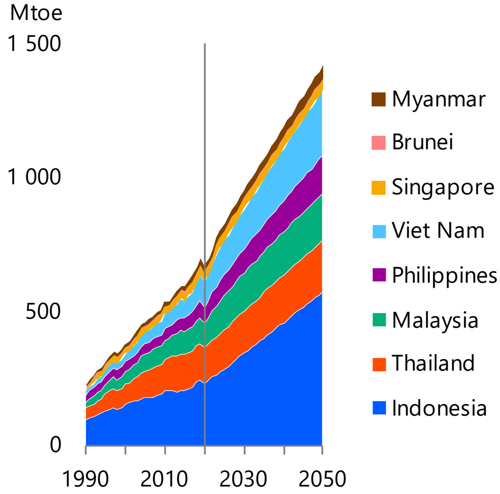


Figure 2-20 | ASEAN primary energy consumption [Reference Scenario]



China's economy grew 14.2-fold from $1 trillion in 1990 to $14.6 trillion in 2020 and will expand 3.0-fold from 2020 to $44.4 trillion in 2050. China's population increased from 1.14 billion in 1990 to 1.41 billion in 2020; it will peak around 2030 before slipping below the 2020 level to 1.31 billion in 2050. The economy will continue expanding, but the population will decline; around 2030, energy consumption will begin to decline even though its economy will continue to grow, as in Advanced Economies. After energy consumption increased at a high annual rate of 4.7% between 1990 and 2020, China's annual growth rate will decelerate to 0.8% between 2020 and 2030 before cutting back on energy consumption. In 2050, energy consumption will fall below the 2020 level despite the GDP per capita exceeding $34 000 in real terms. China is therefore starting its transition to a mature society, conscious of carbon neutrality. China's share of Asian energy consumption rose from 42% in 1990 to 58% in 2020 and will fall back to 42% in 2050.

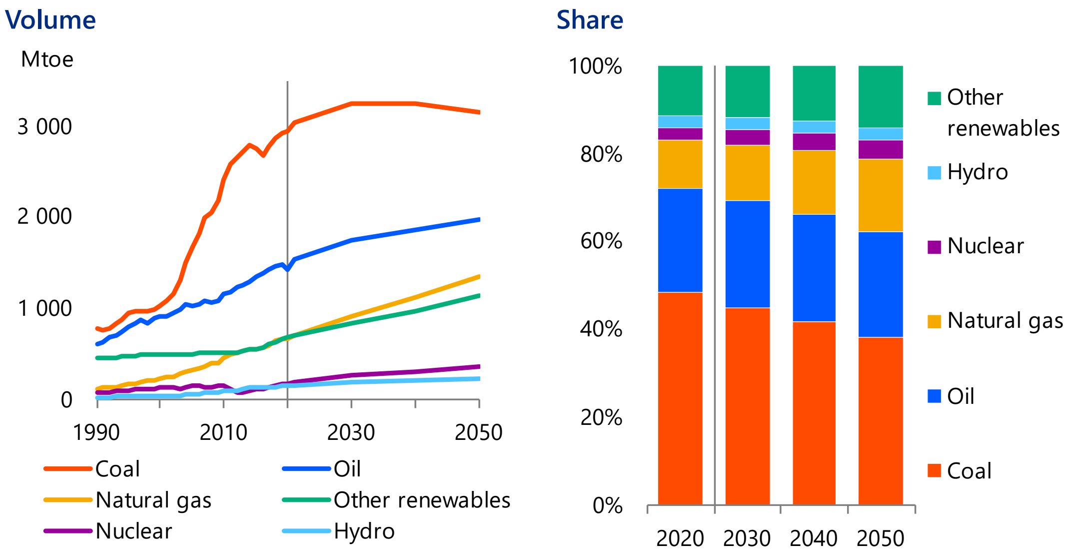
India's economy grew 5.4-fold from $500 billion in 1990 to $2.6 trillion in 2020 and will increase 5.3-fold from 2020 to $13.4 trillion in 2050. Its population rose from 870 million in 1990 to 1.38 billion in 2020 and will surpass China's population around 2024 before reaching 1.66 billion in 2050. As such, the real GDP per capita will rise from $500 in 1990 to $8 000 in 2050, improving incomes and living standards. While India aims to achieve carbon neutrality by 2070, energy consumption will increase by 4.1% annually from 2020 to 2030, a higher rate than from 1990 to 2020. Furthermore, measures for climate change and energy security will become more important in India as the annual rate of increase will continue to be 2.8% from 2030 to 2040 and 2.4% from 2040 to 2050. India's share of Asian energy consumption will expand from 13% in 1990 and 14% in 2020 to 26% in 2050.

ASEAN's economy will increase rapidly from $720 billion in 1990 and $2.8 trillion in 2020 to $9.6 trillion in 2050. ASEAN's population will grow from 430 million in 1990 to 760 million in

2050. As a result, real GDP per capita, which was $1 700 in 1990, will reach $4 400 in 2020 and $13 000 in 2050, thus improving income and living standards. ASEAN's energy consumption will increase by 3.6% per year from 2020 to 2030, the same rate of increase as from 1990 to 2020. Furthermore, the annual growth rate will decelerate steadily to 2.2% from 2030 to 2040 and 1.8% from 2040 to 2050, with Indonesia accounting for half of the increase from 2020 to 2050. Despite its announcement of a commitment to achieve carbon neutrality by 2060, Indonesia continues to increase its energy consumption. Therefore, measures for climate change and energy security will become more important for the country. ASEAN's share of Asian energy consumption will widen from 11% in 1990 and 2020 to 17% in 2050.

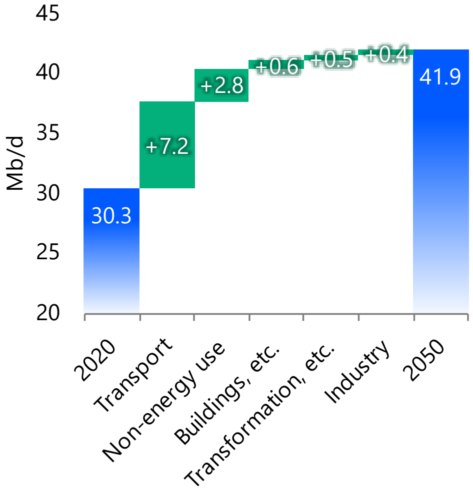
In 2050, when energy consumption in India and ASEAN will still be rising, Asia will continue to depend on fossil fuels from 83% of its energy needs in 2020 to 79% in 2050 (Figure 2-21). Oil and natural gas consumption will keep expanding, mainly in transportation and power generation sectors, respectively. How to reduce Asia's fossil fuel consumption will be critical to achieve a stable global energy supply, carbon neutrality and climate change goals.

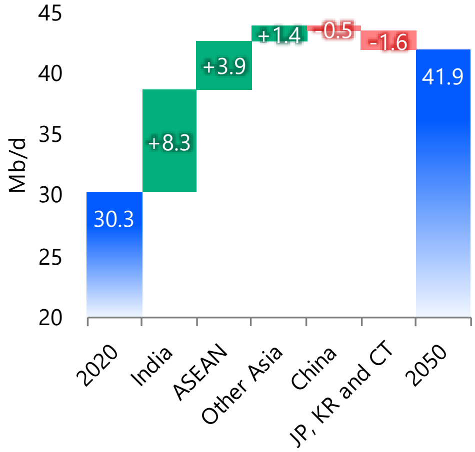
Figure 2-21 | Asian primary energy consumption [Reference Scenario]



Asia's oil consumption growth will decelerate from 2.9% per year between 1990 and 2020 to 1.1% between 2020 and 2050. The transport sector will account for 63% of the growth through 2050, the non-energy use sector for 24% and the buildings sector for 5% (Figure 2-22). India will account for 72% of the growth, and ASEAN for 34%. The share of India and ASEAN combined exceeds 100% because -Japan and Korea are cutting consumption. To suppress oil consumption, the transport sector in India, ASEAN and China should promote fuel efficiency improvements including electrification. As Asia's oil consumption growth accounts for 54% of global growth, its oil consumption trend will affect the entire world.

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





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

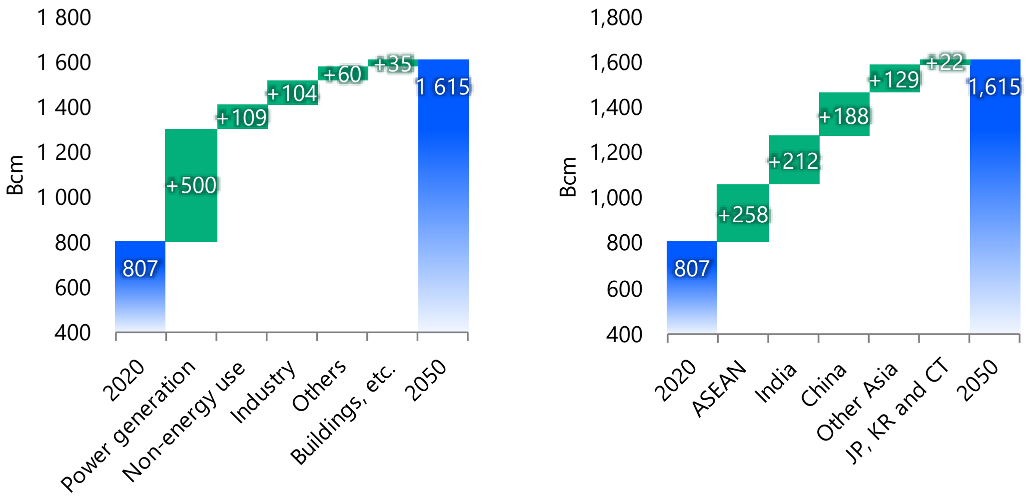
To secure stable oil supplies and address environmental problems, switching from oil to other energy sources and greatly increasing oil consumption efficiency will be essential to the policies of Asian countries.

The growth in Asia's natural gas consumption stood at 6.0% per year between 1990 and 2020 and will decelerate to 2.3% between 2020 and 2050. Of the 2020-2050 growth, the power generation sector will account for 62%, the industry sector for 13% and the non-energy use sector for 13% (Figure 2-23). ASEAN will account for 32% of the growth, India for 26% and China for 23%. To suppress natural gas consumption, China, India and ASEAN will have to raise efficiency, reduce electricity transmission and distribution losses, and promote co-firing with hydrogen in the power generation sector, as well as improve insulation and other efficiencies in the buildings sector. As Asia's natural gas consumption growth accounts for 44% of the global growth, suppressing the three economies' consumption would contribute directly to a global reduction.

Although natural gas emits less CO_2 than oil and coal, it is still a fossil fuel that emits CO_2 when combusted. Accordingly, it is important for the Emerging Market and Developing Economies to promote a highly efficient natural gas consumption through measures to raise the engineers' skills in the operation and maintenance of equipment, encourage the power generation sector to construct natural gas-fired combined cycle plants and adopt co-firing with hydrogen.

LNG imports will help cover shortages in natural gas supply to Asia. Asia's LNG consumption will more than double from 273 million tonnes (Mt) in 2021 to 551 Mt in 2050. Japan and Korea were early users and large importers of LNG, but in 2021 China surpassed Japan to become the world's largest importer. The share of Asia's LNG consumption will fall from 52% in 2021 to 29% in 2050 for Japan, Korea and Chinese Taipei combined, while rising from 43% to 62% for China, India and ASEAN combined. The latter will need to secure a stable supply of LNG.

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



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

In contrast to Asia's oil or natural gas consumption, local coal consumption will peak in the middle of the 2030s. Coal's annual growth in Asia will decelerate from 4.5% between 1990 and 2020 to 0.7% between 2020 and 2035 before declining at an annual rate of 0.2% through 2050. Coal-fired power plants have come under scrutiny due to climate change and air pollution issues. Coal consumption in Asia will decline for industry and buildings from 2020 levels, but its consumption will increase for power generation. As coal will remain Asia's largest energy source in 2050, Asian countries should promote the efficient use of their abundant coal resources and mitigate their environmental impact. Through the introduction of measures and with the assistance of Advanced Economies, they should promote efficient coal-fired power plants with carbon capture, utilisation and storage (CCUS) and/or ammonia co-firing.

Asia's non-fossil energy consumption, though being less than oil or natural gas consumption in volume, will increase at a high annual rate of 1.8%. The increase in renewables, other than traditional biomass, will be equivalent to the entire Asian non-fossil energy consumption growth between 2020 and 2050, while increases in nuclear (26% of the total growth) will equal the losses in biomass. China will account for 44% of the renewable energy consumption growth (excl. traditional biomass), ASEAN for 27% and India for 20%. China will capture 54% of the nuclear energy consumption growth, followed by 26% for India. Asia's share of the global non-fossil energy consumption will rise from the present level by 11 percentage points to 62% in 2050.

In September 2020, China declared that it would aim for carbon neutrality by 2060, setting a policy of suppressing oil and coal consumption and promoting natural gas and non-fossil energy consumption toward 2050. Given China's huge fossil fuel consumption, however, it will have to greatly enhance energy efficiency and its decarbonisation policies. Meanwhile, India, which accounts for most of the incremental energy consumption in Asia by 2050, has pledged to achieve carbon neutrality by 2070, while many of the ASEAN nations, led by Indonesia, have announced they will be carbon neutral. India and ASEAN will have to be proactive and take steps to accelerate energy conservation and decarbonisation, making use of the continued and improved technical and financial assistance from Japan, Korea, China and other countries. These commitments to tackling climate change from China, India and ASEAN will contribute to the development of stable energy supplies, including LNG.

2.2 Final energy consumption

Global final energy consumption in 2050 will increase 1.2-fold from 2020

In the Reference Scenario, global final energy consumption will increase 1.2-fold from 9 573 Mtoe in 2020 to 11 951 Mtoe in 2050. The increase represents an average annual growth of 0.7%. The change in global final consumption between 2020 and 2050 presents two features.

First, India, ASEAN and MENA will play a central role in boosting global final energy consumption through 2050. Therefore, any event that greatly affects final energy consumption in the three economies/regions will affect the trends in global final energy consumption. For this reason, a particular attention should be paid to fluctuating factors such as, economic growth, the details and strengths of their energy-related policies, the technological development and diffusion of equipment using energy.

Second, there will still be a certain degree of final energy consumption for all major energy sources in 2050. Final energy consumption for coal and renewable energy will follow a downward trend but will not bottom out even by 2050. If policy guidance and investment targets are extremely biased toward specific energy sources to address climate change, which is a major global issue, the energy supply-demand balance for many energy sources may be lost over the medium to long term. It will be important to develop a market that sufficiently supplies each energy source, while considering demand trends and their impacts on climate change.

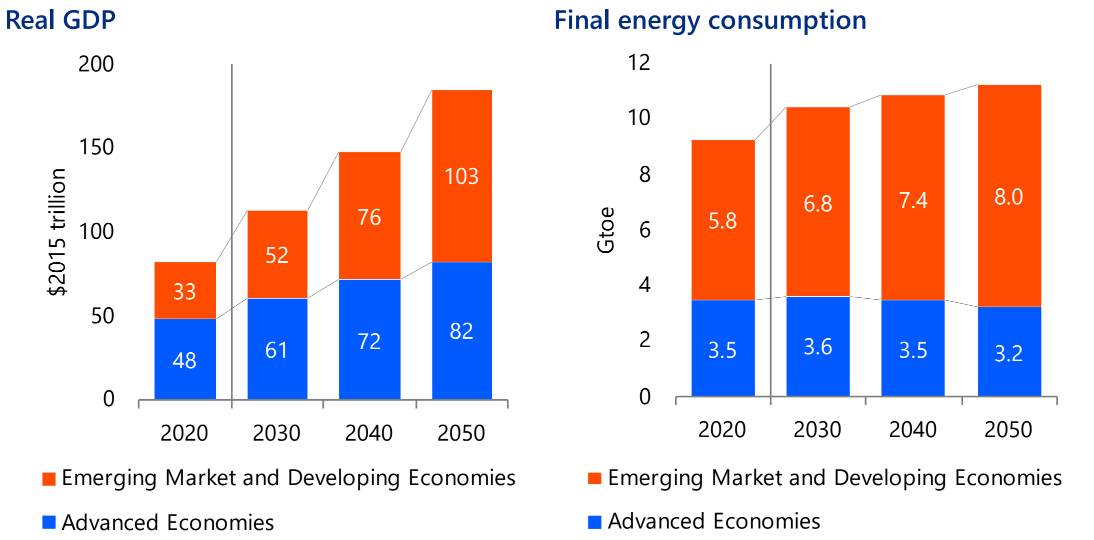
The following provides insights on final energy consumption changes in the Reference Scenario by economy group, region, sector and energy source between 2020 and 2050.

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

The increase in global final energy consumption from 2020 to 2050 will be driven by the Emerging Market and Developing Economies (Figure 2-24). Although final energy consumption in Advanced Economies will decline over the same period, a steady consumption growth in Emerging Market and Developing Economies will offset and more than exceed the decline in Advanced Economies. Therefore, the global final energy consumption will rise through 2050.

In the Emerging Market and Developing Economies, final energy consumption in 2050 will be 7 971 Mtoe, an increase from 2020 of 1.4-fold (1.1% per annum). Those economies will follow a growth trajectory in the medium to long term. As the progress in energy efficiency improvements is coupled with an expanding service sectors, the increase in consumption between 2020 and 2050 will be much slower than the real annual GDP growth of 3.8%.

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



On the other hand, in Advanced Economies, final energy consumption in 2050 will be 3 247 Mtoe, 10% lower than in 2020, an average annual decline rate of 0.2%, despite a real GDP growth of 1.8% per year over the same period. Amid economic growth in these countries, final energy consumption has been on a downward trend since the late 2000s, due to the progress in energy efficiency and growth in the service sectors. As a result, the energy-GDP elasticity[4] in the Advanced Economies will change from 0.21 between 1990 and 2020 to −0.12 between 2020 and 2050.

Energy efficiency improvement is one of the key decarbonisation measures that have been attracting global attention. In both the Advanced Economies and the Emerging Market and Developing Economies, the final energy consumption sectors will be required to promote initiatives to improve energy efficiency.

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

In terms of changes by region in final energy consumption from 2020 to 2050, India, MENA and ASEAN will strongly lead the growth in global final energy consumption (Figure 2-25). India, MENA and ASEAN together will account for a dominant share of more than 70% (Figure 2-26) of the global increase over the same period.

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

Figure 2-25 | Final energy consumption growth in selected countries/regions [Reference Scenario, 2020-2050]

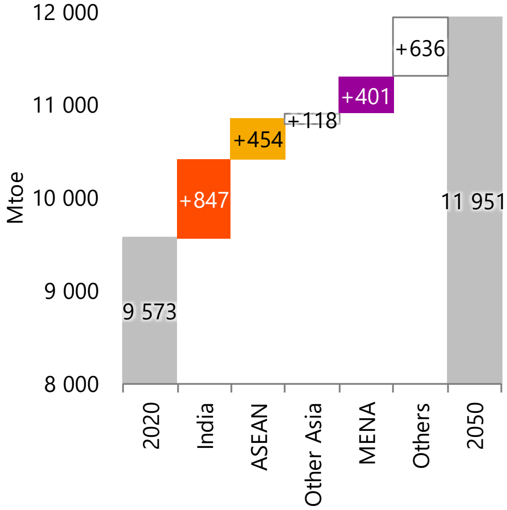
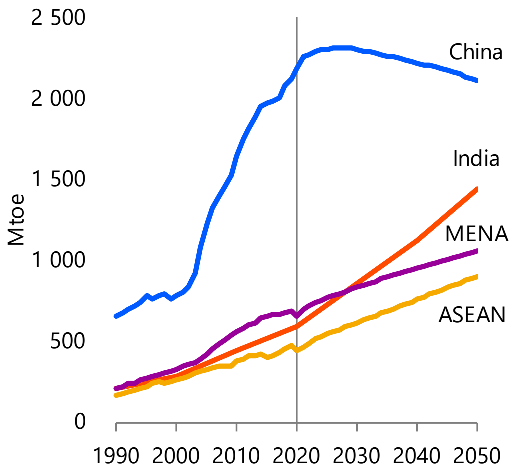


Figure 2-26 | Final energy consumption in China, India, MENA and ASEAN [Reference Scenario]



As a result of the strong demand growth in India and ASEAN, Asia's share of global final energy consumption will widen from 41.0% in 2020 to 44.0% in 2050. In the future, Asia will become an even more significant energy consumption centre.

India's population will surpass China's in the first half of the 2020s and top 1.6 billion in 2050. Its GDP will grow at an annual rate of 5.7% between 2020 and 2050, with GDP per capita increasing 4.4-fold, reflecting the progress of urbanisation. Backed by population and GDP growth, India's final energy consumption in 2050 will increase 2.4-fold (an annual rate of 3.0%) from 596 Mtoe in 2020 to 1 443 Mtoe. The incremental impact of final energy consumption in India alone is large enough to account for 60% or more of the incremental energy consumption in Asia as a whole. The presence of India is evident not only within Asia: its share of global final energy consumption will expand from 6.2% in 2020 to 12.1% in 2050. Thus, India will become even more relevant in terms of global energy supply and demand.

Final energy consumption in ASEAN will rise at a rate of 2.4% per year from 447 Mtoe in 2020 to 901 Mtoe in 2050, in part due to growth in Indonesia and Viet Nam. Of the 454 Mtoe in final energy consumption growth in ASEAN, Indonesia will account for 174 Mtoe and Viet Nam for 101 Mtoe. The increase in final energy consumption in those two countries reflects their population and economic growth. As their population will increase from 270 million (the largest among ASEAN members) in Indonesia and 97 million (the third largest) in Viet Nam in 2020, the GDP per capita will increase 3.3-fold in Indonesia between 2020 and 2050 and 4.2-fold in Viet Nam. Backed by such population and economic growth, Indonesia's final energy consumption will exceed that of Japan from the late 2030s.

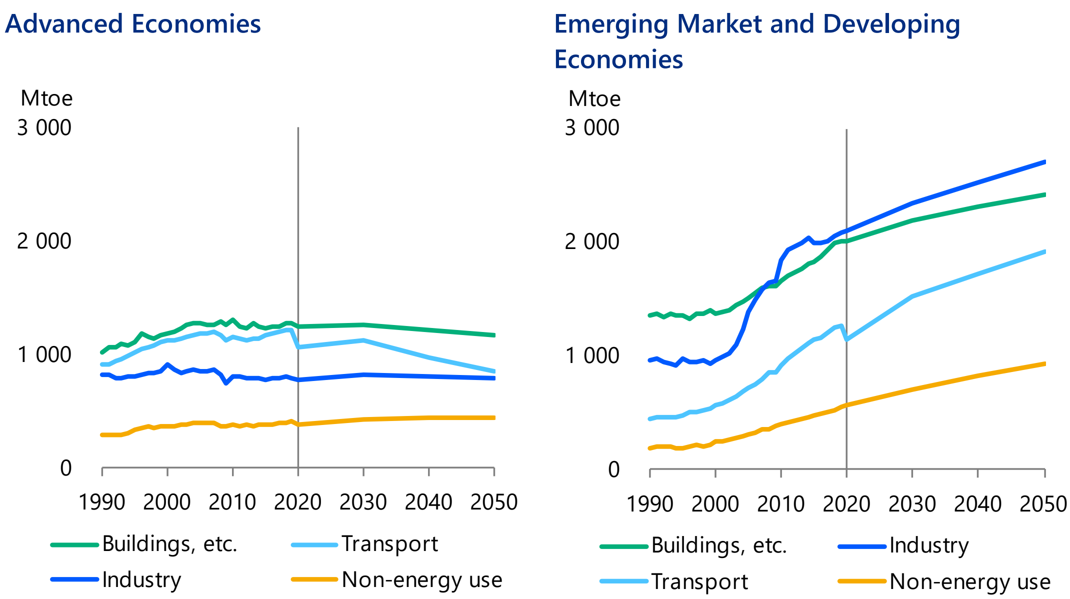
China's final energy consumption will decline from 2 182 Mtoe in 2020 to 2 105 Mtoe in 2050. Despite peaking in the late 2020s and declining thereafter, the country will continue to be the world's largest final energy consumer over the period. Such pattern will differ from the constant uptrend in India or ASEAN. The industry sector will be a key contributor to China's peaking its final energy consumption. The energy-intensive steelmaking and cement industries, in particular, will substantially reduce their energy consumption. As initiatives to eliminate excess production capacity take effect, cement production peaked around the mid-2010s and crude steel production will soon start to decline.

Final energy consumption in MENA will increase at an annual rate of 1.6% from 656 Mtoe in 2020 to 1 057 Mtoe in 2050. Of particular interest, consumption will rise by 99 Mtoe in North Africa, by 98 Mtoe in Saudi Arabia and by 96 Mtoe in Iran. The three will thus account for most of MENA's consumption growth of 401 Mtoe. Supported by combined increases in population and economic growth, their GDP per capita will grow 2.3-fold in North Africa, 1.7-fold in Saudi Arabia and 1.8-fold in Iran although their increases are much smaller and fall short of those in India and ASEAN.

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

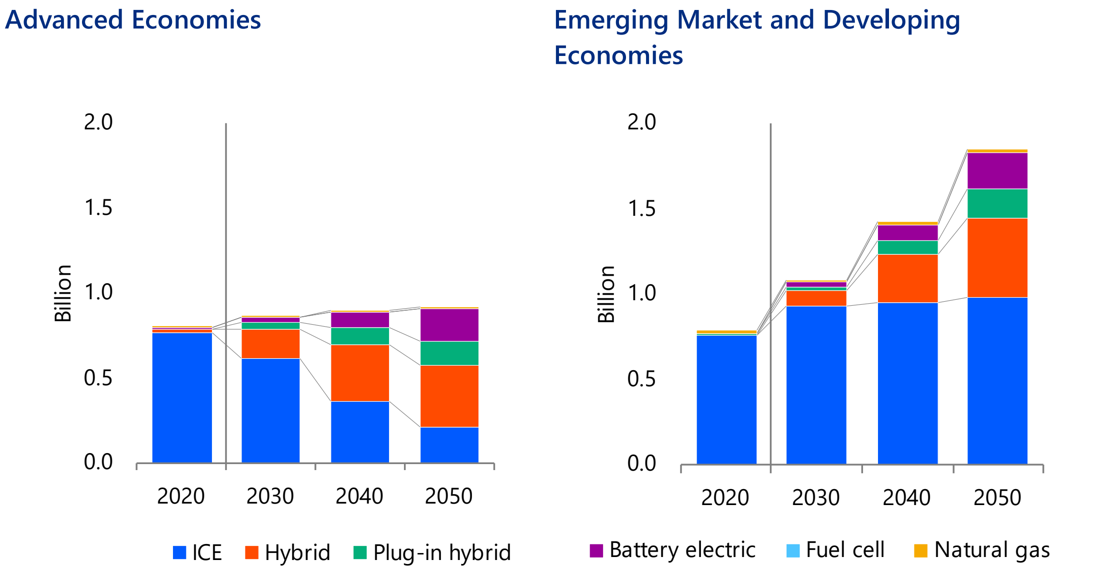
Final energy consumption will increase in all sectors between 2020 and 2050, driven by the Emerging Market and Developing Economies. In the Advanced Economies, final energy consumption will slightly decrease in all sectors other than the non-energy use sector (Figure 2-27).

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



In the transport sector, final energy consumption will increase at an annual rate of 1.1% from 2 507 Mtoe in 2020 to 3 502 Mtoe in 2050, supported by growth in the road sector of the Emerging Market and Developing Economies. The growth will reach 995 Mtoe, capturing 42% of the overall global rise in final energy consumption. In the Emerging Market and Developing Economies, driven by the economic growth, the ownership of internal combustion and electrified vehicles will grow over the same period (Figure 2-28). Therefore, final energy consumption in the Emerging Market and Developing Economies will grow at an annual rate of 1.7%. In the Advanced Economies, electricity consumption will increase due to the diffusion of electrified vehicles under policy guidance. On the other hand, the road sector's oil consumption will decline substantially thanks to improvements in fuel efficiency and a decrease in internal-combustion vehicle ownership. As a result, final energy consumption in the transport sector of the Advanced Economies will fall at an annual rate of 0.7%.

Figure 2-28 | Vehicle ownership [Reference Scenario]



Note: ICE stands for internal combustion engine.

In the industry sector, final energy consumption (mainly electricity and natural gas) will expand at an annual rate of 0.7% from 2 873 Mtoe in 2020 to 3 497 Mtoe in 2050 due to the development of the manufacturing industries in the Emerging Market and Developing Economies. The sector's consumption growth will reach 624 Mtoe, accounting for 26% of the overall rise in final energy consumption. As the manufacturing and other industries have strong incentives to save energy to increase their products' cost competitiveness, the global industry sector's final energy consumption between 2020 and 2050 will increase at a slower pace than value added by the secondary industry annual average growth rate of 2.5%.

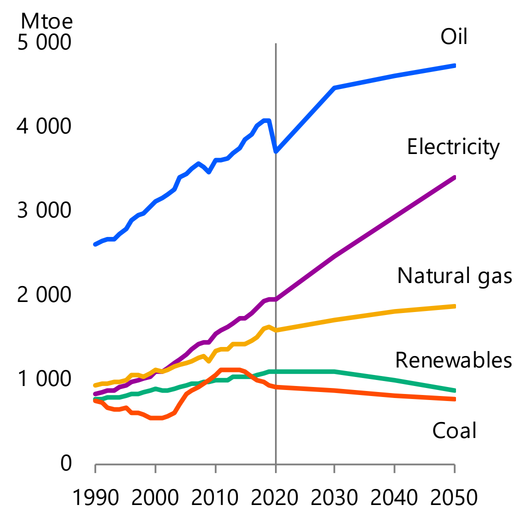
In the buildings sector, final energy consumption will increase at an annual rate of 0.3% from 3 248 Mtoe in 2020 to 3 578 Mtoe in 2050, with growth in the consumption of electricity, natural gas and petroleum products in the commercial and residential sectors of the Emerging Market and Developing Economies. The buildings sector's consumption growth will total 329 Mtoe, accounting for 14% of the overall rise in final energy consumption. In the Emerging Market and Developing Economies, access to modern energy and appropriate equipment will gradually increase, in line with the improvement in living standards. In particular, the share of traditional biomass (fuel wood and manure) in the buildings sector energy consumption will drop in Africa from 80% in 2020 to 37% in 2050 and from 23% to 5% in Asia.

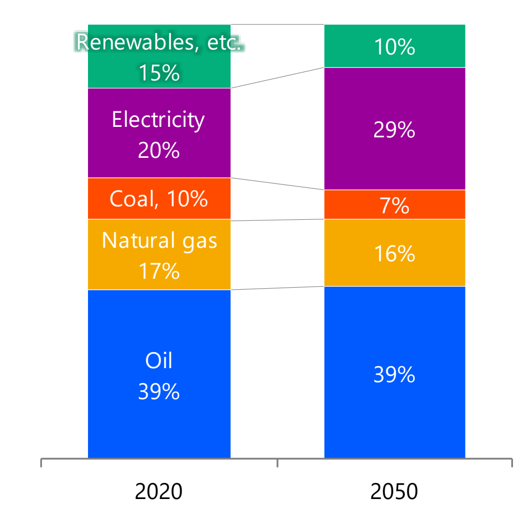
In the non-energy use sector, final energy consumption will rise at an annual rate of 1.3% from 946 Mtoe in 2020 to 1 375 Mtoe in 2050, driven mainly by growth in oil and natural gas consumption in the Emerging Market and Developing Economies. The sector's consumption growth will stand at 429 Mtoe, capturing 18% of the overall rise in final energy consumption. In the Emerging Market and Developing Economies, consumption of petrochemical products such as plastics will increase as living standards improve. In the Advanced Economies, the non-energy use sector will require a very small consumption growth between 2020 and 2050. In North America, non-energy use by the chemical industry will increase as shale gas production expansion allows feedstocks to be procured at low prices. 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 2020 to 2050 by major types of energy resource can be broadly categorised into those with a share that follows an uptrend and those with a downtrend (Figure 2-29). Only the share of electricity will increase, oil's share will remain almost flat, and those of coal, natural gas and renewables will decrease. Even in 2050, however, there will still be demand for coal and renewable energy, not to mention natural gas. Fossil fuels (coal, oil and natural gas) will see their share of global final energy consumption fall from 65% in 2020 to 62% in 2050, and will remain the leading energy sources accounting for most of the consumption.

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





Final oil consumption will increase at a rate of 0.8% per year from 3 700 Mtoe in 2020 to 4 718 Mtoe in 2050, led by growth in the transport sector including the road sector in the Emerging Market and Developing Economies, as noted in the above sector-by-sector analysis. Oil consumption growth in the road sector in Asia as a whole, including India and ASEAN which are undergoing motorisation, will reach 342 Mtoe, exceeding the decrease in the

Advanced Economies of 316 Mtoe. The non-energy use sector will post the second fastest oil consumption growth after the transport sector. In the non-energy use sector, the Middle East as well as Asia will expand oil consumption by taking advantage of abundant local resources.

Final electricity consumption will grow at an annual rate of 1.9% from 1 958 Mtoe in 2020 to 3 408 Mtoe in 2050, thanks primarily to consumption growth in the buildings and industry sectors. Electricity is the only energy source that will post consumption growth in the Advanced Economies. While it will increase in North America and Europe, Asia including China, India and ASEAN will drive the global consumption growth. Generally, as people’s income grows, electricity is preferred for its convenience. Another factor behind the growth in electricity consumption is the penetration of digitalisation, which boosts the number of electricity-consuming machines and devices. Electricity’s share of global final energy consumption will rise from 20% in 2020 to 29% in 2050. As various economic and social systems grow more and more dependent on electricity, damages resulting from disruptions to electricity supply will increase. While the decarbonisation of power sources is a significant issue, it is also important to ensure a stable supply from the viewpoint of energy security.

Final natural gas consumption will rise at an annual rate of 0.6% from 1 580 Mtoe in 2020 to 1 880 Mtoe in 2050, supported by growth in the industry and non-energy use sectors of the Emerging Market and Developing Economies. In India, ASEAN and MENA where manufacturing will prosper, mainly processing and assembly industries will lead natural gas consumption. In the non-energy use sector, India and ASEAN with their growing demand for chemicals and the Middle East seeking to expand the gas chemical industry will drive the growth of global natural gas consumption.

Final coal consumption will decrease at 0.6% per year from 924 Mtoe in 2020 to 780 Mtoe in 2050 due primarily to reductions in China’s industry and buildings sectors. As noted in the region-by-region analysis, China’s coal-consuming steelmaking and cement industries will reduce production over the medium to long term and overall coal consumption in China’s industry sector in 2050 will decline to about half of the 2020 level. To reduce air pollution and health damage accompanying coal consumption, China’s buildings sector will switch from coal to natural gas and electricity.

Final renewable energy consumption will decline at an annual rate of 0.8% from 1 101 Mtoe in 2020 to 878 Mtoe in 2050 due mainly to progress in the energy transition in Asian and African Emerging Market and Developing Economies. An example of renewable energy in the final consumption sector which is attracting attention is biofuels for automobiles and aircraft. However, traditional biomass, including fuel wood and manure used in the Emerging Market and Developing Economies, accounted for the largest share at 72% in 2020, followed by 13% for fuel wood mainly for heating in Europe and North America, 10% for biofuels and 5% for others. As pointed out in the sector-by-sector analysis, modern energy will replace traditional biomass gradually in Emerging Market and Developing Economies in Asia and Africa, leading final renewable energy consumption in the world to gradually decrease from the second half of the 2020s.

2.3 CO_2 emissions

Short- and medium-term efforts need to be strengthened, with the current situation a headwind

The tide of decarbonisation accelerated toward the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP26), held after two years due to COVID-19. As of November 2021, when COP26 ended, 154 countries and one region declared that they would aim to achieve carbon neutrality by 2050 or other years. The energy-related CO_2 emissions in these countries accounted for 79% of the world's total.[5]

At COP26, an agreement was reached on remaining agenda topics, such as the implementation guidelines of the market mechanism under Article 6 of the Paris Agreement, leading to the completion of the Paris Agreement rulebook. The need for tougher short- and medium-term efforts to achieve climate goals was reaffirmed.

The Working Group 3 of the Sixth Assessment Report of the IPCC prepared its report after an 8-year interval. According to the report, the nationally determined contributions (NDC) (without conditions) announced before COP26, would reduce global greenhouse gas (GHG) emissions in 2030 to 53 billion tonnes of CO_2 equivalent ($GtCO_2$-eq), compared to the 59 $GtCO_2$-eq of 2019. A reduction of only 6 $GtCO_2$-eq (or 10%) is far from the 21% and 43% targets needed for the 2°C and 1.5°C emission paths. At COP26, the parties were requested to revisit and strengthen their NDCs, as necessary, to align them with the Paris Agreement temperature goal by the end of 2022.

On the other hand, the current situation faces a headwind. In 2020, global energy-related CO_2 emissions decreased by as much as 5.8% from the previous year due to COVID-19. However, according to the IEA's preliminary figures[6], emissions rebounded in 2021, returning to the level of 2019. In addition, Russia's invasion of Ukraine triggered an energy crisis, forcing countries to place energy security as their top priority, and reducing their relative interest in climate change. In the short term at least, the possibility of a continued slowdown in climate change efforts cannot be ruled out and needs to be closely monitored.

Emission growth in Emerging Market and Developing Economies, including India, exceeds the decline in China and the United States

Figure 2-30 shows the global energy-related CO_2 emissions by major country/region and Figure 2-31 presents the annual rate of change in global energy-related CO_2 emissions and the contribution by major countries and regions. In the Reference Scenario, emissions will gradually increase at a slower pace, but will rise until 2050, reaching 35.5 Gt in 2030 (12.2% increase from 2020) and 37.0 Gt in 2050 (16.9% increase from 2020). Emissions from China, the largest emitter, will peak in 2027, while emissions from other Emerging Market and Developing Economies such as India and ASEAN will increase by more than the decline in China and the United States.

[5] "Annual Report on Energy in FY2021" (Energy White Paper 2022), Ministry of Economy, Trade and Industry

[6] IEA (2022), Global Energy Review: CO_2 Emissions in 2021

Figure 2-30 | Energy-related CO_2 emissions [References Scenario]

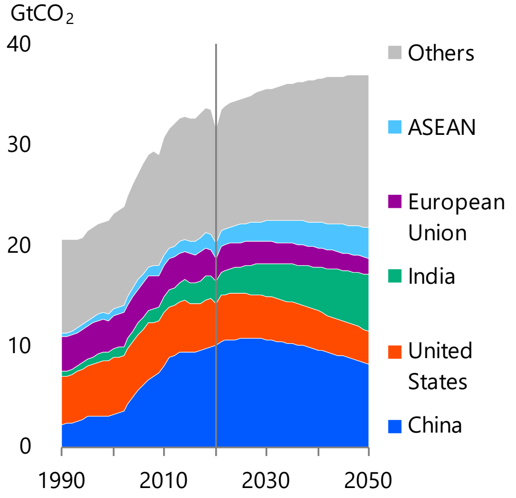


Figure 2-31 | Changes and contribution in energy-related CO_2 emissions [Reference Scenario]

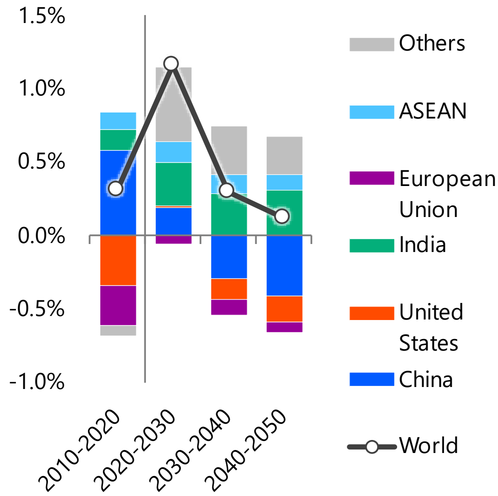
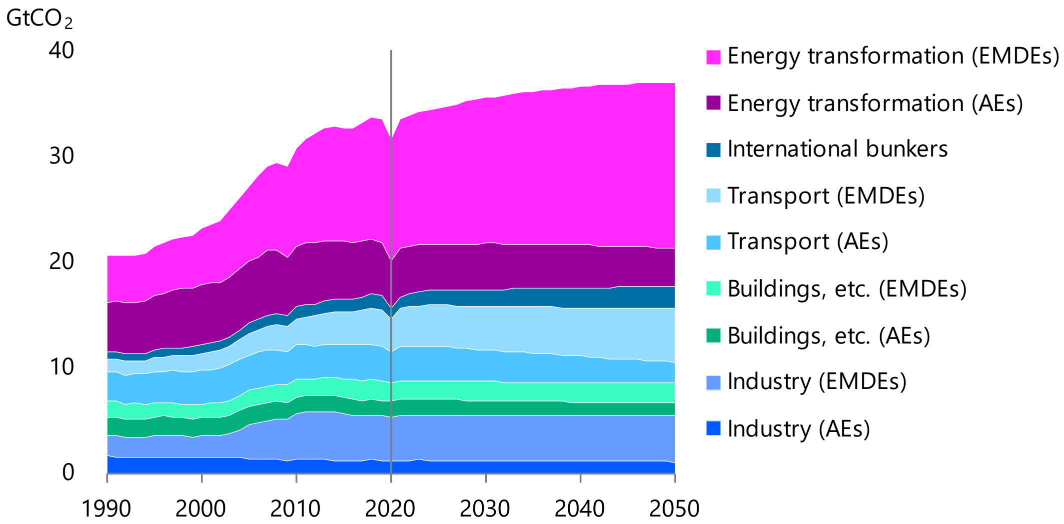


Figure 2-32 shows energy-related CO_2 emissions by the Advanced Economies, the Emerging Market and Developing Economies as well as those associated with international bunkers. Emissions from energy transformation and transport sectors will decline in the Advanced Economies, while they will increase in Emerging Market and Developing Economies. Emissions related to international bunkers will increase.

Figure 2-32 | Energy-related CO_2 emissions in the world [Reference Scenario]



Notes: AEs stands for Advanced Economies, EMDEs stands for Emerging Market and Developing Economies.

3. Energy supply

3.1 Crude oil

Supply of crude oil before and after the invasion of Ukraine

OPEC Plus, which consists of the Organization of Petroleum Exporting Countries (OPEC) and non-OPEC major oil-producing countries, have been coordinating production cuts since 2017. During the early stage of the COVID-19 pandemic, in March-April 2020, the group had temporarily abandoned its production cuts. They were resumed one month later, in May, and were gradually eased afterward. However, due to deteriorating political instability and insecurity, a lack of upstream investments and other factors, the production goals have not often been reached since 2021. In the United States, the world's largest oil producer, production plunged as the collapsing oil price in the early days of the pandemic worsened upstream economics, squeezing financing for E&P projects. Oil prices started to rise in the second half of 2020, but upstream investment was still slow to recover resulting in sluggish production. From the third quarter of 2020 to the first quarter of 2022, the oil market experienced a continued excess of demand, while the supply side was greatly affected by the OPEC Plus production cuts and by the slow recovery of production in the United States.

In response to Russia's invasion of Ukraine, Western countries moved away from Russian oil. Despite some variations in the timing and extent of implementation, the Group of Seven (G7) and the European Union (EU) have decided to embargo Russian oil. These actions will affect Russia more severely from the second half of 2022, forcing it to constrain crude oil production in the short to medium term. The production target of OPEC Plus have substantially lost their meaning due to frequent failure to reach the target, and the focus shifted to the extent of the production increases by Saudi Arabia and the United Arab Emirates, which account for most of the spare production capacity. Meanwhile, as oil prices rise, production by the United States is finally recovering, highlighting the importance of the country as an alternative supply source to Russia.

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

In the Reference Scenario, world oil demand will continue to increase until 2050, mainly in developing economies such as India, the Association of Southeast Asian Nations (ASEAN) and Africa, on the back of economic growth and an increase in the number of middle-class households.

Over the medium term through 2030, global oil demand will increase at an annual rate of 1.6%, prompting OPEC and non-OPEC oil-producing countries to expand production. OPEC member countries, led by the Middle East Gulf countries which enjoy overwhelming cost competitiveness, will drive the increase in world crude oil supply during this period. Europe and Eurasia, where production was expected to decline in the medium to long term, even before the war in Ukraine, will accelerate the speed of decrease as Russia's lack of upstream investment worsens due to embargoes and sanctions by Western countries. Meanwhile, production in North America, mainly the United States which grew enormously in the 2010s, will peak around 2030. Countries such as Brazil and Guyana will increase their production and boost overall output in South America, while production in Africa will level off and those in Asia and Oceania will continue to decline.

From 2030, while production in Latin America will increase, production in non-OPEC regions such as North America, Europe and Eurasia and Asia will decrease, highlighting the increased presence of Middle East OPEC member countries with ample crude oil reserves. These countries, led by Saudi Arabia, will capture most of the increase in demand from 2030 to 2050. As a result, the share of OPEC crude oil in the world oil supply will expand from 34% in 2020 to 44% in 2050.

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

(Mb/d)

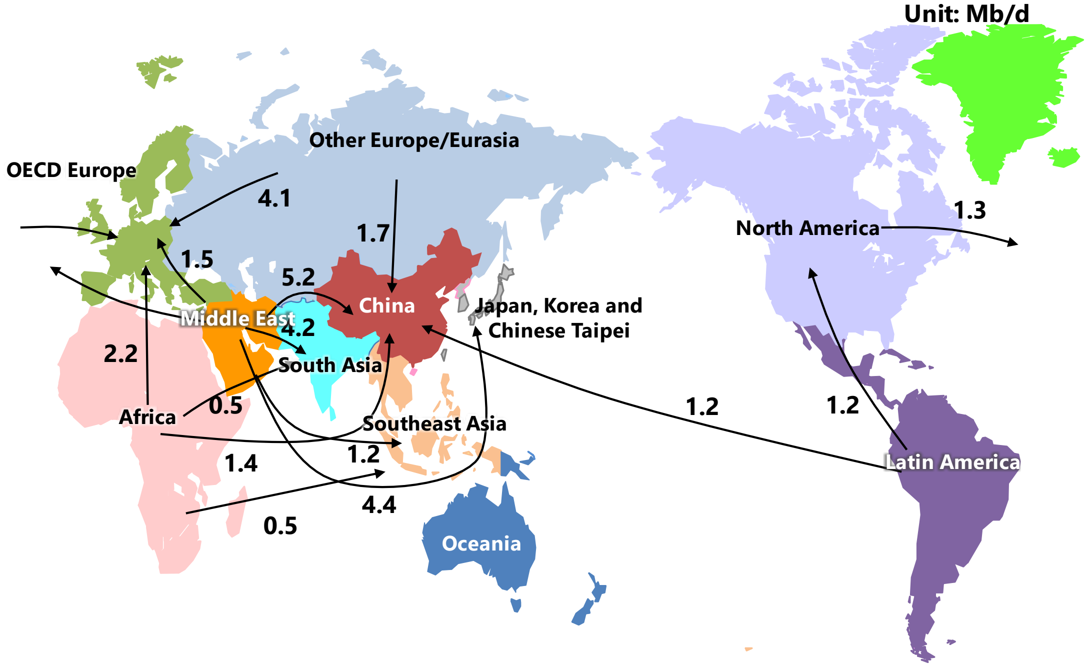
	2020	2030	2040	2050	2020-2050	
					Changes	CAGR
Crude oil production	89.6	108.5	111.7	113.2	23.6	0.8%
OPEC	31.3	41.9	48.0	51.5	20.2	1.7%
Middle East	25.0	34.2	39.6	42.2	17.2	1.8%
Others	6.3	7.7	8.4	9.3	3.0	1.3%
Non-OPEC	58.3	66.6	63.6	61.7	3.4	0.2%
North America	21.0	28.4	27.1	25.2	4.2	0.6%
Latin America	7.7	9.2	10.6	11.6	4.0	1.4%
Europe and Eurasia	17.4	16.4	14.3	13.6	-3.8	-0.8%
Middle East	2.9	3.6	3.9	4.2	1.3	1.2%
Africa	1.4	1.6	1.6	1.7	0.2	0.5%
Asia and Oceania	7.9	7.4	6.2	5.3	-2.6	-1.3%
Processing gains	2.1	2.9	3.2	3.4	1.3	1.6%
Oil supply	91.7	111.4	114.8	116.6	24.9	0.8%

Note: Crude oil includes NGL.

Asia growing dependent on Middle Eastern crude oil

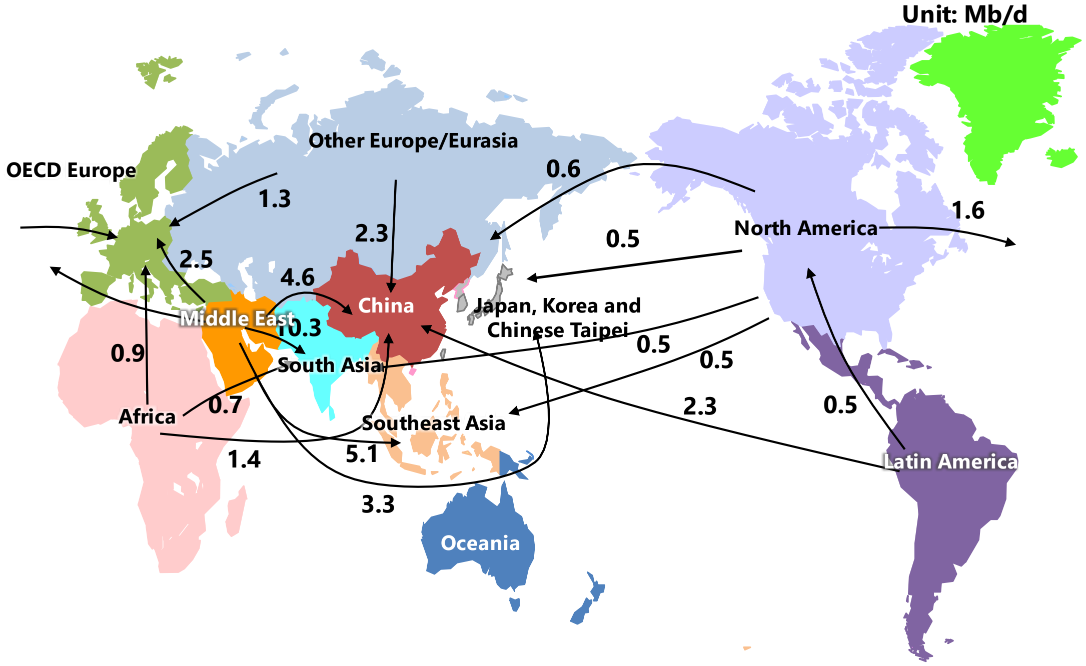
Crude oil trade in the world totalled about 42 million barrels per day (Mb/d) in 2021. The Middle East, the largest exporting region, accounts for about 16 Mb/d, or 39% of global exports, followed by Non-OECD Europe/Central Asia, led by Russia, at about 6.4 Mb/d, and North America at about 6.0 Mb/d. 80% of Middle East exports are destined for Asia, while 60% of Non-OECD Europe/Central Asia exports are for Europe and 30% for Asia. Trade in North America is mainly intra-regional (e.g. between the United States and Canada), accounting for 60% of the total, with 20% destined for Asia.

Figure 3-1 | Major interregional crude oil trade flows [2021]



Note: Flows of 0.5 Mb/d or more are covered.
Source: "BP Statistical Review of World Energy 2021", 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.

As for imports, Asia is by far the largest importing region with about 23 Mb/d, of which China, the world's largest importer, accounts for 10 Mb/d. Imports by OECD Europe are also large at about 10 Mb/d. The largest supplier for Asia is the Middle East, with 60% dependency for Asia as a whole. The region supplying most to OECD Europe is Non-OECD Europe/Central Asia, and the overall dependency of OECD Europe on Non-OECD Europe/Central Asia is 40% (European Union's dependency on Russia is 30%).

Global crude oil trade will increase as demand grows in non-oil-producing countries. In Organisation for Economic Co-operation and Development (OECD) countries, where demand is declining, imports also will continue to shrink, but imports from non-OECD countries will increase at a faster pace than from OECD countries. While China's imports will peak around 2030, those of India and ASEAN are increasing remarkably, boosting Asia's dependence on imports. Non-OECD Europe/Central Asia, led by Russia, will increase their dependency on the Chinese market as supplies to Europe decelerate. While flows from the Americas to Asia will increase, the Middle East will remain the largest supplier for Asia.

3.2 Natural gas

Abundant supply potential sustaining expansion of the LNG market, but the outlook is uncertain

The global liquefied natural gas (LNG) and natural gas markets have experienced unprecedented price increases and high levels since late 2021.

After the COVID-19 pandemic caused demand to decrease in 2020, and so the supply side was slow to respond to the rebound in late 2020 onward, resulting in a supply-demand imbalance. In addition, planned and unplanned stoppages or slowdowns of production activities at LNG facilities and upstream gas production sites led contributed to supply shortages in 2021.

In Asia, LNG production at the Bintulu LNG facility in Malaysia experienced a shortage of feedstock gas from some gas fields after August 2021. At the Tangguh LNG facility in Indonesia's Papua Province, start-up of the third production train currently under construction is delayed by more than a year, until 2023. The Prelude floating LNG production facility off the coast of Western Australia, which had been shut down for an investigation at the order of Australian Maritime Safety Authority due to a fire in December 2021, resumed operations only in May 2022 and in July, a labour dispute affected LNG shipments. In Russia, the Sakhalin 2 LNG facility in Sakhalin Oblast experienced a shutdown of two trains for some period during maintenance from July to August 2021, before the invasion of Ukraine.

In the Atlantic, the Snøhvit LNG facility in Norway suspended LNG production until mid-June 2022 after a fire in September 2020. The Peru LNG production facility in South America, suspended LNG production for four months due to problems at the end of May 2021. In Trinidad and Tobago, one of the three Atlantic LNG production trains has been shut down since mid-2021 for an indefinite period due to a shortage of feedgas. In Nigeria, West Africa, production of LNG dropped by about 20% during 2021 also due to a shortage of feedgas. Construction of the 7th train expansion plan in the same project started in June 2021; it is expected to commence production around 2025. Equatorial Guinea suspended LNG production from October to November 2021 due to an interruption in the supply of feedgas.

In mid-June 2022, a fire broke out at the Freeport LNG export facility in the Gulf of Mexico in the United States, which halted LNG production. The shutdown led to a cumulative decline in supply of several million tonnes (Mt).

Regarding the trend of supply growth, the U.S. Energy Information Administration (EIA) foresees a steady increase in LNG exports from 2022 to 2023. The construction of the 6th train in the LNG export facility of Cheniere's Sabine Pass in Louisiana was completed in February 2022. The first LNG cargo from this facility was shipped at the end of 2021. Venture Global LNG's Calcasieu Pass export facility in the same state shipped its first LNG cargo in February 2022. As a result, despite the temporary decline in Freeport LNG exports mentioned above, the United States exported estimated 77 Mt of LNG in 2022, making the country one of the world's largest LNG exporters, along with Australia and Qatar.

In 2021, new LNG transactions, mainly bound for China, with an estimated annual volume of over 60 Mt of LNG were concluded, exceeding 50% of the total volume for 2020. However, among the new contracts in 2021, only one-third were signed for planned production volumes from the projects prior to the final investment decision (FID), which was deemed somewhat insufficient to support new project investment decisions. The remainder were additional sales from projects that have already achieved production or are being planned or under construction.

In 2022, LNG procurement activities gained speed, especially after Russia's invasion of Ukraine. By the end of July, purchase commitments of approximately 50 Mt had been secured, including commitments to purchase approximately 40 Mt of sale and purchase agreements (SPAs) with heads of agreements (HOAs), which have a high probability of being converted into SPAs. Unlike those in 2021, these are all for new projects and are expected to support new investment in the LNG production sector. Furthermore, all of these are North American LNG production projects, mainly in the United States.

The United States led the expansion of LNG production in 2022. From then onward, trends in construction progress and investment decisions to increase supply capacity, especially after 2025, will also be of great interest. Another factor attracting attention is the construction status, expected completion and potential cost overruns in Canada and Mozambique in East Africa, which have made investment decisions and plan to join new LNG exporters.

In terms of investment decisions in the LNG production sector, the capacity alone marked 50 Mt/year in 2021, the third highest level in history for a single year. However, a breakdown of the capacity reveals that 32 Mt was associated with a huge expansion project in Qatar while one Australian project of 5 Mt was due to a brownfield expansion project, not a genuinely new development project.

In the United States, future expansion is expected in view of investment decisions for new projects, in addition to those currently under construction. As the global pandemic caused uncertainties, about 70 Mt/year of expected projects for 2021 have been delayed until 2022 or later. Smooth progress of these projects will be key to a healthy development of the LNG market. Among these projects, two investment decisions, worth 23.33 Mt/year, were announced by July in 2022.

Meanwhile, projects in which investments have already been decided or those under construction include projects in Russia (Arctic LNG 2: 19.8 Mt/year, Ust Luga: 13 Mt/year), but their prospects are uncertain. If these projects are not successful, there is a growing concern about the future supply capacity. However, if such shortfall cannot be offset by corresponding demand, this may drive the promotion of projects in other regions. Assisted also by these uncertainties, a wave of LNG production projects is emerging, particularly in the United States. Large-scale projects outside of North America include the above-mentioned huge expansion project in Qatar for which investment is decided. It has been announced that five international companies decided to participate in the project after the end of June 2022.

In the past half century, natural gas supply in the world has expanded faster than the overall energy supply. LNG supply through international trade and marine transportation has increased faster than the overall natural gas supply. In 2019 in particular, LNG supply expanded significantly, with rapid ramping-up of LNG production facilities in the United States, Australia and Russia, resulting in double-digit growth rates and the largest absolute volume increase ever. By volume, the increase came to a record of 41 Mt. While U.S. LNG production capacity further expanded in 2020, capacity utilisation rates fell due to a plunge in global LNG demand and trade in the second and third quarters. As a result, the LNG market expansion in the year was limited. In 2021, the LNG market has quickly expanded so as to absorb the increased production capacity, thanks to robust Northeast Asian demand including Chinese consumption. In 2022, to the global LNG market expanded by about 5% in volumes.

Expanding presence of U.S. LNG and its impact on the global market

As mentioned above, the United States will play a major role for the time being with regard to projects with a high likelihood of future investment decisions. LNG projects in the United States are not vertically integrated, unlike traditional LNG projects in other regions with upstream gas fields closely connected. Furthermore, project construction and investment decisions have been made within loose commitments on LNG purchasing that do not necessarily fix the final consumption destination. On the other hand, in 2021-2022, long-term contracts which tend to specify the end-user gained momentum. Thus, as the volume grows, the structure of projects is becoming increasingly diverse.

The emergence of such U.S. LNG projects in the global market is stimulating structural changes in the LNG market. In 2019, U.S. LNG supply to Japan expanded and demonstrated its price advantage being indexed to gas prices in the United States, compared to prices for most traditional contracts for LNG supply to Asia which were high. In 2020, U.S. LNG supply flexibly absorbed demand fluctuations amid weak gas prices. In 2021, U.S. LNG also demonstrated its flexibility and price advantage amid a global gas price hike, solidifying its position as a supply source for various regions. By 2022, the United States has become one of the world’s three largest LNG exporter.

The increasing presence of the United States in the global LNG market has begun to exert impacts on LNG procurement contract negotiations for the United States and other suppliers. For the moment, Australia reached the final phase of its LNG production capacity expansion in 2019 and boosted its LNG production in 2020 and 2021 above that of Qatar, which had been the world’s largest LNG exporter since 2006. Russia has increased LNG production from its

Arctic region, expanding its share of the European market and its exports to Europe posted record-highs in 2022.

This evolving LNG production trend has brought about structural changes in the LNG consumption market. Northeast Asia has remained a main consumer of LNG, but its share of the global LNG market narrowed from 62% in 2018 to 56% in 2019 and 2020 and rose back to 59% in 2021. The share for Japan also dropped from 25% in 2018 to 20% in 2021. Despite a slow growth rate, China's LNG imports exceeded those of Japan in 2021. Note that in 2022, China's LNG imports declined, making Japan the world's largest LNG importer again.

In response to the expansion of U.S. LNG exports, Europe rapidly increased its LNG imports from the fourth quarter of 2018. In 2019, the European Union (EU) and the United Kingdom combined imported more LNG than Japan or China. In 2022, their LNG imports surpassed those of Japan and China again due to the increase in LNG imports associated with the EU's efforts to reduce dependence on Russia. Underground gas storage facilities have played a key role in boosting LNG imports in the European Union. These facilities have a total LNG capacity of 70 Mt as of 2022. Reflecting the growth in LNG imports, the level of inventories at the facilities fluctuated wildly.

Shift of LNG logistics to Europe and normalisation of high global gas prices

Since 2021, LNG inflows to Europe have been increasing, mainly from the United States. In the first quarter of 2022, shipments of U.S. LNG to the world market totalled 22 Mt, the largest volume ever exported by a single country in a single quarter. During this period, 65% of the U.S. LNG shipments were accounted for by the European Union plus the United Kingdom, doubling the 30% share in 2020 and 2021. In 2022, LNG imports from Japan and China, the world's two largest LNG importers, declined while Europe's presence in the market expanded.

In parallel with this, high prices have become common, particularly among European natural gas spot and market prices and Asian spot LNG prices. These prices have risen rapidly since August 2021 and have remained at their highest level ever since the following October. Thereafter, the prices have frequently been extremely high.

Factors for the above phenomena include the rapid demand recovery from the latter half of 2020 (after the pandemic-induced slump in the first half of the year) and the relatively slow recovery of natural gas production which had declined due to sluggish demand. In the medium to long term, it can be stated that construction and investment for additional production of natural gas and LNG has not caught on.

Another factor is the troubles at existing LNG production facilities. As a result, prices are expected to remain generally high till around 2025 and will surge especially during the winter in the northern hemisphere when gas demand peaks. The gas supply outlook remains uncertain in view of the situation in Ukraine. The EU's policy of using non-Russian gas means additional procurement from other sources, causing concerns over gas supplies to other markets. For the time being, amid unprecedentedly high prices, the stable procurement of natural gas is a critical issue in the markets around the world.

In Japan, LNG import prices reached record highs in terms of yen currency in April, May and July 2022, driven by a rapid depreciation of the yen. Japan's LNG import prices are expected to stay high due to high crude oil prices, which long-term LNG contracts are mainly linked to.

In the United States, which is one of the LNG supply sources for the international market, the Henry Hub natural gas futures contract price exceeded $9 per million Btu in early June 2022, the highest domestic gas price since the shale revolution. The factors behind the high price include a slightly slower pace of growth in domestic gas production, robust domestic demand for gas for power generation, and strong demand for feedstock gas for LNG exports from the United States.

With high prices far above past records now common, LNG procurement is accelerating, with signs that development and investment in LNG production are approaching record levels. Japanese companies did not show their presence in the procurement activities until late 2022, despite many commitments by Chinese firms by that time. To respond to gas demand in Japan and Asia in the late 2020s, commitment and international collaboration by Japanese companies and policy responses to support them will be important.

These large-scale projects used to require a long period of time, typically four to five years, from the investment decision to the start of LNG exports. In order to shorten the construction term, efforts are being made to speed up the engineering and assembly construction period through standardising and modularising some of the units; and they are producing results. In addition, some of the emerging project companies have announced the completion of 1.4 Mt/year LNG liquefaction facilities in one to two years, which is significantly faster than usual.

In future LNG projects, components of controlling greenhouse gas (GHG) emissions will greatly affect the competitiveness and viability of the projects. Most of the LNG production projects currently planned are being designed to incorporate carbon capture and storage (CCS) or consider renewable energies as a power source.

In the past two years, high LNG prices have been a headwind for existing LNG importers, as well as for LNG introduction in emerging markets such as Southeast and South Asia. However, improvements in the conditions of sales contracts, especially in terms of prices, will accelerate the establishment of LNG import projects. These improvements will also lead to increased initiatives for LNG bunkering in marine transportation and expanded LNG-fuelled vessels.

Gas resources development supporting LNG expansion in the long term

The United States, the world's largest producer and consumer of natural gas, will continue to increase its production of natural gas, primarily shale gas, throughout the outlook period. Its natural gas production will rise at an annual rate of some 1% until around 2030 before stabilising. LNG exports will play a key role in increasing natural gas sales channels and improving the country's trade balance. Shale gas production was at low levels until U.S. natural gas prices increased around 2005, stimulating its development. Since 2008, shale gas production has expanded substantially as its economic efficiency has improved thanks to the advancement and diffusion of hydraulic fracturing and horizontal drilling technologies. As of 2022, shale gas production accounts for 80% of natural gas production in the United States.

Natural gas prices in the United States have been at low levels, a result of production growth since 2008. As gaps between natural gas and oil prices have expanded, development technologies have been applied for liquid production and improved, thus boosting the production of natural gas liquids (NGLs) and crude oil, as well as associated natural gas. In the international market, meanwhile, the gaps between U.S. natural gas and oil prices have been reflected in those between U.S. natural gas and oil-indexed Asian LNG prices, leading to the successive launch of plans to develop U.S. LNG export projects.

The competitiveness of U.S. LNG in the international LNG market will be affected by price trends relative to other competing LNG or pipeline gas supplies. This is particularly true for oil price trends, which traditional Asian LNG supplies are linked to, as well as European spot natural gas prices, which link to Russian pipeline gas. This has contributed greatly to fluctuations in the LNG trade flow in the global market from 2020 to 2022.

In the case of LNG production projects in the eastern part of the United States., including the Gulf of Mexico, access to Asian markets is mainly via the Panama Canal. This will create the need for optimising supply sources and routes, such as swapping LNG cargoes depending on the situation, thus promoting alliances among various players. While the LNG trade volume through the canal is still increasing, there is a growing need for optimising LNG transport because the market was unable to respond to the Asian buyers for more cargoes from the United States during the rapid increase in LNG demand in Asia during the 2020-2021 winter season.

In the United States, LNG production capacity now in operation and some capacity under construction are expected to export about 82 Mt of LNG annually as early as 2022, potentially making the country the world's largest LNG exporter, surpassing Australia and Qatar after 2023. If capacity under construction and capacity still subject to final investment decisions by July 2022 are added, the annual U.S. LNG production capacity will exceed 120 Mt.

LNG exports from the United States are priced, in general, based on U.S. natural gas market prices, whose absolute price level is low, instead of the traditional Asian LNG pricing indexed to oil prices. U.S. LNG exports, though they may be influenced by prices of other energies in Asia, can provide competitive prices in the Asian market and are expected to promote changes in the traditionally rigid Asian LNG pricing mechanism. Given that U.S. LNG exports are mostly based on contracts under which destinations are not specified, they are bringing about great changes in global LNG transactions. In addition, the flexibility of U.S. LNG is expected to facilitate the development of emerging markets, leading to the emergence of new LNG importing countries in Latin America, Europe, and elsewhere.

Also in North America, Canada, which had been exporting nearly half of its gas production to the United States via pipeline before the U.S. shale revolution, has high hopes for the LNG export market to expand in the future. The shale revolution has squeezed its sales channel in the United States. Multiple LNG export projects are planned on both the Pacific and Atlantic sides with one large Pacific coast project that has reached a final investment decision. These projects will pave the way for Canada to expand gas production particularly after 2030.

Table 3-2 | U.S. shale revolution and global LNG market trends

	United States	International LNG market	Bilateral relations
–2007	U.S. gas price hikes and U.S. gas development promotion	Rising global gas and oil prices	Increased investment in LNG-producing countries
2008–	Start of shale revolution and widening gap between gas and oil prices	Expansion of LNG exports from Qatar, Russia, etc.	Pronounced Asian premium in LNG prices (especially after the nuclear disaster in Japan)
2014–	Progress of LNG export projects; start and expansion of exports	Major expansion and progress of LNG export projects, particularly in Australia	Emergence of U.S. LNG stimulating flexibility in international LNG trading
2019	Decision to invest in LNG export facilities of 30 Mt/year	LNG/gas price declines due to supply growth	Gaps in U.S. domestic and international market prices accelerating decisions on additional investment
2020	Frequent cancellation of LNG exports in the summer season in the northern hemisphere	Simultaneous drop of global LNG and gas prices to historical lows International gas prices unified at low levels	Frequent cancellation of U.S. LNG in the summer season in the northern hemisphere due to sluggish world gas prices
2021	De facto monopoly of the increase in world LNG supply	Price spike and continued high prices in the second half Troubles in LNG production facilities also affecting price rises	High international LNG and gas prices unable to lead the LNG investment decisions in the U.S. due to uncertainty about the future
2022	Becoming the world's leading LNG exporter Steady gas prices reaching the levels immediately before the shale revolution	Continued high prices and frequent wild price hikes Rapid increase in purchase of LNG by Europe	Continued high prices in the international market accelerating LNG production and development not only in the U.S. but also in other parts of the world

LNG exports from Western Australia to Japan were launched in 1989 under a large LNG production project, which has been expanded in two phases. This project has been combined with the expansion of the domestic gas supply system, becoming a model project for LNG development in Australia. LNG exports started under a project in Australia's Northern Territory in 2006 and under a second project in Western Australia in 2012. In the 2010s, LNG production began under multiple additional projects in Western Australia and new projects in eastern Queensland in response to the growth of LNG demand in Asia, including Japan and China. Production started under these projects by 2019, bringing Australia's annual LNG production capacity to more than 80 Mt. As of 2020, Australia replaced Qatar as the world's largest LNG producer. These projects are operated by different parties including Japanese companies, providing different terms and conditions for LNG supply. Furthermore, Japanese and other Asian LNG buyers have acquired minor equity stakes in these projects, paving the way for future flexible LNG supply including equity-based off-taking. Upstream gas development projects currently planned include those for providing gas to existing LNG production facilities, allowing for the stable operation of LNG facilities to provide a platform for sustainable upstream gas production. Production is expected to smoothly expand under these projects before its growth decelerates after 2030.

Russia has been exporting LNG under a Sakhalin project on the Pacific Coast since 2009 and an Arctic project since late 2017. The Arctic project provides Russian LNG not only to Pacific LNG-consuming countries but also to the European market, which has traditionally received Russian gas supply via pipelines. In Arctic Russia, a second large LNG project received a final investment decision, and construction is underway. However, the outlook has become uncertain due to the invasion of Ukraine by Russian forces since February 2022. Until then, the project had been expected to supply LNG not only to the nearby European market but also to other regions thanks to the planned development of terminals for transferring LNG from ice-breaking LNG tankers that can operate in the Arctic region to conventional LNG carriers to optimise transportation. This will bring about additional structural changes in LNG supply.

In addition, frontier regions in East and West Africa will expand natural gas production including LNG. For offshore or small and medium-sized gas fields in these regions, floating LNG production facilities are realistic options for LNG development. In Cameroon, West Africa, a floating LNG production project has already come into operation. Investment decisions were made in 2017 for a floating LNG production project off Mozambique in East Africa, in 2018 for off Senegal and Mauritania in West Africa, and in 2022 for 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.

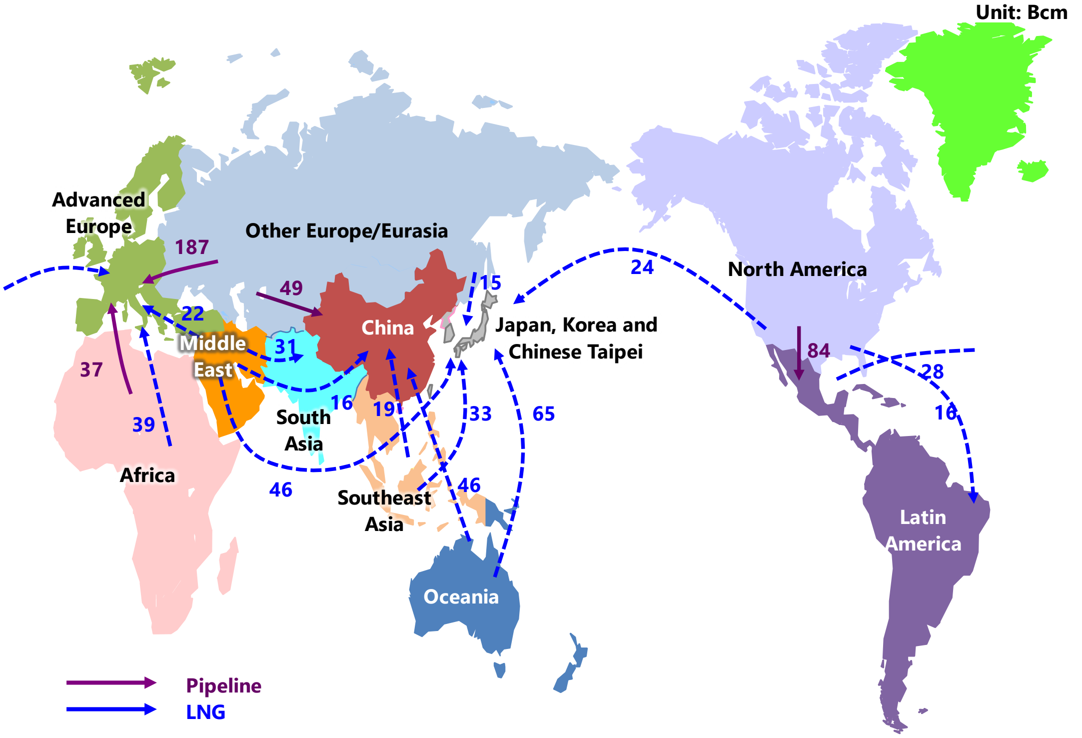
Mozambique is planning multiple onshore LNG production projects in addition to its floating LNG production project. An investment decision was made on one of them in June 2019. Unfortunately, as of 2021-2022, construction is suspended due to the deteriorating local security situation. Mozambique which 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 over the long term. Backed by the abovementioned projects, natural gas production will increase steadily.

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

(Bcm)

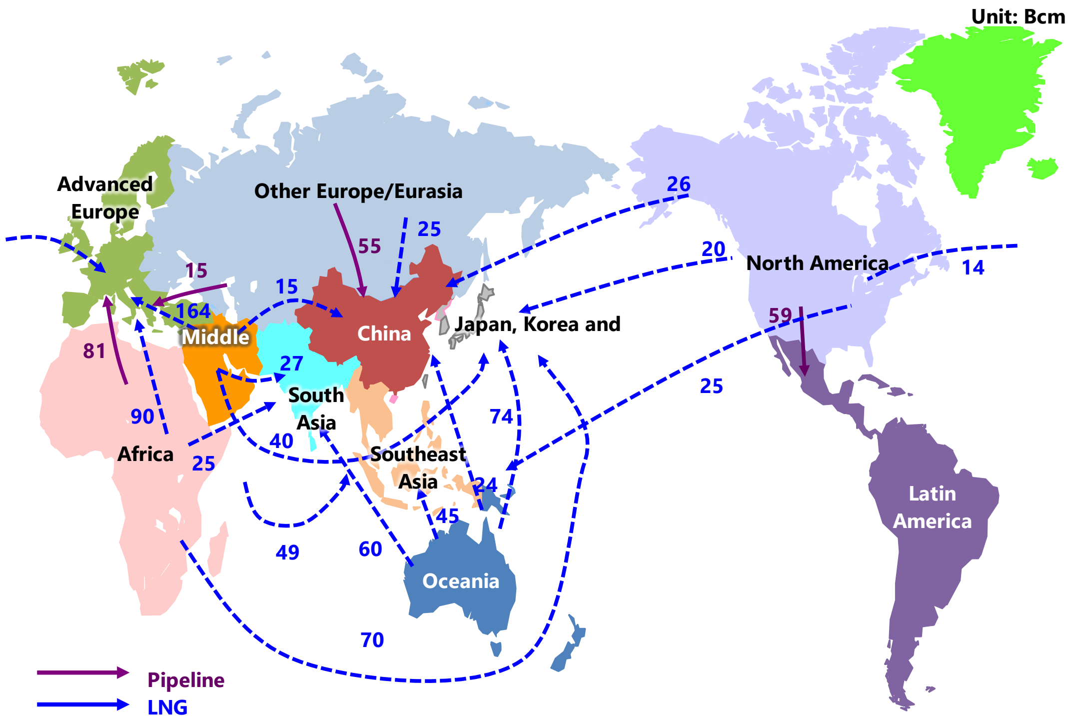
	2020	2030	2040	2050	2020-2050 Changes	2020-2050 CAGR
World	4 028	4 626	5 292	5 871	1 843	1.3%
North America and Mexico	1 177	1 370	1 412	1 435	258	0.7%
Latin America excluding Mexico	123	205	269	322	199	3.3%
OECD Europe	201	164	162	135	-66	-1.3%
Non-OECD Europe/Central Asia	970	903	879	902	-69	-0.2%
Russia	720	650	610	605	-115	-0.6%
Middle East	675	828	957	1 141	466	1.8%
Africa	240	301	585	726	486	3.8%
Asia	482	668	783	945	463	2.3%
China	195	245	300	380	185	2.2%
India	28	50	83	110	82	4.6%
ASEAN	199	234	247	256	58	0.9%
Oceania	159	186	245	265	106	1.7%

Figure 3-3 | Major interregional natural gas trade flows [2021]



Note: Major trade flows are covered.

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



Note: Major trade flows are covered. Some pipeline gas flows could be replaced with LNG flows.

3.3 Coal

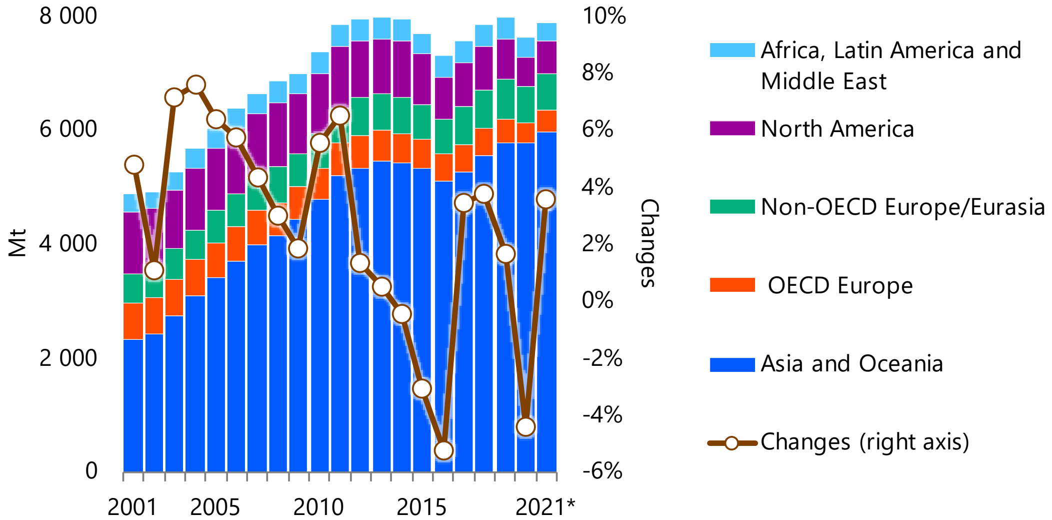
Stagnant supply amid recovering demand

In 2021, coal consumption increased in many countries due to the resumption of economic activities. On the other hand, production rose sluggishly due to supply disruptions caused by various factors, including natural disasters, accidents, and personnel shortages caused by the spread of COVID-19.

Global coal consumption in 2021 recovered to 7 958 Mt from a large decline in 2020 due to the pandemic (up 6.0% or 447 Mt from the previous year), 199 Mt more than in 2019. Coal consumption increased in many countries. In China, where consumption grew by 99 Mt year on year even in 2020, consumption increased by a further 186 Mt in 2021. In India, consumption increased by 160 Mt over the same period, and 108 Mt above 2019. Meanwhile, coal consumption in North America and OECD Europe respectively increased by 69 Mt and 54 Mt, but decreased by 37 Mt and 42 Mt, compared to 2019, indicating that coal consumption in Europe and North America has been shrinking.

Meanwhile, global coal production in 2021 marked 7 877 Mt (up 3.6% or 271 Mt from the previous year) along with the recovery of demand, though failing to reach 7 958 Mt reached in 2019 before the spread of COVID-19 (Figure 3-5). By region, the increase (or decrease in some regions) varied. In Asia and Oceania, the year-on-year increase was 3.4% (+195 Mt), but most of it was from China and India, 4.0% (+153 Mt) and 9.4% (+71 Mt), respectively. In other regions, North America increased production by 7.7% (+41 Mt), OECD Europe by 9.6% (+33 Mt), and Non-OECD Europe and Eurasia by 2.3% (15 Mt), while Africa, Latin America, and the Middle East decreased production by 3.5% (−12 Mt).

Figure 3-5 | Global coal production



Note: Figures for 2021 are provisional.
Source: IEA "World Energy Statistics and Balances 2022"

Looking at the production trends in 2021 in major exporting countries, Australia experienced a shiploader accident at the Port of Newcastle at the end of 2020 which took considerable time to restore, followed by a rainstorm in March 2021 which caused damage to the coal transportation network. In addition, China's embargo on Australian coal caused exports to decrease, lowering production by 33 Mt year on year. In Indonesia, exports to China expanded due to the Australian coal embargo, but production grew by only 3 Mt year on year due to the export ban on some production companies (August 2021) and the spread of COVID-19. In Colombia, mainly targeting the European market, Glencore stopped production at its wholly owned subsidiary Predeco in April 2020 due to low prices and the impact of COVID-19, and returned the mining rights to the Colombian government in 2021. In Cerrejón, protesting mineworkers blocked the railroad (for a month from 5 May), while inland, frequent accidents occurred at small-scale underground mines. The country's coal production declined to 50 Mt in 2020, down 40% year on year, but increased only 3 Mt in 2021 from 2020. In South Africa, which mainly targets India and ASEAN countries as its market, production fell by 19 Mt year on year due to factors such as the spread of COVID-19 and heavy rains from the end of 2021. Meanwhile in Russia, production increased by 34 Mt from the previous year due to expanded domestic demand.

Invasion of Ukraine amid continued excess demand

The global coal market experienced continued excess demand even in 2022. Supply has been curtailed because of unstable weather since the end of 2021, the spread of COVID-19 in Australia and South Africa, the coal export ban in Indonesia (originally planned for one month from 1 January, but lifted on 14 January), as well as the heavy rains in Australia in March and

April. In addition, heavy rains in New South Wales, Australia stopped the transport of coal by rail in early July.

In the meantime, concerning the supply-demand situation for the top four coal importing countries in the first half of 2022, China experienced a supply-demand crunch in 2021 due to a lack of domestic production, but it has been increasing its domestic production in 2022, resulting in a year-on-year decrease in imports. In India, shortages of electricity and coal were reported in March, but since then, domestic production has increased and coal imports have grown year-on-year since March. Japan and Korea (January-June) also saw year-on-year increases in coal imports. An additional factor to this situation is the demand for an alternative to Russian coal due to the European Union's and Japan's bans on Russian coal imports as economic sanctions in response to Russia's invasion of Ukraine (The European Union began an embargo on 10 August while Japan intends to gradually reduce its ban while monitoring the procurement status). To resolve the supply-demand imbalance, it is necessary for the supply side to return to normal, for production to increase to meet demand, and for alternative sources to be secured. It should be noted that some countries that disagree with imposing economic sanctions on Russia, including China and India, are increasing their share of coal imports from Russia.

International coal prices in 2022 were on an upward trend due to supply-side issues and concerns about the Ukraine situation amid excess demand for both steam coal and coking coal. Prices spiked after Russia invaded Ukraine, temporarily declined afterward but soared again after the European Union and Japan announced an embargo on Russian coal while heavy rains in Australia in April onward affected production. An overview of price fluctuations suggests that the price of steam coal (FOB price from the port of Newcastle, Australia) rose gradually to the \$250/t range, followed by a momentary surge to nearly \$400/t in early March after the invasion of Ukraine. The price subsequently returned to the upper \$200/t range, but in April it began to rise again, once exceeding \$400/t in May. The price then hovered around \$400/t, until it rose again to well above \$400/t in late August. The price of coking coal (Australian high-quality heavy coking coal FOB price) rose gradually to the low \$400/t range, followed by a temporary surge to over \$600/t in early March after the invasion of Ukraine. The price subsequently returned to the upper \$400/t range, but in April it began to rise again, once exceeding \$500/t in May. As supply subsequently recovered, the price fell below \$300/t in July, then to \$200/t in August, but returned to the upper \$200/t range in late August. Since the second half of June, the price of steam coal has been above that of coking coal.

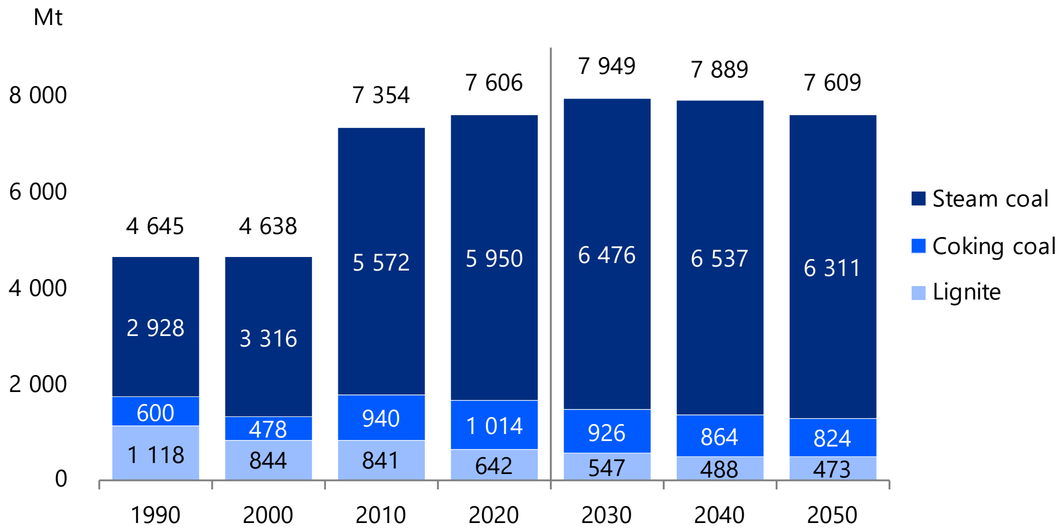
Maintaining a supply system that meets demand

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. As such, many countries now share a common recognition of the need to strictly curb the consumption and production of fossil fuels, especially coal. Coal consumption in Europe and the United States is already declining, while in India and ASEAN, where demand for coal is expected to grow, the speed of demand growth is slowing down. On the supply side, amid the trend of shifting away from coal, sluggish coal prices starting from 2019 and reduced demand for coal due to the spread of COVID-19 are increasingly causing major resource companies, Japanese trading companies and others to abandon coal, especially steam coal.

Given the energy status in each country and current coal demand situation, however, the global phase-out of coal is expected to be a long-term effort in practice. Coal consumption in 2021 increased from the previous year, but not all countries and regions have returned to the levels before the pandemic. Demand will continue to rise in 2022 in many countries. In addition, the ban on Russian coal imports as one of the economic sanctions against Russia is disrupting the 2022 coal market, and resulting changes in coal trade flows will affect the production in coal supplying countries in the short to medium term. Again, looking at the global coal demand in the short to medium term, demand will expand in Asia and Africa, including China, India, and ASEAN countries, following economic growth. In the long term, demand will increase in Asia, including India and ASEAN, excluding China, and Africa. Producing countries will be required to respond to domestic demand and export demand under severe investment and financing restrictions in the upstream coal industry.

World coal production will increase until the early 2030s in line with demand, then start to decline, with the downward trend intensifying in the 2040s. Production volume will increase from 7 606 Mt in 2020 to 7 949 Mt in 2030 followed by a decrease to 7 609 Mt in 2050 (Figure 3-6). By coal type, steam coal production will increase until the late 2030s mainly in line with growth in demand for coal for power generation. The production volume will expand from 5 950 Mt in 2020 to 6 537 Mt in 2040, followed by a decrease to 6 311 Mt in 2050. Meanwhile, coking coal production mainly for steelmaking will gradually decline from 1 014 Mt in 2020 to 824 Mt in 2050. Production of lignite, a locally produced and consumed energy resource, will gradually decrease from 642 Mt in 2020 to 473 Mt in 2050 along with the abolishment of existing lignite-fired power plants.

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



In the future, coal-supplying countries will produce in response to the export demand, namely, the international coal market, after meeting their own demand. On the other hand, countries that produce but also consume much coal, such as China and India, will expand domestic production to meet domestic demand and import the shortfall from other supplying countries. Countries such as Japan, where coal resources are scarce and production is not economical, will depend on imports.

Looking at 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 more difficult to either develop new coal mines, expand production at those in operation, or invest in transportation infrastructure. In Australia, domestic consumption and export of coal is an important concern that divides public opinion. Governments of coal-producing states are exploring means of earning foreign currency other than coal exports and tightening approvals for coal mine development. As Asia, a major coal export destination for Australia, is reducing the construction of coal-fired power plants, investments in coal mines will be discouraged even further. As such, no substantial increase in Australian coal supply (especially steam coal) is expected.

In Colombia, which has served as a supplier of coal mainly for Europe, companies from advanced economies will withdraw from coal production. The country may not increase production significantly in the medium to long term, although it will maintain a certain production volume for exports to Asian markets. 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 the existing coalfields of South Africa are being depleted forcing it to shift to new coalfields. Indonesia, a major exporter of steam coal, has been expanding production, but to restrain production volume and protect its coal resources, the government is announcing production targets every year. Its domestic demand is expanding, and the government is prioritising domestic supply and imposing coal supply obligations, which will lead to decreased exports in the long term.

Meanwhile, China and India have rapidly constructed coal-fired power plants and consume their domestic coal resources. While Chinese demand will peak around 2030 before declining, Indian demand will increase toward 2050. Both countries will continue to be important purchasers in the international market, receiving imported coal mainly in coastal areas, while maintaining their supply systems from domestic mines.

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

(Mt)

	2020	2030	2040	2050	2020-2050	
					Changes	CAGR
World	5 950	6 476	6 537	6 311	361	0.2%
North America	404	326	212	96	-308	-4.7%
United States	391	318	206	89	-302	-4.8%
Latin America	53	96	97	102	49	2.2%
Colombia	45	86	86	92	46	2.4%
OECD Europe	47	48	38	30	-17	-1.5%
Non-OECD Europe/Eurasia	361	346	360	386	24	0.2%
Russia	240	235	235	248	8	0.1%
Middle East	0	0	0	0	0	2.3%
Africa	253	266	284	302	49	0.6%
South Africa	245	253	267	280	34	0.4%
Asia	4 562	5 102	5 258	5 098	537	0.4%
China	3 227	3 422	3 124	2 664	-563	-0.6%
India	679	990	1 354	1 625	947	3.0%
Indonesia	562	578	654	678	116	0.6%
Oceania	269	293	286	296	27	0.3%
Australia	268	292	285	296	28	0.3%

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

(Mt)

	2020	2030	2040	2050	2020-2050	
					Changes	CAGR
World	1 014	926	864	824	-189	-0.7%
North America	75	82	84	87	12	0.5%
United States	50	55	56	56	7	0.4%
Latin America	8	9	10	10	1	0.5%
Colombia	4	5	6	7	2	1.3%
OECD Europe	14	16	16	16	1	0.3%
Non-OECD Europe/Eurasia	94	82	84	87	-8	-0.3%
Russia	90	77	79	81	-10	-0.4%
Middle East	1	1	1	1	0	0.1%
Africa	7	18	25	32	25	5.3%
Mozambique	4	16	22	29	25	6.6%
Asia	629	520	438	374	-255	-1.7%
China	561	423	303	196	-366	-3.5%
India	38	71	110	154	117	4.8%
Mongolia	26	20	19	17	-8	-1.3%
Oceania	185	197	207	218	34	0.6%
Australia	184	196	205	217	33	0.6%

Coal trade volume will increase by 90 Mt from 1 331 Mt in 2020 to 1 421 Mt in 2030, before gradually increasing to 1 484 Mt in 2050, as imports from Asia and Africa including India and

ASEAN increase. By type of coal, as China's imports will peak in 2030 and decline thereafter, the increase in steam coal trade volume will gradually shrink and then will start to decline in the late 2040s. On the other hand, trade of coking coal will decrease slightly in Europe and other Advanced Economies as well as in China toward 2050, but will gradually rise due to a significant increase in imports from India.

Among major coal exporters, Australia, Russia and Africa will expand their exports in response to coal market growth mainly in Asia. Exports from Russia will decline in the short to medium term due to the European Union's and Japan's embargo policy on Russian coal, but will increase in the long term mainly toward ASEAN and other Asian countries. By coal type, steam coal exports will increase from major exporting countries, but in Indonesia, they will decline after peaking around 2040 due to increased domestic demand. Coking coal exports will increase from major coking coal exporting countries, led by Australia, which accounts for more than half of its exports, and Mozambique will post a dramatic increase in exports, mainly to India.

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

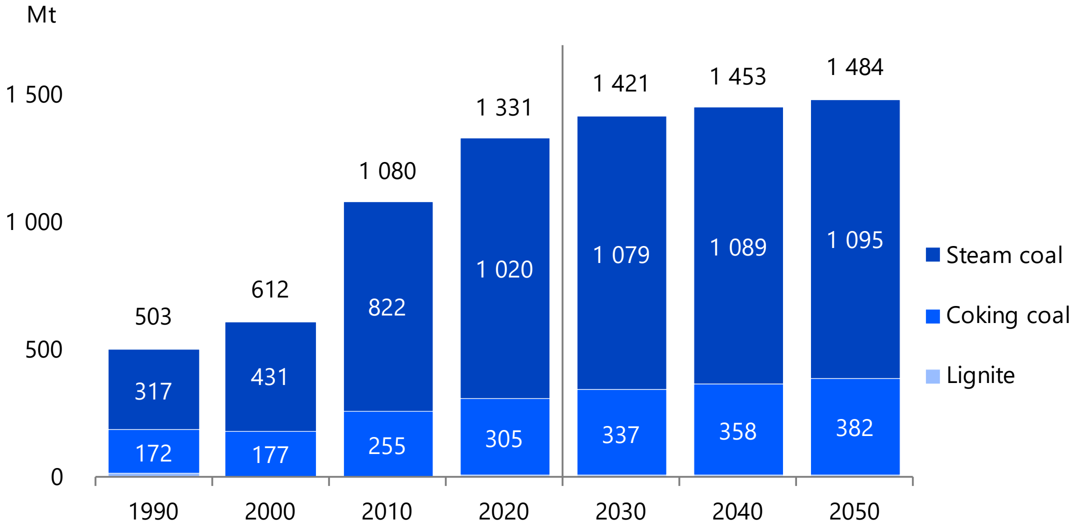
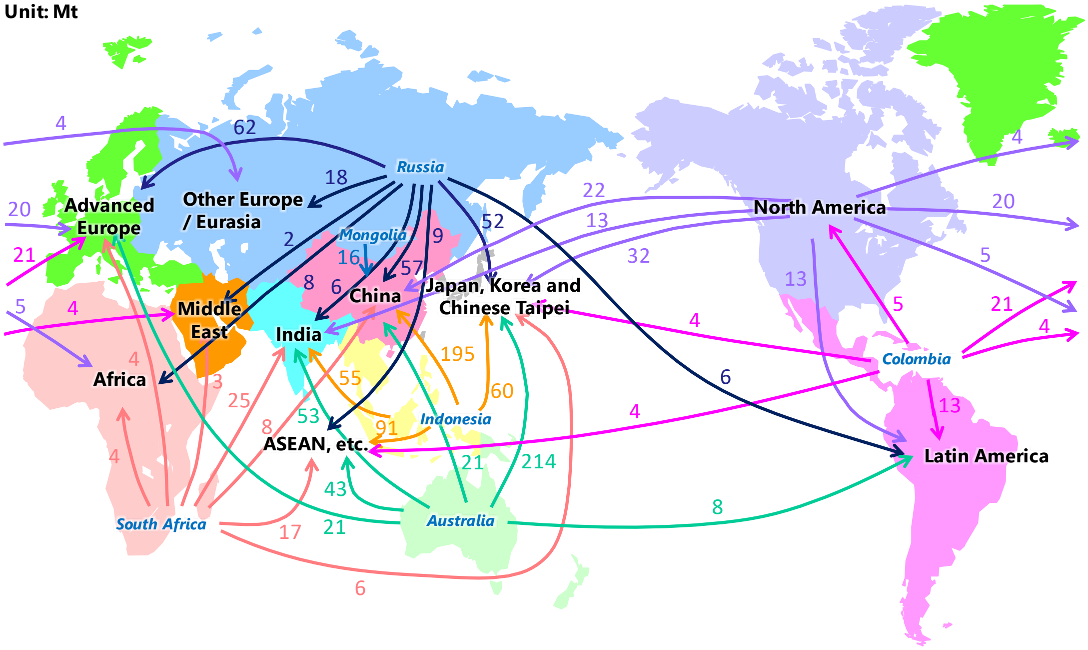


Figure 3-8 | Major interregional coal trade flows [2021]

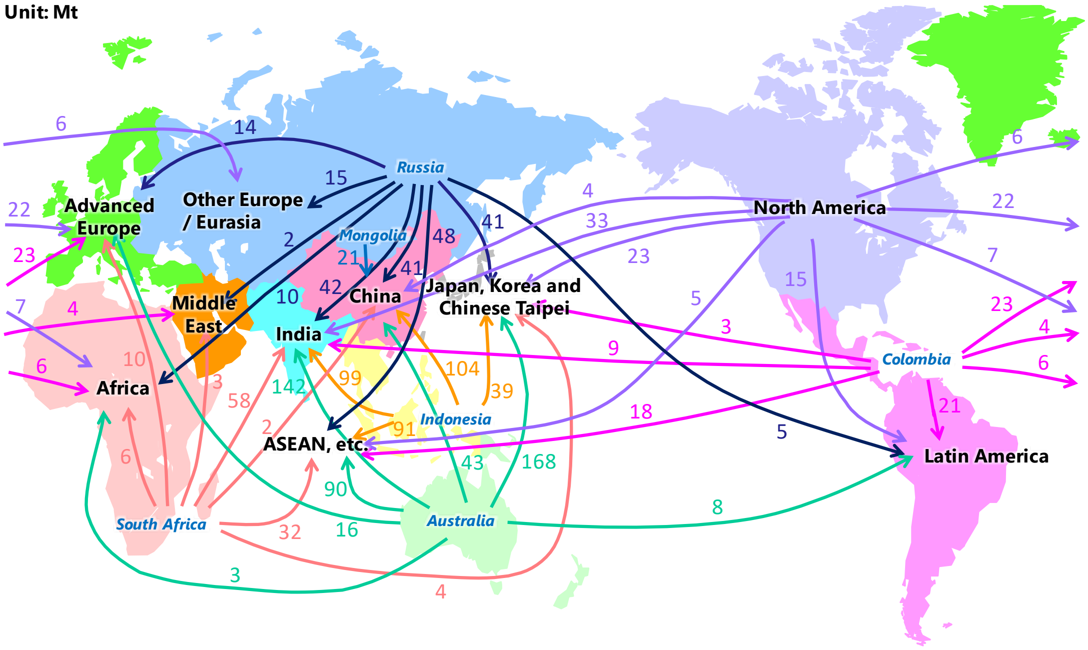
Unit: Mt



Notes: Sum of steam coal and coking coal. 2 Mt or more listed. South Africa includes Mozambique.
Sources: Estimated based on IEA "Coal Information 2021", TEX Report, etc.

Figure 3-9 | Major interregional coal trade flows [Reference Scenario, 2050]

Unit: Mt



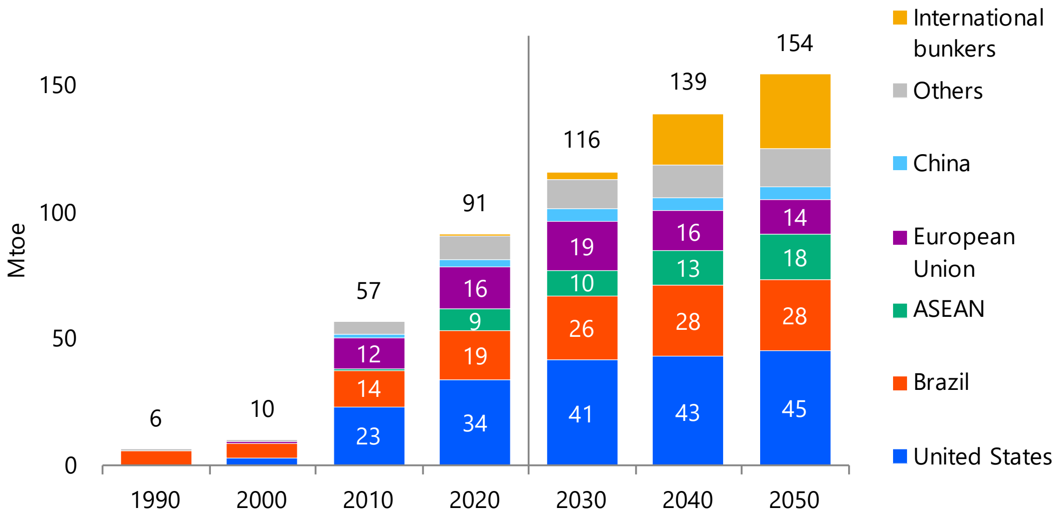
Notes: Sum of steam coal and coking coal. 2 Mt or more listed. South Africa includes Mozambique.

3.4 Biofuels for transport

The penetration of liquid biofuels including bioethanol and biodiesel has made progress as part of measures on climate change, energy security and agriculture promotion. However, biofuel consumption for automobiles remains concentrated in the United States, Brazil and the European Union, which accounted for nearly 80% of global biofuel consumption of 69 million tonnes of oil equivalent (Mtoe) in 2020.

While biofuel consumption has substantially increased since the 1990s, investment in biofuel has remained stagnant since 2010. Over the long term, biofuel consumption will recover as climate change countermeasures are enhanced, but will decelerate compared with the past as vehicles are being electrified. Nevertheless, by 2050 the consumption of biofuels for automobiles will reach 125 Mtoe (Figure 3-10). As concerns grow over the environmental impact of first-generation biofuels and their competition with food production, initiatives will be enhanced for the development of next-generation biofuels including cellulosic and algae-derived fuels and for cost reductions. Although biofuel demand in ASEAN will increase sharply, biofuel consumption in Asia will fall short of rivalling U.S. or Brazilian levels. Biofuel consumption for international aviation and shipping, which is minimal at present except for automobiles, will expand in the future.

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



3.5 Power generation

Recent trends

Recovery of electricity demand

During the decade from 2010, global electricity demand grew at a rate of 3% per year, but in 2020, power generation declined by 0.9% year on year due to the spread of COVID-19. However, in the following year, 2021, the global economy recovered rapidly, resulting in a 6%

growth in power generation[7]. The largest contributor to this increase in power generation was increased demand in industry, followed by demand in the commercial and residential sectors.

In recent years, there has been a growing trend away from coal-fired power, but in 2021 its generation increased by 9% over the previous year. Factors behind this include, in addition to increased electricity demand, the fact that coal has become a competitive power source as a result of rising natural gas prices, mainly in Europe. Renewables continued to grow steadily, again with a 6% year on year increase. Natural gas and nuclear increased by 2% and 4%, respectively, returning to the pre-COVID levels of 2019.

Supply-demand crunch worsening

From 2021, the recovery of demand after the pandemic, severe cold and hot weather, and fuel supply disruptions have led to simultaneous multiple rises in electricity prices and supply-demand crunches in Japan, China, Europe, and other parts of the world.

In Japan, unusually cold weather boosted demand for electricity in January 2021. The supply-demand balance in the Asian LNG market tightened remarkably as cold waves and demand growth, amid an economic recovery, coincided with supply troubles in Australia and the United States. As a result, spot LNG prices shot up temporarily above $30/MBtu, forcing Japan's power supply-demand balance to tighten greatly. While no power outage was experienced, electric utilities urged consumers to reduce electricity consumption. Spot electricity prices on the Japan Electric Power eXchange (JEPX) hit a record JPY251/kWh. The recent spate of coal- and oil-fired power plant shutdowns and a drop in solar photovoltaic power generation due to bad weather also contributed to the tighter power supply-demand balance.

In China, in autumn 2021, limits on domestic coal production, restrictions on Australian coal imports and increased demand caused power shortages, resulting in rolling blackouts, sometimes without prior notice. This slowed mainly industrial production, hindering the recovery from the pandemic. In Brazil, an unprecedented drought caused a shortage of output from hydropower, which typically accounts for about 60% of power generation, and the resulting increase in thermal power generation caused electricity prices to skyrocket.

In Europe, a combination of bad weather that lowered the wind power capacity factor and increased demand, accompanied by soaring natural gas prices and lower inventories, caused electricity prices to surge, with Germany and Spain experiencing electricity prices more than triple the previous year's level. In the United Kingdom, steel mills and other plants were forced to suspend operations during peak demand periods.

Although these situations were attributable to weather conditions such as unprecedented cold temperatures and drought, there were other background factors such as fuel supply troubles for natural gas-fired power plants, reduced capacity factors of variable renewables and decreased dispatch power sources such as coal-fired power plants. These situations highlighted the need to secure stable power supplies in the process of low-carbonisation and decarbonisation of power sources.

[7] IEA, Electricity Market Report (2022)

Furthermore, in March 2022, sanctions were imposed following Russia's invasion of Ukraine, and concerns about disruptions to natural gas supplies exacerbated the power supply-demand crunch. These trends are leading to the reconsideration of both short- and long-term power supply plans, notably in Europe. For example, in July, Germany examined whether to continue operating three nuclear power plants that were originally scheduled to close at the end of 2022 due to concerns about natural gas supply disruptions. Also, in the United Kingdom, the Department for Business, Energy and Industrial Strategy (BEIS) required domestic power generators to extend the operation of coal-fired power plants scheduled to be decommissioned in 2022. As such, in the short term, there are moves toward securing alternative power generation facilities. In addition, the new REPowerEU Plan newly established for 2030 aims to reduce dependence on natural gas compared to the previous FIT for 55 package and to use coal-fired power, renewables and nuclear power.

Outlook

Power generation will rapidly increase in Asia

Over the long term, electricity consumption will resume its uptrend as the global economy recovers from the impacts of COVID-19 and the Ukraine situation. Global electricity generated will increase at an annual rate of 1.8% to 45 777 terawatt-hours (TWh) in 2050, a 1.7-fold rise from the 2020 level (Figure 3-11). The growth of 18 819 TWh through 2050 is 2.4 times the electricity currently generated in China, the largest power generator in the world, with 95% of the growth coming from Emerging Market and Developing Economies. Among these, electricity generated in the rapidly growing Asia will expand at an annual rate of 2.1% from 12 432 TWh in 2020 to 23 313 TWh in 2050, accounting for more than half of the global total (Figure 3-12).

Figure 3-11 | Global electricity generated and final consumption of electricity [Reference Scenario]

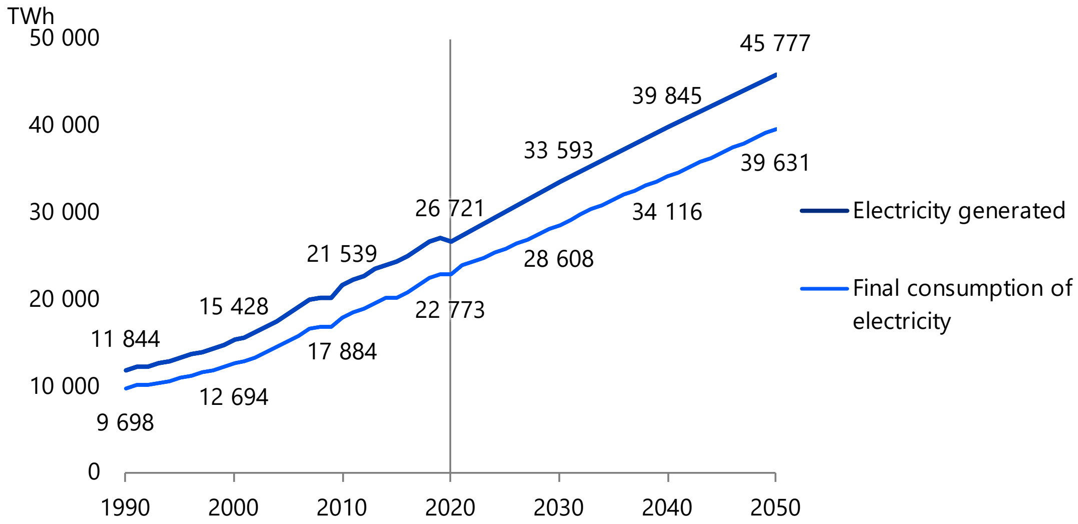
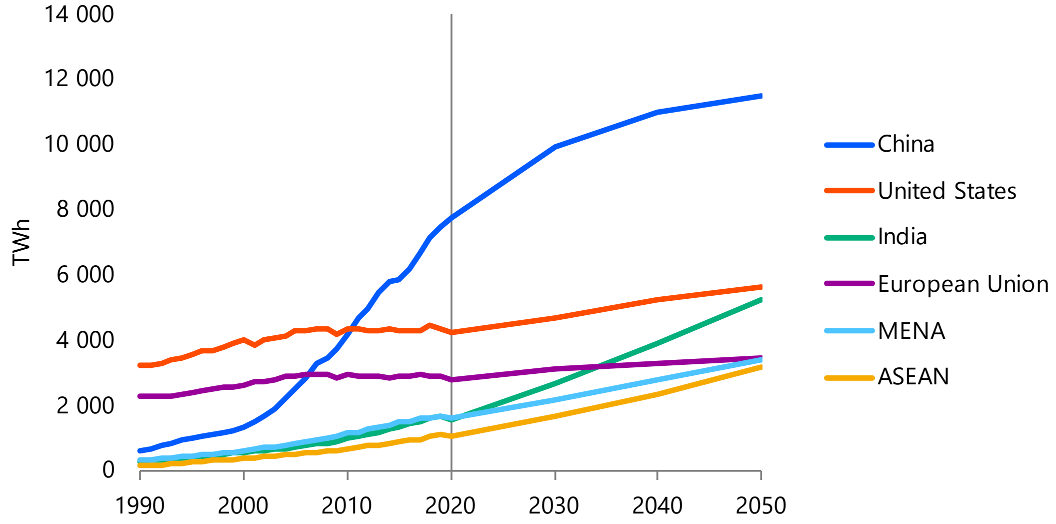


Figure 3-12 | Electricity generated in selected countries/regions [Reference Scenario]



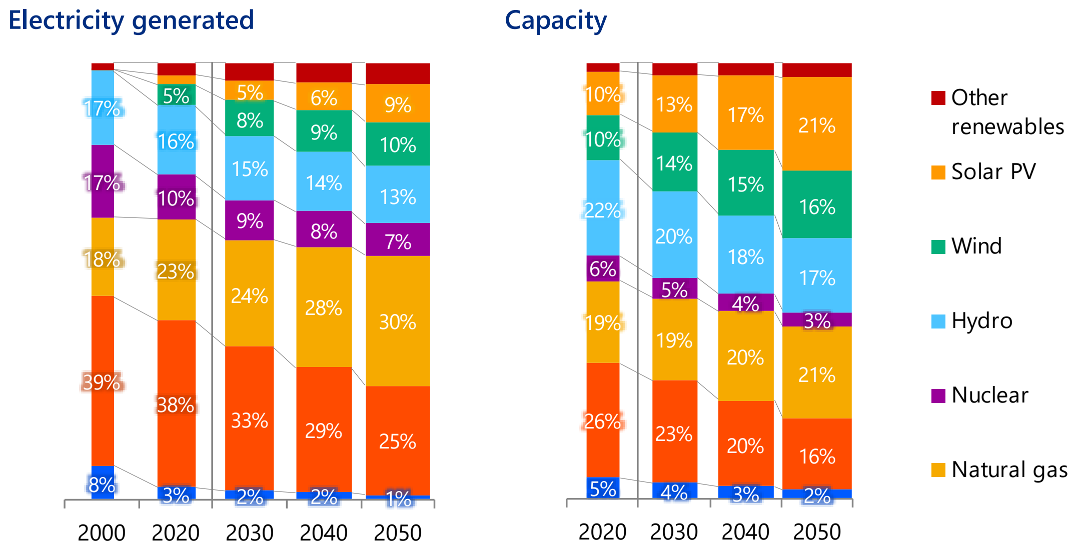
Power generation mix: Natural gas will become the largest power source

Coal now 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 3-13). Natural gas will continue to serve as both a base and peak power sources. Its role in balancing the power supply-demand will become even more important as variable renewable power generation expands. Currently, power generation is temporarily declining due to supply disruptions amid the Ukraine crisis and resulting price hikes. With stabilised supply, the need for dispatchable power sources due to less coal-fired power generation will boost the natural gas market share again toward 2030. Cheap and stable natural gas supplies will continue to be an important issue in the mid- to long-term regardless of whether it is in Advanced Economies or in the Emerging Market and Developing Economies.

Advanced Economies such as Italy, Canada, the United Kingdom, France and Germany have announced plans to phase out coal-fired power generation. In Emerging Market and Developing Economies, coal will lose share due to the introduction of natural gas and renewables, but continue to serve as a baseload power source. Because of high generation cost, oil-fired power will follow a downtrend not only in Advanced Economies but also in others, including the oil resource-rich Middle East.

Nuclear power plant construction will make progress mainly in Asia as a measure to ensure energy security and help mitigate climate change. However, the growth of nuclear power generation will fail to exceed that of electricity demand through 2050, leading the nuclear share of electricity generated to fall to 7% in 2050. Wind, solar photovoltaics, geothermal and other renewables generation will expand at a rapid annual rate of 5% on the strength of policy support and cost reduction, boosting its share in the power generation mix to 24% in 2050.

Figure 3-13 | Global power generation mix [Reference Scenario]



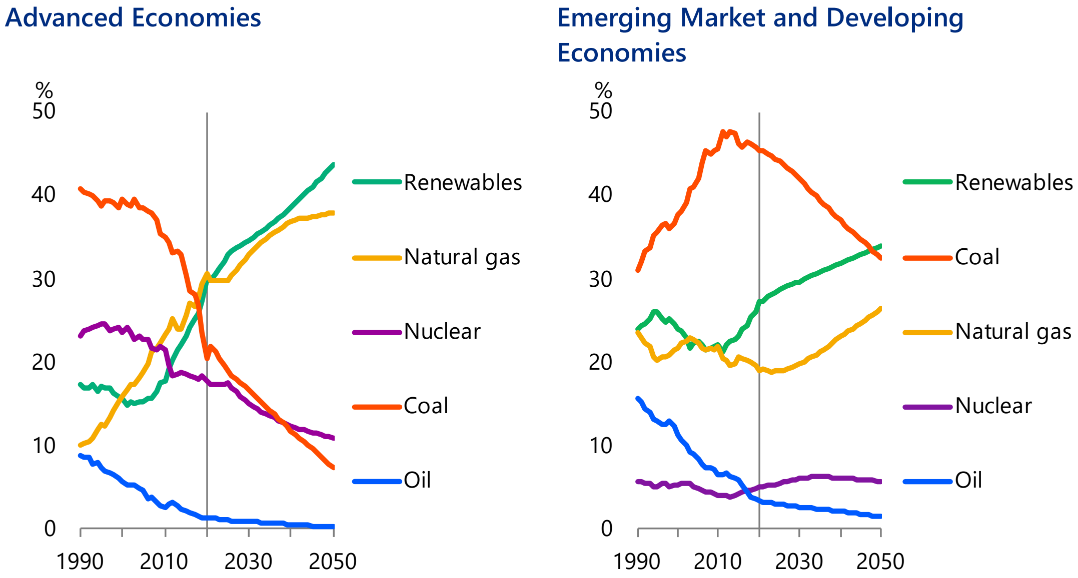
Note: Bar widths are proportionate to total electricity generated.

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

In Advanced Economies, the rapid introduction of renewables will cause them to overtake natural gas to become the largest power source by the early 2020s (Figure 3-14). The share of renewables in the total electricity generated will reach 35% in 2030 and 44% in 2050, among which output-variable solar photovoltaics and wind power will account for 25% of generation in 2050. Measures to cope with these output variations as well as the enhancement of grids that connect power generating areas to demand areas will be the challenges. Coal's share, which was the largest ten years ago, will substantially decline to 7% in 2050 under a policy of shifting away from coal-fired power generation in such countries as Canada and Italy and under a financial institutions' policy of refraining from making investments in and providing loans to coal-fired power generation projects. The installed capacity of thermal power including coal will account for 49% of the total power generation capacity in 2020, before dropping to 45% by 2050. The current issue of tight supply and demand of electricity due to decreased thermal power facilities will remain a major challenge for the future. Accordingly, while promoting the decarbonisation of all power sources, efforts are required to secure the necessary installed capacity, expand power storage facilities, and promote demand response.

In the Emerging Market and Developing Economies, renewables including wind will increase and replace coal as the largest power source by 2050. The share of coal, though falling, will remain the largest until the mid-2040s. As coal-fired power generation plays a great role in supporting robust electricity demand, the development of a highly predictable investment environment and solutions to air pollution and other environmental problems will be urgently required. Natural gas also continues to increase in both Advanced Economies and Emerging Market and Developing Economies, and securing a stable supply of natural gas remains both an urgent and long-term issue.

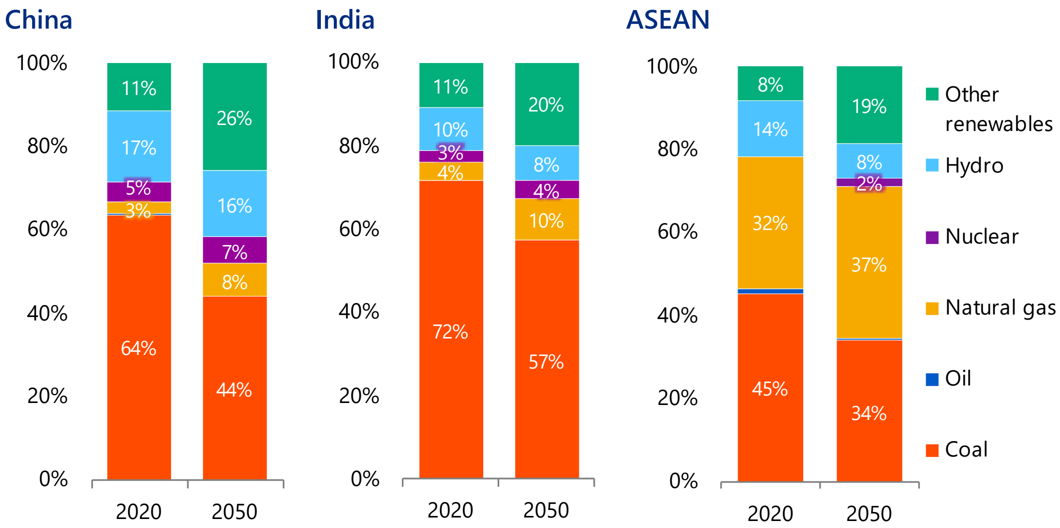
Figure 3-14 | Power generation mix in Advanced Economies and in Emerging Market and Developing Economies [Reference Scenario]



Coal's share of the generation mix will decline also in Asia but it will remain the largest power source; how to address environmental problems will be a challenge

In Asia, coal-fired power generation currently accounts for a large share, but future trends will vary depending on each country. In India, coal will still account for most of the electricity generated in 2050. Coal's share in China will decline due to national policies to expand renewable energy, and in ASEAN, namely Thailand and Viet Nam, it will decline due to policies to phase out coal-fired power. ASEAN will expand natural gas-fired and renewable power generation capacity to meet the growth in electricity demand (Figure 3-15).

Figure 3-15 | Chinese, Indian and ASEAN power generation mix [Reference Scenario]

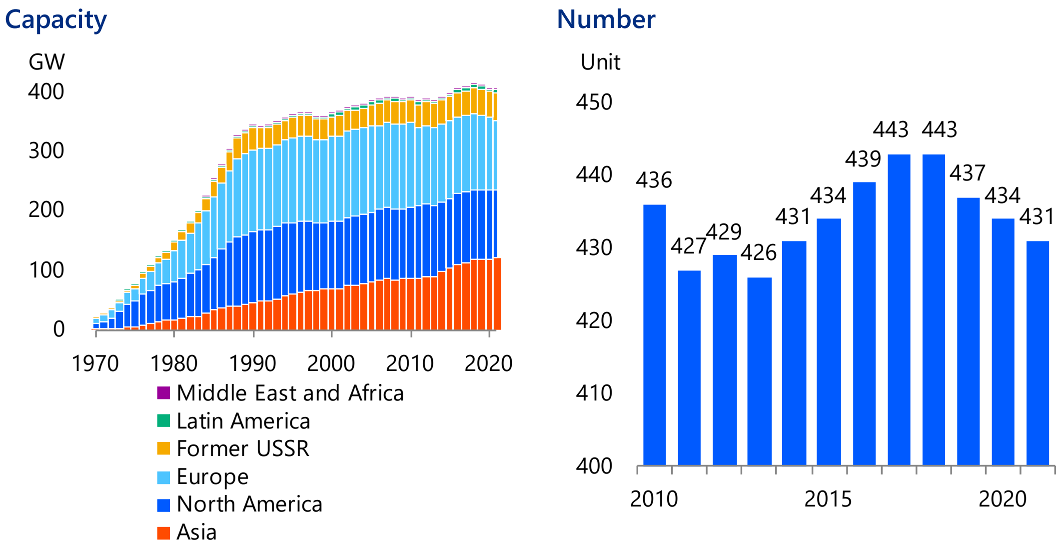


Nuclear

Russia's ambitious export plans continue: Can western countries regain the upper hand?

Global installed nuclear power generation capacity and the number of nuclear reactors in the world increased from 2014 to 2018 but slightly declined for three consecutive years from 2019 to 2021 (Figure 3-16). This was due mainly to successive closures resulting from the ageing of existing reactors and deteriorating economics, particularly in Europe and the United States. Meanwhile, in China and Russia, new construction plans are proceeding relatively smoothly, highlighting the dominance of the two countries in the world's new construction market. In particular, Russia is an ambitious exporter of nuclear power. Following Russia's invasion of Ukraine in February 2022, Finland terminated new construction contracts with Russian companies, while Russian reactors are being deployed in China, Türkiye, Iran, India, and Bangladesh. In July 2022, construction of Egypt's first nuclear power plant began. Meanwhile, in Europe and the United States, new nuclear power plant construction projects have been postponed or frozen, highlighting the urgent need to reform fundraising and project management arrangements to regain market dominance.

Figure 3-16 | Capacity and number of nuclear reactors



In Europe and the United States, there has been a widespread movement toward the effective use of existing reactors. In the United States, many reactors have operated for more than 40 years and been allowed by the Nuclear Regulatory Commission (NRC) to operate for 20 more years (a total of 60 years). Some reactors have been subjected to the second licence renewal approval to operate for a total of 80 years. In France as well, the Nuclear Safety Authority, Autorité de sûreté nucléaire (ASN) has clarified rules for the extended operation of nuclear reactors that have operated for more than 40 years, paving the way for reactors to operate longer.

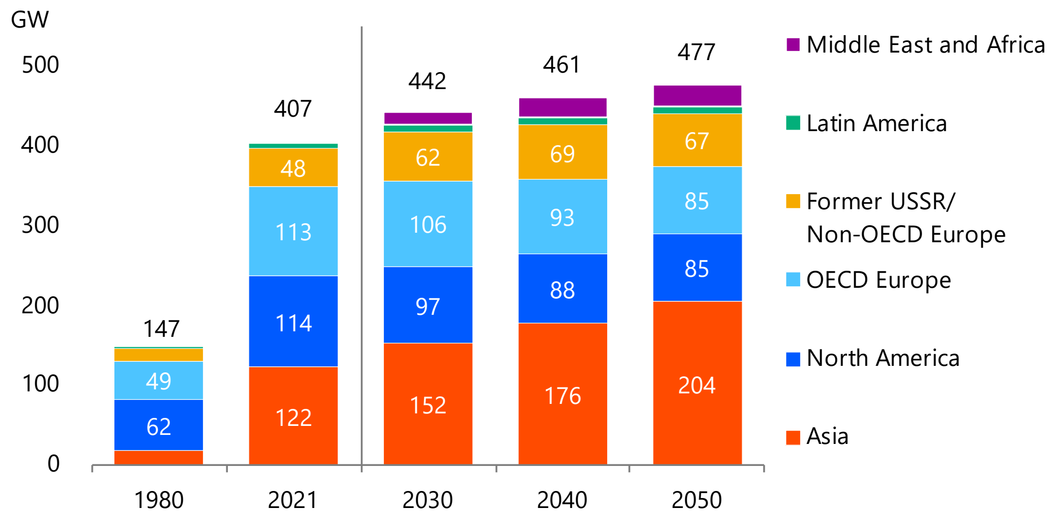
In addition to these trends, efforts have recently been made to clarify the policies for new construction projects. In February 2022, before the invasion of Ukraine, France announced its energy policy to achieve carbon neutrality by 2050, which included the construction of at least six (and up to eight more) new model European Pressurised Water Reactors (EPR 2). The United Kingdom, in its energy security strategy announced in April 2022 in response to the invasion of Ukraine, set a goal of installing up to 24 GW of nuclear capacity by 2050 to cover 25% of its electricity supply. Behind this trend is not only the desire for low-carbon power sources as a climate change countermeasure, but also the recent global surge in fossil fuel prices and reduced dependence on Russia. However, since new construction projects in Europe and the United States have been largely delayed or abandoned in recent years, making good use of the lessons learned from these failures will enable these countries to ride the recent “tailwind”.

Attracting attention in recent years is the progress that has been made in the development of new nuclear reactors such as small modular reactors (SMRs) and generation IV reactors. In the United States, taking over from the former Trump Administration, the Biden Administration has launched aggressive support measures, while in the United Kingdom, the SMR consortium led by Rolls-Royce requested, in March 2022, the Office for Nuclear Regulation (ONR) to quickly start its design certification reviews. Meanwhile in China, the construction of demonstration reactors including fast reactors and SMRs is underway. In Russia, the offshore floating reactor has already started operation and the country is also planning to launch a land-based SMR scheduled to start operation in 2028.

Outlook: Nuclear will increase in Asia and continue to be used as a key low-carbon, stable power source in Europe and the United States

As the Fukushima Daiichi Nuclear Power Station accident triggered changes in public opinion about nuclear, some nuclear power plant construction knowhow has been lost during the long absence of such construction. It is now difficult for Japan, Europe and the United States to construct new nuclear reactors as planned earlier. As existing reactors built in the 1970s or 1980s are closing, nuclear power generation may decrease in many countries. Given that competitive nuclear reactors are important low-carbon baseload power sources and contributors to energy security, serving as business resources for electric power companies, these countries will maintain nuclear power generation to some extent. In contrast, many countries including China are planning to promote nuclear energy while Middle Eastern and some other countries may start nuclear power generation in the future. Therefore, global installed nuclear power generation capacity will gradually increase through 2050 (Figure 3-17).

Figure 3-17 | Installed nuclear power generation capacity [Reference Scenario]



The United States, though being the world's largest nuclear power generating country with 93 reactors, includes states where decisions have been taken to close existing reactors earlier than planned for economic reasons. Under electricity market liberalisation, nuclear power plants are exposed to competition from natural gas-fired and renewable energy power plants. Although the installed capacity will decline through 2050, the United States will make no change to its policy of positioning nuclear as an important energy source. The Biden Administration is seeking to realise net-zero GHG emissions by 2050, recognising the significance of nuclear power generation as one of the means to do so. Both Democrats and Republicans have admitted the importance of nuclear energy, and thus there is little chance that the United States will change its nuclear business policy. In this situation, decisions to extend the lifespan of nuclear power plants and construct new ones will be made, depending on electricity market conditions and the investment climate. The federal government and some states plan to take measures to support economically distressed reactors, limiting the early closure of existing nuclear reactors.

In France, known as the largest nuclear energy promoter in Europe, the Energy Transition Law, enacted in July 2015, aimed at reducing the nuclear's share of power generation to 50% by 2025 (from around 75% in 2015). In view of its GHG emission reduction goal, however, France has concluded that it is difficult to attain this reduced target for nuclear power and decided to extend the target year to 2035. Therefore, France may maintain the present nuclear power generation capacity or slightly reduce the capacity in the immediate future as the closure of some reactors coincides with the construction of new ones. As mentioned earlier, France declared the construction of at least six new reactors (and up to eight more) in February 2022, but after 2035, decommissioning of existing reactors will accelerate due to ageing, leading to a continued decline of nuclear power overall. In the meantime, as initiatives have been taken to pave the way for reactors to operate longer, electric utilities will consider the balance between nuclear and renewables power generation and maintain nuclear power generation capacity provided profitability is secured.

In the United Kingdom, the government has indicated a policy of maintaining nuclear power, but the installed nuclear power generation capacity will decline until around 2030 due to decommissioning of outdated reactors. On the other hand, although there was a case recently where Horizon Nuclear Power's project was held up, a new construction project is planned based on the energy security strategy. Thanks to such efforts, nuclear power generation capacity may recover to nearly the current level by around 2045.

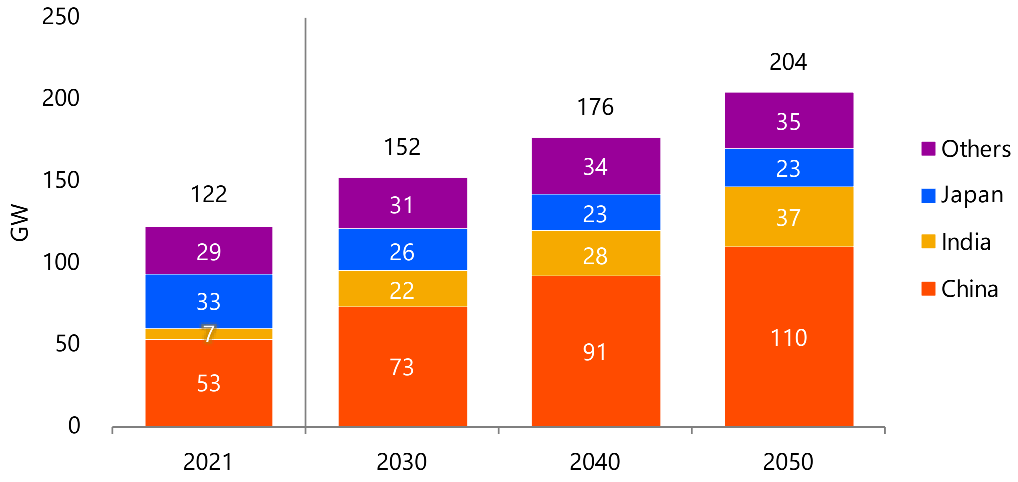
Switzerland has made clear their nuclear phase-out plans in response to the Fukushima Daiichi accident and will cease nuclear power generation by 2035 under the government's decommissioning plan. Belgium had also planned to close all of its reactors by 2025, but has decided to extend the operation periods of at least two reactors by 10 years considering the recent situation, delaying its nuclear power phase-out. Germany had planned to close all its reactors by the end of 2022, but recently announced a policy of maintaining two reactors as reserve power until April 2023 to ensure a stable power supply during the winter season. These decisions, however, will not significantly affect the long-term outlook. Other OECD European countries will reduce their capacity through 2050, despite some moves to construct new capacity, as unprofitable reactors are being decommissioned.

Russia has vowed to proactively use nuclear energy at home and abroad. Its domestic installed nuclear power generation capacity will increase from 30 GW in 2021 to 45 GW in 2035. Around 2030, Russia will replace Japan as the world's fourth largest nuclear power generation capacity owner. Given its proactive nuclear reactor exports, its presence in the global nuclear energy market will be greater than indicated by its domestic capacity. Russia has not only promoted the use of its existing large light-water reactors but also introduced the world's first floating nuclear power station as noted above. 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 energy industry.

From 2030, Middle Eastern, African, Latin American and other countries, which have so far developed little nuclear power generation capacity, will rise as nuclear power generators. The United Arab Emirates, Saudi Arabia and Iran will lead the Middle East and raise the region's installed nuclear power generation capacity to 22 GW by 2050. In Latin America, mainly Brazil and Argentina are planning to introduce nuclear power generation to satisfy the growing domestic electricity demand and will construct a few nuclear power plants.

The presence of Asia, especially China and India, will increase further also in the nuclear power field. Emerging Market and Developing Economies in Asia, which are experiencing remarkable economic growth, are highly motivated to introduce nuclear energy which is low-carbon and a stable large-scale power source. China will boost its installed nuclear power generation capacity to 82 GW in 2035, replacing the United States as the largest nuclear power generator in the world (Figure 3-18). Asia's installed nuclear power generation capacity will surpass the combined OECD Europe and North American capacity around 2045, reaching 204 GW in 2050. China and India combined will account for more than 70% of Asia's capacity.

Figure 3-18 | Asia's installed nuclear power generation capacity [Reference Scenario]



Renewables

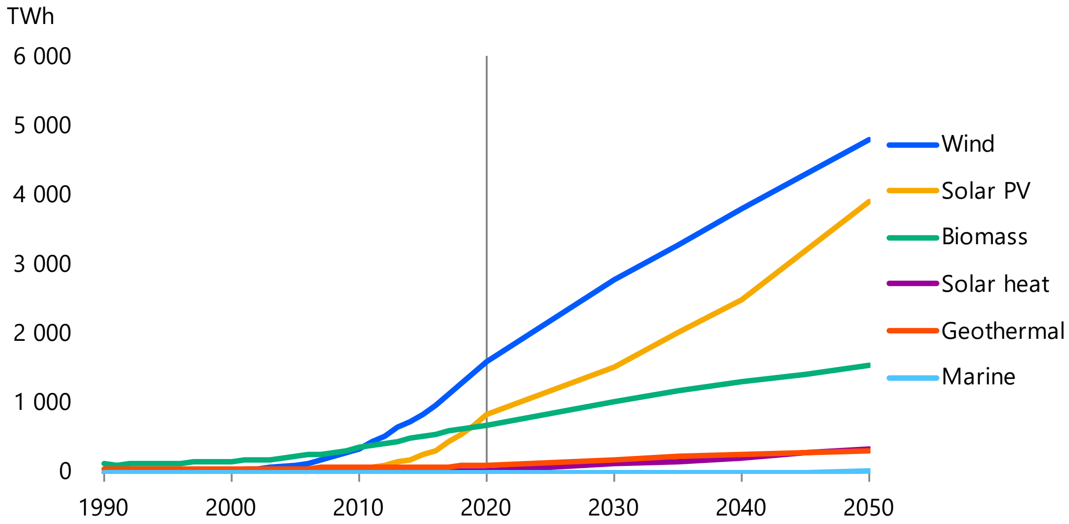
Great hopes are placed globally on renewable energy. Since the mid-2000s, variable renewable energy power sources such as wind and solar photovoltaics (PVs) have remarkably increased due to cost drops as well as incentive policies mainly in major European countries, Japan, the United States and China. As the economic efficiency of renewables power generation has improved, governments have accelerated efforts to modify or scale down their incentive policies for wind and solar PV power generation in recent years. On the other hand, the number of economies committing to long-term carbon neutrality goals has increased, paving the way for the further diffusion of renewables.

Table 3-6 | Goals for introducing renewables in major 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	45% share of renewables in final energy consumption by 2030 REPowerEU Plan, review of Renewable Energy Directive (passed by the European Parliament in September 2022, negotiations with Member States ongoing) (European Commission, European Parliament)
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 be increased to 25% by 2030 (including 1 200 GW of installed wind and solar photovoltaic power generation capacity) 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 from renewables by 2025 ASEAN Plan of Action and Energy Cooperation Phase II, announced in November 2020 (adopted at the 38th ASEAN Senior Officials of Meeting on Energy)

Electricity generated from variable renewables will increase from 2 437 TWh in 2020 to 9 067 TWh in 2050 (Figure 3-19). Variable renewables will boost their share of global power generation from 9.4% in 2020 to 20% in 2050, increasing their presence in the electricity system.

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



Europe, China and North America are currently major wind power generating markets and they will continuously drive the growth of wind power generation (Figure 3-20). Global installed wind power generation capacity will more than triple from 731 GW in 2020 to 2 243 GW in 2050. Onshore wind power will increase but at a slower pace due to issues concerning transmission line constraints and fewer suitable development sites. Meanwhile, offshore wind power, the business potential of which has been improving in recent years, will contribute to the expansion. Installed offshore wind power generation capacity in the world increased from 3 GW in 2010 to 34 GW in 2020[8]. Europe is the world's most mature offshore wind power generation market, with supply chains developed for wind farms. In recent years, bids have been invited for unsubsidised offshore wind power generation projects, with successful bidders' electricity sales prices falling close to $50/MWh (for projects to commence power generation in or after 2025). In the United States as well, many offshore wind power generation projects are being implemented. In March 2021, the Biden Administration announced a plan to expand offshore wind power generation capacity to 30 GW by 2030. In Asia, the rapid growth of the offshore wind power generation markets in China, Chinese Taipei, Korea and Viet Nam are attracting attention. In Japan, the development of offshore projects has been stimulated by the enactment of the Maritime Renewable Energy Resources Act[9] in April 2019. The government is proactively supporting the enhancement of relevant domestic supply chains and the development of domestic industries, while expanding the introduction of offshore wind power generation. Global installed offshore wind power generation capacity will increase more than five-fold from 34 GW in 2020 to 179 GW in 2050.

[8] International Energy Agency, *Offshore Wind Outlook 2019*, 2019, https://www.iea.org/reports/offshore-wind-outlook-2019

[9] Act on Promoting the Utilization of Sea Areas for the Development of Marine Renewable Energy Power Generation Facilities

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

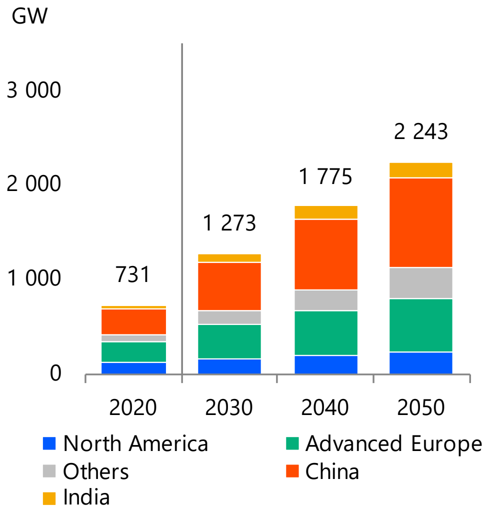
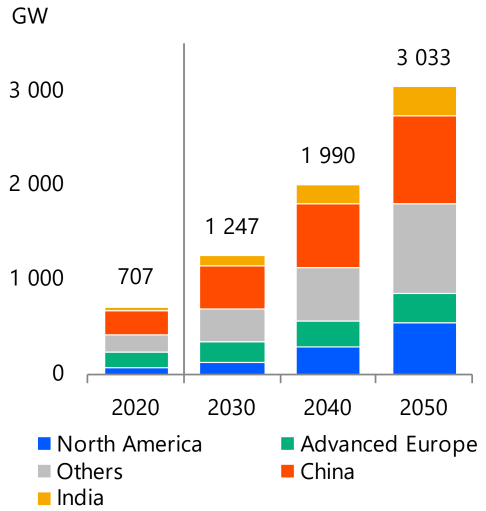


Figure 3-21 | Global solar PV power generation capacity [Reference Scenario]



With robust subsidisation policies, solar PV power generation has spread from Europe, the United States, China and Japan to the rest of the world, thanks to substantial cost drops (Figure 3-21). In large-scale solar PV auctions in Chile, the United Arab Emirates, Saudi Arabia and other countries with much solar radiation, bid prices of less than $10/MWh have been recorded. Costs for distributed solar PV power generation systems installed at urban housing and commercial facilities have fallen to grid parity levels, competing with electricity retail prices. The competitiveness of solar PVs is expected to continue to rise in the future. Global installed solar PV power generation capacity will increase more than four-fold from 707 GW in 2020 to 3 033 GW in 2050. As costs continue to fall over the long term, global net capacity growth will accelerate greatly in the second half of the outlook period, reaching 1 043 GW between 2040 and 2050.

The use of renewable energy will contribute to reduced carbon emissions from power supply, lower dependence on foreign energy sources and improved resilience of energy systems. Renewable energy sources will continue to increase robustly. Given that the electrification of final energy demand will make further progress to realise long-term climate change targets, the decarbonisation of electricity sources will grow even more important. Renewable energy power generation must spread more than is assumed in the Reference Scenario. As awareness of climate change solutions is increasing worldwide, more and more private companies intend to procure renewables. As of 2021, 315 companies have joined RE100, an international initiative that aims to provide 100% of electricity consumed from renewables, and the total electricity consumption of these companies was 340 TWh (as of 2021), equivalent to the power consumed in the United Kingdom[10]. RE100 companies have business hubs globally, thus playing a role in expanding renewable energy installations around the world. At a time when renewables power generation is growing more independent, there is a growing need to establish systems and

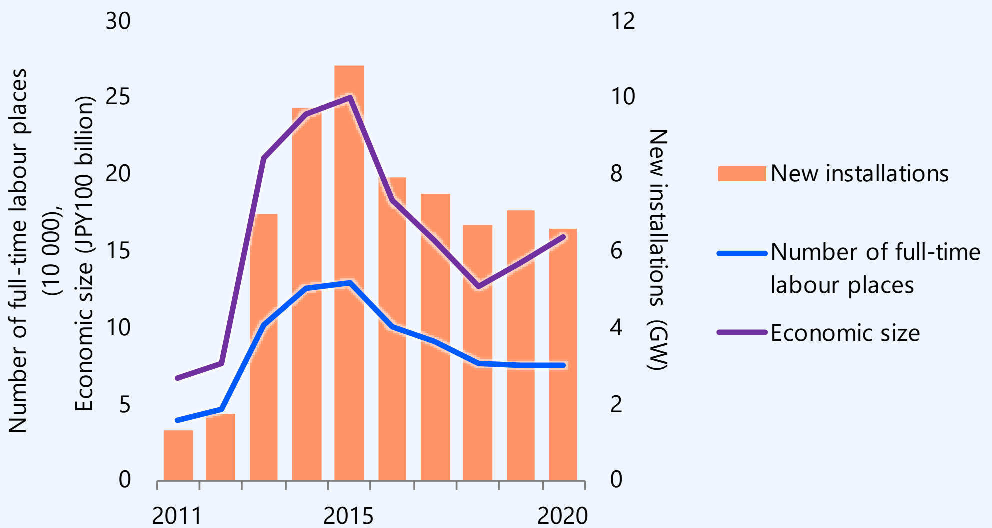
[10] RE100 "RE100 Annual Disclosure Report 2021 – Stepping up: RE100 gathers speed in challenging markets" (January 2022), https://www.there100.org/stepping-re100-gathers-speed-challenging-markets

markets that would allow consumers to sign direct power purchase agreements (PPAs) with generators. Renewables' harmony with energy and social systems will also become a key challenge. To achieve such harmony, variable renewables should be coupled with technologies and institutions for integrating them into the electricity system. Policy guidance should be promoted for developing projects to benefit communities that accept renewables power generation facilities. Offshore wind and geothermal power generation should be considered in light of environmental protection and career training should be provided to promote employment in the renewable energy field.

Box 3-1 | How to address the growing dependence on overseas producers of solar PV power equipment

Since 2012, when Japan introduced a feed-in tariff (FIT) for renewables, the amount of solar PV power generation has increased rapidly. Although the installations have stalled in the last few years, the economic size (sales) and the number of people employed in the solar PV power industry have increased along with the growth of the market (Figure 3-22). Increased deployment of renewables has a positive impact on the economy and contributes to reducing the consumption and imports of fossil fuels such as LNG. On the other hand, there are also issues caused by the increased import share of related equipment. In Japan, domestically produced solar PV panels accounted for almost 100% of domestic use until FY2008, but they began to decline in FY2009, reaching only 16% in FY2020 (Figure 3-23).

Figure 3-22 | Economic scale of Japan's solar PV industry, employment, and annual PV installations

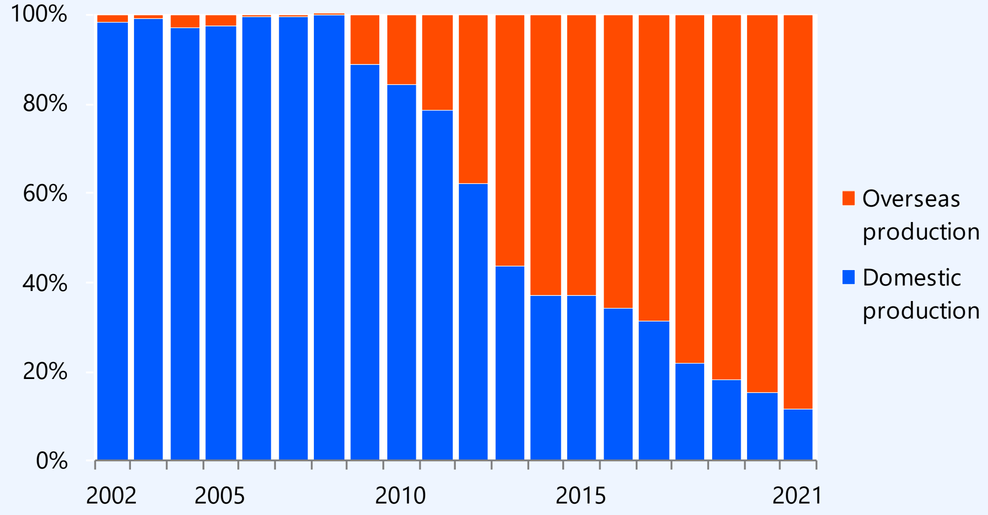


Sources: International Energy Agency, Photovoltaic Power Systems Programme (economic scale and employment)[11]; International Renewable Energy Agency (annual installations)[12]

[11] IEA PVPS, National Survey Report, https://iea-pvps.org/national-survey-reports/?year_p=&country=&order=DESC&keyword=Japan

[12] IRENA, Renewable Electricity Capacity and Generation Statistics, https://www.irena.org/Statistics

Figure 3-23 | Composition of domestic shipments of solar PV panels in Japan



Sources: "Energy White Paper", Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry[13], Japan Photovoltaic Energy Association

Globally, the production of solar PV panels is highly dependent on China. China accounts for more than 80% of all stages of solar PV panel manufacturing including polysilicon, ingots, wafers, cells, and modules/panels[14]. Considering disclosed plans to expand production capacity, China's share is likely to increase even further in the future. It is true that China has made a significant contribution to reducing the cost of solar PV equipment in the world, however, excessive dependence of a supply chain on specific countries is a potential risk to the stable supply of products in the future. There are increased concerns about product supply disruptions caused by infectious diseases, disasters, diplomatic issues and other factors, as well as price controls.

Global solar PV installed capacity was 710 GW at the end of 2020, rising to 1 247 GW in 2030 and 3 033 GW in 2050 under the Reference Scenario. To achieve carbon neutrality, further expansion of solar PVs will be required. This will contribute to the expansion of green investment and green employment, but in view of energy security, it is also important to strengthen the solar PV supply chain.

To achieve this, Japan must first reinforce its domestic manufacturing of solar PV power generation facilities, as in the case of semiconductors. Since solar PV panels made in China are price-competitive, government support is needed to ensure the profitability of manufacturers of solar PV-related products. For example, measures could include subsidies for the cost of electricity which accounts for a large part of the production costs of key elements of solar PV panels such as polysilicon, wafers, and ingots. Other measures

[13] Ministry of Economy, Trade and Industry, "Annual Report on Energy in FY2021" (Energy White Paper 2022), https://www.enecho.meti.go.jp/about/whitepaper/2022/html/2-1-3.html

[14] IEA (2022), "Special Report on Solar PV Global Supply Chains"

could include tax incentive policies for land use for larger production plants, which are required to improve investment efficiency.

To foster the solar PV industry for the future, support is also necessary for the development of next-generation solar PV technologies and demonstrations for their social implementation. Solar PV power generation is included as one of the priority areas for support in the JPY2 trillion Green Innovation Fund that the Japanese government created to achieve the 2050 carbon neutrality goal. A total of JPY20 billion will be provided from FY2021 to FY2025 to support projects that aim to commercialise perovskite solar cells[15]. These cells are characterised by low weight, allowing them to be installed in low load-bearing areas, and the flexibility to fit curved surfaces, while having the potential to rival existing solar cells in terms of conversion efficiency. There are high hopes for the practical application and expanded use of this technology, but there are also some pitfalls. For example, although Japanese researchers invented and developed the products in 2009, overseas patents were not obtained and in 2022, a Chinese start-up company commenced the world's first mass production of the products. This reality illustrates the need for government support not only for research and development but also for fundamental intellectual property management in order to commercialise domestically developed technologies in Japan and capture global market share.

Next, in order to strengthen domestic production, the development and commercialisation of technology for recycling solar PV panels are also required. It would reduce dependence on imports, as in the case of critical minerals, if technologies could be developed to separate glasses and metals from used equipment to appropriately recycle them.

While it is important to somehow expand domestic production of hardware, from another perspective a strategy to capture domestic and overseas markets in regard to software is also possible. In other words, to cope with the growing market share of foreign-made solar PV panels, domestic manufacturers could aim to shift their strategy from providing products and components to providing solutions. Solutions might include, for example, providing Net Zero Energy House (ZEH) systems equipped with solar PV panels, storage batteries, home energy management systems (HEMSs), etc. Other examples include PPA[16] businesses for consumers that could be developed by domestic solar PV manufacturers collaborating with electric power companies and trading companies. It is also important in the future to explore the domestic and global deployment of systems that combine these types of solar PV power generation equipment with storage batteries and Internet of Things (IoT) technology.

[15] New Energy and Industrial Technology Development Organization (NEDO), Green Innovation Fund Project to develop next-generation solar cells, https://www.nedo.go.jp/news/press/AA5_101501.html
[16] Direct power sales contracts by power producers to consumers

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 acceptability to society. Each country and region will actively implement aggressive energy efficiency and decarbonisation policies that contribute to securing a stable energy supply, enhancing climate change measures, and accelerating the development and introduction of innovative technologies globally. Supported by the introduction of environmental regulations and national targets, by the enhancement of technological development and by the promotion of international technological cooperation, the demand side will actively diffuse energy efficient equipment and the supply side will further promote renewables, nuclear energy, hydrogen and carbon capture and storage (CCS) (Table 4-1). Note that this outlook is a forecast-type analysis, calculated based on assumptions such as the introduction of technologies, not a backcast-type analysis, which first sets a future "landing point" and then charts a path to get there.

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

2020 → 2050 (Reference 2050)

	Advanced Economies	Emerging Market and Developing Economies
Thermal power generation	Developing an initial investment finance scheme	
	Installing CCS for new plants from 2030 (Countries with carbon storage potential excluding aquifers)	
[Natural gas-fired efficiency (stock basis)]	50.0% → 62.1% (60.8%)	38.2% → 56.5% (48.6%)
[Coal-fired efficiency (stock basis)]	37.3% → 38.5% (42.8%)	34.0% → 39.4% (39.2%)
[IGCC share of newly installed plants]	0% → 60% (20%)	
Nuclear power generation	Maintaining appropriate wholesale power prices	Developing an initial investment finance framework
[Capacity]	2020年: 294 GW → 309 (208)	2020年: 113 GW → 458 (269)

2020 → 2050 (Reference 2050)

	Advanced Economies	Emerging Market and Developing Economies
Renewables power generation	System cost reduction	
	Grid stabilisation technology cost reduction	Low-cost finance
	Efficient grid operation	Advancing power systems
[Wind capacity]	358 GW → 1 559 (870)	374 GW → 2 901 (1 373)
[Solar PV capacity]	340 GW → 2 339 (1 089)	368 GW → 3 675 (1 944)
Biofuels for automobiles	Developing next-generation biofuels	Biofuel cost reduction
	Diffusing flexible-fuel vehicles	Agricultural policy position
[Consumption]	54 Mtoe → 87 (64)	36 Mtoe → 88 (62)
Industry	Full diffusion of best available technologies in 2050	
Transport	Reducing fuel-efficient vehicle costs	
	Doubling zero-emission vehicle (ZEV) travel distances	
[New passenger car fuel efficiency]	16.1 km/L → 49.6 (33.0)	13.9 km/L → 37.4 (24.9)
[ZEV share of new passenger car sales]	3.5% → 78.3% (50.5%)	2.4% → 63.0% (34.4%)
Buildings	Improving efficiency and insulation efficiency of new and newly constructed appliances and equipment	
	Doubling improvement speed (approx. 15% improvement from Reference Scenario in 2050)	
	Electrifying space/water heating and cooking equipment, clean cooking	

Box 4-1 | Factoring hydrogen into Advanced Technologies Scenario

The Advanced Technologies Scenario in the IEEJ Outlook 2023 incorporates the full-scale introduction of hydrogen. The introduction of hydrogen is assumed to be appropriate for the Advanced Technologies Scenario as one of the decarbonisation technologies in the Circular Carbon Economy/4Rs Scenario described in the IEEJ Outlook 2022 (Table 4-2).

In the assumptions, conditions for the introduction of technologies were carefully determined according to the current situation in each country and region. Hydrogen for power generation was assumed to be used separately as hydrogen itself and as ammonia. Synthetic methane and synthetic fuels (E-fuel), one of the carbon recycling technologies, were assumed to be introduced, especially in Advanced Economies, as a promising decarbonisation measure in applications where electrification remains difficult as of 2050.

Table 4-2 | Assumptions for introducing hydrogen technologies

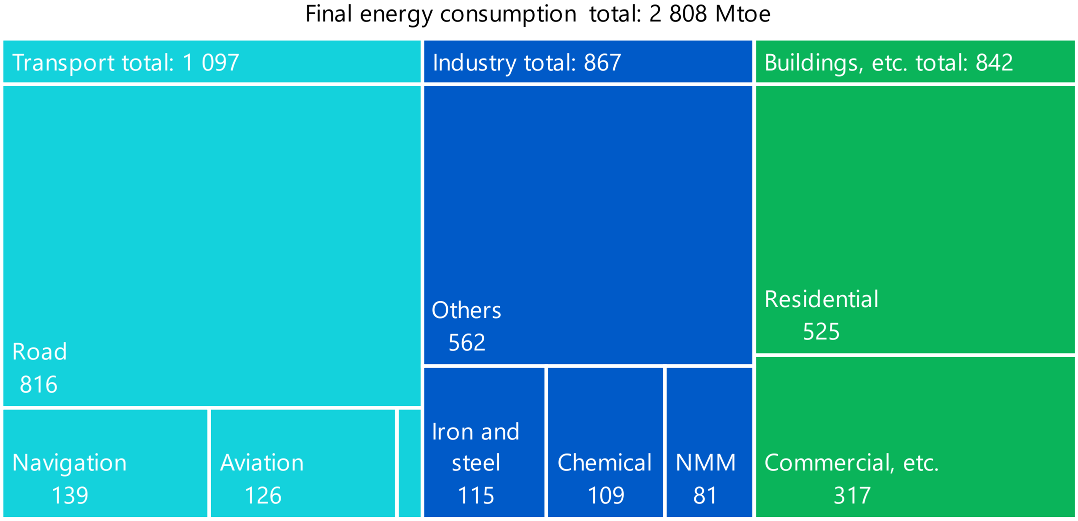
Technology assumed in the scenario	Details of assumption
Hydrogen use in the power generation sector	Introduce hydrogen-fired power generation (including ammonia-fired) in 30%–50% of coal-fired and gas-fired power generation without CCS by 2050.
Hydrogen use in the transport sector	Replace 5% to 10% of road sector transport energy demand to hydrogen in 2050 in Advanced Economies and countries with abundant domestic hydrogen supplies.
Hydrogen use in the industry sector	Replace 20% of industrial energy demand to hydrogen in 2050 in Advanced Economies and countries with abundant domestic hydrogen supplies.
Hydrogen direct reduction in steelmaking	Introduce hydrogen direct reduction technology using blue hydrogen for 10% of crude steel production in Advanced Economies and 5% of crude steel production in China and India in 2050.
Hydrogen use in buildings sector	Replace 10% of energy demand for buildings sector to hydrogen in Advanced Economies in 2050.
Synthetic methane	Replace 10% of industrial and buildings energy demand by synthetic methane in Advanced Economies in 2050.
Synthetic fuels	Replace 10% of transport energy demand by synthetic fuels in Advanced Economies in 2050.
Carbon capture and storage	Additionally implement CCS required for blue hydrogen production.

Energy efficiency

Final energy consumption in the Advanced Technologies Scenario will be 567 million tonnes of oil equivalent (Mtoe) or 5.2% less in 2030 and 2 808 Mtoe or 23.5% less in 2050 than in the Reference Scenario. Savings in final energy consumption in 2050 are equivalent to 29% of final energy consumption in 2020. Of the energy savings, the transport sector will account for 1 097 Mtoe, the industry sector for 867 Mtoe and the buildings sector for 842 Mtoe (Figure 4-1).

The road sector will be responsible for 816 Mtoe in the transport sector and the residential sector for 525 Mtoe in the buildings, etc. sector. This is because vehicles and energy-consuming home appliances offer huge potential for improving energy efficiency. The Emerging Market 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 Market and Developing Economies actually realise the potential energy savings is key to the progress of global energy savings.

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



Note: NMM stands for Non-metallic minerals.

By using already available high-efficiency technologies for steel, cement, chemical, pulp and paper, and other energy-intensive industries, these industries will improve their energy intensity in 2030 by 2%–3% from the Reference Scenario, and by a further 20%–24% in 2050 due to the faster expansion of highly efficient technologies (Table 4-3). Through energy intensity improvements, the Emerging Market and Developing Economies' industry sector will reduce energy consumption by 697 Mtoe from the Reference Scenario. Asia, where basic materials industries account for a large share of production, will account for about 60% of the global energy savings. The introduction of highly efficient technologies will make great contributions to improving energy efficiency in the Emerging Market and Developing Economies. It is hoped that energy efficiency improvement technologies will be developed and proactively diffused globally including in the Emerging Market and Developing Economies.

In the transport sector, fuel efficiency and vehicle fleet mix improvements will make further progress. By type of vehicle, in addition to hybrid vehicles, electric, plug-in hybrid and fuel cell vehicles will diffuse further. These zero-emission vehicles (ZEVs) will expand their share of new vehicle sales by 13 percentage points in 2030 and 25 points in 2050 from the Reference Scenario. Due to fuel efficiency and vehicle fleet mix improvements, the global average new vehicle fuel efficiency in 2050 will improve by 13.4 km/L from the Reference Scenario to 39.9 km/L (2.5 L/100 km). The transport sector will post the largest energy savings among sectors in the Advanced Economies as ZEVs' share of the vehicle fleet mix in those economies increases faster than in the Emerging Market and Developing Economies. International bunkers will make progress in energy conservation through technological innovation and operational improvements. At the same time, given their great potential to switch fuels, natural gas will account for 9.2% of international marine bunkers in 2030 and 43% in 2050. In international aviation, the share of biofuel will be 5.3% in 2030 and 27% in 2050.

Table 4-3 | World energy indicators

			Reference		Adv. Tech.	
		2020	2030	2050	2030	2050
Industry	Intensities (2020=100)					
	Iron and steel	100	94.3	78.9	92.8	62.7
	Non-metallic minerals	100	93.4	82.0	90.4	62.7
	Chemical	100	95.0	79.6	92.9	60.4
	Paper and pulp	100	95.8	87.8	92.7	68.2
	Other industries	100	91.9	71.7	89.4	54.0
Transport	New passenger vehicle fuel efficiency (km/L)	14.7	18.4	26.5	23.6	39.9
	ZEVs' share of vehicle sales	2.3%	12%	33%	25%	59%
	Natural gas's share in intl. marine bunkers	0.1%	5.4%	22%	9.2%	43%
	Biofuel's share of intl. aviation bunkers	0.0%	1.0%	6.8%	5.3%	27%
Buildings	Overall energy efficiency (2020 = 100)					
	Residential	100	84.2	62.1	77.3	46.5
	Commercial	100	77.2	46.3	75.0	37.9
	Electrification rate					
	Residential	26%	31%	47%	35%	63%
	Commercial	55%	60%	71%	62%	84%

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

It is more difficult for energy conservation incentives to work in the buildings sector than in the industry sector that is highly conscious of energy conservation for economic reasons. Therefore, the buildings sector has great potential to reduce energy consumption. The overall global residential energy efficiency will improve by 8% in 2030 and by 25% in 2050 from the Reference Scenario. In addition, the overall efficiency of commercial sector will improve by 3% in 2030 and 18% in 2050. Energy efficiency improvements for space and water heating systems in cold regions and insulation improvements in the Emerging Market and Developing Economies will make great contributions to saving energy. Since city gas, liquefied petroleum gas, kerosene and other fuels are used for water and space heating in various ways depending on national conditions, fuel consumption for these applications will be greatly reduced. Traditional biomass consumption including inefficient fuel wood and manure will be most reduced through the expansion of electrification and the diffusion of modern cooking equipment in rural areas. Electricity consumption will decline substantially as energy efficiency improvements in wide-ranging fields such as space cooling, power and lighting more than offset the effect of the electrification of appliances.

Renewable energies

In the Advanced Technologies Scenario, variable renewables such as wind and solar PV will be introduced at a faster pace. In the scenario, renewables (including hydro) will increase their share of primary energy consumption from 15% in 2020 to 18% in 2030, 2 percentage points higher than in the Reference Scenario, and 13 points higher to 31% in 2050. The share of variable renewables will expand from 2% in 2020 to 4% in 2030 and 14% in 2050.

Meanwhile, expanded use of variable renewables also raises challenges in terms of electricity system operations. For example, challenges attributable to the time variability of wind and solar PV power generation include rapid output fluctuations (frequency fluctuations), surplus electricity, and cloudy or windless weather observed 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[17], as well as the negative impacts on the natural environment, ecosystems and economic activities around renewable power source locations. Such impacts include adverse effects of large-scale solar PV facilities on forest development, those of onshore wind power facilities on birds and those of offshore wind power generation on fishing.

Technological, institutional and political measures are 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 acceptability of electricity infrastructure construction. Technologies supporting the spread of variable renewables in the Advanced Technologies Scenario will include power generation prediction, output control, energy storage (mainly pumped hydro storage and batteries), output adjustments for backup power sources, power supply adjustments using electric vehicles, grid enhancement and interregional power supply, and smart grid systems combining these and information technologies. For these technologies to diffuse, policies and legal systems to promote the harmony of power sources with the natural environment and the regional acceptance of renewables will be required to support the sustainable spread of renewables.

Installed capacity for onshore and offshore wind power generation will increase in all regions faster than in the Reference Scenario, reaching 1 982 GW in 2030 and 4 460 GW in 2050 (Figure 4-2). Onshore wind power generation will remarkably expand in China and India as enhanced power transmission infrastructure and cost cuts for energy storage technologies ease the spatial and temporal unevenness of the distribution of wind resources. Offshore wind power generation will increase in Asia (including China, Chinese Taipei and Japan) and the United States as well as in Europe, which has so far led the world in offshore power generation. 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 and adjustment based on a better understanding of 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. It will account for 44% of global wind power generation capacity in 2030 and 38% in 2050.

[17] Synchronous power sources with rotation energy have the inertial force of rotating turbines, as well as a synchronising force 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 PV and wind power generation.

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

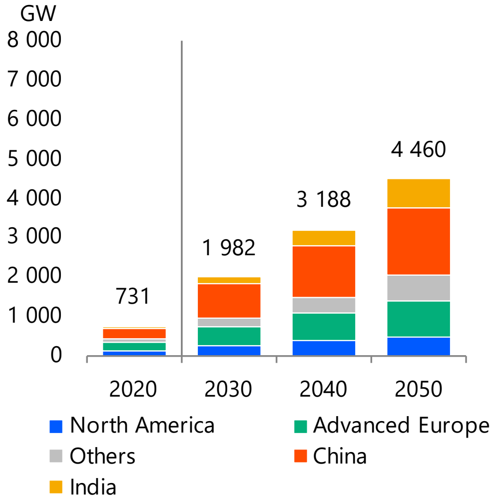
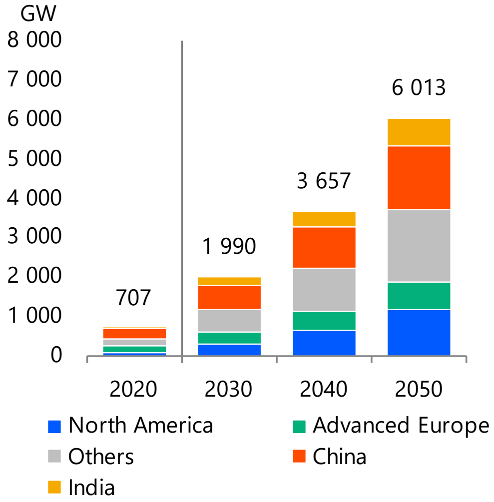


Figure 4-3 | Global solar PV power generation capacity [Advanced Technologies Scenario]



Solar PV power generation is also being introduced ambitiously, with global installed capacity reaching 1 990 GW in 2030 and 6 013 GW in 2050 (Figure 4-3). In addition to the current major solar PV power generation markets such as China, European Advanced Economies, the United States and Japan, India will increase its presence as a solar PV power generator on the strength of falling costs for solar PV power generation and storage batteries. Furthermore, the growth of solar PV power generation will accelerate in the Sun Belt which has abundant sunlight resources, including the Middle East, Africa and Latin America. Combined installed solar PV power generation capacity in China, the United States and India will come to 3 478 GW in 2050, accounting for 58% of the global total. The Middle East, Africa and Latin America will have a combined total of 585 GW in 2050. This is 1.8 times as much as in the Reference Scenario and 19 times as much as in 2020, becoming major solar PV power generation markets.

Carbon neutrality initiatives have grown globally in recent years. The diffusion of 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.

Hydrogen is expected to serve not only as an electricity storage technology but also as a gas fuel through power-to-gas technology. Hydrogen has the superior feature that it can be used in a variety of applications. Conceptual design and demonstration tests for power-to-gas systems have been actively conducted in recent years, particularly in Europe, to use hydrogen as a fuel for transportation and heat supply in the industry and buildings sectors and as feedstock for industrial processes. In particular, hydrogen is expected to be used in sectors where decarbonisation through electricity is difficult. Also, technologies to synthesise hydrogen from renewable energy and CO_2 into fuel or feedstock are attracting attention recently. Fuel synthesis processes include methanation and liquid fuel synthesis (Fischer-Tropsch) processes. These would allow surplus electricity from renewables to be utilised across multiple sectors while methane and liquid hydrocarbon fuels could be used without turning existing energy supply infrastructure into stranded assets. If energy system integration to combine the electricity grid with other sectors such as city gas networks and transport sectors to promote decarbonisation makes progress, renewables power generation could be expanded. To realise energy system integration, however, a new institutional design that can deal with electricity and gas integrally will be required. Different perspectives other than decarbonisation are also important. Unlike storage batteries, which suffer self-discharge losses, hydrogen and hydrogen-derived synthetic fuels can be used as stockpiles because long-term energy storage is possible, contributing to a stable energy supply and improved energy security.

Nuclear

Nuclear power generation is useful for multiple policy objectives including climate change mitigation, air pollution control and energy security. Therefore, nuclear power generation in the Advanced Technologies Scenario will spread 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. Meanwhile, powerful policy measures will be implemented to commercialise new nuclear reactors such as small modular reactors (SMRs) and Generation IV reactors. These new reactors have been under development for decades without being commercialised. In recent years, some potential users have emerged in the United States and Canada and are considering introducing such new reactors, while in China, the construction of actual plants has already begun. The introduction of these new reactors will depend on whether planned or current projects for demonstration reactors sufficiently satisfy the potential users in the world.

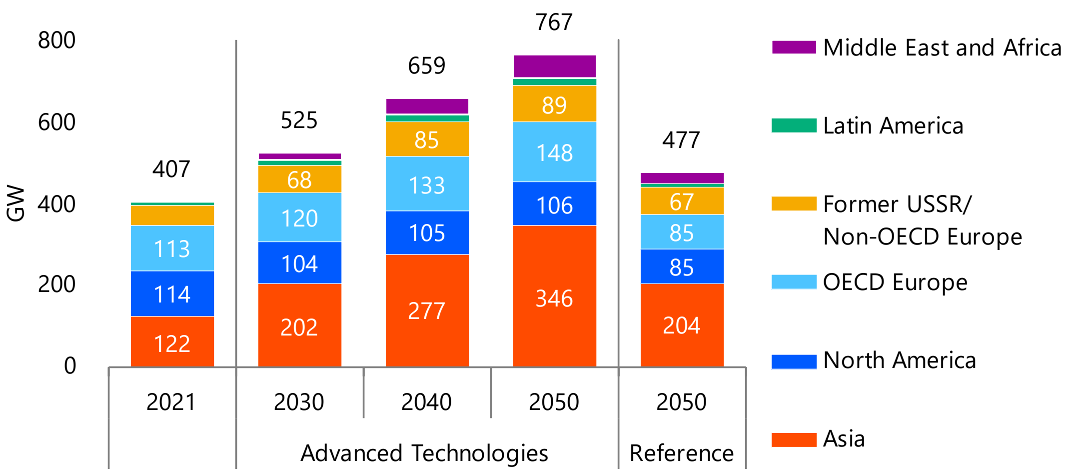
Efforts in non-power sectors will also be important for substantial decarbonisation throughout society. Therefore, nuclear energy is expected to be used not only for power generation but also for multiple other purposes such as district and industrial heat supply, hydrogen production and seawater desalination. However, nuclear power which is currently used as a baseload power source, will be assumed to remain that way until 2050. The effective use of surplus electricity and heat will be considered only after the primary role of nuclear energy for 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 the reduction. Even the United Kingdom will construct more new reactors than in the Reference Scenario, with the installed capacity exceeding that of the current facilities during the period until 2050. Some of the countries that have announced their nuclear phase-out policies in response to 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 Market 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 energy is to acquire large stable power sources to meet energy demand, Emerging Market and Developing Economies with islands or remote territories are expected to introduce small nuclear reactors for small grids of such areas.

In the Advanced Technologies Scenario under these assumptions, global installed nuclear power generation capacity will increase from 407 GW in 2021 to 767 GW in 2050 (Figure 4-4), about 1.6 times the amount of 477 GW in the Reference Scenario.

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



In North America, the installed capacity will slightly decline after 2025, but will remain around 105 GW until 2050, by carrying out the necessary maintenance of existing reactors and by constructing new reactors. The U.S. federal government and some state governments are increasingly giving higher ratings to nuclear energy's low carbon contribution and reliability of energy supply. In the Advanced Technologies Scenario in which such policy trends will be maximised, support for innovative nuclear technology development and extension of the lifespans of existing nuclear power plants will be greater than in the Reference Scenario. The United States and Canada are proactively promoting the development of SMRs and Generation IV reactors, which will 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.

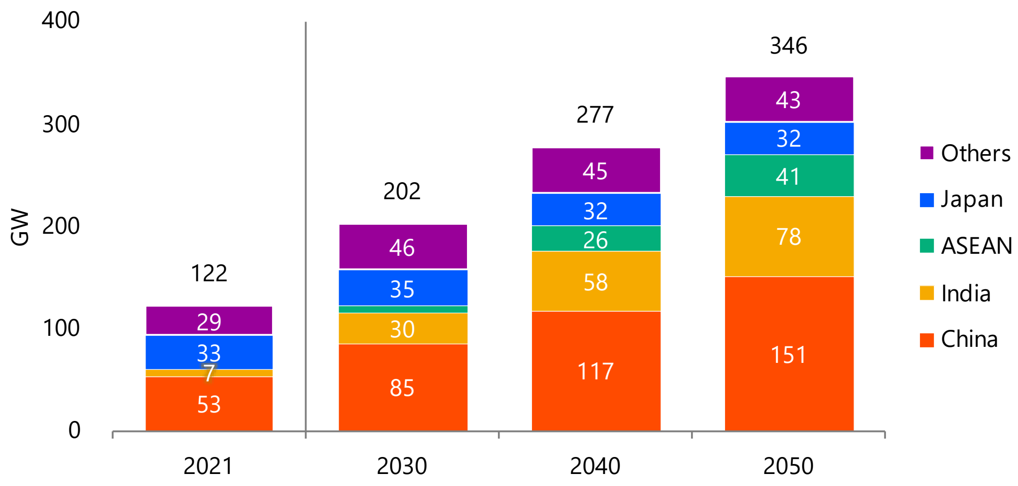
In European Advanced Economies that are aiming at ambitious targets for reducing greenhouse gas (GHG) emissions, the construction of additional nuclear power plants and the replacement of outdated reactors will be politically promoted, leading to a rise in installed nuclear power generation capacity from 113 GW in 2021 to 148 GW in 2050. In France, the largest nuclear power user in Europe, installed nuclear power generation capacity will decline more slowly than in the Reference Scenario through 2050, as the number of nuclear 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-scaled light-water (Generation III plus) reactors has been substantially delayed due to the loss of construction know-how for new reactors and design modifications. 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 business operators. This will drive the expansion of nuclear capacity. In countries such as the United Kingdom and France, potential sites and constructors, financial frameworks and other factors concerning the newly announced construction projects should be promptly determined and publicly disclosed to enable the private sector to make management decisions.

Russia will accelerate its new nuclear power plant construction, expanding the installed nuclear power generation capacity from 30 GW in 2021 to 46 GW around 2035. Thereafter, however, the installed capacity in Russia will decline due to the closure of ageing reactors and other factors. By contrast, exports from Russia will actively proceed against the backdrop of economic growth in the Emerging Market and Developing Economies and growing energy demand. Russia has already been promoting cooperative relations with many Emerging Market 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 energy markets, will commence operation of new reactors from around 2025 and steadily expand installed nuclear power generation capacity thereafter. In the Middle East where policy priority will be given to breaking away from heavy dependence on fossil fuels, installed nuclear power generation capacity will reach 15 GW in 2030 and 37 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 for nuclear power plant construction.

As in the Reference Scenario, Asia will have the world's largest installed nuclear power generation capacity in 2050 in the Advanced Technologies Scenario (Figure 4-5). Asia's installed capacity will exceed the combined capacity of OECD Europe and North America (at 230 GW) in 2035 and reach 346 GW in 2050. The increase will be driven by China and India, as in the Reference Scenario. In addition, Southeast Asian countries, now just planning to introduce nuclear power generation, will also make progress in introducing nuclear capacity as they require stable and economically efficient low-carbon power sources to meet their growing power demand. As many of these countries need to achieve stable electricity supply on their islands, the introduction of SMRs or floating nuclear reactors is being considered. With this background, ASEAN's installed nuclear power generation capacity, though zero as of 2021, will reach 41 GW in 2050, exceeding Japan's installed capacity of 32 GW at that year. Commercial nuclear power generation starts around 2030.

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



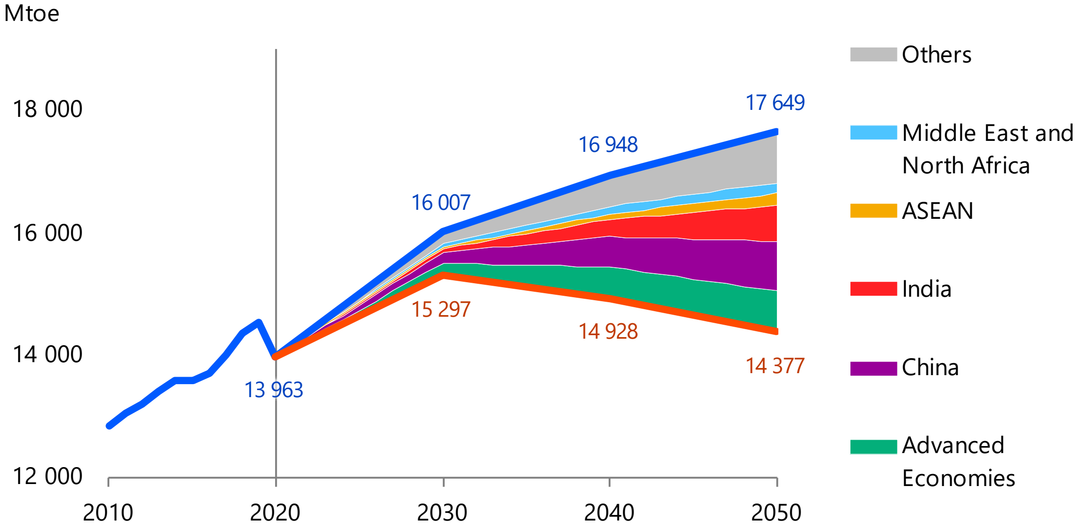
4.2 Energy supply and demand

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 in 2030 in the Advanced Technologies Scenario will increase from 2020 but will be −710 Mtoe (−4.4%), lower when compared with the Reference Scenario (Figure 4-6). After 2030, primary energy consumption will begin to decline due to further progress in energy efficiency improvements, and the reduction in primary energy consumption relative to the Reference Scenario in 2050 will reach 3 273 Mtoe (18.5%). Cumulative savings by 2050 will be 45.3 Gtoe. Playing a great role in realising the Advanced Technologies Scenario will be the Emerging Market and

Developing Economies such as India, the Middle East and North Africa (MENA) and ASEAN, which have great potential to save energy and introduce non-fossil energies.

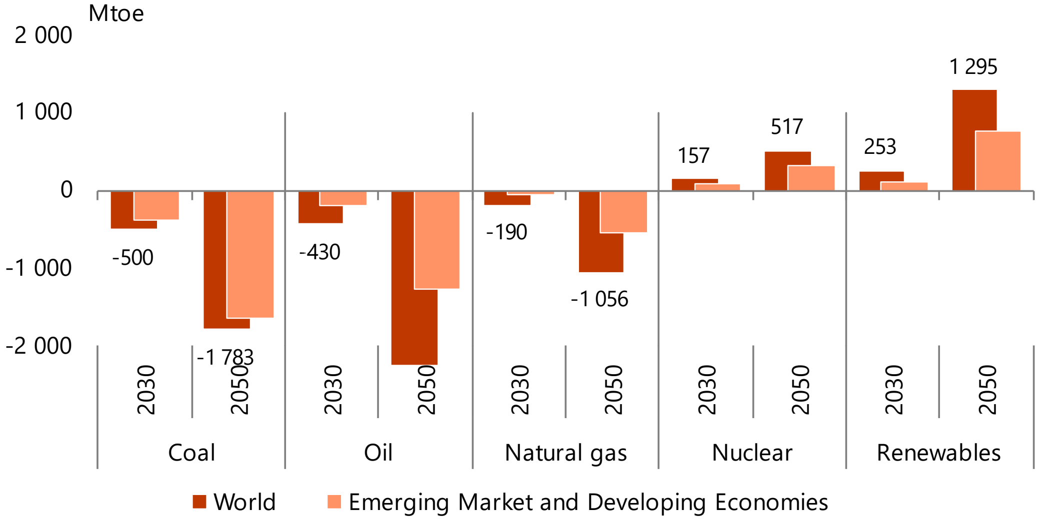
Figure 4-6 | Global primary energy consumption and energy savings (relative to Reference Scenario) [Advanced Technologies Scenario]



The Emerging Market and Developing Economies will account for 74% of global energy savings from the Reference Scenario in 2050. Particularly, India, MENA and ASEAN will capture a combined share of 29%. Extraordinary efforts to boost energy efficiency improvements and decarbonisation will be key to global energy security and climate change countermeasures.

By energy source, fossil fuels will decrease by only 5.1 Gtoe (31%) in 2050 compared to the Reference Scenario, with a cumulative reduction of 67.6 Gtoe (Figure 4-7), although fuel switching will also progress. Coal for power generation is being switched in Emerging Market and Developing Economies, with these countries accounting for 80% of the reduction in 2030 and 90% in 2050. Oil consumption will decrease by 0.4 Gtoe in 2030 which is less than coal, but from 2030 onward, the spread of electrified vehicles will contribute to its highest energy savings of 2.2 Gtoe in 2050. Natural gas consumption will decline only by 0.2 Gtoe in 2030 and by 1.1 Gtoe in 2050. The small saving in natural gas consumption in 2050, however, might partly result from an increase in the use for feedstock for hydrogen production. Non-fossil energy consumption will increase by 0.4 Gtoe in 2030 and by 1.8 Gtoe in 2050. Nuclear and renewable energy consumption will rise by 60% and 41%, 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.

Figure 4-7 | Primary energy consumption changes (relative to Reference Scenario) [Advanced Technologies Scenario]

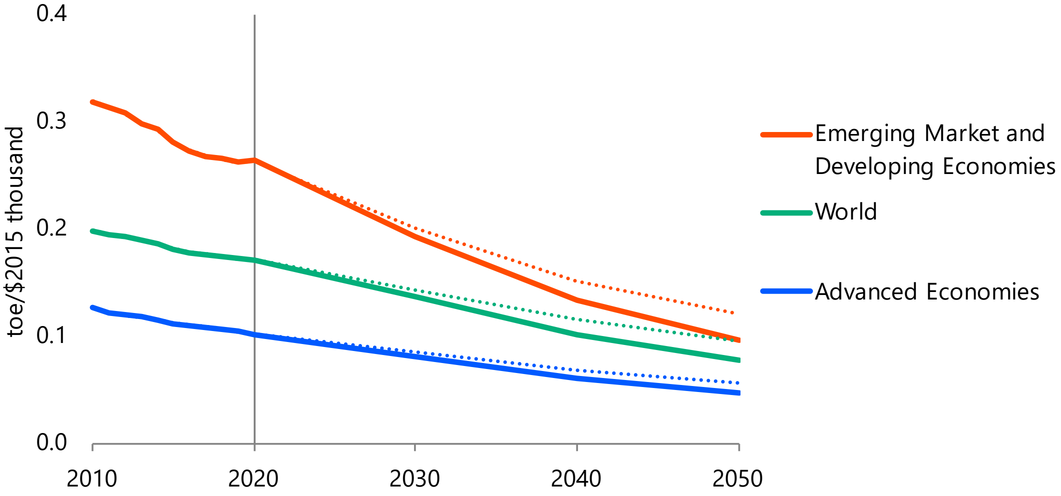


Realisation of the Advanced Technologies Scenario is not easy. The Emerging Market and Developing Economies will account for 92% of the coal consumption savings from the Reference Scenario in 2050, with India, MENA and ASEAN capturing a combined 38%. The Emerging Market and Developing Economies will account for 64% and 59% of the consumption growth in nuclear and renewable energy respectively. India, MENA and ASEAN will account for 30% of the nuclear growth and 38% of the renewable energy growth. The Advanced Technologies Scenario thus urges the Emerging Market and Developing Economies to realise such contributions to coal consumption savings and nuclear and renewable energy consumption growth in a short period of 30 years. During the process of realising the Advanced Technologies Scenario, the Emerging Market and Developing Economies are required to implement their energy transition far faster than the Advanced Economies did in the past.

In the Advanced Technologies Scenario, the decrease in energy intensity per unit of GDP in the Advanced Economies and in the Emerging Market and Developing Economies will fall short of bringing the world to carbon neutrality (Figure 4-8). The Advanced Economies will post a decline of 53% in their energy intensity from 2020 to 2050, compared with a fall of 63% for the Emerging Market and Developing Economies which have greater potential to improve energy efficiency. The global energy intensity per unit of GDP will have to decrease by 80% from 2020 if the global energy consumption of 6.4 Gtoe in 2050 in the Advanced Technologies Scenario is covered by only nuclear, renewables and fossil fuels for blue hydrogen[18], and achieve carbon neutrality. The decrease would be far steeper than the declines in the Emerging Market and Developing Economies and in China, demonstrating the considerable difficulty for the world to realise global carbon neutrality in 2050.

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

Figure 4-8 | Primary energy intensity per GDP [Advanced Technologies Scenario]



Note: Dotted lines represent the Reference Scenario.

If the Advanced Technologies Scenario is realised and further CO_2 emission cuts are made, both the Advanced Economies and the Emerging Market and Developing Economies will have to improve energy efficiency at a high pace and promote the decarbonisation of energy sources. Thus, the Advanced Economies' development of energy efficiency improvement technologies, their transfer to the Emerging Market and Developing Countries, international fundraising capabilities and the elimination of barriers to energy savings including insufficient awareness will become indispensable. Each country will have to adopt different energy conservation and decarbonisation approaches for urban and rural areas, while setting energy-efficient appliances incentives for low-income people busy with day-to-day life. It will also be important to improve national and regional education programmes to enhance energy efficiency awareness over the long term.

All policy means will have to be mobilised to plan and implement these CO_2 emission reduction measures, including subsidy, tax, regulatory and other public policies and their exploitation for private businesses. Advanced Economies' bilateral cooperation with Emerging Market and Developing Economies, multilateral cooperation frameworks such as the ASEAN+3 and Asia-Pacific Economic Cooperation forums, and the utilisation of international organisations like the International Monetary Fund and the World Bank will also be required.

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

Oil will account for more than half the net final energy consumption savings in 2050 in the Advanced Technologies Scenario (Figure 4-9). 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 diffuse electrified vehicles, various policy incentives will have to be combined with the acceleration of charging facility expansion, battery production capacity enhancement and relevant cost cuts.

Figure 4-9 | Global final energy consumption changes (relative to Reference Scenario) [Advanced Technologies Scenario, 2050]

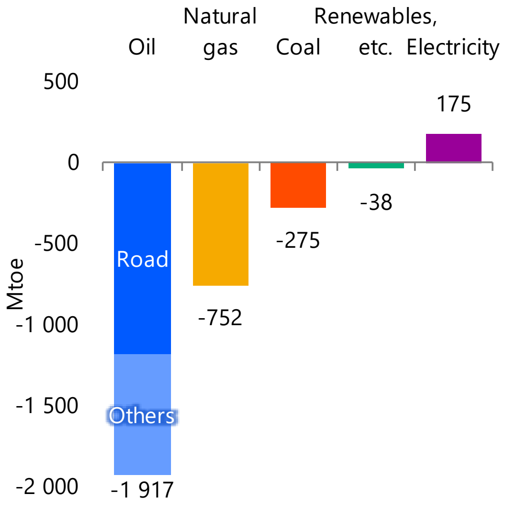
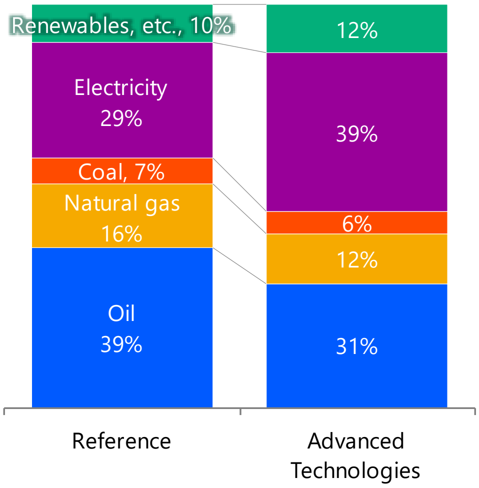


Figure 4-10 | Global final energy consumption mix [2050]



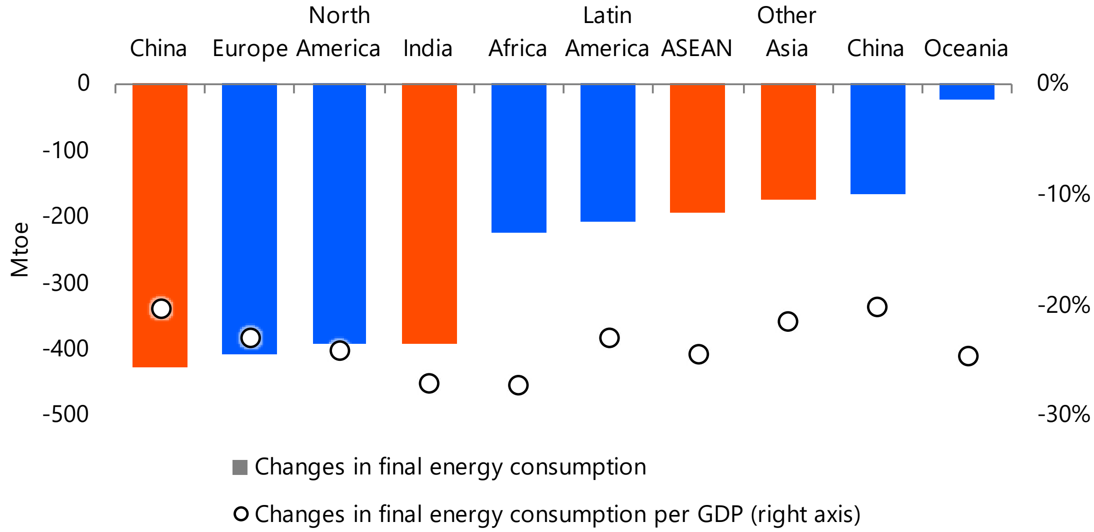
Given oil's large share of total energy savings, steady fuel efficiency improvements and vehicle fleet mix changes will become a key contributor to bringing final energy consumption closer to the Advanced Technologies Scenario path.

While in the Advanced Technologies Scenario, final energy consumption of oil, natural gas, coal, renewables and other energy sources will be reduced compared to the Reference Scenario, consumption of electricity will be increased by incorporating technological progress such as higher efficiency power generation, co-firing of hydrogen and ammonia, and thermal power generation with CCS. Along with this, electricity's share of energy consumption will increase by 10 points in the Advanced Technologies Scenario in 2050. However, differences between energy mixes in the two scenarios will be limited except for electricity and demand for all major energy sources will continue to exist (Figure 4-10). It will thus be important to stably supply each energy source in the Advanced Technologies Scenario as in the Reference Scenario.

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

Asia including China and India will account for the largest share of final energy consumption savings in 2050, followed by Europe, North America and Africa (Figure 4-11). Steady progress in energy efficiency improvements in China, India, Europe, the United States 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 4-11 | 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 1 201 Mtoe, accounting for as much as 43% of global savings. China with 429 Mtoe in savings and India with 391 Mtoe will account for a combined 30% of global savings, highlighting their great presence. Progress in the two countries' energy savings will affect not only their energy security but also climate change and other economies' energy security. They will substantially reduce oil consumption in the road sector and coal consumption in the industrial sector, reflecting the effects of various technologies assumed in the Advanced Technologies Scenario. It will be important to achieve steady progress in the two countries' energy efficiency improvements through various measures such as Advanced Economies' transfer of highly efficient technologies to them.

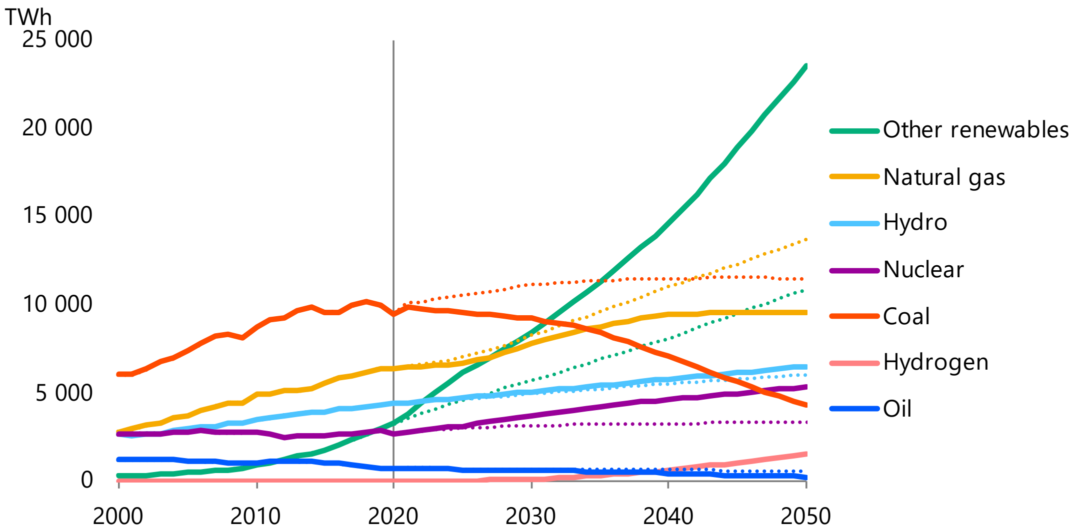
Final energy consumption savings in Europe will total 407 Mtoe, accounting for 15% of global savings. It is notable that about half of the savings will be accounted for by the buildings sector. Mainly led by the Organisation for Economic Co-operation and Development (OECD) countries, more efficient equipment for households and commercial use will be actively introduced. Final energy consumption savings in North America will total 392 Mtoe, accounting for 14% of global savings. The decline in oil consumption mainly in the road sector will account for about half of the savings in North America. As automobiles are frequently used as mobility or transportation means in North America, oil demand in the road sector is the second largest in the world after that in Asia. Therefore, oil consumption in the road sector will decline substantially, driven by improvements in vehicle fuel efficiency and changes in the vehicle fleet mix.

Africa is unique in terms of savings by sector. Africa will feature renewable energy consumption savings in the residential sector that will account for more than half of the region's final energy consumption savings of 224 Mtoe. This will contribute to leading final energy consumption per GDP to post a 27% decline, steeper than in any other region. The savings in renewable energy consumption will be led by the modernisation of energy consumption and the utilisation of highly efficient energy consumption appliances. It will be important for Africa to diffuse highly efficient energy consumption appliances at affordable prices for a wider range of consumers and to develop arrangements for providing modern energy sources to steadily implement residential sector energy savings.

Power generation mix

Electricity generated in 2050 in the Advanced Technologies Scenario will be 1 423 TWh higher than in the Reference Scenario. The share of electricity in final demand will increase by 10 percentage points from 29% in the Reference Scenario due to the progress of electrification. Additionally, increased electricity input for hydrogen production will contribute. As Advanced Economies take the lead in promoting policies to phase out coal, coal-fired power generation will decline substantially from the 2020s to less than half the current level in 2050 (Figure 4-12). In contrast, renewables including solar PV, wind and biomass will become the largest power source. Variable renewables will account for 37% of total electricity generated, making the handling of variable output a key challenge in each region. Full-scale introduction of hydrogen will start around 2040, to replace existing coal- and natural gas-fired power generation as a dispatch power source, mainly in regions with poor CCS storage potential.

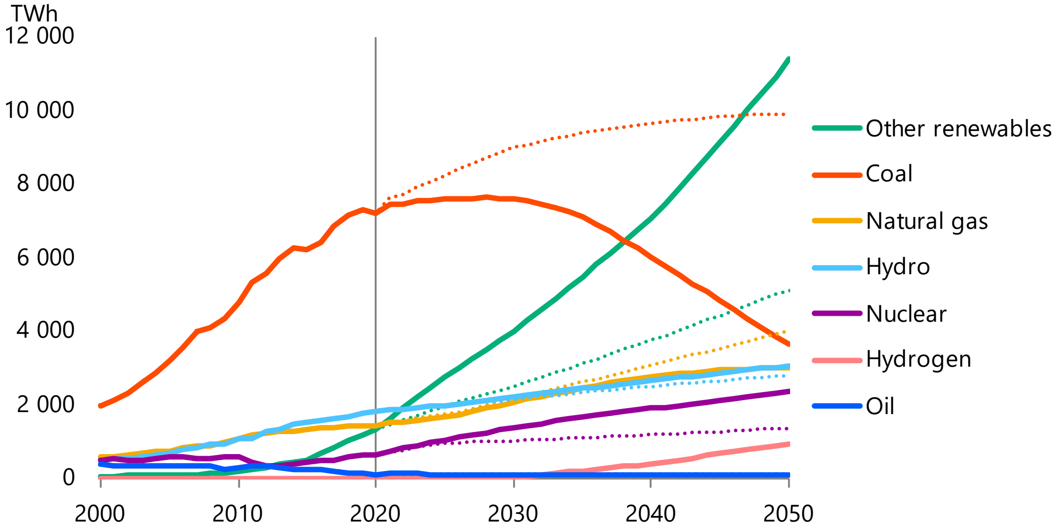
Figure 4-12 | Global electricity generated [Advanced Technologies Scenario]



Note: Dotted lines represent the Reference Scenario.

Coal-fired power generation in Asia will peak before 2030 and substantially decrease thereafter (Figure 4-13). Even in 2050, however, coal will account for some 17% of total power generation, being the second largest power source. In Asia, more efficient coal-fired power generation and air pollution countermeasures are important, and it is also desirable to reduce CO_2 in the future by adopting CCS. Renewables will rapidly expand in China and India. As these economies sustain growth, their challenge will be to harmonise renewable energy expansion with affordable and stable electricity supply.

Figure 4-13 | Asia's electricity generated [Advanced Technologies Scenario]



Note: Dotted lines represent the Reference Scenario.

Crude oil production

In the Advanced Technologies Scenario, oil demand growth will be suppressed due to rapid progress in the electrification of automobiles and other fuel switching measures in final consumption sectors, as well as further progress in energy efficiency improvements. Oil demand will peak by 2030, and the demand per day will be 63.6 million barrels per day (Mb/d) in 2050, 44% less than in the Reference Scenario. This decrease in demand will cause production to decline in all regions that are less cost-competitive than the Organization of the Petroleum Exporting Countries (OPEC). Production will decline also in non-Middle Eastern OPEC countries, but cost-competitive Middle Eastern OPEC countries will maintain their production at 24.3 Mb/d even in 2050. As a result, OPEC's market share will increase faster than in the Reference Scenario, reaching 46% in 2050.

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

(Mb/d)

	2020	2030	2040	2050	2020-2050	
					Changes	CAGR
Crude oil production	89.6	99.0	82.8	63.6	-26.0	-1.1%
OPEC	31.3	38.0	34.9	29.8	-1.5	-0.2%
Middle East	25.0	29.7	27.8	24.3	-0.8	-0.1%
Others	6.3	8.3	7.1	5.6	-0.7	-0.4%
Non-OPEC	58.3	61.0	47.9	33.8	-24.5	-1.8%
North America	21.0	25.4	18.3	13.8	-7.2	-1.4%
中南米Latin America	7.7	8.5	8.2	6.3	-1.4	-0.7%
Europe and Eurasia	17.4	15.6	12.6	7.6	-9.9	-2.7%
Middle East	2.9	3.3	2.9	2.3	-0.6	-0.7%
Africa	1.4	1.4	1.2	0.9	-0.5	-1.5%
Asia and Oceania	7.9	6.7	4.6	2.9	-5.0	-3.3%
Processing gains	2.1	2.6	2.3	1.9	-0.2	-0.3%
Oil supply	91.7	101.6	85.1	65.5	-26.2	-1.1%

Note: Crude oil includes natural gas liquid.

Natural gas supply

As progress in energy efficiency improvements and other energy utilisation technologies suppresses natural gas consumption in the Advanced Technologies Scenario, natural gas production will be 12% less than in the Reference Scenario in 2040 and 20% less in 2050. However, better management of GHG emissions may lead to a greater share for greener natural gas production capacity.

A wide production gap between the Reference and Advanced Technologies Scenarios will be seen in OECD Europe where natural gas development and production costs are relatively higher. The region’s natural gas production in 2050 in the Advanced Technologies Scenario will be 40%–50% less than in the Reference Scenario. In North America, production in the United States and Canada will not surge after 2030. Meanwhile, growth in production in non-OECD Europe, including Russia, will also slow down. In the Middle East, Qatar and Saudi Arabia will sharply increase production even in the Advanced Technologies Scenario, but production in the entire Middle East will slightly decrease after 2040.

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 4-5 | Natural gas production [Advanced Technologies Scenario]

(Bcm)

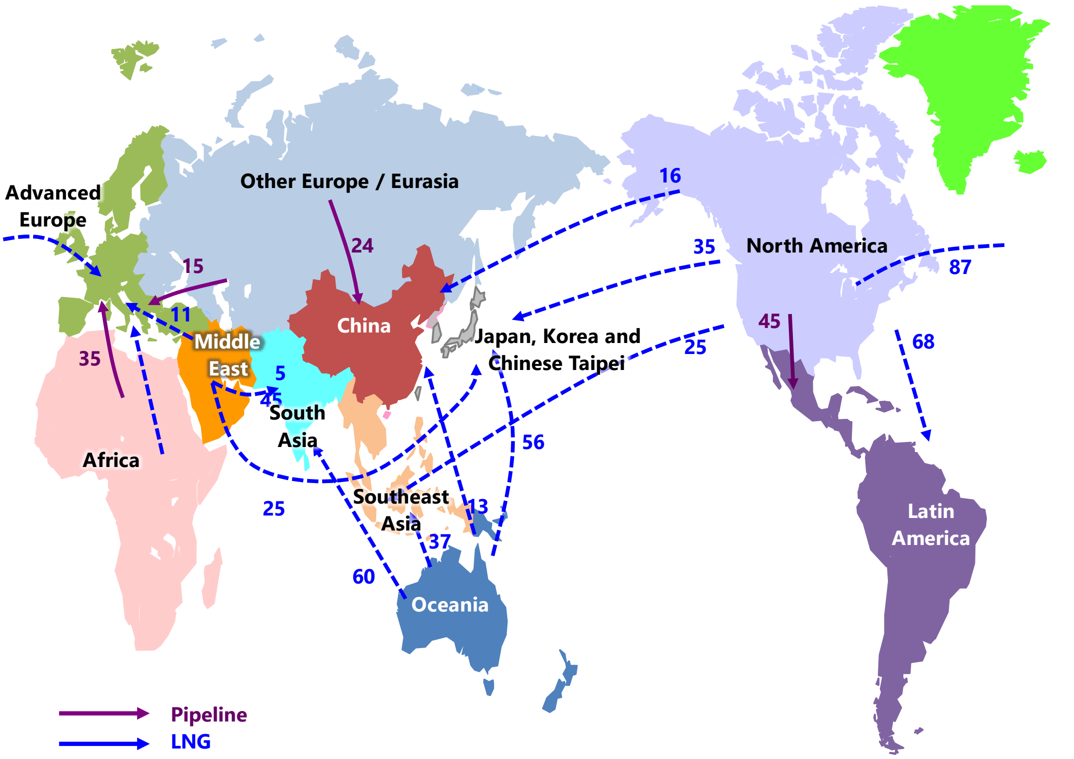
	2020	2030	2040	2050	2020-2050	
					Changes	CAGR
World	4 028	4 372	4 642	4 570	1 843	1.3%
North America and Mexico	1 177	1 240	1 238	1 273	258	0.7%
Latin America excluding Mexico	123	202	222	156	199	3.3%
OECD Europe	201	121	83	74	-66	-1.3%
Non-OECD Europe/Central Asia	970	850	811	829	-69	-0.2%
Russia	720	600	560	555	-115	-0.6%
Middle East	675	815	808	810	466	1.8%
Africa	240	334	506	482	486	3.8%
Asia	482	621	741	712	463	2.3%
China	195	242	362	300	185	2.2%
India	28	58	72	73	82	4.6%
ASEAN	199	216	207	211	58	0.9%
Oceania	159	190	233	233	106	1.7%

Net natural gas-importing regions will reduce their imports by 20%–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 90% from the Reference Scenario. In North America, demand will decline from the Reference Scenario faster than production and its net export volume in 2050 will rise more than two-fold from the Reference Scenario, though being affected by international price falls.

In the Advanced Technologies Scenario, changes in natural gas trade will depend on progress in relevant companies' cooperation and efforts to rationalise and optimise the trading of natural gas and liquefied natural gas (LNG). Such changes will also depend on progress in relevant countries' cooperation and support policies and regulations (monitoring and regulating fuel efficiency and emissions for marine transportation). Regarding 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.

Progress in marine transportation technologies for LNG and compressed natural gas (CNG) carriers will contribute to developing sustainable natural gas trade. Improvements in compressor efficiency, leak detection and surveillance technologies as well as relevant policy support for pipeline gas trade will also contribute.

Figure 4-14 | Major interregional natural gas trade flows [Advanced Technologies Scenario, 2050]



Notes: Major trade flows are covered. Some pipeline gas flows could be replaced with LNG flows.

Coal supply

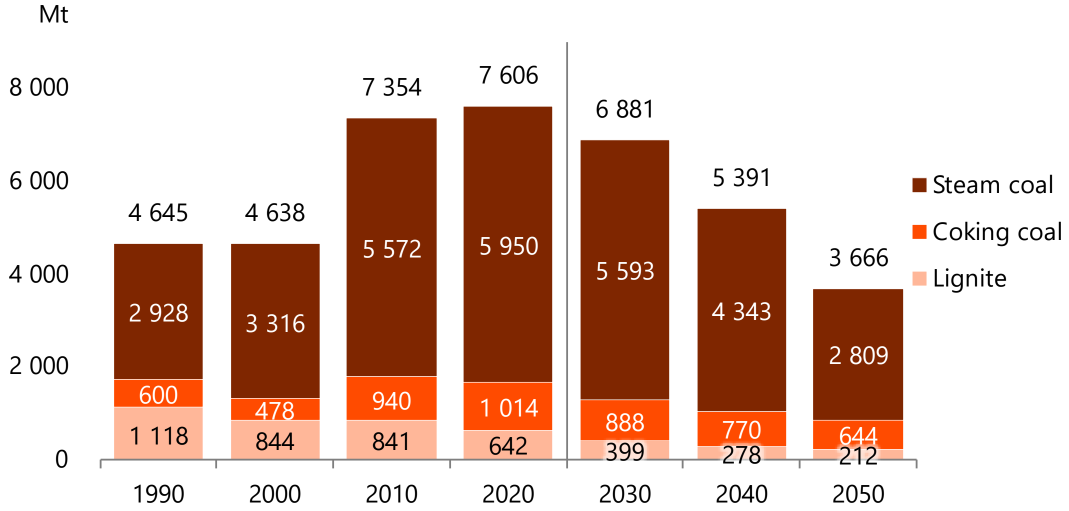
As efforts to replace coal with other fuels and to increase the efficiency of coal use are enhanced toward carbon neutrality, initiatives to minimise coal use will make progress in various sectors including power generation, steelmaking and other industries. Coal's share of the power generation mix will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

Advanced Economies will suspend or terminate inefficient coal-fired power plants. Even if some coal-fired power plants are replaced, technologies to fully minimise coal consumption by high thermal efficiency and co-firing technologies will be adopted, including integrated coal gasification combined cycle (IGCC) and ammonia or hydrogen co-firing. Coal consumption efficiency at individual power plants and industrial facilities will improve while CO_2 emission intensities will decline.

Emerging Market 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 new large plants. Coal demand will be suppressed due to technological progress to cut costs, enabling other fuels and power sources to be promising alternatives.

Consequently, coal production will decrease from 7 606 million tonnes (Mt) in 2020 to 3 666 Mt in 2050 (Figure 4-15). By coal type, steam coal production will decline from 5 950 Mt in 2020 to 2 809 Mt in 2050, coking coal production from 1 014 Mt to 644 Mt and lignite production from 642 Mt to 212 Mt. From the Reference Scenario, total coal production in 2050 will decrease by 3 942 Mt, with steam coal plunging by 3 502 Mt and lignite by 261 Mt, as well as coking coal decreasing by 180 Mt.

Figure 4-15 | Global coal production [Advanced Technologies Scenario]



Coal production will decline in all regions in the world due to decreased demand. In particular, production in the United States will plunge due to declining domestic demand. Production in 2050 will be 15% of the 2020 level. Meanwhile in Asia, production in 2050 will be 50% of the 2020 level due to decreased domestic demand in China and India.

Table 4-6 | Steam coal production [Advanced Technologies Scenario]

(Mt)

	2020	2030	2040	2050	2020-2050	
					Changes	CAGR
World	5 950	5 593	4 343	2 809	-3 141	-2.5%
North America	404	250	104	30	-374	-8.3%
United States	391	244	100	27	-364	-8.5%
Latin America	53	74	57	40	-13	-0.9%
Colombia	45	67	52	37	-9	-0.7%
OECD Europe	47	35	18	10	-37	-5.0%
Non-OECD Europe/Eurasia	361	313	266	211	-150	-1.8%
Russia	240	215	170	123	-117	-2.2%
Middle East	0	0	0	0	0	1.8%
Africa	253	229	189	142	-111	-1.9%
South Africa	245	218	180	136	-109	-2.0%
Asia	4 562	4 442	3 522	2 257	-2 304	-2.3%
China	3 227	3 041	2 180	1 206	-2 021	-3.2%
India	679	826	812	601	-78	-0.4%
Indonesia	562	473	432	361	-201	-1.5%
Oceania	269	250	187	118	-151	-2.7%
Australia	268	250	186	117	-150	-2.7%

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

(Mt)

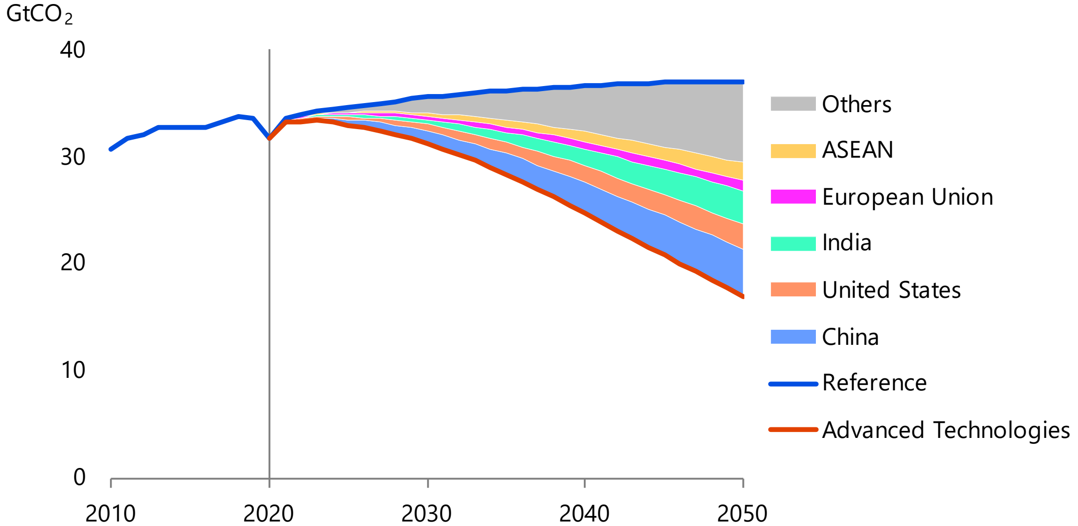
	2020	2030	2040	2050	2020-2050	
					Changes	CAGR
World	1 014	888	770	644	-369	-1.5%
North America	75	77	74	67	-8	-0.4%
United States	50	51	48	43	-7	-0.5%
Latin America	8	9	9	9	0	0.2%
Colombia	4	5	5	6	1	0.8%
OECD Europe	14	15	15	14	-1	-0.2%
Non-OECD Europe/Eurasia	94	82	77	70	-24	-1.0%
Russia	90	77	72	65	-25	-1.1%
Middle East	1	1	1	1	0	-0.3%
Africa	7	18	22	26	19	4.6%
Mozambique	4	15	20	23	19	5.8%
Asia	629	500	389	286	-343	-2.6%
China	561	408	276	158	-403	-4.1%
India	38	65	89	107	70	3.6%
Mongolia	26	21	19	16	-10	-1.7%
Oceania	185	185	183	172	-13	-0.2%
Australia	184	184	181	170	-13	-0.2%

4.3 CO_2 emissions

Difficulties in achieving the 2030 target, with large reductions due to energy efficiency in Emerging Market and Developing Economies

Under the Advanced Technologies Scenario, global energy-related CO_2 emissions will be 31.2 Gt in 2030 (1.4% less than in 2020) and 16.9 Gt in 2050 (46.5% less) (Figure 4-16). Under this scenario, the reduction of CO_2 emissions will be as large as in the Announced Pledges Scenario in the World Energy Outlook 2021 by the International Energy Agency (IEA), but it will still be far from net-zero global emissions by 2050. Reductions from the Reference Scenario amount to 20.1 Gt in 2050, of which 7.7 Gt (38.1%) is accounted for by China and India.

Figure 4-16 | Global energy-related CO_2 emissions [Advanced Technologies Scenario]



In 2050, while 3.0 Gt of emissions will be emitted by Advanced Economies, 12.8 Gt will be from Emerging Market and Developing Economies, accounting for 75% of global emissions (Figure 4-17).

Table 4-8 compares 2030 energy-related CO_2 emissions and 2030 goals for major emitting countries. One of China's 2030 goals is to reduce CO_2 emissions per GDP by more than 65% (compared to 2005), which is almost equivalent to the level in the Reference Scenario. India updated its emission reduction goal per GDP in August 2022 from 33%–35% to 45% relative to 2005 levels. The new goal will be roughly equal to the level in the Advanced Technologies Scenario. On the other hand, reduction goals set by the Advanced Economies such as the United States (50%–52% below 2005 levels), the European Union (55% below 1990 levels), and Japan (45% below 2013 levels[19]) will not be reached even under the Advanced Technologies Scenario.

[19] Energy-related CO_2

Figure 4-17 | Energy-related CO_2 emissions [Advanced Technologies Scenario]

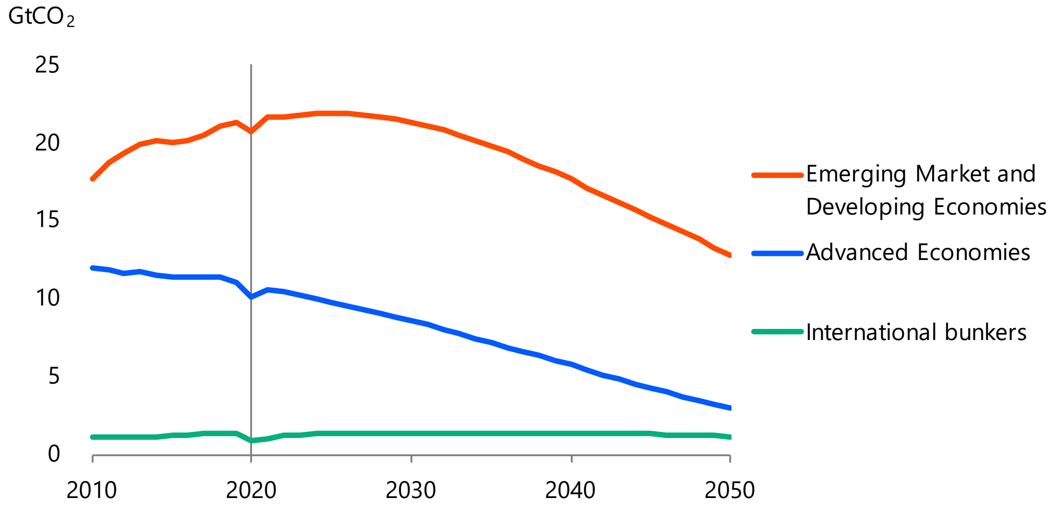


Table 4-8 | Comparison of 2030 energy-related CO_2 emissions and 2030 goals for major countries and regions

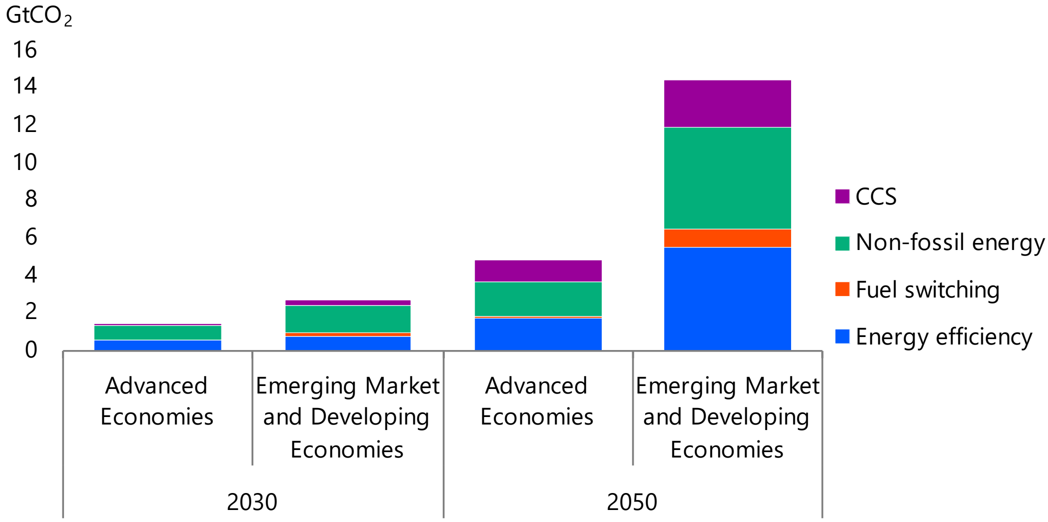
(Gt)

Country or region	2030 goal (equivalent)	Reference	Advanced Technologies
China	10.7	10.7	9.5
India	2.7	3.2	2.7
United States	2.7–2.8	4.3	3.7
European Union	1.6	2.2	1.9
Japan	0.68	0.88	0.78

Notes: The 2030 goals of China and India are emission per-GDP reduction goals converted to absolute equivalents based on the GDP assumptions in this Outlook. The 2030 goals of both countries include renewable energy introduction targets which are not reflected in the above table.

What factors will bring about emission reductions from the Reference Scenario? The results are shown in Figure 4-18. The four factors (energy efficiency, fuel switching, non-fossil energy, and CCS) all contribute to emission reductions, with the effect of emission reductions from energy efficiency in Emerging Market and Developing Economies being notably large. In 2050, they are comparable to emission reductions in Advanced Economies as a whole. The fact that there is high potential for energy efficiency in Emerging Market and Developing Economies can be proven by the primary energy supply per GDP in these regions in 2020, which was 2.6 times that of Advanced Economies.

Figure 4-18 | Decomposition analysis of energy-related CO_2 emission reductions [Advanced Technologies Scenario]



The future focus will be on not only strengthening Nationally Determined Contributions (NDC) in Emerging Market and Developing Economies including China, but also on whether the entire world can promote efficient emission reductions through international cooperation by using voluntary market mechanisms and international initiatives that have attracted attention in recent years.

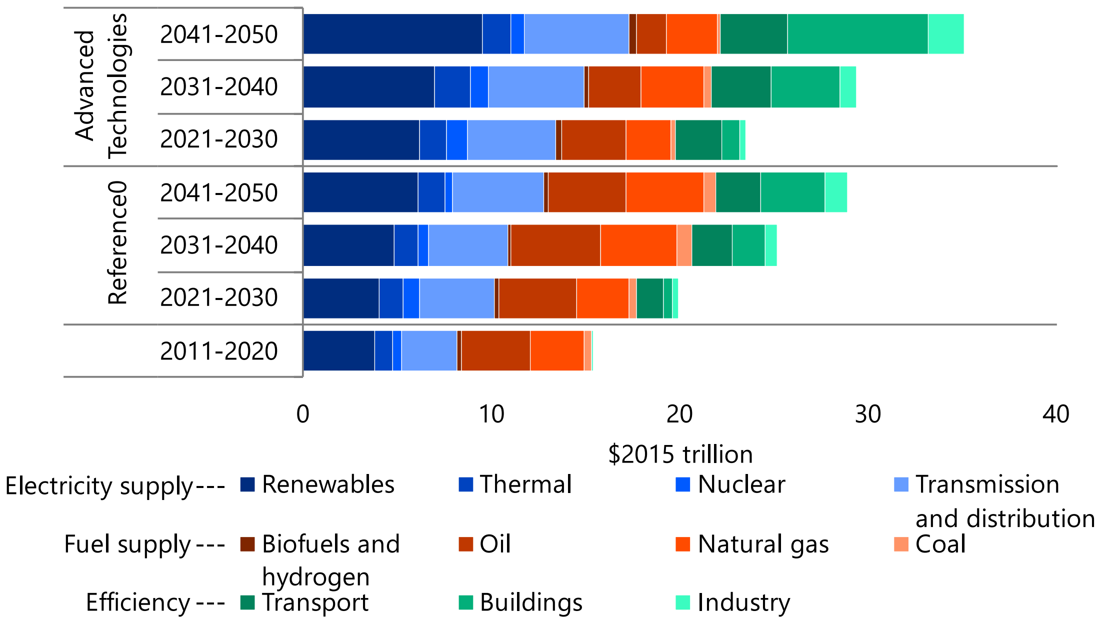
5. Energy-related investments

5.1 Recent trends and outlook

Most energy-related investments are made to oil production, natural gas production and renewables. In the 2010s, investments have targeted primarily electric infrastructure such as renewables and transmission and distribution facilities, followed by facilities related to oil and natural gas production. In the 2020s and onward, investments in renewables and energy-efficiency are expected to increase due to reduced capital costs for renewable energy equipment as well as the shift from fossil fuel dependence on Russia.

In the Reference Scenario, energy-related investments[20] will increase 1.9 times from $15 trillion (in 2015 dollars) in the 2010s to $29 trillion in the 2040s (Figure 5-1). 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 the necessary investments in the 2040s being $35 trillion, up $20 trillion from the 2010s. Cumulative global energy investments required by 2050 will reach $88 trillion (annual average of $2.9 trillion).

Figure 5-1 | Global energy-related investments



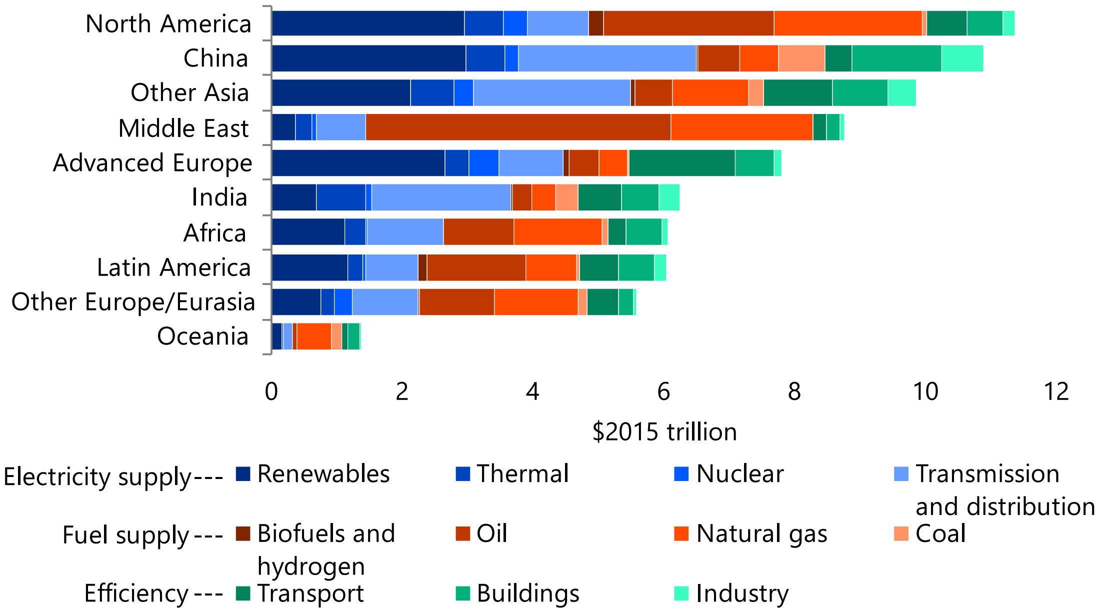
Note: 2011-2020 are estimates.

Energy-related investments have unique regional characteristics (Figure 5-2). For example, in Advanced Europe which is moving away from dependence on fossil fuels, investments in

[20] 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.

renewables and energy-efficiency will account for more than half of the total investments. On the other hand, in Oceania and the Middle East, among fossil fuel suppliers, fossil fuel supply investments account for a large share of the total investments, with renewable energy investments commanding a smaller share.

Figure 5-2 | Energy-related investments [Reference Scenario, cumulative total for 2021-2050]



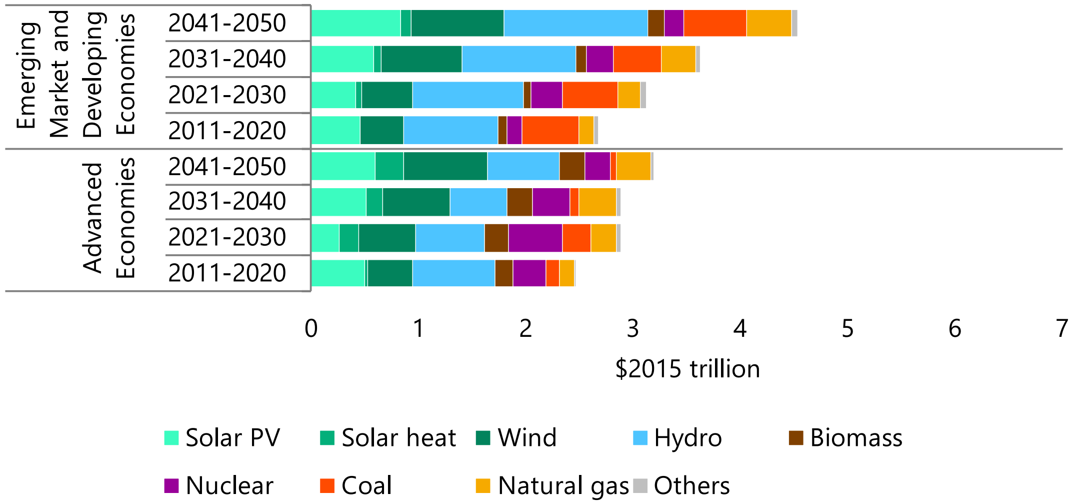
In the United States, investments in renewables will account for about a quarter of total investments, while those in the production of fossil fuels, such as the development of shale gas, will hold a large portion. In China, as with the United States, renewable energy investments will account for about a quarter of total energy-related investments. However, investments in power transmission and distribution networks will exceed renewable energy investments as such networks are required to expand to meet the growth in electricity demand.

5.2 Electricity investments

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

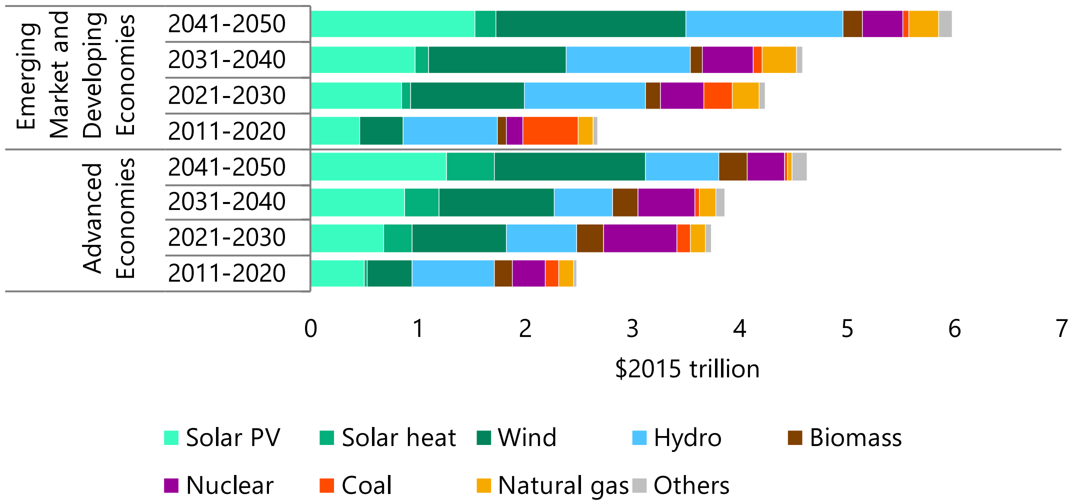
Of the investments in power generation equipment, those in renewable energy facilities account for the largest share (Figures 5-3 and 5-4). In the 2010s, feed-in tariffs and net metering systems contributed to active investments in renewable energy facilities in many regions. From the 2020s onward, investments in Emerging Market and Developing Economies will increase significantly both in the Reference and the Advanced Technologies Scenarios.

Figure 5-3 | Power generation equipment investment [Reference Scenario]



Note: 2011-2020 are estimates.

Figure 5-4 | Power generation equipment investment [Advanced Technologies Scenario]



Note: 2011-2020 are estimates.

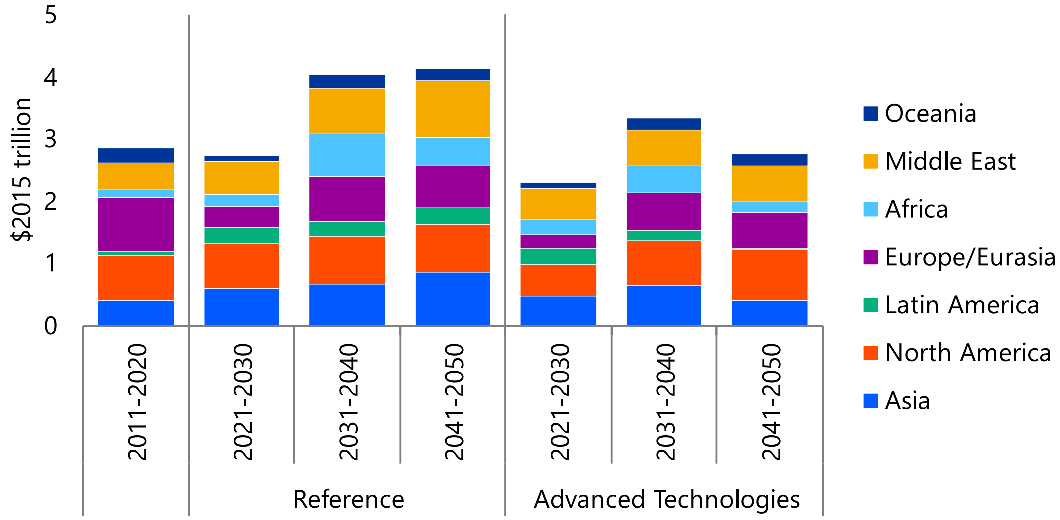
In the Reference Scenario, investments by Advanced Economies in the 2020s onward will be less than or equal to those in the 2010s. In the 2010s, capital costs for renewable energy were relatively high, but feed-in tariffs and other policy incentives promoted the introduction of renewables, resulting in high investment amounts. From the 2020s onward, while renewable energy will be further introduced, investments will decline due to decreased capital costs resulting from the installation of larger wind turbines and other factors. In Emerging Market and Developing Economies, a remarkable increase in hydro and wind power generation will result in larger investments from the 2020s onward. In the Advanced Technologies Scenario, renewables and nuclear power will be more actively introduced, leading to larger investments compared with the Reference Scenario.

5.3 Investments in natural gas and oil

Although there are moves toward carbon neutrality and a shift from dependence on certain regions including Russia for fossil fuel supply, investments in natural gas and oil which enjoy increasing demand will not necessarily decline in the future.

Investments in natural gas will increase in the Reference Scenario, mainly in Africa and the Middle East, expanding about 1.5 times in the 2040s from the 2010s (Figure 5-5). In the Advanced Technologies Scenario, as well, where renewables and nuclear power generation will increase, investments in the 2040s will be almost equivalent to those in the 2010s.

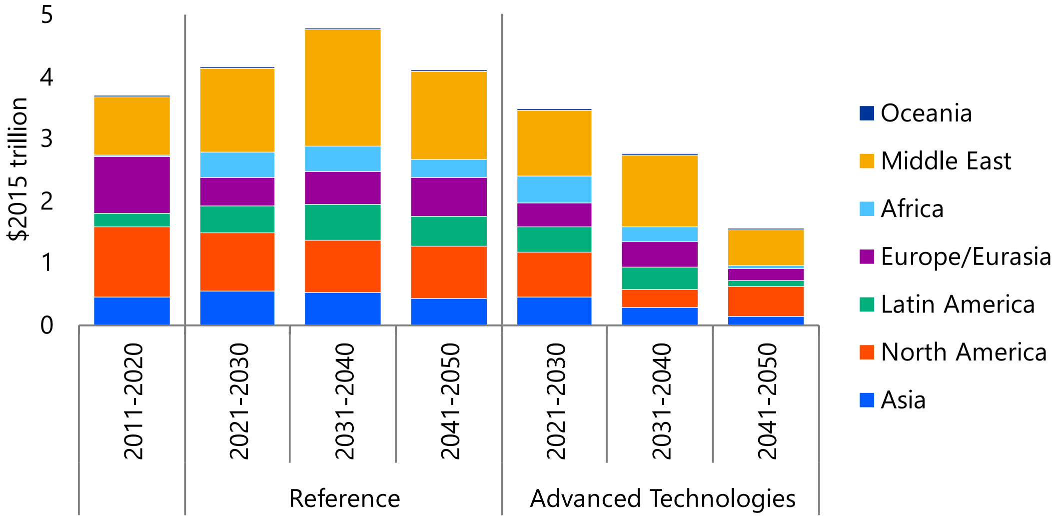
Figure 5-5 | Investment in the natural gas sector



Note: 2011-2020 are estimates.

Investment in oil will peak in the 2030s in both the Reference and the Advanced Technologies Scenarios, followed by a gradual decline (Figure 5-6). Investments in North America, where crude oil production will be below the current level in 2050 and costs are high, will contribute significantly to these trends.

Figure 5-6 | Investment in the oil sector



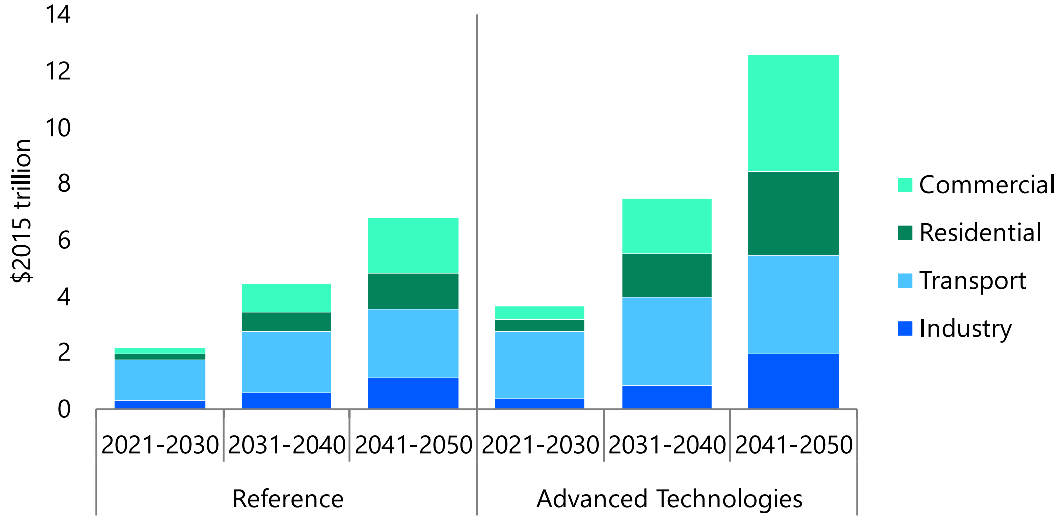
Note: 2011-2020 are estimates.

5.4 Energy efficiency investments

On the demand side, the buildings and transport sectors will account for the dominant share of investments for introducing more energy-efficient[21] equipment (Figure 5-7). In the buildings sector, investments in the commercial sector will exceed those in the residential sector. In the transport sector, investments will increase as the shift from gasoline- and diesel-fuelled vehicles to electrified vehicles takes place. In the Advanced Technologies Scenario, more electrified vehicles will be introduced than in the Reference Scenario, resulting in a significant increase in investments.

[21] Energy efficiency levels in 2019 are considered as the baseline.

Figure 5-7 | Global energy efficiency investments



Part II

Energy security challenges and response strategies under new circumstances

6. Energy security strategy in light of the Ukraine crisis and energy transition

6.1 Issues for a response strategy to phase out the dependence on Russian natural gas

Phasing out dependence on Russia: fundamental differences between Europe and Japan

The European Union's goal of "phasing out dependence on Russian fossil fuels by 2027" is a political declaration and is not currently legally-binding. As such, even though European Union member states are formulating and implementing concrete measures such as introducing more liquefied natural gas (LNG) and reducing natural gas consumption, much remains in flux due to the different levels of dependence and the geographical position of the member states.

Meanwhile, after Russia's invasion of Ukraine, Japan has rectified its energy procurement policy to gradually reduce its overall dependence on Russia. However, it has no plans in the short term to voluntarily abandon LNG produced in Sakhalin. Thus, Japan's response is to maintain project concession and purchase agreements while preparing for contingencies.

Behind the European Union's declaration is the region's traditional heavy dependence on Russia, especially for natural gas. On the other hand, Japan's main aim in using Russian LNG is to diversify supply sources and strengthen energy supply security.

Challenges for Japan

On 30 June 2022, a Russian presidential decree was issued which stated that the rights and obligations of the Sakhalin 2 project would be transferred to a Russian company that will soon be established. The project's foreign corporate shareholders were unilaterally notified that unless they express within one month their intention to remain in the project under the new conditions and subsequently receive approval from the Russian government, their shares would be sold in Russia and any proceeds would be frozen within the country.

In line with the presidential decree, on 2 August, a cabinet order was issued to determine the Russian corporation that will take over operation of the project, and it was established on 5 August. Of the existing foreign shareholders, the two Japanese companies have expressed their intention to participate under the new conditions and will stay in the project.

The continued participation of the Japanese companies in the project and the delivery of LNG supplies to those companies is desirable. At the same time, it is important to prepare against contingencies in both capital participation and supply going forward. If the LNG supply from the project is threatened, both short- and long-term actions will be needed to secure other sources to replace around 6 million tonnes (Mt) of LNG per year.

For the period from the winter of 2022-2023 to 2025, Japan is relying on securing supplies from other projects and from portfolio players (such as majors), as well as surpluses from Chinese players. The Sakhalin 2 project was the centrepiece of efforts to diversify nearby supply sources.

The current situation will be a test of Japan's supply diversification efforts for sources located further afield. The LNG procured from the project is largely based on long-term contracts with oil-linked pricing, and so the import prices have been competitive compared to other supply sources. There are concerns that procurement from alternative sources may push up LNG prices.

From 2026, it will be vital for Japan to secure long-term LNG contracts from other sources, including new projects. In addition to Sakhalin 2, Japanese companies are involved in the Arctic LNG 2 and Kamchatka FSU projects. The outlook for these projects and their impact on supply must be examined.

This decree will be a setback for new LNG development projects in Russia, and will make it harder for Russia to regain trust as an investment destination and supply source. However, with a view to the long-term, Japan should make it clear both in and outside the country that Russia should not be threatening with a unilateral announcement any capital participation in and sourcing from the Sakhalin 2 project, which are within Japan's legitimate rights.

Note on the European Union's measures to phase out dependence on Russia

The European Union authorities have proposed the following measures for phasing out dependence on Russia: securing gas supplies by increasing LNG imports from Qatar, the United States, Egypt, and West Africa and by increasing pipeline gas imports from Azerbaijan, Algeria, and Norway; exploring cooperation on the medium-term gas market in consultation with the Group of Seven (G7) countries and major gas importing countries including Japan, Korea, China, and India; increasing biomethane production in the region; and improving energy efficiency, installing heat pumps, increasing non-gas energy supplies, chiefly clean energy such as wind and solar photovoltaics, and saving electricity and gas. In practical terms, the measures also include increasing the operation of coal-fired power generation and reviewing nuclear power generation.

Though not in all member states, European companies as well as European regulators in some countries, are moving toward increasing LNG purchases. This has led to an increase in front-loaded purchasing even before the demand period, both for the short, and medium to long term. There will be an increase in long-term contracts for LNG once the baseload demand is determined. More European LNG buyers, who have had difficulties in making long-term commitments due to the greenhouse gas (GHG) reduction policy, are now securing LNG under 15- to 20-year contracts.

In addition, the European Commission competition authorities have terminated an investigation into the Qatari LNG contract that had been ongoing since 2018, causing speculation that this is a compromise to secure Qatari LNG for the European Union. Further, the Directorate-General for Energy of the European Commission has established a task force on energy security with the United States government to actively secure long-term LNG contracts.

These developments should hopefully raise awareness of the role of LNG and the importance of upstream investment. Japan and Europe should explore ways to cooperate on the development of LNG production projects. Indeed, the G7 Energy Ministers' Joint Statement issued at the end of June 2022 has reaffirmed the importance of LNG investment.

Meanwhile, attention should also be paid to the destabilising impact of the European Union's moves on the short-term market. For example, the 37 Mt of additional LNG that the European Union is planning to import in 2022 would theoretically absorb the entire increase in the global LNG supply expected in the year. Also, European gas prices will remain high to attract and redirect cargoes from Asia to Europe, which in turn will cause Asian LNG prices to increase. Although additional non-Russian pipeline gas imports should be a more realistic solution, there is no guarantee of supply stability.

Another round of measures to reduce gas demand has been submitted, but it is not clear whether the targets will be met or how effective they will be, as they exempt some member states and the energy situation varies among countries.

The greatest concern is the impact on the global gas market. First, the European Union's policy will make it more likely for the world's gas prices to exceed previous projections for the remainder of the 2020s. This raises the risk that the emerging gas demand and energy transition in Asia will be disrupted or delayed.

The European Union has also set a political goal of "phasing out dependence on Russia by 2027", which means reducing Russian gas supplies to zero by the end of 2027. This also implies that the European Union needs Russia to supply gas consistently (in terms of both volume and price) according to the remaining contracts for the five years until the supply reaches zero.

Is it conceivable that a supplier that is to be phased out would continue to provide gas stably? How would any penalties and dismantling costs be handled in case a contract is terminated mid-term? As such, gas supplies via the Nord Stream 1 pipeline from Russia to Germany via the Baltic Sea were reduced to 40% of capacity in early June, to 20% in late July, and to zero at the end of August.

Already the operator company of Nord Stream 1 pipeline has cited problems in restoring equipment after maintenance due to economic sanctions, oil leaks during maintenance, and other issues. If declines of this scale continue, they could reduce the annual supply by about 40 Mt of LNG equivalent, which would cause supply crunches in the world's gas and LNG markets, not just the European gas market. In the longer term, when the conflict somehow comes to an end and Russia returns to normalcy, the issue of how to re-establish economic relations, including gas and other fossil fuel supplies, will also arise.

6.2 The role and challenges of natural gas in Asia's energy transition and energy security

Asia's shift toward reducing and removing carbon emissions

More and more Asian countries are declaring carbon neutrality targets. For example, China has declared that it will become carbon neutral by 2060, India by 2070, Indonesia by 2060, Malaysia by 2050, Thailand by 2065, and Viet Nam by 2050.

However, their specific methods for achieving carbon neutrality remain unclear. For example, India relies on coal for 43% of its primary energy supply and 72% of its power generation (2020, IEA). To become carbon neutral, India must replace all the coal with renewable energy, nuclear power, ammonia, and hydrogen. Some sectors of industry are hard to decarbonise in an economical and rational way using current technologies. Consequently, negative emission technologies are required to remove carbon dioxide (CO_2) emissions (namely BECCS, which combines biomass-fired power generation with carbon capture and storage (CCS), and DAC, which captures CO_2 from the atmosphere). Further, in addition to building a new energy infrastructure with no carbon emissions, it is also necessary to deal with the mass disposal of existing facilities and reallocation of jobs associated with the restructuring of the energy system. They are all major problems without easy solutions, all to be done in the limited time frame of the next 3 to 4 decades. Thus, in practice, there is great uncertainty regarding how to achieve carbon neutrality.

A sustained economic growth and weak financial base are two examples of factors that add to the difficulty of the energy transition in Asian Emerging Market and Developing Economies. These economies still have much room for growth and as economic growth and energy demand are highly correlated, one of the greatest concerns for these countries is how to secure a stable energy supply to meet the increase in demand. Some countries do not have sufficient renewable energy resources or unable to fully provide for a stable supply yet while many of the promising decarbonisation technologies are still in the demonstration stage even in developed countries. An example of the former is the mass deployment of variable renewable energy, and that of the latter is hydrogen-fired power generation. It is understandable that countries that must secure a stable supply to meet ever-increasing demand hesitate to adopt uncertain technologies like these.

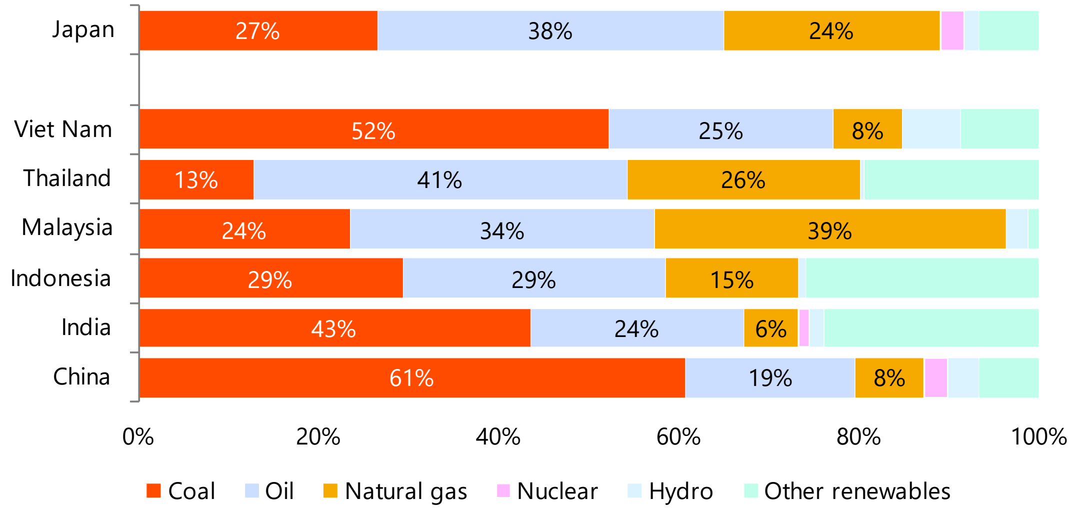
Equally or even more important than a stable supply is the question of affordability. Some countries still have a sizeable poor population, and governments must provide low-cost energy even by providing subsidies to poorer citizens. Furthermore, as the viability of their industries also rests partly on cheap energy and labour, rising energy costs can undermine the competitiveness of their still-growing industries, the livelihoods of their citizens as well as the governments that provide subsidies. Meanwhile, many decarbonisation technologies are unfortunately more expensive than conventional technologies. Or some, like nuclear power, require extremely large initial investments. Naturally, the cost of new technologies will gradually come down as they become more widely used. However, Emerging Market and Developing Economies cannot wait for those costs to fall while their energy demand is growing rapidly. Pressed to make investment decisions, it would be understandable if they hesitate to adopt technologies that are more costly than existing ones. This tendency is even more visible now that fossil fuel prices are at historically high levels, even spurring a back-to-coal movement.

Realistic means to decarbonise

As described so far, while Asia is setting an ambitious goal of going carbon-neutral by mid-century, it faces various difficulties in the actual energy transition stemming from energy security (securing a stable energy supply at reasonable costs). What would be a realistic energy transition path for Asia? The key is a two-step decarbonisation process that takes advantage of the unique features of natural gas.

The first feature of natural gas is its ability to supply large and stable amounts of energy, and for Asia, it enhances its energy security by diversifying the energy mix (recent problems arising from Russia's invasion of Ukraine are discussed in subsequent sections). Only a few countries in Asia use natural gas extensively (Figure 6-1) because very few have sufficient natural gas resources, and their geography makes it hard to use pipelines, which is a less expensive means of transport.

Figure 6-1 | Primary energy supply in selected Asian countries [2020]



Source: International Energy Agency "World Energy Balances July 2022"

Meanwhile, the region's major countries of China, India, and Indonesia have ample coal resources and have been using them actively for a long time. This makes the continued use of coal the rational option for energy security, but not an acceptable solution to address climate change. Finance for coal investments will for sure dwindle going forward, so the region must find an alternative to coal and this is where natural gas comes in. Natural gas, like coal and unlike renewables, has a high energy density and can be transported and supplied in large amounts. This makes natural gas suitable for emerging and developing countries where energy demand will certainly increase, and for industrialised countries with sizeable demand.

The second feature is that by switching their main energy source from coal to natural gas, many Asian countries can start the decarbonisation of their energy systems while maintaining supply levels. Table 6-1 is a simplified estimate conducted under fixed conditions. We can see that switching to natural gas would reduce CO_2 emissions by a nonnegligible amount when compared to Japan's 2020 CO_2 emissions of 1 038 Mt-CO_2eq (IEA).

Table 6-1 | Coal dependency and resulting CO_2 emissions reduction of switching to natural gas in selected Asian countries [2020]

	Share of coal in power generation	Share of coal in industry	CO_2 reduced by switching to natural gas ($Mt\text{-}CO_2eq$)
China	64%	43%	1 086
India	72%	37%	328
Indonesia	62%	36%	65
Malaysia	47%	9%	23
Thailand	21%	27%	16
Viet Nam	50%	57%	52

Notes: 50% of the coal used for power generation and for industry is switched to natural gas. We assume an increase in efficiency of an average 15% in the power generation sector and an average 10% in the industrial sector.
Source: International Energy Agency, "World Energy Balances July 2022"

By taking advantage of these two features of natural gas—its high energy density and low carbon emissions—we can chart a realistic decarbonisation pathway for Asia. Renewable energy is ideal in terms of decarbonisation, but its energy density is low and therefore not powerful enough for countries that must introduce large amounts of additional energy supply in a short time. In addition, renewable energy is still expensive to deploy depending on the country and energy type, making it unlikely to be selected in the market or by countries with limited financial strength. These issues can be addressed by conducting decarbonisation in a two-phase process by adding an intermediate phase, in which coal and oil are replaced with natural gas. The first phase is the shift from coal and oil to natural gas, for which we will calculate the supply volume needed in the short to medium term and present a realistic solution to the cost issue. In the second phase, a variety of measures will be added to achieve carbon neutrality, including the decarbonisation of natural gas (hydrogen and carbon capture, utilisation and storage [CCUS]), as well as renewable energy. Another important advantage of the two-phase approach is that it will enable countries to "buy time" until hydrogen, CCUS and other technologies, which the world is currently intensively developing, become available and prevent natural gas investments from turning into stranded assets, therefore justifying current investments in natural gas.

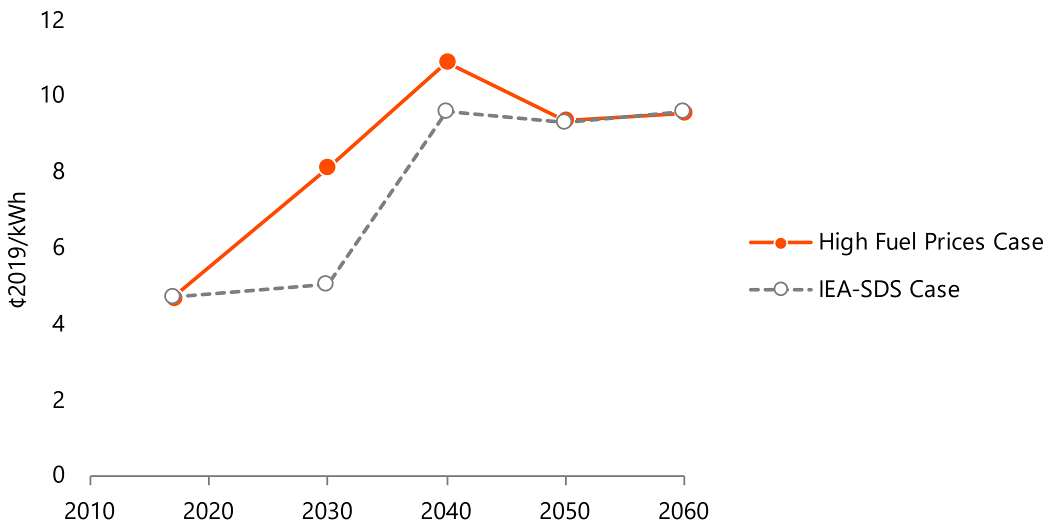
Uncertainties related to natural gas supply

As described above, natural gas could play an important role in Asia's energy transition, but the recent supply-demand tightening and soaring prices of natural gas, especially LNG, have cast a shadow over this scenario. Western countries, chiefly in Europe, which aim to become independent from Russian energy, are scrambling to secure supplies of natural gas and LNG other than from Russia. Europe currently uses vast amounts of natural gas from Russia, and there is no immediate alternative country that can export natural gas anywhere in the world. This has inevitably tightened the world's supply and demand for natural gas, resulting in unusually high prices. The current price levels are unsustainable not only for emerging and developing Asian countries but even for developed countries and have caused those Asian countries to hesitate to use natural gas.

The only way to resolve this issue is to increase investment in natural gas and LNG production and transportation outside of Russia. Fortunately, there are ample natural gas reserves remaining in the world and many projects have been prepared to develop them. As these development projects make progress, the world's natural gas supply and demand will eventually balance out and prices will settle down.

Another challenge is to change the attitude toward financing natural gas investments. Coal divestment by international financial institutions and those in developed countries is now an irreversible trend. There are also signs of caution toward natural gas, though such signs have receded somewhat since it became essential to deal with the recent tight gas supply-demand balance. If natural gas divestment becomes a decisive trend as top priority is placed on climate action again, Asia's energy transition and energy security will become more costly and its relative economic power may weaken. As shown in Figure 6-2, if fossil fuel prices, including natural gas, remain high through 2030 as a result of limited investment in additional supplies, the marginal cost of electricity in the Association of Southeast Asian Nations (ASEAN) would be approximately 60% higher in 2030 than projected under the fossil fuel price assumption of the Sustainable Development Scenario (SDS) of the International Energy Agency's "World Energy Outlook".

Figure 6-2 | Impact of fossil fuel prices on ASEAN's marginal electricity cost



If such investments are indeed conducted, they would not only stabilise the currently volatile natural gas and LNG markets, but would also help reduce the cost of the energy transition and energy security in Asia and prevent negative impacts on regional economies.

For this to happen, Asian countries must assign a clear role to natural gas as a transition energy in their long-term strategy, provide risk money for necessary natural gas-related investments, develop technologies that decarbonise their natural gas assets for use in the future (CCS, CCUS, hydrogen and ammonia), and support their implementation.

Lastly, we discuss scenarios about natural gas prices. If prices fall to acceptable levels within a few years, the "two-phase decarbonisation process using natural gas" will re-emerge as a realistic option for Asia. Conversely, if very high natural gas prices remain the norm for five or ten years, natural gas may cease to be the energy of choice, and instead investments in carbon-free energy systems such as renewables, nuclear power, and storage batteries may rapidly increase. Whether investments to develop natural gas will be made in the next few years to ease the supply-demand balance and lower prices will be crucial for the two-phase decarbonisation process.

6.3 Importance of market stability for decarbonising fossil fuels

Market stability is always essential for fossil fuel supply, but the stability of fossil fuel markets, especially natural gas markets, will be key for decarbonising fossil fuels in the future.

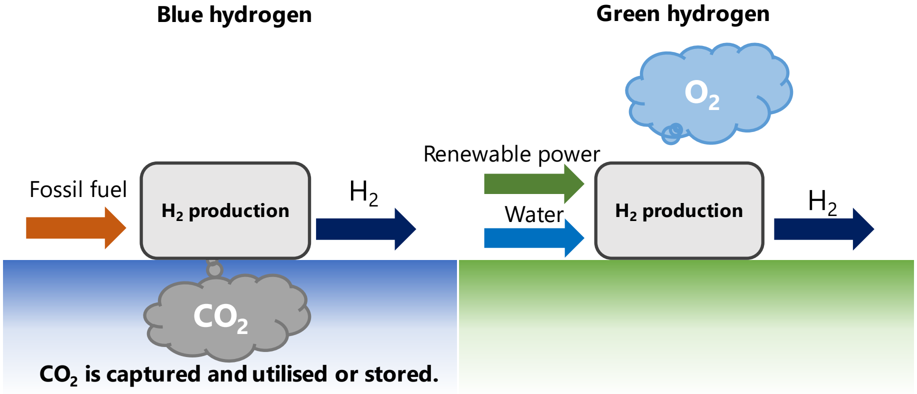
Fossil fuel decarbonisation discussed here refers to reducing emissions from the use of fossil fuels while continuing to use them in the existing supply infrastructure. The tools for realising this concept are the so-called "4R technologies" presented in the IEEJ Outlook 2021 and 2022[22]. Among them, the core technologies for decarbonising fossil fuels are manufacturing blue hydrogen, which is produced with the recovery of CO_2 generated during its production, introducing CCS in manufacturing plants and power plants that emit large amounts of CO_2, and carbon recycling technology that reuses the captured CO_2 for other purposes.

The concept of fossil fuel decarbonisation, as noted in past issues of the IEEJ Outlook, presents very realistic and effective carbon reduction options as the world proceeds with decarbonisation. On the other hand, if fossil fuel prices and supply are unstable and uncertain, investments in the supply and use of fossil fuels themselves will naturally stagnate, hampering the concept of decarbonising fossil fuels by leveraging their supply infrastructure. The development of many of the 4R technologies for decarbonising fossil fuels is incomplete and is expected to continue for a long time. Sufficient investment is required throughout the supply chain from fossil fuel production to transportation, refining, and end-use to ensure the supply of fossil fuels, as it is also a prerequisite for the development of those technologies.

Blue hydrogen and blue ammonia are produced from technologies that will play a central role in fossil fuel decarbonisation. They are produced from fossil fuels while the CO_2 emitted during the production process is captured and stored in the ground or reused (Figure 6-3). Green hydrogen, which is produced by electrolysing water with renewable energy, is another option but a difficult one to adopt when hydrogen must first be introduced in view of both quantity and price. Thus, blue hydrogen and ammonia are also tasked with the role of forming the market when they are initially introduced. If the price of natural gas, the primary feedstock for blue hydrogen and ammonia, is high, they will not be competitive and thus will not be introduced easily. In this sense, for hydrogen to become a commonly and globally used carbon-free fuel as soon as possible, it is necessary to first introduce blue hydrogen and ammonia, and that requires a stable natural gas market.

[22] IEEJ Outlook 2022, pp. 145-156; IEEJ Outlook 2021, pp. 137-147

Figure 6-3 | Blue hydrogen and green hydrogen



Notes: H_2 and O_2 stand for hydrogen and oxygen, respectively.

7. Measures to strengthen power supply stability and the importance of nuclear power generation

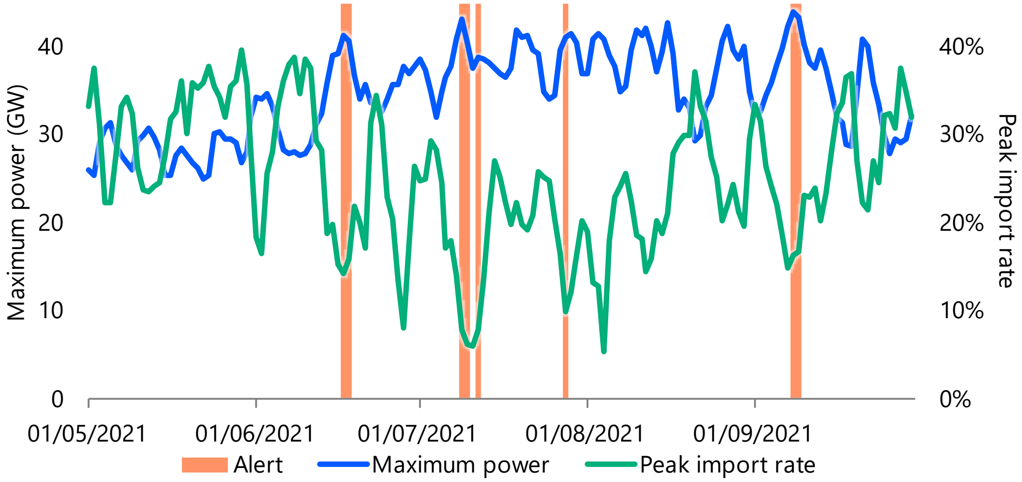
7.1 Challenges for power supply stability under liberalised markets, mass introduction of renewable energy, and rising fuel prices

In the past, power supply stability has been disrupted by major power outages such as the California electricity crisis in the summer of 2000 and winter of 2001, the Northeast blackout in North America in August 2003, the blackout in Italy in September 2003, and the blackout in Western Europe in November 2006. However, except for the California electricity crises, which were caused mainly by Enron's market manipulation, the others were caused by inadequate monitoring of the transmission system; the blackouts in Northeast United States and Italy were caused by transmission lines coming into contact with trees, and the Western Europe blackout by the disconnection of a powerline that failed to meet reliability standards to let a ship pass. Thereafter, reliability standards were revised and given legal binding force and wide-area grid monitoring was enhanced in the United States and the European Union, making similar outages less likely to occur.

Under a liberalised power system, generation facilities that do not trade in the "market" or are used (generate power) infrequently have no choice but to be suspended or closed. The introduction of renewable power generation that was expanded with government support, resulted in a gradual increase in the suspension and closure of thermal power generation plants in many developed countries and regions as their capacity factor dropped and profitability deteriorated. This caused the overall supply capacity of the power system to decrease, resulting in sporadic cases of supply-demand crunches when power plants failed to keep up with surging electricity demand during times of extreme heat or severe winters, or when power plants reduced their output or shut down due to heat waves and cold waves.

The California Independent System Operator (ISO) implemented planned blackouts on 14 and 15 August 2020 due to a tight supply-demand balance caused by heat waves, and in 2021, heat waves resulted in the issuance of eight power conservation requests between June and September (Figure 7-1). Japan also issued a power supply alert when electricity demand soared due to low temperatures on 22 and 23 March 2022, after several power plants were shut down due to an earthquake off Fukushima prefecture on 16 March 2022. Another alert was issued when demand soared again between June 27th and 30th, due to a sudden rise in temperature.

Figure 7-1 | California ISO maximum power and peak import rates for summer 2021



Source: Created based on California ISO, "Today's Outlook"

Power plants located inland that take in cooling water from rivers face a risk of causing supply shortages when a heat wave strikes and water levels run low, forcing them to reduce their power output. Indeed, surplus capacity shrank in Europe when a heat wave struck in late July 2022. Although this did not result in a supply-demand crunch, it did cause wholesale electricity prices to skyrocket. An example of a power cut caused by cold weather is the planned blackouts that the Electric Reliability Council of Texas (ERCOT) experienced in February 2021. In this incident, power supply shortages occurred as a result of wind turbines freezing, pipe failings at natural gas-fired power plants, and natural gas supplies falling due to wellhead freezing at natural gas production facilities and natural gas processing plant shutting down. The PJM area in Northeastern United States also saw an increase in power generation equipment failures due to cold weather in January 2014. As a countermeasure, the Capacity Performance system was introduced in 2018, in which additional compensation is paid in the capacity market to generating facilities that have made remodelling investments[23] so that they can continue to operate during severe weather conditions. In January 2018, shortly after its launch, a more severe cold snap than the one in 2014 hit, but the number of facilities that failed and shut down was reportedly smaller than in 2014. This type of cold wave protection is known as winterisation in the United States and is being implemented in more and more regions that are at risk of cold weather. However, though electric utilities have taken measures, as in the case of Texas' ERCOT, no mechanisms are in place to urge natural gas supply facilities to introduce cold weather protection, and this remains an issue.

In addition, typhoons and hurricanes can also cause widespread power outages by triggering the failure of electricity network facilities. An example of a well-known widespread power outage in the United States was caused by Hurricane Sandy, which hit the U.S. East Coast from late October through early November 2012, leaving 930 000 houses without power in Connecticut, Maryland, New Jersey, New York, Pennsylvania and West Virginia. The damage

[23] Measures taken to prevent fuel, conveyors and piping from freezing during cold waves.

took a long time to recover, sparking severe criticism, and resulted in the establishment of a cooperation system across power companies, which shortened the time to recover from hurricane-induced power outages thereafter. Japan also experienced widespread power outages in the Kansai Electric area caused by Typhoon No. 21 (Typhoon Jebi) and in the Chubu Electric area caused by Typhoon No. 24 (Typhoon Trami), both in 2018. Widespread power outages occurred also in the following year when Typhoon No. 15 (Typhoon Faxai) and Typhoon No. 19 (Typhoon Hagibis) struck, resulting in power outages in the area of Tokyo Electric and the areas of Tokyo Electric, Chubu Electric and Tohoku Electric, respectively. These power outages highlighted problems in how to gather and provide information and led to the introduction of a mechanism to facilitate smooth wide-area cooperation, including the establishment of a mutual aid system for disaster recovery costs.

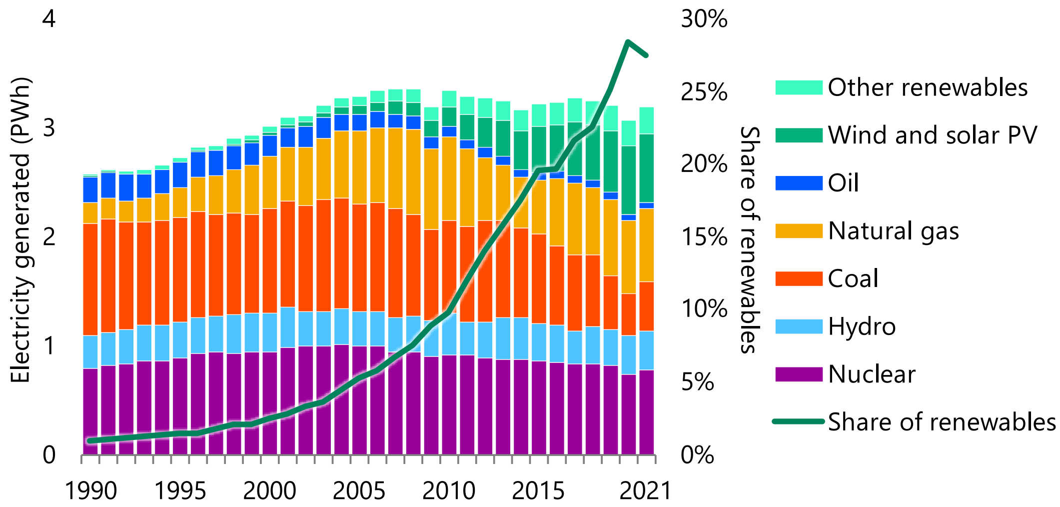
Surplus supply is shrinking in more and more countries and regions due to the liberalisation of electricity markets. As a result, some countries have established capacity markets where the supply capacities needed for stable supply (including excess supply capacity that was not used in case there was no heat wave or severe winter) can be purchased for a price. Previously, retail operators had been made responsible for securing supply capacities in the United States until a system was launched for regional transmission operators (RTOs) that operate wide-area markets and ISOs to bulk-purchase supply capacities on behalf of retail operators and charge fees to the operators. The California ISO mentioned earlier also has a capacity payment system in which retail operators pay compensation for supply capacities that are secured in advance. However, even by offering incentives to secure supply capacity with systems like these, it has sometimes been impossible to secure adequate supply during the summer months when demand increases.

In several European countries, it is becoming more and more difficult to build new natural gas-fired power plants due to the goal of decarbonisation, even though governments are promoting a policy to phase out coal-fired power plants. As a result, in Europe as a whole, conventional power plants such as nuclear power and thermal power are on the decline, and renewables are the only power source that is increasing. As such, advanced countries are now facing the problem of a growing share of natural gas-fired and renewable power generation in their power mix, causing difficulty in the construction of new conventional power plants. Because natural gas-fired power generation emits carbon dioxide (CO_2), it is difficult to build those plants now in California due to protests from environment-conscious residents. This has effectively made it impossible to deploy any power source other than renewables and storage batteries in California.

Just as it is difficult to predict wholesale electricity market prices, it is hard to foresee the closure of thermal power plants due to worsening finances over the long term. This is making it difficult for any developed country to conduct a long-term reliability assessment, which is a measure of long-term supply stability. As a result, it is no longer possible to reliably predict medium- to long-term electricity supply and demand, which is making it harder to make decisions to invest in new power plants. Meanwhile, the United Kingdom has announced plans to provide policy support for new power plant construction projects that contribute to both decarbonisation and supply stability, through systems that help ensure that investments can be recouped while taking the features of individual technologies into account (such as a revenue cap and floor system for international transmission lines, Contract for Difference [CfD] system for hydrogen-fired power generation, regulatory asset-base [RAB] system for nuclear power generation, and so on). Other advanced countries are likely to adopt similar systems.

In Europe, where the power generation mix has become increasingly skewed, natural gas spot prices began to soar in the fall of 2021 due to declining wind power output and insufficient natural gas inventories. Initially, it was expected that the spike in natural gas prices would subside after March 2022 as natural gas demand declined, but due to Russia's invasion of Ukraine it is not clear how long this situation will continue. The decline in Russian natural gas supplies is becoming a problem, and a disruption in supply would likely cause power shortages in Europe. Meanwhile, China and India, which have a high share of coal-fired power generation in their power generation mix, both suffered power shortages in 2021 due to coal shortages. A shortage of generating capacity relative to demand is called a kW shortage, while a supply-demand crunch caused by a fuel shortage such as the one above is called a kWh shortage. Japan too has experienced a kWh shortage when an unexpected cold wave hit in December 2020 and caused a shortage of liquefied natural gas (LNG), resulting in wholesale electricity spot prices to spike in the first half of January 2021. The Northeastern United State maintains a reasonable number of natural gas-fired power plants that can also burn oil, so as to help secure a stable supply by switching to oil when natural gas procurement runs short. Europe and Japan, whose power generation mix has become increasingly skewed, also need to develop technologies to secure alternatives like these.

Figure 7-2 | Electricity generated in the 28 European Union member states



Source: International Energy Agency "World Energy Balances"

Until now, future supply security has been evaluated by assessing the possible shortage of generation capacity (kW shortage) to meet the increase in demand. In recent years, however, supply crunches have occurred due to heat waves and cold waves, even when long-term assessments indicate that supply will remain stable. Efforts have been made to improve short-term reliability assessments by sampling and assessing past severe events, as is being done by the North American Electric Reliability Corporation (NERC). However, no quantitative method has been established to evaluate fuel security issues such as electricity generation shortages (kWh shortages) in case of an unforeseen event, due to the variety of fuel procurement methods and the difficulty of quantifying supplier country risk. As decarbonisation policies are implemented further, countries are expected to become more dependent on fewer types of power sources and how to evaluate the risk of kWh shortages for these power sources is another major issue for the future.

7.2 Renewed interest in nuclear energy, and future challenges

As countries set ambitious greenhouse gas (GHG) reduction targets, nuclear power is receiving renewed attention as a zero-emission baseload power source. Nuclear power is expected to play a role in achieving a low-carbon economy while limiting cost increases of the overall electricity system. Simultaneously with these discussions, some countries are developing new types of reactors, such as small modular reactors (SMRs) and Generation IV reactors, aiming for higher safety and economic efficiency and to meet demands (such as heat) not fulfilled by conventional reactors.

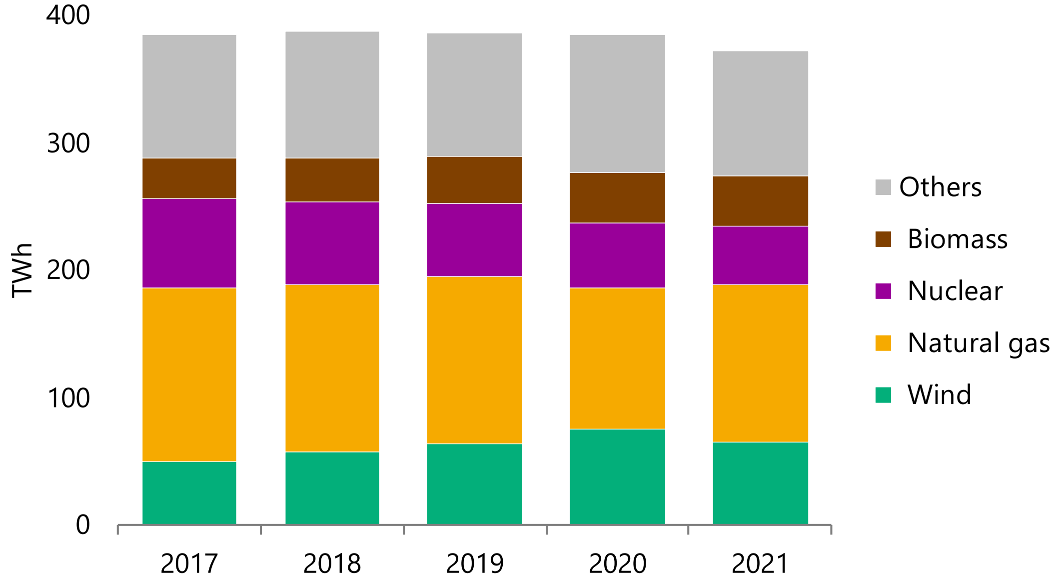
As decarbonisation remained the dominant theme of discussions, global fossil fuel prices began to surge from 2021, and with the invasion of Ukraine by Russia on 24 February 2022, it became even more important to secure a stable supply of energy. Though the invasion made the risk of military attacks on nuclear power plants real, the role of nuclear power in energy security, as well as the importance of its utilisation, is being recognised anew in Japan, Europe, and other countries. Renewable energy, which helps reduce the dependence on fossil fuels and boosts energy self-sufficiency, suffers from a varying output that depends on natural conditions. This means that nuclear power could play a unique role as a stable, large-scale baseload power source under thermal power constraints.

At the end of June 2022, the International Energy Agency (IEA) published a report titled Nuclear Power and Secure Energy Transition. This was the first time since May 2019 that the IEA issued a report focusing on nuclear energy. The basic argument of the report was the same as in 2019 , pointing out nuclear energy's potential to play an important role in achieving sustainable development with economic efficiency. However, this report emphasises the growing importance of nuclear power, referring to the soaring fossil fuel prices and the invasion of Ukraine, and sharply reflecting the growing concern about energy security.

In response to Russia's invasion of Ukraine, the United Kingdom published its British Energy Security Strategy in early April 2022. The strategy outlines a comprehensive development policy for wind, solar photovoltaics and hydrogen energy as a means of increasing self-sufficiency. It also sets a target of installing up to 24 GW of nuclear power generation capacity by 2050 to provide 25% of the nation's electricity supply. This is a very ambitious target that far exceeds the United Kingdom's installed nuclear power generation capacity of approximately 8 GW as of 1 January 2022. In May, the United Kingdom government announced the establishment of a £120 million nuclear energy fund to achieve this goal. The United Kingdom is also widely introducing renewable energy, especially wind power generation, with the installed capacity increasing each year, although the electricity output declined in 2021 mainly because of a drop in wind power compared with an average year. The decline was compensated mainly with natural gas-fired power (Figure 7-3), but the United

Kingdom appears to be focusing on the supply stability of nuclear power in its strategy because the country needs to end its dependence on fossil fuels in the future.

Figure 7-3 | The United Kingdom's power generation mix



Source: International Energy Agency "World Energy Balances July 2022"

The United Kingdom had indicated its intention to build new reactors amid a series of closures of its existing plants, but no significant progress had been made. The United Kingdom plans to apply a CfD to the ongoing Hinkley Point C project as a support measure, but the base price[24] of £92.5/MWh has been criticised as being too high. In addition, because the CfD is designed such that support can be received only after power generation starts, it had not been able to fully alleviate the uncertainty of nuclear power generation, which requires enormous investments and many years for the construction phase. As such, the United Kingdom government is considering a new support system called the RAB model (regulated asset based), which makes it possible to secure revenues with some level of certainty early on and is thus expected to reduce the uncertainty associated with CfD and make it easier to attract investment. Since failure to agree on the financing method was one of the reasons why Hitachi, Ltd. pulled out of the Wylfa Newydd construction project, it is important to increase the possibility of financing by implementing risk mitigation measures like this one.

France, Europe's largest nuclear energy user, has also declared that it will continue to use nuclear energy. In his speech on 10 February 2022, President Emmanuel Macron announced his policy of phasing out dependence on fossil fuels by expanding nuclear power and renewable energy. In particular, for nuclear power, he revealed plans to build at least six new European Pressurised Reactors (EPR2) and to consider building eight more. As this speech was made prior to the invasion of Ukraine, it was not suddenly been prepared as a response. It

[24] Also called the strike price. The difference between this price and the price of electricity in the market is paid to the power producer.

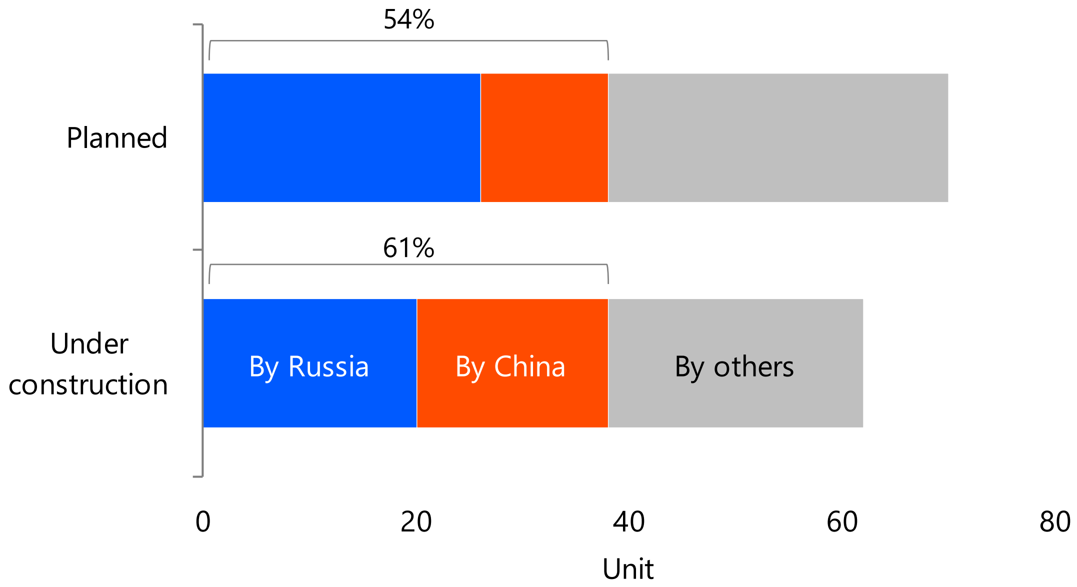
included a passage that reiterates France's long-term quest for energy self-sufficiency and phasing-out of fossil fuel dependence.

It is noteworthy that President Macron had mentioned plans to restart the construction of new nuclear plants already in October and November 2021. Furthermore, in France, transmission system operator RTE conducted an analysis of the long-term power generation mix and published the key results in October 2021. The analysis examined six main scenarios, ranging from one in which nuclear power is phased out and renewable energy is increased to 100% by 2050, to one in which 14 EPR2s and several small modular reactors are built. The analysis indicated that the total electricity system cost tends to be lower for scenarios with nuclear new builds compared to those without, and recognises nuclear power as a stable power source from an economic perspective. President Macron's declaration to build new plants is believed to be based on the results of this analysis. Since the decision to build a nuclear power plant and the actual construction take a long time, it would be ideal to have a long-term perspective, develop a plan before a crisis emerges, and steadily proceed with the plan, rather than suddenly reacting after something like the invasion of Ukraine.

In July 2022, Prime Minister Élisabeth Borne announced the decision to nationalise Electricité de France (EDF) 100% in order to strongly promote decarbonisation. As mentioned earlier, nationalisation is one viable option because building new nuclear power plants requires large investments and long lead time. Policies like these, including the RAB model in the United Kingdom, appear to run counter to the liberalisation of the electricity market in European countries to date. However, it also means that both the United Kingdom and France have taken bold decisions to realise ambitious policy goals, regardless of going against liberalisation in some respects. This has very important implications for Japan's energy policy.

As mentioned, the importance of nuclear energy for energy security is being recognised, but it also matters which country's companies are involved in nuclear-related development. For example, Finland has cancelled its contract with Russia's state-owned nuclear company Rosatom for the construction of Hanhikivi Unit 1 in May 2022, while Ukraine, the victim of Russia's invasion, plans to install a total of nine AP1000 light water reactors manufactured by U.S. Westinghouse. Ukraine's neighbour, Poland, is working with U.S. and French companies to introduce new nuclear power plants. On the other hand, the construction of Russian-made reactors continues in China, India, Türkiye, Bangladesh, and Hungary, and in July 2022, Rosatom began the construction of Egypt's first nuclear power plant, El Dabaa Unit 1. When classified by country of manufacturer, a high percentage of the reactors currently under construction or planned are made in China or Russia, indicating their dominance of the current reactor market (Figure 7-4).

Figure 7-4 | Reactors under construction or being planned worldwide [1 January 2022]



Source: Compiled and prepared based on "Trends in Global Nuclear Power Development", 2022 Edition by the Japan Atomic Industrial Forum

A series of new construction projects by Western companies are seeing significant overruns of construction periods and costs from initial plans, including Vogtle Units 3 and 4 in the United States., Flamanville Unit 3 in France, and Olkiluoto Unit 3 in Finland. The main reasons have been the sharp decline in the number of new construction projects which has caused a loss of construction expertise, and having to change the design after construction has begun to meet regulatory requirements. If these problems cannot be remedied in future projects, it will be difficult for Western countries to regain their share in the global market. Even if security is becoming more important in decision-making in energy policy, it is hard to imagine that this alone will enable Western companies to attract business. It is becoming ever more important whether a company can offer sufficiently attractive conditions to entice customers.

8. Critical mineral issues and energy and economic security

8.1 Introduction

The use of fossil fuels is expected to drop significantly when the world becomes carbon neutral, mitigating geopolitical security challenges caused by the heavy distribution of fossil fuel resources in the Middle East and Russia. However, to achieve carbon neutrality, widespread deployment and use of low-carbon technologies such as renewable energy, electrified vehicles and hydrogen are essential. This is expected to cause a rapid increase in demand for rare metals, which are considered essential for these technologies. These mineral resources are also distributed unevenly around the globe, giving rise to new energy security issues. Accordingly, in collaboration with Japan Organization for Metals and Energy Security (JOGMEC) and Mitsubishi UFJ Research and Consulting Co., Ltd. (MURC), we conducted a quantitative analysis of the future supply-demand balance of critical minerals that will play an important role in achieving carbon neutrality and attempted to identify possible issues.

It should be noted that the analysis results are just one of numerous simulations and that the current energy intensity is applied to all years through 2050 (without considering technological progress regarding the mineral intensity itself).

Further, in addition to the supply-demand simulation charts for each type of mineral, a comparison of reserves and demand is included for reference. The figures for reserves were prepared using data from the United States Geological Survey (USGS) and therefore are not linked with the simulation data.

8.2 Critical mineral supply and demand outlook

Estimation method

The future demand for various types of critical minerals is estimated by multiplying the quantity of each carbon neutral technology that is expected to be deployed based on this Outlook by the amount of minerals required per unit of each technology (intensity). The target carbon neutral technologies and types of minerals are listed in Table 8-1. Thermal power generation and conventional vehicles (ICVs) are not low-carbon technologies, but they are replaceable by carbon neutral technologies. The future critical mineral demand was estimated comprehensively by offsetting increases in mineral demand due to the spread of carbon neutral technologies against decreases in mineral demand resulting from the retirement of conventional technologies.

Table 8-1 | Analysis scope (types of minerals, carbon neutrality-related technologies) and mineral intensity

		Copper	Lithium	Nickel	Cobalt	Graphite	Silicon
Onshore wind	t/GW	2,880	-	430	-	-	-
Offshore wind	t/GW	8,000	-	270	-	-	-
Stationary LIB	t/GWh	340	120	531	173	881	-
Stationary VRF	t/GWh	-	-	-	-	-	-
Automotive batteries	t/GWh	425	120	531	173	881	-
Passenger ICV	t/1 000 unit	15	-	-	-	-	-
Passenger HEV	t/1 000 unit	17	0	1	0	1	-
Passenger PHEV	t/1 000 unit	22	1	5	2	8	-
Passenger BEV	t/1 000 unit	32	6	27	9	44	-
Passenger FCV	t/1 000 unit	19	0	1	0	13	-
Heavy duty ICV	t/1 000 unit	30	-	-	-	-	-
Heavy duty HEV	t/1 000 unit	35	0	1	0	2	-
Heavy duty PHEV	t/1 000 unit	43	2	9	3	16	-
Heavy duty BEV	t/1 000 unit	63	12	53	17	89	-
Heavy duty FCV	t/1 000 unit	38	0	1	0	27	-
Water electrolysis	t/GW	229	-	423	0	-	-

		Dyspro-sium	Neodym-ium	Vanadium	Platinum	Palladium	Rhodium
Onshore wind	t/GW	2	28	-	-	-	-
Offshore wind	t/GW	15	235	-	-	-	-
Stationary LIB	t/GWh	-	-	-	-	-	-
Stationary VRF	t/GWh	-	-	2,920	-	-	-
Automotive batteries	t/GWh	-	-	-	-	-	-
Passenger ICV	t/1 000 unit	-	-	-	0.000453	0.001499	0.000154
Passenger HEV	t/1 000 unit	0.036	0.324	-	0.000453	0.001499	0.000154
Passenger PHEV	t/1 000 unit	0.060	0.540	-	0.000453	0.001499	0.000154
Passenger BEV	t/1 000 unit	0.060	0.540	-	-	-	-
Passenger FCV	t/1 000 unit	0.060	0.540	-	0.020000	-	-
Heavy duty ICV	t/1 000 unit	-	-	-	0.000907	0.002999	0.000309
Heavy duty HEV	t/1 000 unit	0.072	0.648	-	0.000907	0.002999	0.000309
Heavy duty PHEV	t/1 000 unit	0.120	1.080	-	0.000907	0.002999	0.000309
Heavy duty BEV	t/1 000 unit	0.120	1.080	-	-	-	-
Heavy duty FCV	t/1 000 unit	0.120	1.080	-	0.040000	-	-
Water electrolysis	t/GW	-	-	-	0.010000	-	-

Notes: The mineral intensity values are fixed at the current level throughout the projection period. LIB stands for lithium-ion battery, VRF for vanadium redox flow battery, HEV for hybrid electric vehicle, PHEV for plug-in hybrid electric vehicle, BEV for battery electric vehicle and FCV for fuel cell vehicle. Car batteries are assumed to be replaced after 8 years on average.
Sources: IEA, "The Role of Critical Minerals in Clean Energy Transitions"; CSIRO, "Critical Energy Minerals Roadmap"; German Mineral Resources Agency (DERA), "Raw materials for emerging technologies 2021"; and others

Supply was estimated by aggregating the amount available from mining with the amount of recycled minerals. The production from mines was estimated taking into account the development stage and production capacity of each mine in the mining database[25]. However, when supply exceeded demand, restrictions were applied by assuming that there is no further development of mines. In other words, we assumed that development progresses only when supply is smaller than demand, and that production begins to meet the demand in the most recent year, starting with the mines considered at an advanced stage of development and with a large supply potential. The amount of minerals from recycling was estimated by projecting the quantity of each type of mineral disposed of in the future and multiplying it by the weight percentage of the amount that will be recycled (product recovery rate × recycling rate). The weight percentage of the waste to be recycled was set for future periods based on existing literature.

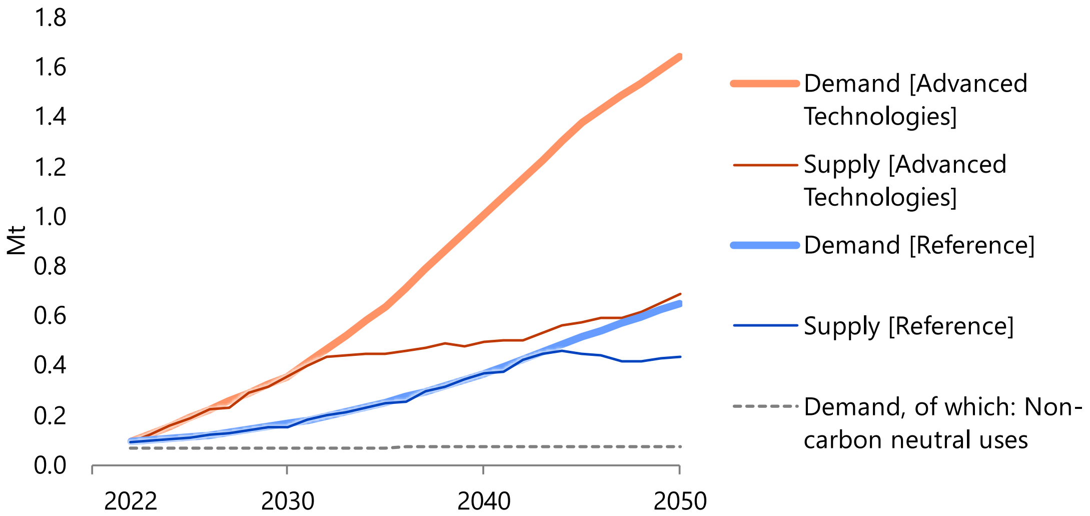
Estimation results

Lithium

Lithium is used primarily in storage batteries, and demand for it will grow greatly with the spread of electrified vehicles. In the Advanced Technologies Scenario, in which automotive electrification makes dramatic progress, demand will increase 18-fold from the current level by 2050. Automotive batteries degrade particularly quickly and should desirably be replaced after about eight years. It is necessary to consider not only the demand at the time of new car sales, but also of replacement. Under the Advanced Technologies Scenario, demand will exceed supply in around 2030. Note that the lithium supply from new mines was projected based only on those mines whose production output is clear and whose production volume and grade of mineral are known. We assumed that exploration would occur only for those mines with high prospects for development as of now; if exploration makes progress in mines that are currently unexplored or whose production output is unknown, future supply is likely to increase. The cumulative demand through 2050 will be on par with current reserves, but reserves may vary depending on economic factors. In addition, since the figures for reserves include a significant amount of undeveloped reserves, exploration and development of new mines will continue to be necessary. Recycling will also play an important role in avoiding supply shortages in 2050 and beyond.

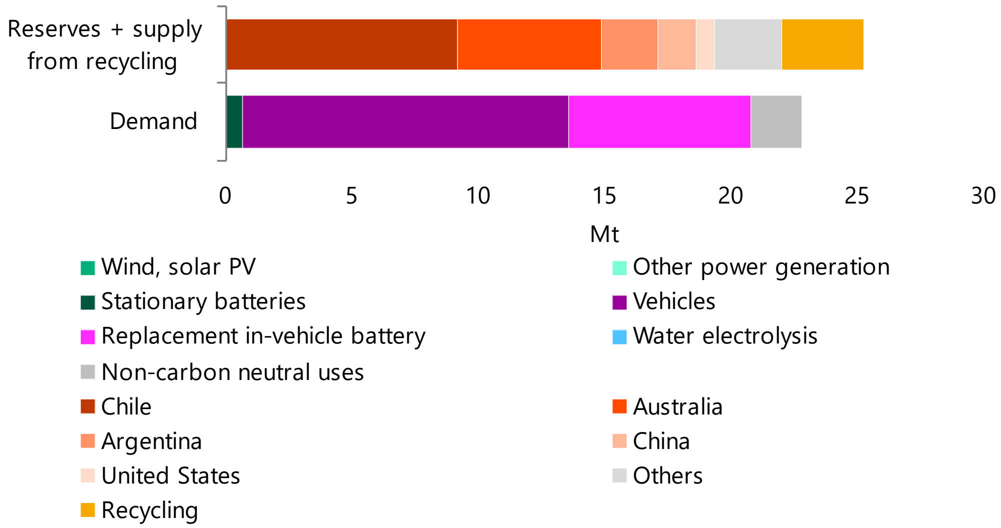
[25] Primarily S&P Global's database was used; Roskill's database was used for some cases.

Figure 8-1 | Global lithium supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-2 | Global lithium demand [Advanced Technologies Scenario, cumulative for 2022-2050] and lithium reserves

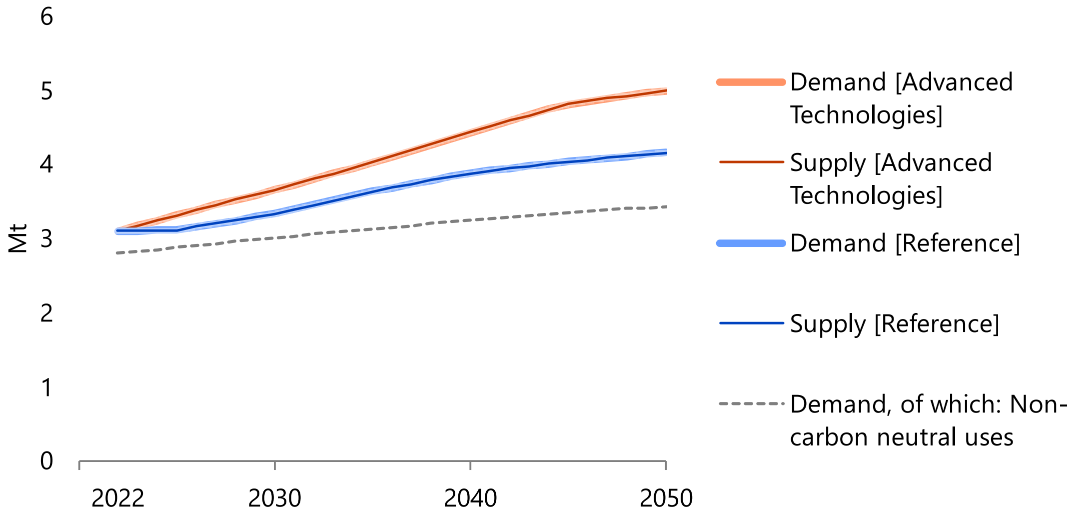


Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; United States Geological Survey

Silicon

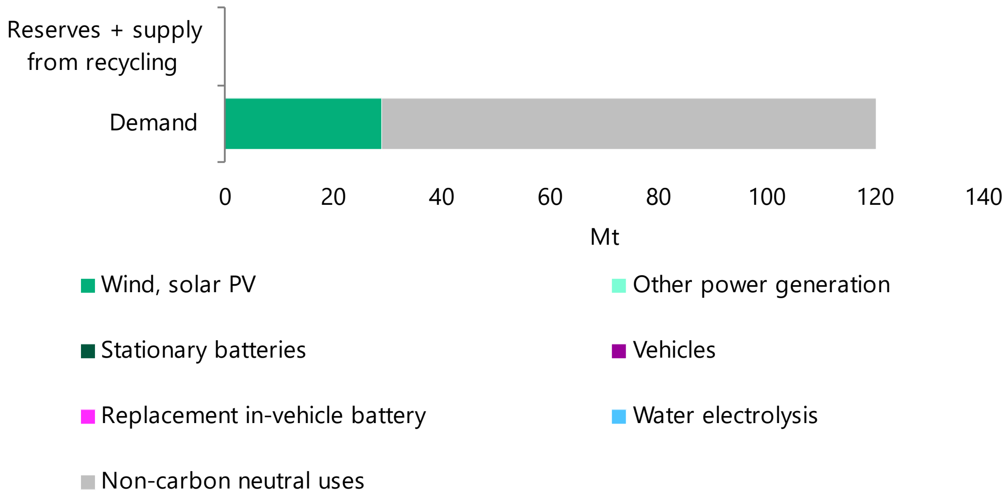
Silicon is used in a variety of applications, including as an additive in steel and semiconductors and, in relation to carbon neutral technologies, it is used in solar photovoltaic (PV) panels. In both the Reference Scenario and the Advanced Technologies Scenario, demand for silicon will increase significantly with the spread of solar PV power generation. Silicon itself is the second-most abundant element after oxygen, and has extremely large reserves. As such, for reserves as a whole, there is no concern of a supply-demand crunch.

Figure 8-3 | Global silicon supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-4 | Global silicon demand [Advanced Technologies Scenario, cumulative for 2022-2050] and silicon reserves



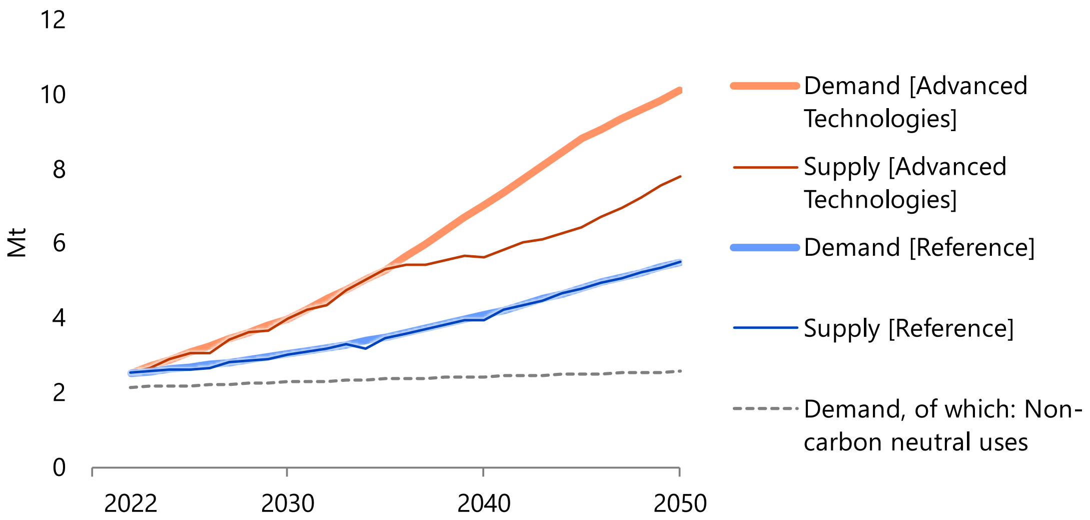
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Nickel

The primary applications of nickel are stainless steel and heat-resistant steel. Regarding carbon neutral technologies, it is used as a cathode material (nickel-cobalt-aluminium [NCA]-based or nickel-manganese-cobalt [NMC]-based) in lithium-ion batteries. Accordingly, under the

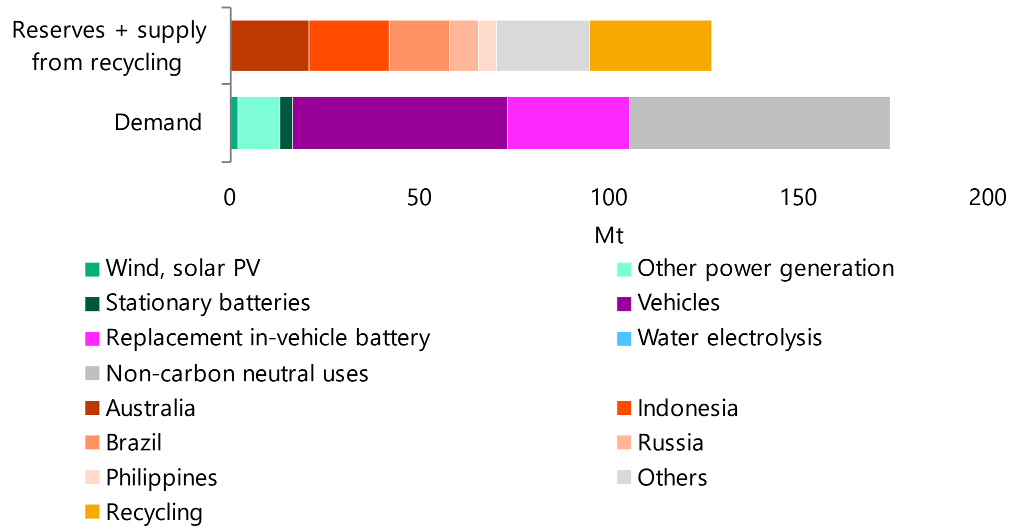
Advanced Technologies Scenario, in which automotive electrification makes dramatic progress, demand will increase four-fold from the current level by 2050. In addition, the demand for application to heat-resistant steel used in geothermal power plants cannot be ignored. Given these factors, demand will exceed supply in the late 2030s. Reserves (including supply from recycling) fall short of the cumulative demand under the Advanced Technologies Scenario, and there is a possibility of a supply shortage. Note that the nickel supply from new mines was projected based only on those mines whose production output is clear and whose production volume and grade of the mineral are known. We assumed that exploration would occur only for those mines with high prospects for development as of now; if exploration makes progress for mines that are currently unexplored or whose production output is unknown, future supply is likely to increase. Along with exploration and development of mines and improvement of recycling rates, it is necessary to develop and disseminate carbon neutral technologies such as storage batteries that use little or no nickel.

Figure 8-5 | Global nickel supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-6 | Global nickel demand [Advanced Technologies Scenario, cumulative for 2022-2050] and nickel reserves

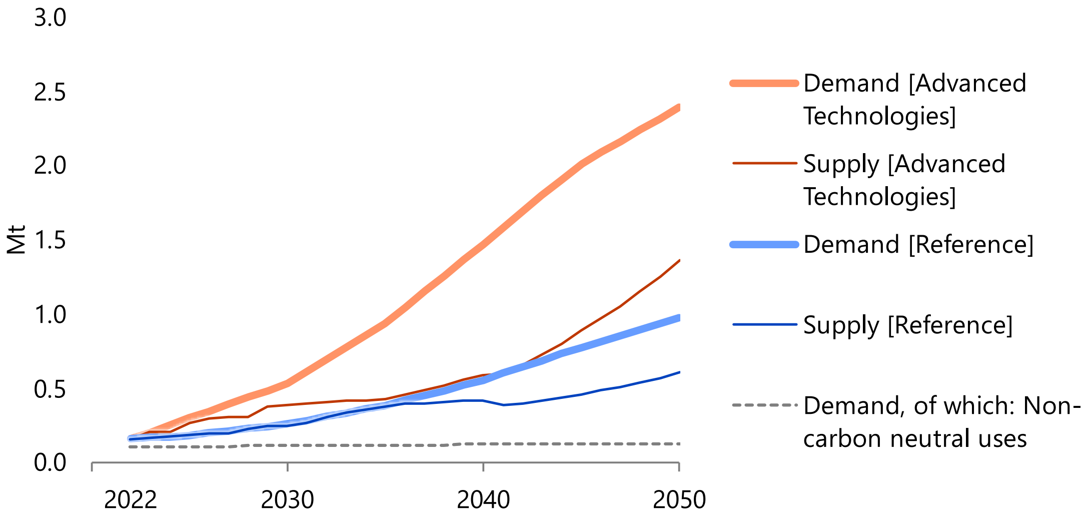


Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; United States Geological Survey

Cobalt

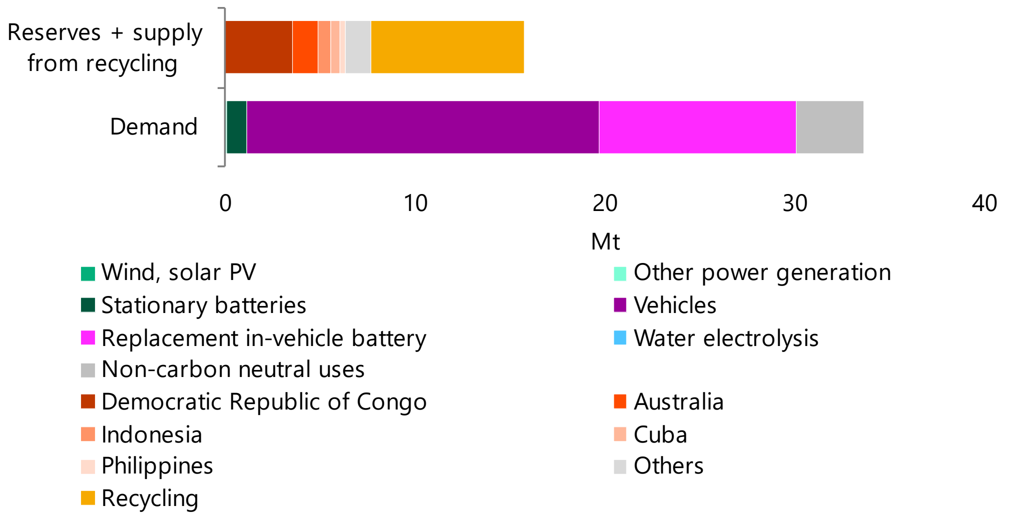
Cobalt is used primarily as a cathode material in lithium-ion batteries. Accordingly, under the Advanced Technologies Scenario, in which automotive electrification makes dramatic progress, demand will exceed supply in the mid-2020s and increase to 15 times the current level by 2050. Reserves are very small compared to cumulative demand, and supply could run short early on. Note that the cobalt supply from new mines was projected based only on those mines whose production output is clear and whose production volume and grade of the mineral are known. We assumed that exploration would occur only for those mines with high prospects for development as of now; if exploration makes progress in mines that are currently unexplored or whose production output is unknown, future supply is likely to increase. Along with exploration and development of mines and improvement of recycling rates, it is necessary to develop and disseminate carbon neutral technologies such as storage batteries that use little or no cobalt. Further, cobalt is generally produced as a by-product of ore types that are used mainly to produce copper and nickel, but in this simulation, no association between cobalt and the main products was considered.

Figure 8-7 | Global cobalt supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-8 | Global cobalt demand [Advanced Technologies Scenario, cumulative for 2022-2050] and cobalt reserves

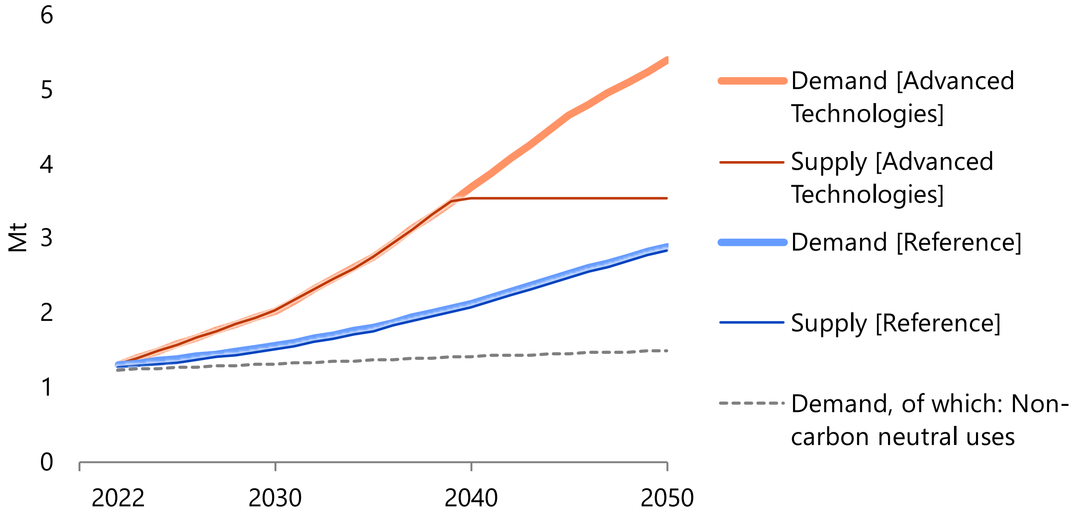


Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; United States Geological Survey

Graphite (natural)

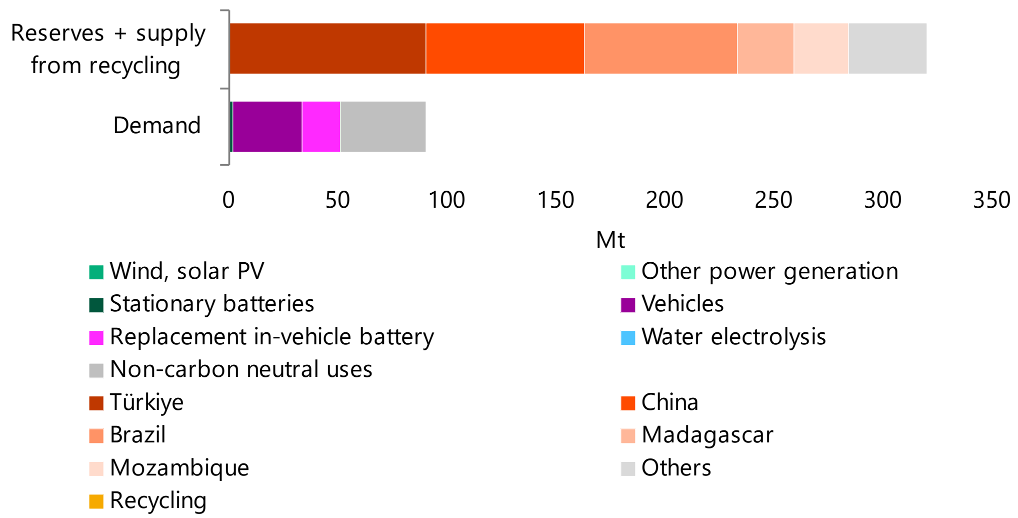
Graphite has excellent heat resistance and is used primarily for refractories, followed by crucibles for metals, moulds, and electric furnace electrodes. In recent years, it is used increasingly as an anode material in lithium-ion batteries. Accordingly, under the Advanced Technologies Scenario, in which automotive electrification makes dramatic progress, demand for natural graphite will exceed supply around 2040 and increase to at least four times the current level by 2050. Reserves are sufficiently larger than cumulative demand, but in order to avoid a supply shortage, it is necessary to develop new mines and recycling technologies, which are currently hard to develop. Note that this simulation does not take into account the supply and demand of artificial graphite.

Figure 8-9 | Global natural graphite supply and demand



Notes: The present mineral intensity values are applied throughout the projection period. The demand for natural graphite is estimated to be one-third of the demand for graphite as a whole.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-10 | Global natural graphite demand [Advanced Technologies Scenario, cumulative for 2022-2050] and natural graphite reserves

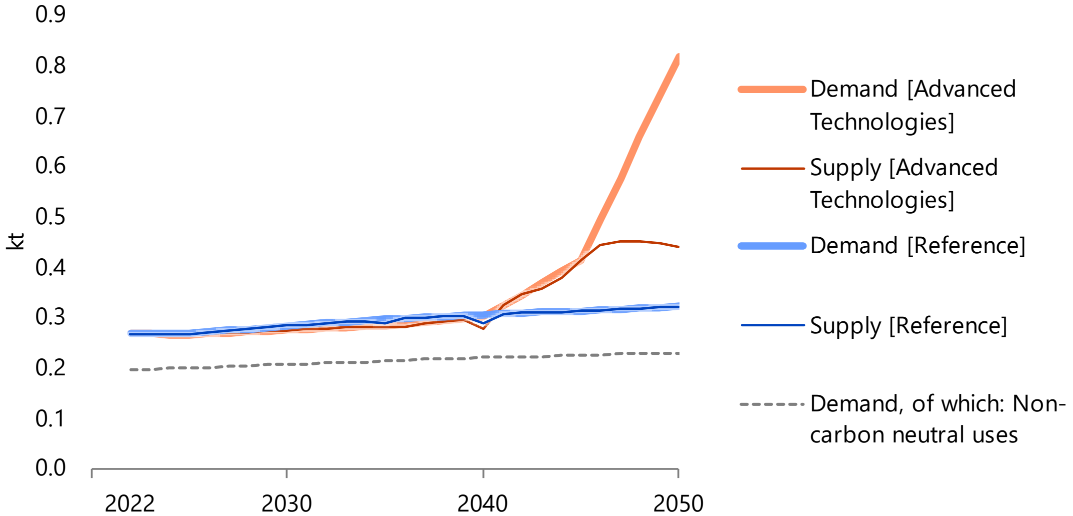


Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; United States Geological Survey

Platinum

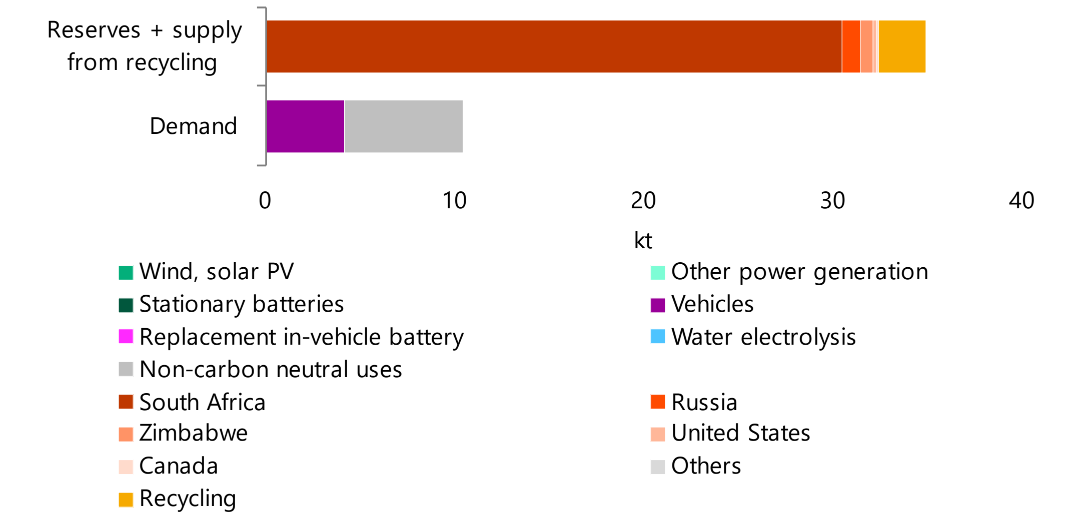
Platinum is widely used in medical and industrial applications, as well as for jewellery, due to its high melting point and chemical stability. In particular, it is indispensable as an automotive exhaust gas catalyst (three-way catalyst). It is also used as an electrocatalyst in fuel cells and water electrolysis systems. In the Advanced Technologies Scenario, while the demand for conventional engine vehicles will decline, the demand for platinum will increase significantly for fuel cell vehicles in 2040 onward. In the mid-2040s, the demand under the Advanced Technologies Scenario will exceed the supply, including recycled platinum. Note that the platinum supply from new mines was projected based only on those mines whose production output is clear and whose production volume and grade of the mineral are known. We assumed that exploration would occur only for those mines with high prospects for development as of now; if exploration makes progress in mines that are currently unexplored or whose production output is unknown, future supply is likely to increase. Although platinum is often found together with palladium and other minerals, we did not set any relationships between the data of different types of minerals in this simulation. Reserves are ample, but new mine development and higher recycling rates will be needed to avoid a supply shortage.

Figure 8-11 | Global platinum supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-12 | Global platinum demand [Advanced Technologies Scenario, cumulative for 2022-2050] and platinum reserves



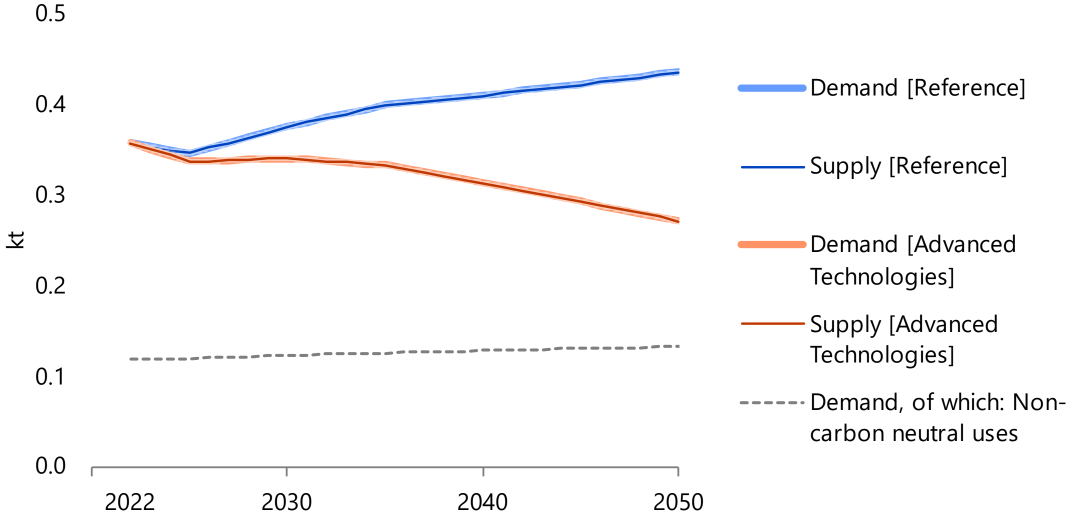
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; Hughes (2021)[26]

Palladium

Palladium is also a member of the platinum group (PGM) and is essential as an automotive exhaust gas catalyst (three-way catalyst). Demand for palladium will remain flat or decline slightly in the Advanced Technologies Scenario which has fewer conventional engine vehicles. The demand for palladium can be met consistently by supply, including from recycling, and it will not be in short supply until 2050. There are sufficient reserves to meet cumulative demand, and it will be possible to avoid supply shortages by developing new mines and maintaining the level of recycling. Palladium is also often found with nickel, platinum, and other minerals, but we did not set any relationships between the different types of minerals in this simulation.

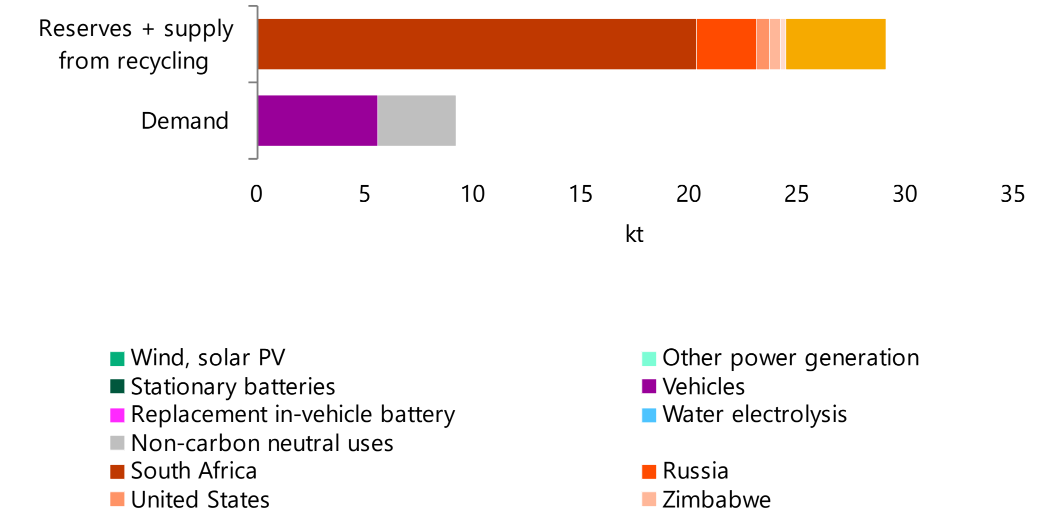
[26] Hughes, et al. (2021), Platinum Group Metals: A Review of Resources, Production and Usage with a Focus on Catalysts

Figure 8-13 | Global palladium supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-14 | Global palladium demand [Advanced Technologies Scenario, cumulative for 2022-2050] and palladium reserves

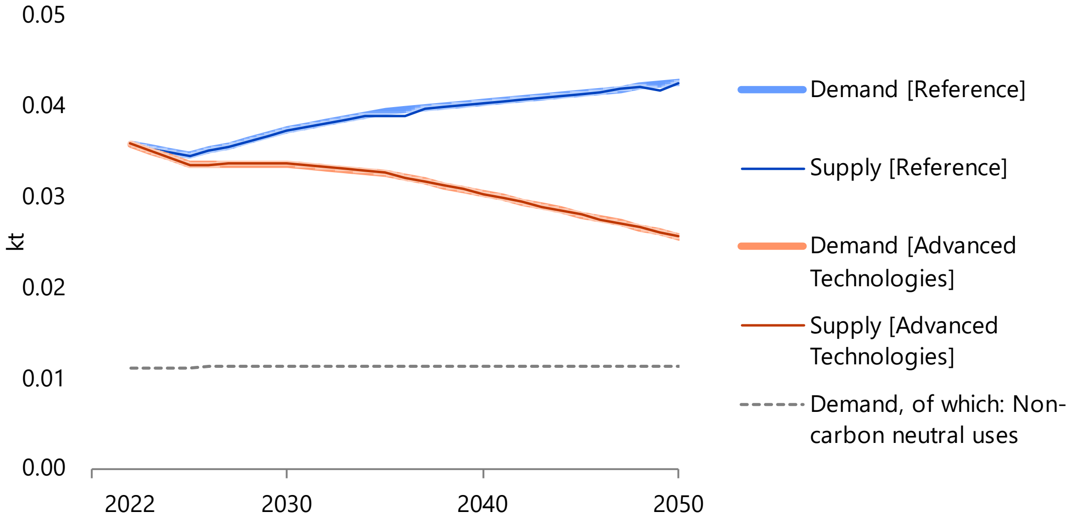


Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; Hughes (2021)

Rhodium

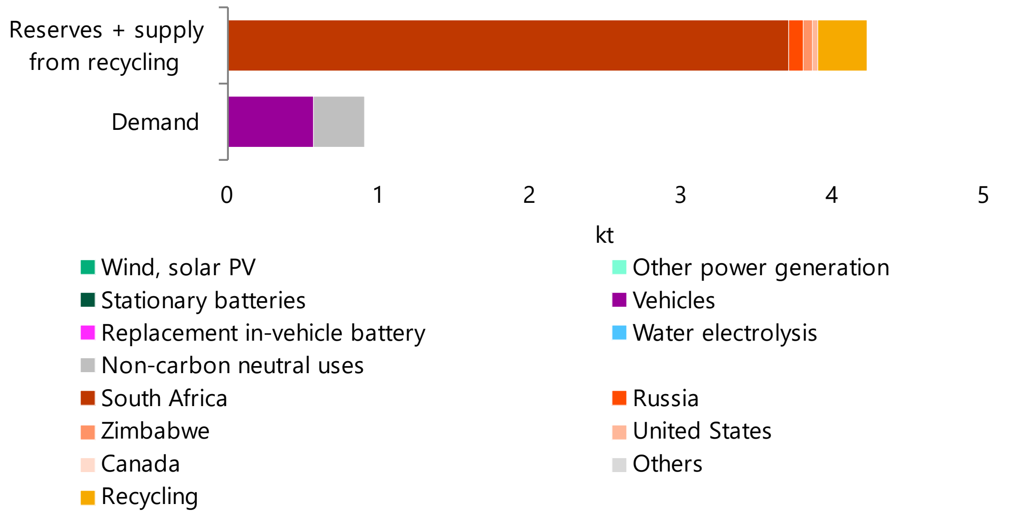
Rhodium is another member of the PGM group. It has very high hardness and is used in alloys to increase strength. Like other PGMs, it is also an essential mineral as an automotive exhaust gas catalyst (three-way catalyst). Fuel cells and water electrolysis technologies using rhodium are also being developed but are not accounted for in this Outlook and, as such, demand for rhodium will remain flat or decline slightly in the Advanced Technologies Scenario which has fewer conventional engine vehicles. The demand for rhodium can be met consistently by supply, and it will not be in short supply until 2050. There are sufficient reserves to meet cumulative demand, and it will be possible to avoid supply shortages by developing new mines and maintaining the level of recycling. For rhodium as well, no association with other symbiotic ore species has been set.

Figure 8-15 | Global rhodium supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-16 | Global rhodium demand [Advanced Technologies Scenario, cumulative for 2022-2050] and rhodium reserves

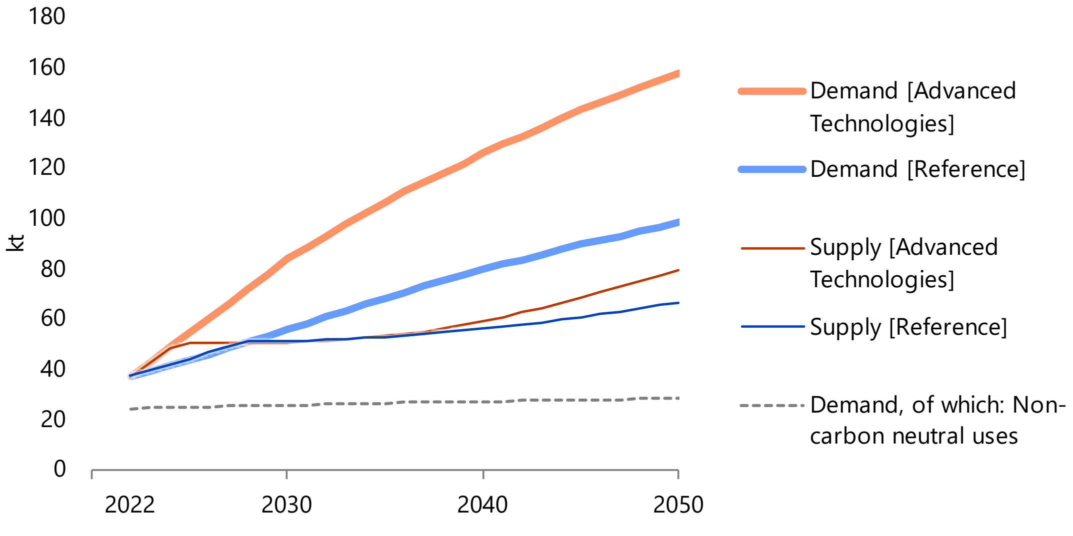


Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; Hughes (2021)

Neodymium

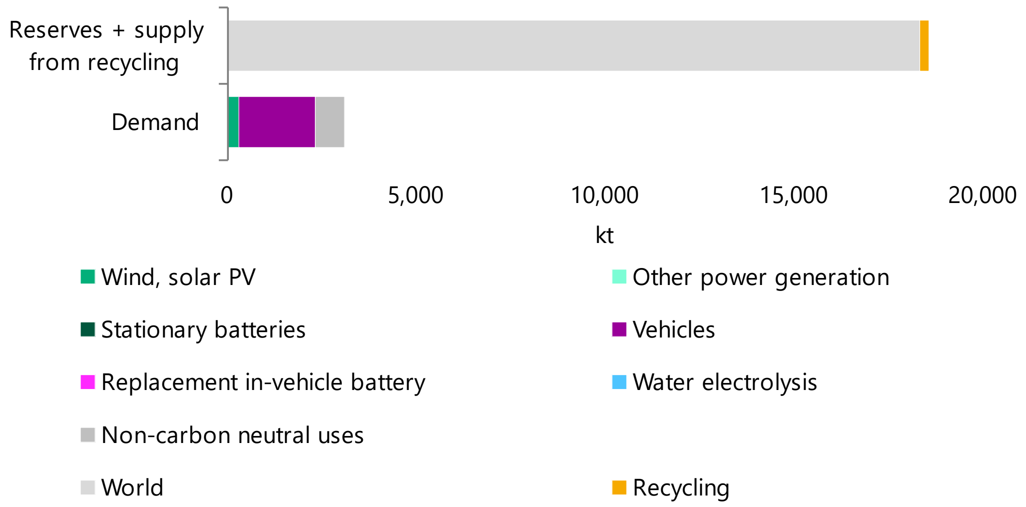
Neodymium is a type of rare earth element and is mainly used as a material for magnets. Such magnets are called neodymium magnets and are characterised by their extremely strong magnetic force. As such, it is used in various electrical devices, and in carbon neutral technologies it is used in electric vehicle motors and in magnets inside wind turbine generators. Demand for neodymium in the Advanced Technologies Scenario will exceed supply in the next few years and increase to at least four times the current level by 2050. To avoid supply shortages, it is necessary to develop and disseminate carbon neutral technologies such as magnets that use little or no neodymium, and to quickly establish recycling technologies and systems. Note that the neodymium supply from new mines was projected based only on those mines whose production output is clear and whose production volume and grade of the mineral are known. We assumed that exploration would occur only for those mines with high prospects for development as of now; if exploration makes progress in mines that are currently unexplored or whose production output is unknown, future supply is likely to increase. Further, for the supply projection from existing mines, we assumed that current production would remain unchanged until 2050. However, though we assumed that the production volume in China, the main producer country, will remain at the current level, the regulated production volume may change in the future depending on demand.

Figure 8-17 | Global neodymium supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-18 | Global neodymium demand [Advanced Technologies Scenario, cumulative for 2022-2050] and neodymium reserves

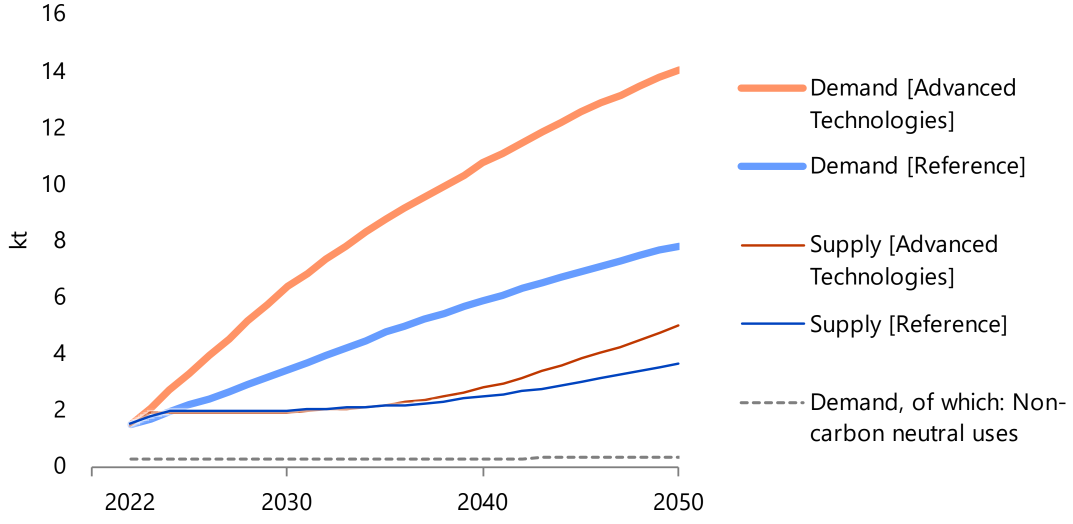


Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; estimates from United States Geological Survey

Dysprosium

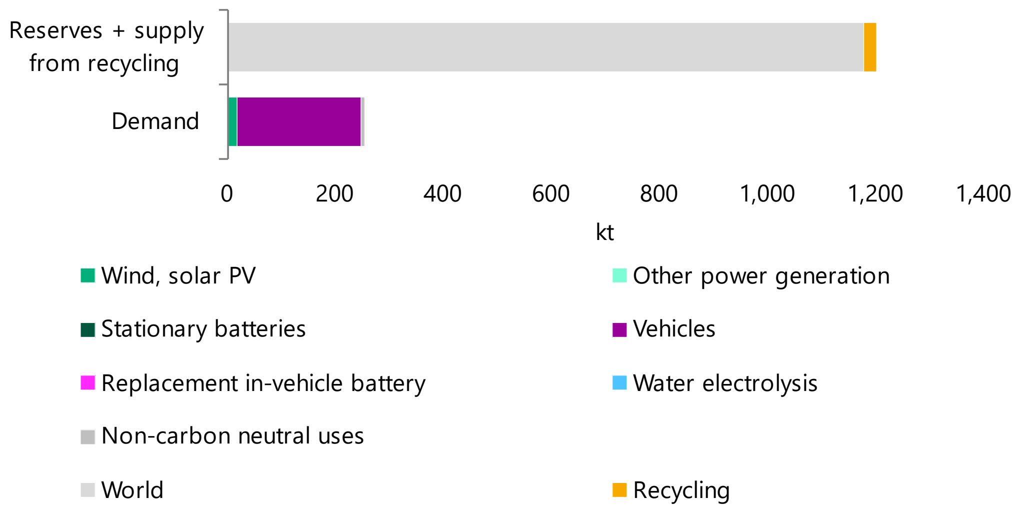
Dysprosium, like neodymium, is a type of rare earth element and is mainly used as an additive in neodymium magnets. Demand under the Advanced Technologies Scenario, in which electrified vehicles and wind power generation become more prevalent, will exceed the production potential, including mines in the development or planning phase, in the next few years, increasing to ten times the current level by 2050. To avoid supply shortages, it is necessary to develop and disseminate carbon neutral technologies such as magnets that use little or no dysprosium, and quickly establish recycling technologies and systems. We assumed that exploration would occur only for those mines with high prospects for development as of now; if exploration makes progress in mines that are currently unexplored or whose production output is unknown, future supply is likely to increase. Also, as with neodymium, China's production regulation policy may change depending on the demand conditions.

Figure 8-19 | Global dysprosium supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-20 | Global dysprosium demand [Advanced Technologies Scenario, cumulative for 2022-2050] and dysprosium reserves

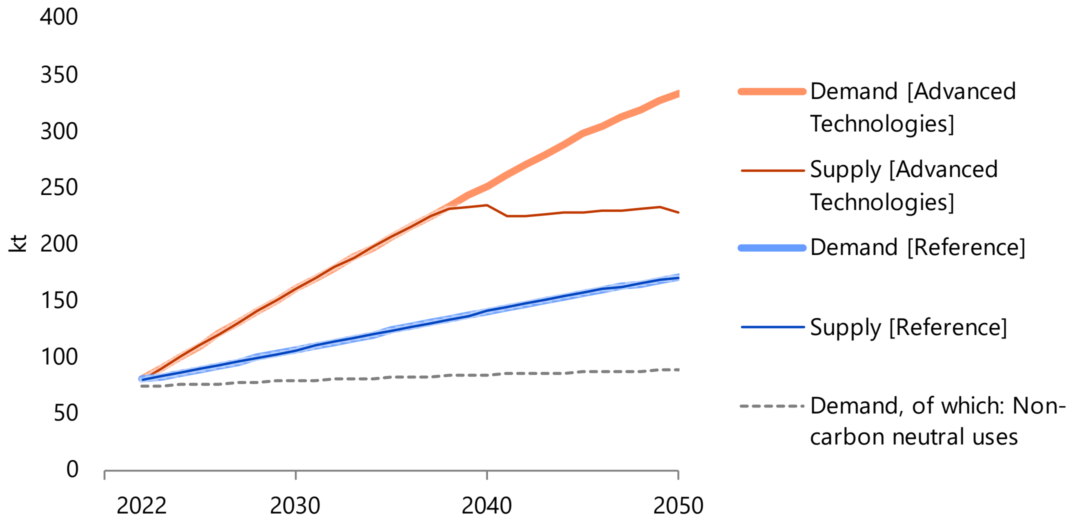


Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; estimates from United States Geological Survey

Vanadium

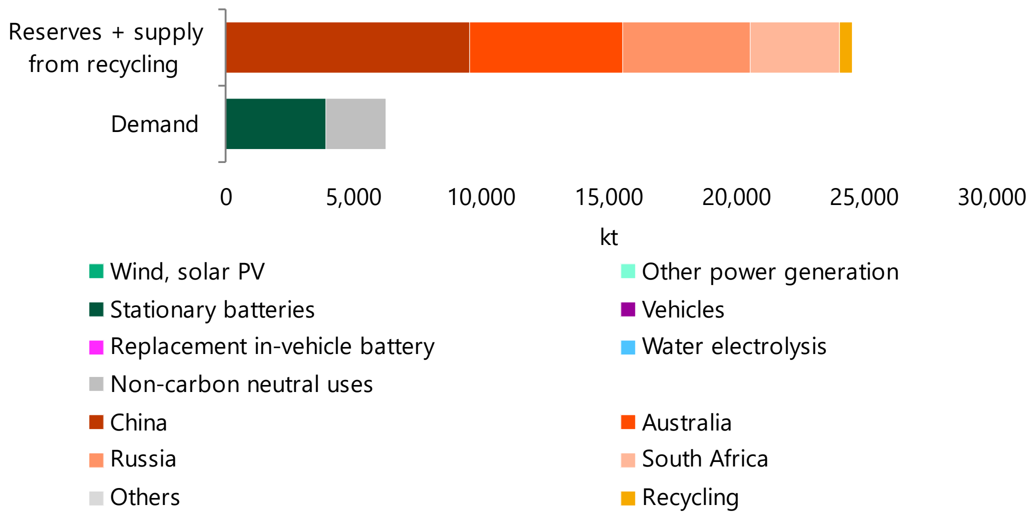
Vanadium is mostly used as an additive in steel to increase its toughness and heat resistance. Regarding carbon neutral technologies, it is used in the electrolytes of redox flow batteries. Redox flow batteries are characterised by their ability to be used semi-permanently by leveraging the redox reaction of active materials in the electrolyte. They are expected to be in higher demand as storage batteries for variable renewable power sources. Vanadium demand under the Advanced Technologies Scenario will increase to four times the current level by 2050. Demand will exceed supply in the late 2030s. Although reserves are ample, new mine development and higher recycling rates will be needed to avoid a supply shortage.

Figure 8-21 | Global vanadium supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

Figure 8-22 | Global vanadium demand [Advanced Technologies Scenario, cumulative for 2022-2050] and vanadium reserves

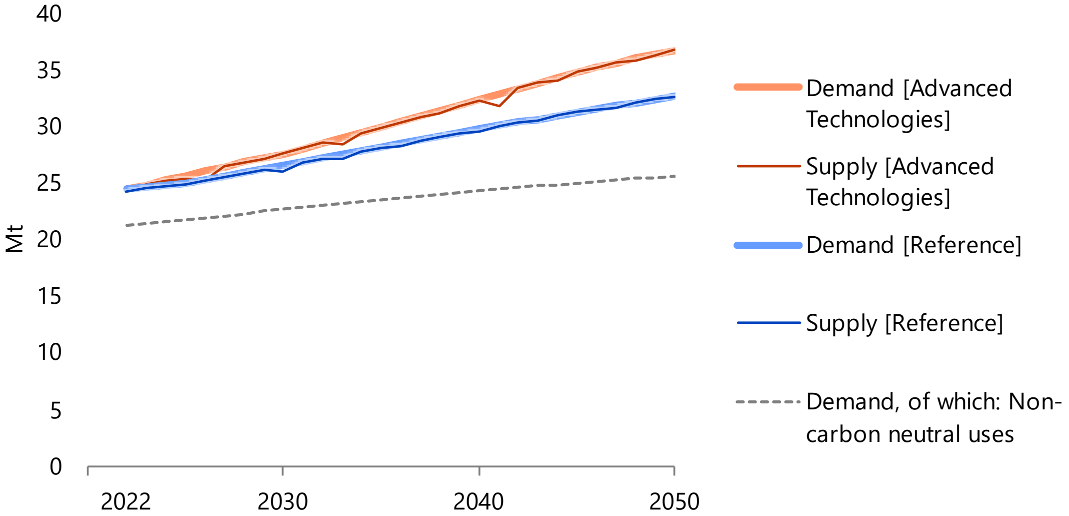


Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; United States Geological Survey

Copper

Copper is used in a variety of applications and is in high demand for uses other than the carbon neutral technologies defined in this Outlook[27]. For carbon neutral technologies, demand will grow significantly in wind and solar PV power generation, electrified vehicles, and storage batteries. Demand is higher in the Advanced Technologies Scenario than in the Reference Scenario, though being partially offset by reduced demand in conventional technologies such as thermal power generation and engine vehicles. On the other hand, supply is not expected to fall significantly short of demand until at least 2050 if, in addition to current production, mining from existing undeveloped projects makes progress, and if a recycling system is established. The cumulative demand over the next roughly 30 years will be on par with current reserves, but reserves may also vary depending on economic factors. In addition, since the figures for reserves include a significant amount of undeveloped reserves, exploration and development of new mines will continue to be necessary. Recycling will also play an important role in avoiding supply shortages in 2050 and beyond.

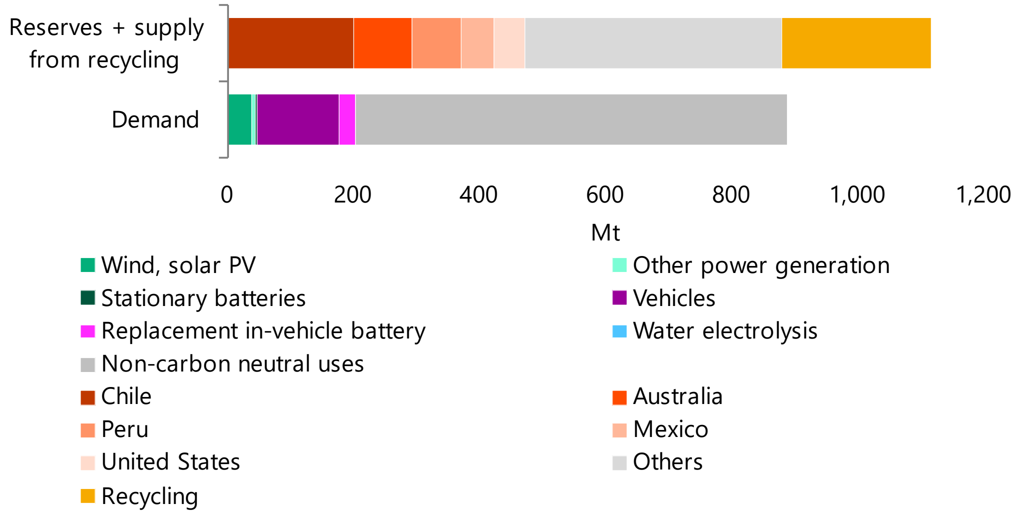
Figure 8-23 | Global copper supply and demand



Note: The present mineral intensity values are applied throughout the projection period.
Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting

[27] We attempted to estimate the demand for minerals other than from carbon neutral technologies based on population, economic and other projections.

Figure 8-24 | Global copper demand [Advanced Technologies Scenario, cumulative for 2022-2050] and copper reserves

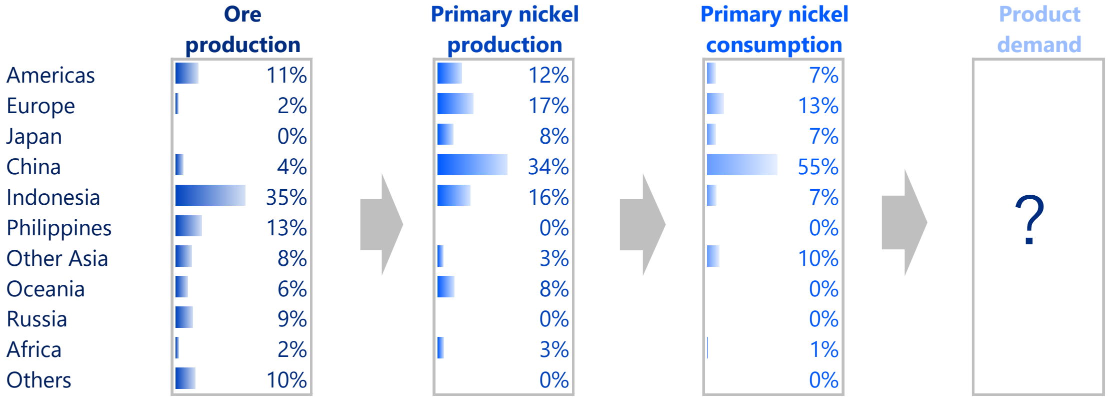


Sources: The Institute of Energy Economics, Japan; Mitsubishi UFJ Research and Consulting; United States Geological Survey

8.3 Challenges and summary

The material flow of mineral resources is complex. Figure 8-25 shows the share of each country or region in each stage of the material flow for nickel in 2019. The flow from upstream to downstream can be divided roughly into ore production, primary nickel production, production of intermediate materials such as stainless steel, heat-resistant steel, etc. from primary nickel (primary nickel consumption), and final product demand. Indonesia has the largest share in ore production but China has the largest share in primary nickel production and consumption. In other words, nickel depends on China most in terms of final product demand. As this example for nickel illustrates, it is difficult to accurately identify the challenges and bottlenecks of a mineral resource supply chain based only on ore production and end-product demand, and often requires an in-depth analysis of the supply chain, which varies by each final product. In addition, the current supply chains may not remain as they are now for a long time to come. As such, there are many issues in conducting an analysis, but it is useful to start by identifying issues in the supply-demand balance of minerals and their uneven geographical distribution.

Figure 8-25 | Material flow for nickel [2019]



Source: Prepared based on JOGMEC's Mineral Resources Material Flow, Nickel (Ni), August 2020,

Table 8-2 shows the outlook of supply and demand for critical minerals, and the challenges and implications expected under the Advanced Technologies Scenario.

For many critical minerals, reserves and recycled volume will exceed cumulative demand. However, this simulation showed that the demand for lithium, cobalt, neodymium and dysprosium will exceed supply by the mid-2030s. The demand for nickel, graphite, platinum and vanadium may also exceed supply in the future. It will therefore be necessary to increase production from existing mines in the short term, and to develop new mines and improve the recycling rate in the medium to long term. However, it should be noted that the simulation is based on the status quo without considering possible changes in the intensity for the demand volume and the regulation of rare-earth production. If these assumptions change, the supply-demand balance will change significantly.

Table 8-2 | Summary of supply-demand outlook for critical minerals under the Advanced Technologies Scenario

	Reserves (plus recycled supply) vs. cumulative demand	Year supply runs short	Unevenness of distribution of geopolitical risk
Copper	>	Unlikely	Low (Chile, Australia, Peru, Mexico)
Lithium	>	Around 2030	Medium (Chile, Australia, Argentina, China)
Silicon	≈	-	-
Nickel	<	Late 2030s	High (Indonesia, Philippines, Russia, Australia, Brazil)
Cobalt	< <	Mid-2020s	High (Democratic Republic of Congo, Australia, Indonesia)
Graphite	> >	Around 2040	High (Türkiye, China, Brazil)
Platinum	> >	Mid-2040s	High (South Africa, Russia, Zimbabwe)
Palladium	> >	Unlikely	High (South Africa, Russia, United States)
Rhodium	> >	Unlikely	High (South Africa, Russia, Zimbabwe)
Neodymium	> >	Mid-2020s	High (China)
Dysprosium	> >	Mid-2020s	High (China)
Vanadium	> >	Late 2030s	High (China, Australia, Russia, South Africa)

Under the Advanced Technologies Scenario, in which automotive electrification makes dramatic progress, demand for nickel as a cathode material for lithium-ion batteries will grow rapidly, while main suppliers will be limited to Indonesia and the Philippines. The demand for cobalt is also expected to grow rapidly with the progress in automotive electrification, but the Democratic Republic of the Congo accounts for about 70% of global production. The supply of graphite is dominated by Türkiye, China and Brazil, while South Africa and Russia have large shares in the supply of platinum, palladium and rhodium. The production of the rare earths neodymium and dysprosium is concentrated in China. The supply of vanadium is dominated by China, Australia, Russia and South Africa, of which China has a share of over 50%. As described above, the supply of critical minerals is dominated by several countries, and if resource-supplier countries impose restrictions on resource development projects and exports, including tariffs, it may lead to supply constraints in resource-consumer countries. Accordingly, policy trends in resource-supplier countries warrant close attention.

It is necessary to maximise the development and practical application of recycling technology for the future as a means to reduce dependence on other countries for critical minerals[28]. Resources are being secured and their stable supply ensured by acquiring concessions and long-term sales contracts from the perspectives of energy and economic security, but recycling is also important because it is independent of these conventional approaches. As an example, lithium is a critical mineral that is hard to recycle, with no established recycling technology. However, it is important to actively introduce technologies such as battery-to-battery recycling (not battery-to-other recycling), not only for economic efficiency but also for the social objective of realising a circular economy globally[29]. Lithium is not a scarce metal resource and is abundant throughout the world, but there are limits to the amount that can be mined and produced economically on land. Lithium exists also in seawater, and although in trace amounts and lower concentrations, its reserves are estimated to be 5 000 times greater than those on land. Therefore, attempts are being made to develop and commercialise a technology to recover and separate trace amounts of lithium from seawater and concentrate it to a high purity[30]. Along with recycling, it is also important to develop shifting technologies (to stop or reduce the use of lithium). Efforts are also underway to develop sodium-ion batteries as a replacement for lithium-ion batteries, and to stop the use of lithium and to reduce and eliminate the use of cobalt in lithium-ion batteries (less-cobalt and cobalt-free batteries). As these examples indicate, attention must also be paid to the development trends of key elemental technologies that affect mineral intensity.

Decentralising the dependence on critical minerals must also be considered. The need for energy storage technologies will inevitably increase as more natural variable renewable energies are deployed; however, the reliance on lithium can be reduced by using vanadium redox flow batteries and hydrogen fuel cells, for example.

As described above, a stable supply of critical minerals calls for a multi-faceted response that includes strengthening resource diplomacy, exploring and developing new mines, promoting recycling, developing shifting technologies and diversifying. However, there are uncertainties regarding the policies of resource-supplier countries as well as the prospects for recycling, resource conservation and the development of alternative technologies. In addition, this analysis is based on the Advanced Technologies Scenario, and if the entire world aims to achieve carbon neutrality by around 2050, there will be even more concern about the stability of supply. Therefore, from the perspective of energy and economic security, it will also be necessary to select carbon-neutral technologies in a well-balanced manner without relying excessively on a specific technology.

Meanwhile, it should be noted that critical minerals affect energy and economic security in a different way than oil and gas. Many countries cannot secure the critical minerals needed

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[28] Note that it is difficult to cover all the necessary amount only with recycling while the cumulative amount of important minerals introduced (= stock + newly introduced amount − waste) is expanding; external supply will be necessary.

[29] JX Metals (2022), "'Automotive LiB Recycling by Closed Loop Recycling' selected by NEDO Green Innovation Fund", https://www.nmm.jx-group.co.jp/newsrelease/2022/20220420_01.html

[30] Royal Society of Chemistry (30 March 2021), "Continuous electrical pumping membrane process for seawater lithium mining", https://pubs.rsc.org/en/content/articlehtml/2021/ee/d1ee00354b

under the Advanced Technologies Scenario within their own country, and will have to rely on imports even if the recycling rate is raised to the maximum. However, if we look at renewables power generation with storage batteries in terms of energy and economic security, even if the supply of critical minerals is disrupted, the critical minerals that have already been imported will continue to be used. In other words, even if the import dependence is high, critical minerals are expected to have a limited negative effect on the stable supply of energy in the short term even if supplies are cut off, unlike other energy resources. This is an advantage of critical minerals compared to fossil fuels such as oil and natural gas, for which a disruption to supplies would lead directly to an energy crisis.

9. Economic impact of green investments

9.1 Background

IEEJ Outlook 2022 raised a number of issues that should be considered in the process of going carbon neutral. The report noted the concern that despite high expectations, "green growth", in which climate investments spur a virtuous cycle of emissions reduction and economic growth, may actually not occur or may play out differently depending on country or entity. The Outlook suggested that this could lead to new disparities: (1) among advanced countries and among emerging/developing countries, (2) between advanced countries and emerging/developing countries, (3) between countries that depend on fossil fuel exports and those that do not, and (4) among the nationals/citizens of the same country.

In view of this issue, this chapter quantitatively assesses how climate investment (green investment) affects each country and region, and what kinds of disparities may arise.

9.2 Analysis method

Overview of analysis method

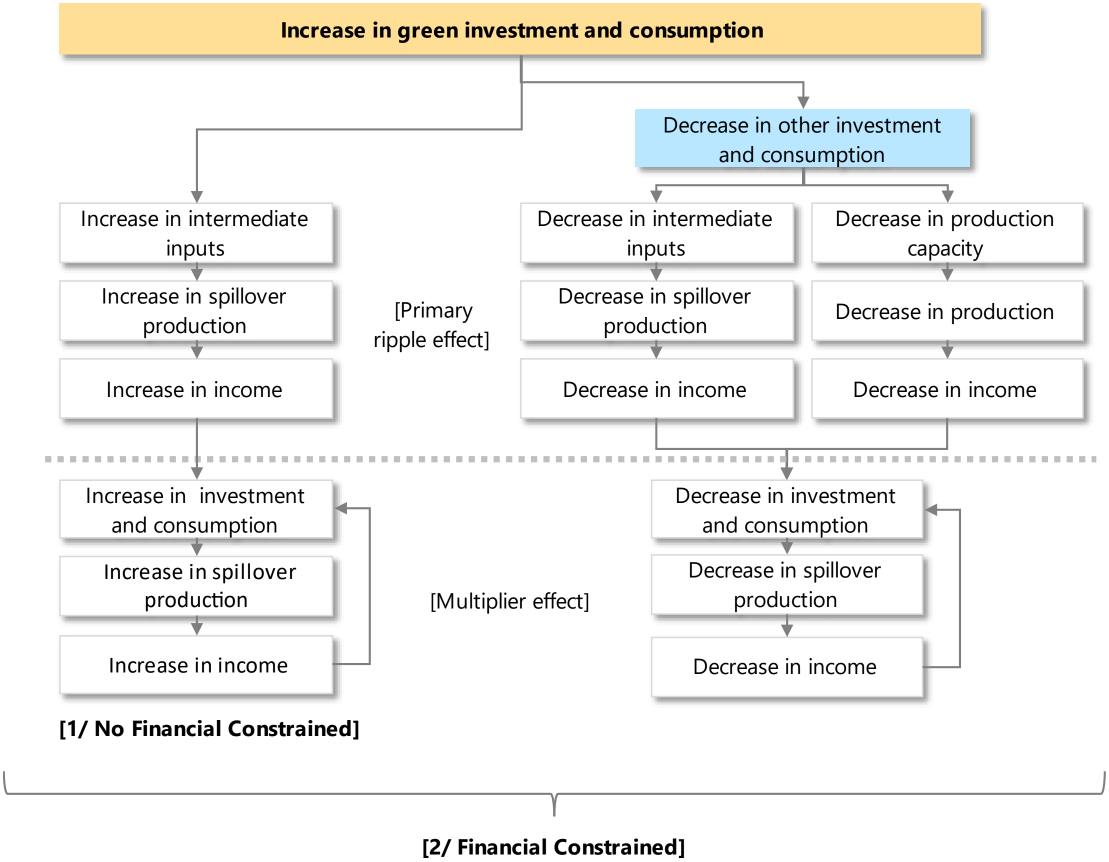
An input-output analysis was conducted to measure the ripple effects caused by green investment and consumption[31] by entities of different countries. We determined the economic impact of green investment and consumption by measuring the difference in energy-related investment between the Advanced Technologies Scenario and the Reference Scenario. The amounts of energy-related investment are based on the estimates in this Outlook (Chapter 5 Energy-related investments). We also considered the increase or decrease in the amount of energy expenditures resulting from green investments relative to the Reference Scenario.

To measure the ripple effects, two cases were analysed: (1) "No Financial Constrained", in which the total amount of investment and consumption can be increased freely, and (2) "Financial Constrained", in which the total amount of funds cannot be increased due to limitations on financial capability or fund-raising capacity.

In the former case, any additional green investment or consumption is expected to have a positive ripple effect (Figure 9-1). The additional investment and consumption will generate a commensurate amount of demand for goods, increase incomes in the corresponding industries, and in turn spur further consumption of goods and services (which is the basic concept of green growth).

[31] For the purpose of the input-output analysis, the final expenditures made by firms were categorised as investment and those made by households as consumption.

Figure 9-1 | Conceptual scheme of measurement of green investment ripple effects



In reality, however, funds for investment and consumption budgets are limited, and spending on green investment and consumption may reduce other investments and consumption. Individual firms and households usually try to keep their spending in balance with their income, and even when money is borrowed to fund additional green investments and consumption, there is always a possibility for other investments and consumption to be restrained when money markets tighten and interest rates increase. Furthermore, since green investment itself does not expand production capacity, production and income of a company may decrease if production capacity decreases due to cuts in other investments[32].

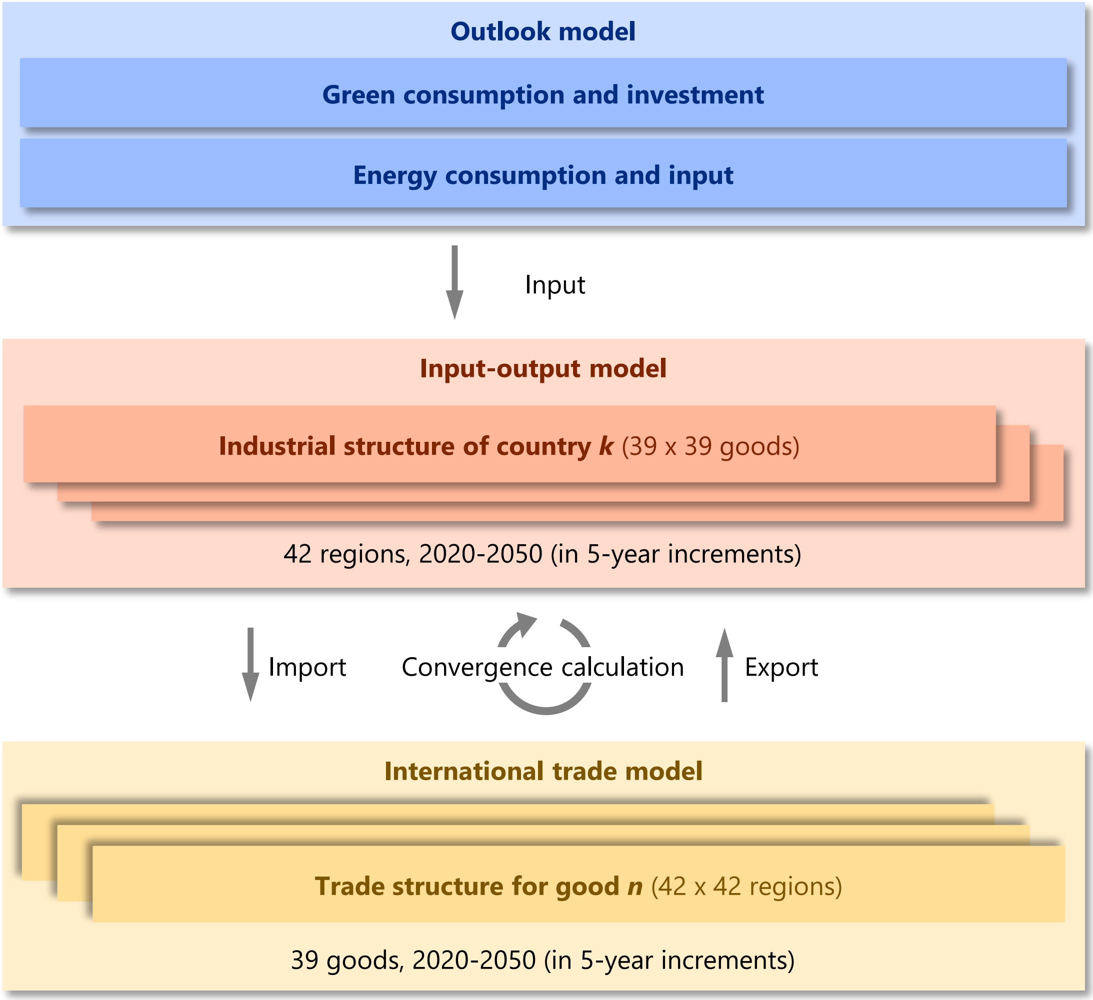
In practice, it is unlikely that green investment would be added to overall investment without funding constraints, or that the entire green investment would be funded by reducing the investment budgets for other areas. The economic impact of green investment and consumption will be evaluated within a range bound by upper and lower limits.

[32] One easy-to-understand example is a transportation company. For example, the payload capacity per truck is the same for a $50 000 engine truck and a $100 000 electric truck. The green investment (the $50 000 difference) is not contributing in any way to production expansion. If a company's truck purchase (investment) budget is $100 000, it can purchase two engine-powered trucks, but only one electric one. Green investment under budget constraints leads to lower production capacity than normal investment, and hence lower sales.

Model structure

The model used in the analysis consists of two modules: the input-output model for each country and an international trade model (Figure 9-2). In the input-output model, the amount of green investment and consumption and the resulting increase or decrease in energy input and consumption are given as initial inputs, and the economic ripple effects are measured for each country. In this process, any change in imports that results from a change in demand for a good or service is converted into a change in the corresponding country's exports using the international trade model. Then, this change in the country's exports is measured again using the input-output model as an economic ripple effect. Calculations are repeated between the input-output model and the international trade model of various countries until the ripple effects are converged.

Figure 9-2 | Overview of the model structure



Box 9-1 | Structural equations for input-output model and international trade model

The structural equations for the input-output model and the international trade model are as follows:

Input-output model for country k

Input-output model: $A_k \boldsymbol{x}_k + \boldsymbol{d}_k + \boldsymbol{e}_k - \boldsymbol{m}_k - \boldsymbol{t}_k = \boldsymbol{x}_k$

Domestic demand: $\boldsymbol{d}_k = \boldsymbol{c}_k + \boldsymbol{i}_k + \boldsymbol{g}_k$

Consumption: $\boldsymbol{c}_k$ (Input: green consumption + change in energy consumption)

Investment: $\boldsymbol{i}_k$ (Input: green investment)

Government spending: $\boldsymbol{g}_k$

Export: $\boldsymbol{e}_k$

Import: $\boldsymbol{m}_k = M_k (A_k \boldsymbol{x}_k + \boldsymbol{d}_k)$

Taxes (indirect taxes + import taxes): $\boldsymbol{t}_k = T^d{}_k (A_k \boldsymbol{x}_k + \boldsymbol{d}_k) + T^m{}_k \boldsymbol{m}_k$

Domestic production: $\boldsymbol{x}_k = [I - (I - T^d{}_k - (I + T^m{}_k) M_k) A_k]^{-1} [(I - (I - T^d{}_k - (I + T^m{}_k) M_k) \boldsymbol{d}_k + \boldsymbol{e}_k]$

Gross domestic product (GDP): $y_k = \boldsymbol{y}^{va}{}_k{}^T \boldsymbol{x}_k$

Input coefficient: A_k (Input: change in energy input)

Diagonal matrix of import ratios: M_k

Diagonal matrix of indirect tax rates: $T^d{}_k$

Diagonal matrix of import tax rates: $T^m{}_k$

Value added ratio: $\boldsymbol{y}^{va}{}_k$

where uppercase letters are the square matrix of industries (39 × 39), I is the identity matrix (39 × 39), bold lowercase letters are the industry vector (39 × 1), and the superscript T is the transposition.

International trade model for good n

Import value: $M^r{}_{[n]}$ (diagonal matrix of the n-th element of $\boldsymbol{m}_k$ in the input-output model of 42 countries)

Import matrix: $M_{kl} = M^r{}_{[n]} M^s{}_{kl}$ (value of imports to country k from country l)

Export matrix: $E_{kl} = M_{lk} = M_{kl}{}^T$ (value of exports from country k to country l)

Composition of import sources: $M^s{}_{kl}$ (composition of country k's imports by source country)

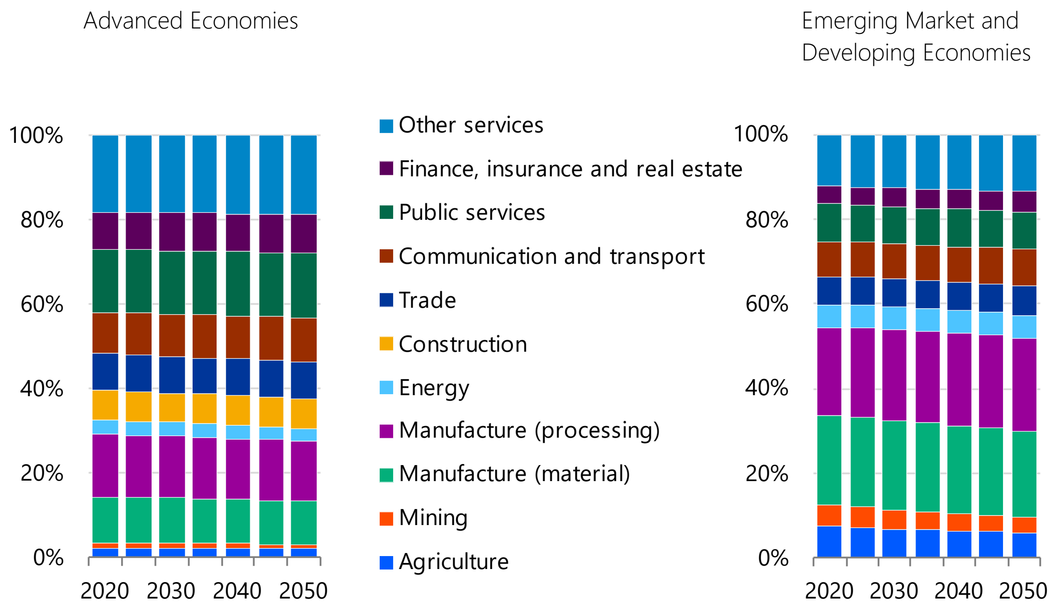
where uppercase letters are the square matrix (42 × 42) of the regions.

Economic structure of the Reference Scenario

To measure the economic ripple effects, we estimated the input-output table for each country up to 2050 based on the Reference Scenario. For past results, we created 39 × 39 industry tables for 42 regions using the input-output tables (2004, 2007, 2011 and 2014) of the Global Trade Analysis Project's (GTAP's) GTAP 10 Data Base. Figures were estimated at 5-year intervals from 2020 through 2050, and the size of the economy was based on the economic assumptions made in this Outlook (1.2 Major assumptions). The RAS method was used to estimate the changes in the intermediate input structure, and each demand structure was estimated based on past trends and other factors. Further, the energy consumption of each sector and power generation mix in this Outlook's Reference Scenario were also incorporated.

The estimates show no significant change in the industrial structure up to 2050 for Advanced Economies (Figure 9-3). For Emerging Market and Developing Economies, on the other hand, primary industries decline and industrial and service sectors expand. Especially in Emerging Market and Developing Economies, the share of food in the consumption mix will decline significantly as income levels rise, and the share of industrial goods and services will increase. In addition, industrial products will replace primary products (agriculture and mining) in the composition of their exports, and the industrialisation of the economy will make significant progress.

Figure 9-3 | Composition of production value

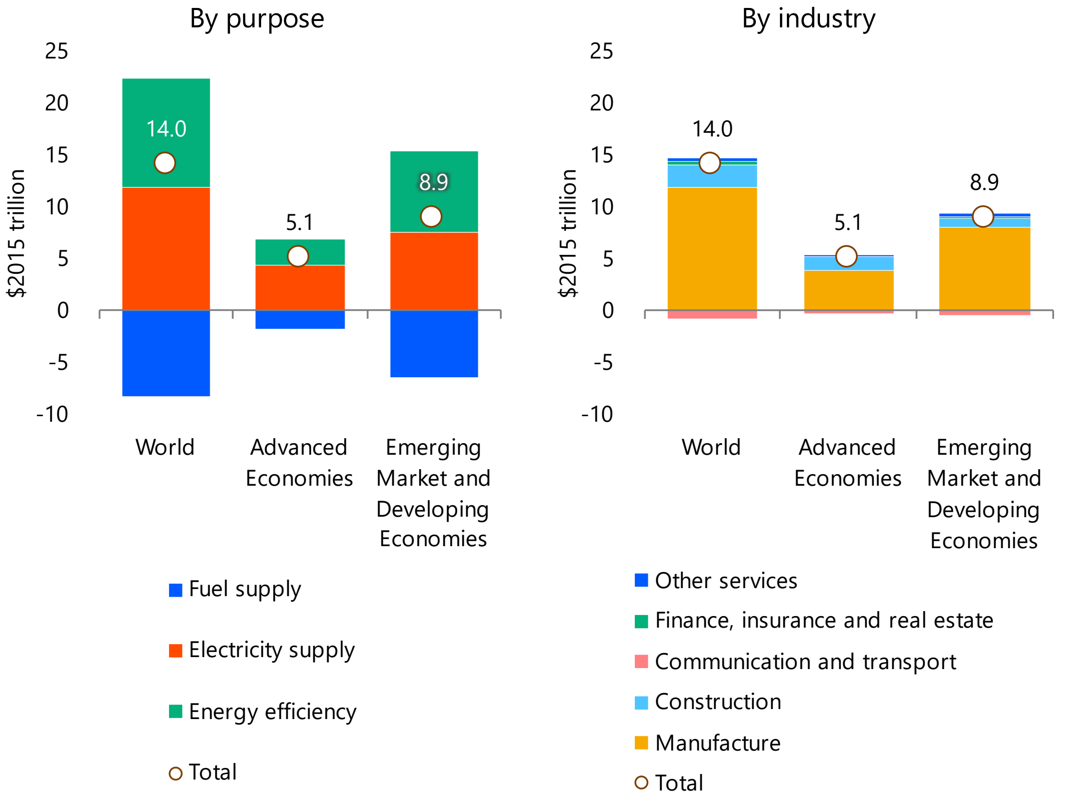


Assumptions for initial input

The green investment and consumption and the change in energy input and consumption (the difference between the Advanced Technologies Scenario and the Reference Scenario) in the Outlook are given as initial shocks to the input-output table (Reference Scenario) estimated in the previous section.

The cumulative green investment and consumption (the difference in investment between the Reference Scenario and the Advanced Technologies Scenario) through 2050 amounts to $14 trillion (at 2015 prices) globally (Figure 9-4). Emerging Market and Developing Economies, which have more scope for decarbonisation, will invest more than Advanced Economies. The annual average is $470 billion, with a ratio to GDP of about 0.4% on average.

Figure 9-4 | Change in green investment and consumption (relative to the Reference Scenario) [cumulative for 2021-2050]



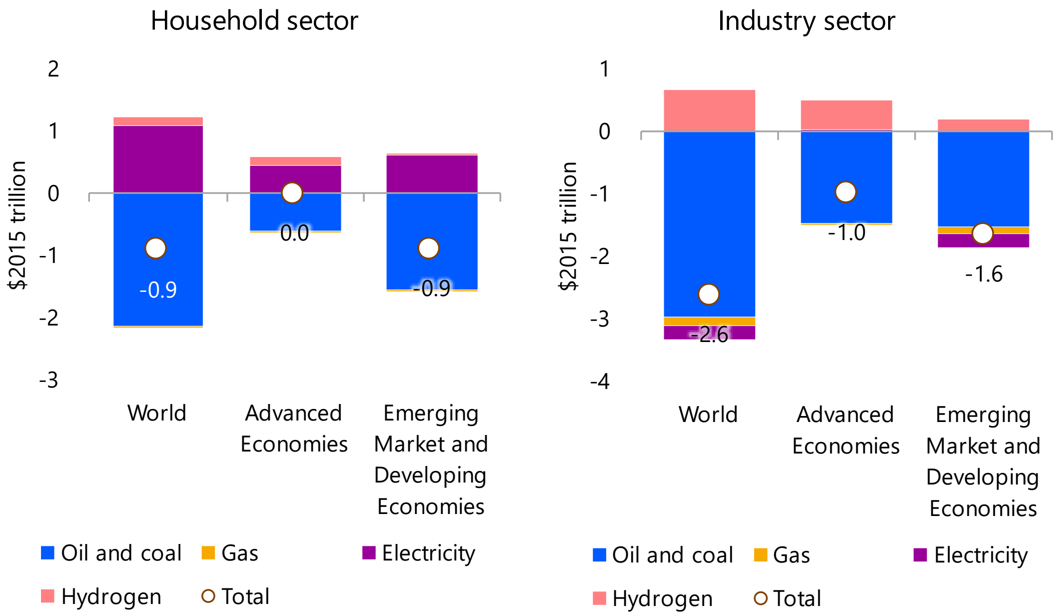
The amount of energy-related investment and consumption is distributed to each industry according to the breakdown of the technological elements and entered as consumption and investment. By industry, the increase in electricity supply investment is offset by the decrease in fuel supply investment in the construction sector, and as a result, investment is mainly in the manufacturing sector. Note that if there are funding constraints, other investment and consumption decrease by an amount equivalent to green investment and consumption (the decrease is allocated to each industry based on the percentage in the investment and consumption structures). In addition, production capacity will decrease as a result of the decline in non-green investment[33].

[33] Assumed a linear homogeneous Cobb-Douglas production function for capital and labour, assuming that the decrease in investment results in lower capital stock and in turn causes a decrease in GDP through the production function.

The cumulative decrease in energy spending (the difference between the Advanced Technologies Scenario and the Reference Scenario) amounts to $28.8 trillion worldwide. Emerging Market and Developing Economies, which have more scope for energy conservation, will see a larger decrease than Advanced Economies. The annual average is $960 billion, with the ratio to GDP of about 0.7% on average.

The change in consumption of each energy source is included in consumption for the household sector and in intermediate input for the industry sector. The household sector will see a significant decline in oil consumption while spending on electricity will increase. The budget surplus from reduced energy consumption is assumed to be used for consumption of other goods and services (assuming there are budget constraints; the increase in each good and service allocated based on the percentages in the consumption structure). The industry sector will see a significant decline in oil and coal consumption while spending on electricity and gas will also decrease. The amount that remains due to the decrease in intermediate inputs will be used to increase value added (assuming that prices do not change; the increase in the added value ratio is about 0.3 percentage points). We also take into account that an increase in value added (= income) will induce consumption.

Figure 9-5 | Change in energy input and consumption (relative to the Reference Scenario) [2050]



Note: Gas includes liquefied petroleum gas (LPG).

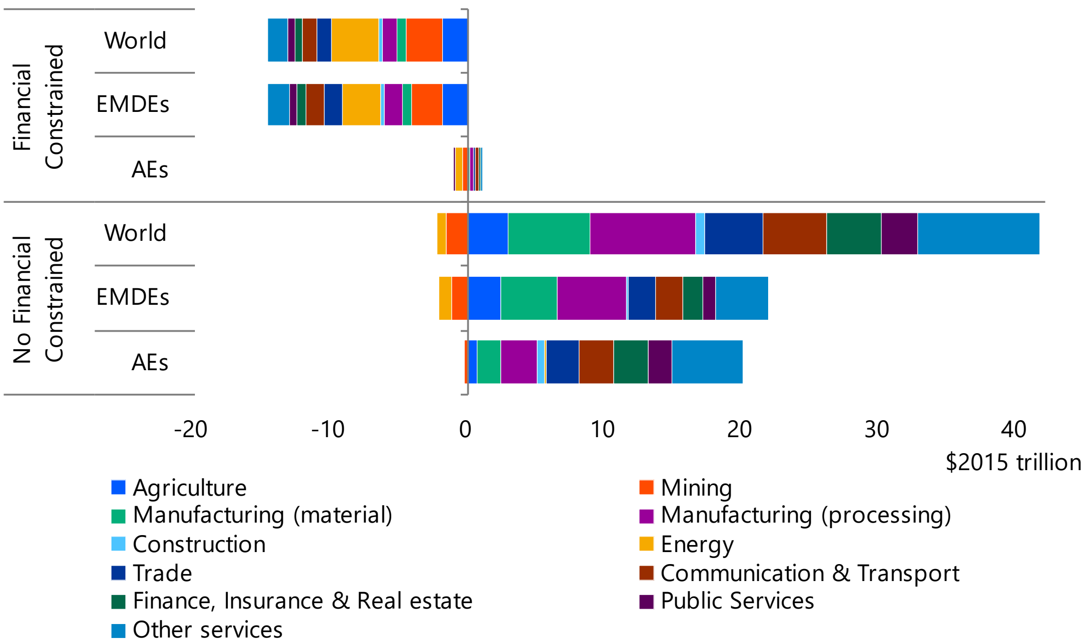
9.3 Analysis results

Impact on production value

If green investment and consumption are conducted without funding constraints, global production in 2050 would be $39.3 trillion (9.8%) higher than in the Reference Scenario. The rate of increase will be relatively high in Advanced Economies and lower in Emerging Market and Developing Economies. By region, production value will increase considerably in Advanced Europe (+16.9%), Asian Emerging Market and Developing Economies other than China (+16.5%), and Advanced Asia (+11.5%), but will decrease in the Middle East (−11.4%), which is highly dependent on mining (fossil fuels). By industry, production value will increase in most industries but will decrease in mining (−16.1%) and energy supply (−4.3%), which are related to fossil fuel supply.

If there are funding constraints on investment and consumption, global output in 2050 will decline by $14.7 trillion (3.7%) (Figure 9-6). The decline would be particularly large in Africa (−25.4%), the Middle East (−18.8%), and Other Europe/Eurasia (−17.0%) (Figure 9-7). In contrast, Advanced Europe (+2.6%) will not see a decline in production even with funding constraints. Countries with heavy dependence on imported energy will tend to show a large reduction in energy import value as a result of green investment and consumption, which exceeds the decrease in investment in other areas resulting from funding constraints. While many Advanced Economies showed a similar trend, countries with relatively large fossil fuel industries, such as North America and Australia, will still see a decline in production value. By industry, as with the No Financial Constrained Case, mining (−26.4%) and energy supply (−19.9%) will see large declines, as will agriculture, forestry and fisheries (−12.4%) mainly in Emerging Market and Developing Economies (Figure 9-8).

Figure 9-6 | Change in production value (relative to the Reference Scenario) [2050]



Notes: AEs stands for Advanced Economies. EMDEs stands for Emerging Market and Developing Economies.

Figure 9-7 | Percent change in production value (by region, relative to the Reference Scenario) [2050]

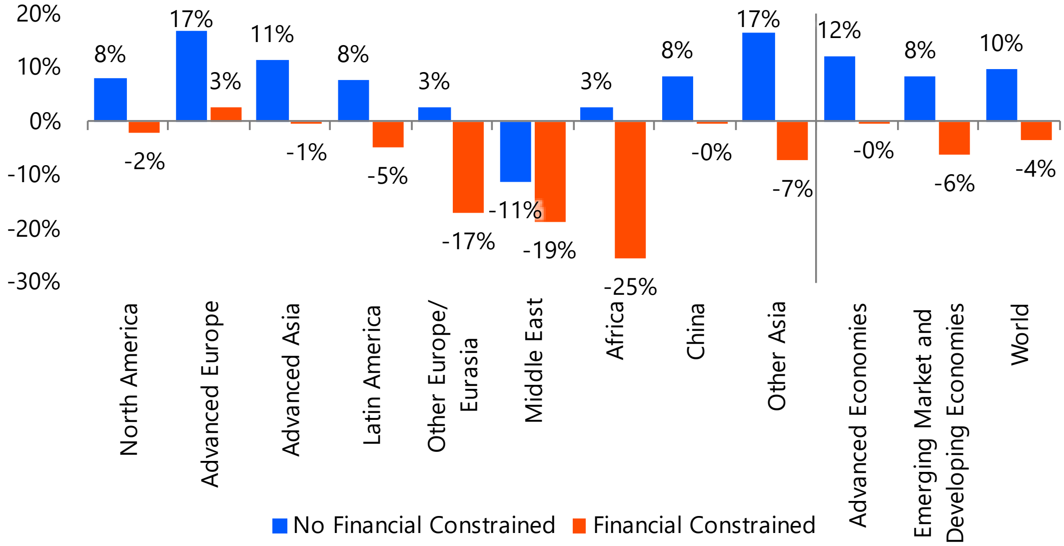
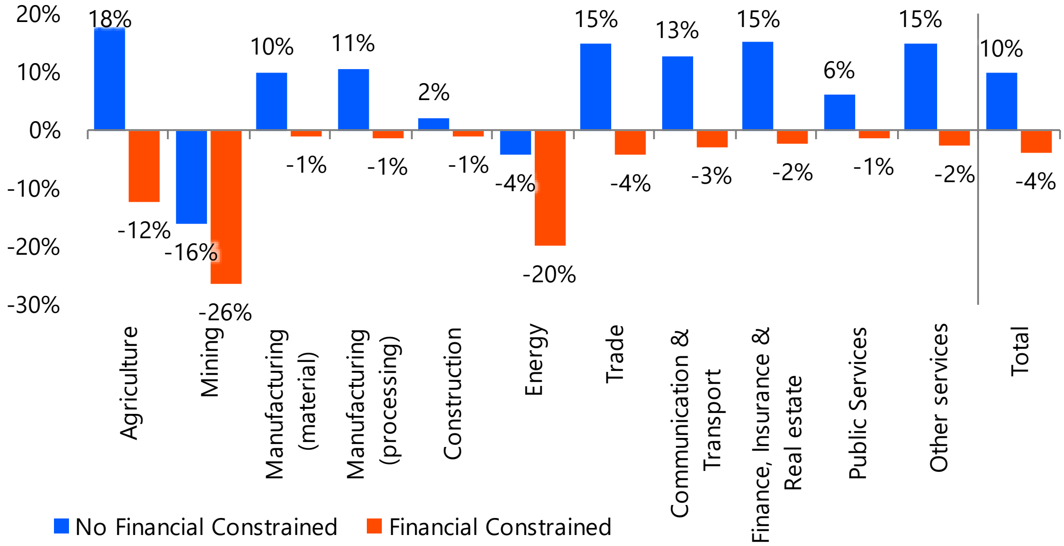


Figure 9-8 | Percent change in production value (by industry, relative to the Reference Scenario) [2050]



Impact on GDP and compensation of employees

If green investment and consumption are conducted without funding constraints, the global GDP in 2050 would be $20 trillion higher (11.2%, 0.4% on annual average) than in the Reference Scenario (Figure 9-9). As with the impact on production value in the previous section, GDP would increase in many countries but decrease in Middle Eastern countries and former Soviet Union countries that depend heavily on mining (fossil fuels). Meanwhile, if there are funding constraints, GDP would be $6.2 trillion (3.5%, or 0.1% on annual average) lower than in the

Reference Scenario. GDP would decline in many countries but increase in some Advanced Economies.

Figure 9-9 | Percent change in GDP and global compensation of employees (relative to the Reference Scenario) [2050]

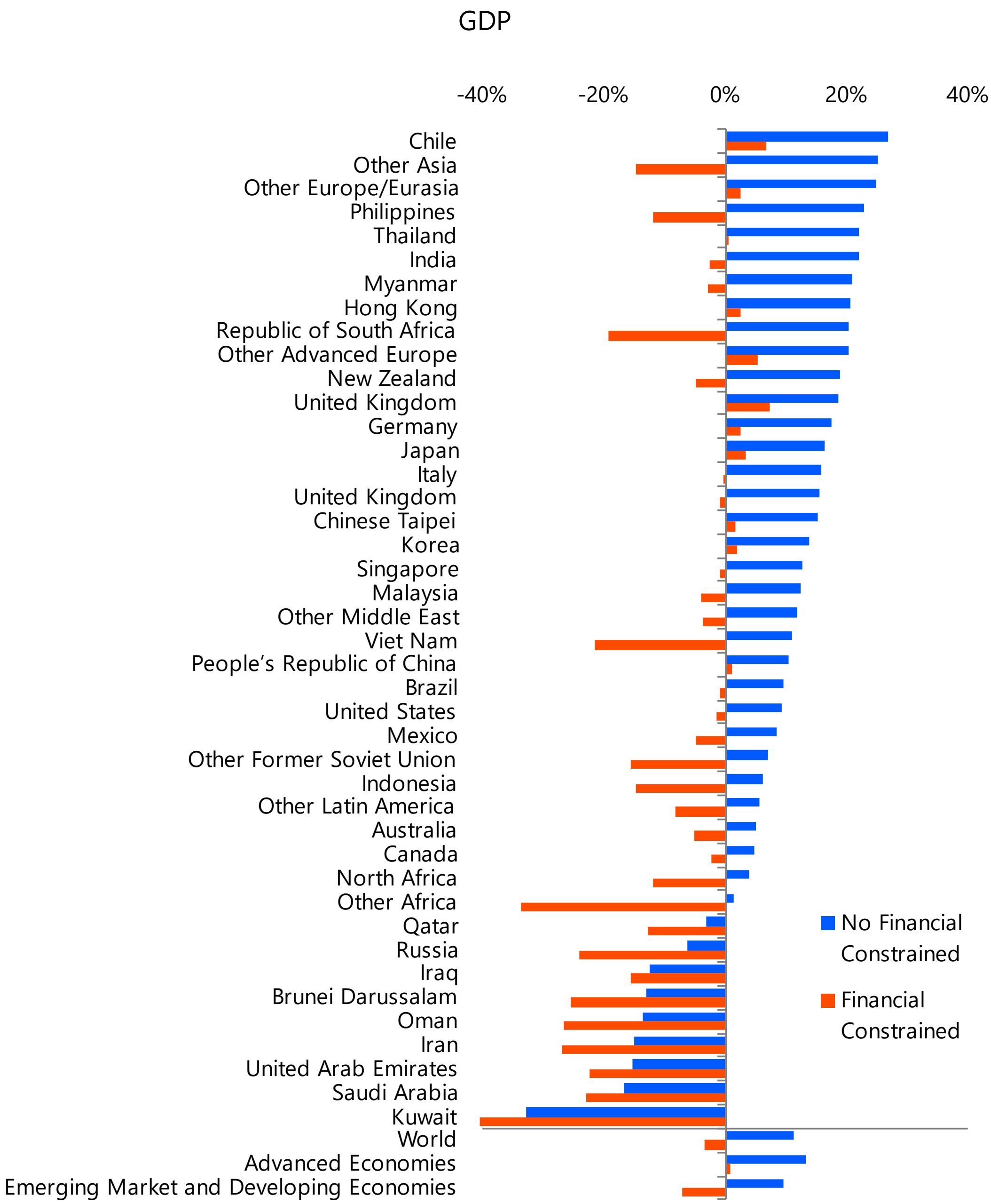
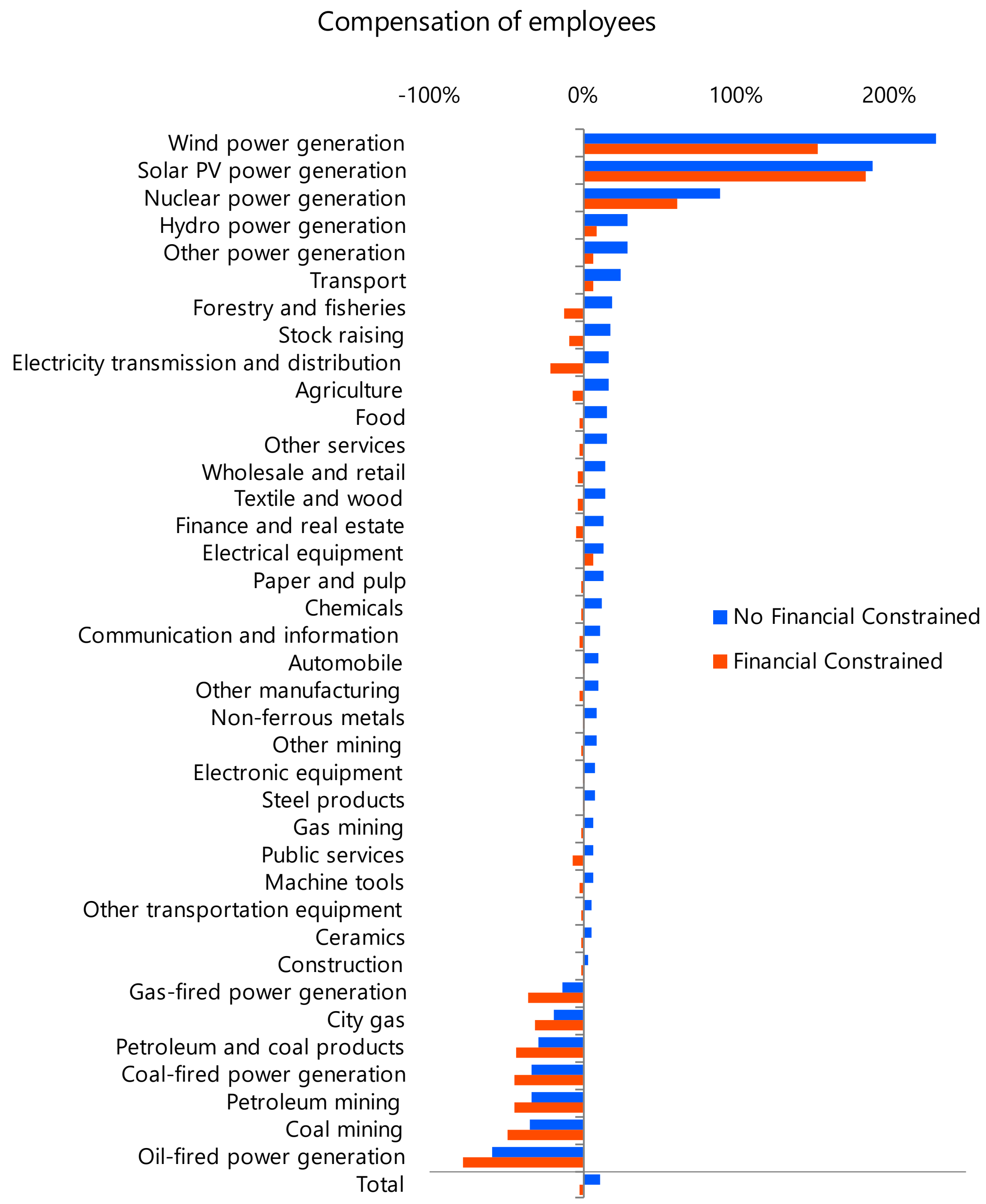


Figure 9-9 | Percent change in GDP and global compensation of employees (relative to the Reference Scenario) [2050] (continued)



Note: Industries do not include “hydrogen supply”.

Compensation of employees[34] would increase by \$10.1 trillion (11.2%) over the Reference Scenario for the case with no funding constraints while it would decrease by \$2.2 trillion (2.5%) if there are funding constraints. Solar photovoltaics (PVs), wind, and nuclear power generation will increase with or without funding constraints. On the other hand, fossil fuel supply and thermal power generation will decrease with or without funding constraints. In a society aiming to decarbonise, some industries will inevitably decline while others will grow. Worker retraining (reskilling) will be important to mitigate employment mismatches.

9.4 Conclusion

Investment constitutes new demand and a source of growth. "Green growth" is based on the idea of growing the economy by multiplier effects, in which green investment creates new demand, which in turn creates new jobs and income (and thus new consumption). However, if there are constraints on funds and budget, and other investments must be cut back to make new investments, then no new demand will be created as a whole. In addition, green investment itself is not likely to generate growth because it does not expand production capacity.

The foremost purpose of green investment is to reduce carbon dioxide (CO_2) emissions and, primarily, fossil fuel use. The funds freed up by reducing fuel input and consumption can be reallocated to the consumption of other goods and services, and consequently create new demand. However, for suppliers of fossil fuels, a decrease in fuel demand will lead to fewer jobs and lower incomes, resulting in a negative multiplier effect. This negative impact is significant for countries in the Middle East and Former Soviet Union regions, which depend heavily on such industries, as well as mining, fuel supply, and thermal power generation.

If funds are plentiful and there are no budget constraints, green investment would have a positive multiplier effect for many countries (that are not heavily dependent on the fossil fuel industry)[35]. Green technologies (or their materials or necessary services) that cannot be produced domestically must be sourced through international trade, and this would yield larger positive effects for Advanced Economies, whose advanced component and service industries are more developed. This is also true for the case with funding constraints, where some Advanced Economies will enjoy positive impacts while many countries will suffer negative economic impacts. In other words, regardless of funding constraints, Advanced Economies are more likely to enjoy green growth, while Emerging Market and Developing Economies may not. In addition, although this analysis was conducted with and without financial constraints equally for all countries, in the real world, Advanced Economies have sufficient funds while Emerging Market and Developing Economies do not, and the economic gap between the two could widen further.

Meanwhile, if there are funding constraints, many countries would not be able to enjoy green growth. In other words, easing funding constraints and providing sufficient funds are the keys

[34] Compensation of employees can be broken down into the number of employees and wages per capita, but the details are unknown. If wages per capita are constant, the rate of change in compensation of employees and the rate of change in the number of employees will match.

[35] However, in the case of a supply shortage and excess demand, there is a risk that price hikes may accelerate.

to achieving green growth. These measures are also essential for future climate change countermeasures, not only for enjoying the fruits of green growth. We must remember that the primary purpose of green investment is to achieve carbon neutrality, not green growth. The Reference Scenario will require on average $2.5 trillion per year in energy-related investments by 2050, and the Advanced Technologies Scenario will require $2.9 trillion on average. More investment will be needed if the world is to become carbon neutral earlier (this will lead to even greater economic disparities as some countries will have funding constraints while others will not). Furthermore, this analysis only includes investments in low-carbon technologies that are in practical use, and not those in the development stage. Smooth financing, including in these areas, will be vital.

So far, much of the funding for the development and spread of low-carbon technologies has come from government budgets, including subsidies. However, as government funds alone are clearly not enough for achieving carbon neutrality, there is increasing attention on green finance, which is mainly funded by the private sector. Green finance raises funds through green bonds (environmental bonds), infrastructure funds, etc., with the sole purpose of funding the development and spread of green technologies. Their share in the financial market is still small but has been growing rapidly in recent years. However, green finance still faces many challenges before growing in use, one of which is the uncertainty of investment risk. To limit risk and spur investment appetite, it is essential to clarify where the environmental policy is headed.

Meanwhile, economies that depend heavily on fossil fuel exports will suffer negative effects with or without funding constraints. As has long been said, these economies need to cut their dependence on those industries and diversify to others, including green industries. For example, if they can produce hydrogen and ammonia by decarbonising their fossil fuels and develop their export into a major industry, it might provide stable export incomes in a carbon-neutral world. Naturally, changing the industrial structure involves pain, such as employment mismatches. Reskilling workers so they can migrate smoothly from declining industries will be essential. Finance also plays an important role in the creation of new industries.

As pointed out in IEEJ Outlook 2022, as the world aims to become a low-carbon society, new disparities may emerge among nations and industries. Moreover, green investment may not necessarily lead to green growth. However, not leading to growth does not mean the investments are not required. We should establish a public consensus that the purpose of green investment is achieving carbon neutrality and that any negative economic impact of green investment is a cost associated with the low-carbon transition. Of course, there are limits to acceptable costs, and it is important to control negative economic impacts and even out the impacts as equally as possible among nations and industries. In particular, if the existence of funding constraints causes wider disparities, Advanced Economies that have sufficient funds to provide financial support will need to provide financial support to Emerging Market and Developing Economies with tight finances. The argument that climate change measures always have a positive effect on the economy should at least be put on hold.

Annex

Table A1 | Regional groupings

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

		Others	Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Iceland, Ireland, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, and Türkiye
	Other Europe/Eurasia	Russia	
		Other Former Soviet Union	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, 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	Republic of South Africa		
	North Africa	Algeria, Egypt, Libya, Morocco, and Tunisia	
	Others	Angola, Benin, Botswana, Cameroon, Democratic Republic of Congo, Congo, Côte d'Ivoire, Eritrea, 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	Iran		
	Iraq		
	Kuwait		
	Oman		
	Qatar		
	Saudi Arabia		
	United Arab Emirates		
	Others	Bahrain, Israel, Jordan, Lebanon, Syrian Arab Republic, and Yemen	
Oceania	Australia		
	New Zealand		

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

Table A2 | Major energy and economic indicators

				Reference		Advanced Technologies		CAGR (%)		
								1990/	2020/2050	
		1990	2020	2030	2050	2030	2050	2020	Reference	Adv. Tech.
Total primary energy consumption (Mtoe)	**World**	**8 747**	**13 963**	**16 007**	**17 649**	**15 297**	**14 377**	**1.6**	**0.8**	**0.1**
	AEs[*1]	4 467	4 893	5 102	4 575	4 900	3 907	0.3	-0.2	-0.7
	EMDEs[*2]	4 078	8 774	10 392	12 341	9 931	9 933	2.6	1.1	0.4
	Asia	2 081	6 052	7 175	8 200	6 881	6 416	3.6	1.0	0.2
	Non-Asia	6 464	7 615	8 319	8 716	7 950	7 424	0.5	0.5	-0.1
Oil consumption (Mtoe)	**World**	**3 234**	**4 115**	**4 897**	**5 122**	**4 467**	**2 876**	**0.8**	**0.7**	**-1.2**
	AEs	1 824	1 666	1 728	1 306	1 565	665	-0.3	-0.8	-3.0
	EMDEs	1 207	2 153	2 672	3 196	2 474	1 923	1.9	1.3	-0.4
	Asia	615	1 435	1 739	1 982	1 622	1 218	2.9	1.1	-0.5
	Non-Asia	2 416	2 384	2 661	2 520	2 416	1 370	0.0	0.2	-1.8
Natural gas consumption (Mtoe)	**World**	**1 662**	**3 306**	**3 806**	**4 820**	**3 616**	**3 764**	**2.3**	**1.3**	**0.4**
	AEs	827	1 470	1 578	1 598	1 433	1 055	1.9	0.3	-1.1
	EMDEs	835	1 836	2 215	3 139	2 163	2 598	2.7	1.8	1.2
	Asia	116	670	905	1 342	858	907	6.0	2.3	1.0
	Non-Asia	1 547	2 636	2 888	3 395	2 738	2 746	1.8	0.8	0.1
Coal consumption (Mtoe)	**World**	**2 222**	**3 741**	**3 942**	**3 688**	**3 442**	**1 905**	**1.8**	**0.0**	**-2.2**
	AEs	1 089	670	592	342	479	199	-1.6	-2.2	-4.0
	EMDEs	1 133	3 071	3 350	3 346	2 963	1 706	3.4	0.3	-1.9
	Asia	788	2 938	3 238	3 142	2 861	1 578	4.5	0.2	-2.1
	Non-Asia	1 434	803	705	546	581	327	-1.9	-1.3	-2.9
Power generation (TWh)	**World**	**11 844**	**26 721**	**33 593**	**45 777**	**34 600**	**50 800**	**2.7**	**1.8**	**2.2**
	AEs	7 667	10 649	11 954	13 767	12 237	15 175	1.1	0.9	1.2
	EMDEs	4 178	16 071	21 639	32 010	22 363	35 626	4.6	2.3	2.7
	Asia	2 237	12 567	16 925	23 313	17 347	24 447	5.9	2.1	2.2
	Non-Asia	9 607	14 154	16 668	22 464	17 253	26 354	1.3	1.6	2.1
Energy-related carbon dioxide emissions (Mt)	**World**	**20 556**	**31 666**	**35 531**	**37 028**	**31 220**	**16 936**	**1.5**	**0.5**	**-2.1**
	AEs	10 808	10 046	9 966	7 780	8 567	2 996	-0.2	-0.8	-4.0
	EMDEs	9 112	20 690	23 973	27 103	21 259	12 773	2.8	0.9	-1.6
	Asia	4 699	15 889	18 312	19 403	16 143	8 879	4.1	0.7	-1.9
	Non-Asia	15 221	14 847	15 627	15 480	13 682	6 890	-0.1	0.1	-2.5
GDP ($2015 billion)	**World**	**35 843**	**81 578**	**112 310**	**184 952**	**112 310**	**184 952**	**2.8**	**2.8**	**2.8**
	AEs	27 204	48 304	60 587	82 280	60 587	82 280	1.9	1.8	1.8
	EMDEs	8 639	33 275	51 724	102 672	51 724	102 672	4.6	3.8	3.8
	Asia	6 688	27 854	43 113	81 167	43 113	81 167	4.9	3.6	3.6
	Non-Asia	29 155	53 725	69 197	103 785	69 197	103 785	2.1	2.2	2.2
Population (Million)	**World**	**5 272**	**7 753**	**8 448**	**9 597**	**8 448**	**9 597**	**1.3**	**0.7**	**0.7**
	AEs	998	1 196	1 219	1 224	1 219	1 224	0.6	0.1	0.1
	EMDEs	4 274	6 557	7 229	8 373	7 229	8 373	1.4	0.8	0.8
	Asia	2 951	4 230	4 479	4 740	4 479	4 740	1.2	0.4	0.4
	Non-Asia	2 322	3 523	3 969	4 857	3 969	4 857	1.4	1.1	1.1

Table A3 | Population

(Million)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/2020	2020/2030	2030/2040	2040/2050	2020/2050
World	5 272 (100)	6 912 (100)	7 753 (100)	8 448 (100)	9 082 (100)	9 597 (100)	1.3	0.9	0.7	0.6	0.7
Asia	2 951 (56.0)	3 849 (55.7)	4 230 (54.6)	4 479 (53.0)	4 656 (51.3)	4 740 (49.4)	1.2	0.6	0.4	0.2	0.4
China	1 135 (21.5)	1 338 (19.4)	1 411 (18.2)	1 404 (16.6)	1 368 (15.1)	1 305 (13.6)	0.7	0.0	-0.3	-0.5	-0.3
India	873 (16.6)	1 234 (17.9)	1 380 (17.8)	1 498 (17.7)	1 596 (17.6)	1 657 (17.3)	1.5	0.8	0.6	0.4	0.6
Japan	123 (2.3)	128 (1.9)	126 (1.6)	119 (1.4)	112 (1.2)	104 (1.1)	0.1	-0.5	-0.6	-0.7	-0.6
Korea	43 (0.8)	50 (0.7)	52 (0.7)	51 (0.6)	49 (0.5)	46 (0.5)	0.6	-0.1	-0.4	-0.7	-0.4
Chinese Taipei	20 (0.4)	23 (0.3)	24 (0.3)	24 (0.3)	23 (0.3)	22 (0.2)	0.5	0.1	-0.2	-0.5	-0.2
ASEAN	431 (8.2)	575 (8.3)	643 (8.3)	695 (8.2)	735 (8.1)	758 (7.9)	1.3	0.8	0.6	0.3	0.6
Indonesia	181 (3.4)	242 (3.5)	274 (3.5)	294 (3.5)	311 (3.4)	320 (3.3)	1.4	0.7	0.5	0.3	0.5
Malaysia	18 (0.3)	28 (0.4)	32 (0.4)	36 (0.4)	38 (0.4)	40 (0.4)	2.0	1.0	0.7	0.4	0.7
Myanmar	41 (0.8)	51 (0.7)	54 (0.7)	58 (0.7)	60 (0.7)	61 (0.6)	0.9	0.7	0.4	0.1	0.4
Philippines	62 (1.2)	94 (1.4)	110 (1.4)	127 (1.5)	142 (1.6)	155 (1.6)	1.9	1.5	1.2	0.9	1.2
Singapore	3 (0.1)	5 (0.1)	6 (0.1)	6 (0.1)	6 (0.1)	6 (0.1)	2.1	0.6	0.3	-0.1	0.2
Thailand	57 (1.1)	67 (1.0)	70 (0.9)	70 (0.8)	69 (0.8)	67 (0.7)	0.7	0.1	-0.1	-0.4	-0.2
Viet Nam	68 (1.3)	88 (1.3)	97 (1.3)	104 (1.2)	107 (1.2)	108 (1.1)	1.2	0.6	0.3	0.1	0.4
North America	277 (5.3)	343 (5.0)	370 (4.8)	388 (4.6)	406 (4.5)	417 (4.3)	1.0	0.5	0.4	0.3	0.4
United States	250 (4.7)	309 (4.5)	332 (4.3)	347 (4.1)	362 (4.0)	371 (3.9)	1.0	0.5	0.4	0.2	0.4
Latin America	439 (8.3)	587 (8.5)	650 (8.4)	696 (8.2)	731 (8.1)	750 (7.8)	1.3	0.7	0.5	0.3	0.5
Advanced Europe	505 (9.6)	556 (8.0)	581 (7.5)	589 (7.0)	590 (6.5)	583 (6.1)	0.5	0.1	0.0	-0.1	0.0
European Union	420 (8.0)	442 (6.4)	447 (5.8)	449 (5.3)	446 (4.9)	438 (4.6)	0.2	0.0	-0.1	-0.2	-0.1
Other Europe/Eurasia	336 (6.4)	332 (4.8)	342 (4.4)	340 (4.0)	340 (3.7)	339 (3.5)	0.1	0.0	0.0	0.0	0.0
Africa	612 (11.6)	1 005 (14.5)	1 293 (16.7)	1 627 (19.3)	1 993 (21.9)	2 368 (24.7)	2.5	2.3	2.0	1.7	2.0
Middle East	132 (2.5)	213 (3.1)	256 (3.3)	294 (3.5)	330 (3.6)	362 (3.8)	2.2	1.4	1.2	0.9	1.2
Oceania	20 (0.4)	26 (0.4)	31 (0.4)	34 (0.4)	36 (0.4)	38 (0.4)	1.4	0.9	0.7	0.6	0.7
Advanced Economies	998 (18.9)	1 139 (16.5)	1 196 (15.4)	1 219 (14.4)	1 230 (13.5)	1 224 (12.8)	0.6	0.2	0.1	0.0	0.1
Emerging Market and Developing Economies	4 274 (81.1)	5 773 (83.5)	6 557 (84.6)	7 229 (85.6)	7 852 (86.5)	8 373 (87.2)	1.4	1.0	0.8	0.6	0.8

Source: United Nations "Population Estimates and Projections: The 2019 Revision", World Bank "World Development Indicators"

Note: Figures in parentheses are global shares (%).

Table A4 | GDP

($2015 billion)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/2020	2020/2030	2030/2040	2040/2050	2020/2050
World	35 843 (100)	64 655 (100)	81 578 (100)	112 310 (100)	147 292 (100)	184 952 (100)	2.8	3.2	2.7	2.3	2.8
Asia	6 688 (18.7)	17 857 (27.6)	27 854 (34.1)	43 113 (38.4)	61 368 (41.7)	81 167 (43.9)	4.9	4.5	3.6	2.8	3.6
China	1 027 (2.9)	7 554 (11.7)	14 632 (17.9)	23 979 (21.4)	34 465 (23.4)	44 383 (24.0)	9.3	5.1	3.7	2.6	3.8
India	475 (1.3)	1 567 (2.4)	2 551 (3.1)	4 958 (4.4)	8 483 (5.8)	13 446 (7.3)	5.8	6.9	5.5	4.7	5.7
Japan	3 520 (9.8)	4 219 (6.5)	4 381 (5.4)	4 889 (4.4)	5 321 (3.6)	5 739 (3.1)	0.7	1.1	0.9	0.8	0.9
Korea	402 (1.1)	1 261 (2.0)	1 624 (2.0)	2 091 (1.9)	2 499 (1.7)	2 796 (1.5)	4.8	2.6	1.8	1.1	1.8
Chinese Taipei	161 (0.4)	463 (0.7)	597 (0.7)	781 (0.7)	944 (0.6)	1 092 (0.6)	4.5	2.7	1.9	1.5	2.0
ASEAN	720 (2.0)	1 914 (3.0)	2 846 (3.5)	4 495 (4.0)	6 741 (4.6)	9 557 (5.2)	4.7	4.7	4.1	3.6	4.1
Indonesia	270 (0.8)	658 (1.0)	1 028 (1.3)	1 709 (1.5)	2 721 (1.8)	3 994 (2.2)	4.6	5.2	4.8	3.9	4.6
Malaysia	75 (0.2)	233 (0.4)	344 (0.4)	527 (0.5)	745 (0.5)	998 (0.5)	5.2	4.4	3.5	3.0	3.6
Myanmar	7 (0.0)	43 (0.1)	81 (0.1)	90 (0.1)	142 (0.1)	210 (0.1)	8.4	1.1	4.7	3.9	3.2
Philippines	107 (0.3)	229 (0.4)	358 (0.4)	642 (0.6)	988 (0.7)	1 459 (0.8)	4.1	6.0	4.4	4.0	4.8
Singapore	71 (0.2)	247 (0.4)	330 (0.4)	449 (0.4)	538 (0.4)	603 (0.3)	5.3	3.1	1.8	1.1	2.0
Thailand	144 (0.4)	347 (0.5)	433 (0.5)	596 (0.5)	812 (0.6)	1 052 (0.6)	3.7	3.3	3.1	2.6	3.0
Viet Nam	37 (0.1)	145 (0.2)	259 (0.3)	466 (0.4)	775 (0.5)	1 221 (0.7)	6.7	6.1	5.2	4.6	5.3
North America	10 620 (29.6)	17 720 (27.4)	20 902 (25.6)	26 554 (23.6)	32 406 (22.0)	38 238 (20.7)	2.3	2.4	2.0	1.7	2.0
United States	9 805 (27.4)	16 320 (25.2)	19 294 (23.7)	24 520 (21.8)	29 928 (20.3)	35 322 (19.1)	2.3	2.4	2.0	1.7	2.0
Latin America	2 589 (7.2)	4 833 (7.5)	5 130 (6.3)	6 932 (6.2)	9 441 (6.4)	11 959 (6.5)	2.3	3.1	3.1	2.4	2.9
Advanced Europe	11 651 (32.5)	16 908 (26.2)	18 608 (22.8)	23 351 (20.8)	26 826 (18.2)	30 136 (16.3)	1.6	2.3	1.4	1.2	1.6
European Union	9 083 (25.3)	12 898 (19.9)	13 890 (17.0)	17 337 (15.4)	19 839 (13.5)	22 158 (12.0)	1.4	2.2	1.4	1.1	1.6
Other Europe/Eurasia	1 813 (5.1)	2 088 (3.2)	2 487 (3.0)	2 961 (2.6)	3 784 (2.6)	4 763 (2.6)	1.1	1.8	2.5	2.3	2.2
Africa	914 (2.5)	1 992 (3.1)	2 519 (3.1)	3 864 (3.4)	6 255 (4.2)	9 561 (5.2)	3.4	4.4	4.9	4.3	4.5
Middle East	910 (2.5)	2 039 (3.2)	2 529 (3.1)	3 482 (3.1)	4 630 (3.1)	6 001 (3.2)	3.5	3.3	2.9	2.6	2.9
Oceania	658 (1.8)	1 219 (1.9)	1 551 (1.9)	2 053 (1.8)	2 582 (1.8)	3 128 (1.7)	2.9	2.8	2.3	1.9	2.4
Advanced Economies	27 204 (75.9)	42 304 (65.4)	48 304 (59.2)	60 587 (53.9)	71 616 (48.6)	82 280 (44.5)	1.9	2.3	1.7	1.4	1.8
Emerging Market and Developing Economies	8 639 (24.1)	22 351 (34.6)	33 275 (40.8)	51 724 (46.1)	75 676 (51.4)	102 672 (55.5)	4.6	4.5	3.9	3.1	3.8

Source: World Bank "World Development Indicators", etc. (historical)

Note: Figures in parentheses are global shares (%).

Table A5 | GDP per capita

($2015 thousand/person)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/2020	2020/2030	2030/2040	2040/2050	2020/2050
World	6.8	9.4	10.5	13.3	16.2	19.3	1.5	2.4	2.0	1.7	2.0
Asia	2.3	4.6	6.6	9.6	13.2	17.1	3.6	3.9	3.2	2.7	3.2
China	0.9	5.6	10.4	17.1	25.2	34.0	8.5	5.1	4.0	3.0	4.0
India	0.5	1.3	1.8	3.3	5.3	8.1	4.2	6.0	4.9	4.3	5.1
Japan	28.5	32.9	34.8	41.0	47.6	55.0	0.7	1.7	1.5	1.5	1.5
Korea	9.4	25.5	31.3	40.7	50.5	60.8	4.1	2.7	2.2	1.9	2.2
Chinese Taipei	7.9	20.0	25.3	32.8	40.3	48.9	4.0	2.6	2.1	2.0	2.2
ASEAN	1.7	3.3	4.4	6.5	9.2	12.6	3.3	3.9	3.6	3.2	3.6
Indonesia	1.5	2.7	3.8	5.8	8.8	12.5	3.1	4.5	4.2	3.6	4.1
Malaysia	4.1	8.2	10.6	14.7	19.4	24.8	3.2	3.3	2.8	2.5	2.9
Myanmar	0.2	0.8	1.5	1.6	2.4	3.4	7.4	0.4	4.3	3.8	2.8
Philippines	1.7	2.4	3.3	5.1	7.0	9.4	2.1	4.5	3.2	3.1	3.6
Singapore	23.3	48.7	58.1	74.6	87.0	98.5	3.1	2.5	1.6	1.2	1.8
Thailand	2.5	5.2	6.2	8.5	11.7	15.8	3.0	3.2	3.3	3.1	3.2
Viet Nam	0.5	1.6	2.7	4.5	7.2	11.3	5.4	5.4	4.9	4.5	4.9
North America	38.3	51.6	56.6	68.4	79.9	91.7	1.3	1.9	1.6	1.4	1.6
United States	39.3	52.8	58.2	70.6	82.7	95.3	1.3	2.0	1.6	1.4	1.7
Latin America	5.9	8.2	7.9	10.0	12.9	15.9	1.0	2.4	2.6	2.1	2.4
Advanced Europe	23.1	30.4	32.0	39.6	45.5	51.7	1.1	2.2	1.4	1.3	1.6
European Union	21.6	29.2	31.0	38.6	44.5	50.6	1.2	2.2	1.4	1.3	1.6
Other Europe/Eurasia	5.4	6.3	7.3	8.7	11.1	14.0	1.0	1.8	2.5	2.4	2.2
Africa	1.5	2.0	1.9	2.4	3.1	4.0	0.9	2.0	2.8	2.5	2.5
Middle East	6.9	9.6	9.9	11.8	14.0	16.6	1.2	1.8	1.7	1.7	1.7
Oceania	32.2	46.2	50.4	60.7	71.2	81.7	1.5	1.9	1.6	1.4	1.6
Advanced Economies	27.3	37.1	40.4	49.7	58.2	67.2	1.3	2.1	1.6	1.4	1.7
Emerging Market and Developing Economies	2.0	3.9	5.1	7.2	9.6	12.3	3.1	3.5	3.0	2.4	3.0

Source: World Bank "World Development Indicators", International Energy Agency "World Energy Balances", etc. (historical)

Table A6 | International energy prices

Real prices			Reference			Advanced Technologies		
		2021	2030	2040	2050	2030	2040	2050
Oil	$2021/bbl	71	80	90	95	60	55	45
Natural gas								
Japan	$2021/MBtu	10.8	7.6	7.2	7.1	6.5	5.8	4.6
Europe (UK)	$2021/MBtu	16.1	7.5	7.5	7.4	6.9	6.2	5.0
United States	$2021/MBtu	3.9	3.3	3.8	3.8	3.0	3.5	3.5
Steam coal	$2021/t	129	99	96	93	84	77	70

Nominal prices			Reference			Advanced Technologies		
		2021	2030	2040	2050	2030	2040	2050
Oil	$/bbl	71	96	125	148	72	77	70
Natural gas								
Japan	$/MBtu	10.8	9.1	10.0	11.1	7.7	8.1	7.2
Europe (UK)	$/MBtu	16.1	9.0	10.5	11.6	8.3	8.6	7.8
United States	$/MBtu	3.9	4.0	5.3	5.9	3.6	4.9	5.5
Steam coal	$/t	129	119	134	145	101	107	109

Note: 2% per annum of inflation rates are assumed.

Table A7 | Primary energy consumption [Reference Scenario]

(Mtoe)

	1990	2010	2020	2030	2040	2050	CAGR (%)				
							1990/ 2020	2020/ 2030	2030/ 2040	2040/ 2050	2020/ 2050
World	8 747 (100)	12 833 (100)	13 963 (100)	16 007 (100)	16 948 (100)	17 649 (100)	1.6	1.4	0.6	0.4	0.8
Asia	2 081 (23.8)	4 783 (37.3)	6 052 (43.3)	7 175 (44.8)	7 735 (45.6)	8 200 (46.5)	3.6	1.7	0.8	0.6	1.0
China	874 (10.0)	2 536 (19.8)	3 499 (25.1)	3 791 (23.7)	3 662 (21.6)	3 407 (19.3)	4.7	0.8	-0.3	-0.7	-0.1
India	280 (3.2)	667 (5.2)	872 (6.2)	1 299 (8.1)	1 712 (10.1)	2 172 (12.3)	3.9	4.1	2.8	2.4	3.1
Japan	437 (5.0)	500 (3.9)	385 (2.8)	392 (2.5)	363 (2.1)	335 (1.9)	-0.4	0.2	-0.8	-0.8	-0.5
Korea	93 (1.1)	250 (1.9)	276 (2.0)	303 (1.9)	292 (1.7)	268 (1.5)	3.7	0.9	-0.4	-0.8	-0.1
Chinese Taipei	47 (0.5)	109 (0.8)	107 (0.8)	111 (0.7)	108 (0.6)	101 (0.6)	2.8	0.3	-0.3	-0.7	-0.2
ASEAN	231 (2.6)	535 (4.2)	673 (4.8)	954 (6.0)	1 192 (7.0)	1 420 (8.0)	3.6	3.6	2.2	1.8	2.5
Indonesia	99 (1.1)	204 (1.6)	233 (1.7)	346 (2.2)	460 (2.7)	575 (3.3)	2.9	4.0	2.9	2.3	3.1
Malaysia	21 (0.2)	72 (0.6)	92 (0.7)	142 (0.9)	161 (0.9)	172 (1.0)	5.0	4.4	1.3	0.7	2.1
Myanmar	11 (0.1)	14 (0.1)	23 (0.2)	29 (0.2)	39 (0.2)	48 (0.3)	2.5	2.6	2.8	2.3	2.6
Philippines	27 (0.3)	42 (0.3)	58 (0.4)	90 (0.6)	116 (0.7)	144 (0.8)	2.6	4.5	2.5	2.2	3.1
Singapore	12 (0.1)	24 (0.2)	32 (0.2)	37 (0.2)	39 (0.2)	39 (0.2)	3.5	1.5	0.5	0.0	0.7
Thailand	42 (0.5)	118 (0.9)	133 (1.0)	159 (1.0)	179 (1.1)	193 (1.1)	3.9	1.8	1.2	0.8	1.2
Viet Nam	18 (0.2)	59 (0.5)	97 (0.7)	147 (0.9)	195 (1.1)	245 (1.4)	5.8	4.2	2.9	2.3	3.1
North America	2 126 (24.3)	2 475 (19.3)	2 322 (16.6)	2 458 (15.4)	2 382 (14.1)	2 264 (12.8)	0.3	0.6	-0.3	-0.5	-0.1
United States	1 914 (21.9)	2 216 (17.3)	2 038 (14.6)	2 141 (13.4)	2 057 (12.1)	1 943 (11.0)	0.2	0.5	-0.4	-0.6	-0.2
Latin America	467 (5.3)	788 (6.1)	779 (5.6)	959 (6.0)	1 089 (6.4)	1 173 (6.6)	1.7	2.1	1.3	0.7	1.4
Advanced Europe	1 644 (18.8)	1 835 (14.3)	1 607 (11.5)	1 627 (10.2)	1 506 (8.9)	1 398 (7.9)	-0.1	0.1	-0.8	-0.7	-0.5
European Union	1 441 (16.5)	1 527 (11.9)	1 311 (9.4)	1 331 (8.3)	1 225 (7.2)	1 130 (6.4)	-0.3	0.2	-0.8	-0.8	-0.5
Other Europe/Eurasia	1 514 (17.3)	1 112 (8.7)	1 133 (8.1)	1 114 (7.0)	1 154 (6.8)	1 204 (6.8)	-1.0	-0.2	0.4	0.4	0.2
Africa	391 (4.5)	688 (5.4)	830 (5.9)	1 012 (6.3)	1 168 (6.9)	1 300 (7.4)	2.5	2.0	1.4	1.1	1.5
Middle East	223 (2.5)	649 (5.1)	792 (5.7)	989 (6.2)	1 119 (6.6)	1 221 (6.9)	4.3	2.2	1.2	0.9	1.5
Oceania	99 (1.1)	144 (1.1)	151 (1.1)	160 (1.0)	161 (1.0)	156 (0.9)	1.4	0.6	0.1	-0.3	0.1
Advanced Economies	4 467 (51.1)	5 349 (41.7)	4 893 (35.0)	5 102 (31.9)	4 864 (28.7)	4 575 (25.9)	0.3	0.4	-0.5	-0.6	-0.2
Emerging Market and Developing Economies	4 078 (46.6)	7 125 (55.5)	8 774 (62.8)	10 392 (64.9)	11 450 (67.6)	12 341 (69.9)	2.6	1.7	1.0	0.8	1.1

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A8 | Primary energy consumption, coal [Reference Scenario]

(Mtoe)

							CAGR (%)				
	1990	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2040	2040/ 2050	2020/ 2050
World	2 222 (100)	3 654 (100)	3 741 (100)	3 942 (100)	3 867 (100)	3 688 (100)	1.8	0.5	-0.2	-0.5	0.0
Asia	788 (35.5)	2 409 (65.9)	2 938 (78.5)	3 238 (82.1)	3 247 (83.9)	3 142 (85.2)	4.5	1.0	0.0	-0.3	0.2
China	531 (23.9)	1 790 (49.0)	2 125 (56.8)	2 167 (55.0)	1 919 (49.6)	1 597 (43.3)	4.7	0.2	-1.2	-1.8	-0.9
India	93 (4.2)	279 (7.6)	379 (10.1)	571 (14.5)	760 (19.7)	935 (25.3)	4.8	4.2	2.9	2.1	3.1
Japan	77 (3.5)	115 (3.2)	102 (2.7)	91 (2.3)	80 (2.1)	67 (1.8)	1.0	-1.2	-1.3	-1.7	-1.4
Korea	25 (1.1)	73 (2.0)	74 (2.0)	83 (2.1)	79 (2.0)	67 (1.8)	3.6	1.1	-0.5	-1.6	-0.3
Chinese Taipei	11 (0.5)	38 (1.0)	36 (1.0)	41 (1.0)	38 (1.0)	33 (0.9)	4.2	1.2	-0.7	-1.4	-0.3
ASEAN	13 (0.6)	85 (2.3)	178 (4.7)	226 (5.7)	290 (7.5)	340 (9.2)	9.2	2.4	2.5	1.6	2.2
Indonesia	4 (0.2)	32 (0.9)	68 (1.8)	92 (2.3)	129 (3.3)	160 (4.3)	10.4	3.0	3.5	2.2	2.9
Malaysia	1 (0.1)	15 (0.4)	22 (0.6)	22 (0.6)	21 (0.6)	18 (0.5)	9.7	0.3	-0.4	-2.0	-0.7
Myanmar	0 (0.0)	0 (0.0)	1 (0.0)	3 (0.1)	6 (0.1)	9 (0.2)	10.5	9.5	5.5	4.2	6.3
Philippines	1 (0.1)	7 (0.2)	18 (0.5)	22 (0.6)	27 (0.7)	29 (0.8)	8.6	2.4	1.9	0.7	1.6
Singapore	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.0)	1 (0.0)	0 (0.0)	10.5	2.0	-0.2	-1.2	0.2
Thailand	4 (0.2)	16 (0.4)	17 (0.5)	15 (0.4)	15 (0.4)	14 (0.4)	5.1	-1.2	0.0	-1.0	-0.7
Viet Nam	2 (0.1)	15 (0.4)	51 (1.4)	70 (1.8)	91 (2.4)	111 (3.0)	11.0	3.3	2.6	2.0	2.6
North America	484 (21.8)	525 (14.4)	231 (6.2)	178 (4.5)	109 (2.8)	38 (1.0)	-2.4	-2.6	-4.8	-10.0	-5.8
United States	460 (20.7)	501 (13.7)	222 (5.9)	175 (4.4)	109 (2.8)	38 (1.0)	-2.4	-2.3	-4.7	-10.0	-5.7
Latin America	21 (1.0)	39 (1.1)	37 (1.0)	40 (1.0)	47 (1.2)	48 (1.3)	1.9	0.7	1.5	0.3	0.8
Advanced Europe	450 (20.3)	301 (8.2)	183 (4.9)	158 (4.0)	123 (3.2)	104 (2.8)	-3.0	-1.5	-2.4	-1.7	-1.9
European Union	393 (17.7)	252 (6.9)	144 (3.9)	122 (3.1)	95 (2.5)	81 (2.2)	-3.3	-1.6	-2.5	-1.6	-1.9
Other Europe/Eurasia	365 (16.4)	211 (5.8)	199 (5.3)	169 (4.3)	173 (4.5)	183 (5.0)	-2.0	-1.6	0.2	0.6	-0.3
Africa	74 (3.3)	108 (3.0)	105 (2.8)	114 (2.9)	127 (3.3)	138 (3.7)	1.2	0.8	1.1	0.8	0.9
Middle East	3 (0.1)	10 (0.3)	8 (0.2)	10 (0.3)	10 (0.2)	8 (0.2)	3.3	2.3	-0.6	-1.7	0.0
Oceania	36 (1.6)	52 (1.4)	41 (1.1)	36 (0.9)	32 (0.8)	27 (0.7)	0.4	-1.1	-1.2	-1.6	-1.3
Advanced Economies	1 089 (49.0)	1 110 (30.4)	670 (17.9)	592 (15.0)	467 (12.1)	342 (9.3)	-1.6	-1.2	-2.3	-3.1	-2.2
Emerging Market and Developing Economies	1 133 (51.0)	2 543 (69.6)	3 071 (82.1)	3 350 (85.0)	3 400 (87.9)	3 346 (90.7)	3.4	0.9	0.1	-0.2	0.3

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A9 | Primary energy consumption, oil [Reference Scenario]

(Mtoe)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/2020	2020/2030	2030/2040	2040/2050	2020/2050
World	3 234 (100)	4 144 (100)	4 115 (100)	4 897 (100)	5 040 (100)	5 122 (100)	0.8	1.8	0.3	0.2	0.7
Asia	615 (19.0)	1 161 (28.0)	1 435 (34.9)	1 739 (35.5)	1 864 (37.0)	1 982 (38.7)	2.9	1.9	0.7	0.6	1.1
China	119 (3.7)	428 (10.3)	661 (16.1)	749 (15.3)	710 (14.1)	636 (12.4)	5.9	1.3	-0.5	-1.1	-0.1
India	61 (1.9)	162 (3.9)	207 (5.0)	321 (6.6)	444 (8.8)	601 (11.7)	4.2	4.5	3.3	3.1	3.6
Japan	249 (7.7)	201 (4.9)	148 (3.6)	133 (2.7)	110 (2.2)	94 (1.8)	-1.7	-1.0	-1.9	-1.6	-1.5
Korea	50 (1.5)	95 (2.3)	101 (2.5)	109 (2.2)	100 (2.0)	90 (1.8)	2.4	0.7	-0.8	-1.1	-0.4
Chinese Taipei	26 (0.8)	44 (1.1)	39 (0.9)	38 (0.8)	35 (0.7)	30 (0.6)	1.4	-0.1	-1.0	-1.3	-0.8
ASEAN	88 (2.7)	188 (4.5)	225 (5.5)	311 (6.3)	365 (7.2)	412 (8.0)	3.2	3.3	1.6	1.2	2.0
Indonesia	33 (1.0)	67 (1.6)	68 (1.7)	100 (2.0)	123 (2.4)	140 (2.7)	2.4	3.9	2.1	1.4	2.4
Malaysia	11 (0.4)	25 (0.6)	31 (0.8)	41 (0.8)	39 (0.8)	36 (0.7)	3.4	2.8	-0.4	-0.8	0.5
Myanmar	1 (0.0)	1 (0.0)	7 (0.2)	9 (0.2)	13 (0.3)	18 (0.3)	7.7	2.9	4.1	2.9	3.3
Philippines	10 (0.3)	14 (0.3)	16 (0.4)	32 (0.7)	45 (0.9)	59 (1.2)	1.8	6.9	3.3	2.8	4.3
Singapore	11 (0.4)	16 (0.4)	22 (0.5)	25 (0.5)	26 (0.5)	26 (0.5)	2.2	1.2	0.4	0.1	0.5
Thailand	18 (0.6)	45 (1.1)	55 (1.3)	63 (1.3)	68 (1.3)	70 (1.4)	3.8	1.4	0.7	0.3	0.8
Viet Nam	3 (0.1)	18 (0.4)	24 (0.6)	40 (0.8)	50 (1.0)	61 (1.2)	7.6	5.0	2.5	2.0	3.1
North America	833 (25.8)	903 (21.8)	794 (19.3)	860 (17.6)	768 (15.2)	665 (13.0)	-0.2	0.8	-1.1	-1.4	-0.6
United States	757 (23.4)	807 (19.5)	702 (17.1)	762 (15.6)	679 (13.5)	586 (11.4)	-0.2	0.8	-1.1	-1.5	-0.6
Latin America	240 (7.4)	364 (8.8)	294 (7.1)	360 (7.4)	380 (7.5)	373 (7.3)	0.7	2.1	0.5	-0.2	0.8
Advanced Europe	617 (19.1)	606 (14.6)	508 (12.3)	506 (10.3)	419 (8.3)	354 (6.9)	-0.6	0.0	-1.9	-1.7	-1.2
European Union	531 (16.4)	506 (12.2)	418 (10.2)	414 (8.4)	343 (6.8)	290 (5.7)	-0.8	-0.1	-1.8	-1.7	-1.2
Other Europe/Eurasia	459 (14.2)	216 (5.2)	231 (5.6)	226 (4.6)	217 (4.3)	207 (4.0)	-2.3	-0.2	-0.4	-0.5	-0.4
Africa	85 (2.6)	161 (3.9)	176 (4.3)	245 (5.0)	326 (6.5)	420 (8.2)	2.5	3.4	2.9	2.6	2.9
Middle East	146 (4.5)	324 (7.8)	331 (8.1)	412 (8.4)	444 (8.8)	457 (8.9)	2.8	2.2	0.7	0.3	1.1
Oceania	35 (1.1)	48 (1.2)	50 (1.2)	53 (1.1)	49 (1.0)	45 (0.9)	1.2	0.5	-0.7	-0.9	-0.4
Advanced Economies	1 824 (56.4)	1 917 (46.3)	1 666 (40.5)	1 728 (35.3)	1 511 (30.0)	1 306 (25.5)	-0.3	0.4	-1.3	-1.4	-0.8
Emerging Market and Developing Economies	1 207 (37.3)	1 867 (45.1)	2 153 (52.3)	2 672 (54.6)	2 956 (58.7)	3 196 (62.4)	1.9	2.2	1.0	0.8	1.3

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A10 | Primary energy consumption, natural gas [Reference Scenario]

(Mtoe)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/2020	2020/2030	2030/2040	2040/2050	2020/2050
World	1 662 (100)	2 732 (100)	3 306 (100)	3 806 (100)	4 343 (100)	4 820 (100)	2.3	1.4	1.3	1.0	1.3
Asia	116 (7.0)	453 (16.6)	670 (20.3)	905 (23.8)	1 128 (26.0)	1 342 (27.8)	6.0	3.0	2.2	1.8	2.3
China	13 (0.8)	89 (3.3)	265 (8.0)	338 (8.9)	387 (8.9)	421 (8.7)	10.6	2.4	1.4	0.9	1.6
India	11 (0.6)	54 (2.0)	53 (1.6)	99 (2.6)	161 (3.7)	229 (4.7)	5.5	6.5	4.9	3.6	5.0
Japan	44 (2.7)	86 (3.1)	92 (2.8)	87 (2.3)	88 (2.0)	83 (1.7)	2.5	-0.6	0.1	-0.6	-0.4
Korea	3 (0.2)	39 (1.4)	49 (1.5)	57 (1.5)	64 (1.5)	67 (1.4)	10.1	1.3	1.2	0.5	1.0
Chinese Taipei	1 (0.1)	13 (0.5)	21 (0.6)	27 (0.7)	29 (0.7)	31 (0.6)	9.5	2.3	0.9	0.5	1.2
ASEAN	30 (1.8)	125 (4.6)	130 (3.9)	213 (5.6)	277 (6.4)	343 (7.1)	5.0	5.1	2.7	2.2	3.3
Indonesia	16 (1.0)	39 (1.4)	34 (1.0)	58 (1.5)	86 (2.0)	116 (2.4)	2.6	5.4	4.1	3.0	4.2
Malaysia	7 (0.4)	31 (1.1)	36 (1.1)	73 (1.9)	88 (2.0)	104 (2.2)	5.7	7.3	2.0	1.6	3.6
Myanmar	1 (0.0)	1 (0.0)	3 (0.1)	8 (0.2)	13 (0.3)	17 (0.4)	4.7	10.4	4.5	3.1	6.0
Philippines	- (-)	3 (0.1)	3 (0.1)	7 (0.2)	13 (0.3)	21 (0.4)	-	7.6	6.4	5.2	6.4
Singapore	- (-)	6 (0.2)	9 (0.3)	10 (0.3)	11 (0.3)	11 (0.2)	-	1.6	0.5	-0.4	0.6
Thailand	5 (0.3)	33 (1.2)	35 (1.0)	39 (1.0)	41 (0.9)	38 (0.8)	6.7	1.2	0.5	-0.5	0.4
Viet Nam	0 (0.0)	8 (0.3)	7 (0.2)	16 (0.4)	23 (0.5)	34 (0.7)	30.2	8.0	3.8	3.8	5.2
North America	493 (29.7)	632 (23.1)	832 (25.2)	932 (24.5)	974 (22.4)	970 (20.1)	1.8	1.1	0.4	0.0	0.5
United States	438 (26.4)	556 (20.4)	719 (21.7)	786 (20.7)	806 (18.6)	792 (16.4)	1.7	0.9	0.3	-0.2	0.3
Latin America	71 (4.3)	178 (6.5)	204 (6.2)	253 (6.6)	322 (7.4)	386 (8.0)	3.6	2.1	2.4	1.8	2.1
Advanced Europe	267 (16.1)	473 (17.3)	421 (12.7)	416 (10.9)	413 (9.5)	381 (7.9)	1.5	-0.1	-0.1	-0.8	-0.3
European Union	250 (15.0)	363 (13.3)	326 (9.9)	329 (8.6)	326 (7.5)	307 (6.4)	0.9	0.1	-0.1	-0.6	-0.2
Other Europe/Eurasia	596 (35.8)	566 (20.7)	559 (16.9)	526 (13.8)	535 (12.3)	564 (11.7)	-0.2	-0.6	0.2	0.5	0.0
Africa	30 (1.8)	88 (3.2)	133 (4.0)	183 (4.8)	265 (6.1)	355 (7.4)	5.1	3.2	3.8	3.0	3.3
Middle East	72 (4.3)	311 (11.4)	445 (13.5)	533 (14.0)	614 (14.1)	688 (14.3)	6.3	1.8	1.4	1.1	1.5
Oceania	19 (1.1)	31 (1.1)	42 (1.3)	46 (1.2)	51 (1.2)	52 (1.1)	2.7	1.0	1.0	0.1	0.7
Advanced Economies	827 (49.8)	1 283 (47.0)	1 470 (44.5)	1 578 (41.5)	1 633 (37.6)	1 598 (33.1)	1.9	0.7	0.3	-0.2	0.3
Emerging Market and Developing Economies	835 (50.2)	1 449 (53.0)	1 836 (55.5)	2 215 (58.2)	2 668 (61.4)	3 139 (65.1)	2.7	1.9	1.9	1.6	1.8

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A11 | Final energy consumption [Reference Scenario]

(Mtoe)

	1990	2010	2020	2030	2040	2050	CAGR (%)				
							1990/2020	2020/2030	2030/2040	2040/2050	2020/2050
World	6 236 (100)	8 820 (100)	9 573 (100)	10 918 (100)	11 467 (100)	11 951 (100)	1.4	1.3	0.5	0.4	0.7
Asia	1 529 (24.5)	3 159 (35.8)	3 923 (41.0)	4 545 (41.6)	4 892 (42.7)	5 264 (44.0)	3.2	1.5	0.7	0.7	1.0
China	658 (10.5)	1 645 (18.7)	2 182 (22.8)	2 301 (21.1)	2 218 (19.3)	2 105 (17.6)	4.1	0.5	-0.4	-0.5	-0.1
India	215 (3.4)	444 (5.0)	596 (6.2)	859 (7.9)	1 122 (9.8)	1 443 (12.1)	3.5	3.7	2.7	2.6	3.0
Japan	291 (4.7)	314 (3.6)	263 (2.7)	259 (2.4)	237 (2.1)	218 (1.8)	-0.3	-0.2	-0.9	-0.8	-0.6
Korea	65 (1.0)	158 (1.8)	175 (1.8)	192 (1.8)	186 (1.6)	173 (1.5)	3.4	0.9	-0.3	-0.7	0.0
Chinese Taipei	30 (0.5)	70 (0.8)	71 (0.7)	74 (0.7)	73 (0.6)	69 (0.6)	2.9	0.5	-0.2	-0.5	-0.1
ASEAN	171 (2.7)	377 (4.3)	447 (4.7)	618 (5.7)	760 (6.6)	901 (7.5)	3.2	3.3	2.1	1.7	2.4
Indonesia	79 (1.3)	148 (1.7)	152 (1.6)	203 (1.9)	264 (2.3)	326 (2.7)	2.2	3.0	2.6	2.1	2.6
Malaysia	13 (0.2)	42 (0.5)	61 (0.6)	102 (0.9)	116 (1.0)	125 (1.0)	5.2	5.4	1.2	0.8	2.4
Myanmar	9 (0.2)	13 (0.1)	20 (0.2)	22 (0.2)	26 (0.2)	31 (0.3)	2.6	0.7	1.9	1.8	1.5
Philippines	19 (0.3)	25 (0.3)	32 (0.3)	52 (0.5)	69 (0.6)	90 (0.7)	1.8	4.8	2.9	2.7	3.5
Singapore	5 (0.1)	15 (0.2)	18 (0.2)	21 (0.2)	23 (0.2)	23 (0.2)	4.3	2.0	0.6	0.1	0.9
Thailand	29 (0.5)	84 (1.0)	97 (1.0)	114 (1.0)	128 (1.1)	137 (1.1)	4.1	1.6	1.2	0.7	1.2
Viet Nam	16 (0.3)	48 (0.5)	67 (0.7)	102 (0.9)	133 (1.2)	167 (1.4)	4.9	4.3	2.7	2.3	3.1
North America	1 452 (23.3)	1 699 (19.3)	1 651 (17.2)	1 774 (16.2)	1 713 (14.9)	1 627 (13.6)	0.4	0.7	-0.3	-0.5	-0.1
United States	1 294 (20.7)	1 513 (17.2)	1 461 (15.3)	1 568 (14.4)	1 510 (13.2)	1 432 (12.0)	0.4	0.7	-0.4	-0.5	-0.1
Latin America	344 (5.5)	570 (6.5)	550 (5.7)	668 (6.1)	745 (6.5)	798 (6.7)	1.6	2.0	1.1	0.7	1.3
Advanced Europe	1 142 (18.3)	1 288 (14.6)	1 182 (12.3)	1 206 (11.0)	1 113 (9.7)	1 030 (8.6)	0.1	0.2	-0.8	-0.8	-0.5
European Union	995 (16.0)	1 070 (12.1)	963 (10.1)	981 (9.0)	904 (7.9)	834 (7.0)	-0.1	0.2	-0.8	-0.8	-0.5
Other Europe/Eurasia	1 057 (17.0)	711 (8.1)	752 (7.9)	735 (6.7)	739 (6.4)	745 (6.2)	-1.1	-0.2	0.1	0.1	0.0
Africa	285 (4.6)	494 (5.6)	598 (6.2)	708 (6.5)	775 (6.8)	826 (6.9)	2.5	1.7	0.9	0.6	1.1
Middle East	157 (2.5)	451 (5.1)	527 (5.5)	667 (6.1)	754 (6.6)	829 (6.9)	4.1	2.4	1.2	0.9	1.5
Oceania	66 (1.1)	89 (1.0)	94 (1.0)	102 (0.9)	102 (0.9)	100 (0.8)	1.2	0.8	0.0	-0.2	0.2
Advanced Economies	3 057 (49.0)	3 640 (41.3)	3 461 (36.2)	3 636 (33.3)	3 455 (30.1)	3 247 (27.2)	0.4	0.5	-0.5	-0.6	-0.2
Emerging Market and Developing Economies	2 976 (47.7)	4 821 (54.7)	5 816 (60.7)	6 768 (62.0)	7 378 (64.3)	7 971 (66.7)	2.3	1.5	0.9	0.8	1.1

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A12 | Final energy consumption, industry [Reference Scenario]

(Mtoe)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/ 2020	CAGR (%) 2020/ 2030	CAGR (%) 2030/ 2040	CAGR (%) 2040/ 2050	CAGR (%) 2020/ 2050
World	1 795 (100)	2 639 (100)	2 873 (100)	3 161 (100)	3 337 (100)	3 497 (100)	1.6	1.0	0.5	0.5	0.7
Asia	506 (28.2)	1 402 (53.1)	1 650 (57.5)	1 809 (57.2)	1 874 (56.2)	1 959 (56.0)	4.0	0.9	0.4	0.4	0.6
China	234 (13.0)	924 (35.0)	1 073 (37.3)	1 009 (31.9)	866 (25.9)	748 (21.4)	5.2	-0.6	-1.5	-1.5	-1.2
India	59 (3.3)	158 (6.0)	226 (7.9)	362 (11.4)	483 (14.5)	606 (17.3)	4.6	4.8	2.9	2.3	3.3
Japan	108 (6.0)	92 (3.5)	75 (2.6)	75 (2.4)	69 (2.1)	63 (1.8)	-1.2	-0.1	-0.8	-0.9	-0.6
Korea	19 (1.1)	45 (1.7)	46 (1.6)	51 (1.6)	50 (1.5)	46 (1.3)	2.9	1.1	-0.2	-0.8	0.0
Chinese Taipei	12 (0.7)	24 (0.9)	24 (0.8)	27 (0.9)	27 (0.8)	26 (0.7)	2.3	1.2	0.1	-0.4	0.3
ASEAN	41 (2.3)	120 (4.6)	158 (5.5)	215 (6.8)	276 (8.3)	333 (9.5)	4.6	3.1	2.6	1.9	2.5
Indonesia	17 (1.0)	49 (1.9)	56 (1.9)	77 (2.4)	105 (3.1)	131 (3.8)	3.9	3.3	3.1	2.3	2.9
Malaysia	6 (0.3)	15 (0.6)	18 (0.6)	25 (0.8)	32 (0.9)	36 (1.0)	4.0	3.1	2.4	1.4	2.3
Myanmar	0 (0.0)	1 (0.0)	4 (0.1)	4 (0.1)	6 (0.2)	8 (0.2)	7.8	1.4	3.9	2.3	2.5
Philippines	4 (0.2)	6 (0.2)	6 (0.2)	10 (0.3)	12 (0.4)	15 (0.4)	1.3	4.3	2.6	2.3	3.1
Singapore	1 (0.0)	5 (0.2)	6 (0.2)	8 (0.2)	8 (0.2)	8 (0.2)	8.2	2.0	0.5	-0.3	0.7
Thailand	9 (0.5)	26 (1.0)	31 (1.1)	39 (1.2)	46 (1.4)	50 (1.4)	4.4	2.1	1.7	0.9	1.6
Viet Nam	5 (0.3)	17 (0.7)	36 (1.3)	52 (1.6)	67 (2.0)	84 (2.4)	7.2	3.6	2.6	2.3	2.8
North America	331 (18.4)	313 (11.9)	310 (10.8)	322 (10.2)	328 (9.8)	324 (9.3)	-0.2	0.4	0.2	-0.1	0.2
United States	284 (15.8)	270 (10.2)	265 (9.2)	273 (8.6)	276 (8.3)	272 (7.8)	-0.2	0.3	0.1	-0.1	0.1
Latin America	114 (6.3)	180 (6.8)	167 (5.8)	200 (6.3)	239 (7.2)	264 (7.6)	1.3	1.8	1.8	1.0	1.5
Advanced Europe	330 (18.4)	296 (11.2)	285 (9.9)	307 (9.7)	299 (8.9)	286 (8.2)	-0.5	0.7	-0.3	-0.4	0.0
European Union	313 (17.4)	247 (9.4)	232 (8.1)	250 (7.9)	245 (7.4)	236 (6.7)	-1.0	0.8	-0.2	-0.4	0.1
Other Europe/Eurasia	391 (21.8)	205 (7.8)	202 (7.0)	195 (6.2)	210 (6.3)	224 (6.4)	-2.2	-0.4	0.7	0.6	0.3
Africa	53 (3.0)	83 (3.1)	84 (2.9)	110 (3.5)	148 (4.4)	188 (5.4)	1.5	2.8	3.0	2.4	2.7
Middle East	47 (2.6)	134 (5.1)	147 (5.1)	186 (5.9)	207 (6.2)	220 (6.3)	3.9	2.4	1.1	0.6	1.3
Oceania	23 (1.3)	26 (1.0)	27 (0.9)	31 (1.0)	32 (1.0)	32 (0.9)	0.6	1.4	0.5	0.0	0.6
Advanced Economies	825 (46.0)	802 (30.4)	774 (26.9)	822 (26.0)	814 (24.4)	787 (22.5)	-0.2	0.6	-0.1	-0.3	0.1
Emerging Market and Developing Economies	969 (54.0)	1 838 (69.6)	2 099 (73.1)	2 340 (74.0)	2 523 (75.6)	2 710 (77.5)	2.6	1.1	0.8	0.7	0.9

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%).

Table A13 | Final energy consumption, transport [Reference Scenario]

(Mtoe)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/ 2020	2020/ 2030	2030/ 2040	2040/ 2050	2020/ 2050
World	1 577 (100)	2 430 (100)	2 507 (100)	3 167 (100)	3 328 (100)	3 502 (100)	1.6	2.4	0.5	0.5	1.1
Asia	188 (11.9)	494 (20.3)	681 (27.2)	900 (28.4)	999 (30.0)	1 116 (31.9)	4.4	2.8	1.1	1.1	1.7
China	30 (1.9)	197 (8.1)	323 (12.9)	423 (13.4)	417 (12.5)	383 (10.9)	8.2	2.7	-0.1	-0.9	0.6
India	21 (1.3)	65 (2.7)	93 (3.7)	154 (4.9)	228 (6.8)	344 (9.8)	5.1	5.2	4.0	4.2	4.5
Japan	72 (4.6)	79 (3.2)	62 (2.5)	54 (1.7)	42 (1.3)	36 (1.0)	-0.5	-1.5	-2.4	-1.6	-1.8
Korea	15 (0.9)	30 (1.2)	34 (1.4)	36 (1.1)	31 (0.9)	25 (0.7)	2.9	0.4	-1.5	-1.9	-1.0
Chinese Taipei	7 (0.4)	12 (0.5)	12 (0.5)	11 (0.3)	9 (0.3)	7 (0.2)	2.1	-1.1	-2.3	-2.6	-2.0
ASEAN	33 (2.1)	86 (3.6)	122 (4.9)	172 (5.4)	207 (6.2)	241 (6.9)	4.5	3.5	1.8	1.5	2.3
Indonesia	11 (0.7)	30 (1.2)	48 (1.9)	70 (2.2)	87 (2.6)	103 (3.0)	5.1	3.8	2.2	1.8	2.6
Malaysia	5 (0.3)	15 (0.6)	21 (0.8)	25 (0.8)	23 (0.7)	20 (0.6)	4.9	1.8	-0.9	-1.3	-0.1
Myanmar	0 (0.0)	1 (0.0)	2 (0.1)	3 (0.1)	5 (0.2)	7 (0.2)	5.3	4.3	4.8	3.7	4.2
Philippines	5 (0.3)	8 (0.3)	10 (0.4)	22 (0.7)	31 (0.9)	42 (1.2)	2.6	8.1	3.6	3.1	4.9
Singapore	1 (0.1)	2 (0.1)	2 (0.1)	2 (0.1)	2 (0.1)	2 (0.1)	1.8	0.0	-1.0	-1.5	-0.8
Thailand	9 (0.6)	19 (0.8)	27 (1.1)	30 (0.9)	31 (0.9)	32 (0.9)	3.6	1.0	0.6	0.3	0.6
Viet Nam	1 (0.1)	10 (0.4)	12 (0.5)	21 (0.7)	28 (0.8)	35 (1.0)	7.6	5.3	3.0	2.3	3.5
North America	531 (33.7)	656 (27.0)	605 (24.1)	666 (21.0)	597 (17.9)	527 (15.1)	0.4	1.0	-1.1	-1.2	-0.5
United States	488 (30.9)	596 (24.5)	549 (21.9)	603 (19.0)	541 (16.2)	477 (13.6)	0.4	1.0	-1.1	-1.2	-0.5
Latin America	103 (6.6)	197 (8.1)	191 (7.6)	252 (8.0)	272 (8.2)	282 (8.1)	2.1	2.8	0.7	0.4	1.3
Advanced Europe	269 (17.0)	335 (13.8)	309 (12.3)	317 (10.0)	258 (7.7)	220 (6.3)	0.5	0.3	-2.0	-1.6	-1.1
European Union	220 (13.9)	279 (11.5)	252 (10.1)	256 (8.1)	209 (6.3)	178 (5.1)	0.5	0.2	-2.0	-1.6	-1.2
Other Europe/Eurasia	170 (10.8)	145 (6.0)	144 (5.8)	145 (4.6)	135 (4.1)	128 (3.7)	-0.6	0.0	-0.7	-0.5	-0.4
Africa	38 (2.4)	87 (3.6)	112 (4.5)	159 (5.0)	208 (6.3)	265 (7.6)	3.7	3.6	2.7	2.4	2.9
Middle East	51 (3.2)	121 (5.0)	131 (5.2)	178 (5.6)	189 (5.7)	197 (5.6)	3.2	3.1	0.6	0.4	1.4
Oceania	24 (1.5)	35 (1.4)	36 (1.4)	37 (1.2)	35 (1.1)	33 (0.9)	1.4	0.3	-0.6	-0.7	-0.3
Advanced Economies	920 (58.3)	1 151 (47.4)	1 064 (42.5)	1 126 (35.5)	976 (29.3)	852 (24.3)	0.5	0.6	-1.4	-1.4	-0.7
Emerging Market and Developing Economies	454 (28.8)	920 (37.9)	1 146 (45.7)	1 528 (48.3)	1 717 (51.6)	1 917 (54.7)	3.1	2.9	1.2	1.1	1.7

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A14 | Final energy consumption, buildings, etc. [Reference Scenario]

(Mtoe)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/ 2020	2020/ 2030	2030/ 2040	2040/ 2050	2020/ 2050
World	2 387 (100)	2 967 (100)	3 248 (100)	3 443 (100)	3 531 (100)	3 578 (100)	1.0	0.6	0.3	0.1	0.3
Asia	720 (30.1)	975 (32.9)	1 177 (36.2)	1 300 (37.8)	1 419 (40.2)	1 543 (43.1)	1.7	1.0	0.9	0.8	0.9
China	351 (14.7)	411 (13.9)	587 (18.1)	641 (18.6)	695 (19.7)	738 (20.6)	1.7	0.9	0.8	0.6	0.8
India	122 (5.1)	187 (6.3)	223 (6.9)	259 (7.5)	295 (8.4)	345 (9.7)	2.0	1.5	1.3	1.6	1.5
Japan	78 (3.2)	109 (3.7)	96 (2.9)	97 (2.8)	93 (2.6)	88 (2.5)	0.7	0.1	-0.4	-0.6	-0.3
Korea	24 (1.0)	44 (1.5)	45 (1.4)	48 (1.4)	47 (1.3)	44 (1.2)	2.1	0.5	-0.2	-0.6	-0.1
Chinese Taipei	6 (0.3)	12 (0.4)	12 (0.4)	13 (0.4)	13 (0.4)	13 (0.4)	2.2	0.3	0.3	-0.1	0.2
ASEAN	86 (3.6)	130 (4.4)	113 (3.5)	130 (3.8)	157 (4.4)	188 (5.2)	0.9	1.4	1.9	1.8	1.7
Indonesia	44 (1.8)	59 (2.0)	40 (1.2)	43 (1.2)	54 (1.5)	68 (1.9)	-0.3	0.8	2.3	2.3	1.8
Malaysia	2 (0.1)	8 (0.3)	9 (0.3)	12 (0.3)	14 (0.4)	16 (0.4)	4.8	2.9	1.9	1.2	2.0
Myanmar	8 (0.4)	11 (0.4)	14 (0.4)	14 (0.4)	14 (0.4)	15 (0.4)	1.6	-0.1	0.4	0.8	0.4
Philippines	10 (0.4)	11 (0.4)	15 (0.5)	19 (0.6)	23 (0.7)	28 (0.8)	1.4	2.3	2.0	2.0	2.1
Singapore	1 (0.0)	2 (0.1)	3 (0.1)	3 (0.1)	3 (0.1)	3 (0.1)	2.9	1.2	0.6	-0.1	0.6
Thailand	11 (0.5)	20 (0.7)	16 (0.5)	19 (0.5)	20 (0.6)	21 (0.6)	1.4	1.3	0.7	0.4	0.8
Viet Nam	10 (0.4)	18 (0.6)	16 (0.5)	21 (0.6)	28 (0.8)	36 (1.0)	1.6	2.7	2.9	2.6	2.7
North America	456 (19.1)	572 (19.3)	572 (17.6)	589 (17.1)	583 (16.5)	566 (15.8)	0.8	0.3	-0.1	-0.3	0.0
United States	403 (16.9)	511 (17.2)	505 (15.5)	518 (15.1)	513 (14.5)	497 (13.9)	0.8	0.3	-0.1	-0.3	0.0
Latin America	100 (4.2)	148 (5.0)	159 (4.9)	173 (5.0)	185 (5.2)	197 (5.5)	1.5	0.9	0.7	0.6	0.7
Advanced Europe	442 (18.5)	544 (18.3)	485 (14.9)	473 (13.7)	448 (12.7)	418 (11.7)	0.3	-0.2	-0.5	-0.7	-0.5
European Union	374 (15.7)	447 (15.1)	390 (12.0)	380 (11.1)	358 (10.1)	332 (9.3)	0.1	-0.2	-0.6	-0.8	-0.5
Other Europe/Eurasia	431 (18.1)	281 (9.5)	306 (9.4)	298 (8.7)	289 (8.2)	281 (7.8)	-1.1	-0.3	-0.3	-0.3	-0.3
Africa	183 (7.7)	306 (10.3)	383 (11.8)	414 (12.0)	389 (11.0)	336 (9.4)	2.5	0.8	-0.6	-1.4	-0.4
Middle East	40 (1.7)	119 (4.0)	142 (4.4)	168 (4.9)	190 (5.4)	210 (5.9)	4.3	1.7	1.3	1.0	1.3
Oceania	15 (0.6)	23 (0.8)	25 (0.8)	27 (0.8)	28 (0.8)	28 (0.8)	1.7	0.9	0.3	0.0	0.4
Advanced Economies	1 025 (42.9)	1 310 (44.1)	1 242 (38.2)	1 254 (36.4)	1 220 (34.5)	1 163 (32.5)	0.6	0.1	-0.3	-0.5	-0.2
Emerging Market and Developing Economies	1 362 (57.1)	1 657 (55.9)	2 007 (61.8)	2 189 (63.6)	2 311 (65.5)	2 415 (67.5)	1.3	0.9	0.5	0.4	0.6

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%).

Table A15 | Final energy consumption, electricity [Reference Scenario]

(TWh)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/ 2020	2020/ 2030	2030/ 2040	2040/ 2050	2020/ 2050
World	9 698 (100)	17 884 (100)	22 773 (100)	28 608 (100)	34 116 (100)	39 631 (100)	2.9	2.3	1.8	1.5	1.9
Asia	1 822 (18.8)	6 678 (37.3)	10 985 (48.2)	14 657 (51.2)	17 613 (51.6)	20 465 (51.6)	6.2	2.9	1.9	1.5	2.1
China	454 (4.7)	3 450 (19.3)	6 827 (30.0)	8 724 (30.5)	9 682 (28.4)	10 220 (25.8)	9.5	2.5	1.0	0.5	1.4
India	212 (2.2)	720 (4.0)	1 182 (5.2)	2 077 (7.3)	3 103 (9.1)	4 337 (10.9)	5.9	5.8	4.1	3.4	4.4
Japan	765 (7.9)	1 035 (5.8)	907 (4.0)	969 (3.4)	1 009 (3.0)	1 025 (2.6)	0.6	0.7	0.4	0.2	0.4
Korea	94 (1.0)	449 (2.5)	513 (2.3)	610 (2.1)	658 (1.9)	664 (1.7)	5.8	1.8	0.8	0.1	0.9
Chinese Taipei	77 (0.8)	218 (1.2)	252 (1.1)	287 (1.0)	310 (0.9)	319 (0.8)	4.0	1.3	0.8	0.3	0.8
ASEAN	130 (1.3)	601 (3.4)	992 (4.4)	1 509 (5.3)	2 127 (6.2)	2 865 (7.2)	7.0	4.3	3.5	3.0	3.6
Indonesia	28 (0.3)	147 (0.8)	276 (1.2)	448 (1.6)	700 (2.1)	1 043 (2.6)	7.9	5.0	4.6	4.1	4.5
Malaysia	20 (0.2)	111 (0.6)	152 (0.7)	224 (0.8)	300 (0.9)	370 (0.9)	7.0	4.0	3.0	2.1	3.0
Myanmar	2 (0.0)	6 (0.0)	20 (0.1)	33 (0.1)	54 (0.2)	83 (0.2)	8.5	4.9	5.2	4.3	4.8
Philippines	21 (0.2)	55 (0.3)	83 (0.4)	136 (0.5)	200 (0.6)	276 (0.7)	4.7	5.1	3.9	3.3	4.1
Singapore	13 (0.1)	42 (0.2)	51 (0.2)	62 (0.2)	68 (0.2)	69 (0.2)	4.7	2.0	0.9	0.1	1.0
Thailand	38 (0.4)	149 (0.8)	187 (0.8)	251 (0.9)	311 (0.9)	362 (0.9)	5.4	3.0	2.2	1.5	2.2
Viet Nam	6 (0.1)	87 (0.5)	218 (1.0)	349 (1.2)	488 (1.4)	657 (1.7)	12.6	4.8	3.4	3.0	3.7
North America	3 051 (31.5)	4 264 (23.8)	4 300 (18.9)	4 773 (16.7)	5 321 (15.6)	5 786 (14.6)	1.2	1.0	1.1	0.8	1.0
United States	2 633 (27.1)	3 788 (21.2)	3 777 (16.6)	4 174 (14.6)	4 647 (13.6)	5 054 (12.8)	1.2	1.0	1.1	0.8	1.0
Latin America	516 (5.3)	1 127 (6.3)	1 286 (5.6)	1 669 (5.8)	2 162 (6.3)	2 667 (6.7)	3.1	2.6	2.6	2.1	2.5
Advanced Europe	2 248 (23.2)	3 107 (17.4)	3 016 (13.2)	3 455 (12.1)	3 728 (10.9)	3 931 (9.9)	1.0	1.4	0.8	0.5	0.9
European Union	1 887 (19.5)	2 510 (14.0)	2 384 (10.5)	2 739 (9.6)	2 952 (8.7)	3 103 (7.8)	0.8	1.4	0.8	0.5	0.9
Other Europe/Eurasia	1 448 (14.9)	1 193 (6.7)	1 250 (5.5)	1 383 (4.8)	1 681 (4.9)	2 015 (5.1)	-0.5	1.0	2.0	1.8	1.6
Africa	256 (2.6)	541 (3.0)	667 (2.9)	999 (3.5)	1 532 (4.5)	2 302 (5.8)	3.2	4.1	4.4	4.2	4.2
Middle East	199 (2.0)	722 (4.0)	1 012 (4.4)	1 366 (4.8)	1 734 (5.1)	2 091 (5.3)	5.6	3.0	2.4	1.9	2.4
Oceania	158 (1.6)	252 (1.4)	255 (1.1)	306 (1.1)	345 (1.0)	373 (0.9)	1.6	1.8	1.2	0.8	1.3
Advanced Economies	6 429 (66.3)	9 410 (52.6)	9 338 (41.0)	10 511 (36.7)	11 490 (33.7)	12 218 (30.8)	1.3	1.2	0.9	0.6	0.9
Emerging Market and Developing Economies	3 270 (33.7)	8 473 (47.4)	13 434 (59.0)	18 097 (63.3)	22 626 (66.3)	27 413 (69.2)	4.8	3.0	2.3	1.9	2.4

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%).

Table A16 | Electricity generated [Reference Scenario]

(TWh)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/ 2020	2020/ 2030	2030/ 2040	2040/ 2050	2020/ 2050
World	11 844 (100)	21 539 (100)	26 721 (100)	33 593 (100)	39 845 (100)	45 777 (100)	2.7	2.3	1.7	1.4	1.8
Asia	2 237 (18.9)	7 990 (37.1)	12 567 (47.0)	16 925 (50.4)	20 264 (50.9)	23 313 (50.9)	5.9	3.0	1.8	1.4	2.1
China	621 (5.2)	4 197 (19.5)	7 732 (28.9)	9 933 (29.6)	10 969 (27.5)	11 473 (25.1)	8.8	2.5	1.0	0.5	1.3
India	289 (2.4)	974 (4.5)	1 533 (5.7)	2 689 (8.0)	3 897 (9.8)	5 240 (11.4)	5.7	5.8	3.8	3.0	4.2
Japan	862 (7.3)	1 164 (5.4)	1 009 (3.8)	1 077 (3.2)	1 116 (2.8)	1 128 (2.5)	0.5	0.7	0.4	0.1	0.4
Korea	105 (0.9)	497 (2.3)	575 (2.2)	683 (2.0)	735 (1.8)	741 (1.6)	5.8	1.7	0.7	0.1	0.8
Chinese Taipei	87 (0.7)	244 (1.1)	277 (1.0)	316 (0.9)	340 (0.9)	350 (0.8)	3.9	1.3	0.8	0.3	0.8
ASEAN	154 (1.3)	675 (3.1)	1 075 (4.0)	1 654 (4.9)	2 344 (5.9)	3 161 (6.9)	6.7	4.4	3.5	3.0	3.7
Indonesia	33 (0.3)	170 (0.8)	292 (1.1)	488 (1.5)	773 (1.9)	1 156 (2.5)	7.6	5.3	4.7	4.1	4.7
Malaysia	23 (0.2)	125 (0.6)	183 (0.7)	263 (0.8)	348 (0.9)	425 (0.9)	7.1	3.7	2.8	2.0	2.9
Myanmar	2 (0.0)	9 (0.0)	20 (0.1)	57 (0.2)	92 (0.2)	135 (0.3)	7.2	11.0	5.0	3.9	6.6
Philippines	26 (0.2)	68 (0.3)	102 (0.4)	166 (0.5)	240 (0.6)	325 (0.7)	4.6	5.0	3.7	3.1	3.9
Singapore	16 (0.1)	46 (0.2)	53 (0.2)	65 (0.2)	72 (0.2)	72 (0.2)	4.2	2.0	0.9	0.1	1.0
Thailand	44 (0.4)	159 (0.7)	179 (0.7)	229 (0.7)	281 (0.7)	323 (0.7)	4.8	2.5	2.1	1.4	2.0
Viet Nam	9 (0.1)	95 (0.4)	240 (0.9)	380 (1.1)	532 (1.3)	717 (1.6)	11.7	4.7	3.4	3.0	3.7
North America	3 685 (31.1)	4 957 (23.0)	4 891 (18.3)	5 419 (16.1)	6 023 (15.1)	6 520 (14.2)	0.9	1.0	1.1	0.8	1.0
United States	3 203 (27.0)	4 354 (20.2)	4 239 (15.9)	4 694 (14.0)	5 215 (13.1)	5 652 (12.3)	0.9	1.0	1.1	0.8	1.0
Latin America	623 (5.3)	1 406 (6.5)	1 591 (6.0)	2 053 (6.1)	2 618 (6.6)	3 167 (6.9)	3.2	2.6	2.5	1.9	2.3
Advanced Europe	2 696 (22.8)	3 624 (16.8)	3 499 (13.1)	3 985 (11.9)	4 279 (10.7)	4 476 (9.8)	0.9	1.3	0.7	0.5	0.8
European Union	2 258 (19.1)	2 956 (13.7)	2 758 (10.3)	3 210 (9.6)	3 421 (8.6)	3 673 (8.0)	0.7	1.5	0.6	0.7	1.0
Other Europe/Eurasia	1 856 (15.7)	1 689 (7.8)	1 752 (6.6)	1 919 (5.7)	2 250 (5.6)	2 582 (5.6)	-0.2	0.9	1.6	1.4	1.3
Africa	316 (2.7)	687 (3.2)	836 (3.1)	1 245 (3.7)	1 877 (4.7)	2 756 (6.0)	3.3	4.1	4.2	3.9	4.1
Middle East	244 (2.1)	888 (4.1)	1 275 (4.8)	1 677 (5.0)	2 123 (5.3)	2 525 (5.5)	5.7	2.8	2.4	1.7	2.3
Oceania	187 (1.6)	298 (1.4)	309 (1.2)	369 (1.1)	411 (1.0)	438 (1.0)	1.7	1.8	1.1	0.6	1.2
Advanced Economies	7 667 (64.7)	10 869 (50.5)	10 649 (39.9)	11 954 (35.6)	13 018 (32.7)	13 767 (30.1)	1.1	1.2	0.9	0.6	0.9
Emerging Market and Developing Economies	4 178 (35.3)	10 670 (49.5)	16 071 (60.1)	21 639 (64.4)	26 827 (67.3)	32 010 (69.9)	4.6	3.0	2.2	1.8	2.3

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%).

Table A17 | Primary energy consumption per capita [Reference Scenario]

(toe/person)

	1990	2010	2020	2030	2040	2050	CAGR (%) 1990/2020	2020/2030	2030/2040	2040/2050	2020/2050
World	1.66	1.86	1.80	1.89	1.87	1.84	0.3	0.5	-0.2	-0.1	0.1
Asia	0.71	1.24	1.43	1.60	1.66	1.73	2.4	1.1	0.4	0.4	0.6
China	0.77	1.90	2.48	2.70	2.68	2.61	4.0	0.9	-0.1	-0.3	0.2
India	0.32	0.54	0.63	0.87	1.07	1.31	2.3	3.2	2.1	2.0	2.5
Japan	3.54	3.90	3.06	3.29	3.24	3.21	-0.5	0.7	-0.2	-0.1	0.2
Korea	2.17	5.05	5.33	5.90	5.90	5.83	3.0	1.0	0.0	-0.1	0.3
Chinese Taipei	2.29	4.69	4.55	4.66	4.60	4.52	2.3	0.2	-0.1	-0.2	0.0
ASEAN	0.54	0.93	1.05	1.37	1.62	1.87	2.3	2.8	1.7	1.4	2.0
Indonesia	0.54	0.84	0.85	1.17	1.48	1.79	1.5	3.2	2.3	1.9	2.5
Malaysia	1.18	2.57	2.85	3.95	4.18	4.27	3.0	3.3	0.6	0.2	1.4
Myanmar	0.26	0.27	0.42	0.51	0.64	0.79	1.6	2.0	2.4	2.1	2.2
Philippines	0.43	0.44	0.53	0.71	0.82	0.93	0.7	3.0	1.3	1.3	1.9
Singapore	3.78	4.63	5.65	6.21	6.33	6.39	1.3	1.0	0.2	0.1	0.4
Thailand	0.75	1.75	1.91	2.26	2.58	2.90	3.2	1.7	1.3	1.2	1.4
Viet Nam	0.26	0.67	1.00	1.42	1.82	2.27	4.6	3.6	2.5	2.2	2.8
North America	7.67	7.21	6.28	6.33	5.87	5.43	-0.7	0.1	-0.8	-0.8	-0.5
United States	7.67	7.16	6.15	6.17	5.69	5.24	-0.7	0.0	-0.8	-0.8	-0.5
Latin America	1.06	1.34	1.20	1.38	1.49	1.56	0.4	1.4	0.8	0.5	0.9
Advanced Europe	3.26	3.30	2.76	2.76	2.55	2.40	-0.5	0.0	-0.8	-0.6	-0.5
European Union	3.43	3.46	2.93	2.96	2.75	2.58	-0.5	0.1	-0.7	-0.6	-0.4
Other Europe/Eurasia	4.50	3.36	3.32	3.27	3.39	3.55	-1.0	-0.1	0.4	0.5	0.2
Africa	0.64	0.68	0.64	0.62	0.59	0.55	0.0	-0.3	-0.6	-0.7	-0.5
Middle East	1.69	3.05	3.09	3.36	3.39	3.37	2.0	0.9	0.1	0.0	0.3
Oceania	4.85	5.46	4.90	4.73	4.44	4.08	0.0	-0.3	-0.6	-0.8	-0.6
Advanced Economies	4.47	4.70	4.09	4.18	3.96	3.74	-0.3	0.2	-0.6	-0.6	-0.3
Emerging Market and Developing Economies	0.95	1.23	1.34	1.44	1.46	1.47	1.1	0.7	0.1	0.1	0.3

Source: World Bank "World Development Indicators", International Energy Agency "World Energy Balances", etc. (historical)

Note: World includes international bunkers.

Table A18 | Primary energy consumption per GDP [Reference Scenario]

(toe/$2015 million)

							CAGR (%)				
	1990	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2040	2040/ 2050	2020/ 2050
World	244	198	171	143	115	95	-1.2	-1.8	-2.1	-1.9	-1.9
Asia	311	268	217	166	126	101	-1.2	-2.6	-2.7	-2.2	-2.5
China	850	336	239	158	106	77	-4.1	-4.1	-3.9	-3.2	-3.7
India	590	426	342	262	202	162	-1.8	-2.6	-2.6	-2.2	-2.5
Japan	124	118	88	80	68	58	-1.1	-0.9	-1.6	-1.5	-1.3
Korea	231	198	170	145	117	96	-1.0	-1.6	-2.1	-2.0	-1.9
Chinese Taipei	290	235	180	142	114	92	-1.6	-2.3	-2.2	-2.1	-2.2
ASEAN	321	280	236	212	177	149	-1.0	-1.1	-1.8	-1.7	-1.5
Indonesia	366	310	227	202	169	144	-1.6	-1.2	-1.8	-1.6	-1.5
Malaysia	284	312	268	269	216	172	-0.2	0.0	-2.2	-2.2	-1.5
Myanmar	1 489	323	279	325	271	231	-5.4	1.5	-1.8	-1.6	-0.6
Philippines	251	182	162	141	117	99	-1.4	-1.4	-1.8	-1.7	-1.6
Singapore	163	95	97	83	73	65	-1.7	-1.5	-1.4	-1.1	-1.3
Thailand	294	340	308	267	220	184	0.1	-1.4	-1.9	-1.8	-1.7
Viet Nam	485	404	376	315	251	201	-0.8	-1.7	-2.3	-2.2	-2.1
North America	200	140	111	93	74	59	-1.9	-1.8	-2.3	-2.1	-2.1
United States	195	136	106	87	69	55	-2.0	-1.9	-2.4	-2.2	-2.2
Latin America	180	163	152	138	115	98	-0.6	-0.9	-1.8	-1.6	-1.4
Advanced Europe	141	109	86	70	56	46	-1.6	-2.1	-2.1	-1.9	-2.1
European Union	159	118	94	77	62	51	-1.7	-2.0	-2.1	-1.9	-2.0
Other Europe/Eurasia	835	533	456	376	305	253	-2.0	-1.9	-2.1	-1.9	-1.9
Africa	428	346	330	262	187	136	-0.9	-2.3	-3.3	-3.1	-2.9
Middle East	245	318	313	284	242	203	0.8	-1.0	-1.6	-1.7	-1.4
Oceania	150	118	97	78	62	50	-1.4	-2.2	-2.2	-2.2	-2.2
Advanced Economies	164	126	101	84	68	56	-1.6	-1.8	-2.1	-2.0	-2.0
Emerging Market and Developing Economies	472	319	264	201	151	120	-1.9	-2.7	-2.8	-2.3	-2.6

Source: World Bank "World Development Indicators", International Energy Agency "World Energy Balances", etc. (historical)

Note: World includes international bunkers.

Table A19 | Energy-related carbon dioxide emissions [Reference Scenario]

(Mt)

							CAGR (%)				
	1990	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2040	2040/ 2050	2020/ 2050
World	20 556 (100)	30 726 (100)	31 666 (100)	35 531 (100)	36 608 (100)	37 028 (100)	1.5	1.2	0.3	0.1	0.5
Asia	4 699 (22.9)	13 030 (42.4)	15 889 (50.2)	18 312 (51.5)	19 075 (52.1)	19 403 (52.4)	4.1	1.4	0.4	0.2	0.7
China	2 202 (10.7)	8 133 (26.5)	10 081 (31.8)	10 703 (30.1)	9 680 (26.4)	8 272 (22.3)	5.2	0.6	-1.0	-1.6	-0.7
India	531 (2.6)	1 587 (5.2)	2 075 (6.6)	3 206 (9.0)	4 391 (12.0)	5 633 (15.2)	4.7	4.4	3.2	2.5	3.4
Japan	1 055 (5.1)	1 137 (3.7)	990 (3.1)	880 (2.5)	772 (2.1)	664 (1.8)	-0.2	-1.2	-1.3	-1.5	-1.3
Korea	211 (1.0)	532 (1.7)	547 (1.7)	591 (1.7)	566 (1.5)	507 (1.4)	3.2	0.8	-0.4	-1.1	-0.3
Chinese Taipei	101 (0.5)	240 (0.8)	247 (0.8)	274 (0.8)	258 (0.7)	230 (0.6)	3.0	1.0	-0.6	-1.1	-0.2
ASEAN	350 (1.7)	1 071 (3.5)	1 507 (4.8)	2 023 (5.7)	2 540 (6.9)	2 988 (8.1)	5.0	3.0	2.3	1.6	2.3
Indonesia	130 (0.6)	396 (1.3)	532 (1.7)	758 (2.1)	1 027 (2.8)	1 262 (3.4)	4.8	3.6	3.1	2.1	2.9
Malaysia	53 (0.3)	192 (0.6)	229 (0.7)	278 (0.8)	292 (0.8)	292 (0.8)	5.0	2.0	0.5	0.0	0.8
Myanmar	4 (0.0)	8 (0.0)	31 (0.1)	57 (0.2)	90 (0.2)	126 (0.3)	7.0	6.5	4.6	3.4	4.8
Philippines	36 (0.2)	75 (0.2)	124 (0.4)	197 (0.6)	263 (0.7)	329 (0.9)	4.2	4.7	2.9	2.2	3.3
Singapore	26 (0.1)	49 (0.2)	44 (0.1)	50 (0.1)	51 (0.1)	49 (0.1)	1.7	1.3	0.3	-0.4	0.4
Thailand	80 (0.4)	222 (0.7)	243 (0.8)	256 (0.7)	262 (0.7)	247 (0.7)	3.8	0.5	0.3	-0.6	0.1
Viet Nam	17 (0.1)	123 (0.4)	294 (0.9)	419 (1.2)	546 (1.5)	675 (1.8)	10.1	3.6	2.7	2.2	2.8
North America	5 146 (25.0)	5 726 (18.6)	4 766 (15.1)	4 857 (13.7)	4 399 (12.0)	3 802 (10.3)	-0.3	0.2	-1.0	-1.4	-0.8
United States	4 755 (23.1)	5 220 (17.0)	4 258 (13.4)	4 299 (12.1)	3 826 (10.5)	3 237 (8.7)	-0.4	0.1	-1.2	-1.7	-0.9
Latin America	868 (4.2)	1 522 (5.0)	1 339 (4.2)	1 627 (4.6)	1 852 (5.1)	1 975 (5.3)	1.5	2.0	1.3	0.6	1.3
Advanced Europe	3 956 (19.2)	3 828 (12.5)	3 014 (9.5)	2 876 (8.1)	2 480 (6.8)	2 141 (5.8)	-0.9	-0.5	-1.5	-1.5	-1.1
European Union	3 467 (16.9)	3 137 (10.2)	2 394 (7.6)	2 226 (6.3)	1 903 (5.2)	1 651 (4.5)	-1.2	-0.7	-1.6	-1.4	-1.2
Other Europe/Eurasia	3 877 (18.9)	2 513 (8.2)	2 419 (7.6)	2 256 (6.3)	2 251 (6.1)	2 313 (6.2)	-1.6	-0.7	0.0	0.3	-0.1
Africa	528 (2.6)	1 013 (3.3)	1 144 (3.6)	1 495 (4.2)	1 964 (5.4)	2 479 (6.7)	2.6	2.7	2.8	2.4	2.6
Middle East	567 (2.8)	1 544 (5.0)	1 761 (5.6)	2 119 (6.0)	2 311 (6.3)	2 422 (6.5)	3.9	1.9	0.9	0.5	1.1
Oceania	279 (1.4)	421 (1.4)	405 (1.3)	396 (1.1)	380 (1.0)	349 (0.9)	1.2	-0.2	-0.4	-0.9	-0.5
Advanced Economies	10 808 (52.6)	11 974 (39.0)	10 046 (31.7)	9 966 (28.0)	8 947 (24.4)	7 780 (21.0)	-0.2	-0.1	-1.1	-1.4	-0.8
Emerging Market and Developing Economies	9 112 (44.3)	17 624 (57.4)	20 690 (65.3)	23 973 (67.5)	25 766 (70.4)	27 103 (73.2)	2.8	1.5	0.7	0.5	0.9

Source: Compiled from International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A20 | World [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	8 747	10 022	12 833	13 963	16 007	16 948	17 649	100	100	100	1.6	1.4	0.5	0.8
Coal	2 222	2 315	3 654	3 741	3 942	3 867	3 688	25	27	21	1.8	0.5	-0.3	0.0
Oil	3 234	3 681	4 144	4 115	4 897	5 040	5 122	37	29	29	0.8	1.8	0.2	0.7
Natural gas	1 662	2 067	2 732	3 306	3 806	4 343	4 820	19	24	27	2.3	1.4	1.2	1.3
Nuclear	526	675	719	697	802	839	864	6.0	5.0	4.9	0.9	1.4	0.4	0.7
Hydro	184	225	297	373	422	471	517	2.1	2.7	2.9	2.4	1.2	1.0	1.1
Geothermal	34	52	61	107	193	251	300	0.4	0.8	1.7	3.9	6.1	2.2	3.5
Solar, wind, etc.	2.5	8.1	49	247	436	634	873	0.0	1.8	4.9	16.5	5.8	3.5	4.3
Biomass and waste	883	997	1 177	1 374	1 505	1 501	1 462	10	9.8	8.3	1.5	0.9	-0.1	0.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	6 236	7 014	8 820	9 573	10 918	11 467	11 951	100	100	100	1.4	1.3	0.5	0.7
Industry	1 795	1 869	2 639	2 873	3 161	3 337	3 497	29	30	29	1.6	1.0	0.5	0.7
Transport	1 577	1 964	2 430	2 507	3 167	3 328	3 502	25	26	29	1.6	2.4	0.5	1.1
Buildings, etc.	2 387	2 565	2 967	3 248	3 443	3 531	3 578	38	34	30	1.0	0.6	0.2	0.3
Non-energy use	477	615	784	946	1 147	1 271	1 375	7.7	9.9	12	2.3	1.9	0.9	1.3
Coal	752	542	1 057	924	871	816	780	12	9.7	6.5	0.7	-0.6	-0.6	-0.6
Oil	2 606	3 126	3 615	3 700	4 457	4 607	4 718	42	39	39	1.2	1.9	0.3	0.8
Natural gas	944	1 119	1 344	1 580	1 717	1 807	1 880	15	17	16	1.7	0.8	0.5	0.6
Electricity	834	1 092	1 538	1 958	2 460	2 934	3 408	13	20	29	2.9	2.3	1.6	1.9
Heat	336	248	275	309	316	304	287	5.4	3.2	2.4	-0.3	0.2	-0.5	-0.2
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	3.5	n.a.
Renewables	764	887	991	1 101	1 096	1 000	878	12	12	7.3	1.2	0.0	-1.1	-0.8

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	11 844	15 428	21 539	26 721	33 593	39 845	45 777	100	100	100	2.7	2.3	1.6	1.8
Coal	4 429	5 995	8 670	9 452	11 078	11 463	11 434	37	35	25	2.6	1.6	0.2	0.6
Oil	1 324	1 188	969	668	659	615	490	11	2.5	1.1	-2.3	-0.1	-1.5	-1.0
Natural gas	1 748	2 771	4 856	6 335	8 220	10 988	13 658	15	24	30	4.4	2.6	2.6	2.6
Nuclear	2 013	2 591	2 756	2 674	3 077	3 220	3 314	17	10	7.2	1.0	1.4	0.4	0.7
Hydro	2 140	2 613	3 449	4 341	4 910	5 476	6 010	18	16	13	2.4	1.2	1.0	1.1
Geothermal	36	52	68	95	191	264	319	0.3	0.4	0.7	3.2	7.3	2.6	4.1
Solar PV	0.1	0.8	32	824	1 516	2 503	3 904	0.0	3.1	8.5	35.5	6.3	4.8	5.3
Wind	3.9	31	342	1 598	2 757	3 768	4 717	0.0	6.0	10	22.2	5.6	2.7	3.7
CSP and marine	1.2	1.1	2.2	15	120	215	352	0.0	0.1	0.8	8.7	23.4	5.5	11.2
Biomass and waste	130	162	362	685	1 030	1 300	1 545	1.1	2.6	3.4	5.7	4.2	2.0	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	20	22	34	34	34	34	34	0.2	0.1	0.1	1.8	0.0	0.0	0.0

Energy and economic indicators

								1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	2020	2030	2050	2050
GDP ($2015 billion)	35 843	48 064	64 655	81 578	112 310	147 292	184 952	2.8	3.2	2.5	2.8
Population (million)	5 272	6 105	6 912	7 753	8 448	9 082	9 597	1.3	0.9	0.6	0.7
CO_2 emissions (Mt)	20 556	23 207	30 726	31 666	35 531	36 608	37 028	1.5	1.2	0.2	0.5
GDP per capita ($2015 thousand)	6.8	7.9	9.4	11	13	16	19	1.5	2.4	1.9	2.0
Primary energy consump. per capita (toe)	1.7	1.6	1.9	1.8	1.9	1.9	1.8	0.3	0.5	-0.1	0.1
Primary energy consumption per GDP[*2]	244	209	198	171	143	115	95	-1.2	-1.8	-2.0	-1.9
CO_2 emissions per GDP[*3]	573	483	475	388	316	249	200	-1.3	-2.0	-2.3	-2.2
CO_2 per primary energy consumption[*4]	2.3	2.3	2.4	2.3	2.2	2.2	2.1	-0.1	-0.2	-0.3	-0.3

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A21 | Asia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	2 081	2 861	4 783	6 052	7 175	7 735	8 200	100	100	100	3.6	1.7	0.7	1.0
Coal	788	1 036	2 409	2 938	3 238	3 247	3 142	38	49	38	4.5	1.0	-0.1	0.2
Oil	615	915	1 161	1 435	1 739	1 864	1 982	30	24	24	2.9	1.9	0.7	1.1
Natural gas	116	233	453	670	905	1 128	1 342	5.6	11	16	6.0	3.0	2.0	2.3
Nuclear	77	132	152	170	265	308	356	3.7	2.8	4.3	2.7	4.5	1.5	2.5
Hydro	32	41	92	156	185	215	240	1.5	2.6	2.9	5.5	1.7	1.3	1.4
Geothermal	8.2	23	31	60	106	132	158	0.4	1.0	1.9	6.9	5.8	2.0	3.3
Solar, wind, etc.	1.3	2.1	16	111	198	295	403	0.1	1.8	4.9	16.0	5.9	3.6	4.4
Biomass and waste	444	480	469	510	538	546	577	21	8.4	7.0	0.5	0.5	0.3	0.4
Hydrogen	-	-	-	-	-	-0.0	-0.0	-	-	-0.0	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	1 529	1 973	3 159	3 923	4 545	4 892	5 264	100	100	100	3.2	1.5	0.7	1.0
Industry	506	654	1 402	1 650	1 809	1 874	1 959	33	42	37	4.0	0.9	0.4	0.6
Transport	188	322	494	681	900	999	1 116	12	17	21	4.4	2.8	1.1	1.7
Buildings, etc.	720	817	975	1 177	1 300	1 419	1 543	47	30	29	1.7	1.0	0.9	0.9
Non-energy use	115	181	288	414	536	599	646	7.5	11	12	4.4	2.6	0.9	1.5
Coal	422	372	894	779	734	686	658	28	20	13	2.1	-0.6	-0.5	-0.6
Oil	463	740	988	1 275	1 561	1 682	1 799	30	33	34	3.4	2.0	0.7	1.2
Natural gas	46	89	200	350	434	496	548	3.0	8.9	10	7.0	2.2	1.2	1.5
Electricity	157	280	574	945	1 260	1 515	1 760	10	24	33	6.2	2.9	1.7	2.1
Heat	14	30	69	130	141	137	130	0.9	3.3	2.5	7.7	0.8	-0.4	0.0
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	426	462	433	444	414	377	369	28	11	7.0	0.1	-0.7	-0.6	-0.6

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	2 237	3 971	7 990	12 567	16 925	20 264	23 313	100	100	100	5.9	3.0	1.6	2.1
Coal	868	1 984	4 776	7 224	8 984	9 653	9 920	39	57	43	7.3	2.2	0.5	1.1
Oil	433	381	262	106	111	108	99	19	0.8	0.4	-4.6	0.5	-0.6	-0.2
Natural gas	237	566	1 096	1 439	2 166	3 071	4 016	11	11	17	6.2	4.2	3.1	3.5
Nuclear	294	505	582	651	1 015	1 184	1 366	13	5.2	5.9	2.7	4.5	1.5	2.5
Hydro	368	477	1 072	1 818	2 151	2 499	2 792	16	14	12	5.5	1.7	1.3	1.4
Geothermal	8.4	20	22	29	61	78	95	0.4	0.2	0.4	4.3	7.5	2.2	4.0
Solar PV	0.1	0.4	5.2	446	851	1 364	2 080	0.0	3.5	8.9	33.9	6.7	4.6	5.3
Wind	0.0	2.4	70	558	1 134	1 711	2 207	0.0	4.4	9.5	38.2	7.3	3.4	4.7
CSP and marine	0.0	0.0	0.0	2.2	9.1	15	26	0.0	0.0	0.1	21.0	15.4	5.5	8.7
Biomass and waste	8.9	15	82	272	422	561	690	0.4	2.2	3.0	12.1	4.5	2.5	3.1
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	20	20	21	21	21	21	21	0.9	0.2	0.1	0.2	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	6 688	10 377	17 857	27 854	43 113	61 368	81 167	4.9	4.5	3.2	3.6
Population (million)	2 951	3 437	3 849	4 230	4 479	4 656	4 740	1.2	0.6	0.3	0.4
CO_2 emissions (Mt)	4 699	6 816	13 030	15 889	18 312	19 075	19 403	4.1	1.4	0.3	0.7
GDP per capita ($2015 thousand)	2.3	3.0	4.6	6.6	9.6	13	17	3.6	3.9	2.9	3.2
Primary energy consump. per capita (toe)	0.7	0.8	1.2	1.4	1.6	1.7	1.7	2.4	1.1	0.4	0.6
Primary energy consumption per GDP[*2]	311	276	268	217	166	126	101	-1.2	-2.6	-2.5	-2.5
CO_2 emissions per GDP[*3]	703	657	730	570	425	311	239	-0.7	-2.9	-2.8	-2.9
CO_2 per primary energy consumption[*4]	2.3	2.4	2.7	2.6	2.6	2.5	2.4	0.5	-0.3	-0.4	-0.3

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A22 | China [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	874	1 133	2 536	3 499	3 791	3 662	3 407	100	100	100	4.7	0.8	-0.5	-0.1
Coal	531	668	1 790	2 125	2 167	1 919	1 597	61	61	47	4.7	0.2	-1.5	-0.9
Oil	119	221	428	661	749	710	636	14	19	19	5.9	1.3	-0.8	-0.1
Natural gas	13	21	89	265	338	387	421	1.5	7.6	12	10.6	2.4	1.1	1.6
Nuclear	-	4.4	19	95	130	163	196	-	2.7	5.7	n.a.	3.1	2.1	2.4
Hydro	11	19	61	114	127	144	155	1.2	3.2	4.5	8.1	1.1	1.0	1.0
Geothermal	-	1.7	3.6	21	25	27	28	-	0.6	0.8	n.a.	1.6	0.6	0.9
Solar, wind, etc.	0.0	1.0	12	86	141	202	256	0.0	2.4	7.5	29.9	5.1	3.0	3.7
Biomass and waste	200	198	133	134	117	113	119	23	3.8	3.5	-1.3	-1.4	0.1	-0.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	658	781	1 645	2 182	2 301	2 218	2 105	100	100	100	4.1	0.5	-0.4	-0.1
Industry	234	302	924	1 073	1 009	866	748	36	49	36	5.2	-0.6	-1.5	-1.2
Transport	30	84	197	323	423	417	383	4.6	15	18	8.2	2.7	-0.5	0.6
Buildings, etc.	351	338	411	587	641	695	738	53	27	35	1.7	0.9	0.7	0.8
Non-energy use	43	58	113	199	228	240	236	6.5	9.1	11	5.2	1.4	0.2	0.6
Coal	311	274	712	576	456	352	275	47	26	13	2.1	-2.3	-2.5	-2.4
Oil	85	180	369	577	659	626	561	13	26	27	6.6	1.3	-0.8	-0.1
Natural gas	8.9	12	73	192	198	196	191	1.3	8.8	9.1	10.8	0.3	-0.2	0.0
Electricity	39	89	297	587	750	833	879	5.9	27	42	9.5	2.5	0.8	1.4
Heat	13	26	62	121	131	127	121	2.0	5.6	5.7	7.7	0.8	-0.4	0.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	200	199	132	128	107	85	78	30	5.9	3.7	-1.5	-1.8	-1.6	-1.6

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	621	1 356	4 197	7 732	9 933	10 969	11 473	100	100	100	8.8	2.5	0.7	1.3
Coal	441	1 060	3 240	4 928	5 897	5 633	5 056	71	64	44	8.4	1.8	-0.8	0.1
Oil	50	47	15	11	10	7.5	4.5	8.1	0.1	0.0	-4.8	-1.1	-4.1	-3.1
Natural gas	2.8	5.8	78	235	516	736	897	0.4	3.0	7.8	16.0	8.2	2.8	4.6
Nuclear	-	17	74	366	498	626	750	-	4.7	6.5	n.a.	3.1	2.1	2.4
Hydro	127	222	711	1 322	1 480	1 669	1 800	20	17	16	8.1	1.1	1.0	1.0
Geothermal	0.1	0.1	0.1	0.1	0.3	0.5	0.5	0.0	0.0	0.0	2.7	10.3	2.2	4.8
Solar PV	0.0	0.0	0.7	261	453	680	945	0.0	3.4	8.2	48.1	5.7	3.7	4.4
Wind	0.0	0.6	45	466	905	1 373	1 712	0.0	6.0	15	51.0	6.9	3.2	4.4
CSP and marine	0.0	0.0	0.0	1.7	2.6	4.0	8.6	0.0	0.0	0.1	20.1	4.3	6.2	5.6
Biomass and waste	-	2.4	34	141	171	239	298	-	1.8	2.6	n.a.	1.9	2.8	2.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	1 027	2 770	7 554	14 632	23 979	34 465	44 383	9.3	5.1	3.1	3.8
Population (million)	1 135	1 263	1 338	1 411	1 404	1 368	1 305	0.7	0.0	-0.4	-0.3
CO_2 emissions (Mt)	2 202	3 217	8 133	10 081	10 703	9 680	8 272	5.2	0.6	-1.3	-0.7
GDP per capita ($2015 thousand)	0.9	2.2	5.6	10	17	25	34	8.5	5.1	3.5	4.0
Primary energy consump. per capita (toe)	0.8	0.9	1.9	2.5	2.7	2.7	2.6	4.0	0.9	-0.2	0.2
Primary energy consumption per GDP*2	850	409	336	239	158	106	77	-4.1	-4.1	-3.5	-3.7
CO_2 emissions per GDP*3	2 143	1 161	1 077	689	446	281	186	-3.7	-4.2	-4.3	-4.3
CO_2 per primary energy consumption*4	2.5	2.8	3.2	2.9	2.8	2.6	2.4	0.4	-0.2	-0.8	-0.6

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A23 | India [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	280	418	667	872	1 299	1 712	2 172	100	100	100	3.9	4.1	2.6	3.1
Coal	93	146	279	379	571	760	935	33	43	43	4.8	4.2	2.5	3.1
Oil	61	112	162	207	321	444	601	22	24	28	4.2	4.5	3.2	3.6
Natural gas	11	23	54	53	99	161	229	3.8	6.0	11	5.5	6.5	4.3	5.0
Nuclear	1.6	4.4	6.8	11	36	46	60	0.6	1.3	2.8	6.7	12.3	2.6	5.7
Hydro	6.2	6.4	11	14	21	28	37	2.2	1.6	1.7	2.7	4.2	2.9	3.3
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	0.0	0.2	2.0	12	35	55	82	0.0	1.4	3.8	26.6	10.8	4.4	6.5
Biomass and waste	108	126	152	196	217	218	229	39	22	11	2.0	1.1	0.3	0.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	215	290	444	596	859	1 122	1 443	100	100	100	3.5	3.7	2.6	3.0
Industry	59	85	158	226	362	483	606	27	38	42	4.6	4.8	2.6	3.3
Transport	21	32	65	93	154	228	344	9.6	16	24	5.1	5.2	4.1	4.5
Buildings, etc.	122	147	187	223	259	295	345	57	37	24	2.0	1.5	1.5	1.5
Non-energy use	13	27	34	55	85	115	148	6.2	9.2	10	4.8	4.4	2.8	3.4
Coal	38	33	87	96	151	191	228	18	16	16	3.1	4.7	2.1	2.9
Oil	50	94	138	194	303	420	570	23	32	39	4.6	4.6	3.2	3.7
Natural gas	6.1	12	19	33	59	88	119	2.8	5.5	8.3	5.8	5.9	3.6	4.4
Electricity	18	32	62	102	179	267	373	8.5	17	26	5.9	5.8	3.7	4.4
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	102	119	138	173	167	155	153	48	29	11	1.8	-0.3	-0.4	-0.4

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	289	561	974	1 533	2 689	3 897	5 240	100	100	100	5.7	5.8	3.4	4.2
Coal	189	387	658	1 097	1 685	2 356	3 006	65	72	57	6.0	4.4	2.9	3.4
Oil	13	25	21	3.2	-	-	-	4.3	0.2	-	-4.5	-100	n.a.	-100
Natural gas	10.0	56	107	66	165	319	529	3.4	4.3	10	6.5	9.6	6.0	7.2
Nuclear	6.1	17	26	43	137	176	230	2.1	2.8	4.4	6.7	12.3	2.6	5.7
Hydro	72	74	125	161	242	330	428	25	10	8.2	2.7	4.2	2.9	3.3
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	0.0	0.1	61	205	367	592	-	4.0	11	n.a.	12.8	5.5	7.9
Wind	0.0	1.7	20	67	164	224	297	0.0	4.4	5.7	29.1	9.3	3.0	5.1
CSP and marine	-	-	-	-	3.2	5.9	9.5	-	-	0.2	n.a.	n.a.	5.6	n.a.
Biomass and waste	-	0.2	17	35	89	118	149	-	2.3	2.8	n.a.	9.7	2.6	4.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	475	817	1 567	2 551	4 958	8 483	13 446	5.8	6.9	5.1	5.7
Population (million)	873	1 057	1 234	1 380	1 498	1 596	1 657	1.5	0.8	0.5	0.6
CO_2 emissions (Mt)	531	891	1 587	2 075	3 206	4 391	5 633	4.7	4.4	2.9	3.4
GDP per capita ($2015 thousand)	0.5	0.8	1.3	1.8	3.3	5.3	8.1	4.2	6.0	4.6	5.1
Primary energy consump. per capita (toe)	0.3	0.4	0.5	0.6	0.9	1.1	1.3	2.3	3.2	2.1	2.5
Primary energy consumption per GDP*2	590	512	426	342	262	202	162	-1.8	-2.6	-2.4	-2.5
CO_2 emissions per GDP*3	1 118	1 091	1 012	813	647	518	419	-1.1	-2.3	-2.1	-2.2
CO_2 per primary energy consumption*4	1.9	2.1	2.4	2.4	2.5	2.6	2.6	0.8	0.4	0.2	0.3

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A24 | Japan [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	437	516	500	385	392	363	335	100	100	100	-0.4	0.2	-0.8	-0.5
Coal	77	97	115	102	91	80	67	18	27	20	1.0	-1.2	-1.5	-1.4
Oil	249	253	201	148	133	110	94	57	38	28	-1.7	-1.0	-1.8	-1.5
Natural gas	44	66	86	92	87	88	83	10	24	25	2.5	-0.6	-0.3	-0.4
Nuclear	53	84	75	10	41	37	37	12	2.6	11	-5.4	15.0	-0.6	4.4
Hydro	7.6	7.2	7.2	6.8	7.9	8.2	8.4	1.7	1.8	2.5	-0.4	1.6	0.3	0.7
Geothermal	1.6	3.1	2.4	2.7	5.3	8.4	11	0.4	0.7	3.2	1.8	7.0	3.7	4.8
Solar, wind, etc.	1.2	0.9	1.1	7.7	9.2	12	16	0.3	2.0	4.8	6.4	1.7	2.9	2.5
Biomass and waste	4.2	5.0	11	15	18	19	20	1.0	4.0	5.9	4.4	1.6	0.5	0.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	291	336	314	263	259	237	218	100	100	100	-0.3	-0.2	-0.8	-0.6
Industry	108	103	92	75	75	69	63	37	29	29	-1.2	-0.1	-0.8	-0.6
Transport	72	89	79	62	54	42	36	25	24	16	-0.5	-1.5	-2.0	-1.8
Buildings, etc.	78	108	109	96	97	93	88	27	36	40	0.7	0.1	-0.5	-0.3
Non-energy use	33	36	35	30	33	32	32	11	11	14	-0.4	1.2	-0.2	0.2
Coal	27	21	23	19	18	16	14	9.3	7.1	6.3	-1.2	-0.3	-1.4	-1.0
Oil	181	206	166	133	123	102	88	62	50	40	-1.0	-0.8	-1.7	-1.4
Natural gas	14	21	29	27	27	25	23	4.7	10	10	2.3	0.2	-0.9	-0.6
Electricity	66	84	89	78	83	87	88	23	30	40	0.6	0.7	0.3	0.4
Heat	0.2	0.5	0.6	0.5	0.6	0.5	0.4	0.1	0.2	0.2	3.4	0.5	-2.0	-1.2
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	3.8	4.1	6.1	6.3	6.6	6.2	5.8	1.3	2.4	2.6	1.8	0.4	-0.7	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	862	1 055	1 164	1 009	1 077	1 116	1 128	100	100	100	0.5	0.7	0.2	0.4
Coal	125	228	317	311	257	236	198	14	31	18	3.1	-1.9	-1.3	-1.5
Oil	250	133	91	32	18	7.1	-	29	3.2	-	-6.6	-5.6	-100	-100
Natural gas	168	255	332	395	371	408	406	19	39	36	2.9	-0.6	0.5	0.1
Nuclear	202	322	288	39	157	141	141	23	3.8	12	-5.4	15.0	-0.6	4.4
Hydro	88	84	84	79	92	96	97	10	7.8	8.6	-0.4	1.6	0.3	0.7
Geothermal	1.7	3.3	2.6	3.0	6.0	9.7	13	0.2	0.3	1.1	1.8	7.2	3.7	4.9
Solar PV	0.1	0.4	3.5	79	86	106	123	0.0	7.8	11	26.6	0.9	1.8	1.5
Wind	-	0.1	4.0	9.0	19	33	64	-	0.9	5.7	n.a.	7.6	6.4	6.8
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	8.1	9.2	21	46	54	63	70	0.9	4.5	6.2	6.0	1.6	1.3	1.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	20	20	21	17	17	17	17	2.3	1.7	1.5	-0.5	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	3 520	3 987	4 219	4 381	4 889	5 321	5 739	0.7	1.1	0.8	0.9
Population (million)	123	127	128	126	119	112	104	0.1	-0.5	-0.7	-0.6
CO_2 emissions (Mt)	1 055	1 160	1 137	990	880	772	664	-0.2	-1.2	-1.4	-1.3
GDP per capita ($2015 thousand)	29	31	33	35	41	48	55	0.7	1.7	1.5	1.5
Primary energy consump. per capita (toe)	3.5	4.1	3.9	3.1	3.3	3.2	3.2	-0.5	0.7	-0.1	0.2
Primary energy consumption per GDP[*2]	124	129	118	88	80	68	58	-1.1	-0.9	-1.6	-1.3
CO_2 emissions per GDP[*3]	300	291	269	226	180	145	116	-0.9	-2.2	-2.2	-2.2
CO_2 per primary energy consumption[*4]	2.4	2.2	2.3	2.6	2.2	2.1	2.0	0.2	-1.4	-0.6	-0.9

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A25 | Korea [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	93	187	250	276	303	292	268	100	100	100	3.7	0.9	-0.6	-0.1
Coal	25	40	73	74	83	79	67	27	27	25	3.6	1.1	-1.0	-0.3
Oil	50	99	95	101	109	100	90	54	37	34	2.4	0.7	-0.9	-0.4
Natural gas	2.7	17	39	49	57	64	67	2.9	18	25	10.1	1.3	0.9	1.0
Nuclear	14	28	39	42	43	36	28	15	15	11	3.8	0.4	-2.1	-1.3
Hydro	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.6	0.1	0.1	-1.6	-0.8	0.0	-0.3
Geothermal	-	-	0.0	0.2	0.4	0.4	0.4	-	0.1	0.2	n.a.	5.5	0.4	2.0
Solar, wind, etc.	0.0	0.0	0.2	2.2	2.8	4.3	6.3	0.0	0.8	2.4	19.7	2.6	4.1	3.6
Biomass and waste	0.7	1.4	3.5	6.5	7.5	7.9	8.0	0.8	2.3	3.0	7.6	1.5	0.3	0.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	65	127	158	175	192	186	173	100	100	100	3.4	0.9	-0.5	0.0
Industry	19	38	45	46	51	50	46	30	26	27	2.9	1.1	-0.5	0.0
Transport	15	26	30	34	36	31	25	22	20	15	2.9	0.4	-1.7	-1.0
Buildings, etc.	24	37	44	45	48	47	44	38	26	25	2.1	0.5	-0.4	-0.1
Non-energy use	6.7	25	38	50	58	59	58	10	28	33	6.9	1.5	0.0	0.5
Coal	12	9.1	9.5	7.3	7.0	5.9	4.6	18	4.2	2.7	-1.5	-0.5	-2.0	-1.5
Oil	44	80	82	93	100	93	83	67	53	48	2.5	0.8	-0.9	-0.4
Natural gas	0.7	11	21	21	22	21	19	1.0	12	11	12.2	0.6	-0.8	-0.3
Electricity	8.1	23	39	44	52	57	57	13	25	33	5.8	1.8	0.4	0.9
Heat	-	3.3	4.3	5.4	5.4	5.0	4.4	-	3.1	2.6	n.a.	0.0	-1.0	-0.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	0.7	1.3	2.7	4.0	4.6	4.8	4.8	1.1	2.3	2.8	5.8	1.5	0.2	0.6

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	105	289	497	575	683	735	741	100	100	100	5.8	1.7	0.4	0.8
Coal	18	111	219	206	256	258	226	17	36	31	8.5	2.2	-0.6	0.3
Oil	19	35	19	7.3	5.2	0.2	-	18	1.3	-	-3.1	-3.3	-100	-100
Natural gas	9.6	29	103	163	205	269	311	9.1	28	42	9.9	2.3	2.1	2.2
Nuclear	53	109	149	160	166	138	109	50	28	15	3.8	0.4	-2.1	-1.3
Hydro	6.4	4.0	3.7	3.9	3.6	3.6	3.6	6.0	0.7	0.5	-1.6	-0.8	0.0	-0.3
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	0.0	0.0	0.8	18	24	35	49	0.0	3.1	6.6	38.6	2.8	3.7	3.4
Wind	-	0.0	0.8	3.2	5.7	9.7	16	-	0.5	2.1	n.a.	6.2	5.2	5.5
CSP and marine	-	-	-	0.5	3.2	4.7	8.0	-	0.1	1.1	n.a.	21.4	4.7	10.0
Biomass and waste	-	0.1	1.1	9.2	12	13	14	-	1.6	1.9	n.a.	2.4	0.9	1.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.3	3.6	3.6	3.6	3.6	-	0.6	0.5	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	402	799	1 261	1 624	2 091	2 499	2 796	4.8	2.6	1.5	1.8
Population (million)	43	47	50	52	51	49	46	0.6	-0.1	-0.5	-0.4
CO_2 emissions (Mt)	211	404	532	547	591	566	507	3.2	0.8	-0.8	-0.3
GDP per capita ($2015 thousand)	9.4	17	25	31	41	51	61	4.1	2.7	2.0	2.2
Primary energy consump. per capita (toe)	2.2	4.0	5.0	5.3	5.9	5.9	5.8	3.0	1.0	-0.1	0.3
Primary energy consumption per GDP[*2]	231	234	198	170	145	117	96	-1.0	-1.6	-2.0	-1.9
CO_2 emissions per GDP[*3]	524	506	422	337	283	227	181	-1.5	-1.7	-2.2	-2.0
CO_2 per primary energy consumption[*4]	2.3	2.2	2.1	2.0	2.0	1.9	1.9	-0.4	-0.1	-0.2	-0.2

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A26 | Chinese Taipei [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	47	82	109	107	111	108	101	100	100	100	2.8	0.3	-0.5	-0.2
Coal	11	28	38	36	41	38	33	23	34	33	4.2	1.2	-1.1	-0.3
Oil	26	38	44	39	38	35	30	55	36	30	1.4	-0.1	-1.2	-0.8
Natural gas	1.4	5.6	13	21	27	29	31	3.0	20	30	9.5	2.3	0.7	1.2
Nuclear	8.6	10	11	8.2	-	-	-	18	7.6	-	-0.1	-100	n.a.	-100
Hydro	0.5	0.4	0.4	0.3	0.4	0.4	0.4	1.2	0.2	0.4	-2.5	5.5	0.1	1.8
Geothermal	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.5	0.0	0.0	0.0
Solar, wind, etc.	0.0	0.1	0.2	0.8	1.7	2.5	3.3	0.0	0.8	3.3	13.7	7.7	3.2	4.7
Biomass and waste	0.0	0.8	1.6	1.5	2.6	2.9	3.0	0.1	1.4	3.0	12.4	5.7	0.7	2.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	30	50	70	71	74	73	69	100	100	100	2.9	0.5	-0.4	-0.1
Industry	12	20	24	24	27	27	26	41	34	38	2.3	1.2	-0.2	0.3
Transport	6.6	11	12	12	11	8.6	6.7	22	17	9.7	2.1	-1.1	-2.4	-2.0
Buildings, etc.	6.5	10	12	12	13	13	13	22	18	19	2.2	0.3	0.1	0.2
Non-energy use	4.4	8.6	22	22	23	24	23	15	31	34	5.5	0.7	-0.1	0.2
Coal	3.4	5.2	6.2	5.2	5.2	4.6	4.0	11	7.4	5.8	1.4	0.0	-1.3	-0.9
Oil	19	29	40	37	37	34	30	63	53	43	2.3	-0.1	-1.1	-0.7
Natural gas	0.9	1.6	2.2	4.1	4.8	5.1	5.1	3.0	5.9	7.3	5.2	1.6	0.2	0.7
Electricity	6.6	14	19	22	25	27	27	22	31	40	4.0	1.3	0.5	0.8
Heat	-	0.0	1.4	1.7	1.9	1.9	1.8	-	2.5	2.6	n.a.	0.7	-0.3	0.1
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	0.0	0.3	0.6	0.5	0.6	0.7	0.8	0.1	0.7	1.1	11.6	2.8	1.0	1.6

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	87	181	244	277	316	340	350	100	100	100	3.9	1.3	0.5	0.8
Coal	24	88	122	126	144	135	119	28	45	34	5.6	1.4	-0.9	-0.2
Oil	22	31	11	4.4	5.1	3.1	0.9	26	1.6	0.3	-5.3	1.5	-8.3	-5.2
Natural gas	1.2	18	60	100	135	161	179	1.4	36	51	15.9	3.1	1.4	2.0
Nuclear	33	39	42	31	-	-	-	38	11	-	-0.1	-100	n.a.	-100
Hydro	6.4	4.6	4.2	3.0	5.2	5.2	5.2	7.3	1.1	1.5	-2.5	5.5	0.1	1.8
Geothermal	0.0	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.5	0.0	0.0	0.0
Solar PV	-	-	0.0	6.1	10	13	16	-	2.2	4.6	n.a.	5.5	2.2	3.3
Wind	-	0.0	1.0	2.4	8.8	14	21	-	0.9	6.1	n.a.	13.7	4.5	7.5
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	0.2	1.8	3.4	3.8	7.2	8.2	8.7	0.2	1.4	2.5	10.1	6.7	0.9	2.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	161	308	463	597	781	944	1 092	4.5	2.7	1.7	2.0
Population (million)	20	22	23	24	24	23	22	0.5	0.1	-0.3	-0.2
CO_2 emissions (Mt)	101	202	240	247	274	258	230	3.0	1.0	-0.9	-0.2
GDP per capita ($2015 thousand)	7.9	14	20	25	33	40	49	4.0	2.6	2.0	2.2
Primary energy consump. per capita (toe)	2.3	3.7	4.7	4.5	4.7	4.6	4.5	2.3	0.2	-0.1	0.0
Primary energy consumption per GDP[*2]	290	268	235	180	142	114	92	-1.6	-2.3	-2.1	-2.2
CO_2 emissions per GDP[*3]	629	655	518	414	351	273	211	-1.4	-1.6	-2.5	-2.2
CO_2 per primary energy consumption[*4]	2.2	2.4	2.2	2.3	2.5	2.4	2.3	0.2	0.7	-0.4	0.0

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A27 | ASEAN [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	231	378	535	673	954	1 192	1 420	100	100	100	3.6	3.6	2.0	2.5
Coal	13	31	85	178	226	290	340	5.4	26	24	9.2	2.4	2.1	2.2
Oil	88	153	188	225	311	365	412	38	33	29	3.2	3.3	1.4	2.0
Natural gas	30	74	125	130	213	277	343	13	19	24	5.0	5.1	2.4	3.3
Nuclear	-	-	-	-	-	9.7	18	-	-	1.3	n.a.	n.a.	n.a.	n.a.
Hydro	2.3	4.1	6.1	13	18	20	22	1.0	1.9	1.6	5.7	3.6	1.1	1.9
Geothermal	6.6	18	25	36	75	96	117	2.9	5.4	8.3	5.8	7.6	2.3	4.0
Solar, wind, etc.	-	-	0.0	2.1	7.4	15	32	-	0.3	2.2	n.a.	13.2	7.5	9.4
Biomass and waste	92	97	106	87	101	115	131	40	13	9.2	-0.2	1.5	1.3	1.4
Hydrogen	-	-	-	-	-	-0.0	-0.0	-	-	-0.0	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	171	269	377	447	618	760	901	100	100	100	3.2	3.3	1.9	2.4
Industry	41	74	120	158	215	276	333	24	35	37	4.6	3.1	2.2	2.5
Transport	33	62	86	122	172	207	241	19	27	27	4.5	3.5	1.7	2.3
Buildings, etc.	86	112	130	113	130	157	188	50	25	21	0.9	1.4	1.9	1.7
Non-energy use	11	21	40	54	101	120	139	6.4	12	15	5.4	6.5	1.6	3.2
Coal	5.3	13	40	54	66	80	91	3.1	12	10	8.0	2.1	1.6	1.8
Oil	67	123	163	200	279	330	375	39	45	42	3.7	3.4	1.5	2.1
Natural gas	7.5	17	29	44	85	107	123	4.4	9.8	14	6.0	6.8	1.9	3.5
Electricity	11	28	52	85	130	183	246	6.5	19	27	7.0	4.3	3.3	3.6
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	81	88	93	65	58	61	66	47	14	7.3	-0.7	-1.1	0.7	0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	154	370	675	1 075	1 654	2 344	3 161	100	100	100	6.7	4.4	3.3	3.7
Coal	28	79	185	485	633	863	1 072	18	45	34	10.0	2.7	2.7	2.7
Oil	66	72	59	13	19	20	15	43	1.2	0.5	-5.3	4.1	-1.2	0.6
Natural gas	26	154	336	344	568	831	1 156	17	32	37	9.0	5.2	3.6	4.1
Nuclear	-	-	-	-	-	37	71	-	-	2.2	n.a.	n.a.	n.a.	n.a.
Hydro	27	47	71	146	208	238	257	18	14	8.1	5.7	3.6	1.1	1.9
Geothermal	6.6	16	19	26	54	67	81	4.3	2.4	2.6	4.7	7.4	2.1	3.8
Solar PV	-	-	0.0	19	59	127	281	-	1.8	8.9	n.a.	12.1	8.1	9.4
Wind	-	-	0.1	5.7	26	48	85	-	0.5	2.7	n.a.	16.5	6.0	9.4
CSP and marine	-	-	-	-	0.1	0.2	0.3	-	-	0.0	n.a.	n.a.	8.3	n.a.
Biomass and waste	0.6	1.0	5.7	36	85	113	142	0.4	3.4	4.5	14.7	8.9	2.6	4.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	720	1 149	1 914	2 846	4 495	6 741	9 557	4.7	4.7	3.8	4.1
Population (million)	431	507	575	643	695	735	758	1.3	0.8	0.4	0.6
CO_2 emissions (Mt)	350	682	1 071	1 507	2 023	2 540	2 988	5.0	3.0	2.0	2.3
GDP per capita ($2015 thousand)	1.7	2.3	3.3	4.4	6.5	9.2	13	3.3	3.9	3.4	3.6
Primary energy consump. per capita (toe)	0.5	0.7	0.9	1.0	1.4	1.6	1.9	2.3	2.8	1.6	2.0
Primary energy consumption per GDP[*2]	321	329	280	236	212	177	149	-1.0	-1.1	-1.8	-1.5
CO_2 emissions per GDP[*3]	486	593	560	529	450	377	313	0.3	-1.6	-1.8	-1.7
CO_2 per primary energy consumption[*4]	1.5	1.8	2.0	2.2	2.1	2.1	2.1	1.3	-0.5	0.0	-0.2

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A28 | Indonesia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	99	156	204	233	346	460	575	100	100	100	2.9	4.0	2.6	3.1
Coal	3.5	12	32	68	92	129	160	3.6	29	28	10.4	3.0	2.8	2.9
Oil	33	58	67	68	100	123	140	34	29	24	2.4	3.9	1.7	2.4
Natural gas	16	27	39	34	58	86	116	16	15	20	2.6	5.4	3.6	4.2
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.5	0.9	1.5	2.1	2.2	2.8	3.3	0.5	0.9	0.6	5.0	0.7	2.0	1.5
Geothermal	1.9	8.4	16	27	58	76	96	2.0	11	17	9.2	8.0	2.6	4.4
Solar, wind, etc.	-	-	0.0	0.1	1.1	3.7	13	-	0.0	2.2	n.a.	35.0	13.0	19.9
Biomass and waste	44	50	48	34	35	40	46	44	14	8.0	-0.9	0.4	1.4	1.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	79	120	148	152	203	264	326	100	100	100	2.2	3.0	2.4	2.6
Industry	17	30	49	56	77	105	131	22	37	40	3.9	3.3	2.7	2.9
Transport	11	21	30	48	70	87	103	14	32	32	5.1	3.8	2.0	2.6
Buildings, etc.	44	59	59	40	43	54	68	55	26	21	-0.3	0.8	2.3	1.8
Non-energy use	7.4	9.8	10	8.0	13	18	23	9.3	5.2	7.1	0.3	5.1	2.9	3.6
Coal	1.5	4.6	17	20	25	33	38	1.9	13	12	9.1	2.3	2.1	2.2
Oil	27	48	55	64	93	114	132	34	42	40	2.9	3.9	1.8	2.4
Natural gas	6.0	12	16	17	26	36	44	7.6	11	13	3.5	4.5	2.6	3.2
Electricity	2.4	6.8	13	24	39	60	90	3.1	16	28	7.9	5.0	4.3	4.5
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	42	49	48	27	20	21	23	53	18	6.9	-1.4	-2.9	0.6	-0.6

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	33	93	170	292	488	773	1 156	100	100	100	7.6	5.3	4.4	4.7
Coal	9.8	34	68	181	255	389	519	30	62	45	10.2	3.5	3.6	3.6
Oil	15	18	34	7.9	11	11	6.7	47	2.7	0.6	-2.2	3.3	-2.4	-0.5
Natural gas	0.7	26	40	48	112	205	324	2.2	16	28	15.0	8.8	5.4	6.6
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	5.7	10	17	24	26	32	39	17	8.3	3.3	5.0	0.7	2.0	1.5
Geothermal	1.1	4.9	9.4	16	34	44	56	3.4	5.3	4.8	9.2	8.0	2.6	4.4
Solar PV	-	-	0.0	0.2	5.8	28	118	-	0.1	10	n.a.	42.2	16.3	24.3
Wind	-	-	0.0	0.5	7.2	15	33	-	0.2	2.8	n.a.	31.3	7.8	15.1
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	0.0	0.1	14	37	49	62	-	5.0	5.3	n.a.	9.8	2.6	5.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	270	395	658	1 028	1 709	2 721	3 994	4.6	5.2	4.3	4.6
Population (million)	181	212	242	274	294	311	320	1.4	0.7	0.4	0.5
CO_2 emissions (Mt)	130	254	396	532	758	1 027	1 262	4.8	3.6	2.6	2.9
GDP per capita ($2015 thousand)	1.5	1.9	2.7	3.8	5.8	8.8	12	3.1	4.5	3.9	4.1
Primary energy consump. per capita (toe)	0.5	0.7	0.8	0.9	1.2	1.5	1.8	1.5	3.2	2.1	2.5
Primary energy consumption per GDP*2	366	394	310	227	202	169	144	-1.6	-1.2	-1.7	-1.5
CO_2 emissions per GDP*3	482	644	602	518	444	378	316	0.2	-1.5	-1.7	-1.6
CO_2 per primary energy consumption*4	1.3	1.6	1.9	2.3	2.2	2.2	2.2	1.8	-0.4	0.0	-0.1

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A29 | Malaysia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	21	48	72	92	142	161	172	100	100	100	5.0	4.4	1.0	2.1
Coal	1.4	2.3	15	22	22	21	18	6.4	24	10	9.7	0.3	-1.2	-0.7
Oil	11	19	25	31	41	39	36	54	34	21	3.4	2.8	-0.6	0.5
Natural gas	6.8	25	31	36	73	88	104	32	39	61	5.7	7.3	1.8	3.6
Nuclear	-	-	-	-	-	3.7	3.7	-	-	2.1	n.a.	n.a.	n.a.	n.a.
Hydro	0.3	0.6	0.6	2.3	3.2	3.6	3.8	1.6	2.4	2.2	6.5	3.5	0.9	1.7
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	0.2	0.5	1.5	2.9	-	0.2	1.7	n.a.	9.7	9.1	9.3
Biomass and waste	1.2	1.3	0.8	1.1	2.1	2.7	3.3	5.9	1.2	2.0	-0.3	6.4	2.4	3.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	13	29	42	61	102	116	125	100	100	100	5.2	5.4	1.0	2.4
Industry	5.6	12	15	18	25	32	36	41	30	29	4.0	3.1	1.9	2.3
Transport	4.9	11	15	21	25	23	20	36	34	16	4.9	1.8	-1.1	-0.1
Buildings, etc.	2.1	4.3	8.2	8.7	12	14	16	16	14	13	4.8	2.9	1.6	2.0
Non-energy use	0.8	2.2	3.7	13	41	47	53	6.3	21	42	9.5	12.3	1.3	4.8
Coal	0.5	1.0	1.8	1.6	1.7	1.7	1.6	3.8	2.7	1.3	3.9	0.8	-0.5	-0.1
Oil	9.3	18	24	28	37	36	33	70	46	26	3.7	2.9	-0.5	0.6
Natural gas	1.1	3.9	6.3	18	43	51	57	8.2	29	46	9.7	9.5	1.4	4.0
Electricity	1.7	5.3	9.5	13	19	26	32	13	22	25	7.0	4.0	2.5	3.0
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	0.8	0.7	0.2	0.7	0.9	1.2	1.5	5.7	1.1	1.2	-0.4	3.0	2.7	2.8

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	23	69	125	183	263	348	425	100	100	100	7.1	3.7	2.4	2.9
Coal	2.9	7.7	43	86	89	87	75	13	47	18	11.9	0.4	-0.9	-0.4
Oil	11	3.6	3.7	1.0	0.7	0.1	-	46	0.5	-	-7.7	-2.5	-100	-100
Natural gas	5.5	51	71	66	127	183	253	24	36	59	8.6	6.7	3.5	4.6
Nuclear	-	-	-	-	-	14	14	-	-	3.3	n.a.	n.a.	n.a.	n.a.
Hydro	4.0	7.0	6.5	26	37	42	44	17	14	10	6.5	3.5	0.9	1.7
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	2.3	5.9	17	33	-	1.3	7.8	n.a.	9.7	9.1	9.3
Wind	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	1.0	1.0	3.4	4.5	5.7	-	0.6	1.3	n.a.	12.7	2.6	5.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	75	148	233	344	527	745	998	5.2	4.4	3.2	3.6
Population (million)	18	23	28	32	36	38	40	2.0	1.0	0.6	0.7
CO_2 emissions (Mt)	53	114	192	229	278	292	292	5.0	2.0	0.2	0.8
GDP per capita ($2015 thousand)	4.1	6.4	8.2	11	15	19	25	3.2	3.3	2.7	2.9
Primary energy consump. per capita (toe)	1.2	2.1	2.6	2.8	4.0	4.2	4.3	3.0	3.3	0.4	1.4
Primary energy consumption per GDP*2	284	326	312	268	269	216	172	-0.2	0.0	-2.2	-1.5
CO_2 emissions per GDP*3	704	770	824	666	528	392	293	-0.2	-2.3	-2.9	-2.7
CO_2 per primary energy consumption*4	2.5	2.4	2.6	2.5	2.0	1.8	1.7	0.0	-2.3	-0.7	-1.3

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A30 | Myanmar [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
											1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total[*1]	11	13	14	23	29	39	48	100	100	100	2.5	2.6	2.5	2.6
Coal	0.1	0.3	0.4	1.4	3.3	5.7	8.6	0.6	6.0	18	10.5	9.5	4.8	6.3
Oil	0.7	2.0	1.3	6.7	8.8	13	18	6.8	29	36	7.7	2.9	3.5	3.3
Natural gas	0.8	1.2	1.3	3.0	8.2	13	17	7.1	13	36	4.7	10.4	3.8	6.0
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.2	0.5	0.9	1.3	1.6	1.8	1.0	4.0	3.7	7.5	3.6	1.6	2.3
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	0.0	0.1	0.2	0.5	-	0.0	0.9	n.a.	41.6	7.0	17.5
Biomass and waste	9.0	9.2	10	11	9.2	7.6	5.8	84	48	12	0.6	-1.6	-2.3	-2.1
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	9.4	11	13	20	22	26	31	100	100	100	2.6	0.7	1.9	1.5
Industry	0.4	1.2	1.3	3.7	4.3	6.3	7.9	4.2	19	25	7.8	1.4	3.1	2.5
Transport	0.4	1.2	0.8	2.1	3.1	5.0	7.2	4.7	10	23	5.3	4.3	4.2	4.2
Buildings, etc.	8.5	9.1	11	14	14	14	15	90	69	50	1.6	-0.1	0.6	0.4
Non-energy use	0.1	0.1	0.1	0.5	0.4	0.5	0.6	1.0	2.4	2.0	5.6	-0.8	1.7	0.8
Coal	0.1	0.3	0.2	0.3	0.3	0.3	0.3	0.5	1.5	1.1	6.1	-1.2	1.1	0.3
Oil	0.6	1.5	1.0	6.6	8.6	13	17	6.2	33	55	8.4	2.7	3.5	3.2
Natural gas	0.2	0.3	0.6	0.6	0.6	0.8	0.9	2.4	3.2	3.0	3.5	-0.1	1.9	1.3
Electricity	0.1	0.3	0.5	1.7	2.8	4.7	7.1	1.6	8.7	23	8.5	4.9	4.8	4.8
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	8.4	9.0	10	11	9.2	7.5	5.7	89	54	18	0.8	-1.6	-2.3	-2.1

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	2.5	5.1	8.6	20	57	92	135	100	100	100	7.2	11.0	4.4	6.6
Coal	0.0	-	0.6	2.3	12	24	40	1.6	12	30	14.5	18.0	6.2	10.0
Oil	0.3	0.7	0.0	0.1	0.4	0.6	0.7	11	0.6	0.5	-2.9	14.3	2.7	6.4
Natural gas	1.0	2.5	1.8	7.0	28	47	68	39	35	50	6.8	14.7	4.6	7.9
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	1.2	1.9	6.2	11	15	18	21	48	53	15	7.5	3.6	1.6	2.3
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	0.0	1.1	1.9	4.6	-	0.2	3.4	n.a.	38.4	7.6	17.0
Wind	-	-	-	0.0	0.3	0.4	0.7	-	0.0	0.5	n.a.	160	4.4	41.4
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	-	0.0	0.0	0.0	0.0	-	0.0	0.0	n.a.	-0.1	0.0	0.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

								1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	2020	2030	2050	2050
GDP ($2015 billion)	7.2	14	43	81	90	142	210	8.4	1.1	4.3	3.2
Population (million)	41	47	51	54	58	60	61	0.9	0.7	0.3	0.4
CO_2 emissions (Mt)	4.0	9.5	8.1	31	57	90	126	7.0	6.5	4.0	4.8
GDP per capita ($2015 thousand)	0.2	0.3	0.8	1.5	1.6	2.4	3.4	7.4	0.4	4.0	2.8
Primary energy consump. per capita (toe)	0.3	0.3	0.3	0.4	0.5	0.6	0.8	1.6	2.0	2.3	2.2
Primary energy consumption per GDP[*2]	1 489	942	323	279	325	271	231	-5.4	1.5	-1.7	-0.6
CO_2 emissions per GDP[*3]	564	700	188	378	636	635	601	-1.3	5.4	-0.3	1.6
CO_2 per primary energy consumption[*4]	0.4	0.7	0.6	1.4	2.0	2.3	2.6	4.3	3.7	1.4	2.2

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A31 | Philippines [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	27	39	42	58	90	116	144	100	100	100	2.6	4.5	2.3	3.1
Coal	1.5	4.8	7.2	18	22	27	29	5.5	30	20	8.6	2.4	1.3	1.6
Oil	9.7	16	14	16	32	45	59	36	28	41	1.8	6.9	3.1	4.3
Natural gas	-	0.0	3.1	3.3	6.9	13	21	-	5.7	15	n.a.	7.6	5.8	6.4
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.5	0.7	0.7	0.6	1.0	1.1	1.1	1.9	1.1	0.8	0.6	5.0	0.5	2.0
Geothermal	4.7	10	8.5	9.2	17	19	21	17	16	15	2.3	6.4	1.1	2.8
Solar, wind, etc.	-	-	0.0	0.2	0.7	1.5	2.6	-	0.4	1.8	n.a.	13.5	6.5	8.8
Biomass and waste	10	7.6	8.7	11	10	9.8	9.9	39	18	6.9	0.1	-0.5	-0.2	-0.3
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	19	23	25	32	52	69	90	100	100	100	1.8	4.8	2.8	3.5
Industry	4.2	4.6	6.0	6.3	9.5	12	15	22	19	17	1.3	4.3	2.5	3.1
Transport	4.5	8.3	8.0	9.9	22	31	42	24	31	46	2.6	8.1	3.3	4.9
Buildings, etc.	10.0	9.9	11	15	19	23	28	53	47	32	1.4	2.3	2.0	2.1
Non-energy use	0.2	0.3	0.1	1.2	1.7	2.7	4.2	1.2	3.6	4.7	5.6	3.9	4.7	4.4
Coal	0.6	0.8	1.9	1.6	2.1	2.4	2.6	3.2	4.8	2.9	3.2	2.8	1.2	1.7
Oil	8.1	13	11	16	31	43	57	43	50	63	2.3	6.7	3.1	4.3
Natural gas	-	-	0.1	0.0	0.1	0.2	0.3	-	0.1	0.3	n.a.	9.2	5.8	7.0
Electricity	1.8	3.1	4.8	7.2	12	17	24	9.6	22	26	4.7	5.1	3.6	4.1
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	8.4	6.4	6.9	7.5	7.1	6.5	6.4	44	23	7.2	-0.4	-0.7	-0.5	-0.5

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	26	45	68	102	166	240	325	100	100	100	4.6	5.0	3.4	3.9
Coal	1.9	17	23	58	78	101	113	7.3	57	35	12.0	3.0	1.9	2.2
Oil	12	9.2	7.1	2.5	4.2	4.4	3.5	47	2.4	1.1	-5.2	5.4	-0.9	1.2
Natural gas	-	0.0	20	19	42	80	139	-	19	43	n.a.	8.0	6.1	6.8
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	6.1	7.8	7.8	7.2	12	12	13	23	7.1	4.0	0.6	5.0	0.5	2.0
Geothermal	5.5	12	9.9	11	20	23	25	21	11	7.6	2.3	6.4	1.1	2.8
Solar PV	-	-	0.0	1.4	4.3	10	19	-	1.3	5.9	n.a.	12.2	7.7	9.2
Wind	-	-	0.1	1.0	4.2	6.9	11	-	1.0	3.3	n.a.	15.1	4.8	8.1
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	0.4	-	0.0	1.3	1.3	1.8	2.2	1.6	1.2	0.7	3.6	0.5	2.6	1.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	107	143	229	358	642	988	1 459	4.1	6.0	4.2	4.8
Population (million)	62	78	94	110	127	142	155	1.9	1.5	1.0	1.2
CO_2 emissions (Mt)	36	66	75	124	197	263	329	4.2	4.7	2.6	3.3
GDP per capita ($2015 thousand)	1.7	1.8	2.4	3.3	5.1	7.0	9.4	2.1	4.5	3.1	3.6
Primary energy consump. per capita (toe)	0.4	0.5	0.4	0.5	0.7	0.8	0.9	0.7	3.0	1.3	1.9
Primary energy consumption per GDP*2	251	273	182	162	141	117	99	-1.4	-1.4	-1.8	-1.6
CO_2 emissions per GDP*3	339	459	330	347	307	267	225	0.1	-1.2	-1.5	-1.4
CO_2 per primary energy consumption*4	1.4	1.7	1.8	2.1	2.2	2.3	2.3	1.6	0.2	0.2	0.2

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A32 | Thailand [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	42	73	118	133	159	179	193	100	100	100	3.9	1.8	1.0	1.2
Coal	3.8	7.7	16	17	15	15	14	9.0	13	7.1	5.1	-1.2	-0.5	-0.7
Oil	18	32	45	55	63	68	70	43	41	36	3.8	1.4	0.5	0.8
Natural gas	5.0	17	33	35	39	41	38	12	26	20	6.7	1.2	0.0	0.4
Nuclear	-	-	-	-	-	1.8	6.2	-	-	3.2	n.a.	n.a.	n.a.	n.a.
Hydro	0.4	0.5	0.5	0.4	0.9	1.0	1.1	1.0	0.3	0.6	-0.2	8.2	0.9	3.3
Geothermal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	14.8	1.1	5.5
Solar, wind, etc.	-	-	0.0	0.7	2.4	4.6	7.2	-	0.5	3.7	n.a.	12.6	5.7	8.0
Biomass and waste	15	15	23	23	35	43	51	35	17	26	1.5	4.2	1.9	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	29	51	84	97	114	128	137	100	100	100	4.1	1.6	1.0	1.2
Industry	8.7	17	26	31	39	46	50	30	32	36	4.4	2.1	1.3	1.6
Transport	9.2	15	19	27	30	31	32	32	28	23	3.6	1.0	0.4	0.6
Buildings, etc.	11	14	20	16	19	20	21	37	17	15	1.4	1.3	0.5	0.8
Non-energy use	0.4	5.8	18	22	27	31	35	1.5	23	25	14.1	1.9	1.3	1.5
Coal	1.3	3.5	9.2	8.5	8.7	8.9	8.5	4.5	8.8	6.2	6.4	0.2	-0.1	0.0
Oil	15	29	43	54	62	66	68	52	56	50	4.3	1.4	0.5	0.8
Natural gas	0.1	1.1	4.6	5.3	6.2	7.7	8.7	0.5	5.5	6.3	12.9	1.5	1.7	1.7
Electricity	3.3	7.6	13	16	22	27	31	11	17	23	5.4	3.0	1.8	2.2
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	9.3	9.4	14	13	15	18	21	32	13	15	1.1	1.7	1.5	1.6

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	44	96	159	179	229	281	323	100	100	100	4.8	2.5	1.7	2.0
Coal	11	18	30	37	28	30	26	25	21	8.1	4.1	-2.6	-0.4	-1.1
Oil	10	10.0	1.1	0.2	-	-	-	23	0.1	-	-12.3	-100	n.a.	-100
Natural gas	18	62	120	113	127	133	118	40	63	36	6.3	1.2	-0.4	0.2
Nuclear	-	-	-	-	-	7.0	24	-	-	7.4	n.a.	n.a.	n.a.	n.a.
Hydro	5.0	6.0	5.6	4.7	10	12	12	11	2.6	3.8	-0.2	8.2	0.9	3.3
Geothermal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	14.8	1.1	5.5
Solar PV	-	-	0.0	5.0	20	42	70	-	2.8	22	n.a.	15.0	6.4	9.2
Wind	-	-	-	3.2	6.7	10	12	-	1.8	3.8	n.a.	7.6	3.0	4.5
CSP and marine	-	-	-	-	0.1	0.2	0.3	-	-	0.1	n.a.	n.a.	8.3	n.a.
Biomass and waste	-	0.5	3.4	17	36	48	60	-	9.3	19	n.a.	8.0	2.6	4.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	144	221	347	433	596	812	1 052	3.7	3.3	2.9	3.0
Population (million)	57	63	67	70	70	69	67	0.7	0.1	-0.3	-0.2
CO_2 emissions (Mt)	80	150	222	243	256	262	247	3.8	0.5	-0.2	0.1
GDP per capita ($2015 thousand)	2.5	3.5	5.2	6.2	8.5	12	16	3.0	3.2	3.2	3.2
Primary energy consump. per capita (toe)	0.7	1.2	1.8	1.9	2.3	2.6	2.9	3.2	1.7	1.3	1.4
Primary energy consumption per GDP*2	294	328	340	308	267	220	184	0.1	-1.4	-1.8	-1.7
CO_2 emissions per GDP*3	552	678	640	562	429	323	235	0.1	-2.7	-3.0	-2.9
CO_2 per primary energy consumption*4	1.9	2.1	1.9	1.8	1.6	1.5	1.3	-0.1	-1.3	-1.1	-1.2

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A33 | Viet Nam [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	18	29	59	97	147	195	245	100	100	100	5.8	4.2	2.6	3.1
Coal	2.2	4.4	15	51	70	91	111	12	52	45	11.0	3.3	2.3	2.6
Oil	2.7	7.8	18	24	40	50	61	15	25	25	7.6	5.0	2.2	3.1
Natural gas	0.0	1.1	8.1	7.4	16	23	34	0.0	7.6	14	30.2	8.0	3.8	5.2
Nuclear	-	-	-	-	-	4.2	8.6	-	-	3.5	n.a.	n.a.	n.a.	n.a.
Hydro	0.5	1.3	2.4	6.3	9.3	10	11	2.6	6.4	4.5	9.1	4.0	0.9	1.9
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	0.0	0.9	2.5	3.6	5.3	-	0.9	2.2	n.a.	10.6	3.8	6.0
Biomass and waste	12	14	15	7.5	8.6	11	14	70	7.7	5.6	-1.7	1.4	2.3	2.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	16	25	48	67	102	133	167	100	100	100	4.9	4.3	2.5	3.1
Industry	4.5	7.9	17	36	52	67	84	28	55	51	7.2	3.6	2.5	2.8
Transport	1.4	3.5	10	12	21	28	35	8.7	18	21	7.6	5.3	2.6	3.5
Buildings, etc.	10	13	18	16	21	28	36	63	24	21	1.6	2.7	2.7	2.7
Non-energy use	0.0	0.1	2.3	1.9	8.6	10	12	0.2	2.9	7.4	15.2	16.1	1.8	6.4
Coal	1.3	3.2	9.8	21	28	34	39	8.3	32	23	9.7	2.8	1.7	2.1
Oil	2.3	6.5	17	19	33	43	53	15	29	32	7.3	5.5	2.4	3.4
Natural gas	-	0.0	0.5	1.4	5.7	7.8	9.9	-	2.1	5.9	n.a.	14.8	2.8	6.7
Electricity	0.5	1.9	7.5	19	30	42	57	3.3	28	34	12.6	4.8	3.2	3.7
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	12	13	14	5.7	5.2	6.6	8.7	74	8.6	5.2	-2.4	-1.0	2.6	1.4

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	8.7	27	95	240	380	532	717	100	100	100	11.7	4.7	3.2	3.7
Coal	2.0	3.1	20	119	169	230	296	23	50	41	14.6	3.5	2.8	3.1
Oil	1.3	4.5	3.4	1.1	2.8	3.5	4.1	15	0.4	0.6	-0.7	10.2	1.9	4.6
Natural gas	0.0	4.4	44	35	67	113	186	0.1	14	26	33.5	6.8	5.2	5.7
Nuclear	-	-	-	-	-	16	33	-	-	4.6	n.a.	n.a.	n.a.	n.a.
Hydro	5.4	15	28	73	108	121	129	62	30	18	9.1	4.0	0.9	1.9
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	9.6	21	25	33	-	4.0	4.6	n.a.	8.1	2.3	4.2
Wind	-	-	0.1	1.0	7.9	16	29	-	0.4	4.0	n.a.	23.1	6.7	11.9
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	0.1	1.7	4.8	6.4	8.1	-	0.7	1.1	n.a.	11.2	2.6	5.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	37	76	145	259	466	775	1 221	6.7	6.1	4.9	5.3
Population (million)	68	80	88	97	104	107	108	1.2	0.6	0.2	0.4
CO_2 emissions (Mt)	17	42	123	294	419	546	675	10.1	3.6	2.4	2.8
GDP per capita ($2015 thousand)	0.5	1.0	1.6	2.7	4.5	7.2	11	5.4	5.4	4.7	4.9
Primary energy consump. per capita (toe)	0.3	0.4	0.7	1.0	1.4	1.8	2.3	4.6	3.6	2.4	2.8
Primary energy consumption per GDP*2	485	376	404	376	315	251	201	-0.8	-1.7	-2.2	-2.1
CO_2 emissions per GDP*3	450	549	848	1 137	899	704	553	3.1	-2.3	-2.4	-2.4
CO_2 per primary energy consumption*4	0.9	1.5	2.1	3.0	2.9	2.8	2.8	4.0	-0.6	-0.2	-0.3

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A34 | North America [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	2 126	2 527	2 475	2 322	2 458	2 382	2 264	100	100	100	0.3	0.6	-0.4	-0.1
Coal	484	565	525	231	178	109	38	23	9.9	1.7	-2.4	-2.6	-7.4	-5.8
Oil	833	958	903	794	860	768	665	39	34	29	-0.2	0.8	-1.3	-0.6
Natural gas	493	622	632	832	932	974	970	23	36	43	1.8	1.1	0.2	0.5
Nuclear	179	227	242	240	199	182	175	8.4	10	7.7	1.0	-1.9	-0.6	-1.1
Hydro	49	53	53	58	62	63	64	2.3	2.5	2.8	0.6	0.7	0.2	0.3
Geothermal	14	13	8.4	9.3	18	31	37	0.7	0.4	1.6	-1.4	6.6	3.8	4.7
Solar, wind, etc.	0.3	2.1	11	46	74	114	171	0.0	2.0	7.5	18.0	4.8	4.2	4.4
Biomass and waste	73	87	101	112	137	141	145	3.4	4.8	6.4	1.4	2.0	0.3	0.9
Hydrogen	-	-	-	-	-	-	-0.0	-	-	-0.0	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	1 452	1 734	1 699	1 651	1 774	1 713	1 627	100	100	100	0.4	0.7	-0.4	-0.1
Industry	331	388	313	310	322	328	324	23	19	20	-0.2	0.4	0.0	0.2
Transport	531	640	656	605	666	597	527	37	37	32	0.4	1.0	-1.2	-0.5
Buildings, etc.	456	533	572	572	589	583	566	31	35	35	0.8	0.3	-0.2	0.0
Non-energy use	134	173	158	164	197	205	209	9.2	9.9	13	0.7	1.8	0.3	0.8
Coal	59	36	30	16	15	13	11	4.1	1.0	0.7	-4.3	-0.6	-1.7	-1.3
Oil	749	870	851	759	825	742	650	52	46	40	0.0	0.8	-1.2	-0.5
Natural gas	346	413	364	406	419	398	369	24	25	23	0.5	0.3	-0.6	-0.3
Electricity	262	342	367	370	410	458	498	18	22	31	1.2	1.0	1.0	1.0
Heat	2.8	6.1	7.1	6.4	6.4	6.1	5.7	0.2	0.4	0.3	2.8	0.0	-0.6	-0.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	33	66	80	94	98	96	94	2.3	5.7	5.8	3.6	0.5	-0.3	0.0

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	3 685	4 631	4 957	4 891	5 419	6 023	6 520	100	100	100	0.9	1.0	0.9	1.0
Coal	1 782	2 247	2 074	894	764	458	112	48	18	1.7	-2.3	-1.6	-9.1	-6.7
Oil	147	133	56	42	32	22	10	4.0	0.9	0.2	-4.1	-2.9	-5.5	-4.7
Natural gas	391	668	1 070	1 753	2 216	2 764	3 078	11	36	47	5.1	2.4	1.7	1.9
Nuclear	685	871	930	921	763	699	671	19	19	10	1.0	-1.9	-0.6	-1.1
Hydro	570	612	614	674	719	736	745	15	14	11	0.6	0.7	0.2	0.3
Geothermal	16	15	18	19	36	64	77	0.4	0.4	1.2	0.5	6.8	3.8	4.8
Solar PV	0.0	0.2	3.3	121	183	420	765	0.0	2.5	12	42.4	4.3	7.4	6.3
Wind	3.1	5.9	104	377	487	560	655	0.1	7.7	10	17.4	2.6	1.5	1.9
CSP and marine	0.7	0.6	0.9	3.4	52	100	174	0.0	0.1	2.7	5.5	31.2	6.3	14.0
Biomass and waste	90	80	82	81	162	197	228	2.5	1.7	3.5	-0.4	7.2	1.7	3.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	6.8	5.2	5.2	5.2	5.2	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	10 620	14 785	17 720	20 902	26 554	32 406	38 238	2.3	2.4	1.8	2.0
Population (million)	277	313	343	370	388	406	417	1.0	0.5	0.4	0.4
CO_2 emissions (Mt)	5 146	6 108	5 726	4 766	4 857	4 399	3 802	-0.3	0.2	-1.2	-0.8
GDP per capita ($2015 thousand)	38	47	52	57	68	80	92	1.3	1.9	1.5	1.6
Primary energy consump. per capita (toe)	7.7	8.1	7.2	6.3	6.3	5.9	5.4	-0.7	0.1	-0.8	-0.5
Primary energy consumption per GDP*2	200	171	140	111	93	74	59	-1.9	-1.8	-2.2	-2.1
CO_2 emissions per GDP*3	485	413	323	228	183	136	99	-2.5	-2.2	-3.0	-2.7
CO_2 per primary energy consumption*4	2.4	2.4	2.3	2.1	2.0	1.8	1.7	-0.5	-0.4	-0.8	-0.7

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A35 | United States [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	1 914	2 273	2 216	2 038	2 141	2 057	1 943	100	100	100	0.2	0.5	-0.5	-0.2
Coal	460	533	501	222	175	109	38	24	11	1.9	-2.4	-2.3	-7.4	-5.7
Oil	757	871	807	702	762	679	586	40	34	30	-0.2	0.8	-1.3	-0.6
Natural gas	438	548	556	719	786	806	792	23	35	41	1.7	0.9	0.0	0.3
Nuclear	159	208	219	214	179	169	168	8.3	11	8.6	1.0	-1.8	-0.3	-0.8
Hydro	23	22	23	25	27	28	28	1.2	1.2	1.4	0.2	0.9	0.2	0.4
Geothermal	14	13	8.4	9.3	18	31	37	0.7	0.5	1.9	-1.4	6.6	3.8	4.7
Solar, wind, etc.	0.3	2.1	11	43	68	106	160	0.0	2.1	8.2	17.7	4.8	4.4	4.5
Biomass and waste	62	73	89	100	123	127	132	3.3	4.9	6.8	1.6	2.1	0.4	0.9
Hydrogen	-	-	-	-	-	-	-0.0	-	-	-0.0	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	1 294	1 546	1 513	1 461	1 568	1 510	1 432	100	100	100	0.4	0.7	-0.5	-0.1
Industry	284	332	270	265	273	276	272	22	18	19	-0.2	0.3	0.0	0.1
Transport	488	588	596	549	603	541	477	38	38	33	0.4	1.0	-1.2	-0.5
Buildings, etc.	403	473	511	505	518	513	497	31	35	35	0.8	0.3	-0.2	0.0
Non-energy use	119	153	135	143	173	181	185	9.2	9.8	13	0.6	2.0	0.3	0.9
Coal	56	33	27	13	12	11	8.8	4.3	0.9	0.6	-4.7	-0.8	-1.6	-1.4
Oil	683	793	762	677	736	660	576	53	46	40	0.0	0.8	-1.2	-0.5
Natural gas	303	360	322	356	367	348	322	23	24	22	0.5	0.3	-0.6	-0.3
Electricity	226	301	326	325	359	400	435	18	22	30	1.2	1.0	1.0	1.0
Heat	2.2	5.3	6.6	6.0	5.9	5.7	5.2	0.2	0.4	0.4	3.5	-0.1	-0.6	-0.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	23	54	70	84	88	87	85	1.8	5.7	5.9	4.4	0.5	-0.2	0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	3 203	4 026	4 354	4 239	4 694	5 215	5 652	100	100	100	0.9	1.0	0.9	1.0
Coal	1 700	2 129	1 994	856	756	456	111	53	20	2.0	-2.3	-1.2	-9.2	-6.6
Oil	131	118	48	37	28	20	10	4.1	0.9	0.2	-4.1	-3.0	-4.9	-4.3
Natural gas	382	634	1 018	1 680	2 072	2 541	2 806	12	40	50	5.1	2.1	1.5	1.7
Nuclear	612	798	839	823	687	649	644	19	19	11	1.0	-1.8	-0.3	-0.8
Hydro	273	253	262	287	313	320	324	8.5	6.8	5.7	0.2	0.9	0.2	0.4
Geothermal	16	15	18	19	36	64	77	0.5	0.4	1.4	0.5	6.8	3.8	4.8
Solar PV	0.0	0.2	3.1	116	176	408	748	0.0	2.7	13	42.2	4.3	7.5	6.4
Wind	3.1	5.7	95	342	425	478	550	0.1	8.1	9.7	17.0	2.2	1.3	1.6
CSP and marine	0.7	0.5	0.9	3.4	52	100	174	0.0	0.1	3.1	5.6	31.2	6.3	14.0
Biomass and waste	86	72	73	71	144	175	203	2.7	1.7	3.6	-0.7	7.4	1.7	3.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	3.7	4.9	4.9	4.9	4.9	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	9 805	13 738	16 320	19 294	24 520	29 928	35 322	2.3	2.4	1.8	2.0
Population (million)	250	282	309	332	347	362	371	1.0	0.5	0.3	0.4
CO_2 emissions (Mt)	4 755	5 629	5 220	4 258	4 299	3 826	3 237	-0.4	0.1	-1.4	-0.9
GDP per capita ($2015 thousand)	39	49	53	58	71	83	95	1.3	2.0	1.5	1.7
Primary energy consump. per capita (toe)	7.7	8.1	7.2	6.1	6.2	5.7	5.2	-0.7	0.0	-0.8	-0.5
Primary energy consumption per GDP[*2]	195	165	136	106	87	69	55	-2.0	-1.9	-2.3	-2.2
CO_2 emissions per GDP[*3]	485	410	320	221	175	128	92	-2.6	-2.3	-3.2	-2.9
CO_2 per primary energy consumption[*4]	2.5	2.5	2.4	2.1	2.0	1.9	1.7	-0.6	-0.4	-0.9	-0.8

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A36 | Latin America [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	467	611	788	779	959	1 089	1 173	100	100	100	1.7	2.1	1.0	1.4
Coal	21	28	39	37	40	47	48	4.6	4.8	4.1	1.9	0.7	0.9	0.8
Oil	240	314	364	294	360	380	373	51	38	32	0.7	2.1	0.2	0.8
Natural gas	71	118	178	204	253	322	386	15	26	33	3.6	2.1	2.1	2.1
Nuclear	3.2	5.3	7.2	8.6	17	18	15	0.7	1.1	1.3	3.3	7.2	-0.7	1.9
Hydro	33	50	63	62	72	78	83	7.1	7.9	7.1	2.1	1.5	0.7	1.0
Geothermal	5.1	6.5	6.4	6.5	20	28	35	1.1	0.8	2.9	0.8	12.0	2.7	5.7
Solar, wind, etc.	0.0	0.2	0.9	14	24	33	44	0.0	1.7	3.7	24.8	5.9	3.0	4.0
Biomass and waste	93	90	128	152	172	183	189	20	20	16	1.7	1.2	0.5	0.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	344	442	570	550	668	745	798	100	100	100	1.6	2.0	0.9	1.3
Industry	114	143	180	167	200	239	264	33	30	33	1.3	1.8	1.4	1.5
Transport	103	140	197	191	252	272	282	30	35	35	2.1	2.8	0.6	1.3
Buildings, etc.	100	122	148	159	173	185	197	29	29	25	1.5	0.9	0.6	0.7
Non-energy use	26	38	45	33	42	49	55	7.6	5.9	6.9	0.7	2.7	1.3	1.8
Coal	8.2	11	15	13	14	15	14	2.4	2.4	1.8	1.5	0.7	0.1	0.3
Oil	178	235	284	253	316	339	344	52	46	43	1.2	2.3	0.4	1.0
Natural gas	38	54	75	62	74	83	88	11	11	11	1.6	1.8	0.8	1.2
Electricity	44	69	97	111	143	186	229	13	20	29	3.1	2.6	2.4	2.5
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	75	74	99	111	120	123	123	22	20	15	1.3	0.8	0.1	0.3

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	623	1 009	1 406	1 591	2 053	2 618	3 167	100	100	100	3.2	2.6	2.2	2.3
Coal	24	44	75	78	89	117	131	3.8	4.9	4.1	4.0	1.3	2.0	1.7
Oil	130	197	189	119	105	83	33	21	7.5	1.0	-0.3	-1.2	-5.7	-4.2
Natural gas	58	141	325	409	556	899	1 276	9.3	26	40	6.7	3.1	4.2	3.9
Nuclear	12	20	28	33	66	70	58	2.0	2.1	1.8	3.3	7.2	-0.7	1.9
Hydro	386	584	731	719	834	904	968	62	45	31	2.1	1.5	0.7	1.0
Geothermal	5.9	8.0	9.9	10	34	49	60	1.0	0.6	1.9	1.8	12.8	2.9	6.1
Solar PV	0.0	0.0	0.1	35	67	103	151	0.0	2.2	4.8	41.7	6.8	4.2	5.0
Wind	0.0	0.3	4.7	105	190	254	332	0.0	6.6	10	47.0	6.1	2.8	3.9
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	7.5	13	43	83	112	139	159	1.2	5.2	5.0	8.3	3.1	1.7	2.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	0.4	0.5	0.3	0.3	0.3	0.3	-	0.0	0.0	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	2 589	3 527	4 833	5 130	6 932	9 441	11 959	2.3	3.1	2.8	2.9
Population (million)	439	517	587	650	696	731	750	1.3	0.7	0.4	0.5
CO_2 emissions (Mt)	868	1 196	1 522	1 339	1 627	1 852	1 975	1.5	2.0	1.0	1.3
GDP per capita ($2015 thousand)	5.9	6.8	8.2	7.9	10.0	13	16	1.0	2.4	2.4	2.4
Primary energy consump. per capita (toe)	1.1	1.2	1.3	1.2	1.4	1.5	1.6	0.4	1.4	0.6	0.9
Primary energy consumption per GDP[*2]	180	173	163	152	138	115	98	-0.6	-0.9	-1.7	-1.4
CO_2 emissions per GDP[*3]	335	339	315	261	235	196	165	-0.8	-1.1	-1.7	-1.5
CO_2 per primary energy consumption[*4]	1.9	2.0	1.9	1.7	1.7	1.7	1.7	-0.3	-0.1	0.0	-0.1

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A37 | Advanced Europe [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	1 644	1 759	1 835	1 607	1 627	1 506	1 398	100	100	100	-0.1	0.1	-0.8	-0.5
Coal	450	331	301	183	158	123	104	27	11	7.4	-3.0	-1.5	-2.1	-1.9
Oil	617	654	606	508	506	419	354	38	32	25	-0.6	0.0	-1.8	-1.2
Natural gas	267	396	473	421	416	413	381	16	26	27	1.5	-0.1	-0.4	-0.3
Nuclear	210	247	239	190	182	161	148	13	12	11	-0.3	-0.4	-1.0	-0.8
Hydro	39	47	48	52	51	52	53	2.4	3.2	3.8	0.9	-0.2	0.3	0.1
Geothermal	4.9	7.1	11	21	28	31	33	0.3	1.3	2.3	5.1	2.7	0.8	1.4
Solar, wind, etc.	0.4	2.9	18	63	105	131	156	0.0	3.9	11	18.9	5.2	2.0	3.0
Biomass and waste	56	72	136	169	179	174	167	3.4	10	12	3.8	0.6	-0.4	0.0
Hydrogen	-	-	-	-	-	-0.0	-0.0	-	-	-0.0	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	1 142	1 235	1 288	1 182	1 206	1 113	1 030	100	100	100	0.1	0.2	-0.8	-0.5
Industry	330	325	296	285	307	299	286	29	24	28	-0.5	0.7	-0.4	0.0
Transport	269	318	335	309	317	258	220	24	26	21	0.5	0.3	-1.8	-1.1
Buildings, etc.	442	477	544	485	473	448	418	39	41	41	0.3	-0.2	-0.6	-0.5
Non-energy use	101	114	113	103	109	108	106	8.9	8.7	10	0.1	0.5	-0.1	0.1
Coal	124	62	55	39	38	31	25	11	3.3	2.5	-3.7	-0.4	-2.0	-1.5
Oil	527	573	537	468	466	386	326	46	40	32	-0.4	0.0	-1.8	-1.2
Natural gas	205	269	285	267	255	240	217	18	23	21	0.9	-0.5	-0.8	-0.7
Electricity	193	234	267	259	297	321	338	17	22	33	1.0	1.4	0.6	0.9
Heat	45	42	53	46	46	44	40	3.9	3.9	3.9	0.1	0.0	-0.7	-0.5
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	48	56	91	102	103	92	83	4.2	8.6	8.1	2.6	0.1	-1.1	-0.7

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	2 696	3 238	3 624	3 499	3 985	4 279	4 476	100	100	100	0.9	1.3	0.6	0.8
Coal	1 030	968	873	471	390	271	206	38	13	4.6	-2.6	-1.9	-3.1	-2.7
Oil	209	180	81	45	36	26	14	7.8	1.3	0.3	-5.0	-2.2	-4.7	-3.9
Natural gas	176	514	857	728	859	1 036	1 067	6.5	21	24	4.8	1.7	1.1	1.3
Nuclear	804	948	916	730	699	619	569	30	21	13	-0.3	-0.4	-1.0	-0.8
Hydro	451	549	560	599	588	605	622	17	17	14	0.9	-0.2	0.3	0.1
Geothermal	3.6	6.2	11	23	30	34	37	0.1	0.6	0.8	6.3	3.0	0.9	1.6
Solar PV	0.0	0.1	23	162	239	280	331	0.0	4.6	7.4	36.0	4.0	1.6	2.4
Wind	0.8	22	153	497	824	1 041	1 227	0.0	14	27	24.0	5.2	2.0	3.1
CSP and marine	0.5	0.5	1.2	5.5	34	47	65	0.0	0.2	1.4	8.3	19.8	3.3	8.6
Biomass and waste	21	48	146	233	280	313	334	0.8	6.7	7.5	8.4	1.8	0.9	1.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	0.3	1.5	4.6	6.2	6.2	6.2	6.2	0.0	0.2	0.1	10.1	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	11 651	14 636	16 908	18 608	23 351	26 826	30 136	1.6	2.3	1.3	1.6
Population (million)	505	527	556	581	589	590	583	0.5	0.1	-0.1	0.0
CO_2 emissions (Mt)	3 956	3 923	3 828	3 014	2 876	2 480	2 141	-0.9	-0.5	-1.5	-1.1
GDP per capita ($2015 thousand)	23	28	30	32	40	46	52	1.1	2.2	1.3	1.6
Primary energy consump. per capita (toe)	3.3	3.3	3.3	2.8	2.8	2.6	2.4	-0.5	0.0	-0.7	-0.5
Primary energy consumption per GDP[*2]	141	120	109	86	70	56	46	-1.6	-2.1	-2.0	-2.1
CO_2 emissions per GDP[*3]	340	268	226	162	123	92	71	-2.4	-2.7	-2.7	-2.7
CO_2 per primary energy consumption[*4]	2.4	2.2	2.1	1.9	1.8	1.6	1.5	-0.8	-0.6	-0.7	-0.7

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A38 | Other Europe/Eurasia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	1 514	988	1 112	1 133	1 114	1 154	1 204	100	100	100	-1.0	-0.2	0.4	0.2
Coal	365	209	211	199	169	173	183	24	18	15	-2.0	-1.6	0.4	-0.3
Oil	459	199	216	231	226	217	207	30	20	17	-2.3	-0.2	-0.4	-0.4
Natural gas	596	481	566	559	526	535	564	39	49	47	-0.2	-0.6	0.4	0.0
Nuclear	55	61	76	85	111	125	119	3.6	7.5	9.9	1.5	2.7	0.4	1.1
Hydro	22	23	26	28	30	32	34	1.5	2.5	2.8	0.8	0.8	0.5	0.6
Geothermal	0.0	0.1	0.6	0.2	0.6	0.7	0.7	0.0	0.0	0.1	8.0	9.2	0.9	3.6
Solar, wind, etc.	-	0.0	0.2	2.9	5.4	8.3	12	-	0.3	1.0	n.a.	6.4	3.9	4.7
Biomass and waste	17	15	19	29	49	66	87	1.1	2.6	7.2	1.9	5.4	2.9	3.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	1 057	647	711	752	735	739	745	100	100	100	-1.1	-0.2	0.1	0.0
Industry	391	205	205	202	195	210	224	37	27	30	-2.2	-0.4	0.7	0.3
Transport	170	110	145	144	145	135	128	16	19	17	-0.6	0.0	-0.6	-0.4
Buildings, etc.	431	285	281	306	298	289	281	41	41	38	-1.1	-0.3	-0.3	-0.3
Non-energy use	65	47	80	100	96	105	113	6.2	13	15	1.4	-0.3	0.8	0.4
Coal	113	36	41	51	44	43	43	11	6.8	5.7	-2.6	-1.4	-0.2	-0.6
Oil	275	144	174	201	203	195	187	26	27	25	-1.0	0.1	-0.4	-0.3
Natural gas	258	200	233	246	227	220	216	24	33	29	-0.2	-0.8	-0.3	-0.4
Electricity	125	86	103	108	119	145	173	12	14	23	-0.5	1.0	1.9	1.6
Heat	274	170	147	126	122	117	111	26	17	15	-2.5	-0.4	-0.5	-0.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	13	11	14	20	20	18	16	1.2	2.7	2.1	1.6	-0.1	-1.1	-0.8

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	1 856	1 415	1 689	1 752	1 919	2 250	2 582	100	100	100	-0.2	0.9	1.5	1.3
Coal	429	338	396	369	379	444	518	23	21	20	-0.5	0.3	1.6	1.1
Oil	252	69	22	16	13	12	10	14	0.9	0.4	-8.8	-2.1	-1.0	-1.4
Natural gas	707	504	671	678	654	781	974	38	39	38	-0.1	-0.4	2.0	1.2
Nuclear	209	234	289	323	425	478	455	11	18	18	1.5	2.8	0.4	1.2
Hydro	259	267	306	324	351	376	391	14	19	15	0.8	0.8	0.5	0.6
Geothermal	0.0	0.1	0.5	0.5	1.8	2.1	2.3	0.0	0.0	0.1	10.2	13.5	1.1	5.1
Solar PV	-	-	0.0	14	26	40	55	-	0.8	2.1	n.a.	6.4	3.9	4.7
Wind	-	0.0	1.2	18	35	53	75	-	1.0	2.9	n.a.	6.7	3.9	4.9
CSP and marine	-	-	-	-	0.0	0.1	0.2	-	-	0.0	n.a.	n.a.	12.7	n.a.
Biomass and waste	0.0	2.6	3.3	8.7	35	64	100	0.0	0.5	3.9	18.9	15.0	5.4	8.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.0	0.2	0.2	0.2	0.2	-	0.0	0.0	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	1 813	1 265	2 088	2 487	2 961	3 784	4 763	1.1	1.8	2.4	2.2
Population (million)	336	334	332	342	340	340	339	0.1	0.0	0.0	0.0
CO_2 emissions (Mt)	3 877	2 341	2 513	2 419	2 256	2 251	2 313	-1.6	-0.7	0.1	-0.1
GDP per capita ($2015 thousand)	5.4	3.8	6.3	7.3	8.7	11	14	1.0	1.8	2.4	2.2
Primary energy consump. per capita (toe)	4.5	3.0	3.4	3.3	3.3	3.4	3.5	-1.0	-0.1	0.4	0.2
Primary energy consumption per GDP*2	835	781	533	456	376	305	253	-2.0	-1.9	-2.0	-1.9
CO_2 emissions per GDP*3	2 138	1 850	1 203	973	762	595	486	-2.6	-2.4	-2.2	-2.3
CO_2 per primary energy consumption*4	2.6	2.4	2.3	2.1	2.0	2.0	1.9	-0.6	-0.5	-0.3	-0.4

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A39 | European Union [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	1 441	1 471	1 527	1 311	1 331	1 225	1 130	100	100	100	-0.3	0.2	-0.8	-0.5
Coal	393	285	252	144	122	95	81	27	11	7.2	-3.3	-1.6	-2.0	-1.9
Oil	531	550	506	418	414	343	290	37	32	26	-0.8	-0.1	-1.8	-1.2
Natural gas	250	309	363	326	329	326	307	17	25	27	0.9	0.1	-0.4	-0.2
Nuclear	190	224	223	178	171	151	136	13	14	12	-0.2	-0.4	-1.2	-0.9
Hydro	24	30	32	30	30	30	31	1.7	2.3	2.7	0.7	-0.1	0.2	0.1
Geothermal	3.2	4.6	5.5	6.9	9.0	9.8	11	0.2	0.5	0.9	2.6	2.7	0.8	1.4
Solar, wind, etc.	0.3	2.5	16	51	80	98	115	0.0	3.9	10	18.5	4.5	1.9	2.7
Biomass and waste	47	65	128	154	163	156	149	3.3	12	13	4.0	0.6	-0.4	-0.1
Hydrogen	-	-	-	-	-	-0.0	-0.0	-	-	-0.0	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	995	1 027	1 070	963	981	904	834	100	100	100	-0.1	0.2	-0.8	-0.5
Industry	313	274	247	232	250	245	236	31	24	28	-1.0	0.8	-0.3	0.1
Transport	220	262	279	252	256	209	178	22	26	21	0.5	0.2	-1.8	-1.2
Buildings, etc.	374	391	447	390	380	358	332	38	40	40	0.1	-0.2	-0.7	-0.5
Non-energy use	88	100	98	90	93	92	89	8.9	9.3	11	0.0	0.4	-0.2	0.0
Coal	109	47	38	26	25	20	17	11	2.6	2.0	-4.7	-0.4	-1.9	-1.4
Oil	445	479	448	384	380	315	267	45	40	32	-0.5	-0.1	-1.7	-1.2
Natural gas	185	220	231	208	201	190	172	19	22	21	0.4	-0.4	-0.8	-0.6
Electricity	162	189	216	205	236	254	267	16	21	32	0.8	1.4	0.6	0.9
Heat	55	43	52	44	44	41	38	5.5	4.6	4.5	-0.7	0.0	-0.7	-0.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	39	50	86	96	96	83	73	4.0	10	8.8	3.0	-0.1	-1.3	-0.9

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	2 258	2 631	2 956	2 758	3 210	3 421	3 673	100	100	100	0.7	1.5	0.7	1.0
Coal	844	846	755	383	312	215	172	37	14	4.7	-2.6	-2.0	-2.9	-2.6
Oil	189	173	82	48	40	28	16	8.4	1.7	0.4	-4.5	-1.9	-4.4	-3.6
Natural gas	188	331	589	560	687	792	872	8.3	20	24	3.7	2.1	1.2	1.5
Nuclear	729	860	854	684	657	578	520	32	25	14	-0.2	-0.4	-1.2	-0.9
Hydro	285	352	373	346	344	352	360	13	13	9.8	0.7	-0.1	0.2	0.1
Geothermal	3.2	4.8	5.6	6.7	10	11	12	0.1	0.2	0.3	2.5	4.2	0.9	2.0
Solar PV	0.0	0.1	22	139	207	245	293	0.0	5.0	8.0	35.6	4.0	1.8	2.5
Wind	0.8	21	140	397	689	889	1 080	0.0	14	29	23.2	5.7	2.3	3.4
CSP and marine	0.5	0.5	1.2	5.5	34	47	65	0.0	0.2	1.8	8.3	19.8	3.3	8.6
Biomass and waste	19	42	129	183	227	257	278	0.8	6.7	7.6	7.9	2.2	1.0	1.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	0.2	1.4	4.4	4.7	4.7	4.7	4.7	0.0	0.2	0.1	10.9	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	9 083	11 260	12 898	13 890	17 337	19 839	22 158	1.4	2.2	1.2	1.6
Population (million)	420	429	442	447	449	446	438	0.2	0.0	-0.1	-0.1
CO_2 emissions (Mt)	3 467	3 267	3 137	2 394	2 226	1 903	1 651	-1.2	-0.7	-1.5	-1.2
GDP per capita ($2015 thousand)	22	26	29	31	39	44	51	1.2	2.2	1.4	1.6
Primary energy consump. per capita (toe)	3.4	3.4	3.5	2.9	3.0	2.7	2.6	-0.5	0.1	-0.7	-0.4
Primary energy consumption per GDP*2	159	131	118	94	77	62	51	-1.7	-2.0	-2.0	-2.0
CO_2 emissions per GDP*3	382	290	243	172	128	96	75	-2.6	-2.9	-2.7	-2.8
CO_2 per primary energy consumption*4	2.4	2.2	2.1	1.8	1.7	1.6	1.5	-0.9	-0.9	-0.7	-0.7

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A40 | Africa [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	391	496	688	830	1 012	1 168	1 300	100	100	100	2.5	2.0	1.3	1.5
Coal	74	90	108	105	114	127	138	19	13	11	1.2	0.8	1.0	0.9
Oil	85	101	161	176	245	326	420	22	21	32	2.5	3.4	2.7	2.9
Natural gas	30	47	88	133	183	265	355	7.6	16	27	5.1	3.2	3.4	3.3
Nuclear	2.2	3.4	3.2	2.6	7.4	12	12	0.6	0.3	0.9	0.5	11.1	2.6	5.3
Hydro	4.8	6.4	9.4	12	17	25	36	1.2	1.5	2.8	3.2	3.3	3.8	3.6
Geothermal	0.3	0.4	0.9	4.4	13	21	29	0.1	0.5	2.3	9.6	11.9	4.0	6.6
Solar, wind, etc.	0.0	0.0	0.3	3.4	14	31	52	0.0	0.4	4.0	34.2	15.6	6.7	9.6
Biomass and waste	195	247	316	393	418	362	258	50	47	20	2.4	0.6	-2.4	-1.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	285	365	494	598	708	775	826	100	100	100	2.5	1.7	0.8	1.1
Industry	53	57	83	84	110	148	188	19	14	23	1.5	2.8	2.7	2.7
Transport	38	54	87	112	159	208	265	13	19	32	3.7	3.6	2.6	2.9
Buildings, etc.	183	238	306	383	414	389	336	64	64	41	2.5	0.8	-1.0	-0.4
Non-energy use	11	15	18	19	24	30	37	3.8	3.2	4.5	1.8	2.6	2.1	2.3
Coal	20	19	17	19	19	21	22	7.0	3.1	2.7	-0.2	0.4	0.7	0.6
Oil	70	89	137	158	217	285	361	25	26	44	2.7	3.3	2.6	2.8
Natural gas	8.6	14	27	41	55	71	87	3.0	6.9	11	5.4	2.8	2.3	2.5
Electricity	22	31	47	57	86	132	198	7.7	9.6	24	3.2	4.1	4.3	4.2
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	164	212	267	323	331	267	157	58	54	19	2.3	0.2	-3.6	-2.4

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	316	442	687	836	1 245	1 877	2 756	100	100	100	3.3	4.1	4.1	4.1
Coal	164	209	259	248	287	344	396	52	30	14	1.4	1.5	1.6	1.6
Oil	41	37	66	47	74	114	159	13	5.6	5.8	0.5	4.7	3.9	4.1
Natural gas	45	106	234	346	504	775	1 207	14	41	44	7.0	3.8	4.5	4.3
Nuclear	8.4	13	12	9.9	28	45	47	2.7	1.2	1.7	0.5	11.1	2.6	5.3
Hydro	56	75	110	145	201	290	423	18	17	15	3.2	3.3	3.8	3.6
Geothermal	0.3	0.4	1.1	5.1	16	24	34	0.1	0.6	1.2	9.6	11.9	4.0	6.6
Solar PV	-	0.0	0.3	12	65	156	300	-	1.4	11	n.a.	18.8	8.0	11.5
Wind	-	0.2	2.4	18	39	68	102	-	2.1	3.7	n.a.	8.2	5.0	6.0
CSP and marine	-	-	-	2.6	20	42	66	-	0.3	2.4	n.a.	22.7	6.2	11.5
Biomass and waste	0.5	1.2	2.2	2.0	11	16	20	0.2	0.2	0.7	4.9	18.2	3.2	8.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	0.1	0.6	1.6	1.6	1.6	1.6	-	0.2	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	914	1 202	1 992	2 519	3 864	6 255	9 561	3.4	4.4	4.6	4.5
Population (million)	612	786	1 005	1 293	1 627	1 993	2 368	2.5	2.3	1.9	2.0
CO_2 emissions (Mt)	528	657	1 013	1 144	1 495	1 964	2 479	2.6	2.7	2.6	2.6
GDP per capita ($2015 thousand)	1.5	1.5	2.0	1.9	2.4	3.1	4.0	0.9	2.0	2.7	2.5
Primary energy consump. per capita (toe)	0.6	0.6	0.7	0.6	0.6	0.6	0.5	0.0	-0.3	-0.6	-0.5
Primary energy consumption per GDP*2	428	413	346	330	262	187	136	-0.9	-2.3	-3.2	-2.9
CO_2 emissions per GDP*3	578	546	509	454	387	314	259	-0.8	-1.6	-2.0	-1.9
CO_2 per primary energy consumption*4	1.4	1.3	1.5	1.4	1.5	1.7	1.9	0.1	0.7	1.3	1.1

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A41 | Middle East [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	223	381	649	792	989	1 119	1 221	100	100	100	4.3	2.2	1.1	1.5
Coal	3.0	8.1	9.8	8.0	10	9.5	8.0	1.3	1.0	0.7	3.3	2.3	-1.1	0.0
Oil	146	226	324	331	412	444	457	66	42	37	2.8	2.2	0.5	1.1
Natural gas	72	145	311	445	533	614	688	32	56	56	6.3	1.8	1.3	1.5
Nuclear	-	-	-	1.5	21	32	39	-	0.2	3.2	n.a.	30.1	3.1	11.4
Hydro	1.0	0.7	1.5	1.9	2.0	2.2	2.3	0.5	0.2	0.2	2.2	0.3	0.8	0.6
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	0.4	0.7	1.3	2.3	7.7	13	23	0.2	0.3	1.9	5.9	12.8	5.6	8.0
Biomass and waste	0.5	0.4	1.0	1.2	1.4	1.6	2.1	0.2	0.1	0.2	3.2	1.9	2.0	2.0
Hydrogen	-	-	-	-	-	-	-0.0	-	-	-0.0	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	157	261	451	527	667	754	829	100	100	100	4.1	2.4	1.1	1.5
Industry	47	71	134	147	186	207	220	30	28	26	3.9	2.4	0.8	1.3
Transport	51	75	121	131	178	189	197	32	25	24	3.2	3.1	0.5	1.4
Buildings, etc.	40	74	119	142	168	190	210	25	27	25	4.3	1.7	1.1	1.3
Non-energy use	20	41	77	106	135	167	202	12	20	24	5.8	2.5	2.0	2.2
Coal	0.2	0.5	1.2	3.3	3.6	3.5	3.3	0.1	0.6	0.4	10.1	0.6	-0.3	0.0
Oil	108	162	240	243	322	359	388	69	46	47	2.7	2.9	0.9	1.6
Natural gas	31	65	146	192	222	240	255	20	36	31	6.2	1.5	0.7	1.0
Electricity	17	33	62	87	117	149	180	11	17	22	5.6	3.0	2.2	2.4
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	0.7	1.0	2.2	1.6	1.8	2.0	2.4	0.5	0.3	0.3	2.7	1.0	1.5	1.3

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	244	472	888	1 275	1 677	2 123	2 525	100	100	100	5.7	2.8	2.1	2.3
Coal	11	30	35	20	30	28	21	4.3	1.5	0.8	2.1	4.1	-1.6	0.3
Oil	108	189	286	289	284	245	162	44	23	6.4	3.3	-0.2	-2.8	-1.9
Natural gas	114	246	549	921	1 191	1 574	1 948	47	72	77	7.2	2.6	2.5	2.5
Nuclear	-	-	-	5.8	80	124	148	-	0.5	5.9	n.a.	30.1	3.1	11.4
Hydro	12	8.0	18	23	23	25	27	4.9	1.8	1.1	2.2	0.3	0.8	0.6
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	0.1	14	51	90	155	-	1.1	6.1	n.a.	13.9	5.7	8.4
Wind	0.0	0.0	0.2	2.2	12	25	43	0.0	0.2	1.7	29.2	18.2	6.7	10.4
CSP and marine	-	-	-	1.0	6.2	11	20	-	0.1	0.8	n.a.	19.4	6.1	10.4
Biomass and waste	-	0.0	0.1	0.0	0.3	0.4	0.6	-	0.0	0.0	n.a.	21.4	2.9	8.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.0	0.2	0.2	0.2	0.2	-	0.0	0.0	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	910	1 364	2 039	2 529	3 482	4 630	6 001	3.5	3.3	2.8	2.9
Population (million)	132	168	213	256	294	330	362	2.2	1.4	1.0	1.2
CO_2 emissions (Mt)	567	943	1 544	1 761	2 119	2 311	2 422	3.9	1.9	0.7	1.1
GDP per capita ($2015 thousand)	6.9	8.1	9.6	9.9	12	14	17	1.2	1.8	1.7	1.7
Primary energy consump. per capita (toe)	1.7	2.3	3.0	3.1	3.4	3.4	3.4	2.0	0.9	0.0	0.3
Primary energy consumption per GDP*2	245	279	318	313	284	242	203	0.8	-1.0	-1.7	-1.4
CO_2 emissions per GDP*3	622	691	757	696	609	499	404	0.4	-1.3	-2.0	-1.8
CO_2 per primary energy consumption*4	2.5	2.5	2.4	2.2	2.1	2.1	2.0	-0.5	-0.4	-0.4	-0.4

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A42 | Oceania [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	99	125	144	151	160	161	156	100	100	100	1.4	0.6	-0.1	0.1
Coal	36	49	52	41	36	32	27	36	27	17	0.4	-1.1	-1.4	-1.3
Oil	35	40	48	50	53	49	45	35	33	29	1.2	0.5	-0.8	-0.4
Natural gas	19	24	31	42	46	51	52	19	28	33	2.7	1.0	0.6	0.7
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	3.2	3.5	3.3	3.4	3.6	3.6	3.6	3.2	2.2	2.3	0.1	0.8	-0.1	0.2
Geothermal	1.5	2.0	3.3	4.8	7.3	7.7	8.0	1.5	3.2	5.1	4.0	4.3	0.5	1.7
Solar, wind, etc.	0.1	0.1	0.9	4.3	6.7	9.6	13	0.1	2.8	8.2	12.5	4.6	3.3	3.8
Biomass and waste	4.7	6.0	5.9	5.7	6.8	7.6	8.4	4.7	3.8	5.4	0.6	1.8	1.1	1.3
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	66	82	89	94	102	102	100	100	100	100	1.2	0.8	-0.1	0.2
Industry	23	28	26	27	31	32	32	34	28	32	0.6	1.4	0.2	0.6
Transport	24	30	35	36	37	35	33	36	38	33	1.4	0.3	-0.7	-0.3
Buildings, etc.	15	19	23	25	27	28	28	22	26	28	1.7	0.9	0.2	0.4
Non-energy use	4.6	6.1	5.4	6.7	7.1	7.2	7.1	6.9	7.1	7.1	1.3	0.6	0.0	0.2
Coal	5.2	4.7	3.1	3.4	3.6	3.4	3.1	7.9	3.6	3.1	-1.4	0.5	-0.8	-0.3
Oil	33	40	45	48	50	46	42	50	51	42	1.2	0.4	-0.8	-0.4
Natural gas	10	14	14	16	17	18	17	16	17	17	1.4	0.8	0.0	0.2
Electricity	14	18	22	22	26	30	32	21	23	32	1.6	1.8	1.0	1.3
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	3.8	5.2	5.3	4.9	5.1	5.2	5.1	5.8	5.2	5.2	0.8	0.5	0.0	0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	187	249	298	309	369	411	438	100	100	100	1.7	1.8	0.9	1.2
Coal	122	176	182	148	156	149	130	65	48	30	0.6	0.5	-0.9	-0.4
Oil	3.6	1.8	6.1	4.5	4.5	3.8	2.8	1.9	1.5	0.6	0.8	-0.1	-2.3	-1.5
Natural gas	20	26	54	62	74	87	93	11	20	21	3.8	1.9	1.1	1.4
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	37	41	38	39	42	42	41	20	13	9.4	0.1	0.8	-0.1	0.2
Geothermal	2.1	2.9	5.9	8.3	13	14	14	1.1	2.7	3.2	4.6	4.4	0.5	1.8
Solar PV	-	0.0	0.4	21	35	50	67	-	6.9	15	n.a.	5.0	3.4	3.9
Wind	-	0.2	6.7	23	38	56	76	-	7.3	17	n.a.	5.2	3.6	4.1
CSP and marine	-	-	0.0	0.0	0.0	0.1	0.2	-	0.0	0.0	n.a.	30.1	6.5	13.8
Biomass and waste	1.6	2.0	3.5	4.1	7.4	10	13	0.9	1.3	2.9	3.2	5.9	2.8	3.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.5	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	658	907	1 219	1 551	2 053	2 582	3 128	2.9	2.8	2.1	2.4
Population (million)	20	23	26	31	34	36	38	1.4	0.9	0.6	0.7
CO_2 emissions (Mt)	279	360	421	405	396	380	349	1.2	-0.2	-0.6	-0.5
GDP per capita ($2015 thousand)	32	39	46	50	61	71	82	1.5	1.9	1.5	1.6
Primary energy consump. per capita (toe)	4.9	5.4	5.5	4.9	4.7	4.4	4.1	0.0	-0.3	-0.7	-0.6
Primary energy consumption per GDP[*2]	150	138	118	97	78	62	50	-1.4	-2.2	-2.2	-2.2
CO_2 emissions per GDP[*3]	425	397	345	261	193	147	112	-1.6	-3.0	-2.7	-2.8
CO_2 per primary energy consumption[*4]	2.8	2.9	2.9	2.7	2.5	2.4	2.2	-0.2	-0.8	-0.5	-0.6

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A43 | Advanced Economies [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	4 467	5 228	5 349	4 893	5 102	4 864	4 575	100	100	100	0.3	0.4	-0.5	-0.2
Coal	1 089	1 114	1 110	670	592	467	342	24	14	7.5	-1.6	-1.2	-2.7	-2.2
Oil	1 824	2 066	1 917	1 666	1 728	1 511	1 306	41	34	29	-0.3	0.4	-1.4	-0.8
Natural gas	827	1 135	1 283	1 470	1 578	1 633	1 598	19	30	35	1.9	0.7	0.1	0.3
Nuclear	463	596	606	490	465	416	388	10	10	8.5	0.2	-0.5	-0.9	-0.8
Hydro	100	111	112	120	125	128	130	2.2	2.5	2.8	0.6	0.4	0.2	0.3
Geothermal	22	25	25	39	59	78	89	0.5	0.8	1.9	1.9	4.3	2.1	2.8
Solar, wind, etc.	2.1	6.1	31	125	200	273	365	0.0	2.5	8.0	14.7	4.8	3.1	3.6
Biomass and waste	138	173	260	311	353	355	354	3.1	6.3	7.7	2.7	1.3	0.0	0.4
Hydrogen	-	-	-	-	-	-0.0	-0.0	-	-	-0.0	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	3 057	3 581	3 640	3 461	3 636	3 455	3 247	100	100	100	0.4	0.5	-0.6	-0.2
Industry	825	906	802	774	822	814	787	27	22	24	-0.2	0.6	-0.2	0.1
Transport	920	1 120	1 151	1 064	1 126	976	852	30	31	26	0.5	0.6	-1.4	-0.7
Buildings, etc.	1 025	1 189	1 310	1 242	1 254	1 220	1 163	34	36	36	0.6	0.1	-0.4	-0.2
Non-energy use	287	366	378	381	435	445	445	9.4	11	14	1.0	1.3	0.1	0.5
Coal	230	138	127	90	87	74	62	7.5	2.6	1.9	-3.1	-0.4	-1.7	-1.3
Oil	1 559	1 808	1 736	1 553	1 618	1 421	1 237	51	45	38	0.0	0.4	-1.3	-0.8
Natural gas	578	732	717	744	748	710	652	19	21	20	0.8	0.1	-0.7	-0.4
Electricity	553	719	809	803	904	988	1 051	18	23	32	1.3	1.2	0.8	0.9
Heat	48	52	66	60	61	57	52	1.6	1.7	1.6	0.8	0.0	-0.7	-0.5
Hydrogen	-	-	-	-	0.0	0.0	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	89	132	185	211	219	205	193	2.9	6.1	6.0	2.9	0.3	-0.6	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	7 667	9 706	10 869	10 649	11 954	13 018	13 767	100	100	100	1.1	1.2	0.7	0.9
Coal	3 129	3 837	3 812	2 171	1 990	1 532	1 014	41	20	7.4	-1.2	-0.9	-3.3	-2.5
Oil	667	539	274	136	101	63	28	8.7	1.3	0.2	-5.2	-2.9	-6.2	-5.1
Natural gas	766	1 528	2 527	3 272	3 936	4 808	5 218	10.0	31	38	5.0	1.9	1.4	1.6
Nuclear	1 776	2 288	2 324	1 881	1 786	1 597	1 489	23	18	11	0.2	-0.5	-0.9	-0.8
Hydro	1 159	1 294	1 304	1 398	1 450	1 487	1 515	15	13	11	0.6	0.4	0.2	0.3
Geothermal	23	27	37	53	86	121	140	0.3	0.5	1.0	2.7	5.0	2.5	3.3
Solar PV	0.1	0.7	31	408	579	905	1 352	0.0	3.8	9.8	32.5	3.6	4.3	4.1
Wind	3.8	29	269	912	1 381	1 714	2 059	0.1	8.6	15	20.0	4.2	2.0	2.8
CSP and marine	1.2	1.1	2.1	9.4	88	152	247	0.0	0.1	1.8	7.1	25.1	5.3	11.5
Biomass and waste	121	142	257	379	526	608	673	1.6	3.6	4.9	3.9	3.3	1.2	1.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	20	22	33	32	32	32	32	0.3	0.3	0.2	1.6	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	27 204	35 742	42 304	48 304	60 587	71 616	82 280	1.9	2.3	1.5	1.8
Population (million)	998	1 070	1 139	1 196	1 219	1 230	1 224	0.6	0.2	0.0	0.1
CO_2 emissions (Mt)	10 808	12 238	11 974	10 046	9 966	8 947	7 780	-0.2	-0.1	-1.2	-0.8
GDP per capita ($2015 thousand)	27	33	37	40	50	58	67	1.3	2.1	1.5	1.7
Primary energy consump. per capita (toe)	4.5	4.9	4.7	4.1	4.2	4.0	3.7	-0.3	0.2	-0.6	-0.3
Primary energy consumption per GDP[*2]	164	146	126	101	84	68	56	-1.6	-1.8	-2.1	-2.0
CO_2 emissions per GDP[*3]	397	342	283	208	164	125	95	-2.1	-2.3	-2.7	-2.6
CO_2 per primary energy consumption[*4]	2.4	2.3	2.2	2.1	2.0	1.8	1.7	-0.5	-0.5	-0.7	-0.6

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A44 | Emerging Market and Developing Economies [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	4 078	4 520	7 125	8 774	10 392	11 450	12 341	100	100	100	2.6	1.7	0.9	1.1
Coal	1 133	1 201	2 543	3 071	3 350	3 400	3 346	28	35	27	3.4	0.9	0.0	0.3
Oil	1 207	1 340	1 867	2 153	2 672	2 956	3 196	30	25	26	1.9	2.2	0.9	1.3
Natural gas	835	933	1 449	1 836	2 215	2 668	3 139	20	21	25	2.7	1.9	1.8	1.8
Nuclear	62	79	113	207	337	423	476	1.5	2.4	3.9	4.1	5.0	1.7	2.8
Hydro	84	113	184	253	297	343	387	2.1	2.9	3.1	3.7	1.6	1.3	1.4
Geothermal	12	27	36	68	135	173	211	0.3	0.8	1.7	6.0	7.0	2.3	3.8
Solar, wind, etc.	0.5	2.0	17	123	236	361	508	0.0	1.4	4.1	20.3	6.8	3.9	4.8
Biomass and waste	745	824	917	1 063	1 149	1 126	1 080	18	12	8.7	1.2	0.8	-0.3	0.1
Hydrogen	-	-	-	-	-	-0.0	-0.0	-	-	-0.0	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050				
Total	2 976	3 158	4 821	5 816	6 768	7 378	7 971	100	100	100	2.3	1.5	0.8	1.1
Industry	969	963	1 838	2 099	2 340	2 523	2 710	33	36	34	2.6	1.1	0.7	0.9
Transport	454	569	920	1 146	1 528	1 717	1 917	15	20	24	3.1	2.9	1.1	1.7
Buildings, etc.	1 362	1 376	1 657	2 007	2 189	2 311	2 415	46	35	30	1.3	0.9	0.5	0.6
Non-energy use	191	249	407	564	711	827	930	6.4	9.7	12	3.7	2.3	1.3	1.7
Coal	521	404	930	834	784	742	718	18	14	9.0	1.6	-0.6	-0.4	-0.5
Oil	844	1 043	1 520	1 852	2 342	2 613	2 861	28	32	36	2.7	2.4	1.0	1.5
Natural gas	367	388	628	836	955	1 055	1 145	12	14	14	2.8	1.3	0.9	1.1
Electricity	281	372	729	1 155	1 556	1 946	2 358	9.4	20	30	4.8	3.0	2.1	2.4
Heat	288	196	209	249	255	247	235	9.7	4.3	2.9	-0.5	0.2	-0.4	-0.2
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	0.0	n.a.
Renewables	675	754	805	889	875	775	656	23	15	8.2	0.9	-0.2	-1.4	-1.0

Electricity generation

	(TWh)							Shares (%)			1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050				
Total	4 178	5 721	10 670	16 071	21 639	26 827	32 010	100	100	100	4.6	3.0	2.0	2.3
Coal	1 300	2 158	4 858	7 282	9 088	9 931	10 420	31	45	33	5.9	2.2	0.7	1.2
Oil	657	649	695	532	559	552	462	16	3.3	1.4	-0.7	0.5	-0.9	-0.5
Natural gas	982	1 244	2 329	3 063	4 284	6 180	8 440	24	19	26	3.9	3.4	3.4	3.4
Nuclear	236	303	432	792	1 292	1 623	1 825	5.7	4.9	5.7	4.1	5.0	1.7	2.8
Hydro	981	1 319	2 145	2 943	3 459	3 989	4 495	23	18	14	3.7	1.6	1.3	1.4
Geothermal	13	25	31	42	106	143	179	0.3	0.3	0.6	4.0	9.6	2.7	4.9
Solar PV	0.0	0.1	1.4	416	937	1 598	2 552	0.0	2.6	8.0	48.4	8.5	5.1	6.2
Wind	0.0	2.8	73	686	1 375	2 054	2 658	0.0	4.3	8.3	38.9	7.2	3.3	4.6
CSP and marine	0.0	0.0	0.0	5.3	32	63	105	0.0	0.0	0.3	24.7	19.6	6.1	10.5
Biomass and waste	8.5	20	105	306	504	691	872	0.2	1.9	2.7	12.7	5.1	2.8	3.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	0.5	1.1	2.2	2.2	2.2	2.2	-	0.0	0.0	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	8 639	12 321	22 351	33 275	51 724	75 676	102 672	4.6	4.5	3.5	3.8
Population (million)	4 274	5 036	5 773	6 557	7 229	7 852	8 373	1.4	1.0	0.7	0.8
CO_2 emissions (Mt)	9 112	10 106	17 624	20 690	23 973	25 766	27 103	2.8	1.5	0.6	0.9
GDP per capita ($2015 thousand)	2.0	2.4	3.9	5.1	7.2	9.6	12	3.1	3.5	2.7	3.0
Primary energy consump. per capita (toe)	1.0	0.9	1.2	1.3	1.4	1.5	1.5	1.1	0.7	0.1	0.3
Primary energy consumption per GDP[*2]	472	367	319	264	201	151	120	-1.9	-2.7	-2.5	-2.6
CO_2 emissions per GDP[*3]	1 055	820	789	622	463	340	264	-1.7	-2.9	-2.8	-2.8
CO_2 per primary energy consumption[*4]	2.2	2.2	2.5	2.4	2.3	2.3	2.2	0.2	-0.2	-0.2	-0.2

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A45 | World [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	8 747	10 022	12 833	13 963	15 297	14 928	14 377	100	100	100	1.6	0.9	-0.3	0.1
Coal	2 222	2 315	3 654	3 741	3 442	2 726	1 905	25	27	13	1.8	-0.8	-2.9	-2.2
Oil	3 234	3 681	4 144	4 115	4 467	3 740	2 876	37	29	20	0.8	0.8	-2.2	-1.2
Natural gas	1 662	2 067	2 732	3 306	3 616	3 837	3 764	19	24	26	2.3	0.9	0.2	0.4
Nuclear	526	675	719	697	959	1 196	1 381	6.0	5.0	9.6	0.9	3.2	1.8	2.3
Hydro	184	225	297	373	433	494	556	2.1	2.7	3.9	2.4	1.5	1.3	1.3
Geothermal	34	52	61	107	238	342	434	0.4	0.8	3.0	3.9	8.3	3.1	4.8
Solar, wind, etc.	2.5	8.1	49	247	653	1 188	2 009	0.0	1.8	14	16.5	10.2	5.8	7.2
Biomass and waste	883	997	1 177	1 374	1 486	1 402	1 448	10	9.8	10	1.5	0.8	-0.1	0.2
Hydrogen	-	-	-	-	-	0.0	0.0	-	-	0.0	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	6 236	7 014	8 820	9 573	10 351	9 763	9 144	100	100	100	1.4	0.8	-0.6	-0.2
Industry	1 795	1 869	2 639	2 873	3 088	2 928	2 630	29	30	29	1.6	0.7	-0.8	-0.3
Transport	1 577	1 964	2 430	2 507	2 912	2 610	2 404	25	26	26	1.6	1.5	-1.0	-0.1
Buildings, etc.	2 387	2 565	2 967	3 248	3 205	2 954	2 736	38	34	30	1.0	-0.1	-0.8	-0.6
Non-energy use	477	615	784	946	1 146	1 270	1 373	7.7	9.9	15	2.3	1.9	0.9	1.3
Coal	752	542	1 057	924	816	650	505	12	9.7	5.5	0.7	-1.2	-2.4	-2.0
Oil	2 606	3 126	3 615	3 700	4 081	3 491	2 801	42	39	31	1.2	1.0	-1.9	-0.9
Natural gas	944	1 119	1 344	1 580	1 628	1 422	1 128	15	17	12	1.7	0.3	-1.8	-1.1
Electricity	834	1 092	1 538	1 958	2 535	3 100	3 583	13	20	39	2.9	2.6	1.7	2.0
Heat	336	248	275	309	295	235	166	5.4	3.2	1.8	-0.3	-0.5	-2.9	-2.1
Hydrogen	-	-	-	-	0.2	77	250	-	-	2.7	n.a.	n.a.	41.6	n.a.
Renewables	764	887	991	1 101	995	787	711	12	12	7.8	1.2	-1.0	-1.7	-1.4

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	11 844	15 428	21 539	26 721	34 600	42 310	50 800	100	100	100	2.7	2.6	1.9	2.2
Coal	4 429	5 995	8 670	9 452	9 182	7 033	4 254	37	35	8.4	2.6	-0.3	-3.8	-2.6
Oil	1 324	1 188	969	668	560	401	203	11	2.5	0.4	-2.3	-1.7	-4.9	-3.9
Natural gas	1 748	2 771	4 856	6 335	7 745	9 421	9 542	15	24	19	4.4	2.0	1.0	1.4
Nuclear	2 013	2 591	2 756	2 674	3 679	4 592	5 300	17	10	10	1.0	3.2	1.8	2.3
Hydro	2 140	2 613	3 449	4 341	5 038	5 742	6 464	18	16	13	2.4	1.5	1.3	1.3
Geothermal	36	52	68	95	248	370	482	0.3	0.4	0.9	3.2	10.1	3.4	5.6
Solar PV	0.1	0.8	32	824	2 483	5 139	9 846	0.0	3.1	19	35.5	11.7	7.1	8.6
Wind	3.9	31	342	1 598	4 189	6 948	10 290	0.0	6.0	20	22.2	10.1	4.6	6.4
CSP and marine	1.2	1.1	2.2	15	174	462	988	0.0	0.1	1.9	8.7	28.0	9.1	15.1
Biomass and waste	130	162	362	685	1 251	1 594	1 938	1.1	2.6	3.8	5.7	6.2	2.2	3.5
Hydrogen	-	-	-	-	18	575	1 459	-	-	2.9	n.a.	n.a.	24.5	n.a.
Others	20	22	34	34	34	34	34	0.2	0.1	0.1	1.8	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	35 843	48 064	64 655	81 578	112 310	147 292	184 952	2.8	3.2	2.5	2.8
Population (million)	5 272	6 105	6 912	7 753	8 448	9 082	9 597	1.3	0.9	0.6	0.7
CO_2 emissions (Mt)	20 556	23 207	30 726	31 666	31 220	24 732	16 936	1.5	-0.1	-3.0	-2.1
GDP per capita ($2015 thousand)	6.8	7.9	9.4	11	13	16	19	1.5	2.4	1.9	2.0
Primary energy consump. per capita (toe)	1.7	1.6	1.9	1.8	1.8	1.6	1.5	0.3	0.1	-0.9	-0.6
Primary energy consumption per GDP[*2]	244	209	198	171	136	101	78	-1.2	-2.3	-2.8	-2.6
CO_2 emissions per GDP[*3]	573	483	475	388	278	168	92	-1.3	-3.3	-5.4	-4.7
CO_2 per primary energy consumption[*4]	2.3	2.3	2.4	2.3	2.0	1.7	1.2	-0.1	-1.0	-2.7	-2.2

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A46 | Asia [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	2 081	2 861	4 783	6 052	6 881	6 765	6 416	100	100	100	3.6	1.3	-0.3	0.2
Coal	788	1 036	2 409	2 938	2 861	2 302	1 578	38	49	25	4.5	-0.3	-2.9	-2.1
Oil	615	915	1 161	1 435	1 622	1 459	1 218	30	24	19	2.9	1.2	-1.4	-0.5
Natural gas	116	233	453	670	858	954	907	5.6	11	14	6.0	2.5	0.3	1.0
Nuclear	77	132	152	170	361	492	610	3.7	2.8	9.5	2.7	7.8	2.7	4.4
Hydro	32	41	92	156	190	228	264	1.5	2.6	4.1	5.5	2.0	1.6	1.8
Geothermal	8.2	23	31	60	127	185	233	0.4	1.0	3.6	6.9	7.8	3.1	4.6
Solar, wind, etc.	1.3	2.1	16	111	315	560	915	0.1	1.8	14	16.0	10.9	5.5	7.3
Biomass and waste	444	480	469	510	544	522	545	21	8.4	8.5	0.5	0.6	0.0	0.2
Hydrogen	-	-	-	-	1.8	62	146	-	-	2.3	n.a.	n.a.	24.5	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	1 529	1 973	3 159	3 923	4 361	4 241	4 063	100	100	100	3.2	1.1	-0.4	0.1
Industry	506	654	1 402	1 650	1 762	1 625	1 441	33	42	35	4.0	0.7	-1.0	-0.5
Transport	188	322	494	681	833	783	747	12	17	18	4.4	2.0	-0.5	0.3
Buildings, etc.	720	817	975	1 177	1 232	1 235	1 230	47	30	30	1.7	0.5	0.0	0.1
Non-energy use	115	181	288	414	535	598	645	7.5	11	16	4.4	2.6	0.9	1.5
Coal	422	372	894	779	690	549	427	28	20	10	2.1	-1.2	-2.4	-2.0
Oil	463	740	988	1 275	1 457	1 324	1 125	30	33	28	3.4	1.3	-1.3	-0.4
Natural gas	46	89	200	350	411	389	332	3.0	8.9	8.2	7.0	1.6	-1.1	-0.2
Electricity	157	280	574	945	1 293	1 567	1 815	10	24	45	6.2	3.2	1.7	2.2
Heat	14	30	69	130	133	107	74	0.9	3.3	1.8	7.7	0.2	-2.9	-1.8
Hydrogen	-	-	-	-	0.1	11	37	-	-	0.9	n.a.	n.a.	38.4	n.a.
Renewables	426	462	433	444	377	294	253	28	11	6.2	0.1	-1.6	-2.0	-1.9

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	2 237	3 971	7 990	12 567	17 347	20 886	24 447	100	100	100	5.9	3.3	1.7	2.2
Coal	868	1 984	4 776	7 224	7 592	6 036	3 635	39	57	15	7.3	0.5	-3.6	-2.3
Oil	433	381	262	106	94	89	74	19	0.8	0.3	-4.6	-1.2	-1.2	-1.2
Natural gas	237	566	1 096	1 439	2 065	2 771	3 019	11	11	12	6.2	3.7	1.9	2.5
Nuclear	294	505	582	651	1 386	1 890	2 341	13	5.2	9.6	2.7	7.8	2.7	4.4
Hydro	368	477	1 072	1 818	2 213	2 648	3 067	16	14	13	5.5	2.0	1.6	1.8
Geothermal	8.4	20	22	29	76	116	151	0.4	0.2	0.6	4.3	10.0	3.5	5.6
Solar PV	0.1	0.4	5.2	446	1 355	2 666	4 823	0.0	3.5	20	33.9	11.8	6.6	8.3
Wind	0.0	2.4	70	558	1 993	3 531	5 438	0.0	4.4	22	38.2	13.6	5.1	7.9
CSP and marine	0.0	0.0	0.0	2.2	13	30	71	0.0	0.0	0.3	21.0	19.4	9.0	12.4
Biomass and waste	8.9	15	82	272	527	695	876	0.4	2.2	3.6	12.1	6.8	2.6	4.0
Hydrogen	-	-	-	-	13	393	930	-	-	3.8	n.a.	n.a.	24.0	n.a.
Others	20	20	21	21	21	21	21	0.9	0.2	0.1	0.2	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	6 688	10 377	17 857	27 854	43 113	61 368	81 167	4.9	4.5	3.2	3.6
Population (million)	2 951	3 437	3 849	4 230	4 479	4 656	4 740	1.2	0.6	0.3	0.4
CO_2 emissions (Mt)	4 699	6 816	13 030	15 889	16 143	13 044	8 879	4.1	0.2	-2.9	-1.9
GDP per capita ($2015 thousand)	2.3	3.0	4.6	6.6	9.6	13	17	3.6	3.9	2.9	3.2
Primary energy consump. per capita (toe)	0.7	0.8	1.2	1.4	1.5	1.5	1.4	2.4	0.7	-0.6	-0.2
Primary energy consumption per GDP*2	311	276	268	217	160	110	79	-1.2	-3.0	-3.5	-3.3
CO_2 emissions per GDP*3	703	657	730	570	374	213	109	-0.7	-4.1	-6.0	-5.4
CO_2 per primary energy consumption*4	2.3	2.4	2.7	2.6	2.3	1.9	1.4	0.5	-1.1	-2.6	-2.1

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A47 | China [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	874	1 133	2 536	3 499	3 617	3 172	2 592	100	100	100	4.7	0.3	-1.7	-1.0
Coal	531	668	1 790	2 125	1 944	1 398	796	61	61	31	4.7	-0.9	-4.4	-3.2
Oil	119	221	428	661	705	571	433	14	19	17	5.9	0.6	-2.4	-1.4
Natural gas	13	21	89	265	324	327	254	1.5	7.6	9.8	10.6	2.0	-1.2	-0.1
Nuclear	-	4.4	19	95	151	209	269	-	2.7	10	n.a.	4.7	2.9	3.5
Hydro	11	19	61	114	129	149	165	1.2	3.2	6.4	8.1	1.3	1.2	1.2
Geothermal	-	1.7	3.6	21	23	20	16	-	0.6	0.6	n.a.	0.9	-1.9	-1.0
Solar, wind, etc.	0.0	1.0	12	86	214	328	449	0.0	2.4	17	29.9	9.6	3.8	5.7
Biomass and waste	200	198	133	134	128	129	144	23	3.8	5.6	-1.3	-0.5	0.6	0.2
Hydrogen	-	-	-	-	0.0	41	68	-	-	2.6	n.a.	n.a.	74.4	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	658	781	1 645	2 182	2 229	1 961	1 676	100	100	100	4.1	0.2	-1.4	-0.9
Industry	234	302	924	1 073	991	772	574	36	49	34	5.2	-0.8	-2.7	-2.1
Transport	30	84	197	323	396	336	275	4.6	15	16	8.2	2.1	-1.8	-0.5
Buildings, etc.	351	338	411	587	616	615	593	53	27	35	1.7	0.5	-0.2	0.0
Non-energy use	43	58	113	199	227	238	235	6.5	9.1	14	5.2	1.4	0.2	0.6
Coal	311	274	712	576	431	286	185	47	26	11	2.1	-2.9	-4.1	-3.7
Oil	85	180	369	577	619	505	386	13	26	23	6.6	0.7	-2.3	-1.3
Natural gas	8.9	12	73	192	185	145	96	1.3	8.8	5.7	10.8	-0.4	-3.2	-2.3
Electricity	39	89	297	587	766	841	852	5.9	27	51	9.5	2.7	0.5	1.2
Heat	13	26	62	121	124	99	69	2.0	5.6	4.1	7.7	0.2	-2.9	-1.9
Hydrogen	-	-	-	-	0.0	6.7	24	-	-	1.4	n.a.	n.a.	45.5	n.a.
Renewables	200	199	132	128	104	79	66	30	5.9	3.9	-1.5	-2.1	-2.2	-2.2

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	621	1 356	4 197	7 732	10 138	11 039	11 164	100	100	100	8.8	2.7	0.5	1.2
Coal	441	1 060	3 240	4 928	5 100	3 651	1 784	71	64	16	8.4	0.3	-5.1	-3.3
Oil	50	47	15	11	9.0	5.1	1.8	8.1	0.1	0.0	-4.8	-2.4	-7.8	-6.0
Natural gas	2.8	5.8	78	235	515	669	599	0.4	3.0	5.4	16.0	8.2	0.8	3.2
Nuclear	-	17	74	366	580	803	1 034	-	4.7	9.3	n.a.	4.7	2.9	3.5
Hydro	127	222	711	1 322	1 497	1 728	1 917	20	17	17	8.1	1.3	1.2	1.2
Geothermal	0.1	0.1	0.1	0.1	0.4	0.6	0.8	0.0	0.0	0.0	2.7	13.3	2.8	6.2
Solar PV	0.0	0.0	0.7	261	653	1 074	1 719	0.0	3.4	15	48.1	9.6	5.0	6.5
Wind	0.0	0.6	45	466	1 574	2 492	3 238	0.0	6.0	29	51.0	12.9	3.7	6.7
CSP and marine	0.0	0.0	0.0	1.7	3.7	12	32	0.0	0.0	0.3	20.1	8.2	11.4	10.3
Biomass and waste	-	2.4	34	141	206	276	352	-	1.8	3.2	n.a.	3.8	2.7	3.1
Hydrogen	-	-	-	-	-	329	486	-	-	4.4	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	1 027	2 770	7 554	14 632	23 979	34 465	44 383	9.3	5.1	3.1	3.8
Population (million)	1 135	1 263	1 338	1 411	1 404	1 368	1 305	0.7	0.0	-0.4	-0.3
CO_2 emissions (Mt)	2 202	3 217	8 133	10 081	9 549	6 818	3 802	5.2	-0.5	-4.5	-3.2
GDP per capita ($2015 thousand)	0.9	2.2	5.6	10	17	25	34	8.5	5.1	3.5	4.0
Primary energy consump. per capita (toe)	0.8	0.9	1.9	2.5	2.6	2.3	2.0	4.0	0.4	-1.3	-0.7
Primary energy consumption per GDP*2	850	409	336	239	151	92	58	-4.1	-4.5	-4.6	-4.6
CO_2 emissions per GDP*3	2 143	1 161	1 077	689	398	198	86	-3.7	-5.3	-7.4	-6.7
CO_2 per primary energy consumption*4	2.5	2.8	3.2	2.9	2.6	2.1	1.5	0.4	-0.9	-2.9	-2.2

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A48 | India [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	280	418	667	872	1 230	1 429	1 590	100	100	100	3.9	3.5	1.3	2.0
Coal	93	146	279	379	484	490	424	33	43	27	4.8	2.5	-0.7	0.4
Oil	61	112	162	207	295	334	341	22	24	21	4.2	3.6	0.7	1.7
Natural gas	11	23	54	53	101	138	151	3.8	6.0	9.5	5.5	6.8	2.0	3.6
Nuclear	1.6	4.4	6.8	11	49	95	128	0.6	1.3	8.1	6.7	16.0	4.9	8.5
Hydro	6.2	6.4	11	14	24	34	46	2.2	1.6	2.9	2.7	5.7	3.3	4.1
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	0.0	0.2	2.0	12	63	149	294	0.0	1.4	19	26.6	17.8	8.0	11.2
Biomass and waste	108	126	152	196	213	186	182	39	22	11	2.0	0.8	-0.8	-0.2
Hydrogen	-	-	-	-	-0.0	3.8	24	-	-	1.5	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	215	290	444	596	813	934	1 052	100	100	100	3.5	3.1	1.3	1.9
Industry	59	85	158	226	344	386	394	27	38	37	4.6	4.3	0.7	1.9
Transport	21	32	65	93	141	175	224	9.6	16	21	5.1	4.3	2.4	3.0
Buildings, etc.	122	147	187	223	243	258	285	57	37	27	2.0	0.9	0.8	0.8
Non-energy use	13	27	34	55	85	115	148	6.2	9.2	14	4.8	4.4	2.8	3.4
Coal	38	33	87	96	140	144	133	18	16	13	3.1	3.9	-0.2	1.1
Oil	50	94	138	194	279	316	324	23	32	31	4.6	3.7	0.8	1.7
Natural gas	6.1	12	19	33	56	71	76	2.8	5.5	7.2	5.8	5.4	1.5	2.8
Electricity	18	32	62	102	189	297	435	8.5	17	41	5.9	6.4	4.2	5.0
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	1.8	5.5	-	-	0.5	n.a.	n.a.	43.6	n.a.
Renewables	102	119	138	173	149	104	78	48	29	7.4	1.8	-1.5	-3.2	-2.6

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	289	561	974	1 533	2 823	4 217	6 097	100	100	100	5.7	6.3	3.9	4.7
Coal	189	387	658	1 097	1 341	1 264	885	65	72	15	6.0	2.0	-2.1	-0.7
Oil	13	25	21	3.2	-	-	-	4.3	0.2	-	-4.5	-100	n.a.	-100
Natural gas	10.0	56	107	66	188	328	399	3.4	4.3	6.5	6.5	11.1	3.8	6.2
Nuclear	6.1	17	26	43	190	364	492	2.1	2.8	8.1	6.7	16.0	4.9	8.5
Hydro	72	74	125	161	279	396	533	25	10	8.7	2.7	5.7	3.3	4.1
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	0.0	0.1	61	393	926	1 783	-	4.0	29	n.a.	20.4	7.9	11.9
Wind	0.0	1.7	20	67	309	748	1 541	0.0	4.4	25	29.1	16.4	8.4	11.0
CSP and marine	-	-	-	-	5.1	12	27	-	-	0.4	n.a.	n.a.	8.8	n.a.
Biomass and waste	-	0.2	17	35	118	158	210	-	2.3	3.4	n.a.	12.9	2.9	6.1
Hydrogen	-	-	-	-	-	21	227	-	-	3.7	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	475	817	1 567	2 551	4 958	8 483	13 446	5.8	6.9	5.1	5.7
Population (million)	873	1 057	1 234	1 380	1 498	1 596	1 657	1.5	0.8	0.5	0.6
CO_2 emissions (Mt)	531	891	1 587	2 075	2 739	2 799	2 450	4.7	2.8	-0.6	0.6
GDP per capita ($2015 thousand)	0.5	0.8	1.3	1.8	3.3	5.3	8.1	4.2	6.0	4.6	5.1
Primary energy consump. per capita (toe)	0.3	0.4	0.5	0.6	0.8	0.9	1.0	2.3	2.6	0.8	1.4
Primary energy consumption per GDP[*2]	590	512	426	342	248	168	118	-1.8	-3.2	-3.6	-3.5
CO_2 emissions per GDP[*3]	1 118	1 091	1 012	813	552	330	182	-1.1	-3.8	-5.4	-4.9
CO_2 per primary energy consumption[*4]	1.9	2.1	2.4	2.4	2.2	2.0	1.5	0.8	-0.7	-1.8	-1.4

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A49 | Japan [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	437	516	500	385	390	335	288	100	100	100	-0.4	0.1	-1.5	-1.0
Coal	77	97	115	102	79	56	31	18	27	11	1.0	-2.6	-4.6	-3.9
Oil	249	253	201	148	124	89	60	57	38	21	-1.7	-1.7	-3.6	-2.9
Natural gas	44	66	86	92	74	63	35	10	24	12	2.5	-2.2	-3.7	-3.2
Nuclear	53	84	75	10	64	59	58	12	2.6	20	-5.4	20.4	-0.5	6.0
Hydro	7.6	7.2	7.2	6.8	8.0	8.5	8.7	1.7	1.8	3.0	-0.4	1.7	0.4	0.8
Geothermal	1.6	3.1	2.4	2.7	6.5	11	16	0.4	0.7	5.4	1.8	9.2	4.5	6.0
Solar, wind, etc.	1.2	0.9	1.1	7.7	12	21	33	0.3	2.0	11	6.4	4.7	5.0	4.9
Biomass and waste	4.2	5.0	11	15	21	23	24	1.0	4.0	8.4	4.4	3.1	0.8	1.6
Hydrogen	-	-	-	-	1.4	5.7	23	-	-	8.0	n.a.	n.a.	15.2	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	291	336	314	263	250	210	176	100	100	100	-0.3	-0.5	-1.7	-1.3
Industry	108	103	92	75	73	63	53	37	29	30	-1.2	-0.2	-1.6	-1.2
Transport	72	89	79	62	50	33	23	25	24	13	-0.5	-2.2	-3.7	-3.2
Buildings, etc.	78	108	109	96	93	82	68	27	36	39	0.7	-0.3	-1.5	-1.1
Non-energy use	33	36	35	30	33	32	32	11	11	18	-0.4	1.2	-0.2	0.2
Coal	27	21	23	19	17	13	9.3	9.3	7.1	5.3	-1.2	-0.8	-3.1	-2.3
Oil	181	206	166	133	116	83	59	62	50	34	-1.0	-1.3	-3.3	-2.6
Natural gas	14	21	29	27	26	20	12	4.7	10	6.9	2.3	-0.4	-3.7	-2.6
Electricity	66	84	89	78	84	87	85	23	30	48	0.6	0.7	0.1	0.3
Heat	0.2	0.5	0.6	0.5	0.5	0.4	0.3	0.1	0.2	0.1	3.4	0.1	-3.8	-2.5
Hydrogen	-	-	-	-	0.0	1.2	3.9	-	-	2.2	n.a.	n.a.	27.3	n.a.
Renewables	3.8	4.1	6.1	6.3	6.4	6.1	6.2	1.3	2.4	3.5	1.8	0.1	-0.1	-0.1

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	862	1 055	1 164	1 009	1 084	1 113	1 113	100	100	100	0.5	0.7	0.1	0.3
Coal	125	228	317	311	202	126	33	14	31	2.9	3.1	-4.2	-8.7	-7.2
Oil	250	133	91	32	9.1	4.5	-	29	3.2	-	-6.6	-11.8	-100	-100
Natural gas	168	255	332	395	291	286	162	19	39	15	2.9	-3.0	-2.9	-2.9
Nuclear	202	322	288	39	247	225	224	23	3.8	20	-5.4	20.4	-0.5	6.0
Hydro	88	84	84	79	93	98	101	10	7.8	9.0	-0.4	1.7	0.4	0.8
Geothermal	1.7	3.3	2.6	3.0	7.5	13	18	0.2	0.3	1.6	1.8	9.6	4.5	6.2
Solar PV	0.1	0.4	3.5	79	113	148	183	0.0	7.8	16	26.6	3.6	2.4	2.8
Wind	-	0.1	4.0	9.0	28	92	196	-	0.9	18	n.a.	12.1	10.2	10.8
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	8.1	9.2	21	46	67	82	91	0.9	4.5	8.1	6.0	3.8	1.5	2.3
Hydrogen	-	-	-	-	9.3	23	90	-	-	8.0	n.a.	n.a.	12.0	n.a.
Others	20	20	21	17	17	17	17	2.3	1.7	1.5	-0.5	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	3 520	3 987	4 219	4 381	4 889	5 321	5 739	0.7	1.1	0.8	0.9
Population (million)	123	127	128	126	119	112	104	0.1	-0.5	-0.7	-0.6
CO_2 emissions (Mt)	1 055	1 160	1 137	990	775	560	317	-0.2	-2.4	-4.4	-3.7
GDP per capita ($2015 thousand)	29	31	33	35	41	48	55	0.7	1.7	1.5	1.5
Primary energy consump. per capita (toe)	3.5	4.1	3.9	3.1	3.3	3.0	2.8	-0.5	0.7	-0.8	-0.3
Primary energy consumption per GDP[*2]	124	129	118	88	80	63	50	-1.1	-1.0	-2.3	-1.8
CO_2 emissions per GDP[*3]	300	291	269	226	159	105	55	-0.9	-3.5	-5.1	-4.6
CO_2 per primary energy consumption[*4]	2.4	2.2	2.3	2.6	2.0	1.7	1.1	0.2	-2.5	-2.9	-2.8

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A50 | ASEAN [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	231	378	535	673	931	1 101	1 217	100	100	100	3.6	3.3	1.4	2.0
Coal	13	31	85	178	191	197	183	5.4	26	15	9.2	0.7	-0.2	0.1
Oil	88	153	188	225	286	277	234	38	33	19	3.2	2.4	-1.0	0.1
Natural gas	30	74	125	130	201	233	248	13	19	20	5.0	4.5	1.1	2.2
Nuclear	-	-	-	-	12	47	75	-	-	6.2	n.a.	n.a.	9.6	n.a.
Hydro	2.3	4.1	6.1	13	18	22	24	1.0	1.9	2.0	5.7	3.9	1.4	2.2
Geothermal	6.6	18	25	36	97	153	200	2.9	5.4	16	5.8	10.4	3.7	5.9
Solar, wind, etc.	-	-	0.0	2.1	15	40	98	-	0.3	8.1	n.a.	21.5	9.9	13.6
Biomass and waste	92	97	106	87	108	123	142	40	13	12	-0.2	2.2	1.4	1.6
Hydrogen	-	-	-	-	-0.0	4.9	9.0	-	-	0.7	n.a.	n.a.	n.a.	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	171	269	377	447	588	658	694	100	100	100	3.2	2.8	0.8	1.5
Industry	41	74	120	158	208	242	254	24	35	37	4.6	2.7	1.0	1.6
Transport	33	62	86	122	158	160	153	19	27	22	4.5	2.6	-0.2	0.7
Buildings, etc.	86	112	130	113	122	135	149	50	25	21	0.9	0.8	1.0	0.9
Non-energy use	11	21	40	54	101	120	139	6.4	12	20	5.4	6.5	1.6	3.2
Coal	5.3	13	40	54	63	68	66	3.1	12	9.5	8.0	1.7	0.2	0.7
Oil	67	123	163	200	257	255	221	39	45	32	3.7	2.6	-0.7	0.3
Natural gas	7.5	17	29	44	82	95	97	4.4	9.8	14	6.0	6.5	0.8	2.7
Electricity	11	28	52	85	131	184	248	6.5	19	36	7.0	4.4	3.3	3.6
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.1	0.4	-	-	0.1	n.a.	n.a.	24.4	n.a.
Renewables	81	88	93	65	55	56	62	47	14	9.0	-0.7	-1.6	0.6	-0.1

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	154	370	675	1 075	1 673	2 402	3 420	100	100	100	6.7	4.5	3.6	3.9
Coal	28	79	185	485	516	548	517	18	45	15	10.0	0.6	0.0	0.2
Oil	66	72	59	13	16	14	8.0	43	1.2	0.2	-5.3	2.4	-3.5	-1.6
Natural gas	26	154	336	344	533	685	791	17	32	23	9.0	4.5	2.0	2.8
Nuclear	-	-	-	-	46	181	287	-	-	8.4	n.a.	n.a.	9.6	n.a.
Hydro	27	47	71	146	213	251	281	18	14	8.2	5.7	3.9	1.4	2.2
Geothermal	6.6	16	19	26	67	102	131	4.3	2.4	3.8	4.7	9.9	3.4	5.5
Solar PV	-	-	0.0	19	118	326	769	-	1.8	22	n.a.	20.0	9.8	13.1
Wind	-	-	0.1	5.7	55	142	373	-	0.5	11	n.a.	25.5	10.0	14.9
CSP and marine	-	-	-	-	0.1	0.2	0.6	-	-	0.0	n.a.	n.a.	9.9	n.a.
Biomass and waste	0.6	1.0	5.7	36	108	145	183	0.4	3.4	5.4	14.7	11.6	2.7	5.5
Hydrogen	-	-	-	-	-	8.0	79	-	-	2.3	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	720	1 149	1 914	2 846	4 495	6 741	9 557	4.7	4.7	3.8	4.1
Population (million)	431	507	575	643	695	735	758	1.3	0.8	0.4	0.6
CO_2 emissions (Mt)	350	682	1 071	1 507	1 733	1 598	1 296	5.0	1.4	-1.4	-0.5
GDP per capita ($2015 thousand)	1.7	2.3	3.3	4.4	6.5	9.2	13	3.3	3.9	3.4	3.6
Primary energy consump. per capita (toe)	0.5	0.7	0.9	1.0	1.3	1.5	1.6	2.3	2.5	0.9	1.4
Primary energy consumption per GDP*2	321	329	280	236	207	163	127	-1.0	-1.3	-2.4	-2.0
CO_2 emissions per GDP*3	486	593	560	529	385	237	136	0.3	-3.1	-5.1	-4.4
CO_2 per primary energy consumption*4	1.5	1.8	2.0	2.2	1.9	1.5	1.1	1.3	-1.8	-2.8	-2.5

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A51 | United States [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	1 914	2 273	2 216	2 038	2 047	1 818	1 634	100	100	100	0.2	0.0	-1.1	-0.7
Coal	460	533	501	222	137	55	14	24	11	0.9	-2.4	-4.7	-10.6	-8.7
Oil	757	871	807	702	682	459	259	40	34	16	-0.2	-0.3	-4.7	-3.3
Natural gas	438	548	556	719	727	677	564	23	35	34	1.7	0.1	-1.3	-0.8
Nuclear	159	208	219	214	193	194	195	8.3	11	12	1.0	-1.0	0.0	-0.3
Hydro	23	22	23	25	29	31	34	1.2	1.2	2.1	0.2	1.5	0.9	1.1
Geothermal	14	13	8.4	9.3	25	41	57	0.7	0.5	3.5	-1.4	10.3	4.2	6.2
Solar, wind, etc.	0.3	2.1	11	43	113	223	380	0.0	2.1	23	17.7	10.2	6.3	7.5
Biomass and waste	62	73	89	100	139	152	166	3.3	4.9	10	1.6	3.4	0.9	1.7
Hydrogen	-	-	-	-	-0.4	-18	-38	-	-	-2.4	n.a.	n.a.	25.4	n.a.

Final energy consumption

	Mtoe							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	1 294	1 546	1 513	1 461	1 494	1 281	1 092	100	100	100	0.4	0.2	-1.6	-1.0
Industry	284	332	270	265	272	250	214	22	18	20	-0.2	0.3	-1.2	-0.7
Transport	488	588	596	549	553	408	312	38	38	29	0.4	0.1	-2.8	-1.9
Buildings, etc.	403	473	511	505	496	442	381	31	35	35	0.8	-0.2	-1.3	-0.9
Non-energy use	119	153	135	143	173	181	185	9.2	9.8	17	0.6	2.0	0.3	0.9
Coal	56	33	27	13	11	8.2	5.9	4.3	0.9	0.5	-4.7	-1.8	-3.1	-2.7
Oil	683	793	762	677	663	463	295	53	46	27	0.0	-0.2	-4.0	-2.7
Natural gas	303	360	322	356	346	255	151	23	24	14	0.5	-0.3	-4.1	-2.8
Electricity	226	301	326	325	367	426	458	18	22	42	1.2	1.2	1.1	1.2
Heat	2.2	5.3	6.6	6.0	5.7	4.6	3.1	0.2	0.4	0.3	3.5	-0.5	-3.0	-2.2
Hydrogen	-	-	-	-	0.1	17	64	-	-	5.9	n.a.	n.a.	42.3	n.a.
Renewables	23	54	70	84	101	107	115	1.8	5.7	11	4.4	1.9	0.6	1.1

Electricity generation

	(TWh)							Shares (%)						
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total	3 203	4 026	4 354	4 239	4 814	5 616	6 202	100	100	100	0.9	1.3	1.3	1.3
Coal	1 700	2 129	1 994	856	565	197	8.5	53	20	0.1	-2.3	-4.1	-18.9	-14.2
Oil	131	118	48	37	23	13	2.9	4.1	0.9	0.0	-4.1	-4.7	-9.9	-8.2
Natural gas	382	634	1 018	1 680	1 833	1 772	864	12	40	14	5.1	0.9	-3.7	-2.2
Nuclear	612	798	839	823	742	744	748	19	19	12	1.0	-1.0	0.0	-0.3
Hydro	273	253	262	287	332	362	393	8.5	6.8	6.3	0.2	1.5	0.9	1.1
Geothermal	16	15	18	19	52	86	119	0.5	0.4	1.9	0.5	10.6	4.2	6.3
Solar PV	0.0	0.2	3.1	116	410	925	1 808	0.0	2.7	29	42.2	13.5	7.7	9.6
Wind	3.1	5.7	95	342	610	985	1 341	0.1	8.1	22	17.0	6.0	4.0	4.7
CSP and marine	0.7	0.5	0.9	3.4	84	217	412	0.0	0.1	6.6	5.6	37.7	8.3	17.3
Biomass and waste	86	72	73	71	158	192	224	2.7	1.7	3.6	-0.7	8.4	1.8	3.9
Hydrogen	-	-	-	-	-	118	278	-	-	4.5	n.a.	n.a.	n.a.	n.a.
Others	-	-	3.7	4.9	4.9	4.9	4.9	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	9 805	13 738	16 320	19 294	24 520	29 928	35 322	2.3	2.4	1.8	2.0
Population (million)	250	282	309	332	347	362	371	1.0	0.5	0.3	0.4
CO_2 emissions (Mt)	4 755	5 629	5 220	4 258	3 694	2 310	986	-0.4	-1.4	-6.4	-4.8
GDP per capita ($2015 thousand)	39	49	53	58	71	83	95	1.3	2.0	1.5	1.7
Primary energy consump. per capita (toe)	7.7	8.1	7.2	6.1	5.9	5.0	4.4	-0.7	-0.4	-1.4	-1.1
Primary energy consumption per GDP[*2]	195	165	136	106	83	61	46	-2.0	-2.3	-2.9	-2.7
CO_2 emissions per GDP[*3]	485	410	320	221	151	77	28	-2.6	-3.7	-8.1	-6.7
CO_2 per primary energy consumption[*4]	2.5	2.5	2.4	2.1	1.8	1.3	0.6	-0.6	-1.5	-5.3	-4.1

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A52 | European Union [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total[*1]	1 441	1 471	1 527	1 311	1 281	1 145	1 048	100	100	100	-0.3	-0.2	-1.0	-0.7
Coal	393	285	252	144	92	60	45	27	11	4.3	-3.3	-4.3	-3.6	-3.8
Oil	531	550	506	418	371	239	147	37	32	14	-0.8	-1.2	-4.5	-3.4
Natural gas	250	309	363	326	287	228	168	17	25	16	0.9	-1.3	-2.6	-2.2
Nuclear	190	224	223	178	197	212	221	13	14	21	-0.2	1.0	0.6	0.7
Hydro	24	30	32	30	30	30	31	1.7	2.3	3.0	0.7	-0.1	0.2	0.1
Geothermal	3.2	4.6	5.5	6.9	10	12	12	0.2	0.5	1.2	2.6	4.0	1.0	2.0
Solar, wind, etc.	0.3	2.5	16	51	106	152	194	0.0	3.9	19	18.5	7.5	3.1	4.5
Biomass and waste	47	65	128	154	174	155	140	3.3	12	13	4.0	1.2	-1.1	-0.3
Hydrogen	-	-	-	-	0.3	7.5	21	-	-	2.0	n.a.	n.a.	24.0	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050				
Total	995	1 027	1 070	963	934	768	637	100	100	100	-0.1	-0.3	-1.9	-1.4
Industry	313	274	247	232	246	220	184	31	24	29	-1.0	0.6	-1.4	-0.8
Transport	220	262	279	252	235	156	121	22	26	19	0.5	-0.7	-3.2	-2.4
Buildings, etc.	374	391	447	390	361	303	247	38	40	39	0.1	-0.8	-1.9	-1.5
Non-energy use	88	100	98	90	93	90	84	8.9	9.3	13	0.0	0.4	-0.5	-0.2
Coal	109	47	38	26	21	14	9.7	11	2.6	1.5	-4.7	-1.8	-3.9	-3.2
Oil	445	479	448	384	342	229	156	45	40	25	-0.5	-1.1	-3.8	-3.0
Natural gas	185	220	231	208	188	138	79	19	22	12	0.4	-1.0	-4.2	-3.2
Electricity	162	189	216	205	244	276	285	16	21	45	0.8	1.8	0.8	1.1
Heat	55	43	52	44	41	31	20	5.5	4.6	3.2	-0.7	-0.7	-3.5	-2.6
Hydrogen	-	-	-	-	0.1	11	40	-	-	6.3	n.a.	n.a.	38.9	n.a.
Renewables	39	50	86	96	97	69	46	4.0	10	7.3	3.0	0.1	-3.6	-2.4

Electricity generation

	(TWh)							Shares (%)			1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050				
Total	2 258	2 631	2 956	2 758	3 349	3 766	4 137	100	100	100	0.7	2.0	1.1	1.4
Coal	844	846	755	383	189	85	35	37	14	0.9	-2.6	-6.8	-8.1	-7.6
Oil	189	173	82	48	30	15	4.1	8.4	1.7	0.1	-4.5	-4.7	-9.4	-7.9
Natural gas	188	331	589	560	519	381	166	8.3	20	4.0	3.7	-0.7	-5.5	-4.0
Nuclear	729	860	854	684	756	814	847	32	25	20	-0.2	1.0	0.6	0.7
Hydro	285	352	373	346	344	352	360	13	13	8.7	0.7	-0.1	0.2	0.1
Geothermal	3.2	4.8	5.6	6.7	11	14	16	0.1	0.2	0.4	2.5	5.4	1.6	2.9
Solar PV	0.0	0.1	22	139	284	451	655	0.0	5.0	16	35.6	7.4	4.3	5.3
Wind	0.8	21	140	397	904	1 236	1 516	0.0	14	37	23.2	8.6	2.6	4.6
CSP and marine	0.5	0.5	1.2	5.5	38	70	99	0.0	0.2	2.4	8.3	21.2	5.0	10.1
Biomass and waste	19	42	129	183	265	308	341	0.8	6.7	8.3	7.9	3.7	1.3	2.1
Hydrogen	-	-	-	-	4.0	36	92	-	-	2.2	n.a.	n.a.	16.9	n.a.
Others	0.2	1.4	4.4	4.7	4.7	4.7	4.7	0.0	0.2	0.1	10.9	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	9 083	11 260	12 898	13 890	17 337	19 839	22 158	1.4	2.2	1.2	1.6
Population (million)	420	429	442	447	449	446	438	0.2	0.0	-0.1	-0.1
CO_2 emissions (Mt)	3 467	3 267	3 137	2 394	1 883	1 231	767	-1.2	-2.4	-4.4	-3.7
GDP per capita ($2015 thousand)	22	26	29	31	39	44	51	1.2	2.2	1.4	1.6
Primary energy consump. per capita (toe)	3.4	3.4	3.5	2.9	2.9	2.6	2.4	-0.5	-0.3	-0.9	-0.7
Primary energy consumption per GDP[*2]	159	131	118	94	74	58	47	-1.7	-2.4	-2.2	-2.3
CO_2 emissions per GDP[*3]	382	290	243	172	109	62	35	-2.6	-4.5	-5.6	-5.2
CO_2 per primary energy consumption[*4]	2.4	2.2	2.1	1.8	1.5	1.1	0.7	-0.9	-2.2	-3.4	-3.0

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A53 | Advanced Economies [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	4 467	5 228	5 349	4 893	4 900	4 352	3 907	100	100	100	0.3	0.0	-1.1	-0.7
Coal	1 089	1 114	1 110	670	479	315	199	24	14	5.1	-1.6	-3.3	-4.3	-4.0
Oil	1 824	2 066	1 917	1 666	1 565	1 075	665	41	34	17	-0.3	-0.6	-4.2	-3.0
Natural gas	827	1 135	1 283	1 470	1 433	1 307	1 055	19	30	27	1.9	-0.3	-1.5	-1.1
Nuclear	463	596	606	490	545	555	576	10	10	15	0.2	1.1	0.3	0.5
Hydro	100	111	112	120	127	133	138	2.2	2.5	3.5	0.6	0.6	0.4	0.5
Geothermal	22	25	25	39	71	99	122	0.5	0.8	3.1	1.9	6.3	2.7	3.9
Solar, wind, etc.	2.1	6.1	31	125	286	485	749	0.0	2.5	19	14.7	8.7	4.9	6.2
Biomass and waste	138	173	260	311	389	388	391	3.1	6.3	10	2.7	2.3	0.0	0.8
Hydrogen	-	-	-	-	1.4	-7.7	7.7	-	-	0.2	n.a.	n.a.	8.9	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	3 057	3 581	3 640	3 461	3 472	2 958	2 509	100	100	100	0.4	0.0	-1.6	-1.1
Industry	825	906	802	774	809	731	617	27	22	25	-0.2	0.4	-1.3	-0.8
Transport	920	1 120	1 151	1 064	1 033	737	566	30	31	23	0.5	-0.3	-3.0	-2.1
Buildings, etc.	1 025	1 189	1 310	1 242	1 194	1 045	881	34	36	35	0.6	-0.4	-1.5	-1.1
Non-energy use	287	366	378	381	435	445	445	9.4	11	18	1.0	1.3	0.1	0.5
Coal	230	138	127	90	78	55	38	7.5	2.6	1.5	-3.1	-1.4	-3.6	-2.9
Oil	1 559	1 808	1 736	1 553	1 474	1 049	719	51	45	29	0.0	-0.5	-3.5	-2.5
Natural gas	578	732	717	744	702	516	298	19	21	12	0.8	-0.6	-4.2	-3.0
Electricity	553	719	809	803	925	1 042	1 089	18	23	43	1.3	1.4	0.8	1.0
Heat	48	52	66	60	57	44	29	1.6	1.7	1.1	0.8	-0.6	-3.4	-2.5
Hydrogen	-	-	-	-	0.2	38	134	-	-	5.3	n.a.	n.a.	39.9	n.a.
Renewables	89	132	185	211	236	214	204	2.9	6.1	8.1	2.9	1.1	-0.7	-0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	7 667	9 706	10 869	10 649	12 237	13 858	15 175	100	100	100	1.1	1.4	1.1	1.2
Coal	3 129	3 837	3 812	2 171	1 480	802	296	41	20	2.0	-1.2	-3.8	-7.7	-6.4
Oil	667	539	274	136	76	37	6.6	8.7	1.3	0.0	-5.2	-5.7	-11.5	-9.6
Natural gas	766	1 528	2 527	3 272	3 361	3 238	1 800	10.0	31	12	5.0	0.3	-3.1	-2.0
Nuclear	1 776	2 288	2 324	1 881	2 092	2 132	2 210	23	18	15	0.2	1.1	0.3	0.5
Hydro	1 159	1 294	1 304	1 398	1 478	1 547	1 609	15	13	11	0.6	0.6	0.4	0.5
Geothermal	23	27	37	53	108	158	201	0.3	0.5	1.3	2.7	7.4	3.2	4.6
Solar PV	0.1	0.7	31	408	963	1 811	3 188	0.0	3.8	21	32.5	9.0	6.2	7.1
Wind	3.8	29	269	912	1 897	2 878	3 910	0.1	8.6	26	20.0	7.6	3.7	5.0
CSP and marine	1.2	1.1	2.1	9.4	126	294	522	0.0	0.1	3.4	7.1	29.6	7.4	14.3
Biomass and waste	121	142	257	379	606	716	801	1.6	3.6	5.3	3.9	4.8	1.4	2.5
Hydrogen	-	-	-	-	18	214	598	-	-	3.9	n.a.	n.a.	19.1	n.a.
Others	20	22	33	32	32	32	32	0.3	0.3	0.2	1.6	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	27 204	35 742	42 304	48 304	60 587	71 616	82 280	1.9	2.3	1.5	1.8
Population (million)	998	1 070	1 139	1 196	1 219	1 230	1 224	0.6	0.2	0.0	0.1
CO_2 emissions (Mt)	10 808	12 238	11 974	10 046	8 567	5 730	2 996	-0.2	-1.6	-5.1	-4.0
GDP per capita ($2015 thousand)	27	33	37	40	50	58	67	1.3	2.1	1.5	1.7
Primary energy consump. per capita (toe)	4.5	4.9	4.7	4.1	4.0	3.5	3.2	-0.3	-0.2	-1.1	-0.8
Primary energy consumption per GDP*2	164	146	126	101	81	61	47	-1.6	-2.2	-2.6	-2.5
CO_2 emissions per GDP*3	397	342	283	208	141	80	36	-2.1	-3.8	-6.6	-5.6
CO_2 per primary energy consumption*4	2.4	2.3	2.2	2.1	1.7	1.3	0.8	-0.5	-1.6	-4.0	-3.2

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Table A54 | Emerging Market and Developing Economies [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
Total*1	4 078	4 520	7 125	8 774	9 931	10 060	9 933	100	100	100	2.6	1.2	0.0	0.4
Coal	1 133	1 201	2 543	3 071	2 963	2 411	1 706	28	35	17	3.4	-0.4	-2.7	-1.9
Oil	1 207	1 340	1 867	2 153	2 474	2 273	1 923	30	25	19	1.9	1.4	-1.3	-0.4
Natural gas	835	933	1 449	1 836	2 163	2 469	2 598	20	21	26	2.7	1.7	0.9	1.2
Nuclear	62	79	113	207	414	641	805	1.5	2.4	8.1	4.1	7.2	3.4	4.6
Hydro	84	113	184	253	306	361	417	2.1	2.9	4.2	3.7	1.9	1.6	1.7
Geothermal	12	27	36	68	167	244	312	0.3	0.8	3.1	6.0	9.3	3.2	5.2
Solar, wind, etc.	0.5	2.0	17	123	367	703	1 260	0.0	1.4	13	20.3	11.6	6.4	8.1
Biomass and waste	745	824	917	1 063	1 080	972	964	18	12	9.7	1.2	0.2	-0.6	-0.3
Hydrogen	-	-	-	-	-1.4	-13	-51	-	-	-0.5	n.a.	n.a.	19.7	n.a.

Final energy consumption

	Mtoe							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	2 976	3 158	4 821	5 816	6 413	6 289	6 098	100	100	100	2.3	1.0	-0.3	0.2
Industry	969	963	1 838	2 099	2 278	2 197	2 013	33	36	33	2.6	0.8	-0.6	-0.1
Transport	454	569	920	1 146	1 414	1 357	1 302	15	20	21	3.1	2.1	-0.4	0.4
Buildings, etc.	1 362	1 376	1 657	2 007	2 011	1 909	1 855	46	35	30	1.3	0.0	-0.4	-0.3
Non-energy use	191	249	407	564	711	825	928	6.4	9.7	15	3.7	2.3	1.3	1.7
Coal	521	404	930	834	738	595	467	18	14	7.7	1.6	-1.2	-2.3	-1.9
Oil	844	1 043	1 520	1 852	2 178	2 050	1 794	28	32	29	2.7	1.6	-1.0	-0.1
Natural gas	367	388	628	836	906	845	719	12	14	12	2.8	0.8	-1.1	-0.5
Electricity	281	372	729	1 155	1 611	2 058	2 495	9.4	20	41	4.8	3.4	2.2	2.6
Heat	288	196	209	249	238	192	137	9.7	4.3	2.2	-0.5	-0.4	-2.7	-2.0
Hydrogen	-	-	-	-	0.1	20	72	-	-	1.2	n.a.	n.a.	41.1	n.a.
Renewables	675	754	805	889	743	530	415	23	15	6.8	0.9	-1.8	-2.9	-2.5

Electricity generation

	(TWh)							Shares (%)			1990/	2020/	2030/	2020/
	1990	2000	2010	2020	2030	2040	2050	1990	2020	2050	2020	2030	2050	2050
Total	4 178	5 721	10 670	16 071	22 363	28 452	35 626	100	100	100	4.6	3.4	2.4	2.7
Coal	1 300	2 158	4 858	7 282	7 702	6 231	3 958	31	45	11	5.9	0.6	-3.3	-2.0
Oil	657	649	695	532	484	364	197	16	3.3	0.6	-0.7	-0.9	-4.4	-3.3
Natural gas	982	1 244	2 329	3 063	4 383	6 183	7 742	24	19	22	3.9	3.6	2.9	3.1
Nuclear	236	303	432	792	1 587	2 460	3 090	5.7	4.9	8.7	4.1	7.2	3.4	4.6
Hydro	981	1 319	2 145	2 943	3 560	4 195	4 855	23	18	14	3.7	1.9	1.6	1.7
Geothermal	13	25	31	42	140	212	281	0.3	0.3	0.8	4.0	12.7	3.5	6.5
Solar PV	0.0	0.1	1.4	416	1 520	3 328	6 658	0.0	2.6	19	48.4	13.8	7.7	9.7
Wind	0.0	2.8	73	686	2 292	4 071	6 380	0.0	4.3	18	38.9	12.8	5.3	7.7
CSP and marine	0.0	0.0	0.0	5.3	48	168	465	0.0	0.0	1.3	24.7	24.7	12.0	16.1
Biomass and waste	8.5	20	105	306	644	879	1 137	0.2	1.9	3.2	12.7	7.7	2.9	4.5
Hydrogen	-	-	-	-	-	361	861	-	-	2.4	n.a.	n.a.	n.a.	n.a.
Others	-	0.5	1.1	2.2	2.2	2.2	2.2	-	0.0	0.0	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1990	2000	2010	2020	2030	2040	2050	1990/ 2020	2020/ 2030	2030/ 2050	2020/ 2050
GDP ($2015 billion)	8 639	12 321	22 351	33 275	51 724	75 676	102 672	4.6	4.5	3.5	3.8
Population (million)	4 274	5 036	5 773	6 557	7 229	7 852	8 373	1.4	1.0	0.7	0.8
CO_2 emissions (Mt)	9 112	10 106	17 624	20 690	21 259	17 628	12 773	2.8	0.3	-2.5	-1.6
GDP per capita ($2015 thousand)	2.0	2.4	3.9	5.1	7.2	9.6	12	3.1	3.5	2.7	3.0
Primary energy consump. per capita (toe)	1.0	0.9	1.2	1.3	1.4	1.3	1.2	1.1	0.3	-0.7	-0.4
Primary energy consumption per GDP*2	472	367	319	264	192	133	97	-1.9	-3.1	-3.4	-3.3
CO_2 emissions per GDP*3	1 055	820	789	622	411	233	124	-1.7	-4.1	-5.8	-5.2
CO_2 per primary energy consumption*4	2.2	2.2	2.5	2.4	2.1	1.8	1.3	0.2	-1.0	-2.5	-2.0

*1 Trade of electricity and heat are not shown, *2 toe/$2015 million,
*3 t/$2015 million, *4 t/toe

Slides

The 442nd Forum on Research Work

IEEJ Outlook 2023

Energy, Environment and Economy

Challenges for achieving both energy security and carbon neutrality

Tokyo, 19 October 2022

The Institute of Energy Economics, Japan

IEEJ Outlook2023

Global Energy Supply and Demand Outlook by 2050

Shigeru SUEHIRO

Econometric and Statistical Analysis Group
The Energy Data and Modelling Center
The Institute of Energy Economics, Japan

What is IEEJ Outlook 2023?

- Quantify the global energy supply and demand structure up to 2050
- Forecast-based outlook using econometric models and other tools
  The forecast type is a method of looking ahead to the future with various assumptions, starting from the present. On the other hand, the backcast type is a method of thinking about how to take measures from the present, setting goals for the future.
- Conduct scenario analyses of technological and policy developments and trends

Reference Scenario

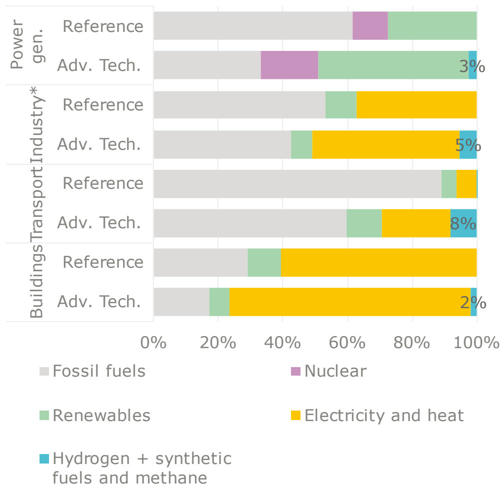
A scenario in which the prevailing changes will continue against the backdrop of current energy and environmental policies

Advanced Technologies Scenario

A scenario in which energy and environmental technologies are introduced to the maximum extent possible to ensure a stable supply of energy and strengthen measures against climate change

A part of last year's "Circular Carbon Economy/4Rs Scenario" is reflected.
- Hydrogen-fired power generation, hydrogen direct combustion, hydrogen reduction ironmaking, fuel cell vehicles, and synthetic fuel and synthetic methane technologies are assumed.
- Supply limited to blue hydrogen or green hydrogen.

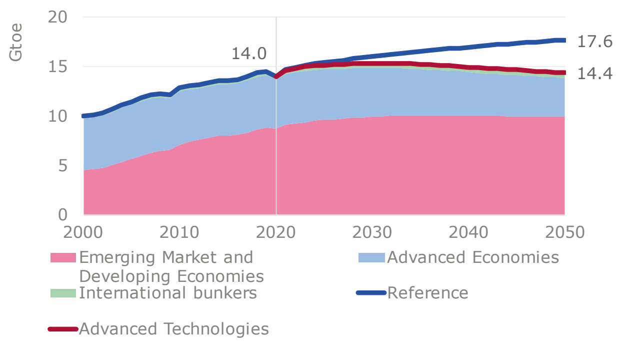
Energy consumption composition (2050)



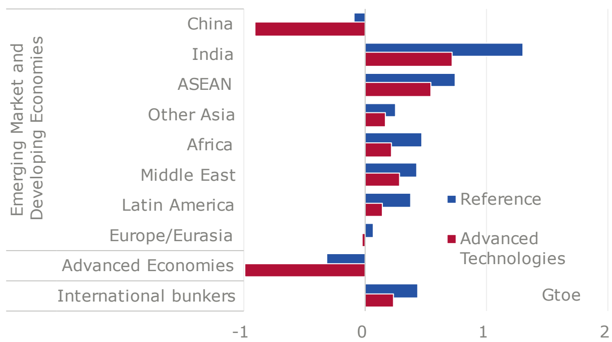
* Includes the steel blast furnace sector

Increase in energy demand centring on India and ASEAN

Primary energy demand outlook



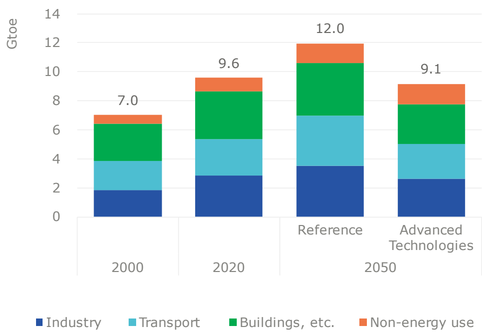
Changes in primary energy demand (2020-2050)



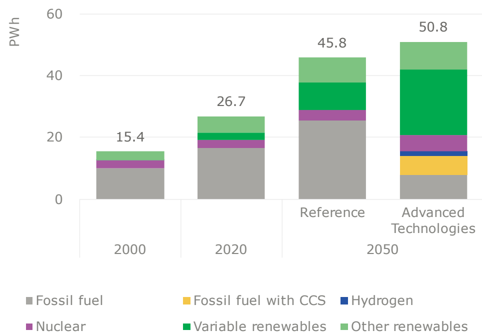
- (Reference) Primary energy demand will continue to grow, increasing 1.3-fold in 2050.
- (Advanced Technologies) After peaking in the early 2030s, it will gradually decrease. Emerging Market and Developing Economies remain largely unchanged after the 2030s.
- In both scenarios, demand growth is centred on India and ASEAN. China, which has been driving demand growth, will ~~also~~ peak by 2030 in the Reference Scenario.

Significant progress will be made in energy efficiency and low-carbon power generation (Advanced Technologies Scenario)

Final energy consumption outlook



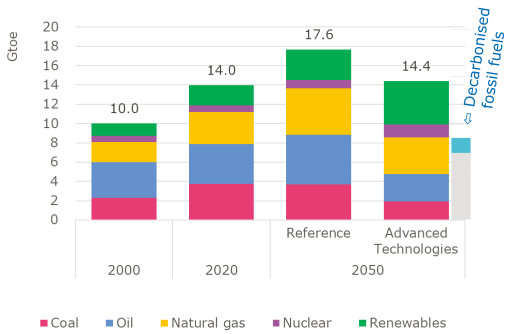
Electricity generated outlook



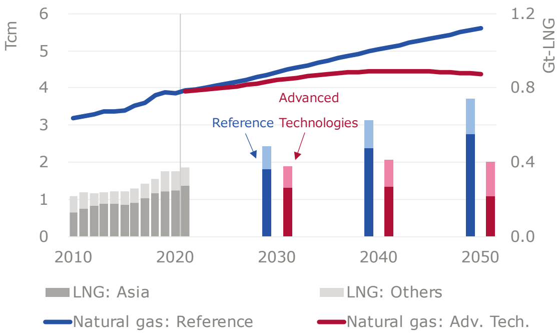
- (Reference) Final consumption increases 1.2-fold. More than 40% of the increase will come from transportation, and more than 60% from electricity.
- (Advanced Technologies) Energy savings of 23% relative to the Reference Scenario. The electrification of consumption is increasing. The share of electricity will rise to 39% (from 20% in 2020).
- Electricity demand will increase significantly in both scenarios. In the Reference Scenario, fossil fuel-fired as well as renewables will meet the increased demand. In the Advanced Technologies Scenario, the share of renewables will rise to 60%. The zero-emission power source, including thermal with CCS, exceeds 80%.

Dependence on fossil fuels continues

Primary energy demand outlook



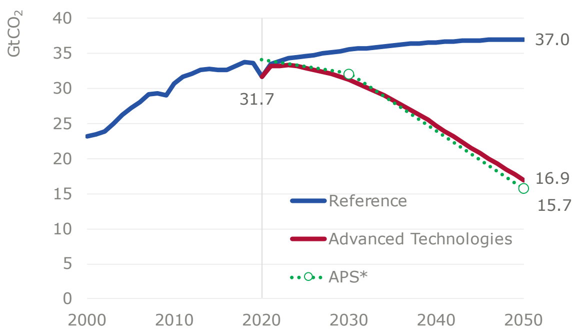
Natural gas and LNG demand outlook



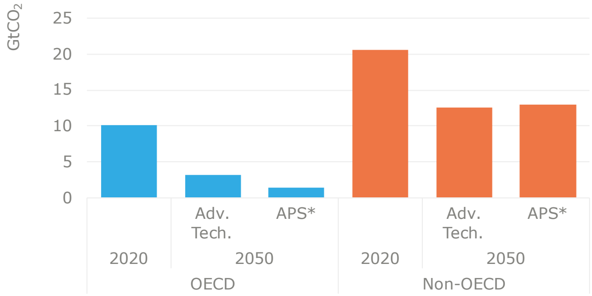
- (Reference) Oil will continue to increase slightly, natural gas will increase 1.5 times, and coal will decline after peaking around 2030. Demand for natural gas, mainly for power generation, grows, while LNG demand doubles. Asian demand, in particular, will be the driving force.
- (Advanced Technologies) Oil and coal will decline in the 2020s, while natural gas will be the only fossil fuel to grow more than it is today. LNG demand remains around 400 million tonnes. Nuclear and renewables will each double, but the share of non-fossil fuels as of 2050 is around 40%. However, about 20% of fossil fuels are decarbonised (by CCS).

Emerging Market and Developing Economies key to achieving carbon neutrality

Energy-related CO_2 emissions outlook



CO_2 emissions outlook by region



- Energy-related CO_2 emissions under the Reference Scenario continue to increase. On the other hand, under the Advanced Technologies Scenario, it will peak in the first half of the 2020s and decrease to 17 $GtCO_2$ by 2050. It would be on a par with the APS*, which incorporates countries' carbon neutral declarations.
- In both the Advanced Technologies Scenario and the APS*, overall non-OECD emissions are only about 40% lower. Reducing emissions in developing countries is key to achieving global carbon neutrality. It will also be necessary to keep an eye on whether developed countries can follow through on the declaration.

*APS: Announced Pledges Scenario (updated), estimates when countries' stated policy goals are realised. Includes industrial processes. IEEJ estimates from IEA "World Energy Outlook 2021" (October 2021) and "Technical note on the emissions and temperature implications of COP 26 pledges" (November 2021).

Conclusion

- Energy demand in China, which has been until recently driving global demand growth, will peak and decline by around 2030. Instead, India and ASEAN will be the focus of increased demand.
- Electricity demand will increase significantly in both the status quo world (Reference Scenario) and the decarbonising world (Advanced Technologies Scenario). Stable power supply and security will become more important in the future.
- Dependence on fossil fuels will continue. Fossil fuels accounts for 80% in 2050 under the Reference Scenario and 60% in the Advanced Technologies Scenario (about 20% of which is decarbonised). Stable supply of fossil fuels remains a key issue.
- Even the Advanced Technologies Scenario is far from achieving global carbon neutrality in 2050. In particular, further promotion of energy conservation and decarbonisation in developing countries will be key to the progress of global decarbonisation.

Challenges and Response Strategies for Energy Security Under the New Reality

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A new reality

- In recent years, climate change has been at the centre of energy and climate policy debates.
- But over the past year or so, the energy security crisis has never been greater.
  - Energy prices in Europe have soared since the middle of 2021 due to weather conditions (low temperatures in Spring 2021, prolonged wind deterioration) and unforeseen factors, such as a decline in natural gas supply due to breakdowns.
  - Russia invaded Ukraine in February 2022. Subsequently, Western countries decided to impose a (gradual) embargo on Russian energy. Russia responded by using its own energy exports as a weapon (Reduce export volume, take over assets).
  - Shortage of physical energy supply, especially natural gas, is a real threat.
  - International prices for all kinds of fossil fuels are at historic highs, in part because of the escalating geopolitical risks of conflict with no way out.
  - In some developing countries, soaring prices of imported energy have strained their finances and hindered fuel procurement.
- Energy security is the foundation of people's lives and all economic activities, and in the short term at least, securing energy supplies has become a top priority.
- However, there is no time to wait for action on climate change, and ***the question is how to reconcile energy security and climate action***.

Key points of this report

1. Energy security strategy in view of war in Ukraine and energy transition
- ✓ Japan needs to prepare for unforeseen circumstances while continuing to seek to maintain its procurement of Russian LNG. To avoid a "scramble under a zero-sum game", it is necessary to reacknowledge the role of LNG and the importance of upstream investment, and to take concrete steps to expand supply.
- ✓ In Asia, decarbonisation, which follows the process of first shifting from coal to natural gas, is considered a realistic path considering the amount of renewable energy available and the economics considering integration costs. If the promotion of natural gas and LNG investment becomes a reality, it will help stabilise markets and avoid the negative impact of Asia's energy transition on regional economies.
- ✓ Blue hydrogen and ammonia will play a major role in the decarbonisation of fossil fuels, but the high price of natural gas makes them uncompetitive. Therefore, it is necessary to stabilise the natural gas market to ensure the introduction of blue hydrogen and ammonia.

2. Strengthening stable power supply and importance of nuclear power generation
- ✓ In advanced countries, lopsided power generation mix and reduced supply capacity have increased vulnerability to risks such as heat waves, cold waves and earthquakes. The shortage of kWh caused by fuel shortages due to fuel price hikes and fuel supplier risk has also become a problem. Securing a stable supply has become an issue.
- ✓ With the growing importance of energy security, the role of nuclear power generation is being reviewed and new plans are being developed. Construction by China and Russia is currently dominant in the global market. Western companies are urged to apply the lessons learned from current projects.

3. Critical mineral issues in energy and economic security
- ✓ The supply and demand for critical minerals such as lithium may become tight as the introduction of electric vehicles, renewable energy and storage batteries increases. A multifaceted response is required to develop new mines, strengthen resource diplomacy, promote recycling, and develop technologies for non-use and reduced usage to ensure a stable supply. In addition, the supply and processing of critical minerals is highly dependent on specific countries, and diversification of the supply chain is also a challenge.

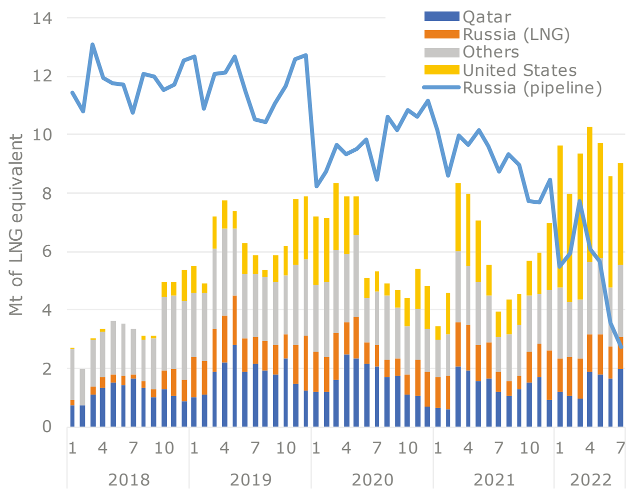
4. Economic impact of green investment
- ✓ In the real world, "green growth" may not be realised depending on the availability of funds and differences in industrial structures. How to limit negative economic impacts and how to even out the different impacts between economies and industries is important.

Structure of this report

1.1 The challenges of response strategies toward ending dependence on Russian natural gas

- The European Union's policy of ending dependence on Russia is different from Japan's.
  - ✓ EU countries were highly dependent on Russian natural gas, but Japan's introduction of Russian LNG was more about source diversification.
- The EU is set to end its dependence on Russia by 2027, but it must ensure stable supplies until the time.
  - ✓ In the short term, they are exposed to Russia's threat amid uncertainty about securing alternative supplies.
  - ✓ This has led to a tightening of the global LNG market.
- For Japan, it is desirable to continue to secure Sakhalin 2 LNG both in terms of equity participation and supply.
  - ✓ Meanwhile, urgently needed to prepare for unexpected loss of equity participation and supply.

LNG and Russian Pipeline Gas Supplies to EU and UK



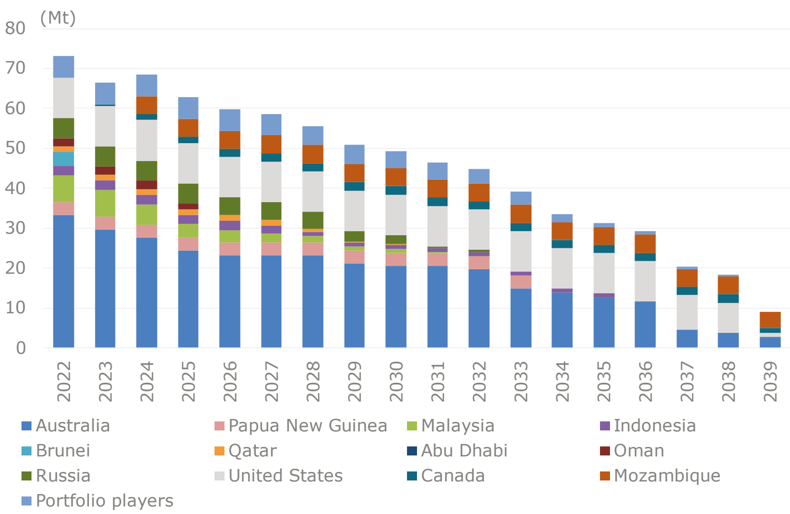
Source: Compiled from Cedigaz LNG Services, Eurostat, British trade statistics, and Gazprom

1.1 The challenges of response strategies toward ending dependence on Russian natural gas

[Measures for Japan]

- Until 2025, Japan is expected to secure supplies from other projects and portfolio players.
- From 2026 onward, it is vital to secure long-term LNG contracts from other sources including new projects, and to ensure investment to support these new projects.
- New development projects in Russia will recede. The path to restoring Russia's future credibility as an investment destination and source of import is even more distant.
- As a way of laying the groundwork for the future, clear message should be advocated that both investment and procurement from the project are legitimate rights under the contract and there is no reason to be threatened by unilateral Russian notification.

Prospect of existing LNG term contracts by Japanese companies



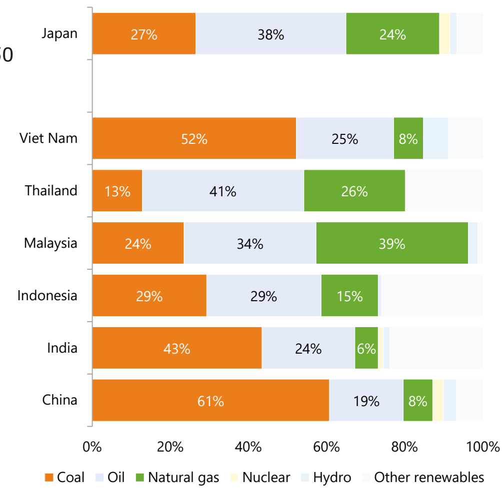
Source: Estimates based on various sources

1.2 The role and challenges of natural gas in Asia’s energy transition and energy security

- A growing number of Asian countries have also declared themselves carbon neutral (CN), but the roadmap to achieve this is unclear.

  e.g., China by 2060, India by 2070, Indonesia by 2060, Viet Nam by 2050
- The energy supply and demand structure of Asian countries is highly carbon intensive, and to realise CN, they need to re-structure energy system in the limited time frame of the next three or four decades.
- In addition, developing countries have unique challenges.
  - ✓ Energy demand will inevitably continue increasing in the future, necessitating a stable supply of large amounts of energy.
  - ✓ Cheap energy supplies are essential in light of protecting low-income people as well as industrial development,.
- Challenges exist in Asia’s energy transition.
  - Renewable energy lacks strength to supply the fast growing energy demand.
  - Some countries have limited renewable energy availability.
  - There is a strong demand for energy affordability, and the cost of integrating variable renewable energy will become an issue.

Energy mix of major Asian countries



Source: Compiled from IEA “World Energy Balance 2022”

1.2 The role and challenges of natural gas in Asia’s energy transition and energy security

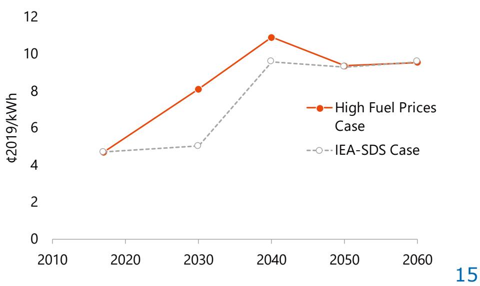
- A two-stage decarbonisation scenario that takes advantage of natural gas (*) could be a realistic solution for Asia, which faces the challenge of energy transition (see previous page). But there are challenges.

  * Can stably supply large amount of energy (high energy density). Can lower GHG emission by switching from coal.

Asian decarbonisation taking advantage of natural gas	Challenges of natural gas
Stage 1: Satisfy energy needs and achieve low carbonisation by switching from coal to natural gas Stage 2: Decarbonisation by commercialising various technologies under development (hydrogen, CCUS) as well as avoiding making natural gas asset stranded.	• The economics of natural gas has declined due to soaring prices. • There is concern that the role of natural gas will diminish as investments in other decarbonised energy increase if the price remains extremely high for an extended period of time.

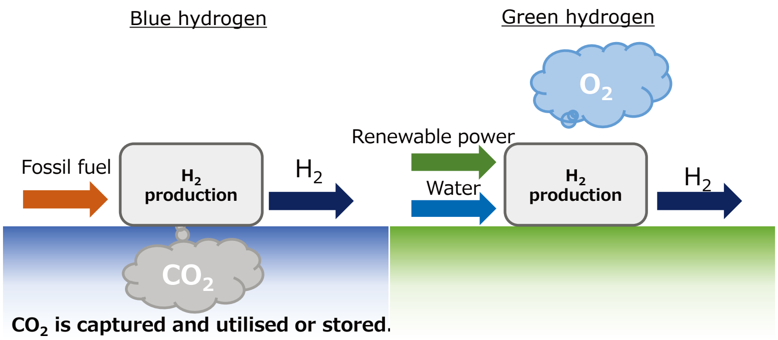
- Asia’s energy transition/security will be more costly (right figure) and could weaken Asia’s relative economic power against other region if constraints on natural gas investment trigger its high price.
- The promotion of natural gas and LNG investment will not only help to stabilise the markets, but will also contribute to curbing the cost of energy transition/security in Asia and averting negative impacts on the regional economy.
- Therefore, it is necessary to develop an environment for appropriate use of natural gas.
  - Clarify its role as a transition energy
  - Promotion of natural gas-related investment
  - Supporting technology to decarbonise natural gas (CCS, CCUS, hydrogen)

The impact of fossil fuel prices on the marginal cost of electricity in ASEAN



1.3 Importance of stabilising markets to decarbonise fossil fuels (natural gas)

- Blue hydrogen and ammonia play a central role in the decarbonisation of fossil fuels.
  - Blue hydrogen/ammonia is also expected to play a role in shaping the market in the early stages of hydrogen/ammonia introduction (Green hydrogen/ammonia is more difficult to implement early in terms of both quantity and price).
  - The natural gas market needs to be stabilised in order to ensure the introduction of blue hydrogen/ammonia because blue hydrogen/ammonia cannot be competitive to materialise the scenario when natural gas price is high.

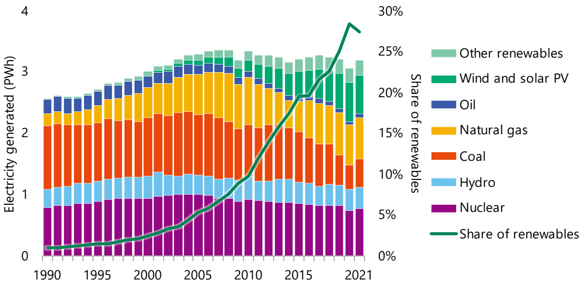


Structure of this report

2.1 The challenges of stable electricity supply under market deregulation, mass introduction of REs and soaring fuel prices

- In advanced economies, the power generation mix has changed significantly throughout the 2010s due to delegulation of electricity market, the promotion of decarbonisation policies, the expansion of renewable power generation, and low primary energy prices through 2020, resulting in a downward trend in conventional power generation capacities. Overall, there is less reserve capacity and greater vulnerability to shocks.
- Electricity supply and demand becomes more vulnerable against external shocks such like heat waves, cold waves, earthquakes, and prolonged bad wind conditions. Examples include tight supply due to summer heat wave at the California ISO from 2020 to 2022, rolling blackout due to cold wave at ERCOT, Texas in February 2021, and tight supply in Tokyo area due to outage of power station due to earthquake combined with cold/heat wave in March/June 2022.
- In advanced economies, increasing number of country/region are introducing capacity markets, which are a mechanism to pay for the availability of supply capacity, to secure investment for new capacities as well as to ensure operation of existing capacities. But even in these countries, there have been cases in which they are fail to secure sufficient supply capacity at a time when demand actually increases.
- Withdrawal of power station for economic reasons is difficult to predict, making long-term reliability assessment difficult thereby investment in new power generation difficult. The United Kingdom is attempting to introduce technologies that can both decarbonise and provide a stable supply through a support mechanism that takes into account the characteristics of each next-generation technology. It is likely that similar policies will prevail among countries and regions.

Electricity generated by source in EU 28



Source: Compiled from IEA "World Energy Balance 2022"

2.1 The challenges of stable electricity supply under market deregulation, mass introduction of REs and soaring fuel prices

- In Europe, where many countries are abolishing coal-fired power generation as a policy in their efforts to decarbonise, wind power generation has become low in output since around the autumn of 2021, and wholesale electricity spot prices have soared due to rising natural gas prices. This, combined with war in Ukraine, has led to a protracted crisis. In addition, during the summer of 2022, a combination of heat waves caused power station to shut down and output to fall, further tightening the reserve capacity. A shortage of natural gas supplies from Russia heading into winter could lead to electricity shortages.
- In China and India, where the share of coal-fired power generation is high, planned power outage due to coal shortages also occurred in 2021 and 2022. In January 2021, wholesale electricity spot prices soared in Japan due to LNG shortages. These are all issues of "kWh shortage" associated with fuel constraints. The conventional kW shortage still needs to be addressed, but in addition, the kWh shortage also needs to be addressed.
- Until now, the adequacy of supply capacity (the possibility of a kW shortage) has been an indicator to assess supply stability. However, on the other hand, quantitative assessment of risk of a kWh shortage, including the risks in the fuel supply countries, is difficult. Quantitative assessment of the kWh shortage risk would be a major issue for future policy response.

2.2 Trends to promote nuclear power under the new reality and future challenges

- Nuclear power generation is promising as a zero-emission baseload power source. In addition, nuclear could play a role by taking advantage of its characteristics as the demand for energy security intensifies.
- In the case of the United Kingdom and France, to reach ambitious policy goal, bold measures are taken that diverge in part from the market deregulation policy. These policy examples may have important implications for Japan.

Examples in United Kingdom

Adhering to the necessity of nuclear
- The Government announced the Energy Security Strategy in early April 2022. The strategy includes an ambitious target for nuclear to cover 25% of electricity supply by installing up to 24 GW by 2050.
  - ✓ Nuclear, which is capable of stable power generation, is considered to have attracted renewed attention because the country is necessary to prepare for the situation in which the output of wind power, which is increasing every year, is not as expected, and it is also necessary to break away from dependence on fossil fuels, including natural gas, in the future.

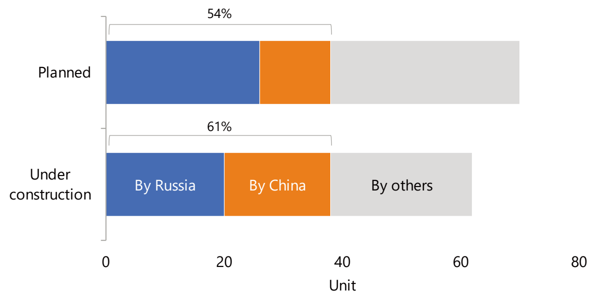
Supporting measures
- A review of the support mechanism (so called RAB model) is under consideration to promote the investment for new reactors.
  - ✓ The current mechanism (Contract for Difference, CfD) is designed to support only when power station start operation, and it does not sufficiently contain the uncertainty of nuclear project, which requires large investments and long construction period before generate a profit.

Examples in France

Strategies based on a long-term perspective
- In February 2022 (before the Russian invasion of Ukraine), President Emmanuel Macron said at least six of the next generation of the European pressurised water reactors (EPR 2) would be built and eight more would be considered.
  - ✓ This strategy is sought to be based on the results of an analysis published in October 2021 by transmission system operator RTE.
  - ✓ Scenario analysis of the long-term power mix. The study resulted to identify that achieving carbon neutrality without new nuclear power capacity is unrealistic, and that the total cost of the electricity system, including integration costs, is cheaper in a scenario where assumes the addition of nuclear capacity.
- Planning and implementation based on the long-term perspective is ideal since decision-making and construction of nuclear power takes a long time.

Strengthening the state-led implementation system
- In July 2022, Prime Minister Élisabeth Borne announced a plan to fully nationalise power giant Électricité de France (EDF) in order to make a strong push for decarbonisation.

- China and Russia dominate the world nuclear market (figure), although there is a trend away from dependence on Russia.
  - Finland cancelled its contract to build the Hanhikivi 1
  - Ukraine plans to install nine Westinghouse-built light water reactors.
  - Poland has established partnerships with U.S. and French companies.
  - On the other hand, construction of Russian nuclear reactors is underway in China, India, Turkey, Bangladesh, Hungary, Egypt and other countries.
- Delays and cost overruns have been seen in new development of Western countries in recent decades due to a sharp decline in the number of new projects and the loss of construction know-how.
  - Growing emphasis on energy security alone cannot ensure Western companies to seize business. The key is whether they can take advantage of the lessons learned from current projects.



World's under construction and planned nuclear reactors (As of 1 January 2022)

Source: Compiled from "World Nuclear Power Plants" (2022 edition) of Nuclear Power in the World, published by the Japan Atomic Industrial Forum.

Structure of this report

Analysis framework

- Analysed supply and demand balance of critical minerals.
  ➔ Comparing supply and demand, and comparing cumulative demand and resource reserves + recycled supply as time series (up to 2050)

Subjected technologies and minerals

- Carbon neutral (CN) technologies: renewable energy, stationary storage batteries, electric vehicles, fuel cell vehicles, water electrolysis, etc. (decreases in mineral demand due to abolish of conventional technologies are also considered. Demand for non-carbon neutral technologies also considered)
- Critical minerals: Copper, lithium, nickel, cobalt, graphite, silicon, dysprosium, neodymium, platinum, palladium, rhodium, and vanadium

Methodology

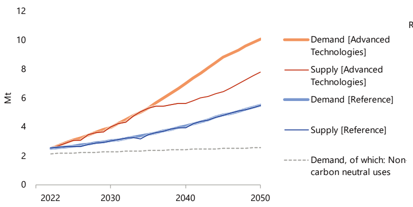
- Demand = Amount of CN technology installed × Mineral resource intensity of technology
  − Conventional technology to be replaced × Mineral resource intensity of technology.
- Supply = Mine production + Recycling supply.
  Production from mine = *f*(mine development stage, production capacity),
  Recycled amount = Waste amount × Product recovery rate × Recycling rate.

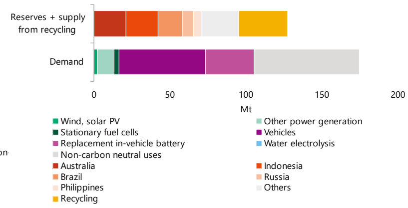
Analysis: example of Nickel and Lithium

	Supply-demand outlook	Comparison of cumulative demand and reserves (+ recycled supply)

Nickel (Ni) (used in lithium-ion batteries)

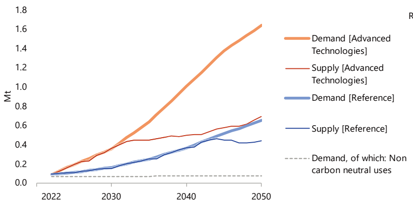
- In the Advanced Technologies Scenario (ATS) in which the electrification of the automobile advances greatly, the demand will increase more than 3 times from current levels by 2050.
- In ATS, demand will exceed supply (mine production + recycling) around 2035.
- Cumulative demand in ATS through 2050 will exceed reserves (+ recycled supply).

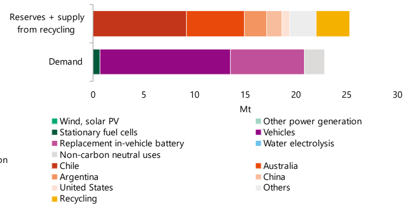




Lithium (Li)

- Demand will grow significantly mainly with the increase in electric vehicles. In ATS, it will increase by more than 10 times from current levels by 2050.
- In ATS, demand will exceed supply (mine production + recycling) around 2030.
- Cumulative demand in ATS through 2050 will be slightly below reserves (+ recycled supply).





Uneven distribution of critical minerals

- Reserves of many critical minerals are unevenly distributed around the globe.
- However, geographical distribution of reserves and downstream processes is often different. For example, Indonesia has the largest share of nickel production, while China has the largest share of primary nickel production after refining.

Country-wise share of reserves

	Cu (copper)	Co (cobalt)	Ni (nickel)	Li (lithium)	V (vanadium)	PGM (platinum group)	REO (rare earth)
United States	5%	1%	0%	3%	0%	1%	2%
Canada	1%	3%	2%	0%	0%	0%	1%
Mexico	6%	0%	0%	0%	0%	0%	0%
Brazil	0%	0%	17%	0%	1%	0%	18%
Peru	9%	0%	0%	0%	0%	0%	0%
Chile	23%	0%	0%	42%	0%	0%	0%
Argentina	0%	0%	0%	10%	0%	0%	0%
Cuba	0%	7%	0%	0%	0%	0%	0%
Australia	11%	18%	22%	26%	25%	0%	3%
Indonesia	3%	8%	22%	0%	0%	0%	0%
Philippines	0%	3%	5%	0%	0%	0%	0%
Viet Nam	0%	0%	0%	0%	0%	0%	18%
China	3%	1%	3%	7%	40%	0%	37%
Kazakhstan	2%	0%	0%	0%	0%	0%	0%
Russia	1%	3%	8%	0%	21%	6%	18%
Zimbabwe	0%	0%	0%	1%	0%	2%	0%
DR Congo	4%	46%	0%	0%	0%	0%	0%
South Africa	0%	0%	0%	0%	15%	90%	1%
Others	33%	9%	21%	11%	0%	0%	4%

Note: Compiled from USGS Mineral Commodity Summaries 2022

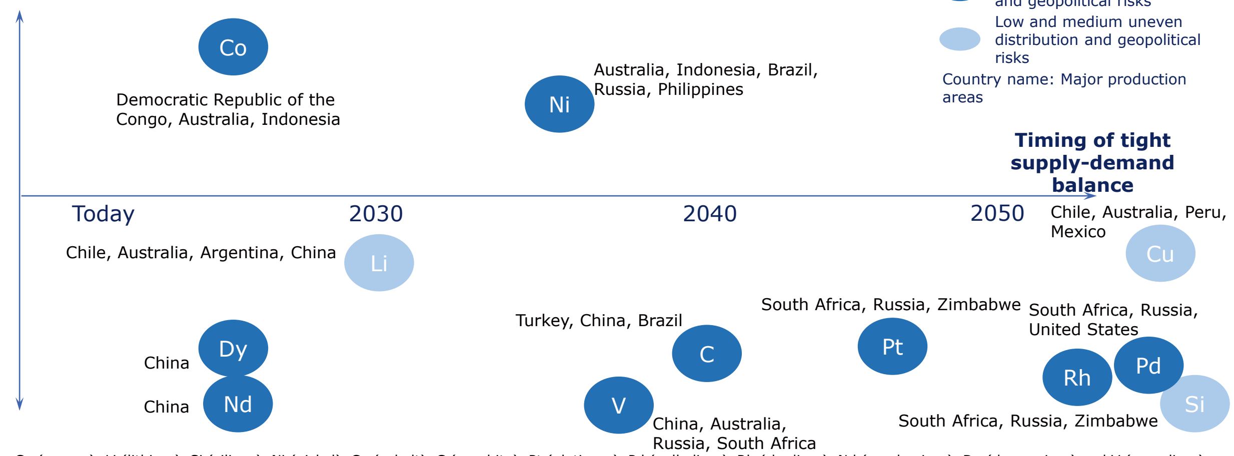
Country-wise production share of ore and primary nickel (2019)

	Ore production	**Primary nickel production**
Americas	11%	12%
Europe	2%	17%
Japan	0%	8%
China	4%	34%
Indonesia	35%	16%
Philippines	13%	0%
Other Asia	8%	3%
Oceania	6%	8%
Russia	9%	0%
Africa	2%	3%
Others	10%	0%

Supply and demand balance (Advanced Technologies Scenario)

- Reserves + recycling < Cumulative demand (until 2050): Nickel and cobalt
- Early supply shortage concerns: lithium, cobalt, neodymium and dysprosium
- Uneven distribution and geopolitical risks: nickel, cobalt, graphite, platinum-group metals, neodymium, dysprosium and vanadium

Cumulative demand through 2050 − (reserves + recycled supply)



Note: Cu (copper), Li (lithium), Si (silicon), Ni (nickel), Co (cobalt), C (graphite), Pt (platinum), Pd (palladium), Rh (rhodium), Nd (neodymium), Dy (dysprosium) and V (vanadium)

Reference: Major uses of critical minerals

Ore	Major uses
Cu (copper)	Wind power generation, solar photovoltaics power generation, electric vehicles, batteries. However, it is often used outside of CN technology.
Li (lithium)	Lithium-ion battery
Si (silicon)	Solar PV. However, it is often used outside of CN technology.
Ni (nickel)	Lithium-ion batteries. However, stainless steel and heat-resistant steel are the main applications.
Co (cobalt)	Lithium-ion batteries, special steel
C (graphite)	Lithium-ion batteries, metal crucibles, molds, electric furnace electrodes, etc.
Pt (platinum)	Exhaust gas catalysts for automobiles, electrocatalysts for fuel cells and water electrolysers
Pd (palladium)	Exhaust gas catalysts for automobiles, electrocatalysts for fuel cells and water electrolysers
Rh (rhodium)	Exhaust gas catalysts for automobiles
Nd (neodymium)	Electric vehicle motors, magnets in wind power generators
Dy (dysprosium)	Electric vehicle motors, magnets in wind power generators
V (vanadium)	Electrolyte for redox flow batteries. Other than CN technology, additives to steel are main.

Response required

- Under the Advanced Technologies Scenario, the cumulative demand for nickel and cobalt by 2050 will exceed the reserves (+ recycled supply). Also, demand for lithium, cobalt, neodymium and dysprosium will exceed supply by around 2030.
- With respect to these critical minerals, it is necessary to develop technologies that contribute to increasing the recycling rate, in conjunction with increasing production at existing mines and developing new mines.
- In order to secure critical minerals, it is necessary to develop recycling, non-use and reduced usage technologies, as well as acquisition or rights and long-term purchase contracts. Diversification of critical minerals is also important.
- Currently, the supply of critical minerals is an oligopoly of several countries. The introduction of new regulations and tax regime on resource development and exports in producing countries may cause supply constraints for demand countries. Therefore, it is necessary to pay close attention to the policy trends of producing countries. Diversification of the supply chain is also an issue to be addressed, since processing such as refining is concentrated in specific countries such as China.
- There are uncertainties in policies of resource producing country, prospects for developing technologies for recycling, non-use and reduced usage. Therefore, it is important to balance technology choices from the perspective of energy and economic security and the sustainability of critical minerals.

Structure of this report

Background of the analysis

Last year, IEEJ Outlook 2022 raised issues that should be considered during the course towards carbon neutrality.

- "Green growth" is expected, in which investments in climate action will form a virtuous cycle of emissions reductions and economic growth, but the effects may vary by economy and actor.

- That can create new gaps: (1) disparities among advanced economies and among developing economies, (2) disparities between advanced and developing economies, (3) disparities between economies that depend on fossil fuel exports and those that do not, and (4) disparities among citizens.

In this background, "IEEJ Outlook 2023" provides a quantitative assessment of how climate change investment (green investment) impacts countries or regions, and what disparities may arise.

Analytical method

- Quantitative assessment of the impact of green investment* on national economies

* Regard difference of investment in the Advanced Technologies Scenario to the Reference Scenario.

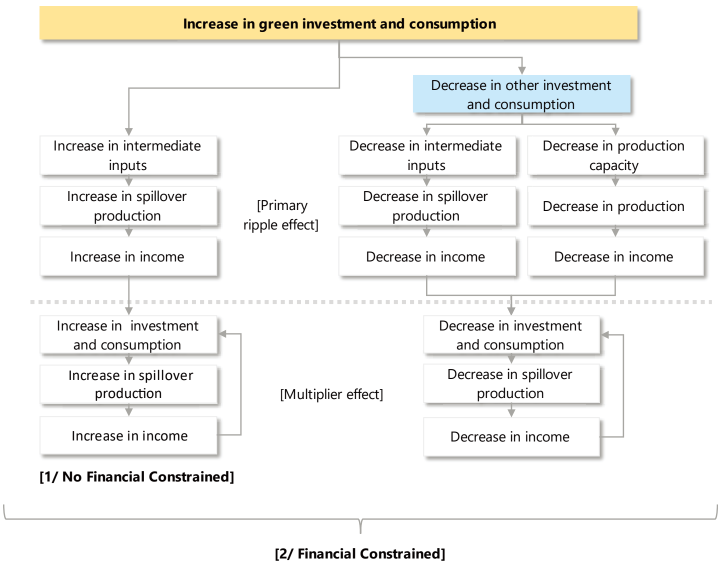
«Case settings»

1/ No Financial Constrained Case

Additional green investment will have a positive spillover effect as well as multiplier effect through 1) an increased demand ➔ 2) Increased income ➔ 3) increased consumption
(This case represent common concept of green growth)

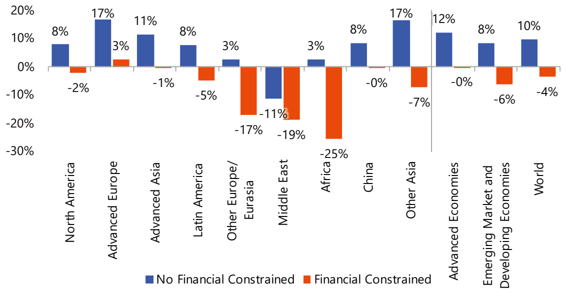
2/ Financial Constrained Case

Since funds have a constrain, the amount spent on green investments reduces other investments. Furthermore, since green investment itself is not an investment to expand production capacity, it is also considered that production and income will decrease through a decrease in production capacity due to a decrease in other investments.

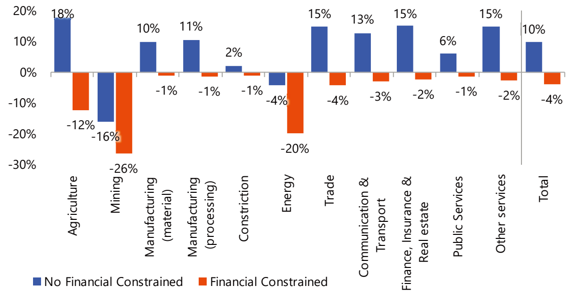


Green growth is unlikely when there are constraints in funds

Changes in production in 2050
(By region. Compared to Reference Scenario)



Changes in production in 2050
(By industry. Compared to Reference Scenario)



- Without financial constraints, global production would increase by 9.8%, while with constraints it would decrease by 3.7%.
- Regardless of financial constraints, the production value will decline in economies such as the Middle East, which is highly dependent on mining (fossil fuels).
- Advanced economies are more likely to enjoy green growth, while developing countries are not.

- Regardless of financial constraints, the production value of mining and energy supply related to fossil fuel will decrease.
- GDP accelerates by an average of 0.4% a year without financial constraints and decelerates by 0.1% with constraints
  (IEA analysed acceleration of 0.4% in the 2020s in their Net Zero Emissions by 2050 Scenario *).

* IEA (2021), Net Zero by 2050 - A Roadmap for the Global Energy Sector

Conclusion

- Although "green growth" is expected in green investment, many economies are unable to enjoy it if there are financial constraints.
- Regardless of financial constraints, advanced economies are more likely to enjoy green growth, whereas emerging and developing economies are not. In the real world, there are advanced economies with money to spare and developing economies without money to spare, and the economic gap between the two can become wider.
- In order to raise funds smoothly, it is necessary to utilise green finance, which mainly consists of private funds, as well as government budgets. It is important to clarify the direction of environmental policy in order to limit risks and encourage investment.
- Regardless of financial constraint, economies highly dependent on fossil fuel exports are negatively affected. It is necessary to break away from dependence on the fossil fuel industry, and re-education (reskilling) of workers will be important for smooth labour movement from declining industries to other industries.
- In a world striving for a low-carbon society, new disparities between economies or industries may arise. It is important to limit negative economic impacts and to even out the different impacts among economies and industries. If the availability of funds lead to greater inequality, it is also necessary for advanced economies to provide financial support to emerging and developing economies that cannot afford it.

Thank you for your attention.

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Reference materials

Geographical coverage

Countries/regions in the world are geographically aggregated into 42 regions.
Especially the Asian energy supply/demand structure is considered in detail, aggregating the area into 15 regions. That of the Middle East is also aggregated into 8 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.

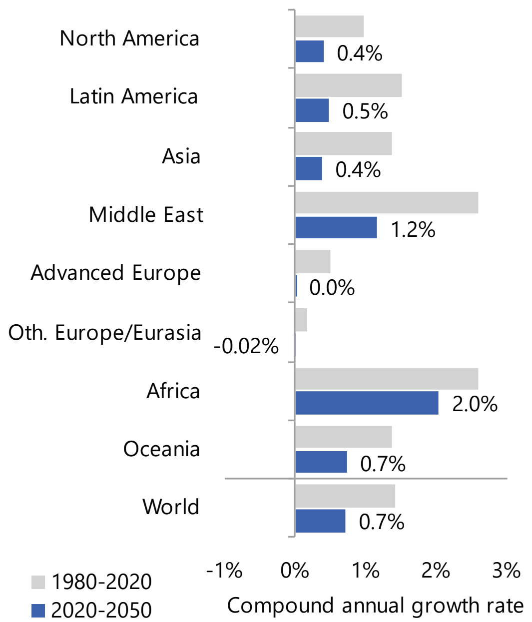
Basic scenarios in IEEJ Outlook

	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
Energy and environmental policies	Gradual reinforcement of low-carbon policies with past pace	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

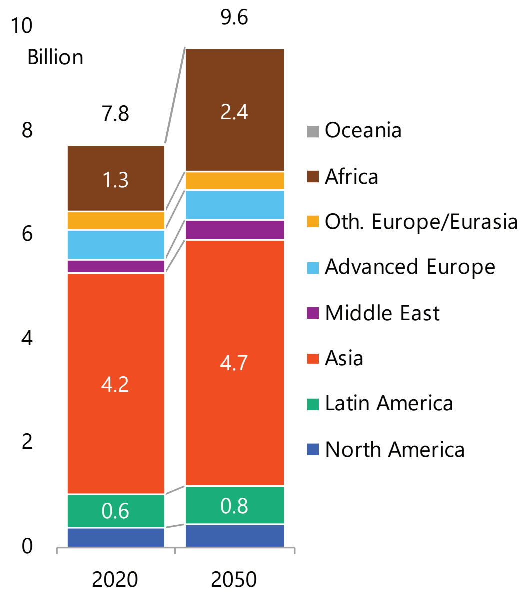
Assumptions

Population

CAGR



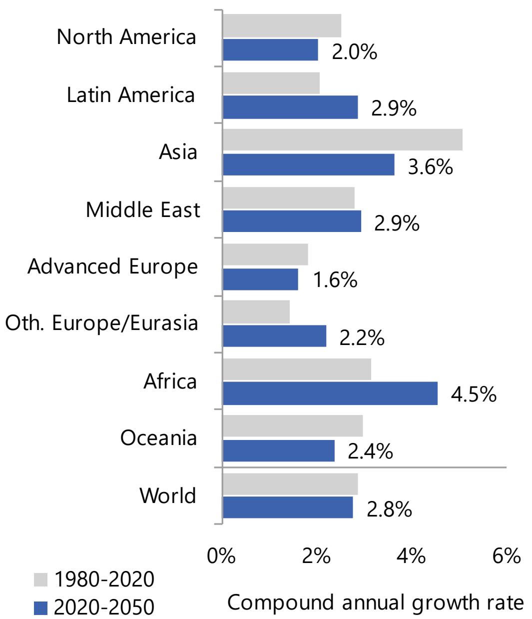
Composition



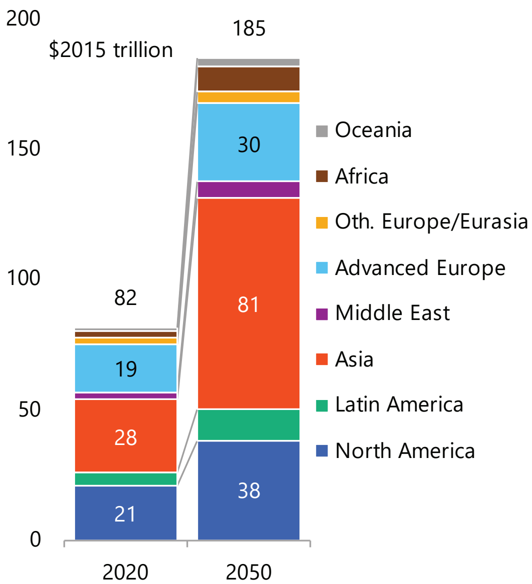
Assumptions

Real GDP

CAGR



Composition

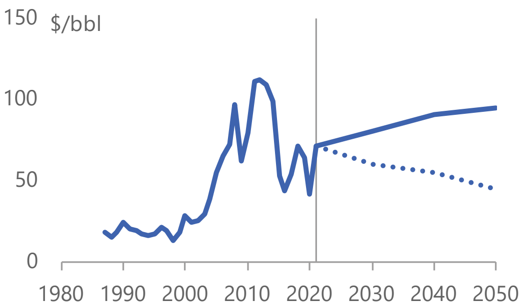


Assumptions

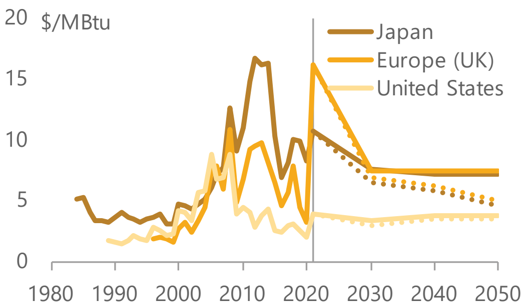
International energy prices

Reference : ——
Advanced Technologies : ·········

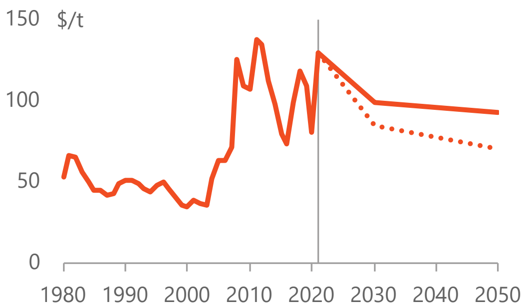
Crude oil



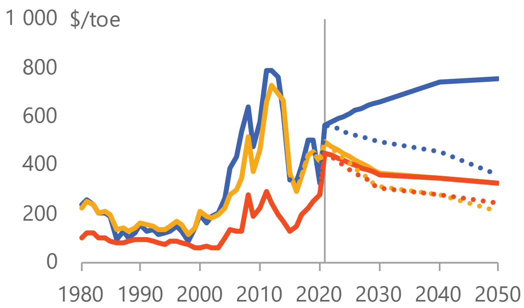
Natural gas



Coal



CIF import prices for Japan



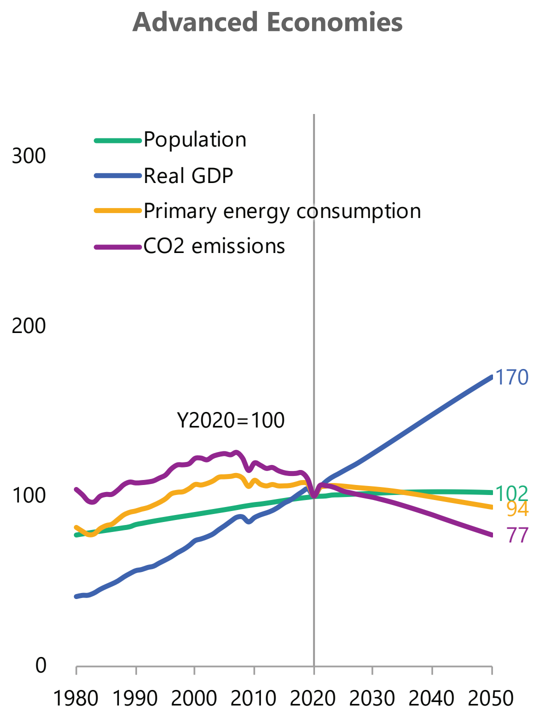
Note: Historical prices are nominal. Assumed future prices as real in $2021.

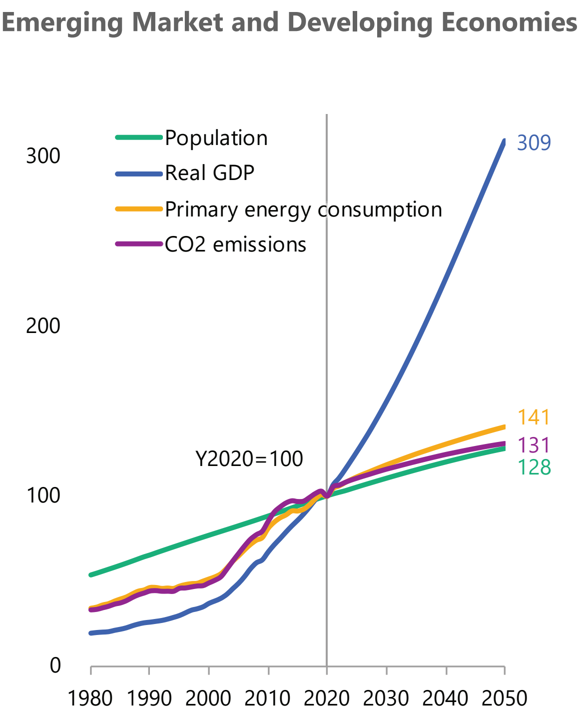
Assumptions

Energy and environmental technology

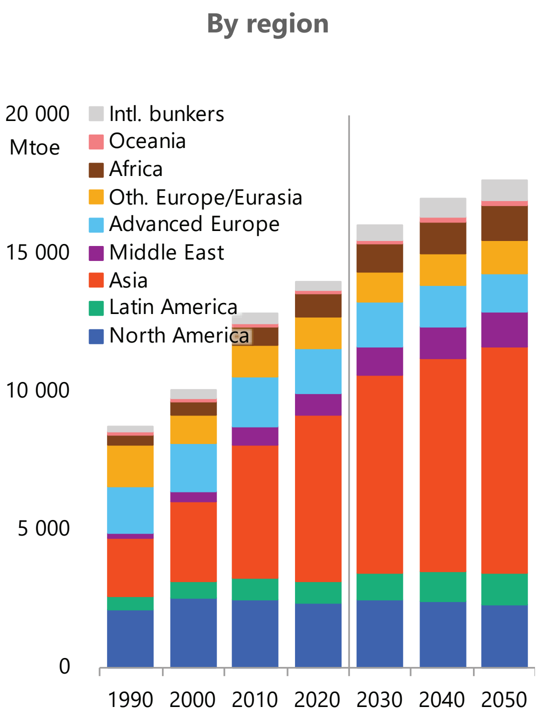
		2020	2050 Reference	2050 Advanced Technologies	Assumptions for Advanced Technologies Scenario
Improving energy efficiency					
Industry	Intensity in steel industry (ktoe/kt)	0.266	0.254	0.200	100% penetration of Best Available Technology by 2050.
	Intensity in non-metallic minerals industry	0.089	0.070	0.054	
Transport	Electrified vehicle share in passenger car sales	8%	66%	95%	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)	14.5	26.7	40.2	
Buildings	Residential total efficiency (Y2020=100)	100	161	215	Efficiency improvement at twice the speed for newly installed appliance, equipment and insulation.
	Commercial total efficiency	100	155	189	Electrification in space heating, water heater and cooking (clean cooking in developing regions).
Power	Thermal generation efficiency (Power transmission end)	38%	45%	46%	Financial scheme for initial investment in high-efficient thermal power plant.
Penetrating low-carbon technology					
Biofuels for transport (Mtoe)		91	154	268	Development of next generation biofuel with cost reduction. Relating to agricultural policy in developing regions.
Nuclear power generation capacity (GW)		408	477	767	Appropriate price in wholesale electricity market. Framework for financing initial investment in developing regions.
Wind power generation capacity (GW)		731	2 243	4 460	Further reduction of generation cost. Cost reduction of grid stabilization technology. Efficient operation of power system.
Solar PV power generation capacity		708	3 033	6 013	
Thermal power generation capacity with CCS (GW)		0	0	1 247	Installing CCS after 2030 (regions which have storage potential except for aquifer).
Zero-emission generation ratio (incl. CCS)		38%	44%	84%	Efficient operation of power system including international power grid.

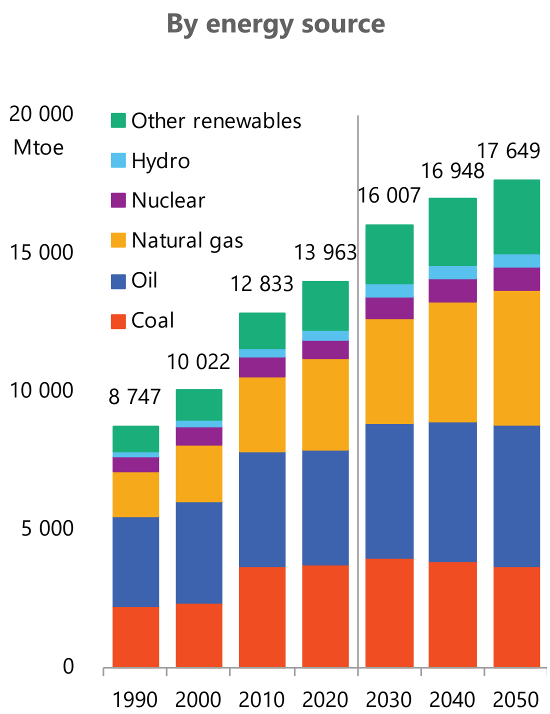
Population, GDP, energy and CO_2





Primary energy consumption

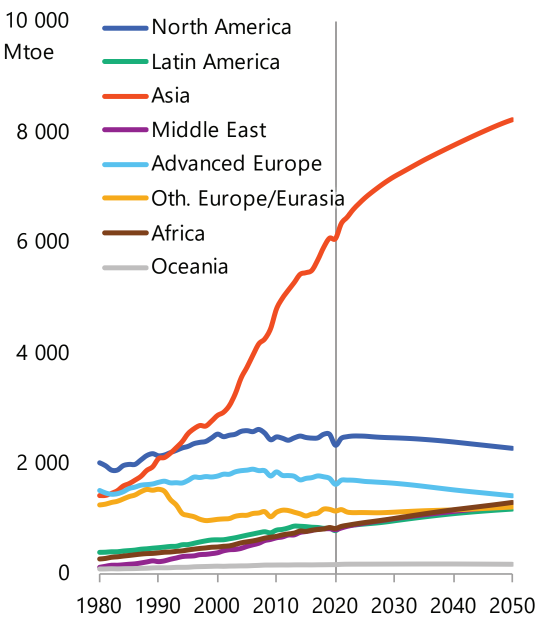




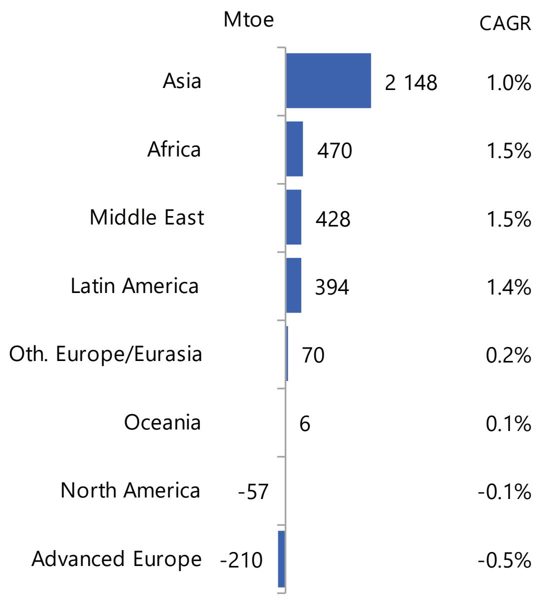
Reference Scenario

Primary energy consumption (by region)

Energy consumption



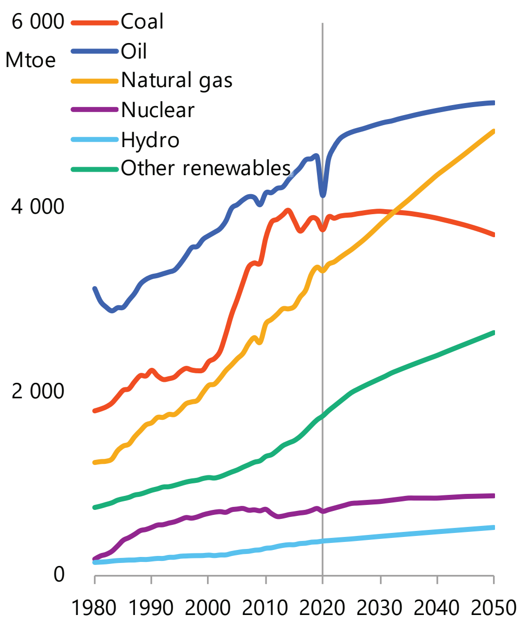
Changes (2020-2050)



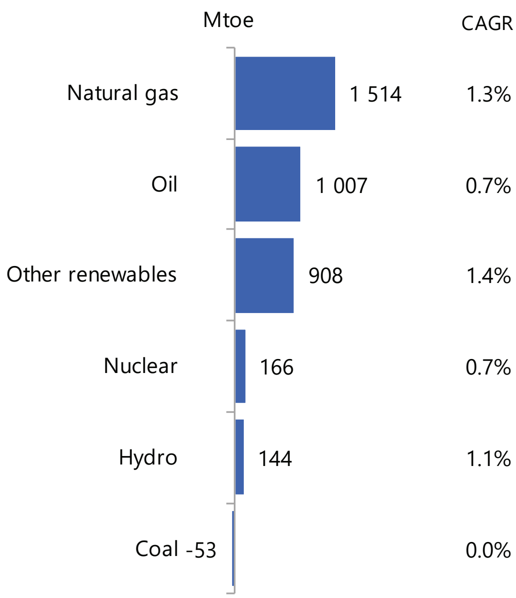
Reference Scenario

Primary energy consumption (by energy source)

Energy consumption



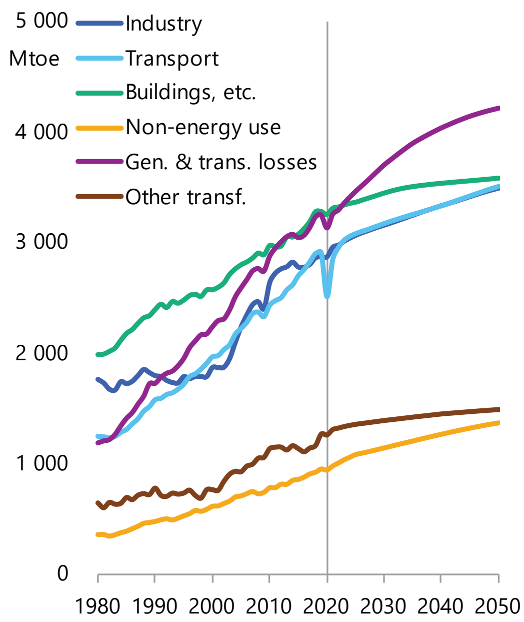
Changes (2020-2050)



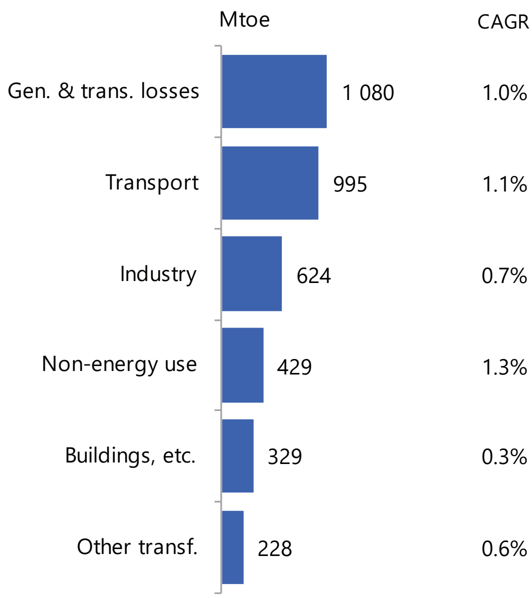
Reference Scenario

Primary energy consumption (by sector)

Energy consumption



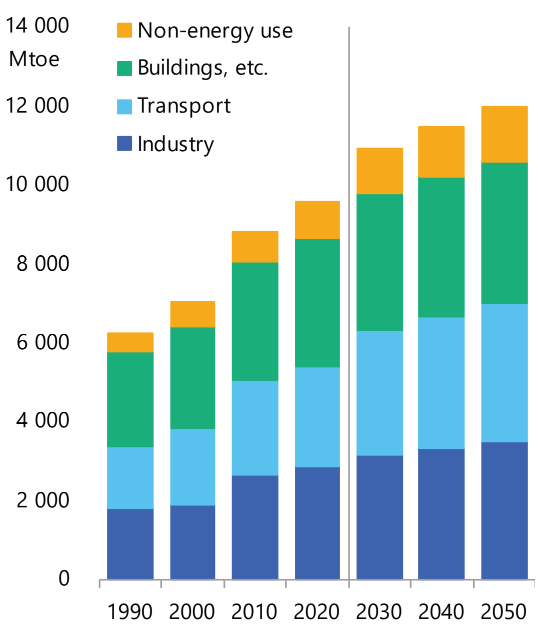
Changes (2020-2050)



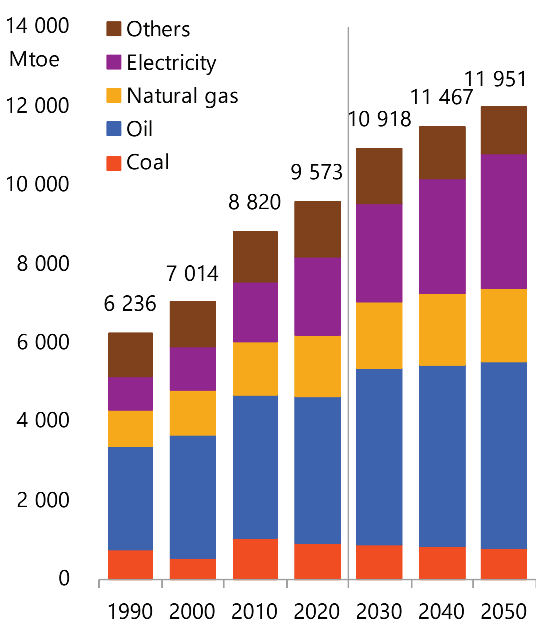
Reference Scenario

Final energy consumption

By sector



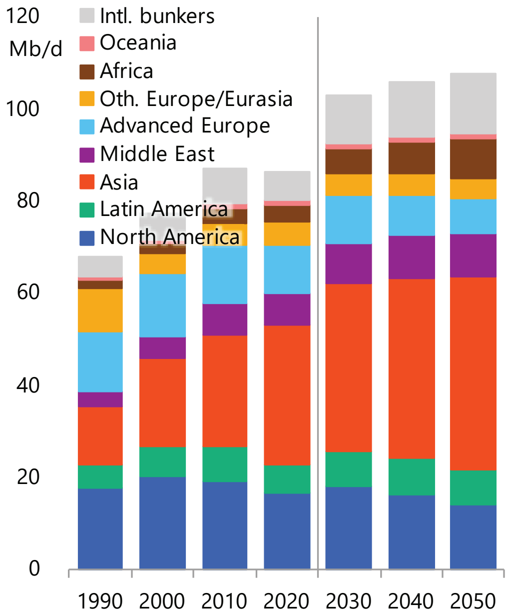
By energy source



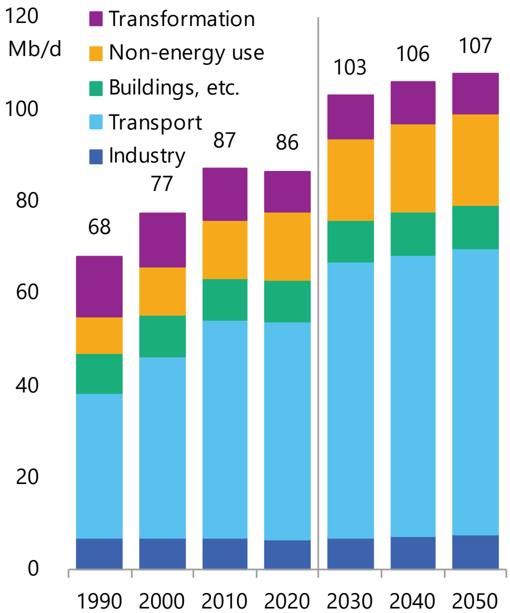
Reference Scenario

Oil consumption

By region



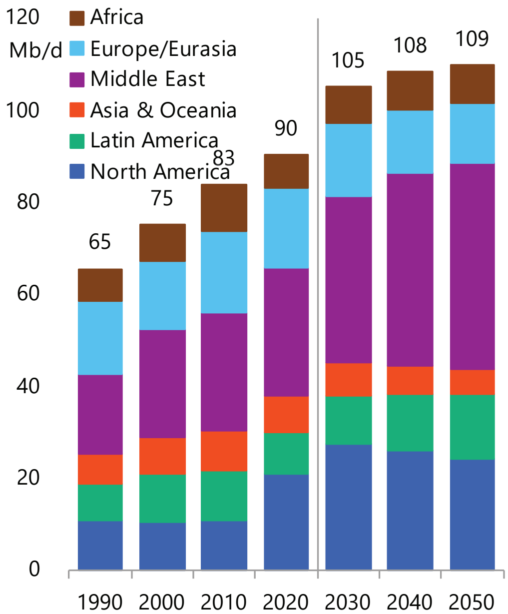
By sector



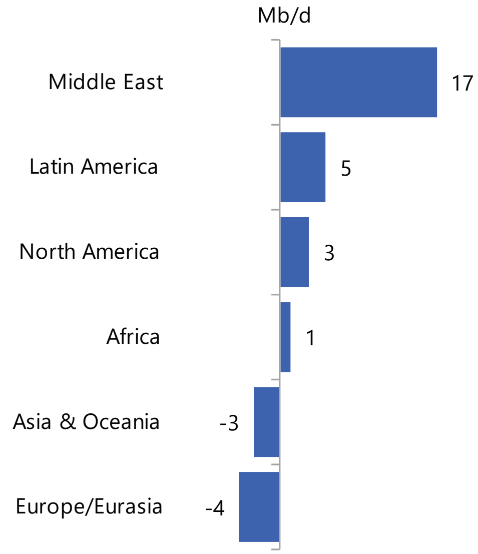
Reference Scenario

Crude oil production

By region

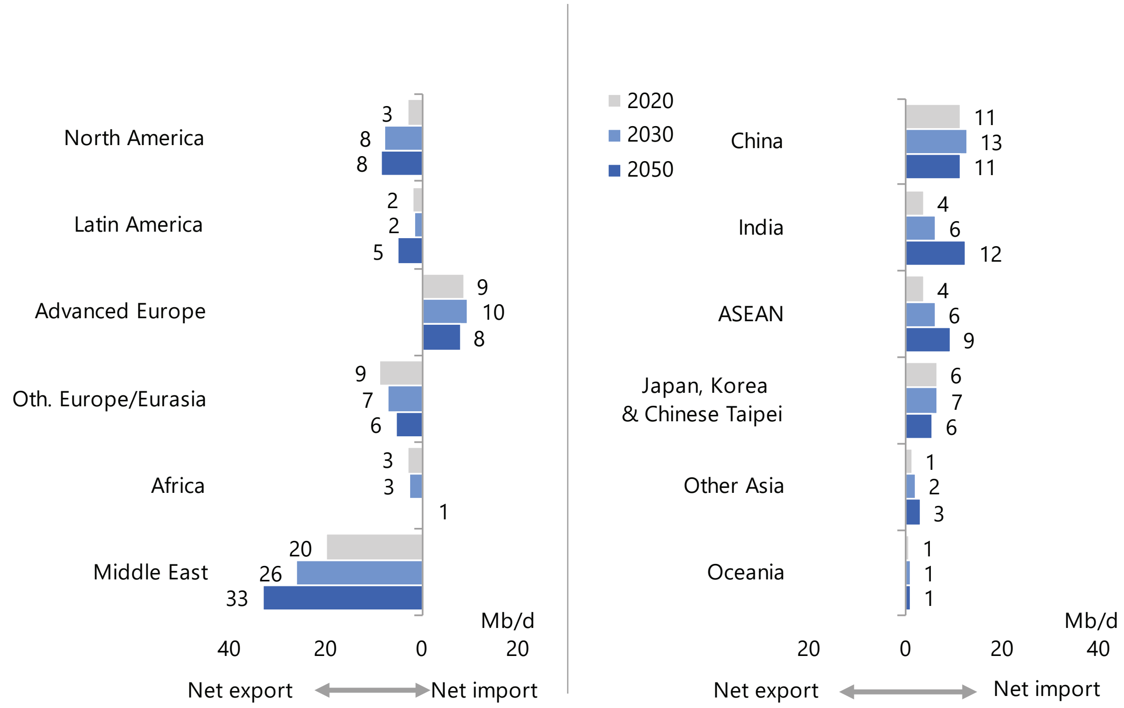


Changes (2020-2050)



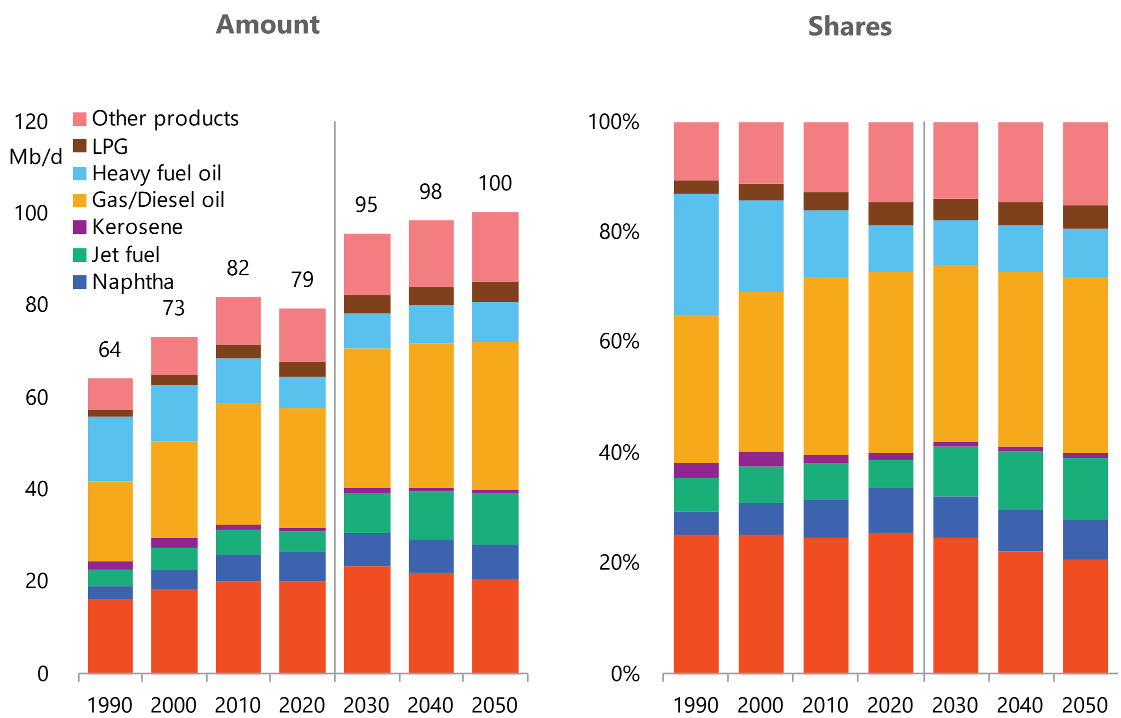
Reference Scenario

Net exports and imports of oil



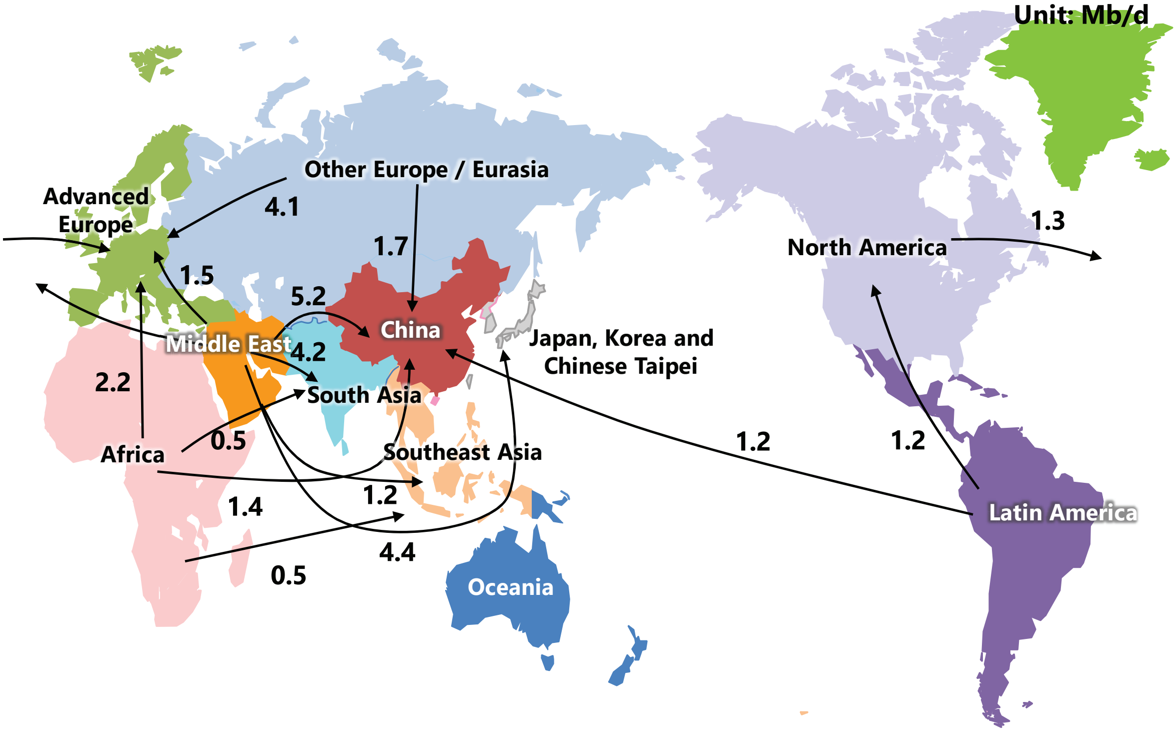
Reference Scenario

Petroleum product consumption



Reference Scenario

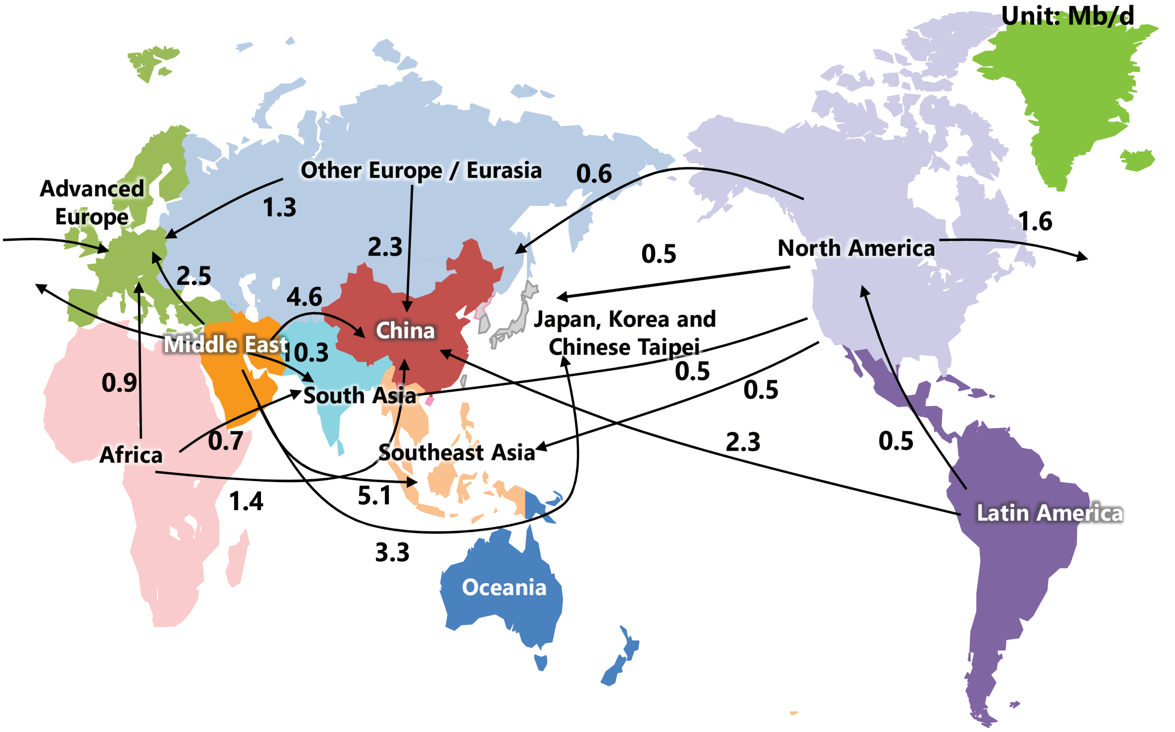
Major trade flows of crude oil (2021)



Note: 0.5 Mb/d or more are shown

Reference Scenario

Major trade flows of crude oil (2050)

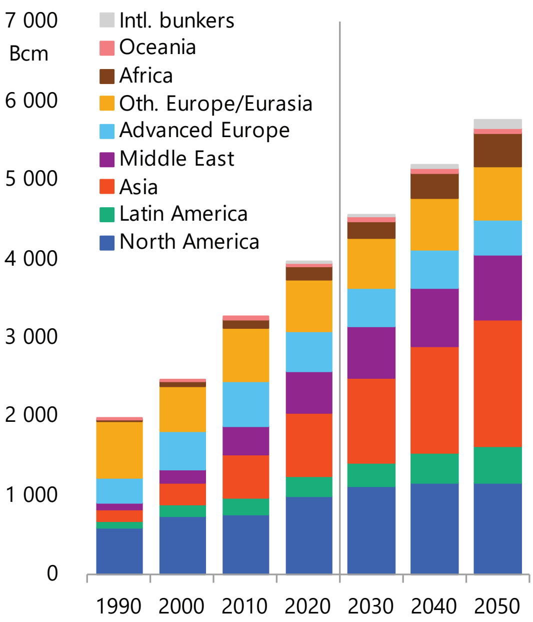


Note: 0.5 Mb/d or more are shown

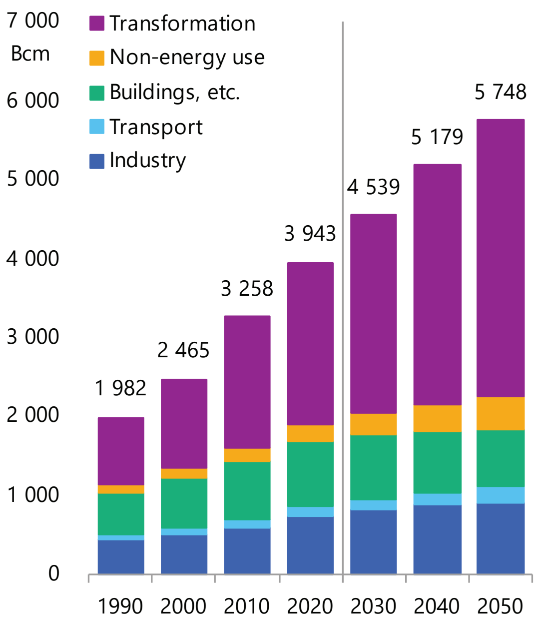
Reference Scenario

Natural gas consumption

By region



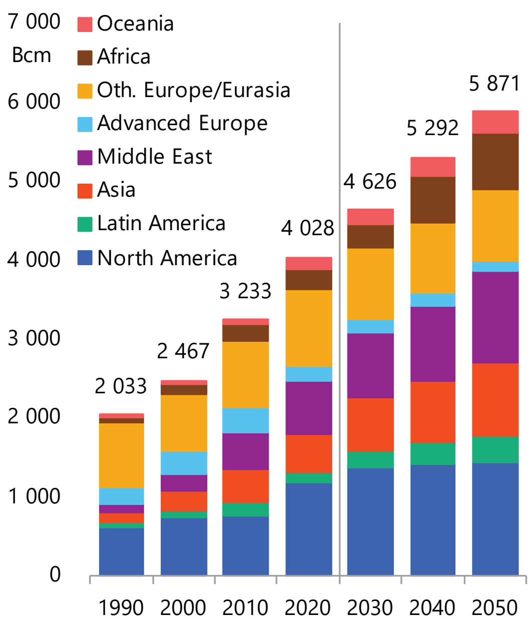
By sector



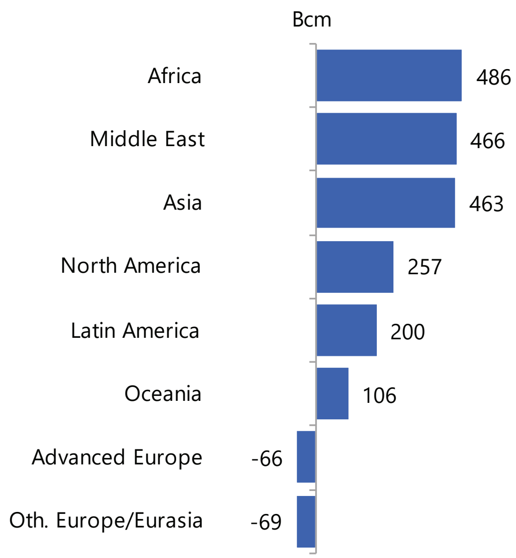
Reference Scenario

Natural gas production

By region

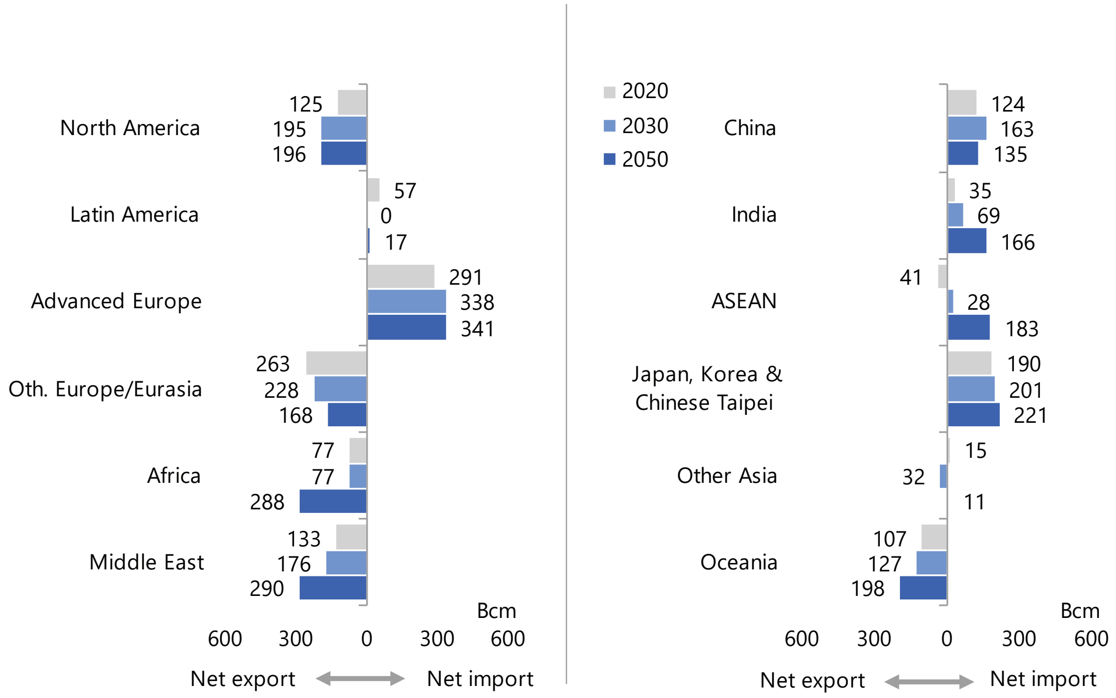


Changes (2020-2050)



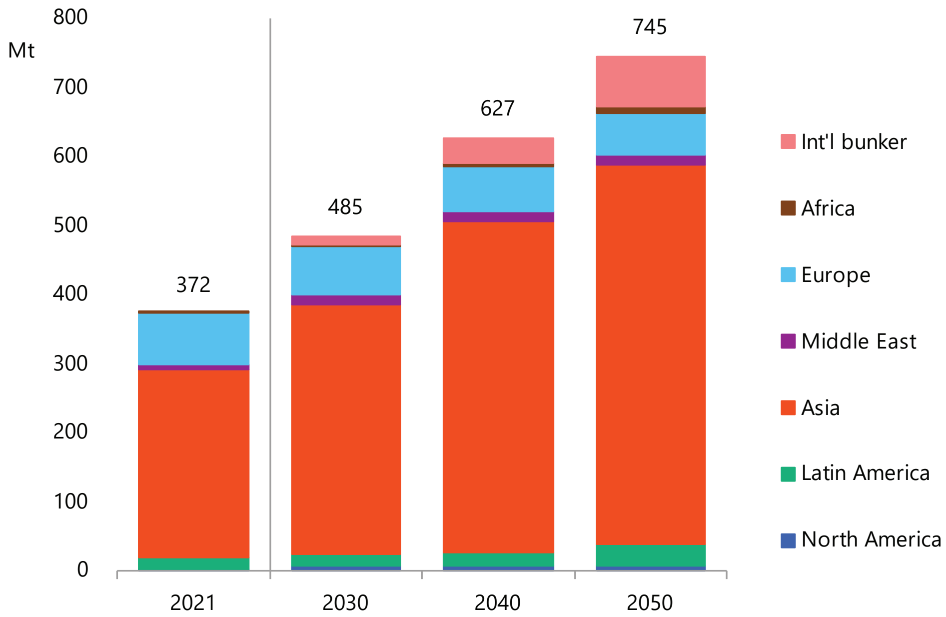
Reference Scenario

Net exports and imports of natural gas



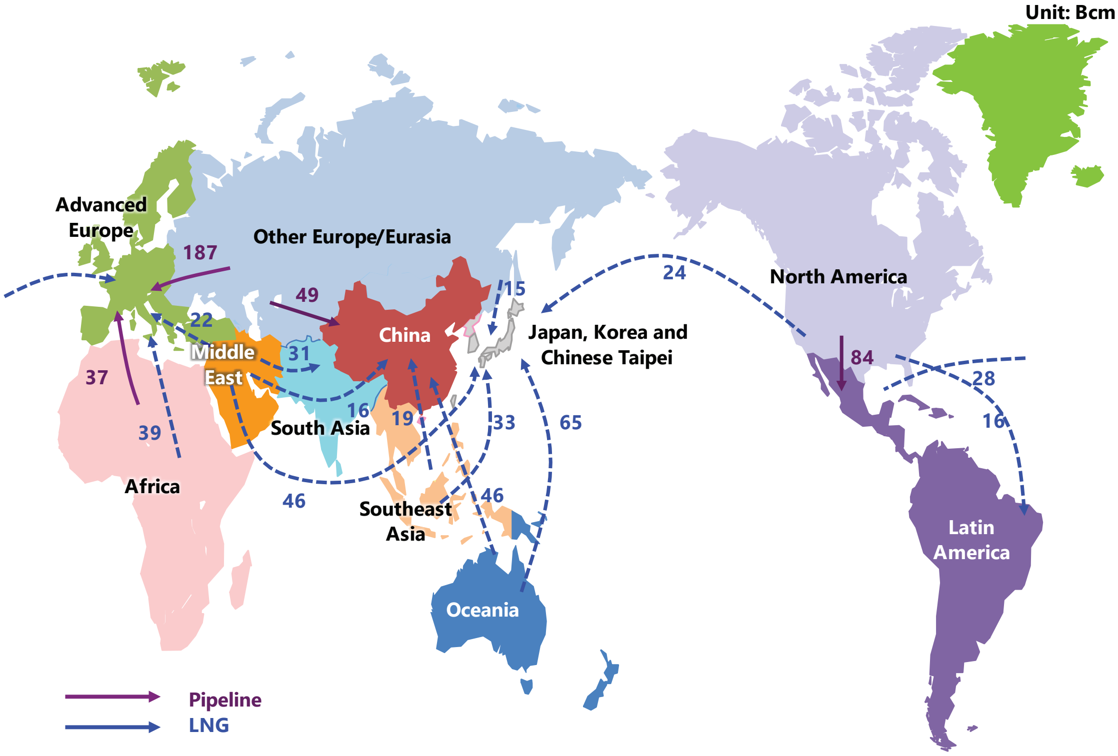
Reference Scenario

LNG demand



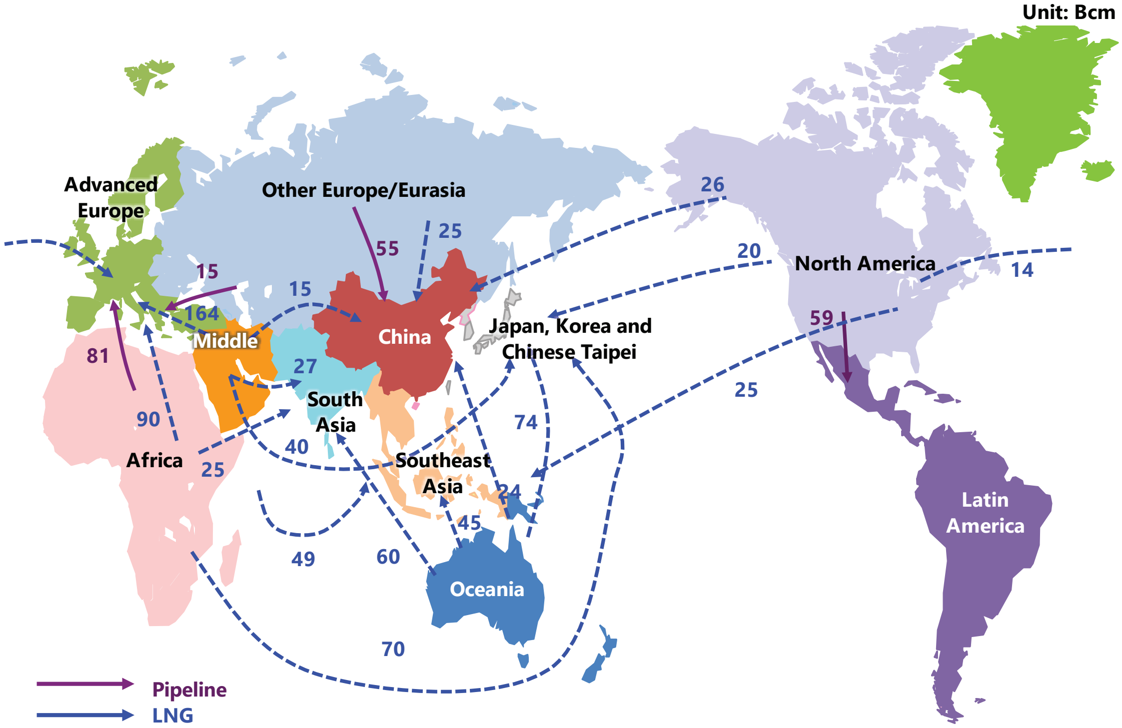
Reference Scenario

Major trade flows of natural gas (2021)



Reference Scenario

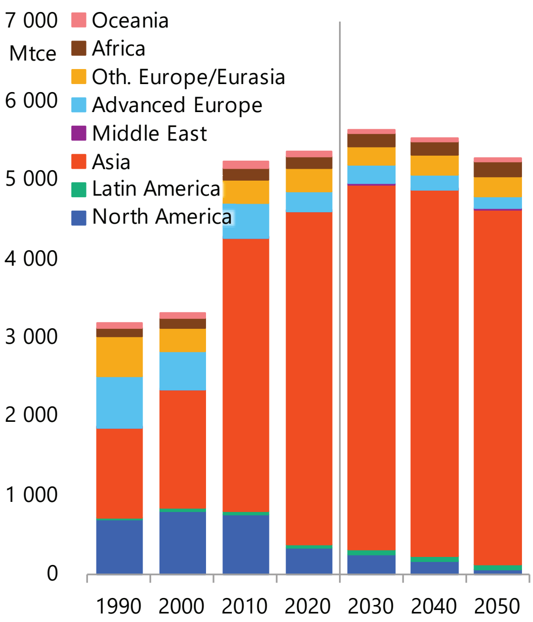
Major trade flows of natural gas (2050)



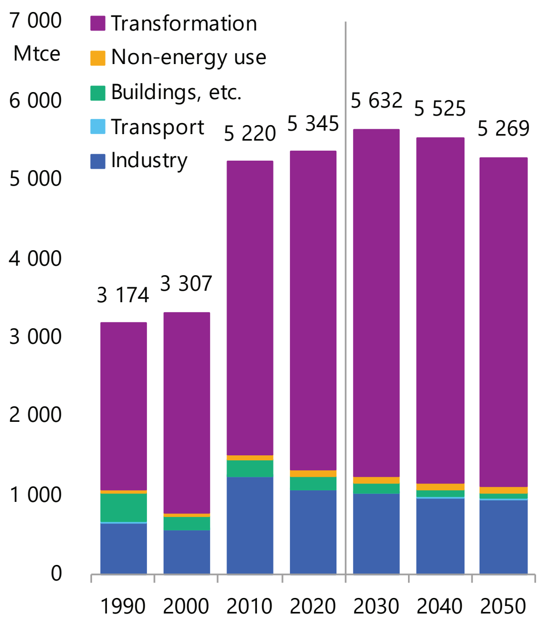
Reference Scenario

Coal consumption

By region



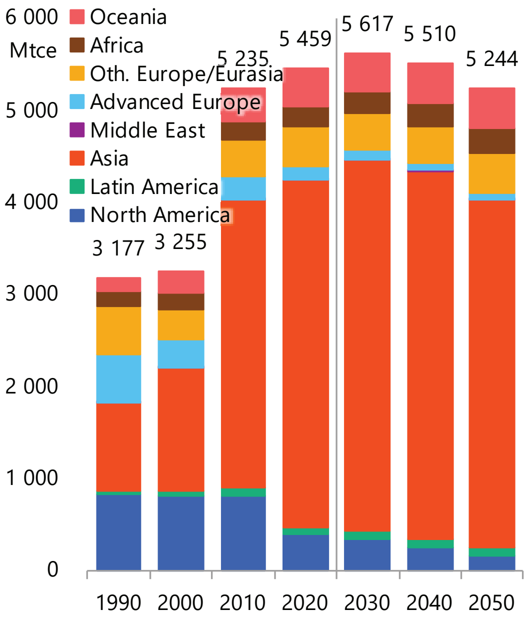
By sector



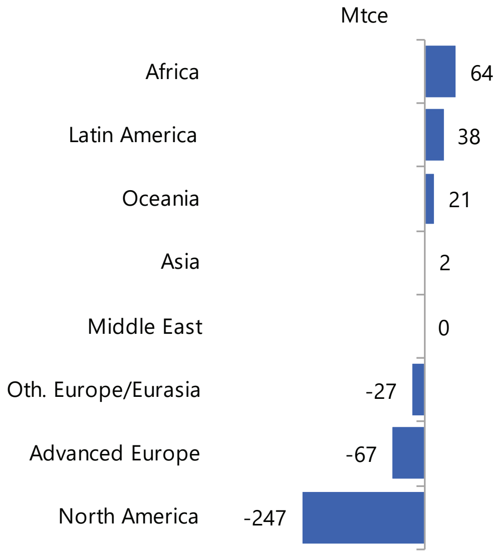
Reference Scenario

Coal production

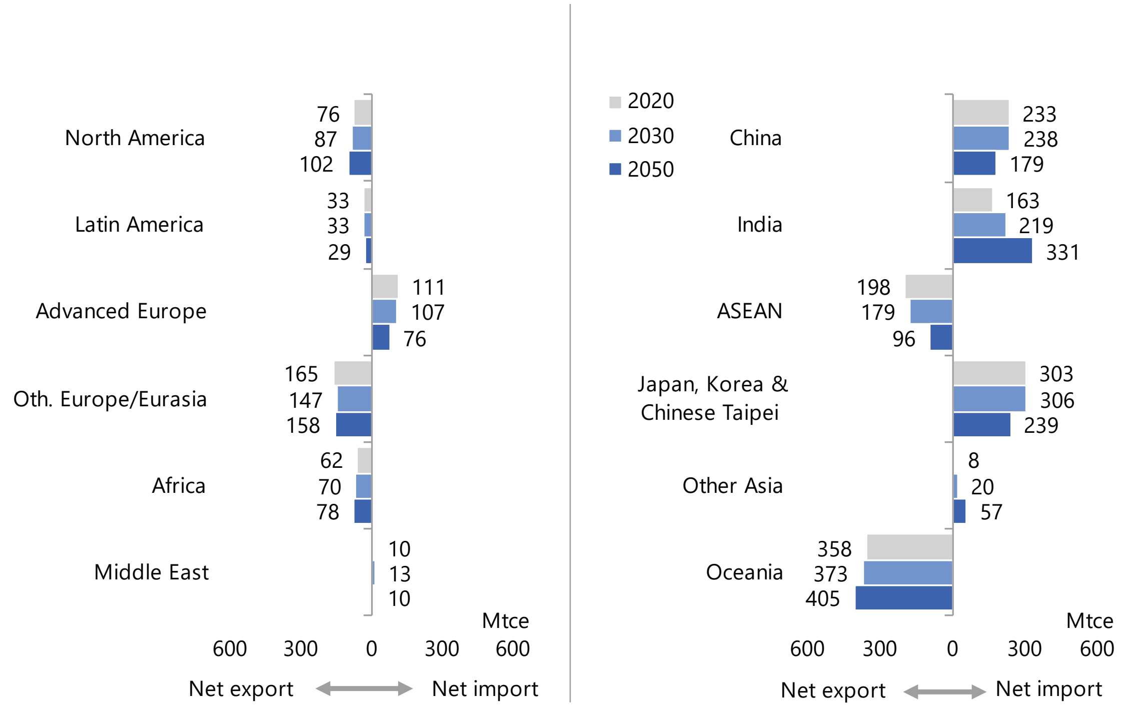
By region



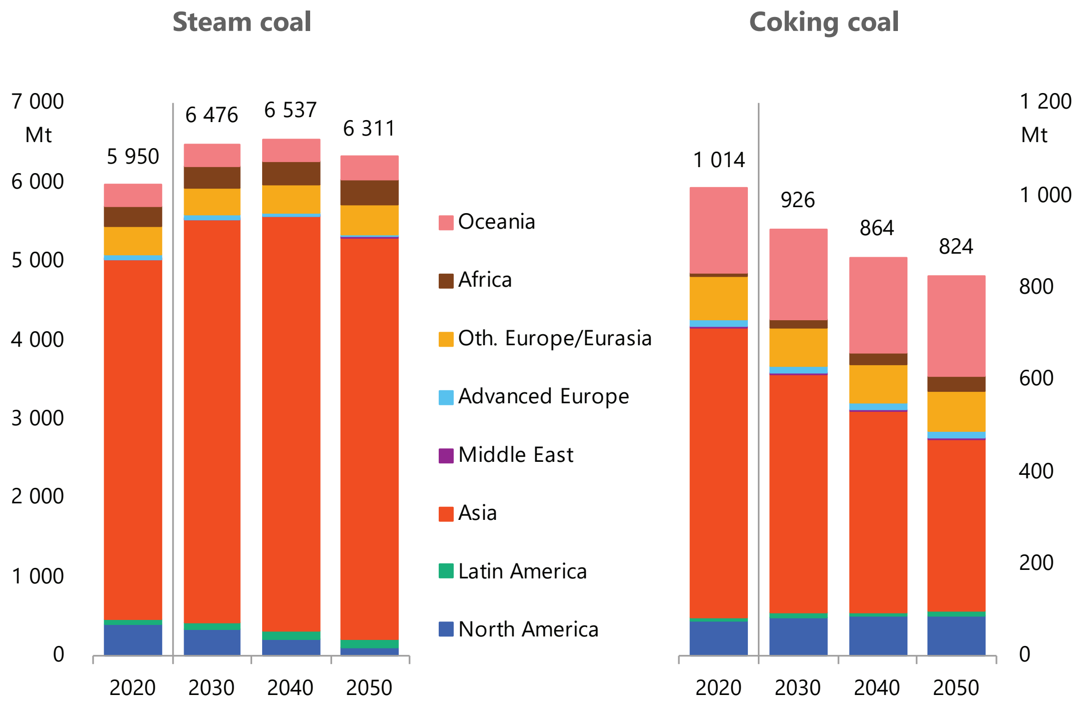
Changes (2020-2050)



Net exports and imports of coal



Coal production (steam and coking coal)

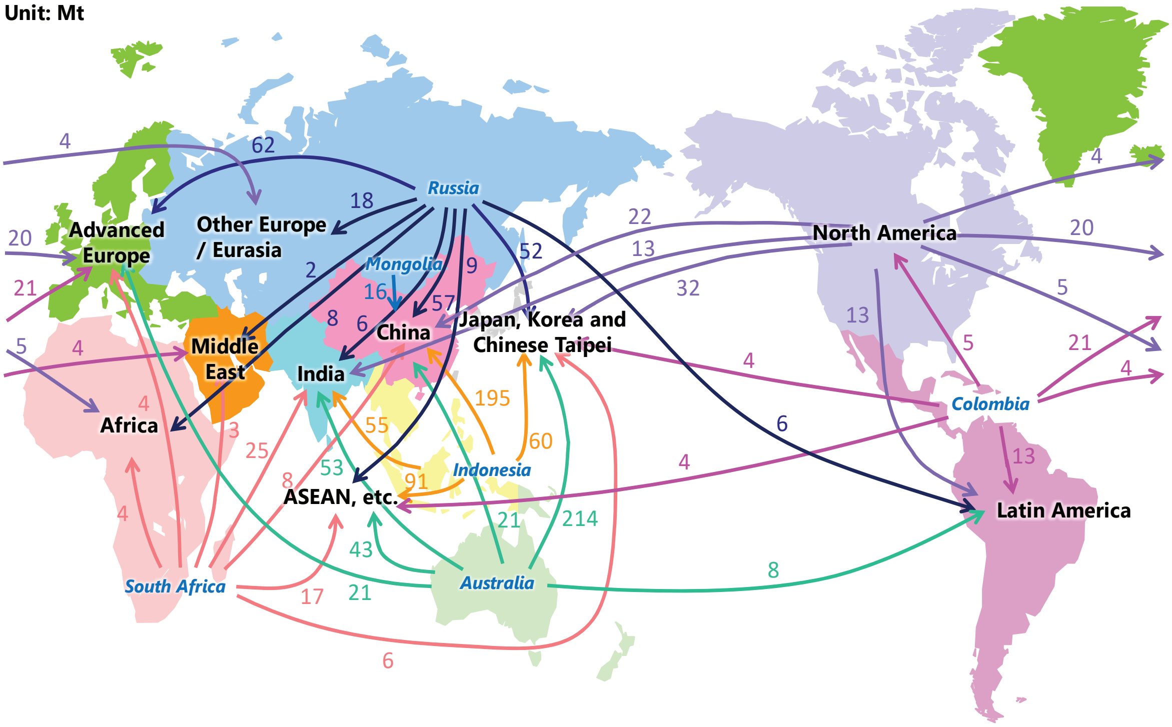


Reference Scenario

Major trade flows of steam and coking coal (2021)

IEE JAPAN

Unit: Mt



Notes: Total value of steam and coking coal. 2 Mt or more are shown. South Africa includes Mozambique.

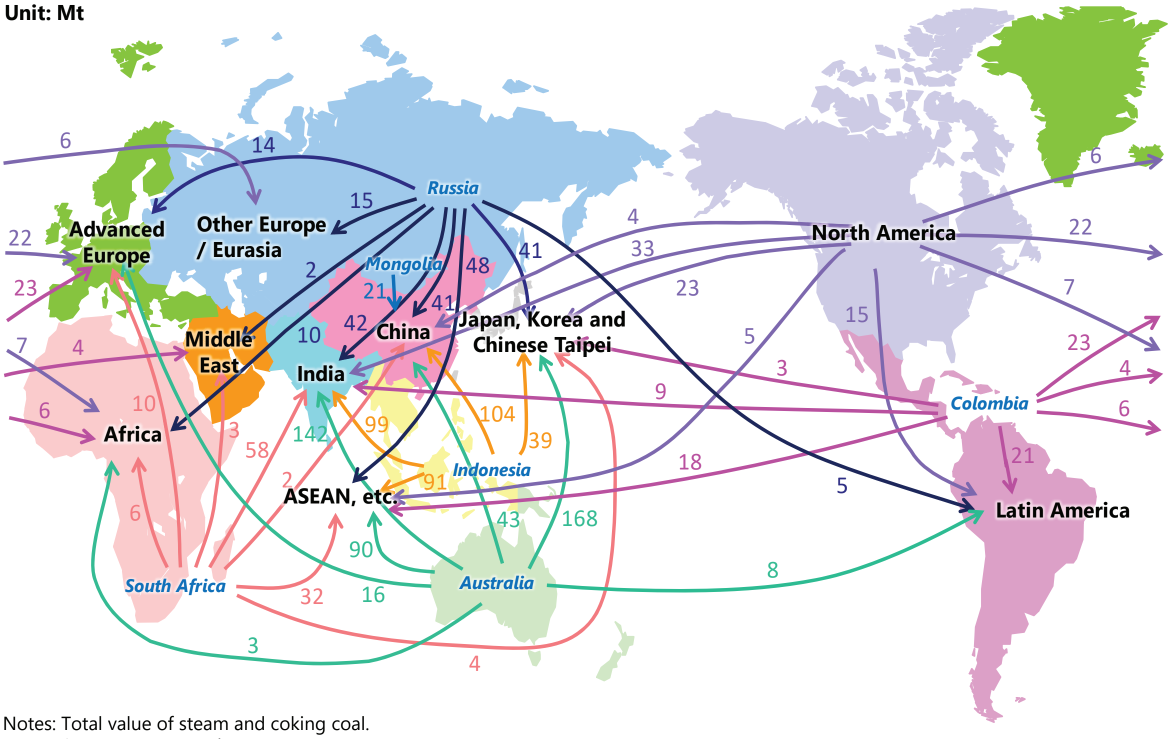
Source: Estimated from IEA “Coal Information 2022”, “TEX Report”, etc.

Reference Scenario

Major trade flows of steam and coking coal (2050)

IEE JAPAN

Unit: Mt

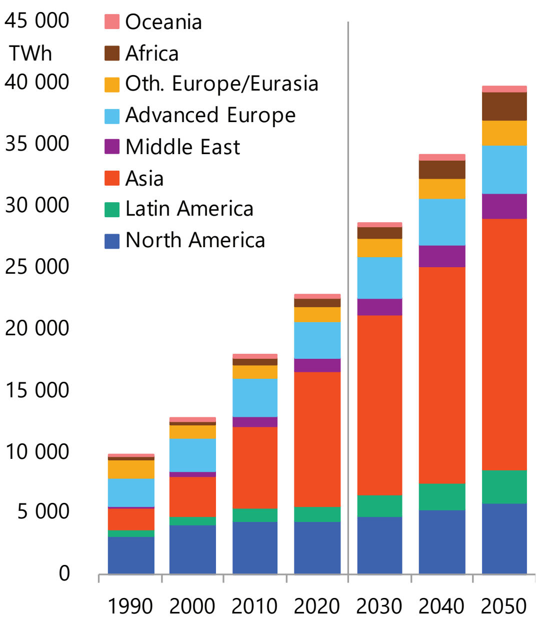


Notes: Total value of steam and coking coal.
2 Mt or more are shown.
South Africa includes Mozambique.

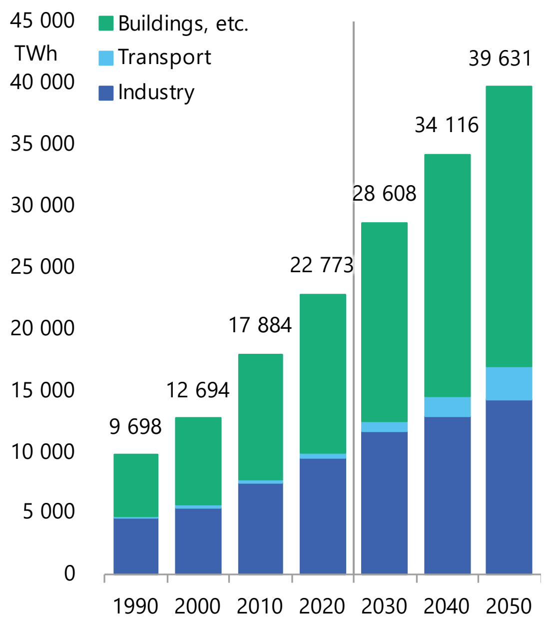
Reference Scenario

Final consumption of electricity

By region



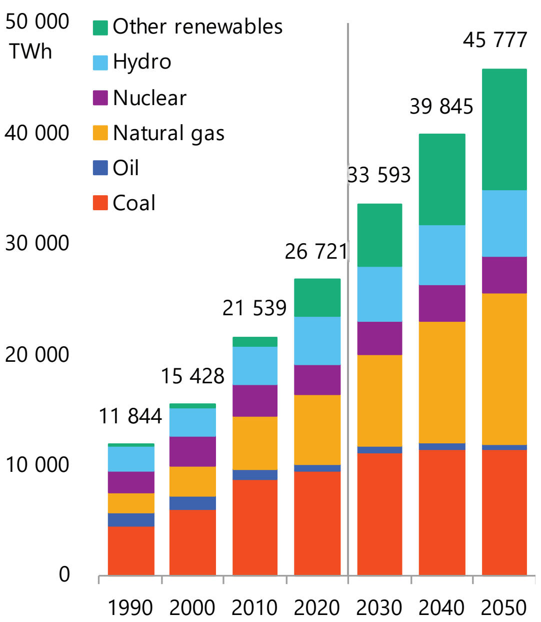
By sector



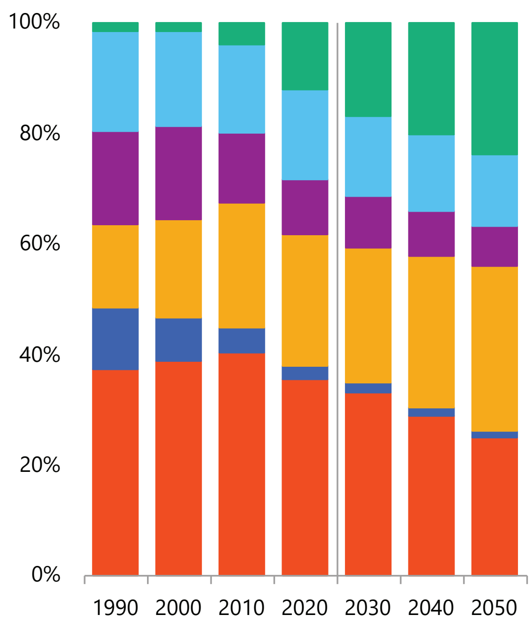
Reference Scenario

Power generation mix

Electricity generated



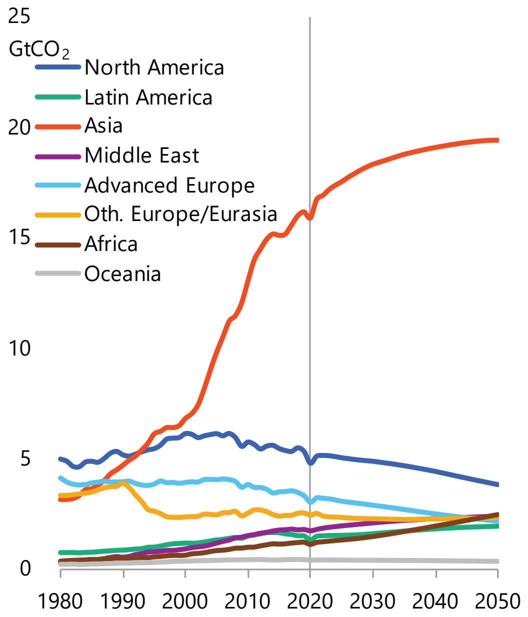
Shares



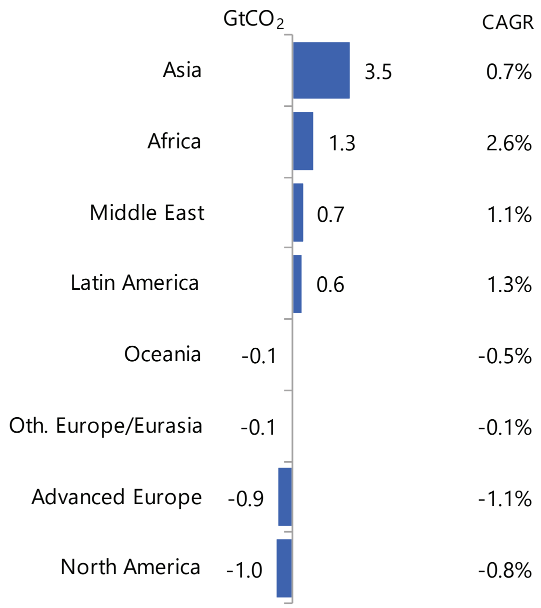
Reference Scenario

Energy-related CO_2 emissions

Emissions



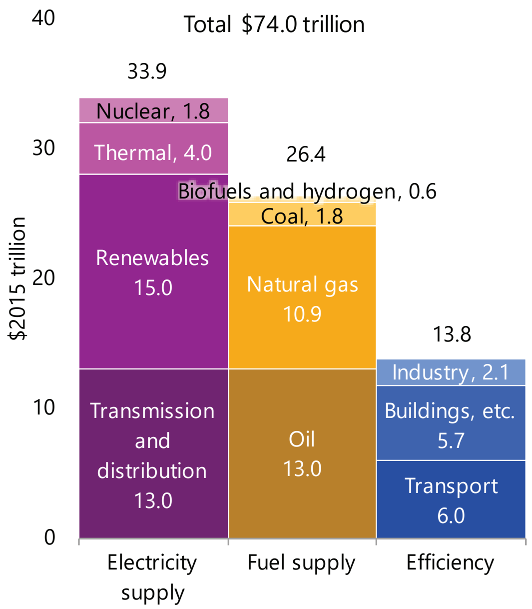
Changes (2020-2050)



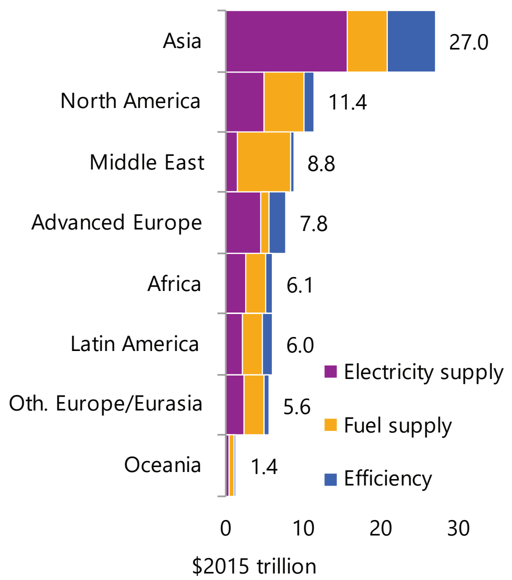
Reference Scenario

Energy-related investments (2021 – 2050)

By sector



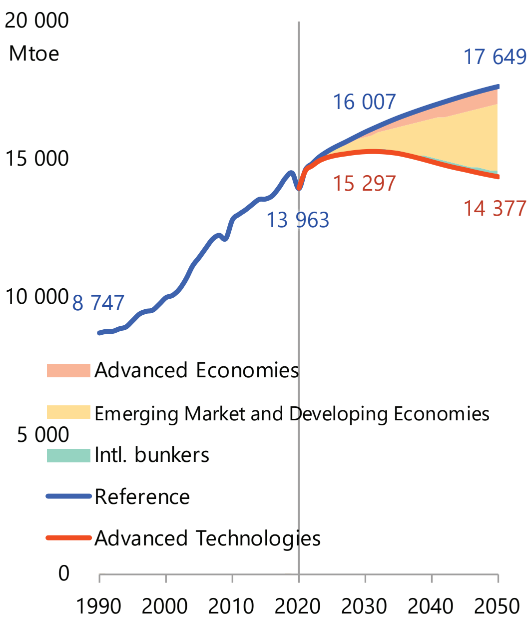
By region



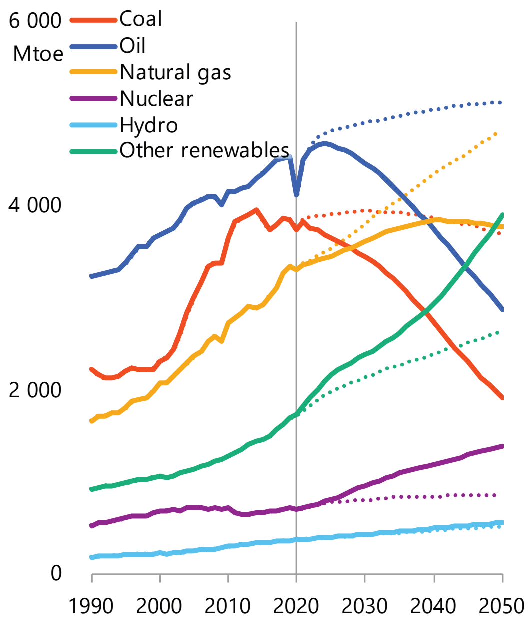
Advanced Technologies Scenario

Primary energy consumption

By region



By energy source

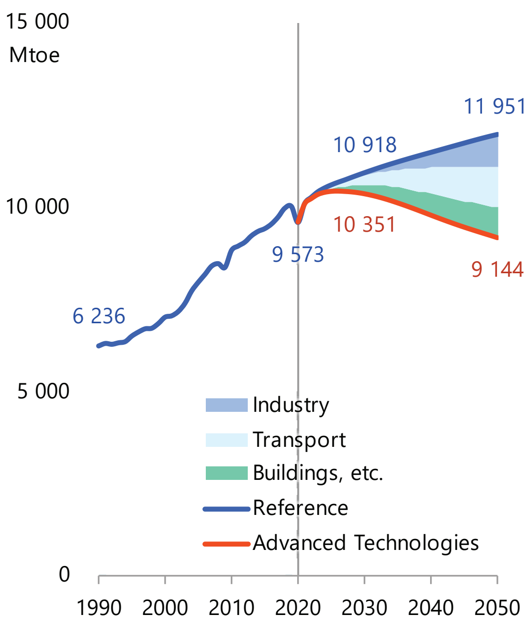


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

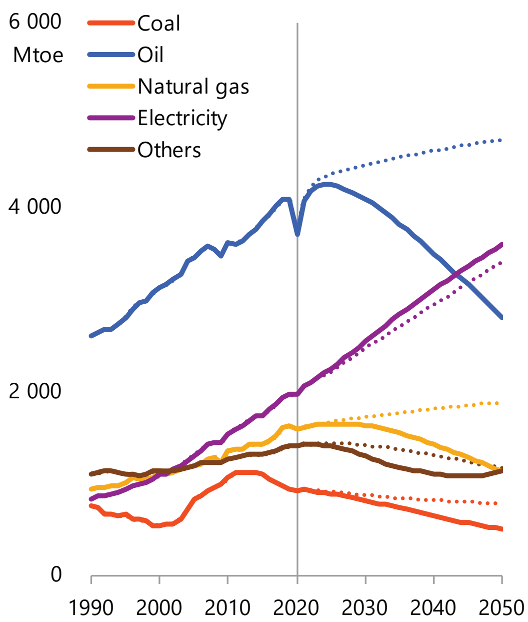
Advanced Technologies Scenario

Final energy consumption

By sector

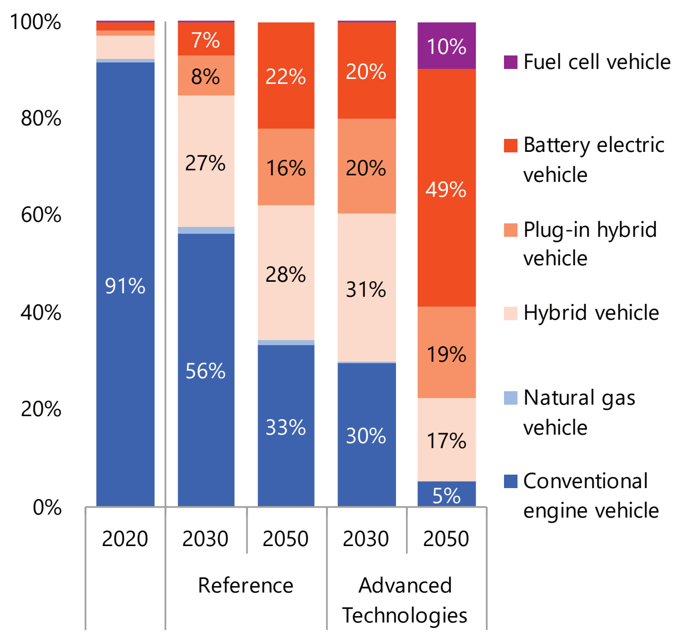


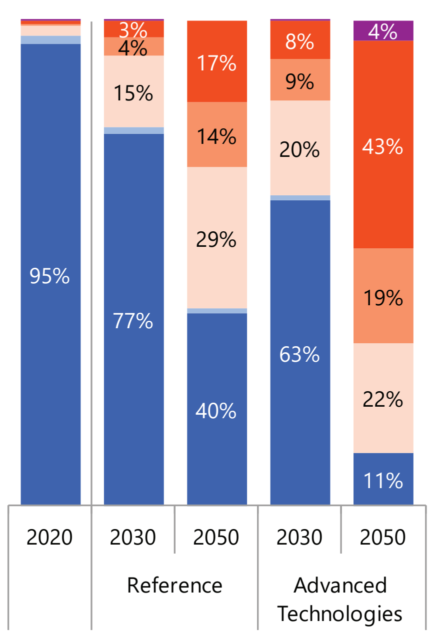
By energy



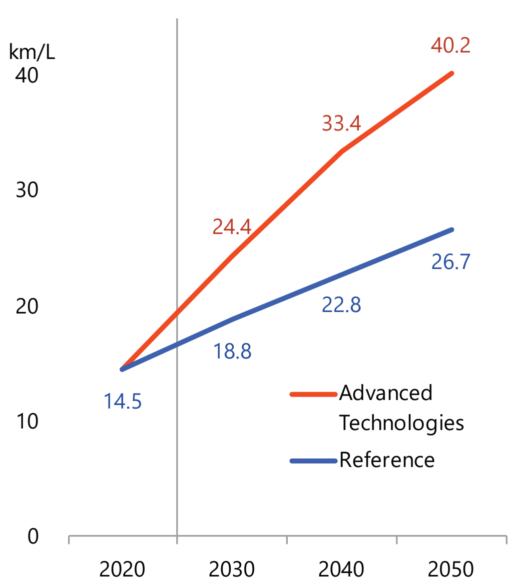
Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

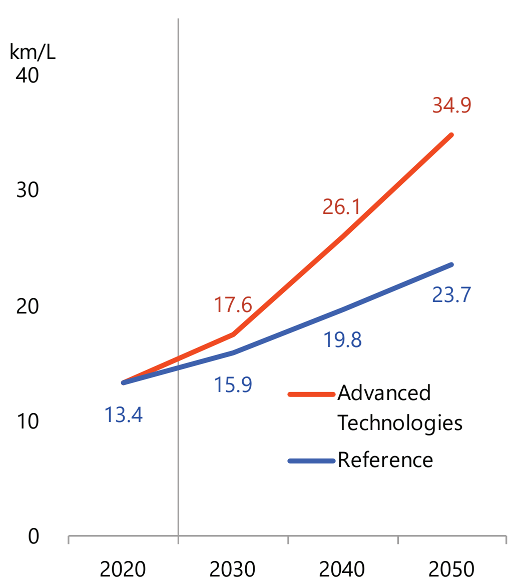
Share of passenger vehicle





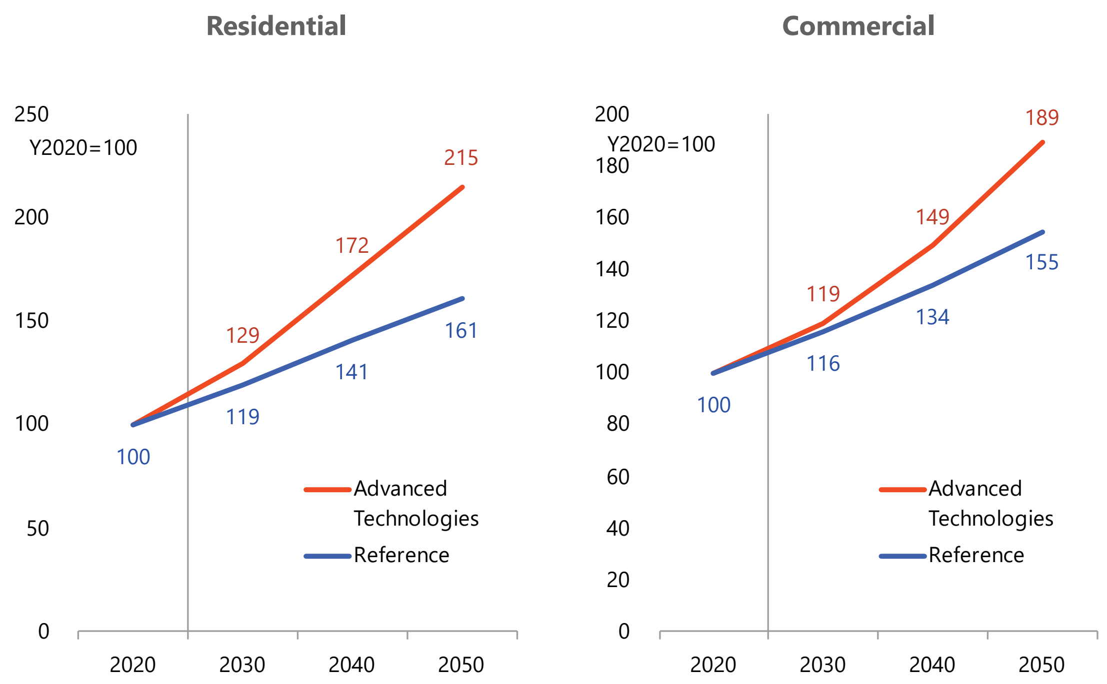
Fuel efficiency of passenger vehicle



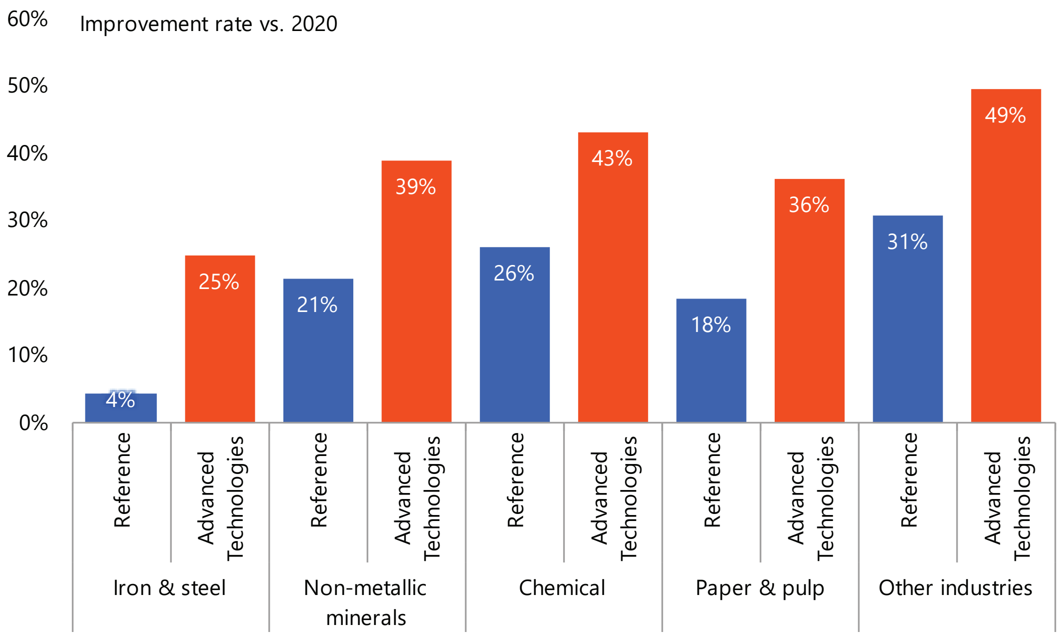


Note: Litres of gasoline equivalent

Energy efficiency in buildings sector



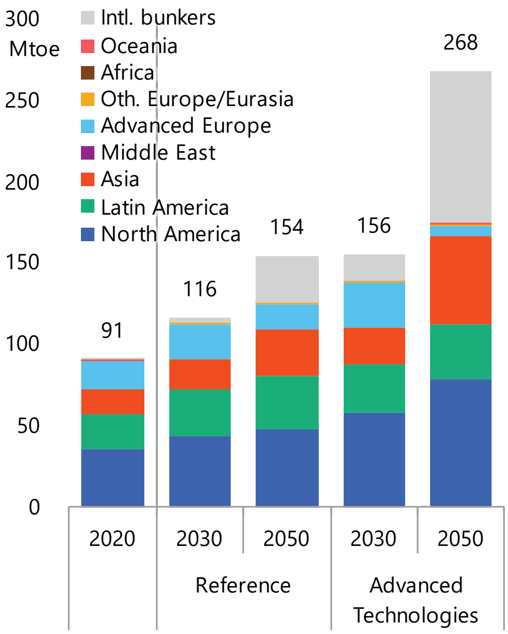
Energy intensity improvement in industry sector



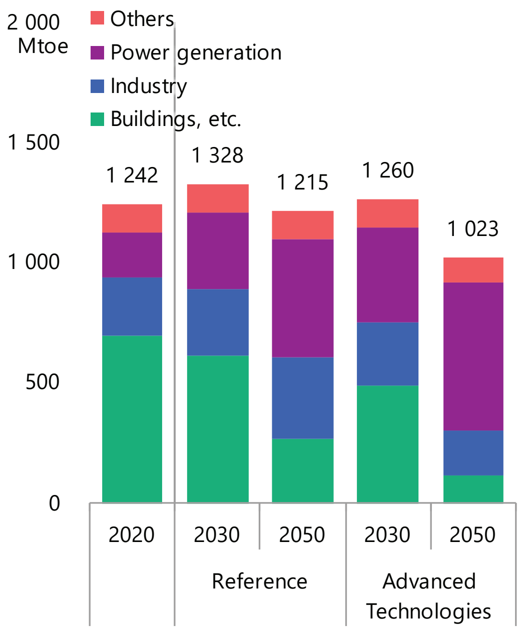
Advanced Technologies Scenario

Biomass

Biofuels for transport



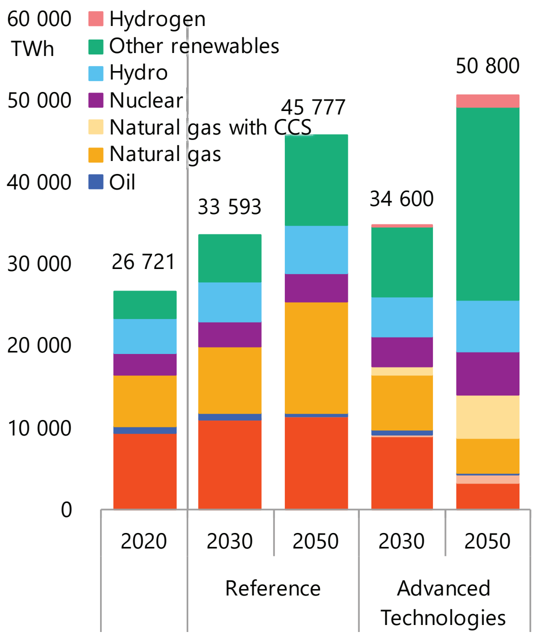
Solid biomass



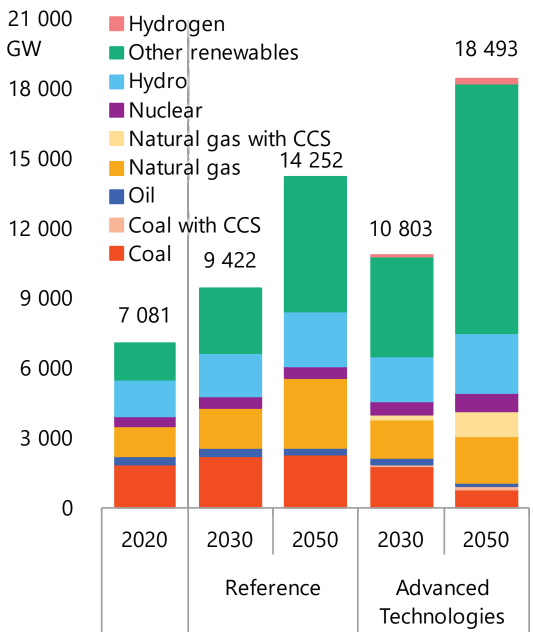
Advanced Technologies Scenario

Power generation mix

Electricity generated

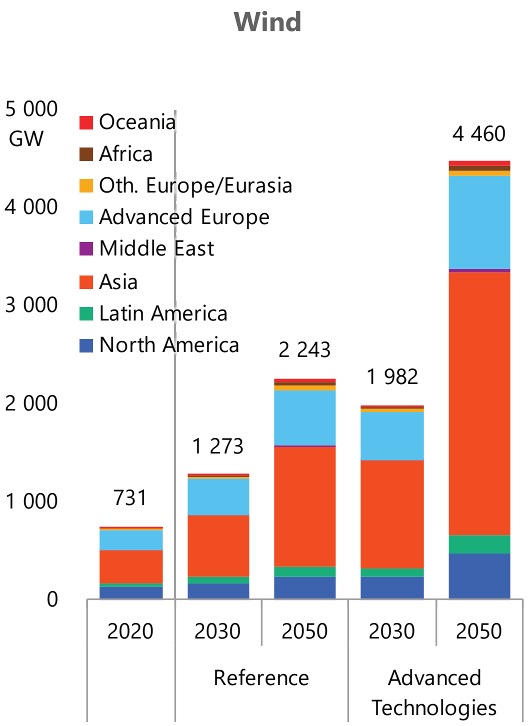


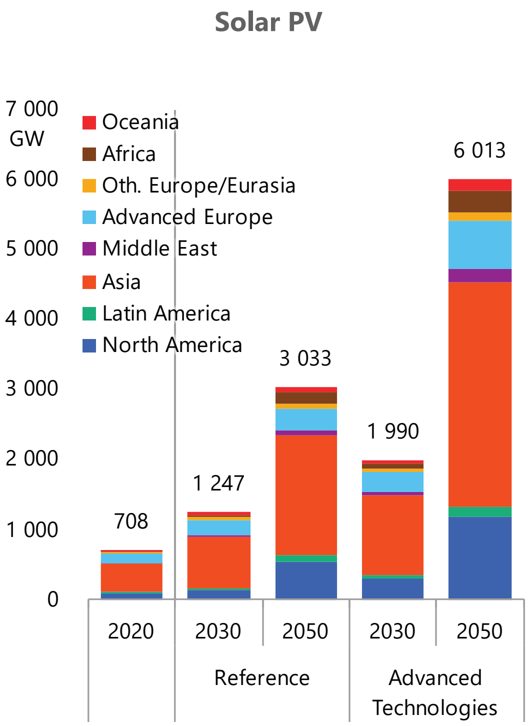
Power generation capacity



Advanced Technologies Scenario

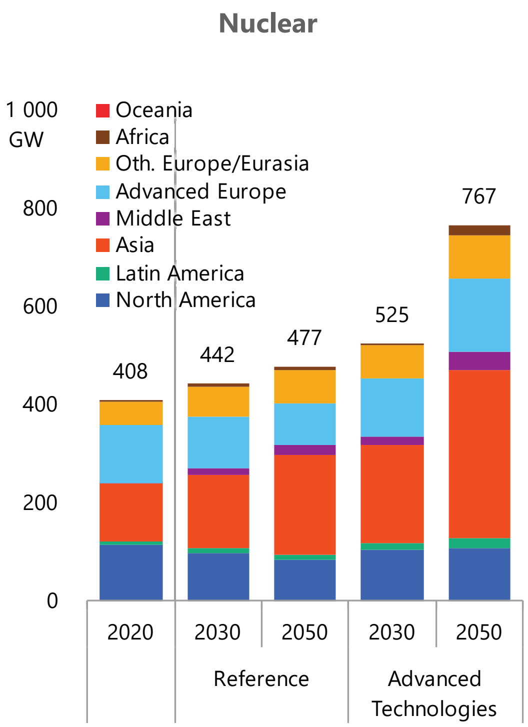
Wind and solar PV power generation capacity

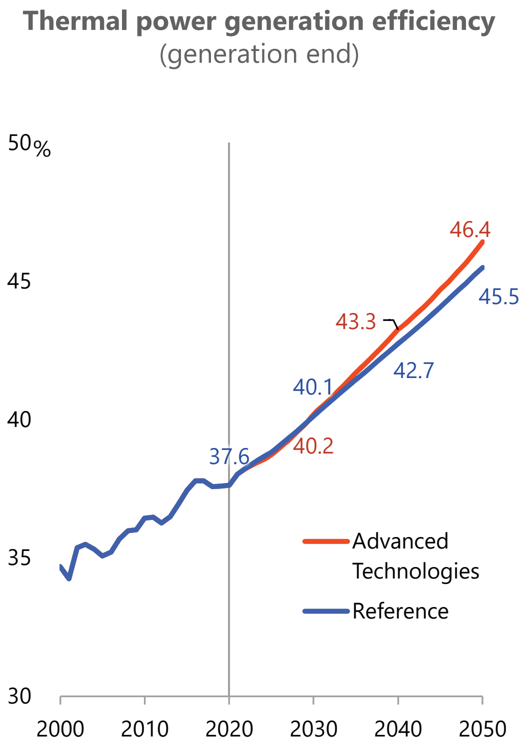




Advanced Technologies Scenario

Nuclear power generation capacity and thermal power generation efficiency

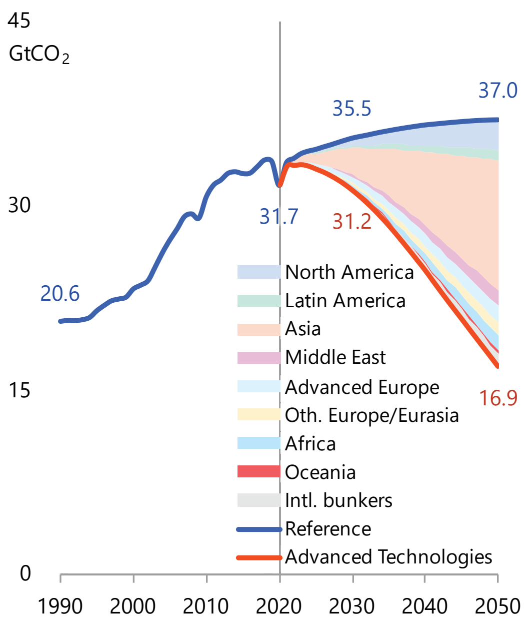




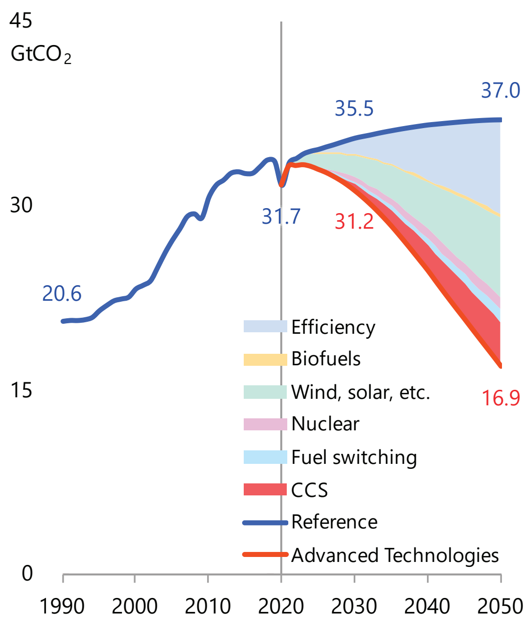
Advanced Technologies Scenario

Energy-related CO_2 emissions

By region



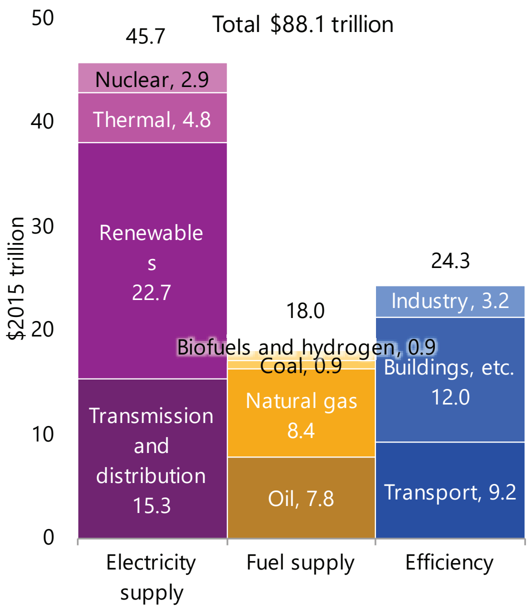
By technology



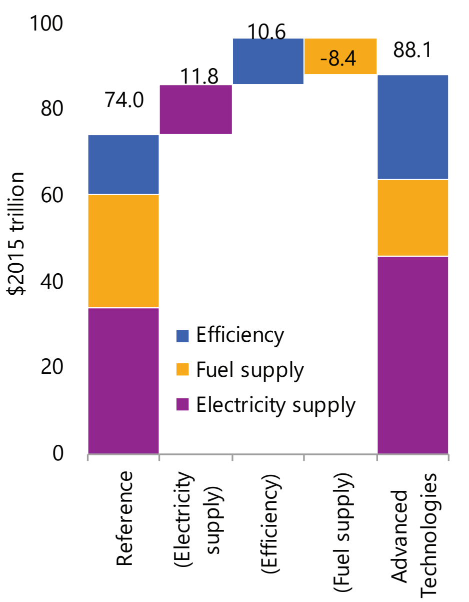
Advanced Technologies Scenario

Energy-related investments (2021 – 2050)

By sector



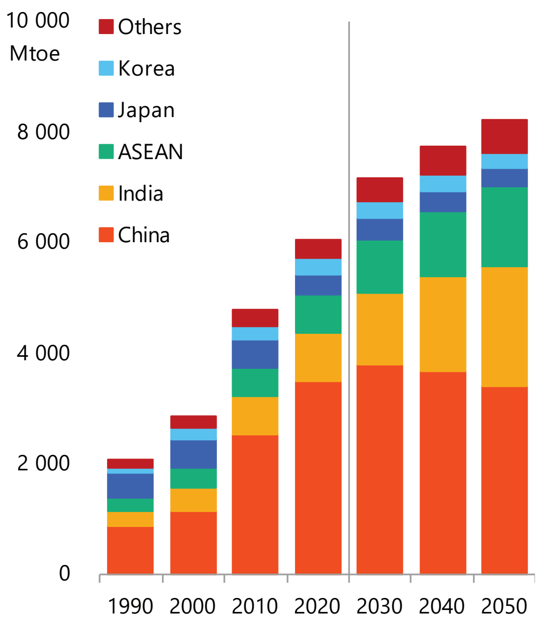
Changes from Reference Scenario



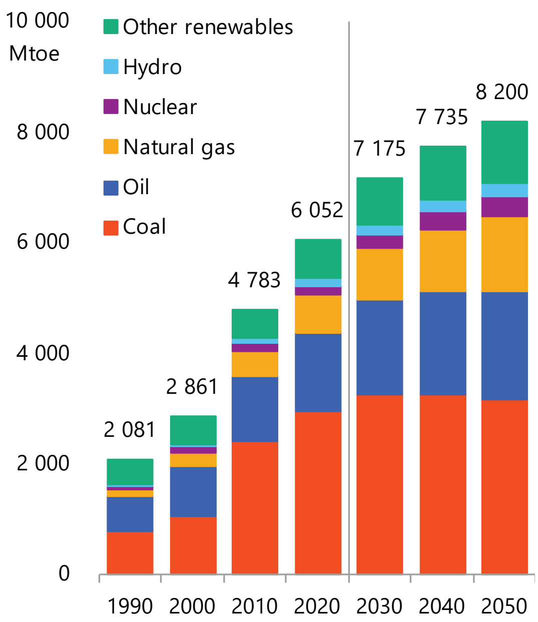
Asia | Reference Scenario

Primary energy consumption

By region



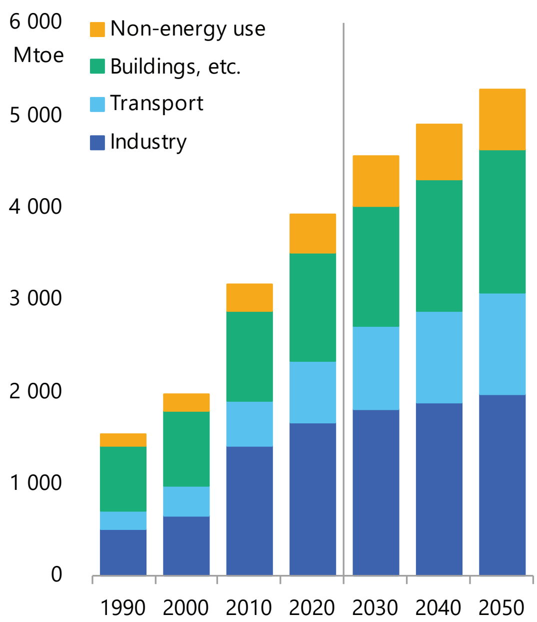
By energy source



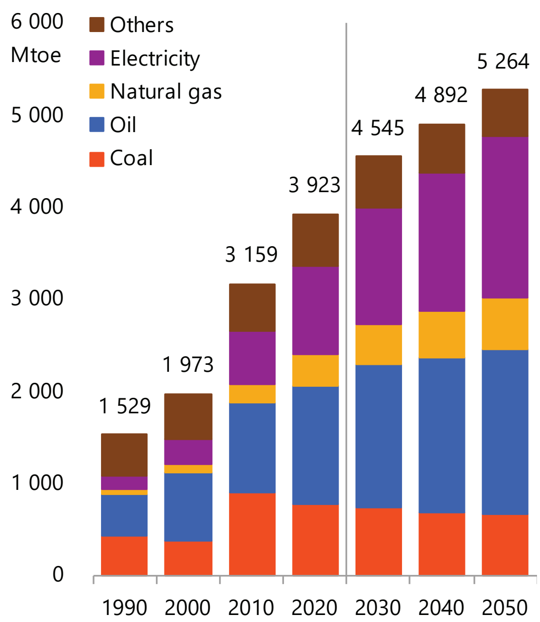
Asia | Reference Scenario

Final energy consumption

By sector



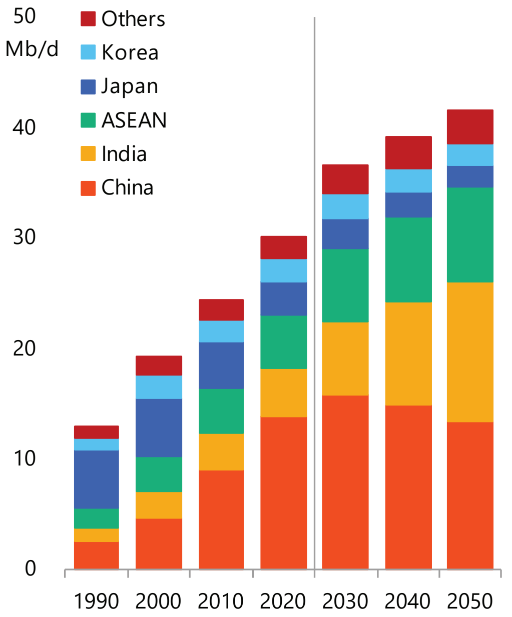
By energy source



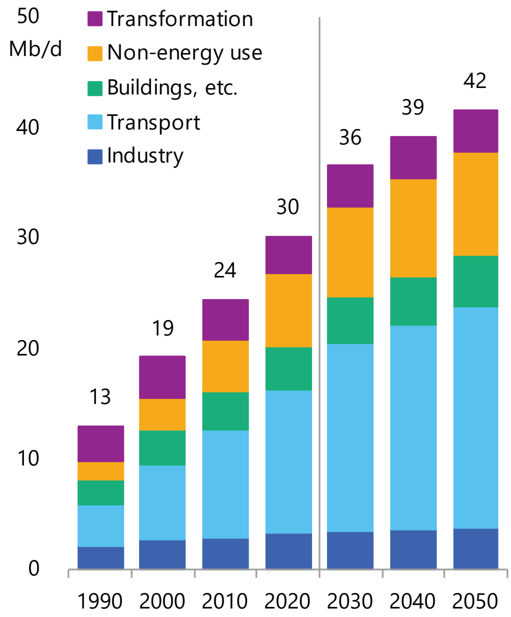
Asia | Reference Scenario

Oil consumption

By region



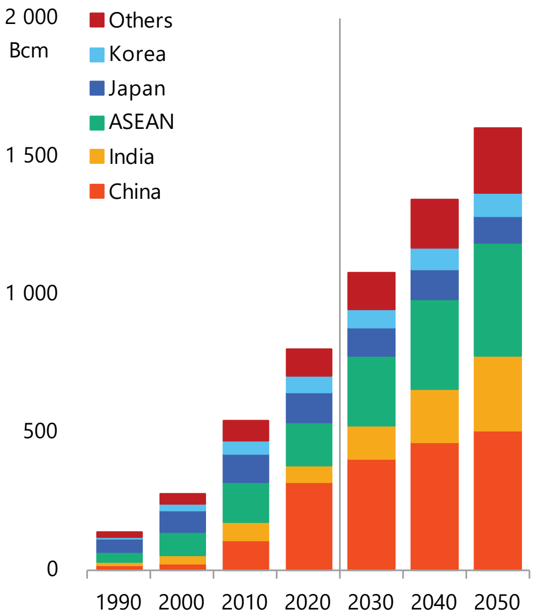
By sector



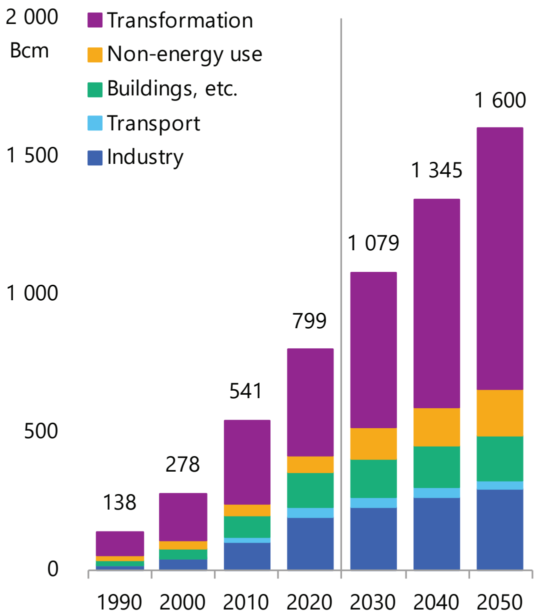
Asia | Reference Scenario

Natural gas consumption

By region

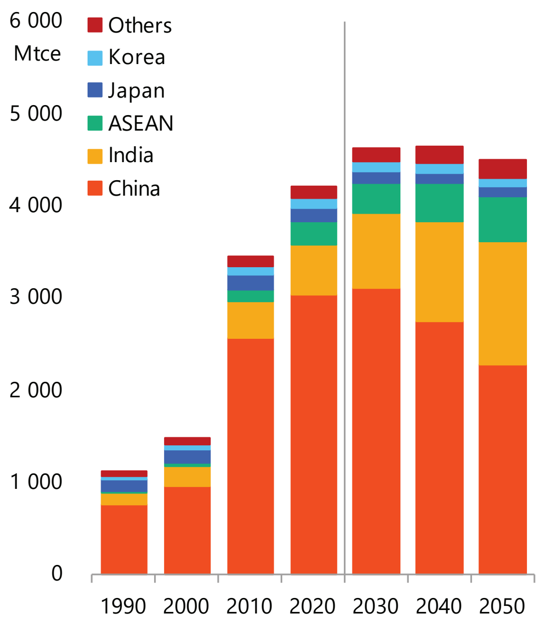


By sector

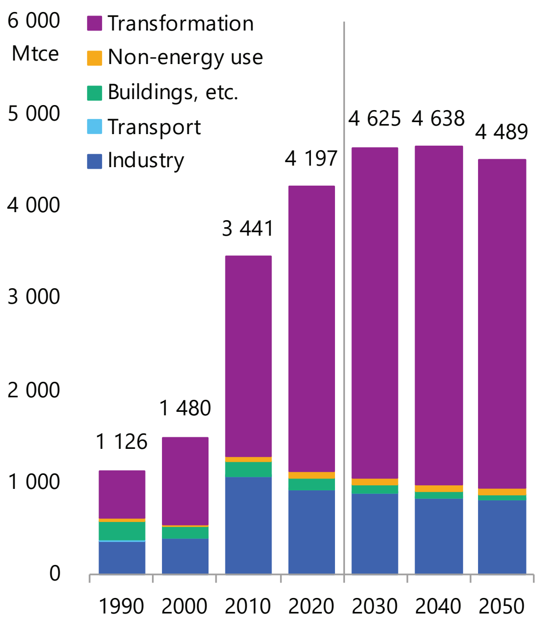


Coal consumption

By region

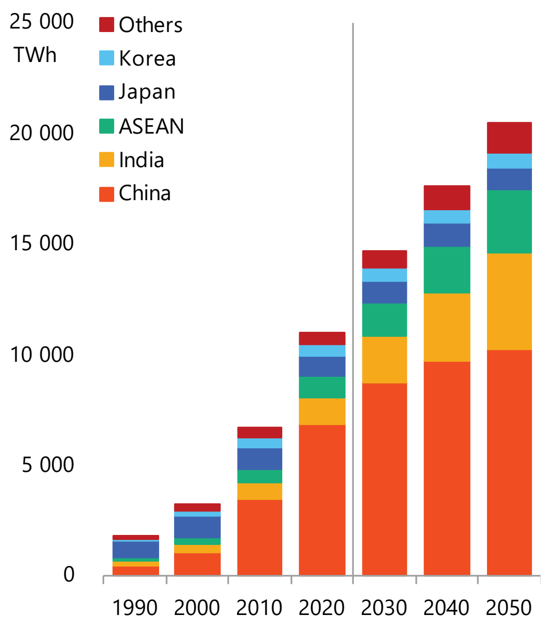


By sector

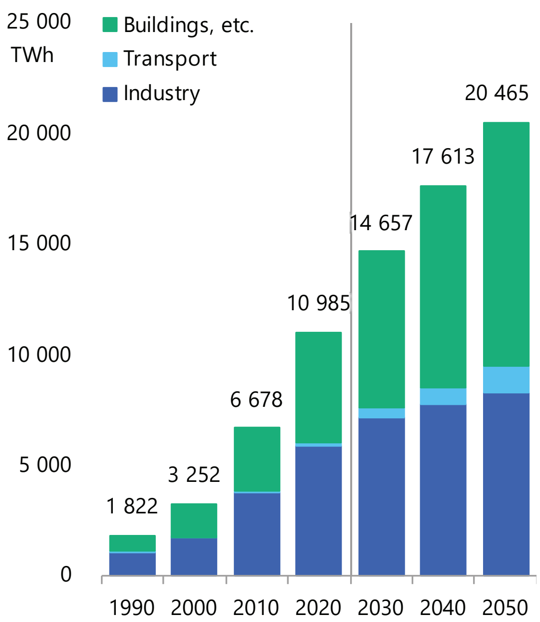


Final consumption of electricity

By region



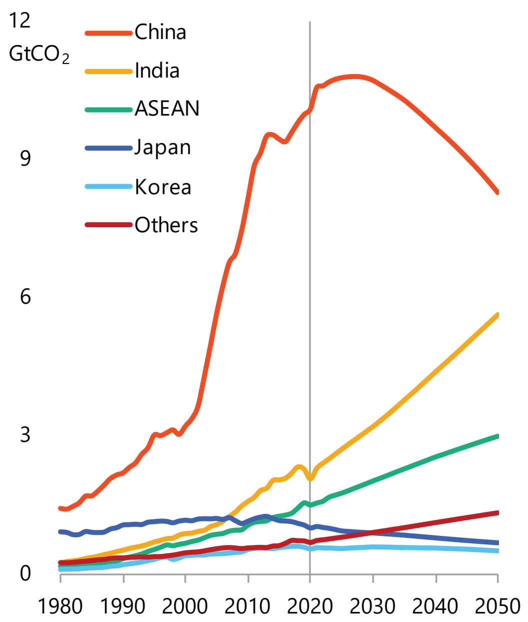
By sector



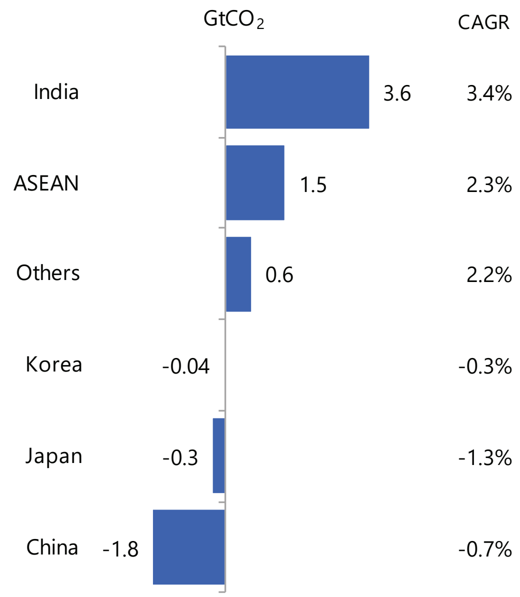
Asia Reference Scenario

Energy-related CO_2 emissions

Emissions



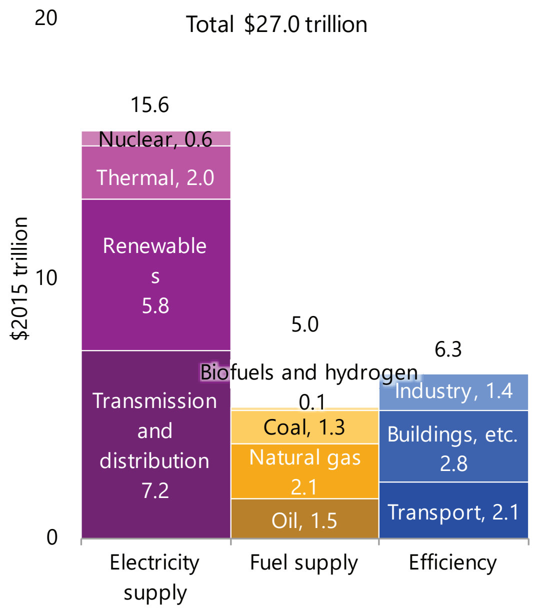
Changes (2020-2050)



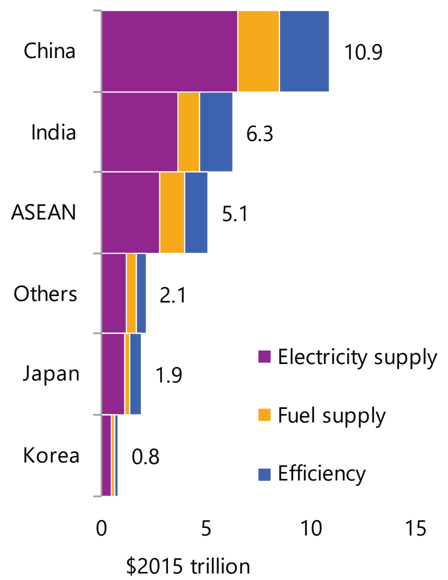
Asia Reference Scenario

Energy-related investments (2021 – 2050)

By sector

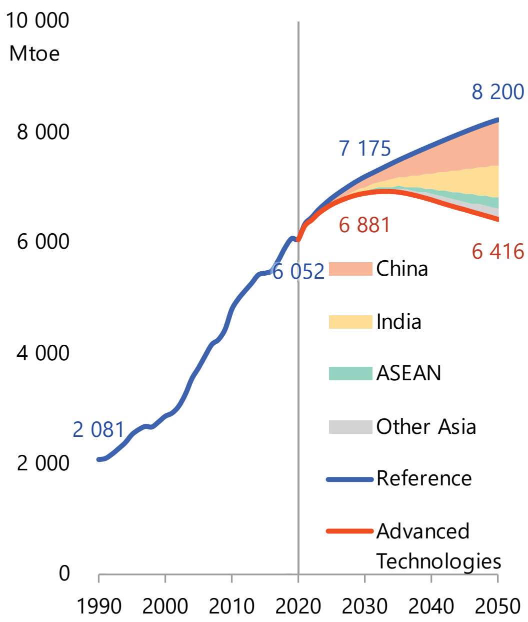


By region

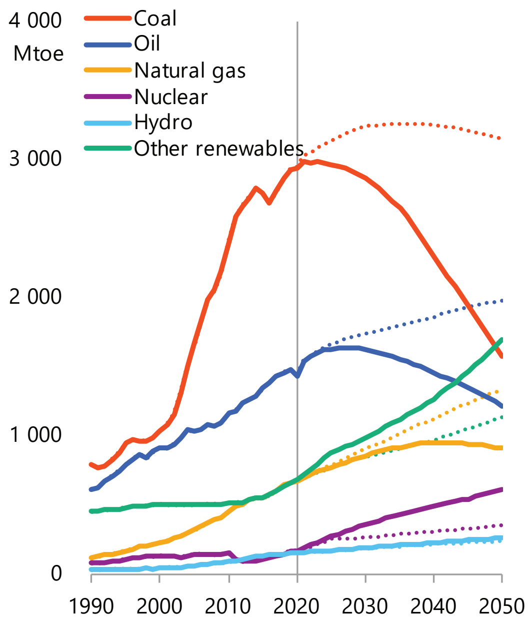


Primary energy consumption

By region



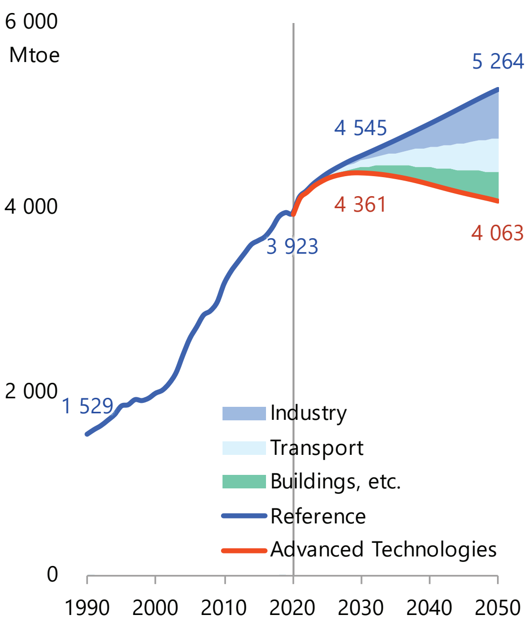
By energy source



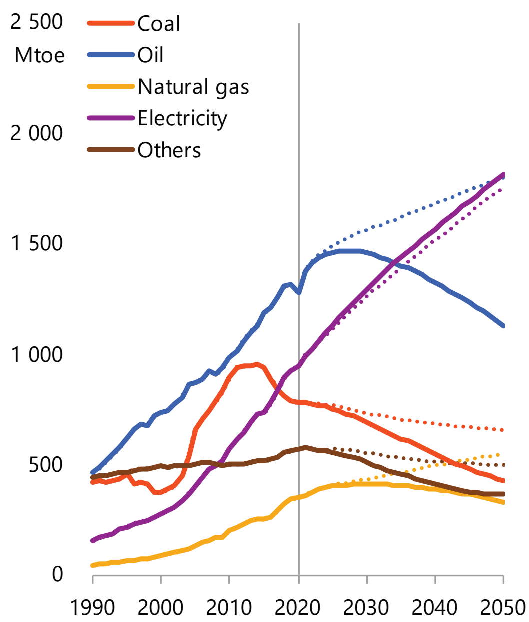
Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Final energy consumption

By sector



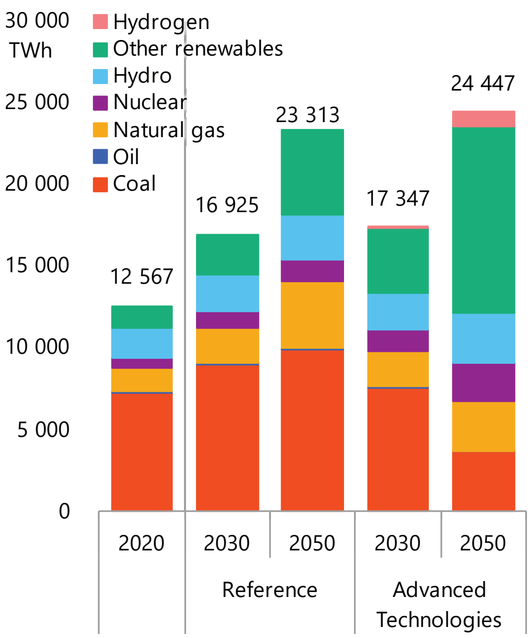
By energy source



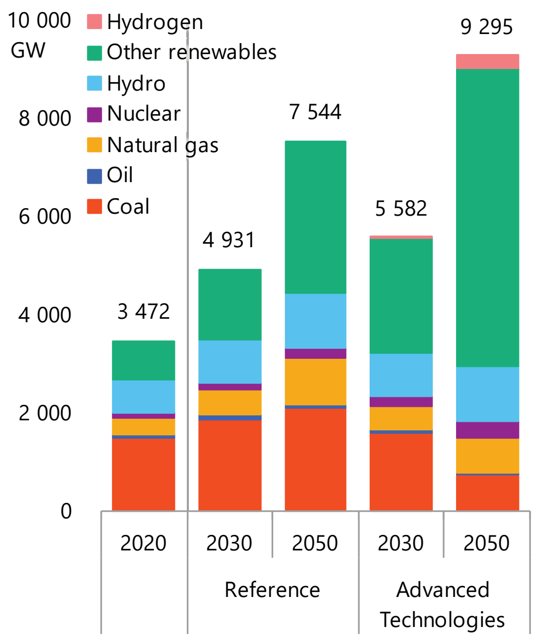
Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Power generation mix

Electricity generated



Power generation capacity

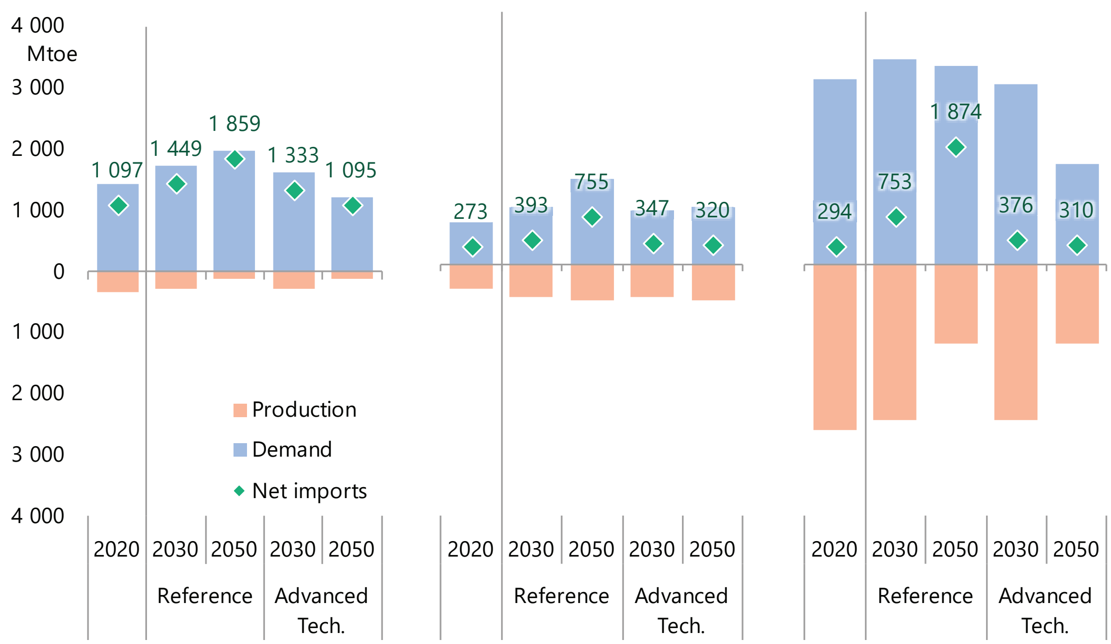


Supply and demand balance of fossil fuels

Oil

Natural gas

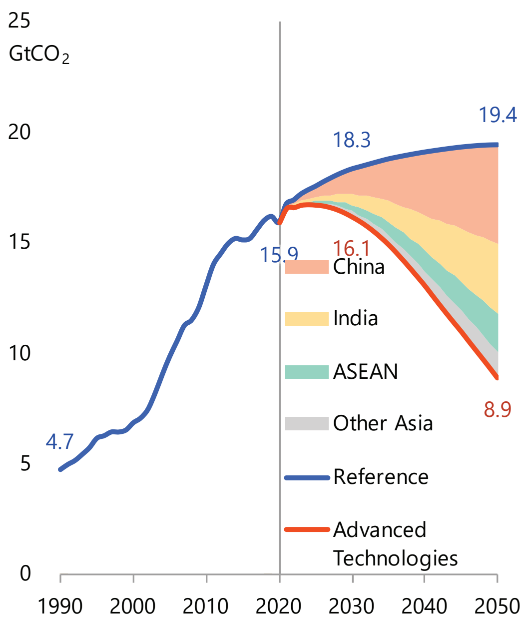
Coal



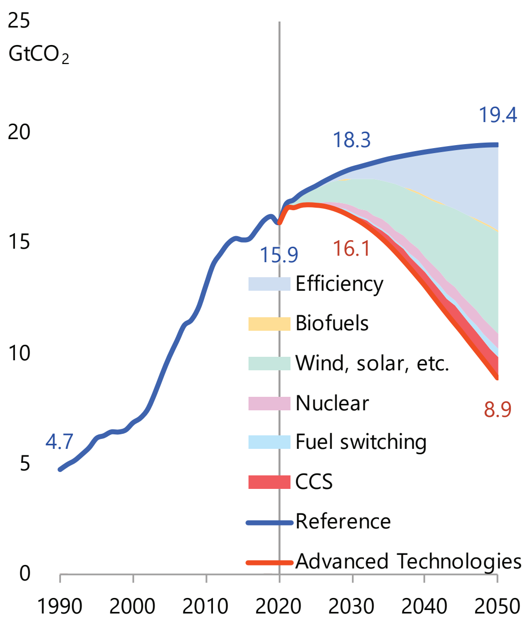
Asia | Advanced Technologies Scenario

Energy-related CO_2 emissions

By region



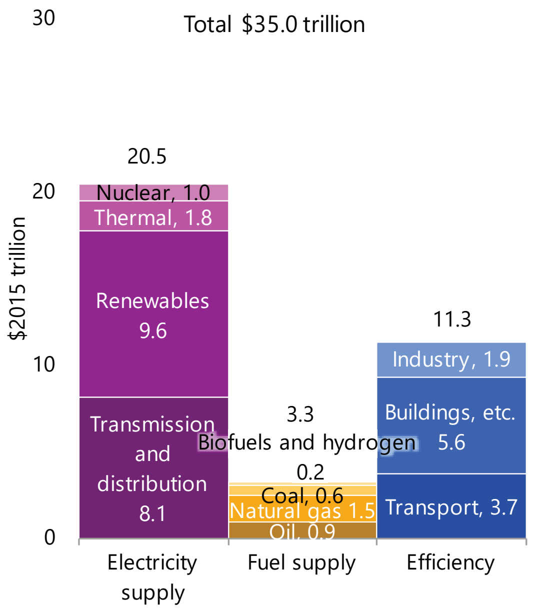
By technology



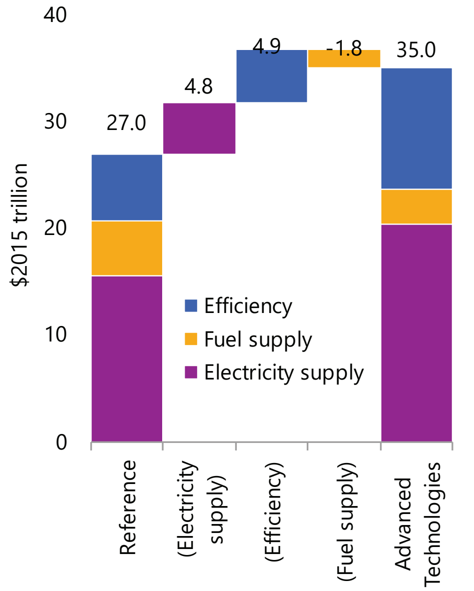
Asia | Advanced Technologies Scenario

Energy-related investments (2021 – 2050)

By sector

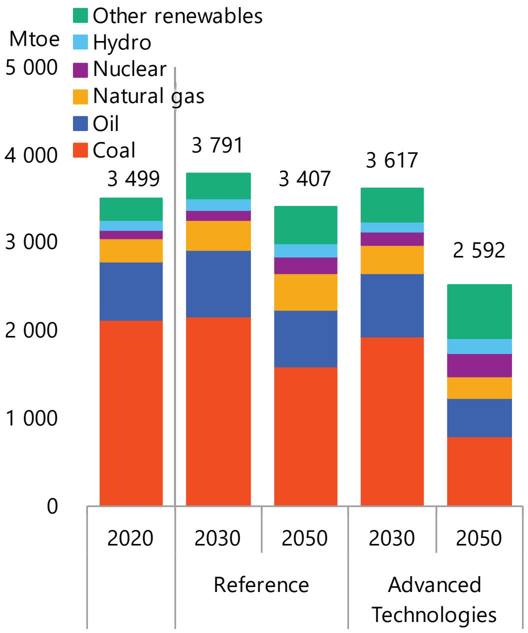


Changes from Reference Scenario

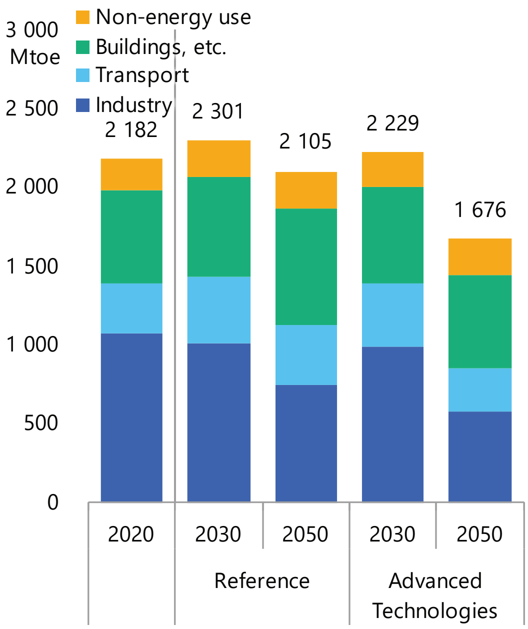


Energy consumption

Primary energy consumption



Final energy consumption

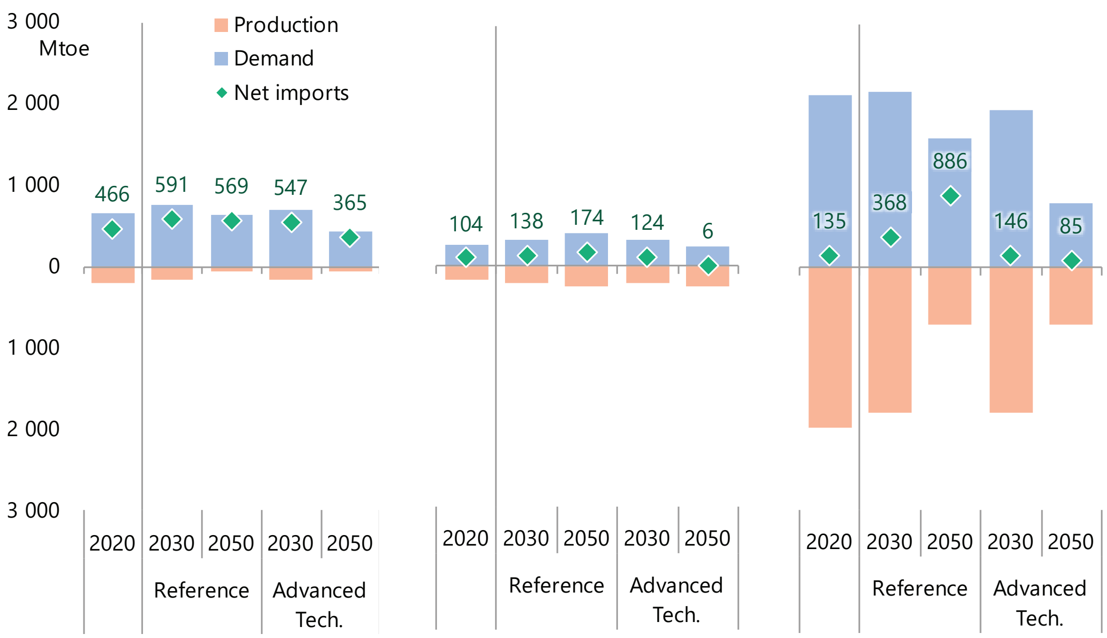


Supply and demand balance of fossil fuels

Oil

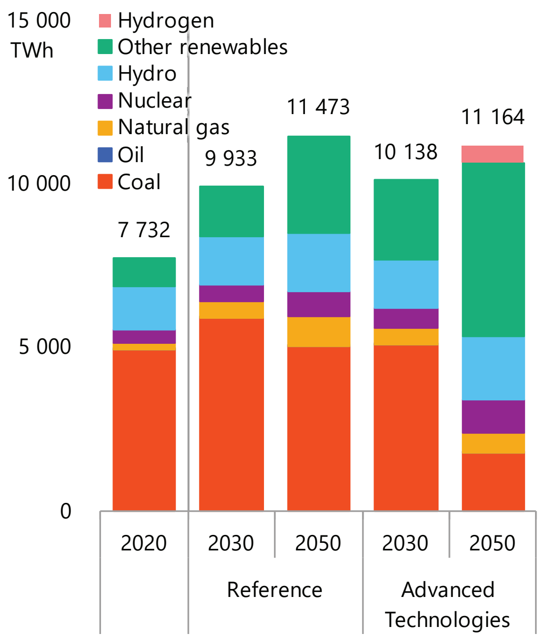
Natural gas

Coal

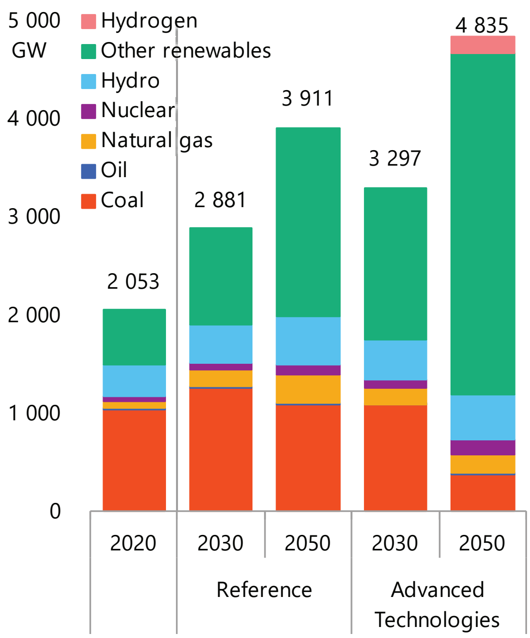


Power generation mix

Electricity generated

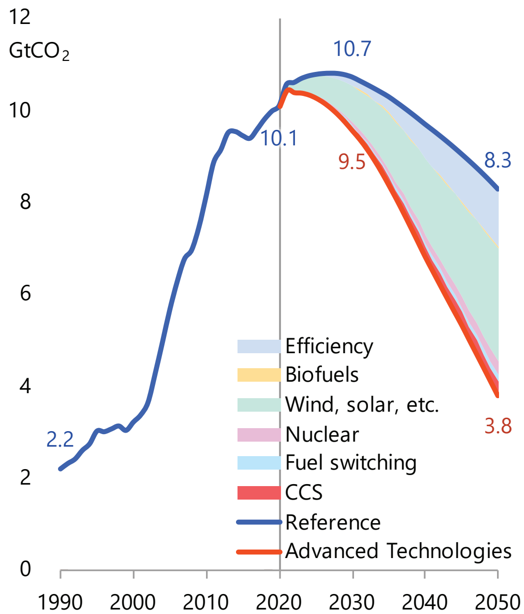


Power generation capacity

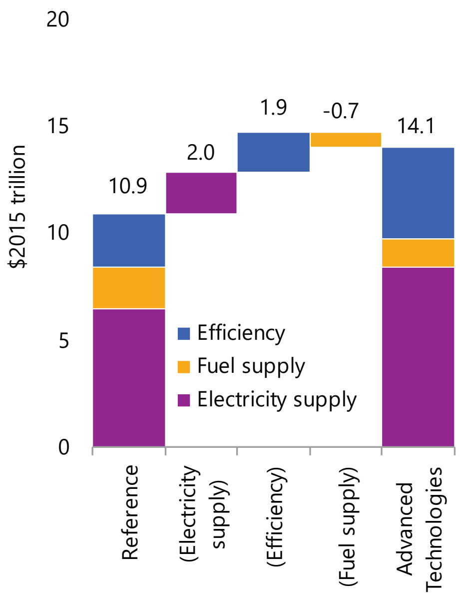


Energy-related CO_2 emissions and investments

CO_2 emissions



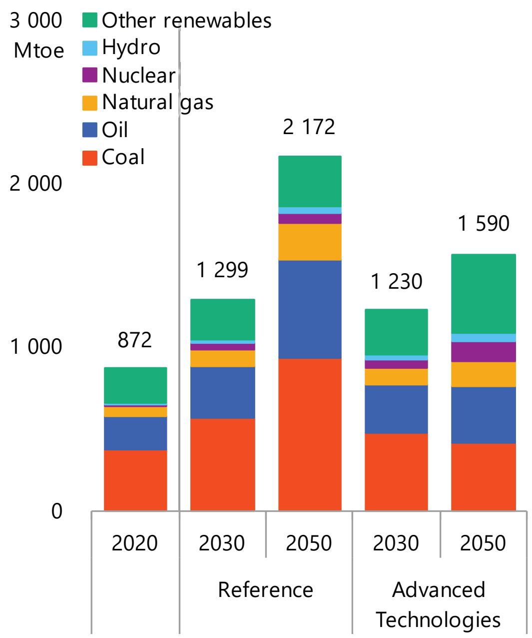
Investments
(2021 – 2050)



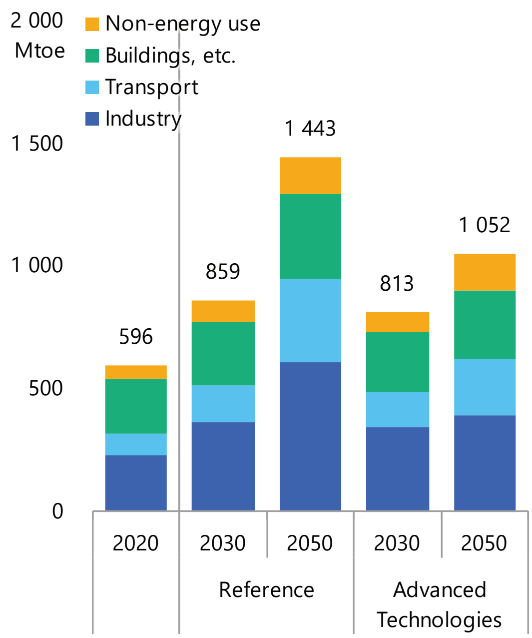
India

Energy consumption

Primary energy consumption



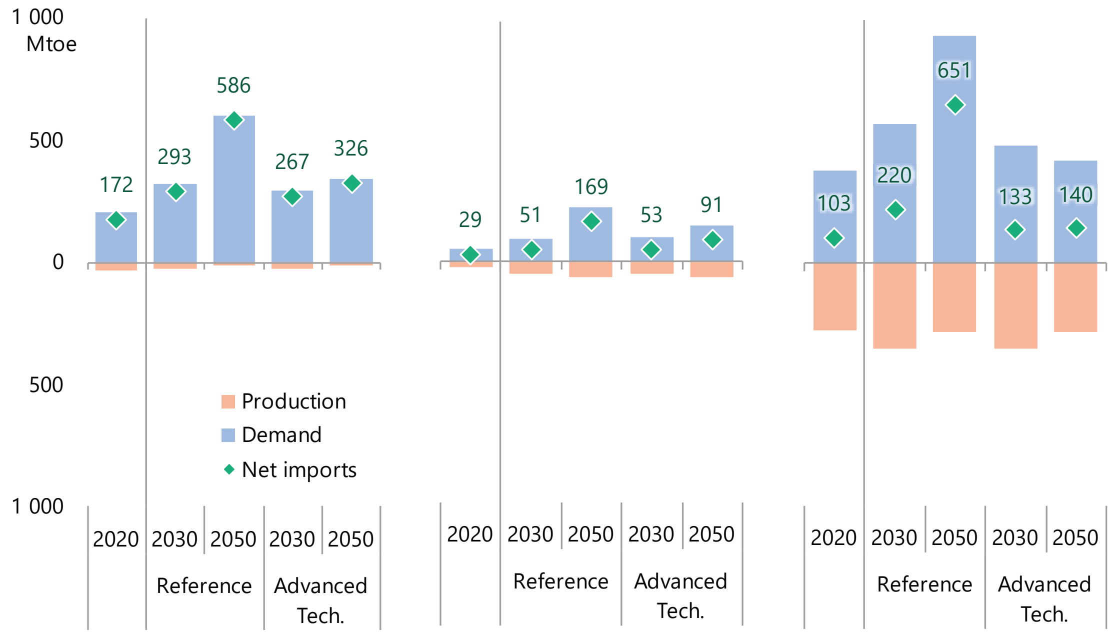
Final energy consumption



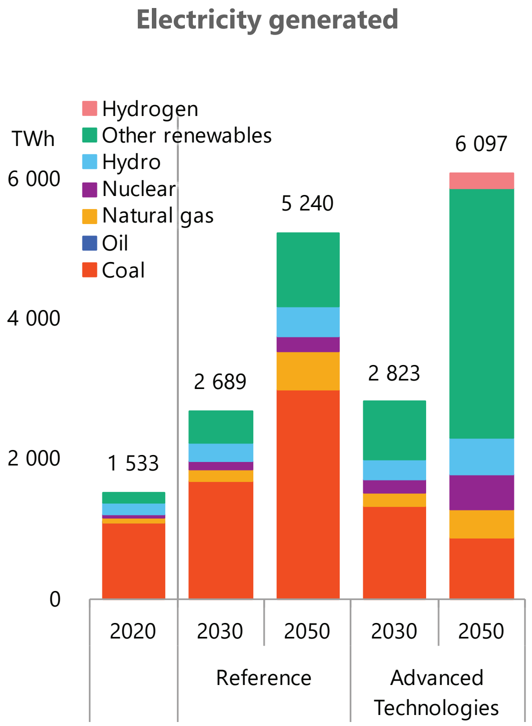
India

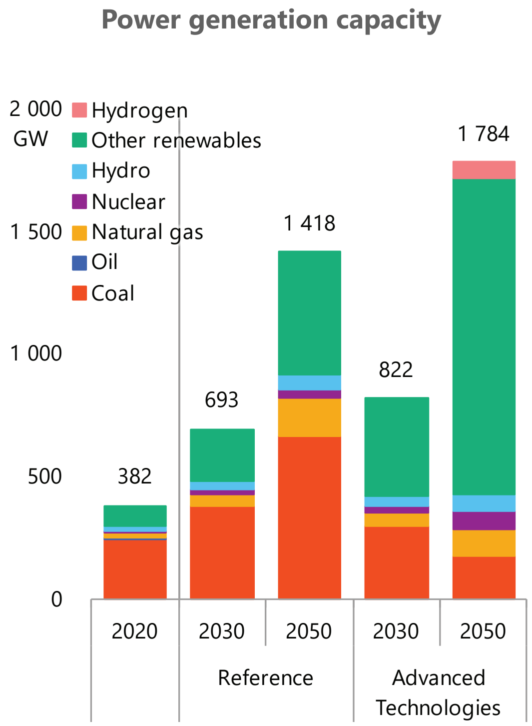
Supply and demand balance of fossil fuels

Oil Natural gas Coal

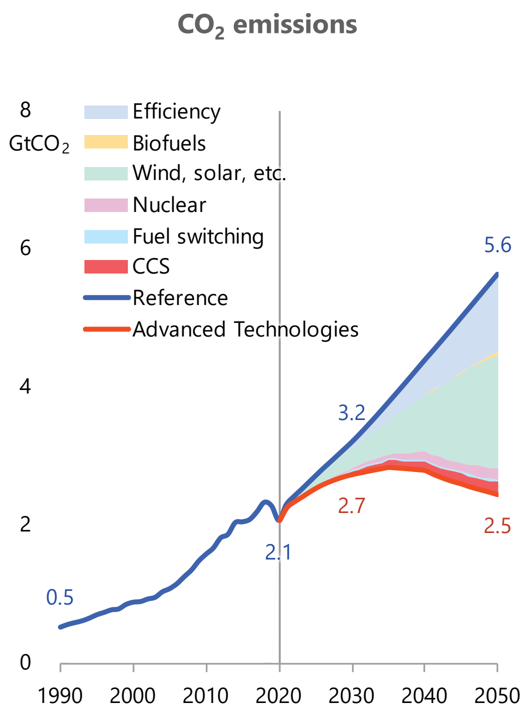


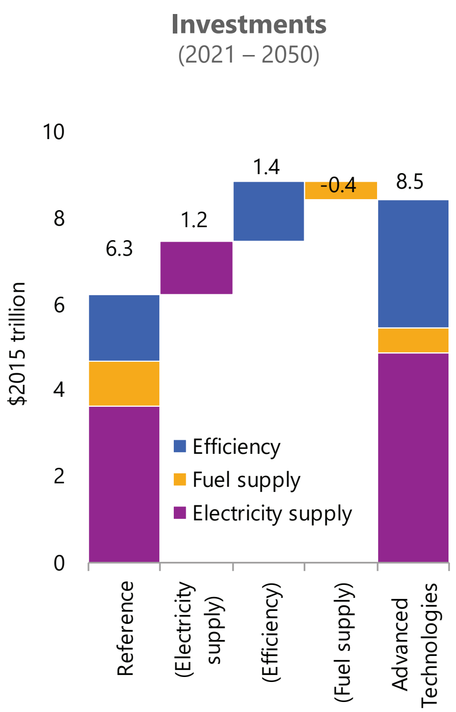
Power generation mix



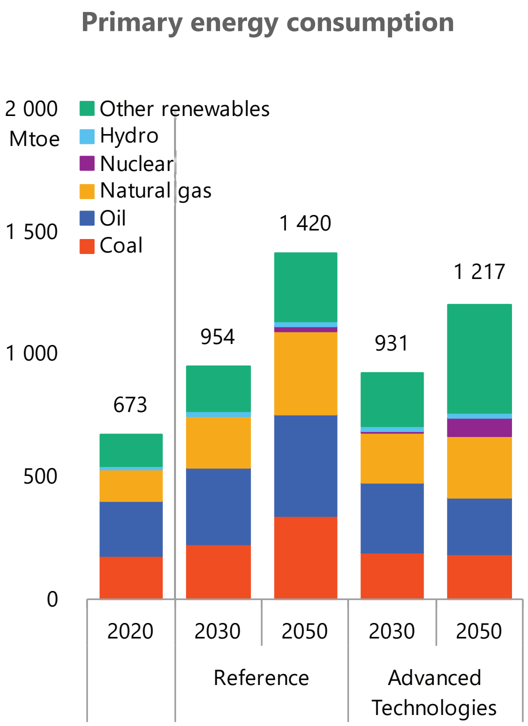


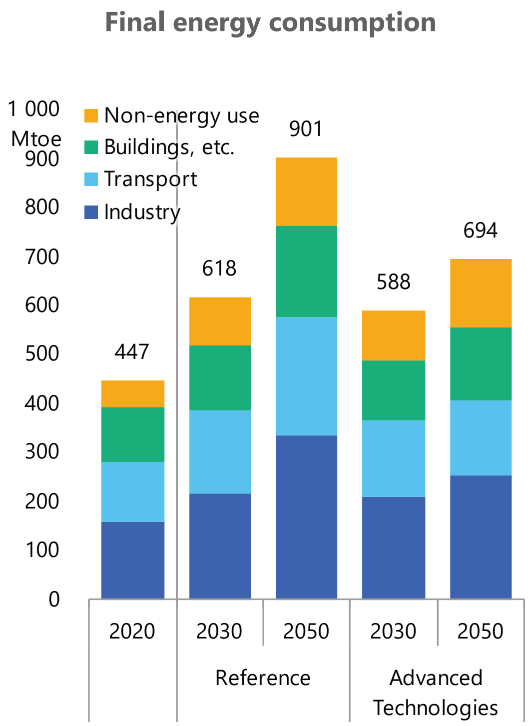
Energy-related CO_2 emissions and investments



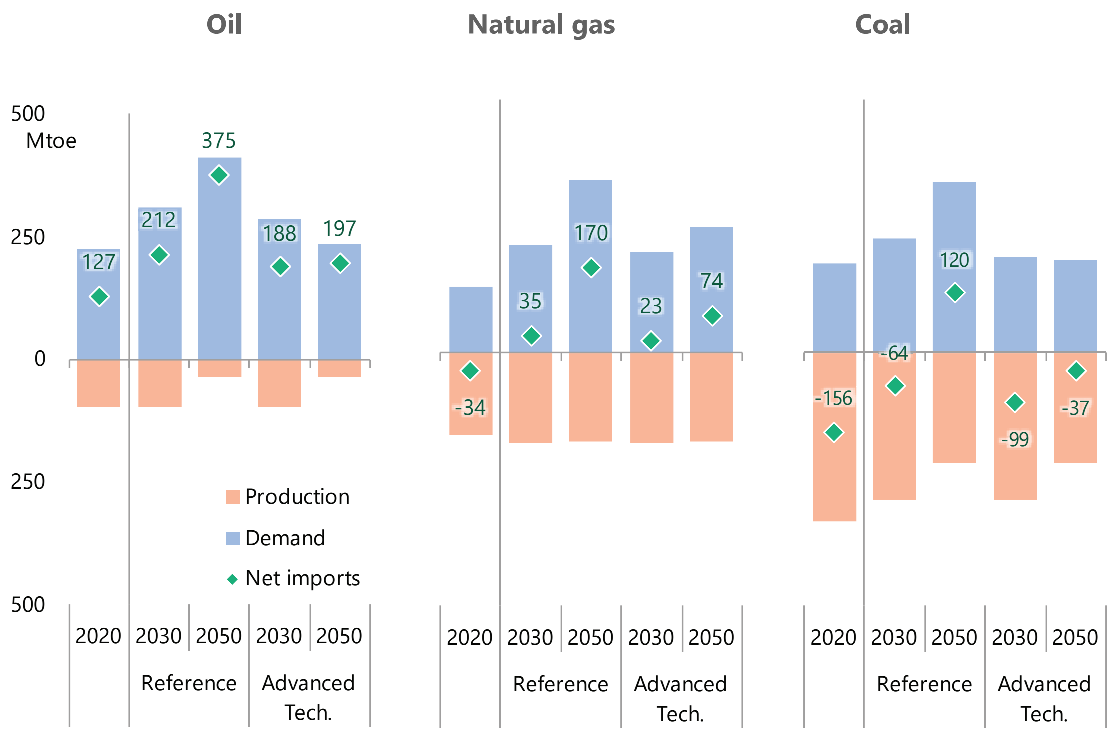


Energy consumption





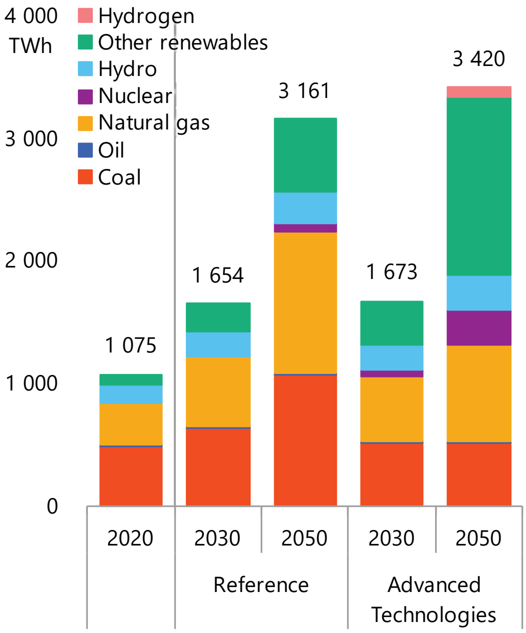
Supply and demand balance of fossil fuels



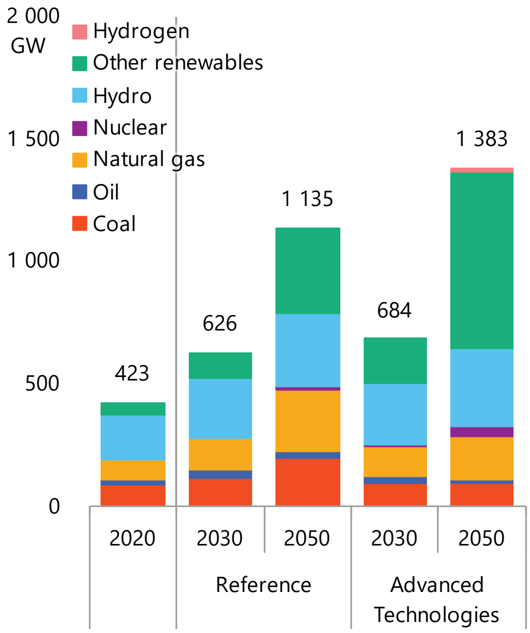
ASEAN

Power generation mix

Electricity generated



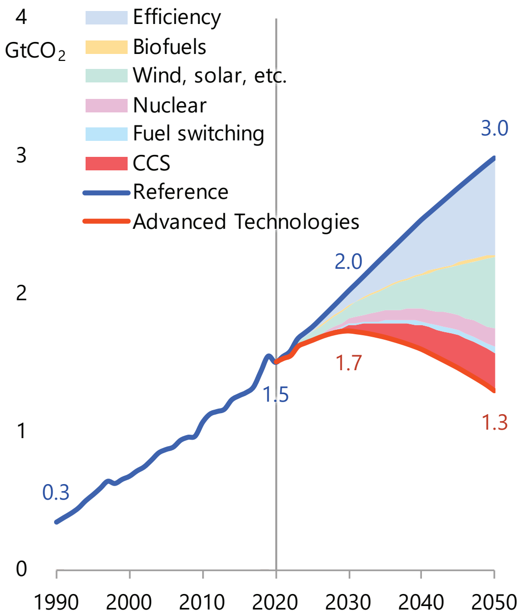
Power generation capacity



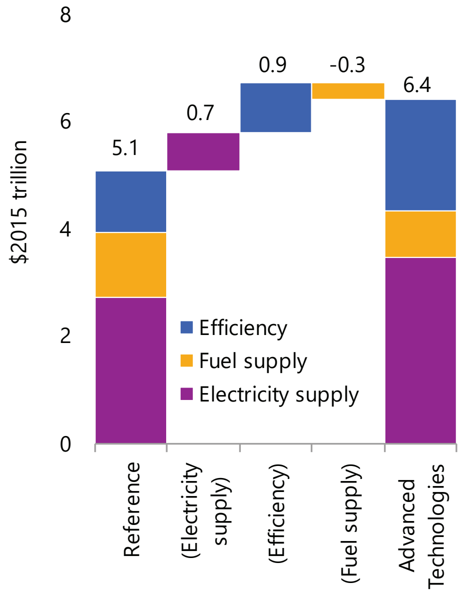
ASEAN

Energy-related CO_2 emissions and investments

CO_2 emissions



Investments
(2021 – 2050)



IEEJ Outlook 2023

October 2022

The Institute of Energy Economics, Japan