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Energy transition in the post corona world

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Global energy supply and demand outlook (Reference Scenario)

Global energy consumption returning to increasing trend

- An impact of the coronavirus (COVID-19) pandemic brings about a decline in the global primary energy consumption at least in the short term. The demand for energy will increase again, however, once vaccines and therapeutic drugs are developed, leading to the global disaster over, and society and the economy return to normal. In this case, under the "Reference Scenario" which reflects changes in energy and environmental policies to date and are expected to continue, energy consumption in 2050 will increase by 1.3 times over the 2018 level.
- Emerging and developing economies are responsible for a significant portion of the recovery in global energy consumption from the impact of COVID-19. As those economies drive the increase in global energy consumption, their global share will increase from 60% in 2018 to 70% in 2050.
- Fossil fuels will continue to play a major role in meeting the enormous global energy consumption. Mainly because of growth in the power sector, natural gas will become the largest contributor and its consumption will grow at an annual rate of 1.4%. By 2050 natural gas consumption will be 1.4 times that of 2018.
- Renewable energy (excluding solid biomass) and nuclear will account for 26% of the increase in primary energy consumption by 2050. It is very difficult and unrealistic to expect that non-fossil energy would cover the entire world's energy consumption; a combination of fossil fuel and non-fossil energy is required.

Middle Eastern oil producers re-emerge as the crude oil supply core

- In the Reference Scenario, the current slump in oil demand is temporary. Crude oil production in both the Organization of Petroleum Exporting Countries (OPEC) and non-OPEC countries will increase in response to an upturn in demand. Reflecting reductions in cost, shale oil production in the United States will increase until around 2030, leading the rise in global crude oil supply.
- In the longer term, OPEC member countries in the Middle East, with their abundant reserves and cheap production costs, will meet about half of the 20 million barrels per day (Mb/d) increase between 2018 and 2050 in world oil demand. Despite being endowed with one of the world's largest reserves, Venezuela, one of the OPEC members, has experienced a remarkable decline in production in recent years. Venezuela deserves attention as to how much it will recover and increase production in the coming year.

Liquefied natural gas (LNG)

- The United States will expand its LNG supply capacity in and after the mid-2020s. The liquefaction capacity would exceed 100 Mt per year when the projects under construction and for which final investment decisions have been made are completed, in addition to operating facilities.
- Australia, which offers one of the largest LNG supply capacity in the world, along with Qatar, will gradually increase its production in and after 2030. Future upstream natural gas resource development projects will centre on providing the required supplemental gas to existing LNG liquefaction facilities.

Coal production remains at high levels until around 2040

- Coal production will continue to decline in the European Union (EU), which guides the acceleration of low-carbonisation in COVID-19 economic support measures, and in North America, where coal demand does not grow. On the other hand, there is steady demand in emerging and developing economies, mainly in Asia, with high production levels expected until around 2040 in the reference scenario. Global coal production will increase until 2030, remain flat for a while, and then gradually decline.
- Steam coal production will increase mainly due to the increase in demand for power generation, but will start to decrease after peaking around 2040. Coking coal, which is mainly used as a raw material for steel production, is on the decline.

Electricity generation is rapidly expanding in Asia. Natural gas-fired power generation will be the largest power source.

- Global electricity generation will increase at an annual rate of 1.7% to 45 201 TWh in 2050, 1.7 times the 2018 level. Asia, with its rapidly growing economy, will increase generation at an annual rate of 2.0%, reaching 22 749 TWh in 2050, more than half of the world's total.
- Coal which is currently the largest power source will continue to be important, mainly in Asia, but its share will decline. Natural gas, expected to play a major role in adjusting for output fluctuation of renewable power generation, will become the largest source of electricity. Its share will reach 30% by 2050. In advanced economies, the trend of decarbonisation remains the same after COVID-19, so renewable energy (including hydro) will be the largest source of electricity.
- It is difficult for Japan, Korea, the United States, and some Western European countries to build nuclear power plants as originally planned. On the other hand, there are several countries, including China, which will further promote the use of nuclear in the future, and some countries, such as those in the Middle East, will introduce nuclear. As a result, global nuclear power generation capacity will gradually increase through 2050.

2% of GDP must be invested until 2050

- There is a growing movement toward "green recovery" in which the economic recovery from the corona crisis could be achieved through environmental investments. The Next Generation EU of €75 billion, by the European Commission, is a good example of that.

- On the other hand, to meet the significant increase in energy consumption in emerging and developing economies, a global investment of $77.4 trillion (in 2010 prices) in resource development, fuel transport, power generation, transmission and distribution facilities will be needed by 2050. As investments in fuel supply represent about 40% of the total, the stability of energy supplies could be threatened by an excessive fossil fuel divestment.

Advanced Technologies Scenario

- The "Advanced Technologies Scenario" envisages the strong implementation of energy and environmental policies that contribute to the securing of a stable energy supply and the introduction of climate change and air pollution countermeasures. The Scenario reduces energy consumption, particularly fossil fuels, by 15% from the Reference Scenario in 2050. Emerging and developing economies, where energy consumption is increasing and potential savings are large, play a major role.
- Oil demand peaks around 2030, due to the progress of efficiency improvement and fuel substitution. Oil demand decreases thereafter and oil supply in 2050 will be reduced to the level of 2017. As competition among suppliers intensifies, the relatively cost-competitive Middle Eastern OPEC members will increase their production the most during the period to 2050.
- Natural gas production in 2050 will be 27% lower than in the Reference Scenario. However, technological advance may lead to larger share of greener gas production capacity with more sophisticated management of greenhouse gas (GHG) emissions.
- The share of coal-fired power generation will decrease due to the progress of low-carbon technologies such as renewable energy, and the thermal efficiency of coal utilisation will increase in each field of coal utilisation such as power generation and steel production. Coal production will decrease from 7 804 Mt in 2018 to 4 413 Mt in 2050. A large drop in steam coal will increase the proportion of coking coal in total coal production.
- The share of renewable energies (includes hydro) in primary energy consumption will increase from 14% in 2018 to 25% in 2050, 9% percentage points above the Reference Scenario. In power generation, renewable energies such as solar, wind, biomass, etc. combined, is the largest sources of power, even if hydro is excluded.
- Nuclear will be introduced not only in advanced economies with ambitious low-carbon targets but also in emerging and developing economies in order to promote low-carbon energy while responding to the rapid expansion of electricity demand. Global nuclear power generation capacity will expand from 414 GW in 2018 to 725 GW in 2050, about 1.5 times the increase in the Reference Scenario.
- Additional investment of $6.7 trillion from the Reference Scenario is required to achieve the Advanced Technologies Scenario, bringing the cumulative investment to $82 trillion. Power generation in 2050 will be 3 900 TWh less than in the Reference Scenario, while plant and equipment investment for power generation and transmission will be $38.1 trillion, up 16% on a cumulative basis by 2050.

Post Corona World Transformation Scenario

- In the aftermath of the Corona disaster, the global economy will be in its worst condition since the Great Depression. Changes in people's behaviour and social and economic activities have dramatically reduced energy demand. It has been pointed out that a decline in energy prices, due to an oversupply, could deal a serious blow to the management of the energy industry and companies and destabilise oil-producing countries.
- In the "Post Corona World Transformation Scenario", the manifested changes in political, economic, and social structures are maintained and strengthened. The Post Corona World Transformation Scenario assumes that a departure from the free trade system and the global supply chain system in the pursuit of cost efficiency optimisation will reduce the global economic growth rate by 0.3% points per year relative to the Reference Scenario. Efforts to low-carbonisation/decarbonisation will be made in accordance with the actual conditions in respective country and region. A "patchy situation" so to speak.
- Growth in global primary energy consumption will also slow down, reaching 17.7 billion tonnes of oil equivalent (Gtoe) in 2050, down 4% from the Reference Scenario. In China, energy consumption is expected to decline by as much as 7%. In India, energy consumption will increase by 2% in ASEAN, as in the Reference Scenario. These regions will become relatively more important in terms of future increases in energy demand and share.
- Digitisation plays an important role in the transformation of the economy, society, lifestyle, etc. As such, an earlier peak in oil demand and the progress of electrification become apparent. Oil demand peaks around 2040 and by 2050, demand will be 14 Mb/d lower than the Reference Scenario level. The share of electricity in final energy consumption will increase to 28% in 2050, up 2% percentage points from the Reference Scenario.
- Efforts will be made to increase the self-sufficiency rate and diversify supply sources in order to strengthen energy security. At the same time, efforts will be made to develop and introduce advanced and innovative energy sources with an emphasis on technological hegemony. Although renewables and nuclear will expand relative to the Reference Scenario, fossil fuels remain the mainstay of energy.

Circular Carbon Economy/4Rs Scenario

- In order to achieve drastic reductions in GHG emissions, it is essential to develop not only energy efficiency and renewable energy technologies but also technologies to further decarbonise fossil fuel use. The importance of "Circular Carbon Economy" (CCE), which realises the final emission reduction of carbon dioxide (CO_2) from the utilisation of fossil fuel is advocated.

- Some technologies of the 4Rs— Reduce, Reuse, Recycle, and Remove — in the Circular Carbon Economy are more or less commercialised. If several representative technologies are fully introduced by 2050, CO_2 emissions will decrease by 20% from the "Advanced Technologies Scenario" of 25.2 Gt. That level of emissions approaches the 17 Gt of the "2°C Minimising Cost Path", which minimises overall costs[1] under conditions that limit the temperature increase in 2150 to less than 2°C.
- In the Circular Carbon Economy/4Rs Scenario developed in this outlook, primary energy consumption remains almost unchanged from the Advanced Technologies Scenario. Decarbonisation of fossil fuels can significantly reduce GHG emissions while utilising fossil fuels. The introduction of *blue* hydrogen in the power and transport sectors will reduce the share of oil and coal. Much of the demand for *blue* hydrogen is generated in emerging and developing economies, where energy demand is greatly expanding. Among the 4R technologies, the amount of reduction achieved by the reduce and recycle technologies that utilise carbon capture and storage accounts for a large portion.
- 80% of *blue* hydrogen comes from natural gas, increasing natural gas consumption. However, the scale of the increase does not reach the level of the Reference Scenario, and there are sufficient resources to expand the use of *blue* hydrogen.

Pragmatic approach to climate change issue

- A practical approach to climate change would be to seek an emission reduction path that minimises the sum of the costs of "mitigation" that curbs GHG emissions, "adaptation" that curbs damage, and "damages" under conditions where temperature returns to 2°C by 2150 – the "2°C Minimising Cost Path". The total cost in this path is significantly lower than in the path that reduces global GHG emissions by half by 2050.
- Among the factors that can have a significant impact on this cost-benefit analysis, the Minimising Cost Path changes significantly by incorporating the collapse of the Antarctic ice sheet. However, even that Path does not lead to GHG emissions levels below the 2°C Minimising Cost Path.

[1] In the model calculation, the approach of utility maximisation is used.

Part Ⅰ

World and Asia energy supply/demand outlook

1. Major 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 environment policies that have been in place so far. This does not mean that policies or technologies may be fixed at the present ones because policies expected through traditional and conventional ways of thinking are incorporated into this scenario. On the other hand, we assume that no aggressive energy conservation or low-carbon policies deviating from the 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 environment policies contributing to securing stable energy supply and enhancing climate change and air pollution countermeasures. 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 taken into account.

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 best-practice industrial process technologies (for steelmaking, cement, paper-pulp, etc.).

■ **Transport**

Further diffusion of clean energy vehicles (highly fuel-efficient vehicles, hybrid vehicles, plug-in hybrid vehicles, electric vehicles, 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 the enhancement of heat insulation.

Supply side technologies

■ **Renewable energies**

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

■ **Nuclear**

Acceleration in nuclear power plant construction and improvement in capacity factor.

■ **Highly efficient fossil fuel-fired power generation technologies promotion**

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

■ **Next-generation power transmission and distribution technologies**

Lower loss type of transformation and voltage regulator will penetrate further.

■ **Carbon capture and storage**

Note: SC stands for super critical power generation, USC for ultra-supercritical power generation, and A-USC for advanced ultra-supercritical power generation.

1.2 Major assumptions

The energy supply and demand structure is subject to population, economic growth and other social and economic factors, as well as energy prices, energy utilisation technologies, and energy and environment policies. The following assumptions for economic growth and population among these factors are common to the Reference and Advanced Technologies Scenarios.

Economy

Recent trends

The coronavirus disease 2019 (COVID-19) pandemic broke out in early 2020 and is unlikely to end in the world until the development and diffusion of specific vaccines or drugs. The pandemic has been coupled with emerging regional political confrontations to exert downward pressure on the global economy.

The United States, currently the largest economy in the world, has the world's largest number of COVID-19 infections which is dragging down its economic activities. Employment and income conditions have remarkably deteriorated, with the unemployment rate rising above 10% temporarily. In addition to a tit-for-tat exchange of tariff hikes amid the U.S.-China trade war, a new cold war or ideological struggle between the two countries has escalated to the point of no return. As the United States has become a major oil and gas producing country since the shale revolution, declines in oil and natural gas prices and demand, as well as the COVID-19 disaster and anti-globalism, have contributed to further dragging down the economy, deepening difficulties further.

The European economy, second to the U.S. economy, had continued economic growth led by Germany and Eastern Europe. As the United Kingdom's exit from the European Union (EU), the populist political parties' rise in some European countries and other changes demonstrated a growing political divides between pro- and anti-EU forces over immigration, refugee, fiscal and monetary policies. Furthermore, a free, open economic system based on the smooth movement of management resources within the union had been malfunctioning for some time. In July 2020, the European Commission, the executive branch of the union, decided to create a €750 billion recovery fund and issue common bonds for the first time in history. Under the fund, EU member governments would receive subsidies and loans from the commission and jointly bear debt, a reminder of their hope to enhance EU solidarity.

Although the impact of COVID-19 has calmed down in China (the world's third largest economy), the country has been confronting issues such as the Western Advanced Economies over human rights, Hong Kong's high-level autonomy ("one country, two systems" policy), information security and others. Those issues are contributing to making the future course of its economy uncertain. Particularly, China's confrontation with the United States has escalated and become serious through the retainment of high tariffs, a U.S. ban on Chinese mobile applications (such as TikTok and WeChat), a U.S. order for China to close a consulate-general and a reciprocal Chinese order. To avoid political risks, foreign companies have been refraining from production in China or relocating investment from China to other countries.

In response to a rapid decline in oil demand amid global economic deceleration, the Organization of the Petroleum Exporting Countries (OPEC) and some other oil-producing countries started joint large-scale production cuts in May 2020. As a result, these OPEC-plus countries including Russia and oil-producing countries in the Middle East and Latin America have been plagued with price and quantitative export drops for oil, their key export good.

Future assumptions

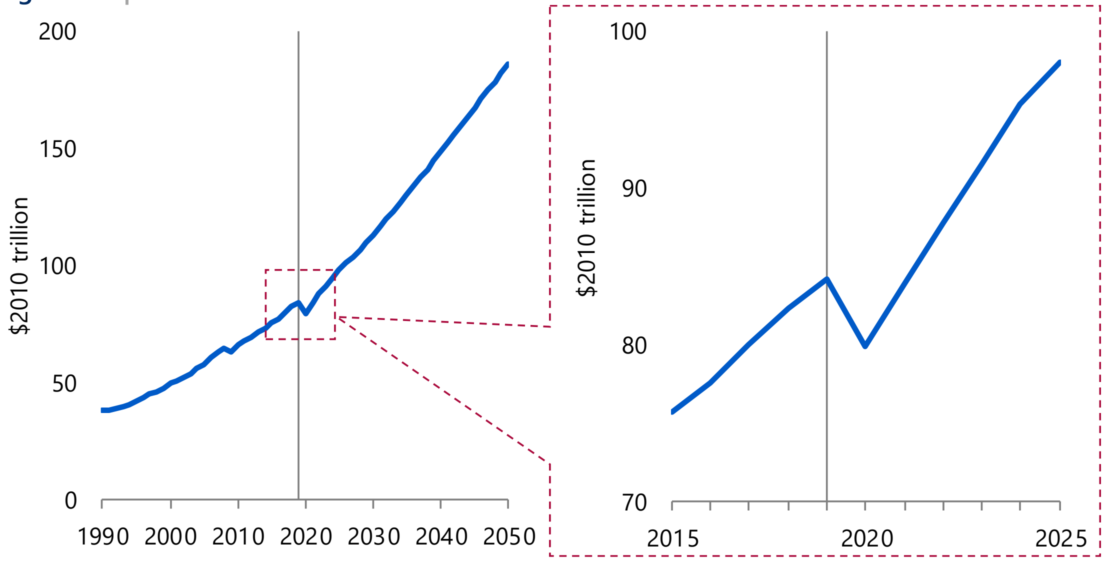
We assume that the world economy will contract due to the COVID-19 pandemic in 2020 before growing back thanks to the end of the pandemic in 2021. However, it would be difficult for the world economy to fully and quickly recover growth lost on COVID-19. Income falls and downward pressure on demand through lifestyle transformation would be combined with production capacity stagnation through sluggish capital investment on the supply side. A decline in international trade through transition from global supply chains to domestic ones would lead gross domestic product (GDP) to decrease.

While referring to government economic development plans and outlooks of think tanks in the world, we assume global economic growth as follows:

COVID-19 will calm down within 2020. From 2021, no country will experience any large-scale COVID-19 expansion or impose strict lockdowns such as those implemented in March and April 2020. The world economy will contract by 5.1% in 2020 before restoring a positive economic growth rate of 5.2% in 2021.

The world economy will grow at an annual rate between 4% and 5% while recovering from the COVID-19 disaster from 2022 through 2024 before the annual growth rate decreases from a 2.5%-3.0% range to a 2.0%-2.5% range from 2025.

Figure 1-3 | Global GDP



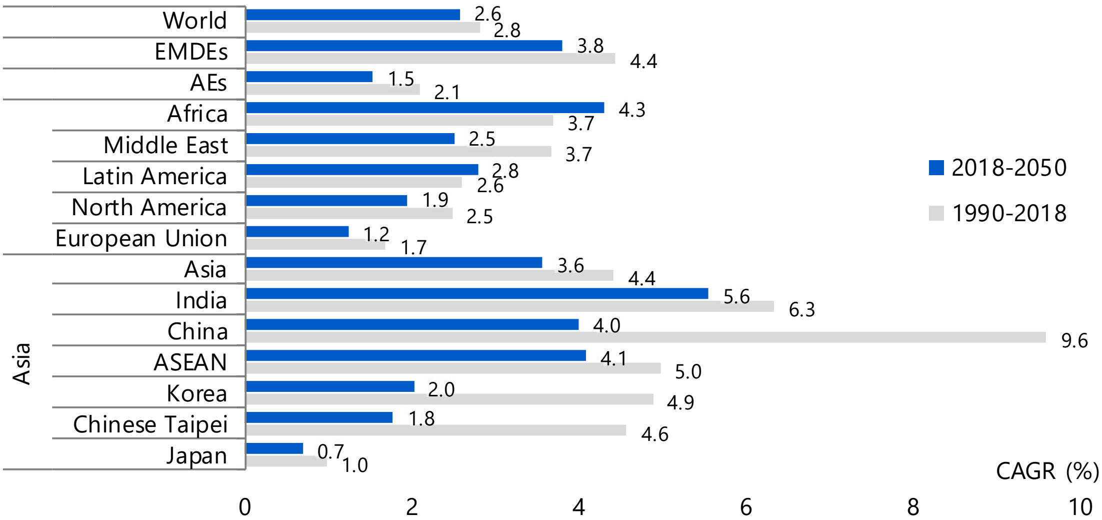
The impacts of COVID-19 on the world economy will be short-lived. Most economies in the world will continue growth over the medium to long term. To this end, however, they will have to improve productivity, achieve technological innovation, and implement appropriate fiscal and monetary policies and international cooperation.

Advanced Economies will grow at the same pace as in the recent past. Emerging Market and Developing Economies in Asia and Africa will remain the driver of global economic growth. Particularly, India, though currently plagued with the negative effects of structural reform and other policies that are slow to penetrate the economy, will grow at the world’s fastest annual pace of 5.6% over the outlook period as these policies promote domestic demand expansion and foreign investment over the long term. China will grow at an annual pace of 4.0%, though with growth continuing to slow down. Africa will post an average annual growth rate of 4.3%, the highest growth among regions, with its economic size almost quintupling from the present level by 2050.

In this way, Emerging Market and Developing Economies are expected to remain the centre of global economic growth. However, rising wages and citizens' growing consciousness of rights will force some of these countries to switch away from economic growth that takes advantage of abundant surplus labour and low costs

In consideration of the above-explained situation, we assume the world's annual economic growth rate at 2.6% over the outlook period (Figure 1-4). In the Post Corona World Transformation Scenario (Chapter 6), economic growth is assumed at lower levels due to social and other changes.

Figure 1-4 | Economic growth rates



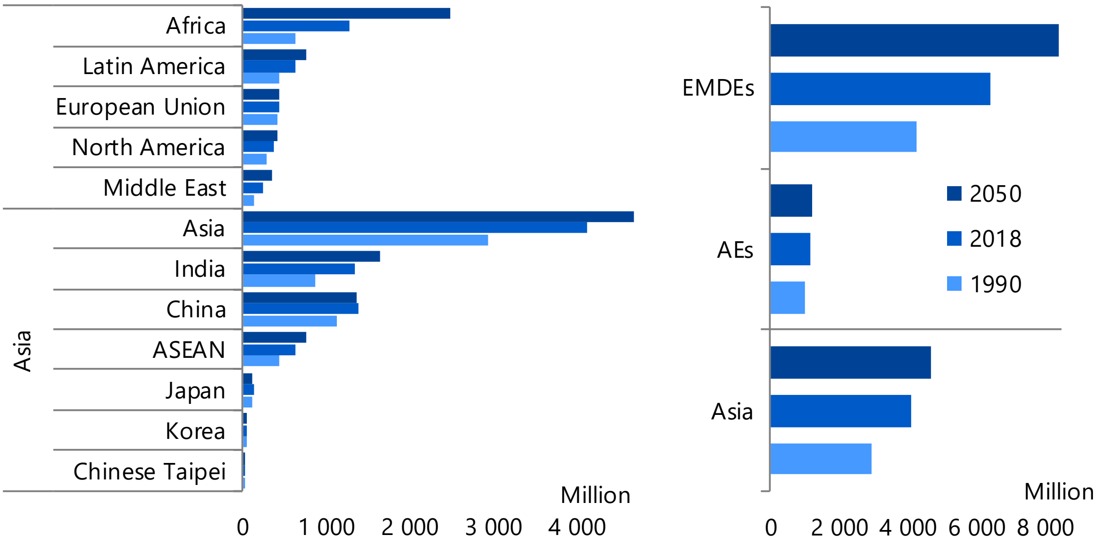
Note: AEs stands for Advanced Economies, and EMDEs for Emerging Market and Developing Economies.

Population

In assuming 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 that would be born to a woman during her lifetime, has slipped below two. Currently, the COVID-19 expansion and subsequent economic stagnation in the world are exerting a downward pressure on population. In Emerging Market and Developing Economies as well, the TFR is trending down in line with income growth and women's increasing social participation. However, their population will continue to increase as the mortality rate is declining due to developing medical technologies and improving food and sanitation conditions. Overall, global population will increase at an annual rate of around 0.8%, expanding to 9.7 billion in 2050 from 5.3 billion in 1990 and 7.6 billion in 2018 (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. In Europe, population will decrease in Germany and Italy while increasing moderately in France and the United Kingdom. The total population of the European Union will increase very moderately before turning downward. In Asia, Japan's population turned down in 2011 and will decrease by some 20% from the current level to 105 million in 2050. In Korea, population will peak out in the middle of the 2020s.

Figure 1-5 | Population



Emerging Market and Developing Economies will continue to increase their population substantially, driven by Africa and India. Africa will nearly double its population from the present level to 2.49 billion in 2050 as a drop in the mortality rate counters a gradual fall in the birth rate. Middle Eastern population will expand about 1.5-fold due to governments' financial incentives for increasing population and a growing population influx from other regions. Population in Other Europe/Eurasia will continue to slightly increase through around 2030 and fall back to the present level in 2050 due to population drops in Russia and Eastern Europe. In Asia, India will maintain a high population growth rate, with its population surpassing the Chinese population soon. By 2050, India will have the world's largest population at about 1.6 billion. China's population, currently the largest in the world, will peak at 1.43 billion around 2030 and decrease by about 60 million toward 2050. China is the only country with more than 100 million elderly people aged 65 or more and will see further population aging. Population in the Association of Southeast Asian Nations (ASEAN) will increase by 130 million to 760 million by 2050.

International energy prices

The COVID-19 pandemic brought about a historic free fall of oil prices. When COVID-19 started a global spread in March 2020, the OPEC-plus's failure to agree on additional production cuts, as well as an unprecedented oil demand loss amid the pandemic, triggered the free fall. Although the OPEC-plus on 12 April agreed to enhance production cuts, the front-month futures contract for the benchmark West Texas Intermediate crude oil plunged into negative territory (-$37.63 per barrel) due to serious U.S. oil storage capacity shortages on 20 April. Oil prices began to rise back in May as oversupply was expected to ease due to business reopening and the enhanced OPEC-plus production cuts. In August 2020, the OPEC-plus began to relax the production cuts. However, COVID-19 infections have continued to increase, with some regions seeing signs of the resumption of the spread of COVID-19. Meanwhile, the U.S.-China confrontation has expanded to involve not only trade but also intellectual property violations, information security, the South China Sea, the Hong Kong national security law and human rights abuses against Uighurs and other ethnic minorities. The world economy is expected to contract in 2020 for the first time since 2009, while the COVID-19 pandemic and the U.S.-China confrontation could potentially worsen. Oil and other international energy prices have come under downward pressure.

Reference Scenario

In the Reference Scenario, oil demand will keep on increasing in line with global economic growth while social pressure on oil consumption rises toward a decarbonised society. While U.S. and other non-OPEC oil production continues an upward trend on the supply side, oil importing countries will still be heavily dependent on OPEC and Russia that are plagued with geopolitical risks. Over the long term, oil production costs will rise on a shift to small and medium-sized, polar, and deep-water fields. Therefore, oil prices are assumed to creep up over the medium to long term, though experiencing high volatility over the short term. The real oil price (in 2019 dollars) is assumed to increase to $87/bbl in 2030 and $107/bbl in 2050 (Table 1-1). Under an assumed annual inflation rate of about 2%, the nominal price is projected to reach $108/bbl in 2030 and $198/bbl in 2050.

Table 1-1 | International energy prices

Real prices			Reference			Advanced Technologies		
		2019	2030	2040	2050	2030	2040	2050
Oil	$2019/bbl	64	87	102	107	71	66	56
Natural gas								
Japan	$2019/MBtu	9.9	8.2	8.2	8.0	7.7	7.0	5.8
Europe (U.K.)	$2019/MBtu	4.8	7.8	7.9	7.9	7.4	6.7	5.6
United States	$2019/MBtu	2.5	3.4	3.9	3.9	3.0	3.6	3.6
Steam coal	$2019/t	109	100	104	107	83	80	74

Nominal prices			Reference			Advanced Technologies		
		2019	2030	2040	2050	2030	2040	2050
Oil	$/bbl	64	108	155	198	89	100	104
Natural gas								
Japan	$/MBtu	9.9	10.2	12.4	14.8	9.5	10.6	10.6
Europe (U.K.)	$/MBtu	4.8	9.6	11.9	14.5	9.2	10.2	10.4
United States	$/MBtu	2.5	4.2	5.9	7.2	3.8	5.4	6.6
Steam coal	$/t	109	124	158	198	103	121	138

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

Natural gas prices in the United States will remain lower than in other regions, backed by abundant supply capacity. In line with relative development and production cost hikes and an increase in demand including exports, however, they will rise from record-low levels in 2020. Japan's real liquefied natural gas (LNG) import price is assumed to fall further in 2020 from $9.9 per million British thermal units (Btu) in 2019 before levelling off until around 2040. LNG exports from the United States have started and are expected to contribute to diversifying LNG supply sources for Japan and eliminating or easing the problem of the so-called destination clause for LNG imports. LNG prices are thus assumed to gradually deviate from oil prices. From 2019 to 2020, slack spot LNG prices expanded their gaps with long-term contract prices for Asia, prompting some LNG buyers to review contract terms and conditions including those for suppliers other than the United States. Despite progress in the optimisation of LNG maritime transportation, LNG prices in Japan will still be higher than in Europe due to limitations on lowering costs.

The coal price (the FOB[3] price of steam coal for shipments from New Castle Port in Australia) peaked out due to oversupply in the middle of 2018 and remained above $60 per tonne from the second half of 2019. As demand declined due to the global COVID-19 spread, the price temporarily slipped below $50/t and approached the low prices posted in early 2016. As production has been adjusted to weak demand and demand has been recovering due to a halt to economic deterioration in China, the world's largest coal consumer, coal prices will turn up in the future. While demand for coal for power generation is expected to increase in other Asian countries as well, tougher environmental regulations are likely to make it difficult to expand coal production capacity. As the supply-demand balance tightens gradually, coal prices will moderately rise over the medium to long term while repeating fluctuations on seasonal factors and temporary collapses of the supply-demand equilibrium. 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 downtrend of natural gas prices and in Europe and other regions that have introduced carbon prices.

Advanced Technologies Scenario

In the Advanced Technologies Scenario, fossil fuel demand will decline on energy efficiency improvement and fuel switching to nuclear and renewable energy. As a result, oil and natural gas price hikes will be slower than in the Reference Scenario. As natural gas demand growth is held down, with arbitrage between regions making further progress, interregional natural gas price gaps will narrow. Steam coal prices will decrease as Asian demand falls due to energy efficiency improvement in the manufacturing sector, the power generation sector's transition to more efficient coal-fired power plants and thermal efficiency improvement amid technological development in other coal-using sectors over the medium to long term.

[3] Free on board

2. Energy demand

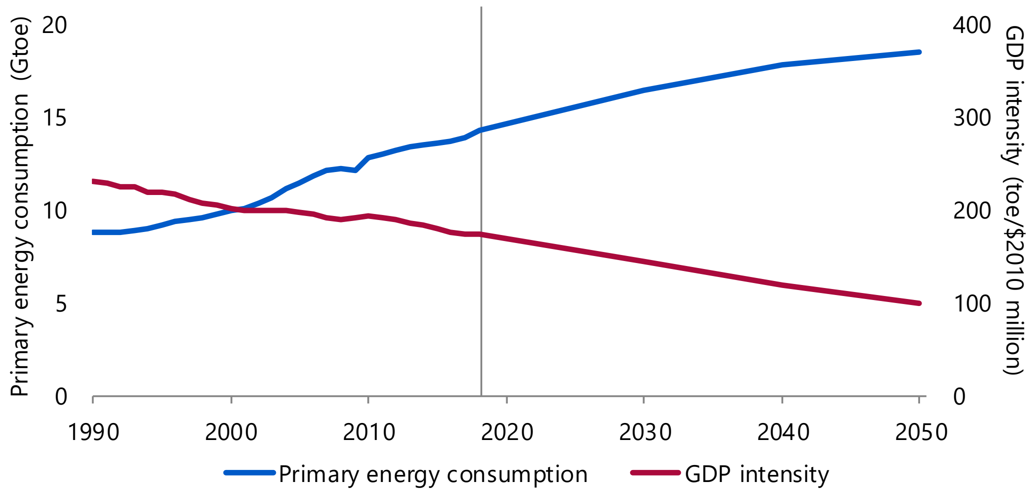
2.1 Primary energy consumption

Economies have the means to reduce the growth in global energy consumption.

As COVID-19 is spreading throughout the world, infections and deaths have continuously been increasing. In an attempt to hold down the spread, countries implemented border and city lockdowns, which stagnated passenger and cargo transportation and industrial production and lowered energy consumption in those sectors. Once COVID-19 vaccines and remedies will be available; however, all countries will experience strong economic activities, boosting the global economy and expanding energy consumption again.

In the Reference Scenario, global primary energy consumption is affected by COVID-19 over the short term, posting a decline in 2020 (Box 6-1). Over the long term, however, primary energy consumption will increase 1.3-fold from the 2018 level (Figure 2-1). As each country improves energy efficiency and reduces their energy intensity, the annual energy consumption growth will fall by one full percent, from 1.8% between 1990 and 2018 to 0.8% between 2019 and 2050.

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



The Emerging Market and Developing Economies will drive the overall growth in global primary energy consumption (Figure 2-2). Their share of global primary energy consumption will expand from 60.0% in 2018 to 70.5% in 2050. The Emerging Market and Developing Economies hold the key to energy consumption recovery from a plunge under the impact of COVID-19. Global energy consumption trends will change depending on what energy sources they will use and on how they will hold down the growth in energy consumption.

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

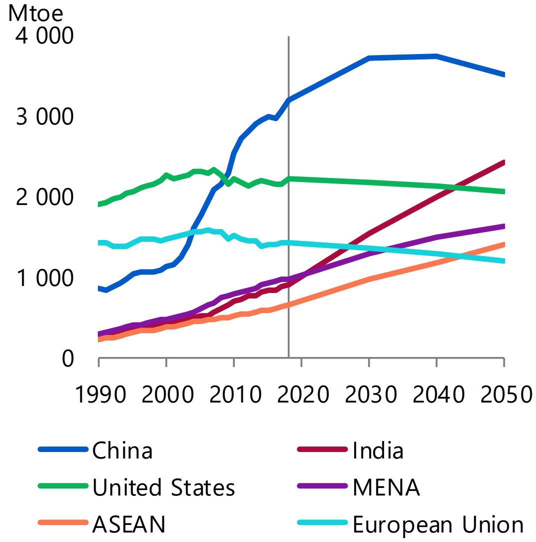
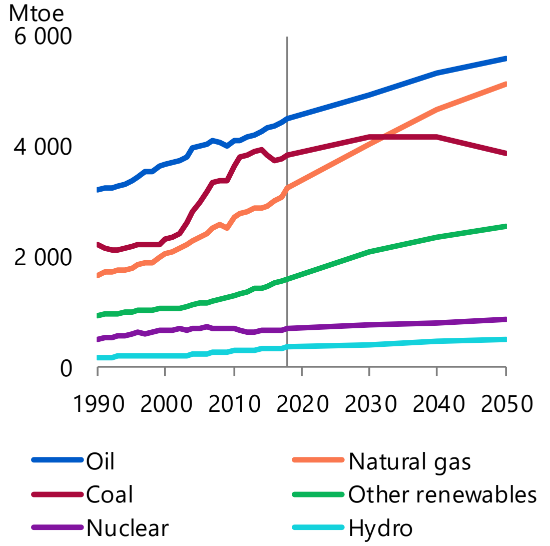


Figure 2-3 | Primary energy consumption by energy source [Reference Scenario]



The Asian Emerging Market and Developing Economies such as China, India, and the Association of Southeast Asian Nations (ASEAN) will increase their share of total energy consumption in the Emerging Market and Developing Economies from 36.0% in 2018 to 42.4% in 2050. Future energy policies and business activities in the Asian Emerging Market and Developing Economies can decouple the link between global economic recovery and energy consumption expansion after the COVID-19 crisis.

India and ASEAN will replace China as the leaders of primary energy consumption in the Asian Emerging Market and Developing Economies. As primary energy consumption in China will decline during the second half of the 2040s, its consumption growth for the period 2018-2050 will be limited to 1.1-fold. In contrast, India and ASEAN will boost their primary energy consumption 2.6-fold and 2.1-fold, respectively. This is because the average annual GDP growth between 2018 and 2050 will remain as high as 5.6% in India and 4.1% in ASEAN while China's GDP growth decelerates to 4.0%, with services becoming dominant in its economy. While it will be important for China to continuously monitor to hold down its energy consumption, it will be a major challenge for India and ASEAN to balance economic growth with energy conservation measures.

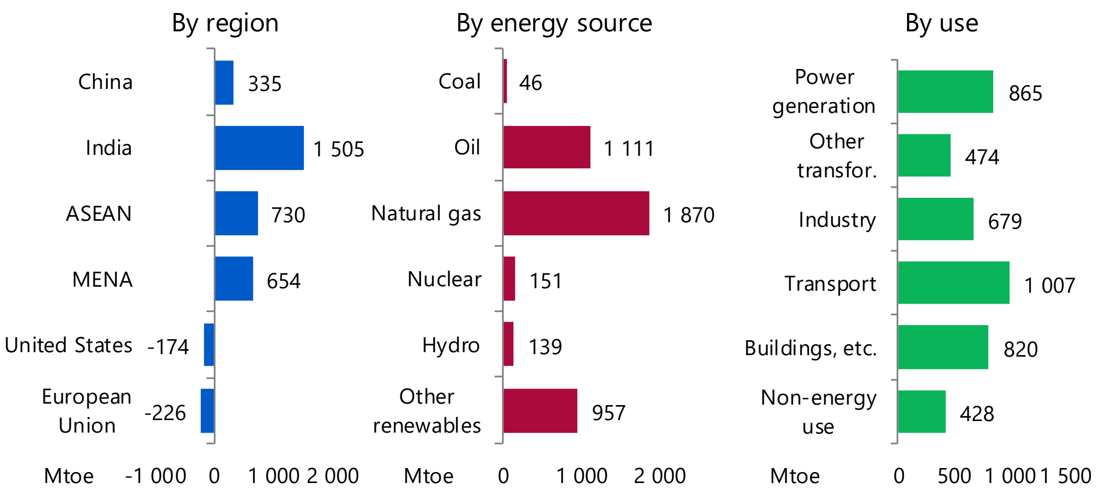
Following the high consumption growth in Asian Emerging Market and Developing Economies, the Middle East and North Africa (MENA) energy consumption will expand 1.7-fold from 2018 to 2050, after rising 3.3-fold from 1990 to 2018. Energy consumption in MENA will surpass that in the European Union in the first half of the 2030s, reaching 1 642 million tonnes of oil equivalent (Mtoe) or 8.9% of the global total in 2050. MENA energy consumption, though falling short of Chinese or Indian consumption, will top ASEAN consumption. Energy conservation in MENA, as in China, India, and ASEAN, will become a major challenge for the world.

In contrast, energy consumption will continue decreasing in such Advanced Economies as the European Union, the United States and Japan. This is because energy efficiency will improve as indicated by a decline in the GDP energy intensity while the three Advanced Economies' combined GDP limits the average annual growth to 1.5%. Their share of global energy consumption declined from 43.3% in 1990 and 28.6% in 2018 and will decline to 19.4% in 2050. Although consumption expansion in the Asian Emerging Market and Developing Economies and MENA strongly influences the decline in the share for the Advanced Economies, the three Advanced Economies must also consider holding down their energy consumption. Given that the Advanced Economies have consumed massive depletable resources and emitted massive greenhouse gases, they are responsible for conserving energy consumption further.

Will global energy consumption be supported by fossil or non-fossil energy sources?

Fossil fuels – oil, natural gas, and coal – will continue to play a great role in satisfying global energy consumption. Among energy sources, natural gas will post the largest consumption growth at 1.6-fold from 2018 to 2050. Natural gas consumption will increase at an annual rate of 1.4%, mainly in support of the power generation sector (Figure 2-4). Oil will show the second largest consumption growth, increasing at an annual rate of 0.7% mainly in the transport sector (including automobiles, aircraft, and ships). Coal consumption will peak in the middle of the 2030s as the world tries to hold down coal consumption in consideration of air pollution and climate change. Fossil fuels' share of global energy consumption in 2050, though falling from 81.2% in 2018, will still be as high as 78.8%, indicating that it will not be easy for the world to meet energy demand without fossil fuels (Figure 2-5).

Figure 2-4 | Primary energy consumption growth [Reference Scenario, 2018-2050]



Consumption of non-fossil energy sources such as nuclear and renewables will continue to expand, with their shares of global energy consumption rising. The growth in nuclear, hydro, and other renewables (excluding solid biomass) will account for 29% of global energy consumption growth from 2018 to 2050. Their share of global consumption, which stood at 18.8% in 1990 and 2018, will rise to 21.2% in 2050. It will be very difficult for non-fossil energy sources alone to meet global energy demand through 2050 and far more rational to use both fossil and non-fossil energy sources.

Among energy consumption sectors, transport and power generation will post the largest consumption growth rates. Supported by income growth, automobiles will account for most of energy consumption increase in the transport sector while energy consumption by aircrafts and ships will also increase sharply. The power generation sector will boost energy consumption as convenient electricity is increasingly used on the strength of income hikes and infrastructure development in unelectrified regions. The electrification rate on the supply side will post rapid growth particularly in Asia (Figure 2-6). The energy consumption expansion in the transport and power generation sectors is premised on the development of transport and power generation infrastructure in Emerging Market and Developing Economies, mainly in Asia. The industry and buildings sectors[4] are expanding their energy consumption by less than the transport and power generation sectors.

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

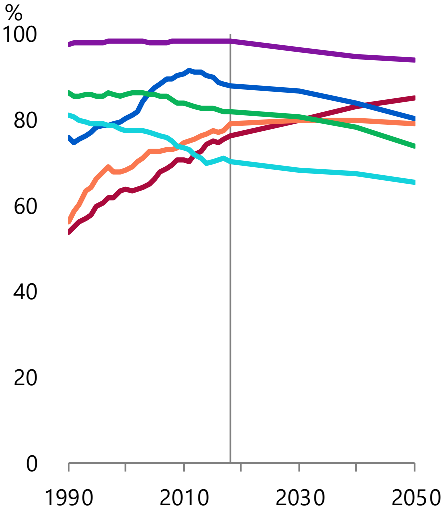
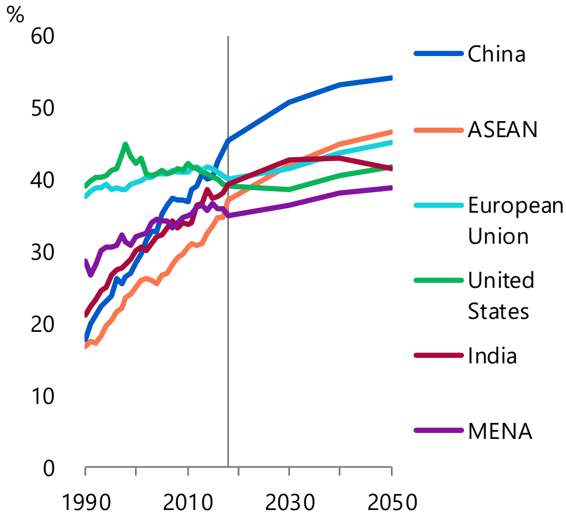


Figure 2-6 | Electrification rates (on the supply side) in selected countries/regions [Reference Scenario]

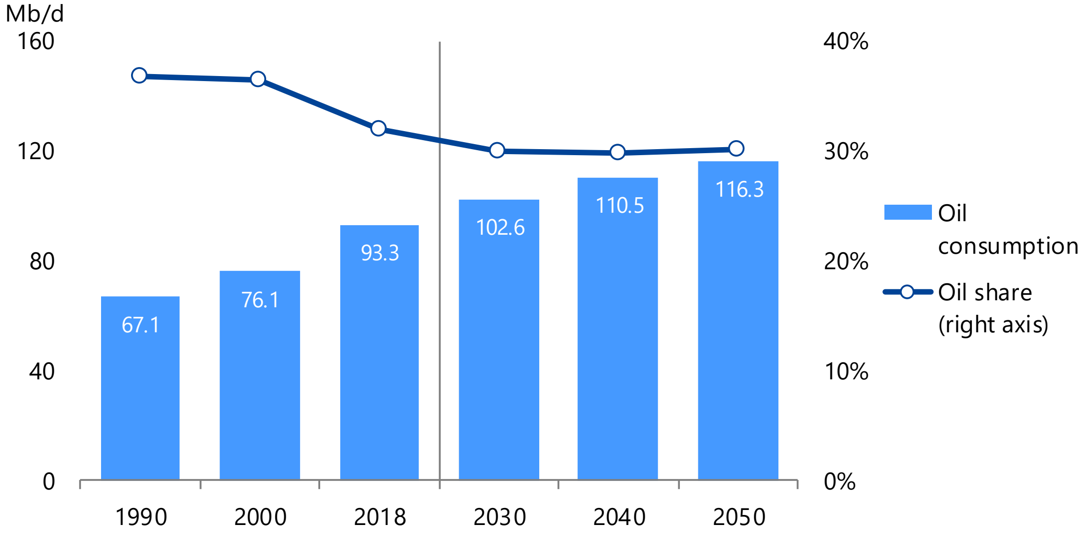


Oil will remain the most consumed energy source

Oil consumption, though falling in 2020, will robustly increase through 2050. After standing at 93.3 million barrels per day (Mb/d) in 2018, oil consumption will top 100 Mb/d in the second half of the 2020s and reach 116.3 Mb/d in 2050 (Figure 2-7). While some people argue that oil consumption will peak, the Reference Scenario indicates that oil consumption will continue increasing, though with its share of primary energy consumption falling slightly. Oil will remain the most consumed energy source.

[4] Buildings sector includes residential, commercial and public services, agriculture/forestry, fishing and non-specified.

Figure 2-7 | Global oil consumption and its share of primary energy consumption [Reference Scenario]



In the Advanced Economies, however, oil consumption has already peaked (Figure 2-8). After falling at an annual rate of 1.0% from the peak in 2004 to 2018, their oil consumption will decrease by 9.2 Mb/d at an annual rate of 0.9% from 2018 to 2050. A major factor behind the oil consumption decline is a fall in automobile fuel consumption due to fuel efficiency improvements for conventional vehicles and the diffusion of electrified vehicles including hybrid cars.

Figure 2-8 | Oil consumption in selected countries/regions [Reference Scenario]

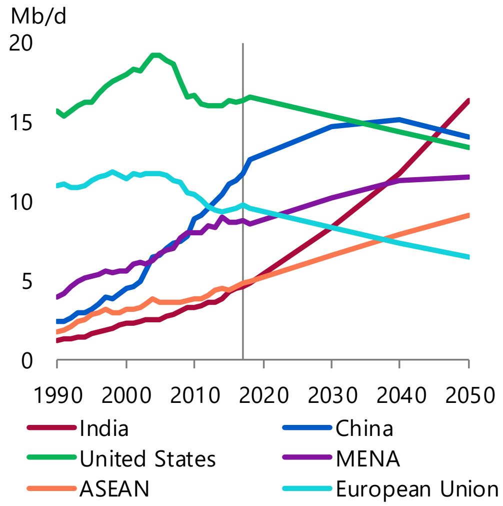
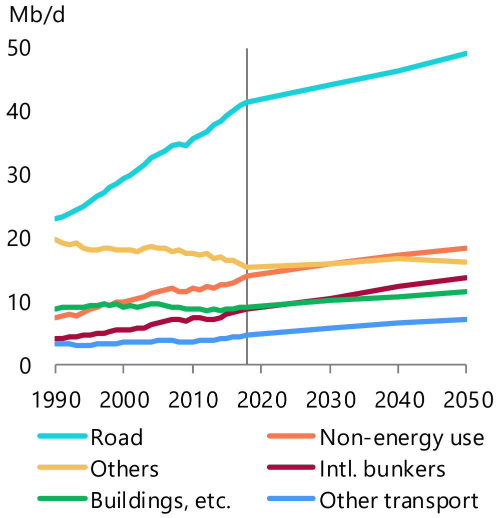


Figure 2-9 | Global oil consumption [Reference Scenario]



Meanwhile, oil consumption in the Emerging Market and Developing Economies will increase firmly (Figure 2-9). Their oil consumption, though falling 1.6% between 2019 and 2020 due to the COVID-19 pandemic, will increase by 27.3 Mb/d from 2018 to 2050 for an average growth rate of 1.5% per year. The transport, non-energy use and buildings sectors will make major contributions to the growth in oil consumption in those economies.

In the transport sector of the Emerging Market and Developing Economies, oil consumption for automobiles will increase from 20.6 Mb/d in 2018 to 35.3 Mb/d in 2050. This is primarily because vehicle ownership will rise 2.7-fold, thanks to income growth and the development of transport infrastructure such as roads and bridges.

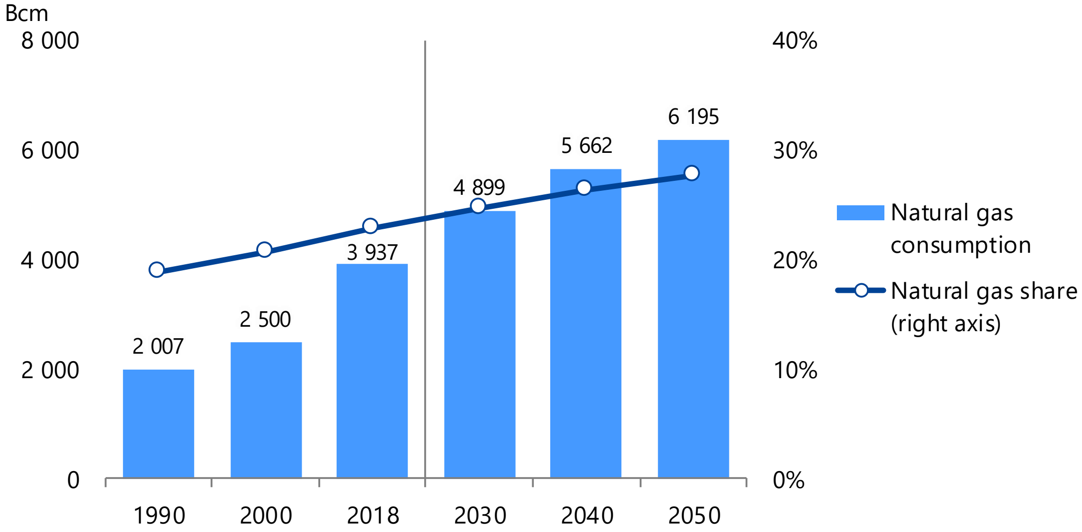
In the non-energy use sector of the Emerging Market and Developing Economies, oil consumption will expand by 4.1 Mb/d, centring on the petrochemical industry. As global demand remains strong for plastics and other petrochemical products on the demand side, oil-supplying countries also hope to develop their petrochemical industry to diversify industries. As the supply side meets the demand side, the non-energy use sector will drive oil consumption growth. Global regulations on plastics will have to be toughened to hold down this sector’s oil consumption.

In the buildings sector of the Emerging Market and Developing Economies, oil consumption will increase by 3.6 Mb/d, centring on water heating and cooking. In line with income growth and for health reasons, consumers will switch from coal and solid biomass to oil which is a relatively cleaner form of energy. Although the switch to electricity or city gas for water heating and cooking will cost much in terms of initial investment and operation, it will make the buildings sector’s oil consumption growth inevitable in Sub-Saharan, South Asian and Southeast Asian countries.

Natural gas will post the largest consumption growth among energy sources

Like oil, natural gas will post a consumption decline due to COVID-19 in 2020 but it will score the largest consumption growth among energy sources through 2050. Natural gas consumption will increase at an annual rate of 1.4% from 3 937 billion cubic metres (Bcm) in 2018 to 6 193 Bcm in 2050 (Figure 2-10). Natural gas will widen its share of primary energy consumption from 22.8% in 2018 to 27.8% in 2050, becoming the second most consumed energy source after oil.

Figure 2-10 | Global natural gas consumption and natural gas' share of primary energy consumption [Reference Scenario]



The Emerging Market and Developing Economies will account for 92.0% of natural gas consumption growth totalling 2 258 Bcm between 2018 and 2050 and the Advanced Economies for 3.3% (Figure 2-11). Among the Emerging Market and Developing Economies, MENA, China, and India will post particularly remarkable growth. MENA natural gas demand will increase by 511 Bcm as the Middle East promotes domestic natural gas consumption to earn foreign currencies with oil exports. Natural gas consumption mainly for the power generation sector will increase by 419 Bcm in China and by 275 Bcm in India over the next three decades. Among the Advanced Economies, Japan will reduce natural gas consumption by 28 Bcm, while the European Union keeps such consumption almost unchanged. Exceptionally, the United States will expand natural gas consumption by 77 Bcm by around 2040 as shale gas consumption rises on production expansion. Given that the Emerging Market and Developing Economies will drive global natural gas consumption growth, the efficient use of natural gas will be required to hold down their consumption.

The power generation, industry, and buildings sectors will be responsible for natural gas consumption growth in the Emerging Market and Developing Economies (Figure 2-12). The power generation sector will account for more than half of their natural gas consumption growth due to higher costs for oil-fired power generation, environmental problems for coal, and difficulties in large-scale power generation and higher grid integration costs for renewable energy. After the power generation sector, the industry sector will post the second fastest growth in natural gas consumption. In view of convenience and environmental considerations, the sector will progressively switch from oil and coal to natural gas. 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 cause health damage and air pollution. To hold down natural gas consumption in those sectors, the Emerging Market and Developing Economies will have to introduce and diffuse highly efficient gas equipment.

Figure 2-11 | Natural gas consumption in selected countries/regions [Reference Scenario]

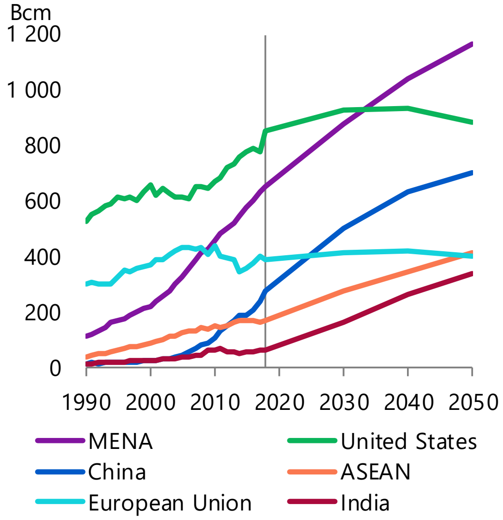
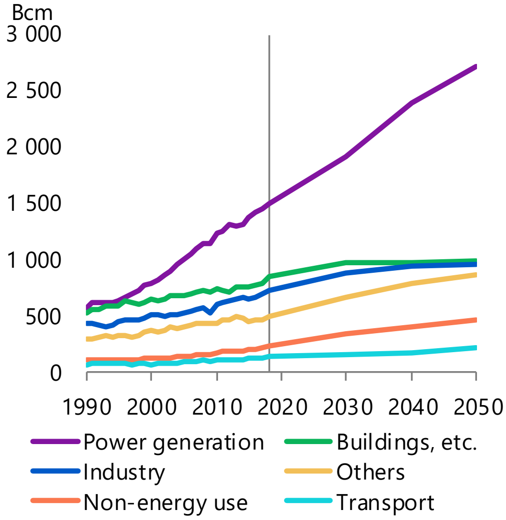


Figure 2-12 | Global natural gas consumption [Reference Scenario]



Coal consumption will peak out around 2035

Coal consumption will also decline due to the pandemic in 2020 but will recover before peaking in the middle of the 2030s, indicating a trend that will differ from those for oil and natural gas consumption (Figure 2-13). Over the short term, coal consumption, which stood at 5 483 million tonnes of coal equivalent (Mtce) in 2018, will fall in 2020 before increasing at an annual rate of 9.5%. However, it will peak at slightly more than 6 000 Mtce around 2035 and decrease thereafter at an annual rate of 7.6%. Coal's share of primary energy consumption will be reduced from 26.9% in 2018 to 20.9% in 2050. It will no longer be the second most consumed energy source after oil, being replaced by natural gas.

While China accounts for 51.6% of global coal consumption, Europe, the United States and Japan for 17.0% and India for 10.8% at present, China and the three Advanced Economies will reduce their respective coal consumption shares, and then India and ASEAN boost theirs (Figure 2-14). Figure 2-15 illustrates global coal consumption by sector. China's coal consumption will peak in the middle of the 2020s. Its coal consumption for power generation increases through the mid-2020s, its steel and cement production will soon be peaking while industrial coal consumption will plunge some 40% by 2050. Coal consumption in Europe, the United States and Japan will continue falling both for industrial production and power generation, posting a 48% drop in 2050. In contrast, India will boost coal consumption 2.6-fold for industrial production and 2.2-fold for power generation. ASEAN will expand consumption 1.9-fold for industrial production and 2.3-fold for power generation. To hold down global coal consumption, China and the three Advanced Economies must further promote conservation, and India and ASEAN will have to address themselves to their coal policies.

Figure 2-13 | Global coal consumption and its share of primary energy consumption [Reference Scenario]

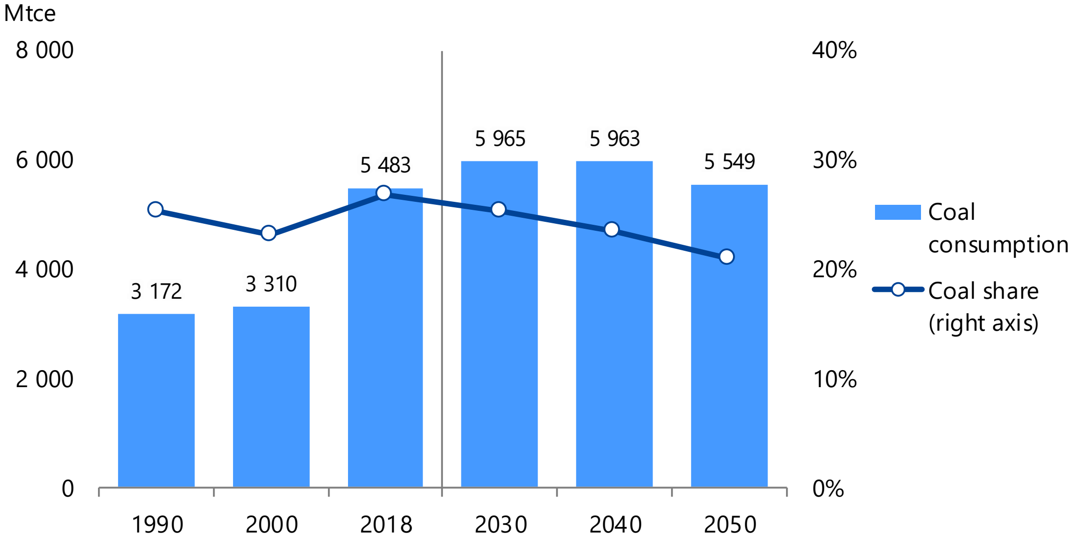


Figure 2-14 | Coal consumption in selected countries/regions [Reference Scenario]

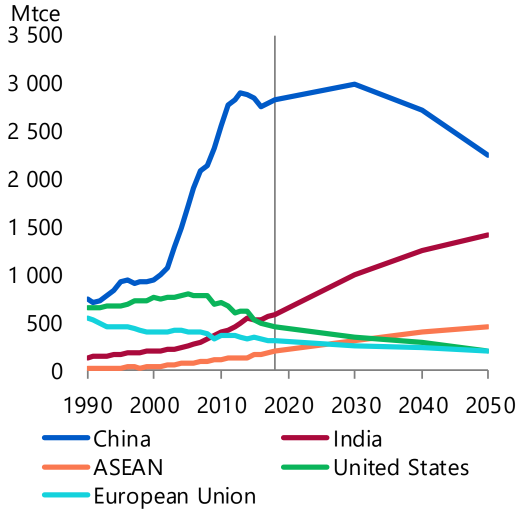
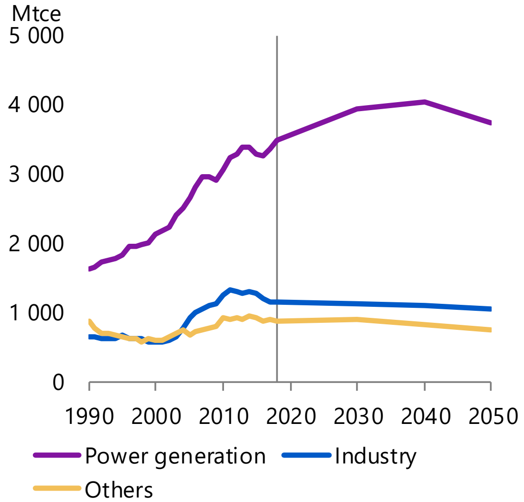


Figure 2-15 | Global coal consumption by sector [Reference Scenario]



Because of the need to address climate change, global coal consumption has come under fire particularly in Europe among the Advanced Economies. Europe has toughened economic burdens with restrictions on CO_2 and mercury emission for coal-fired power plants and enhanced regulations on coal consumption both for power generation and industrial production. Meanwhile, Asian Emerging Market and Developing Economies such as China, India, and ASEAN view coal as an affordable domestic energy source from the viewpoint of energy self-sufficiency and do not necessarily impose severe restrictions on coal consumption. While the less coal-dependent Europe is about to promote coal divestment in cooperation with financial institutions, those in China and India do not necessarily support such divestment. To hold down coal consumption, Asian Emerging Market and Developing Economies will have to introduce and diffuse highly efficient coal consumption equipment both in power generation and industry sectors.

Non-fossil power generation will continue expanding

Despite the growing hopes on the spread of non-fossil energy sources for the economic recovery from the COVID-19 crisis, the non-fossil energy sources' share of primary energy consumption will rise only slightly from 18.8% in 2018 to 21.2% in 2050. At present, 72.5% of non-fossil energy consumption is for power generation, including nuclear and hydro (Figure 2-16). Meanwhile, non-fossil energy consumption for heating is mainly comprised of solid biomass, including firewood and livestock manure used mainly in rural areas of the Emerging Market and Developing Economies (Figure 2-17).

Figure 2-16 | Non-fossil energy consumption for power generation [Reference Scenario]

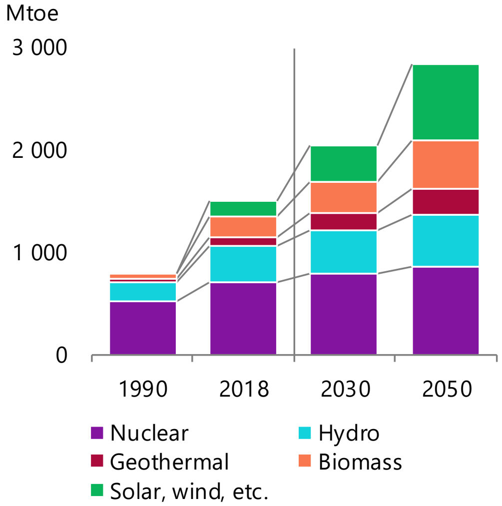
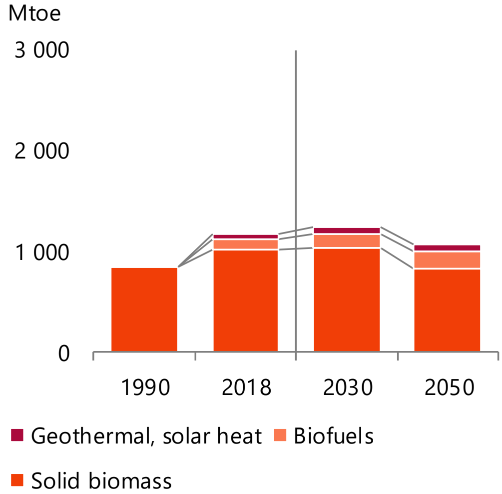


Figure 2-17 | Non-fossil energy consumption for heating [Reference Scenario]



All future non-fossil energy consumption growth will be for power generation and non-fossil energy consumption for heating will grow little before turning downward around 2030. Solar photovoltaics (PV), wind, and other non-hydro renewables will post the largest consumption growth among non-fossil energy sources for power generation. Their consumption increased 260-fold by 2018 from 1 Mtoe in 1990 and will rise 4.6-fold from 2018 to 2050. Growth of nuclear and hydro energy consumption will be limited due to nuclear policy modifications, and environmental and social considerations. Their share of non-fossil energy consumption for power generation will decline from 71.0% in 2018 to 47.8% in 2050. Non-fossil energy consumption for heating will turn downward because rural areas accounting for most of such non-fossil energy consumption will switch from traditional biomass to modern energy sources in line with income and living standard improvements. Liquid biomass fuel and biogas consumption mainly for automobiles and buildings will expand 1.6-fold through 2050;

however, the absolute volume of such consumption will be limited to only 16.0% of non-fossil energy consumption for heating.

Oil and natural gas consumption will continue growing in Asia

Although the Asian economy will contract 1.6% between 2019 and 2020 due to the COVID-19 pandemic, it will grow at a high average annual rate of 3.6% between 2018 and 2050. Particularly, GDP will rise 3.5-fold in China, 5.6-fold in India and 3.6-fold in ASEAN. As a result, the three economies' share of Asian GDP will increase from 64.4% in 2018 to 81.6% in 2050.

In line with their economic expansion, the three economies will capture 97.1% of Asian energy consumption growth between 2018 and 2050 (Figure 2-18). Their combined share of Asian energy consumption will rise from 81.9% in 2018 to 86.6% in 2050. While Asian Advanced Economies including Japan and Korea reduce their combined share of Asian energy consumption, China, India, and ASEAN will increase their influence.

Figure 2-18 | Asian primary energy consumption [Reference Scenario]

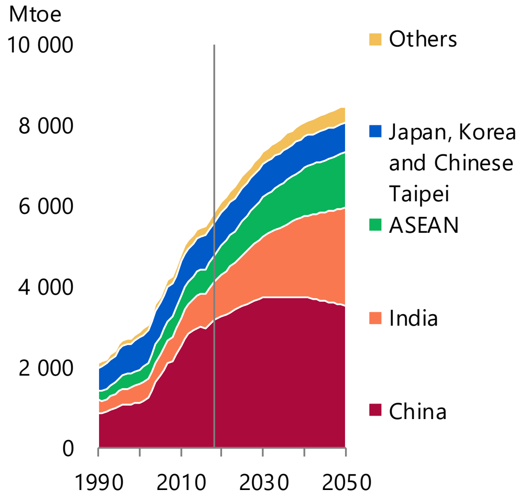
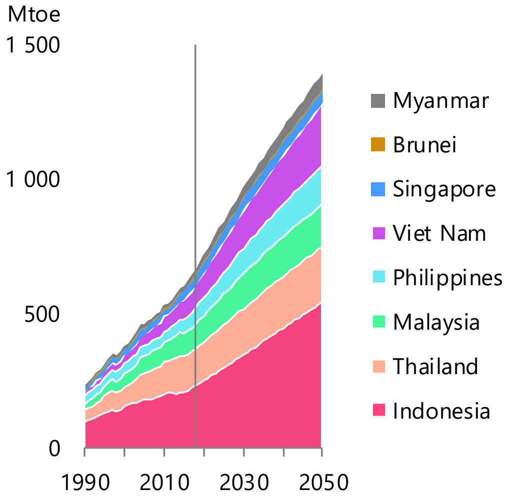


Figure 2-19 | ASEAN primary energy consumption [Reference Scenario]



However, energy consumption trends in China, India, and ASEAN are not essentially the same (Figures 2-18 and 2-19). In China, energy consumption increased at a high annual rate of 4.7% between 1990 and 2018 but will decelerate its average annual growth to 0.7% between 2018 and 2040 before turning downward in the middle of the 2040s. In India, consumption grew at an annual rate of 4.0% between 1990 and 2018 and will continue to rise 3.8% annually between 2018 and 2050. ASEAN, which increased consumption at an annual rate of 3.8% between 1990 and 2018, will continue at the slower speed of 2.3% per year between 2018 and 2050. To explain the distinct trends will be three economies' different economic and population growth paces.

The Chinese economy expanded from $0.8 trillion in 1990 to $10.8 trillion in 2018 and will grow to $38 trillion in 2050. Chinese population increased from 1.14 billion in 1990 to 1.39 billion in 2018 and will peak around 2030 before slipping below the present level to 1.37 billion in 2050.

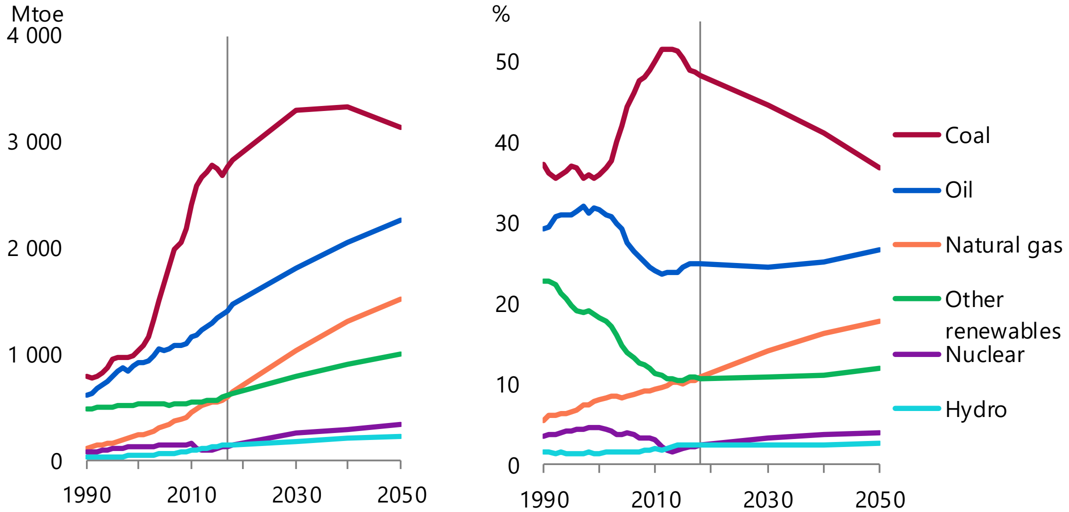
While the economy expands, the population downturn will contribute to a certain degree to holding down energy consumption.

The Indian economy, which stood at $0.5 trillion in 1990, grew 5.6-fold between 1990 and 2018 and will post another 5.6-fold increase between 2018 and 2050. India increased its population from 0.87 billion in 1990 to 1.35 billion in 2018 and will replace China as the most populated country in the world around 2023 before further boosting its population to 1.64 billion in 2050. As GDP per capita will increase to close to $10 000 in 2050 (a combination of population growth with income and living standard improvements), India will continue to expand energy consumption.

ASEAN's share of Asian energy consumption rose from 11.0% in 1990 to 11.5% in 2018 and will rise further to 16.5% in 2050. Its GDP per capita increased from $1 700 in 1990 to $4 500 in 2018 and will grow to $13 700 in 2050. As for India, the ASEAN energy consumption will keep on growing reflecting a population reaching 0.76 billion in 2050 and improvements in per capita income and living standards.

Fossil fuels will continue to account for most of Asian energy consumption (Figure 2-20). Their share of Asian energy consumption stood at 84.3% in 2018 and will still be as high as 81.4% in 2050. Particularly, oil and natural gas consumption will keep on increasing. How to reduce Asian fossil fuel consumption will be extremely significant for global climate change countermeasures.

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



Annual Asian oil consumption growth will decelerate from 3.1% between 1990 and 2018 to 1.4% between 2018 and 2050. The transport sector will account for 63.2% of the future increases, the non-energy use sector for 17.2%, and the buildings sector for 11.3%. India will account for 68.8% of the growth, ASEAN for 25.2%, and China for 8.5%. While Asian oil consumption growth captures 73% of global growth, Asia's oil self-sufficiency rate will decline from 23.9% in 2018 to 13.4% in 2050. To secure stable oil supply and address environmental problems, Asian economies will have to switch from oil to other energy sources and increase oil consumption efficiency.

Figure 2-21 | Asian oil consumption [Reference Scenario]

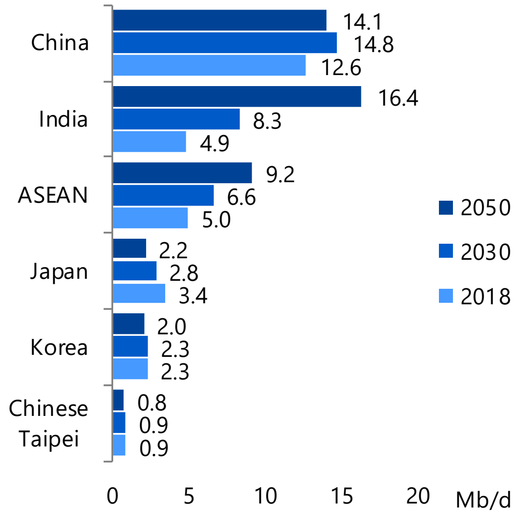
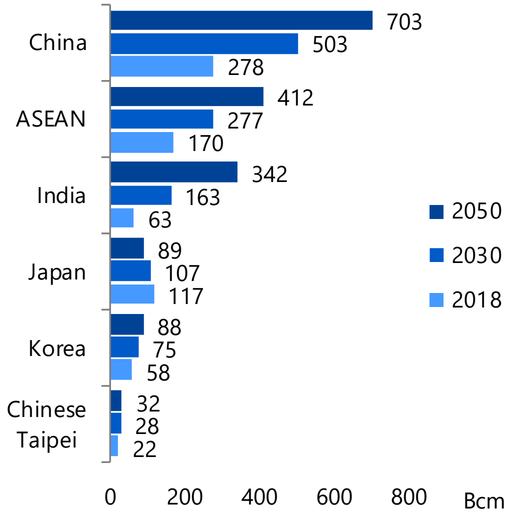


Figure 2-22 | Asian natural gas consumption [Reference Scenario]



Asia's natural gas consumption will grow faster than its oil consumption. The annual growth stood at 6.3% between 1990 and 2018 and will come to 2.7% between 2018 and 2050. Of the 2018-2050 growth, the power generation sector will account for 48.9%, the buildings sector for 16.0%, and the non-energy use sector for 10.7%. China will account for 40.4% of the growth, India for 26.5%, and ASEAN for 23.0%. Asian natural gas consumption growth will capture 46.6% of global growth, but Asia's natural gas self-sufficiency rate will fall from 61.1% in 2018 to 56.5% in 2050 due primarily to a decline in domestic production. Although natural gas is environmentally friendlier than oil or coal, it is important for Asia to promote highly efficient natural gas consumption through such measures as the requirement for the power generation sector to adopt natural gas combined cycle plants.

Liquefied natural gas (LNG) consumption will support Asian natural gas consumption growth, expanding from 238 million tonnes in 2018 to 436 Mt in 2050. The share of Asian LNG consumption will fall from 60.0% in 2019 to 32.0% in 2050 for Japan, Korea, and Chinese Taipei, while rising from 36.8% to 56.1% for China, India, and ASEAN. Emerging Market and Developing Economies will also drive Asian LNG consumption.

In contrast, Asian coal consumption will peak out in the middle of the 2030s, decelerating its annual growth from 4.7% between 1990 and 2018 to 0.8% between 2018 and 2040 before declining at an annual rate of 0.6% through 2050. Coal consumption will greatly increase for power generation while declining for industry and buildings. Even so, coal will remain the largest energy source in Asia. Asian governments will have to efficiently use their abundant indigenous coal resources for economic and energy security purposes while avoiding the construction of coal-fired power plants that lack considerations for climate change or air pollution.

Asian non-fossil energy consumption will increase rapidly, though failing to grow as much as oil or natural gas consumption. Asia's share of global non-fossil energy consumption will rise by 8.4 percentage points from the present level to 57.3% in 2050. Renewables other than traditional biomass will capture 77.3% of Asian non-fossil energy consumption growth, followed by 29.9% for nuclear. Traditional biomass will account for a negative 7.1% of the growth. China will account for 46.0% of renewable energy consumption growth excluding traditional biomass and ASEAN for 25.7%. China will capture 57.1% of nuclear consumption growth, followed by 29.7% for India. China, India, and ASEAN will also drive global and Asian non-fossil energy consumption growth. It is particularly important for Asian Emerging Market and Developing Economies to accelerate the diffusion of non-fossil energy for promoting global climate change countermeasures.

2.2 Final energy consumption

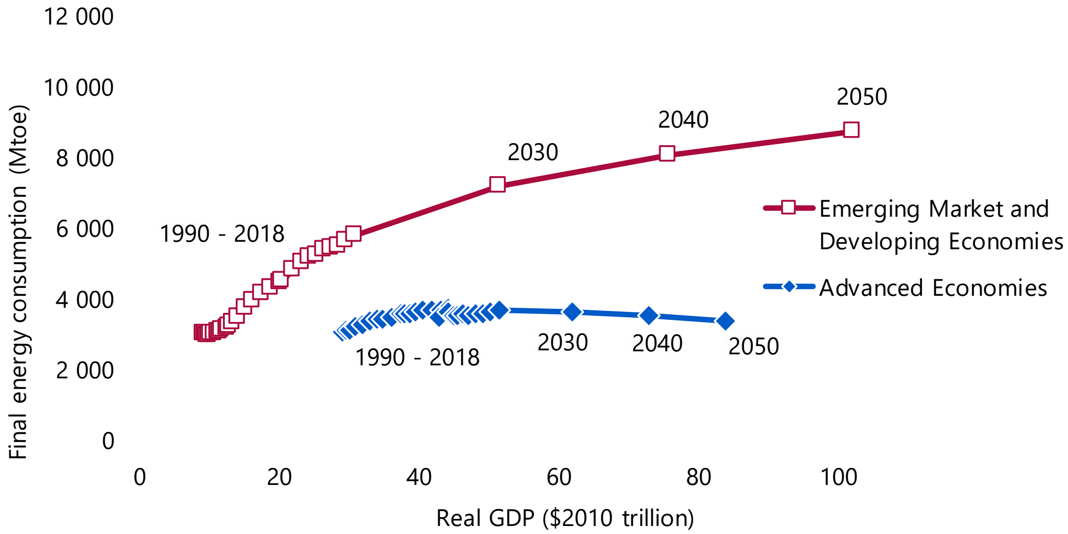
Emerging Market and Developing Economies will continue to drive global demand growth

Final energy consumption in the world has grown at a slower pace than the world economy (Figure 2-23). Between 1990 and 2018, the rate of annual growth in final energy consumption[5] came to 1.7% against the annual real GDP growth rate of 2.8%. The trend has grown clearer in recent years. Since 2010, the rate of annual growth in final energy consumption has been limited to 1.5% against the average economic growth rate of 2.8%. Despite economic expansion, final energy consumption in the Advanced Economies peaked in 2007, as the expansion of the service sector has been coupled with progress in energy efficiency improvement. Meanwhile, the Emerging Market and Developing Economies boosted final energy consumption at an annual rate of 2.4% between 1990 and 2018 due primarily to increasing production in energy-intensive industries and population growth that supported a high average annual economic growth of 4.4%.

In the future, the Advanced Economies will reduce final energy consumption through energy efficiency improvements while boosting real GDP. Their final energy consumption will decline at an annual rate of 0.3% between 2018 and 2050 to 3 382 Mtoe. The Emerging Market and Developing Economies will also improve energy efficiency, lowering the energy-GDP elasticity[6] from 0.53 between 1990 and 2018 to 0.34 between 2018 and 2050. Nevertheless, their final energy consumption in 2050 will increase 1.5-fold from the present level to 8 736 Mtoe. Driven by the growth in the Emerging Market and Developing Economies, global final energy consumption will rise at an annual rate of 0.8% between 2018 and 2050 to a level up 1.3-fold from 2018.

[5] Global total final energy consumption covers international bunkers.
[6] Energy-GDP elasticity = final energy consumption growth ÷ real GDP growth

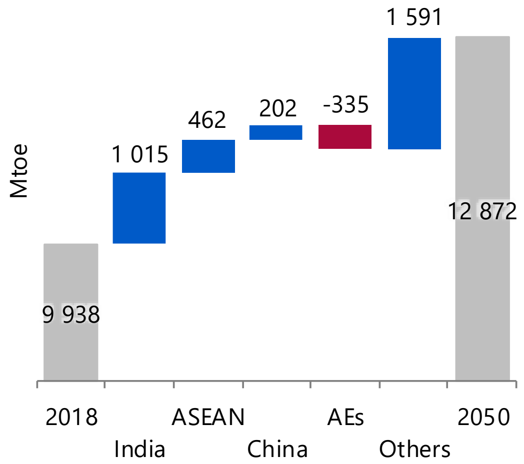
Figure 2-23 | GDP and final energy consumption [Reference Scenario]



Asian Emerging Market and Developing Economies will show different energy consumption growth trends

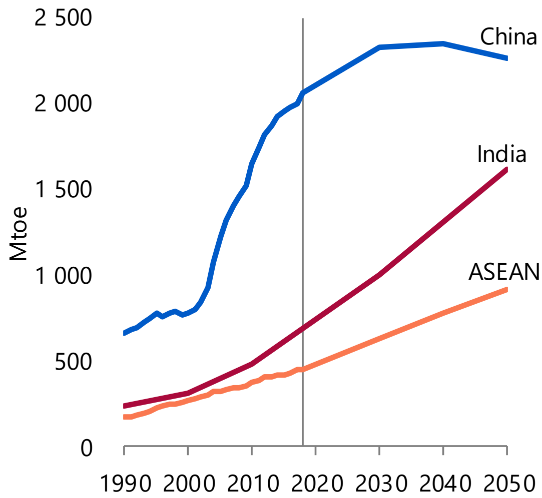
Asia will account for 1 747 Mtoe or 60% of global final energy consumption growth at 2 935 Mtoe between 2018 and 2050 (Figure 2-24). Supported by industrial development, motorisation, urbanisation and living standard improvements in Emerging Market and Developing Economies, Asian final energy consumption will increase at an annual rate of 1.2% from 3 847 Mtoe in 2018 to 5 593 Mtoe in 2050. However, attention should be paid to differences between final energy consumption growth trends in Asian Emerging Market and Developing Economies (Figure 2-25).

Figure 2-24 | Final energy consumption growth for selected countries/regions [Reference Scenario, 2018-2050]



Note: AEs stands for Advanced Economies

Figure 2-25 | Final energy consumption in China, India and ASEAN [Reference Scenario]



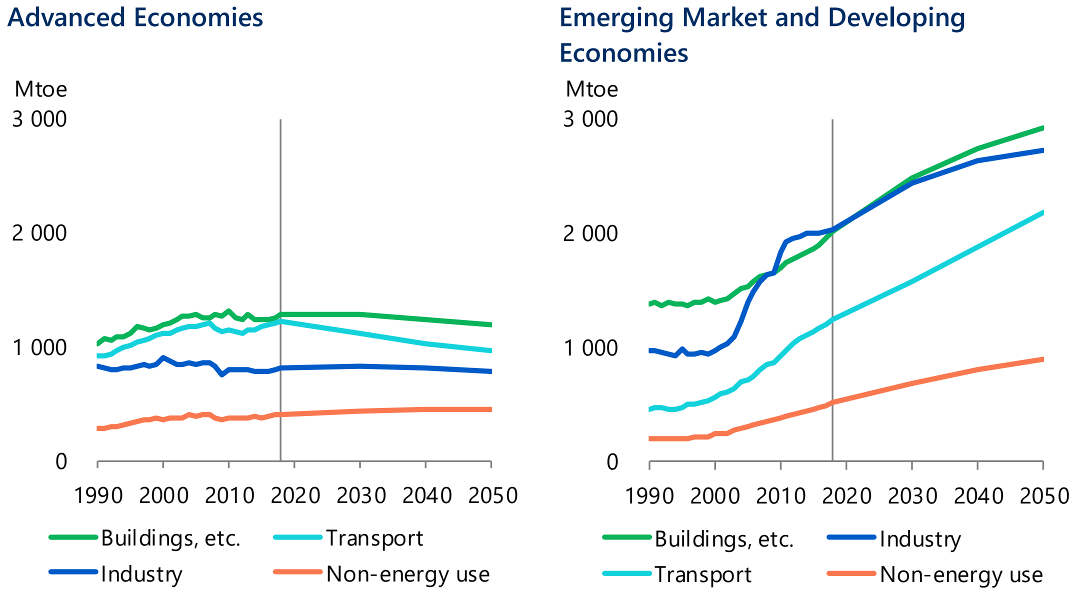
After its rapid economic growth, China boosted its final energy consumption to 2 058 Mtoe in 2018, accounting for 21% of the global total. However, the Chinese economy is in transition from high growth to medium high growth called as "new normal", with its population expected to peak out in the early 2030s. In response to these changes, China's energy consumption growth will soon decelerate and turn downward around the late 2030s. Nonetheless, China's absolute final energy consumption will remain high until 2050. In India that will soon replace China as the world's most populated country, however, final energy consumption will increase rapidly, reaching 1 621 Mtoe in 2050, up 2.7-fold from the current level. While India's absolute energy consumption falls short of the Chinese level, it will capture 58% of Asian consumption growth, indicating a very rapid expansion. ASEAN will also sustain high energy consumption growth, boosting its consumption two-fold from the current level to 917 Mtoe in 2050.

Final energy consumption in the Advanced Economies has turned downward and will decrease about 9% from the current level in 2050. Their share of global final energy consumption will plunge from 37% at present to 26% in 2050, indicating the energy consumption centre's remarkable shift to the Emerging Market and Developing Economies including the Asian ones.

Living standard improvements and modernisation hold the key to energy consumption growth

The transport sector will account for 1 007 Mtoe or about one-third of 2 935 Mtoe in global final energy consumption growth between 2018 and 2050, followed by 820 Mtoe for the buildings sector, 679 Mtoe for the industry sector and 428 Mtoe for the non-energy use sector. During the period, energy consumption will grow at an annual rate of 1.2% for the non-energy use sector, at 0.9% for the transport sector, and at 0.7% for the industry and buildings sectors. Final energy consumption in the Advanced Economies will level off in the buildings and industry sectors, while declining in the transport sector due to vehicle fuel efficiency improvement including the diffusion of electrified vehicles (Figure 2-26). In the Emerging Market and Developing Economies, the buildings, industry, and transport sectors will rapidly expand energy consumption on the strength of living standard improvements and economic development.

Figure 2-26 | Final energy consumption in Advanced, and Emerging Market and Developing Economies [Reference Scenario]



In the buildings sector, global final energy consumption will increase at an annual rate of 0.7% through 2050. In the Emerging Market and Development Economies, particularly, the sector will post an annual final energy consumption growth rate of 1.2% reflecting living standard improvements. In the buildings sector, firewood, livestock manure, and other traditional biomass for cooking and heating in rural areas accounted for 21% of final energy consumption in the world and 32% in the Emerging Market and Developing Economies in 2018. Traditional biomass consumption faces large challenges such as health damage issues caused by smoke and soot during burning and will be replaced with modern energy consumption in line with living standard improvements in the future. In 2050, traditional biomass's share of final energy consumption in the buildings sector will decline to 12% in the world and 15% in the Emerging Market Developing Economies. On the other hand, modern energy consumption in the sector will increase at an annual rate of 1.1% in the world and at 1.9% in the Emerging Market and Developing Economies.

In the transport sector, road energy consumption accounted for 74% of final energy consumption in 2018, indicating that the global vehicle fleet size and fuel efficiency improvements hold the key to the sector's energy consumption trend. While the global vehicle fleet size doubles from 1 464 million vehicles in 2018 to 2 824 million vehicles in 2050, electrically powered automobiles including hybrid and electric vehicles will expand their share of the global vehicle fleet to 57%, leading the transport sector's final energy consumption growth to be limited to 1.3-fold due to substantial efficiency improvements.

In the Advanced Economies, the vehicle fleet size's growth will be limited due to the already high vehicle diffusion rate. Thanks to greater fuel efficiency improvements, their transport sector energy consumption will decrease at an annual rate of 0.7%. In the Emerging Market and Developing Economies, however, energy consumption in the transport sector will increase at an annual rate of 1.8% as an increase of about 2.7-fold in the vehicle fleet size more than offsets the effect of fuel efficiency improvements. Particularly, Asian Emerging Market and Developing Economies will develop motorisation remarkably, leading Asia to account for about 64% of the global vehicle fleet growth.

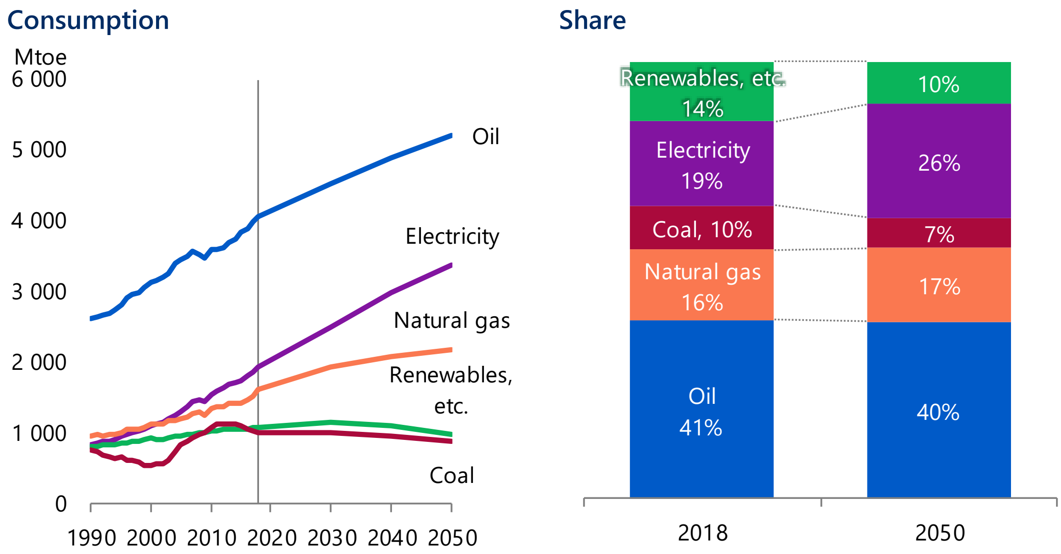
While global manufacturing GDP posts an annual growth rate of 2.5% between 2018 and 2050, driven by the Emerging Market and Developing Economies, the industry sector's final energy consumption growth will be limited to 0.7% per year. The deviation between the industry sector GDP and energy consumption growth rates will be attributable not only to energy efficiency technology development but also to the sector's transition from energy-intensive production to higher value-added non-energy-intensive production in line with economic development. In China, for example, the industry sector's energy consumption will decrease at an annual rate of 0.7% despite an annual manufacturing GDP growth rate of 2.9% through 2050. With the progress of the transition of industrial structure in China, its cement production, which is the typical energy-intensive industry, has already peaked in 2014, and the steel production will also peak out shortly. China's share of global industry sector energy consumption will fall from 35% in 2018 to 23% in 2050. In contrast, the share will expand by 9 percentage points to 16% for India and by 4 points to 9% for ASEAN.

Petrochemical feedstocks account for about 80% of the non-energy use sector's consumption and the remainder includes lubricant oil. Given high demand for plastics and other petrochemical products, the petrochemical industry is expected to enjoy robust growth. Particularly, the Emerging Market and Developing Economies will expand petrochemical demand and production substantially, capturing about 90% of global non-energy use growth. As the expansion of bioplastics is considered for environmental considerations, biomass will be increasingly used as petrochemical feedstocks.

Each energy source's stable supply is important

A breakdown of final energy consumption by energy source shows that electricity will score a high consumption increase among energy sources. Final electricity consumption will rise at an annual rate of 1.8% through 2050, accounting for half the total final energy consumption growth (Figure 2-27). Electricity will post the largest consumption growth among major energy sources in both the Advanced Economies and the Emerging Market and Developing Economies. In the Advanced Economies, particularly, electricity will be the only energy source to post final consumption growth through 2050. The final energy consumption breakdown by energy source also indicates that while coal and renewable energy consumption are capped, oil and natural gas consumption will increase 0.8% and 0.9% per year, respectively, through 2050 in a manner to be driven by the Emerging Market and Developing Economies. Fossil fuels, which account for 67% of final energy consumption at present, will still retain a high share of 64% in 2050 thanks to oil and natural gas consumption growth.

Figure 2-27 | Global final energy consumption (by energy source) [Reference Scenario]

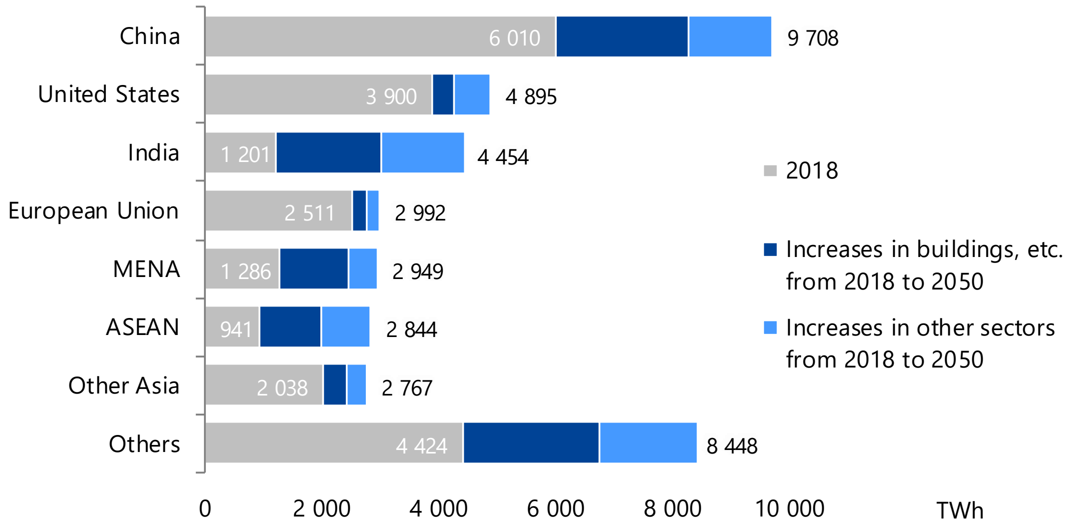


Of final oil consumption in 2018, the transport sector accounted for 65% (including 49% for the road sector, 8% for the aviation sector and 7% for the marine sector), the non-energy use sector for 17% and the buildings sector for 11%. Among these sectors, the transport sector will post the largest oil consumption growth, followed by the non-energy use sector. Particularly, Asian automobile fuel consumption will drive oil demand growth, offsetting most of a decline in the Advanced Economies. As noted above, this is attributable mainly to a rapid increase in vehicle ownership in the Asian Emerging Market and Developing Economies including India and ASEAN. Of consumption growth in the non-energy use sector, Asia will account for about 60%. Asia will capture about 70% of global oil consumption growth, boosting its share of global oil consumption from 32% in 2018 to 40% in 2050.

Of final natural gas consumption in 2018, the buildings sector accounted for 44% (including 30% for the residential sector and 13% for the commercial sector), the industry sector for 37% and the non-energy use sector for 12%. Among these sectors, the industry sector will post the largest growth in future natural gas consumption, followed by the non-energy use sector and the buildings sector. Asia including China and India will capture 56% of industry sector consumption growth and 49% of non-energy use sector consumption growth, followed by the Middle East commanding 19% of industry sector consumption growth and 16% of non-energy use sector consumption growth. China's buildings sector alone will account for 21% of global natural gas consumption growth. Within the Chinese buildings sector, the residential sector will score remarkable natural gas consumption growth. This is partly because the residential sector is rapidly switching from coal and biomass fuels such as firewood to city gas to mitigate indoor and outdoor air pollution. In a bid to ease air pollution and promote low-carbonisation, India has taken policies to promote natural gas consumption in all sectors such as the industry sector including steelmakers. The Middle East is developing the chemical industry using cheap oil-associated gas in pursuit of national finance depending less on oil exports.

Electricity will score the highest final consumption growth among major energy sources both in the Advanced Economies and the Emerging Market and Developing Economies. The global electrification rate (on the consumption side)[7] will rise from 19% in 2018 to 26% in 2050. Generally, people favour highly convenient electricity as their income grows. Another factor behind electricity consumption growth is the penetration of digitalisation into society and economy to boost the number of electricity-consuming machines and devices. Given that troubles in key social infrastructure have great impacts, stable supply of electricity as energy at affordable prices is particularly important. Driving electricity consumption growth will be Asia including China, India, and ASEAN (Figure 2-28). The Emerging Market and Developing Economies including these Asian economies will command as much as 88% of global electricity consumption growth.

Figure 2-28 | Final electricity consumption [Reference Scenario]



By sector, the buildings sector will capture 58% of global electricity consumption growth. Of the sector's electricity consumption growth, residential sector will account for 54%. Particularly, residential electricity consumption will increase in the Emerging Market and Developing Economies due mainly to electricity infrastructure development and the gradual penetration of electrical home appliances among urban middle to high-income consumers. In the Advanced Economies, residential electricity consumption will grow little because future growth in electrical home appliances will be limited and offset by the improvement of their equipment and insulation efficiency.

Global final coal consumption turned downward in the first half of the 2010s. Major coal-consuming countries are considering switching from coal to other energy sources in view of their structural economic changes and environmental protection. Such trend will be combined with the introduction of more efficient coal consumption technologies to lead global final coal consumption to decline at an annual rate of 0.4%. In China known as a massive coal consumer, the coal-intensive cement industry's production peaked in 2014, with steel production

[7] The rate is the ratio of electricity consumption to total final energy consumption.

expected to peak soon. China's industrial coal consumption has followed a downtrend since the first half of the 2010s and will halve from 2018 to 2050. China's coal consumption cut will more than offset growth in India and ASEAN.

Of final renewable energy consumption in 2018, firewood, livestock manure and other traditional biomass used in the Emerging Market and Developing Economies accounted for about 72%, firewood used mainly for fireplaces in Western countries for 13%, biofuels for vehicles for 10%, and solar heat and geothermal energy for the remainder. Global traditional biomass consumption will turn down in the second half of the 2020s as access to modern energy is improved in the Emerging Market and Developing Economies, as noted above.

Climate change countermeasures represent a globally important challenge. Government and private sectors in each country are considering and implementing decarbonisation measures. However, even final energy consumption will fall short of being decarbonised completely by 2050, leaving fossil fuels remaining as key energy sources. As the theme "transition to a clean energy society" attracts attention, various environmental measures including the development and introduction of low-carbon technologies are important. For realising a reasonable, balanced transition process, however, initiatives to stably supply each energy source will be indispensable. It is important to build diversified, resilient energy markets supported by legal, financial, and other infrastructure while developing and introducing technologies for a comprehensive chain covering from energy development and production to transportation, storage, and final consumption.

2.3 CO_2 emissions

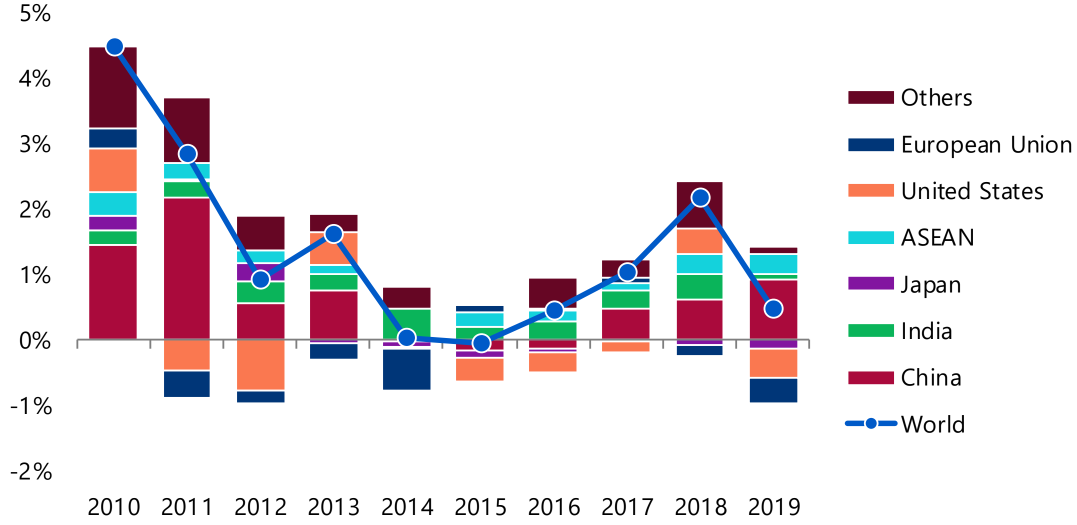
Global CO_2 emission growth in 2019 was limited to 0.47%, with China expanding its contribution to growth

According to BP Statistical Review of World Energy June 2020[8], global CO_2 emission growth in 2019 from the previous year decelerated from 2.19% in 2018 to 0.47% (Figure 2-29). Global GDP growth slowed from 3.1% in 2018 to 2.5% in 2019[9].

China's contribution to the growth expanded to 0.94%, while the United States' contribution turned negative at -0.45%. India's contribution fell to 0.08%. The European Union contributed -0.40% to the growth. Behind these contribution changes were a 2.3% increase in China's coal consumption, a slower natural gas consumption rise and a 14.4% coal consumption fall in the United States, India's coal consumption growth limited to 0.3%, and a 17.8% decrease in coal consumption in the European Union.

[8] bp "Statistical Review of World Energy June 2020"
[9] World Bank, World Development Indicators

Figure 2-29 | Annual CO_2 emission changes and breakdown by selected country/region



Source: Prepared from BP "Statistical Review of World Energy June 2020"

Global CO_2 emissions in 2020 are predicted to decline 4%-8% due to the COVID-19 pandemic spread (Table 2-1).

Table 2-1 | Global CO_2 emission decline due to the COVID-19 spread [2020]

	Emissions in 2020
IEA (2020)[10]	-8%
Le Queré et al (2020)[11]	If emissions restore pre-pandemic levels by the end of June: -4% (-2% to -7%) If some restrictions are left on a global scale until the end of 2020: -7% (-3% to -13%)

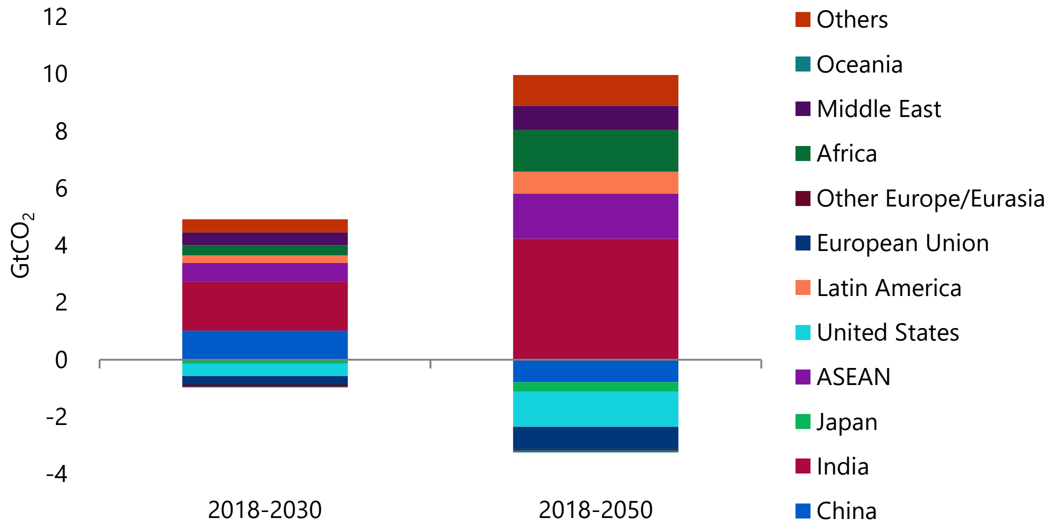
CO_2 emissions will sharply increase in India, ASEAN, and Africa while turning down in the mid-2020s in China

Global energy-related CO_2 emissions will grow from 33.3 Giga-tonnes in 2018 to 37.2 Gt in 2030 and peak at 40.0 Gt just before 2050.

India will account for 4.2 Gt of global CO_2 emission growth at 6.7 Gt between 2018 and 2050, ASEAN for 1.6 Gt, and Africa for 1.5 Gt (Figure 2-30). Emission growth is attributable primarily to a nearly five-fold increase in GDP per capita in India, a three-fold rise in ASEAN, and a two-fold increase coupled with a two-fold population rise in Africa. Their CO_2 emissions per primary energy consumption will increase, indicating that they will switch from firewood and other traditional renewable energy sources to modern energy.

10 IEA (2020) Global Energy Review 2020.
11 Le Queré et al (2020) Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement, Nature Climate Change 10.

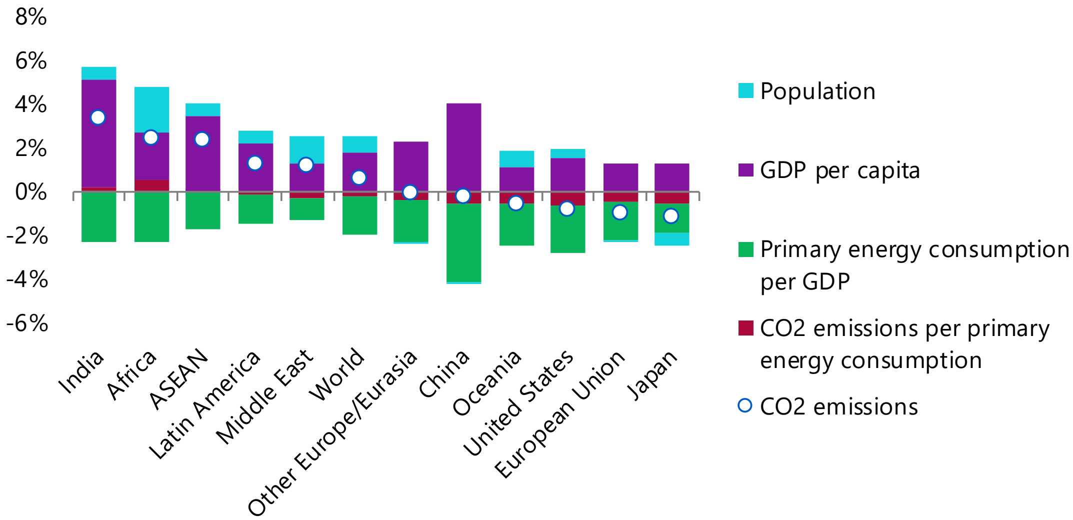
Figure 2-30 | Changes in energy-related CO_2 emission [Reference Scenario]



China's emissions will turn down in the middle of the 2020s. An increase of nearly four-fold in GDP per capita between 2018 and 2050 will be offset by a sharp fall in primary energy consumption per GDP, resulting in the downturn in CO_2 emissions.

The United States will cut CO_2 emissions by 1.2 Gt, China by 0.8 Gt and the European Union by 0.8 Gt. In Japan, the European Union, and the United States where CO_2 emission reduction rates will be high, falls in primary energy consumption per GDP (energy efficiency improvements) will make greater contributions to overall emission decreases than drops in CO_2 emissions per primary energy consumption (low-carbonisation). In Japan, a population decline will also contribute to its emission decrease (Figure 2-31).

Figure 2-31 | Annual CO_2 emission and other changes [Reference Scenario, 2018-2050]



It will be important for India, ASEAN, and Africa to hold down their CO_2 emission growth. Their switching from firewood and other traditional renewable energy sources to modern energy will be desirable for improving their access to cleaner energy sources. However, they should be helped to improve access to low-carbon energy without transitioning to high-carbon energy systems.

3. Energy supply

3.1 Crude Oil

Despite a steep OPEC-plus production cut, a sense of oversupply is still lingering

U.S. crude oil production has increased remarkably in recent years with growth in 2019 reaching 1.24 million barrels per day (Mb/d), slightly less than the 1.64 Mb/d achieved the year before. The U.S. production growth alone thus exceeded the global oil demand growth of 0.7 Mb/d for the same year.

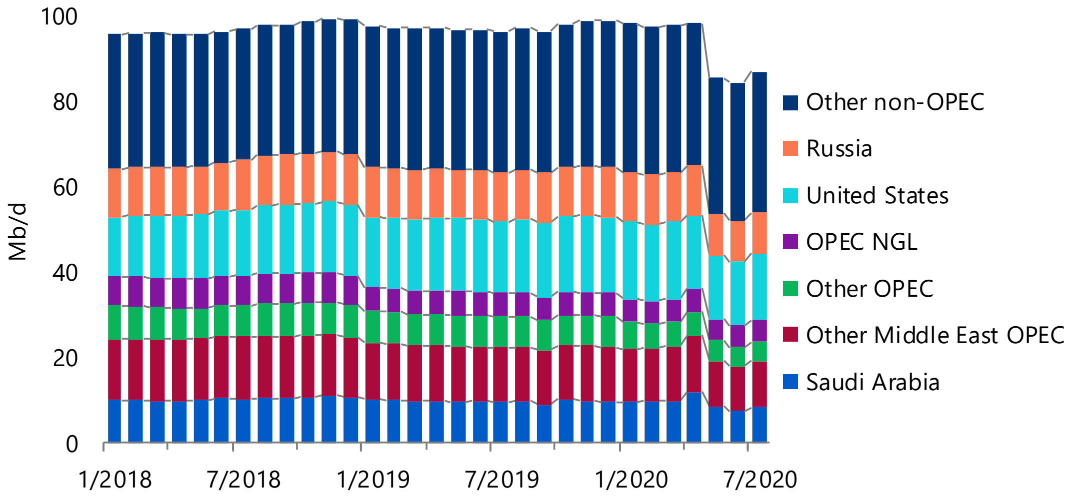
The OPEC-plus, which is comprised of the members of the Organization of the Petroleum Exporting Countries (OPEC) and non-OPEC oil-producing countries such as Russia, has been cutting production since January 2017 to secure a supply-demand equilibrium in support of higher oil prices. From January 2019 to March 2020, the group cut production by 1.2 Mb/d compared to October 2018 and successfully reduced, in February 2020, the commercial oil stocks of the member countries of the Organisation for Economic Co-operation and Development (OECD) to below their five-year average. Oil prices remained relatively stable since 2018 after their recovery from weak prices in 2016 and 2017. The Brent crude oil price averaged about $65/bbl in 2019.

Due to the COVID-19 spread, oil demand has plummeted, triggering rapid changes in oil supply structure and prices. In March 2020, oil prices crashed as the OPEC-plus's negotiations to further cut production broke down (Saudi Arabia and others increased production despite an oil demand plunge amid COVID-19 lockdowns). In April, however, in response to a global oil demand plunged of 20 Mb/d, or some 20%, the OPEC-plus agreed on a large production cut of 9.7 Mb/d. The agreement failed to eliminate a sense of oversupply in the oil market, leading oil prices to decline further. Still fresh in our minds is the fact that the value of the West Texas Intermediate (WTI) front-month futures contract dropped for the first time in history, on 20 April, into negative territory to minus $37.63/bbl. The average Brent price for April and May slipped below $30/bbl, the lowest level in some 16 years.

The oil price weakness also affected the United States, the centre of oil production growth in recent years. Despite technological advancements that reduced the production costs for shale oil or tight oil, which accounted for most of the growth, these costs still exceed the production costs for conventional oil. Hence, the lower oil prices made it difficult for some shale oil producers to continue operations, leading U.S. oil production to decline in March 2020. The United States rig count, a leading indicator of oil and gas production, further declined by 500 during the second quarter of 2020 reaching half the 2016 low count that came under weak oil prices. While the United States refrained from joining the OPEC-plus production cut, the oil price weakness led U.S. production to eventually decrease by some 2 Mb/d.

Although optimism cannot be warranted, oil demand is recovering due to business reopening. The OPEC-plus extended the 9.7 Mb/d production cut for one month, until the end of July 2020, in an attempt to remove the sense of oversupply. Nevertheless, oil demand is unlikely to quickly restore the pre-COVID-19 level, and will remain below the 2019 level in 2021. OECD commercial oil stocks swelled in April and May and will take considerable time to slip below the five-year average again. This is preventing oil prices from rising over the short term.

Figure 3-1 | Recent crude oil production



Note: OPEC production is based on monthly data of OPEC members. Non-OPEC production includes natural gas liquid (NGL). Other non-OPEC production includes processing gains.
Source: Prepared from IEA "Monthly Oil Market Report"

The Middle East will become the crude oil supply centre again

In the Reference Scenario, weak oil demand under the COVID-19 pandemic will be short-lived. Over the long term to 2050, global oil demand will continue increasing due to economic growth, per capita income growth, and oil's advantages such as portability and easy storage.

In response to growing demand, OPEC and non-OPEC will expand production. Over the medium term, until around 2030, U.S. shale oil production will drive the growth in global oil production, thanks to a moderate rise in oil prices and a fall in production costs. Latin America will play a key role in increasing non-OPEC production with Brazil that is stepping up pre-salt oil development on the strength of foreign investment growth, and with Guyana that has discovered a large oilfield and launched production (56 kb/d) under its first offshore oil project in late 2019. The break-even point for crude oil production in Guyana is estimated at between $20/bbl and $30/bbl, indicating a higher profitability than U.S. shale oil. Meanwhile, non-OPEC European, Eurasian, and Asian production will gradually decrease.

U.S. crude oil production will continue to play a central role in expanding oil supply over the medium term but will fail to grow from 2030 due to declining reserves. Over the long term, OPEC members in the Middle East, with abundant reserves and cheap production costs, will satisfy a huge oil demand increase of some 20 Mb/d through 2050. The major players will be Saudi Arabia and Iraq both with abundant surplus production capacity and reserves. How much Venezuela, an OPEC member also with huge oil reserves, would expand production is worthy of attention. Its oil production has plunged by about 90% in the past decade, due to prolonged investment shortages and U.S. sanctions. Its future oil production trend will depend on changes in its regime's socialist policy and acceptance of foreign investment in the oil industry.

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

(Mb/d)

	2018	2030	2040	2050	2018-2050	
					Changes	CAGR
Crude oil production	95.3	102.6	110.5	116.3	21.0	0.6%
OPEC	37.0	40.3	46.9	51.7	14.6	1.0%
Middle East	28.7	31.1	35.8	38.9	10.2	1.0%
Others	8.4	9.2	11.1	12.8	4.4	1.3%
Non-OPEC	58.2	62.3	63.6	64.6	6.4	0.3%
North America	20.9	23.7	23.5	21.9	1.0	0.1%
Latin America	7.1	9.1	11.2	13.3	6.3	2.0%
Europe and Eurasia	18.1	17.3	16.5	16.5	-1.5	-0.3%
Middle East	3.2	3.5	3.8	4.2	1.0	0.8%
Africa	1.4	1.5	1.6	1.7	0.3	0.6%
Asia and Oceania	7.6	7.2	7.0	7.0	-0.7	-0.3%
Processing gains	2.3	2.7	3.1	3.5	1.2	1.3%
Oil supply	97.6	105.3	113.6	119.8	22.2	0.6%

Note: Crude oil includes NGL.

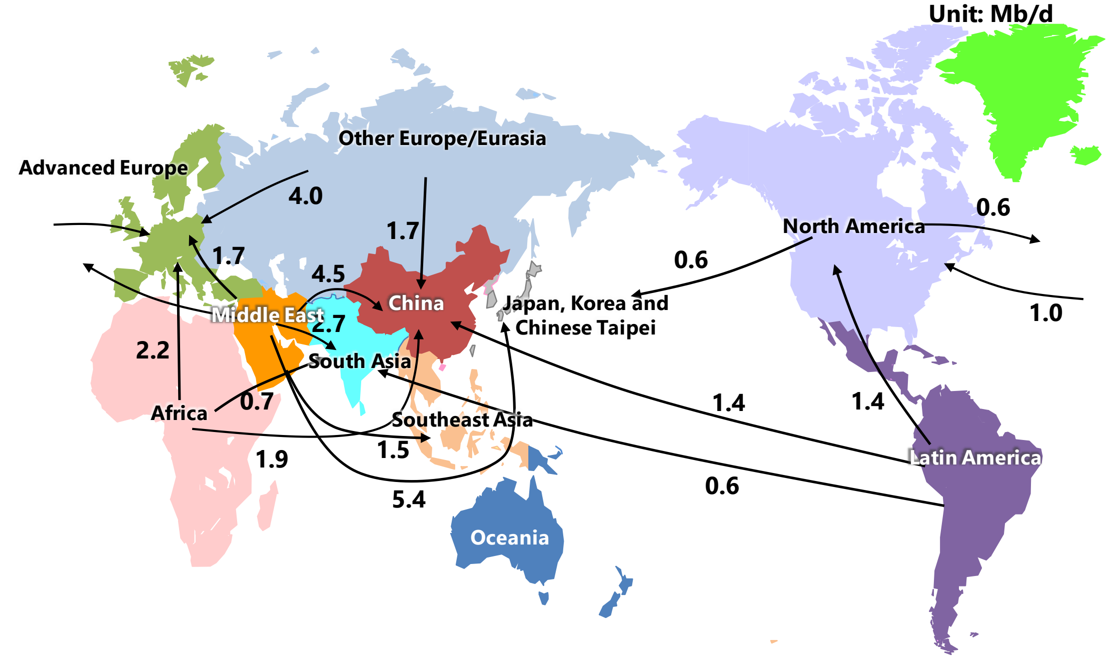
Asia will grow dependent on the Middle East

Crude oil trade between major regions in the world totalled about 43 Mb/d in 2019. The largest export source was the Middle East accounting for 40% of the total. Asian imports captured 56% of the total as 82% of crude oil exports from the Middle East were destined for Asia. Crude oil exports from North America to Asia are also on the rise with imports by Japan, Korea, and Chinese Taipei in 2019 exceeded 0.5 Mb/d for the first time. Other major importers are OECD Europe and North America. OECD Europe imports oil mainly from non-OECD Europe, Central Asia, and Africa, while North America buys oil from Latin America and the Middle East. However, imports into North America, particularly the United States, have been decreasing against the backdrop of remarkable growth in U.S. production. In 2019, U.S. oil imports declined by 1 Mb/d from the previous year.

Crude oil trade will remain almost unchanged. While OECD countries reduce imports due to a declining demand, an increase in imports to meet demand growth in Asian Emerging Market Economies will offset the decline. In 2030, crude oil exports from North America will increase against the backdrop of domestic production growth, somehow holding down the rise in Asia's dependence on the Middle East. Through 2050, however, the Middle East's presence in global oil supply will increase, leading Asia's dependence on the Middle East to rise again. Another factor behind Asia's growing dependence on the Middle East will be that crude oil exports from Africa will fail to increase due to rising African oil demand. In 2050, India will replace China as the largest oil importer in the world.

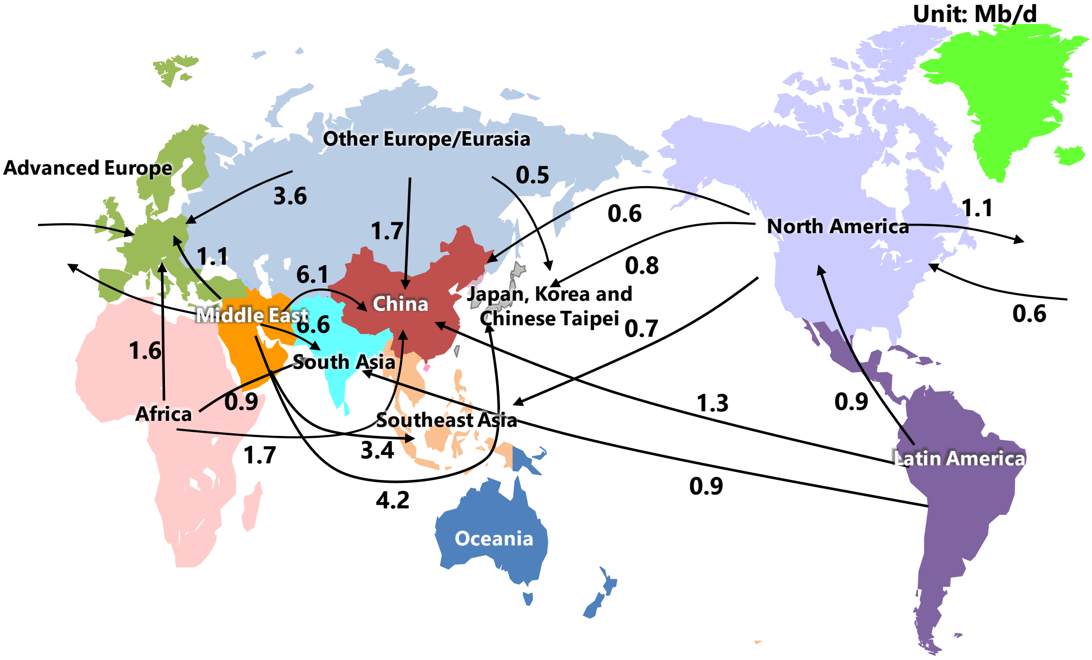
Future oil trade flows will depend on how regional oil refining will develop. As an attempt to counter the risk of falling oil demand, national oil companies from oil-producing countries have recently been participating in a growing number of oil refinery projects in oil-consuming countries. In most of those projects, the national oil companies provide the crude oil, resulting in more rigid crude oil trade flows. Over the short term, oil-refining capacity is expected to increase faster than demand for petroleum products, indicating that oil-importing economies with less competitive refineries may see lower refinery capacity factor and declines in crude oil imports. In contrast, economies with more competitive refineries may refine more crude oil than indicated by their domestic demand and expand petroleum products exports. In other words, interregional refining competitiveness gaps will exert influence on crude oil trade flows.

Figure 3-2 | Major interregional crude oil trade flows [2019]



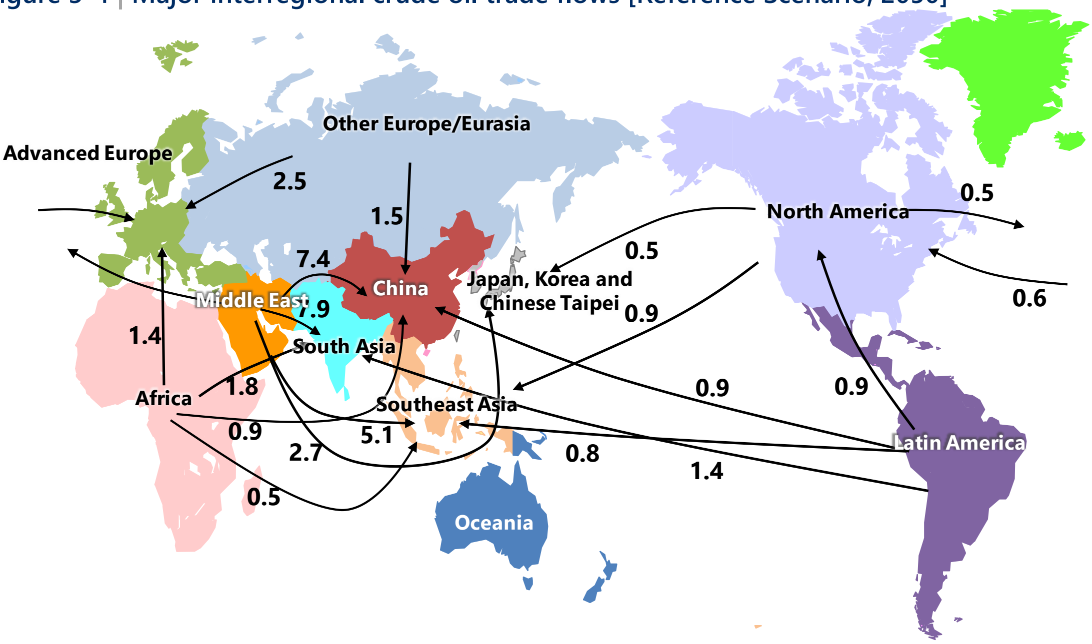
Note: Flows of 0.5 Mb/d or more are covered.
Sources: "BP Statistical Review of World Energy 2020", national trade statistics

Figure 3-3 | Major interregional crude oil trade flows [Reference Scenario, 2030]



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

Figure 3-4 | Major interregional crude oil trade flows [Reference Scenario, 2050]



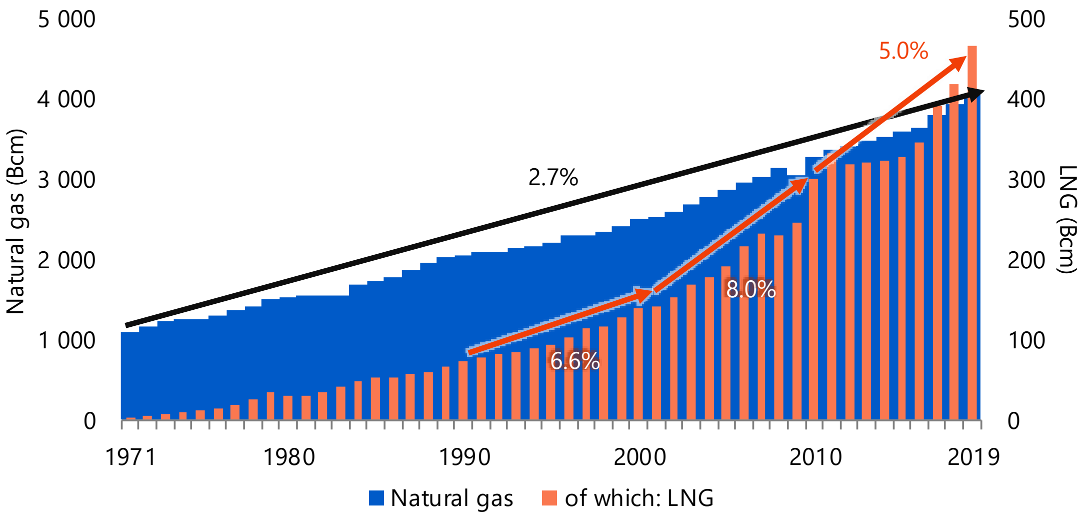
Note: Flows of 0.5 Mb/d or more are covered.

3.2 Natural gas

Abundant supply will accelerate LNG market expansion

Over the past half century, natural gas supply in the world expanded at a faster pace than overall energy supply and liquefied natural gas (LNG) supply through international trade and marine transportation has increased faster than overall natural gas supply. In 2019, particularly, LNG supply continued its substantial expansion, scoring a double-digit increase from the previous year to a record high surpassing the previous high reached in 2010. The increase totalled about 41 million tonnes (Mt). Driving the rapid growth were production launches at U.S., Australian, and Russian LNG facilities. While U.S. LNG production capacity continues expanding in 2020, utilisation rates of the capacity have fallen due to a temporary slowdown in global LNG demand. Over the medium to long term, however, LNG has great potential to keep on expanding because of resource abundance and bullish developments.

Figure 3-5 | Global natural gas and LNG supply



Note: The scale of the right axis for LNG is one-10th of the left axis scale.

Annual LNG production capacity on which final investment decisions were made in the world hit a record high of 71 Mt in 2019, amounting to some 20% of the 350 Mt in global LNG trade in the year. The United States accounted for three projects or about 30 Mt in capacity, indicating its great role in expanding global LNG production. Thanks to more streamlined LNG facility construction and export approval procedures introduced by the federal government and regulators in recent years, new LNG project approval process made significant progress in 2019. Unlike the previous LNG projects, U.S. projects are not necessarily linked to specific upstream gas fields and they feature loose commitments regarding final consumers. The emergence of such U.S. LNG projects in the global market is stimulating structural changes in the LNG market.

In 2019, particularly, U.S. LNG supply to Japan expanded and demonstrated its advantage as LNG prices indexed to oil prices, under most of traditional contracts for LNG supply to Asia, were high. This has had impacts on Japanese LNG buyers' negotiations on contract terms and conditions. Meanwhile, Australia reached the final phase of its LNG production capacity expansion in 2019, boosting its LNG production close to that of Qatar that has remained the world's largest LNG exporter since 2006. Russia for its part has increased LNG production under its Arctic projects, expanding its share of the European market.

Such production trend has brought about structural changes in the consumption market. Northeast Asia has remained a mainstay LNG consumption market, but its share of the global LNG market narrowed from 62% in 2018 to 55% in 2019 and the first quarter of 2020. The share for Japan, the largest LNG importer in the world, also dropped from 25% in 2018 to 20% in 2019. China among other Northeast Asian countries is expanding its LNG market, though at a slower pace than earlier, surpassing Japanese imports in some months.

In response to U.S. LNG export expansion, Europe rapidly increased its imports since the fourth quarter of 2018. In 2019, Europe as a region imported more LNG than Japan or China. Underground gas storage facilities have played a key role in boosting LNG imports in Europe; as of 2020, these facilities have a total capacity of 70 Mt of LNG equivalent. Reflecting LNG import growth, the inventories in the storage facilities represented 97% of the capacity at the end of October and 54% at the end of March 2020, respectively. As Europe's presence in the global LNG market has increased, European spot gas prices, including the Netherlands' Title Transfer Facility, have expanded their influence on the global market.

Weak spot natural gas prices affected Asian spot LNG prices. The gaps with long-term LNG contract prices indexed to oil prices for Asia have expanded to record levels, increasing the need for flexible terms and conditions for LNG contracts and diversification in LNG transactions. This is leading to a downtrend of LNG prices' indexation to crude oil, the introduction of new LNG price benchmarks, the elimination of destination clauses and other measures to improve the liquidity of the LNG market.

Improvements in LNG transaction terms and conditions, including prices, will accelerate new LNG import projects in Southeast and South Asian Emerging Market Economies and lead to more LNG bunkering initiatives and increasing introduction of LNG-fuelled ships.

Natural gas resources subjected to LNG development in various regions

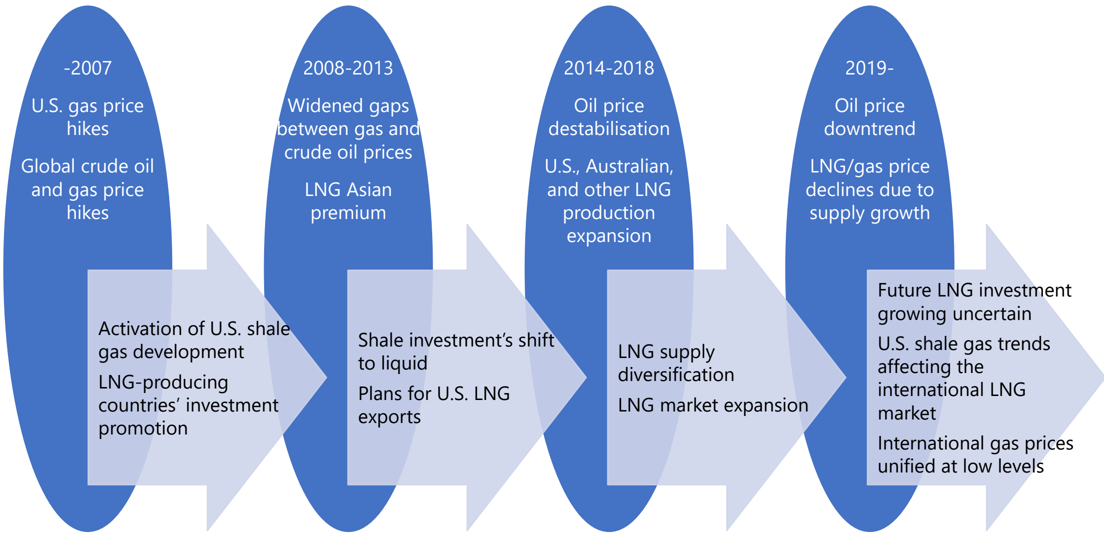
The United States is expected to increase shale and other natural gas production throughout the outlook period. Its natural gas production will rise at an annual rate of some 2% until around 2030 before stabilising. LNG exports will play a key role in increasing natural gas sales channels and improving the trade balance of the United States. Shale gas production remained at low levels until prices increased around 2005, stimulating their development. Since 2008, shale gas production has expanded substantially as its economic efficiency has improved with the advancement and diffusion of hydraulic fracturing and horizontal drilling technologies. As of 2020, shale gas production accounts for 70% of natural gas output in the United States.

The U.S. natural gas production growth since 2008 stabilised prices in the country at low levels. As the price gap between natural gas and crude oil expanded, technologies have been applied and improved for liquid production in a manner to boost NGL and crude oil production, as well as oil-associated natural gas output. In the international market, meanwhile, 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 U.S. LNG export projects to be launched one after another.

U.S. LNG's competitiveness in the international LNG market receives influence from price trends for competing LNG supply sources, including oil prices to which traditional LNG prices for Asian buyers have been indexed. U.S. East Coast LNG production projects including those in the Gulf of Mexico have access to Asia through the Panama Canal, leading to the requirement for optimising supply sources and routes through LNG cargo swaps. In this way, cooperation between various players can be promoted. Given such conditions, not only Japanese and other Asian LNG buyers but also LNG-related companies exploring business opportunities in the global LNG market have increasingly secured contracts for purchases from U.S. LNG projects with no supply destinations specified, as well as capacity contracts. This trend has worked to enhance LNG market liquidity and structurally change the market.

In addition to the 55 Mt of annual LNG operating capacity in the United States, at the end of 2019, a number of projects are either under construction or have reached final investment decisions, leading to a total of 100 Mt of annual capacity after their completion. Furthermore, an additional annual capacity exceeding 170 Mt for U.S. LNG projects is waiting for final investment decisions and regulatory approvals. The United States will thus increase LNG supply capacity beyond the middle of the 2020s, even if all of the projects are not realised.

Figure 3-6 | U.S. shale revolution and global LNG market trends



LNG exports from the United States are priced according to U.S. natural gas market prices that are lower than the traditional Asian LNG pricing mechanism which is indexed to oil prices. U.S. LNG exports, though being subject to other Asian energy prices, can provide competitive prices for the Asian market and are expected to influence 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 will bring about great changes in global LNG transactions. Such flexibility of U.S. LNG may also be useful for exports to Emerging Market Economies.

Canada which used to export nearly half its natural gas production to the United States via pipelines, lost the United States as a gas export destination because of the U.S. shale revolution. It now places great hopes on LNG exports to support future expansions of gas production.

Multiple LNG export projects are planned both for the Atlantic and Pacific sides. These projects will pave the way for Canada to expand natural gas production, particularly after 2030. One large Pacific coast project has been subjected to a final investment decision.

LNG exports from Western Australia to Japan were launched in 1989 under a large LNG production project, which has been completed in two phases. The LNG project was combined with the expansion of a domestic gas supply system and became a model project for LNG development. One project in Australia's Northern Territory began exporting in 2006 and another in Western Australia began in 2012. In the 2010s, LNG production began from multiple additional projects in Western Australia and new projects in Queensland in response to growth in LNG demand in Asia, including Japan and China. Production of these projects reached plateaux by 2019, bringing Australia's LNG production capacity to more than 80 Mt annually. As of 2020, Australia rivals 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 flexible LNG supply, including equity-based off-taking. Future upstream gas development projects include supplying natural gas to existing LNG facilities, providing a platform for sustainable upstream future natural gas projects. LNG production will smoothly expand under these projects before decelerating its growth from 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 has provided Russian LNG not only to Pacific LNG-consuming countries but also to the European market that has traditionally received Russian gas supply via pipelines. In Arctic Russia, the second large LNG project has already reached a final investment decision, with construction going on. The project will be available for LNG supply 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 to conventional LNG carriers to optimise transportation. Such flexibility is destined to 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 is already in operation. Investment decisions were made in 2017 for a floating LNG production project off Mozambique in East Africa and in 2018 for one off Senegal and Mauritania in West Africa, respectively. Large LNG players with global marketing capabilities have made commitments to take delivery of all LNG produced by these projects to underpin development.

Mozambique is well positioned to grow as a major LNG supplier over the long term as it considers multiple onshore LNG production projects in addition to the floating LNG production project. An investment decision was made on one of them in June 2019. It possesses large-scale natural gas resources and is at proximity to South Asia including India. Its strategic location away from significant maritime transportation chokepoints, can access not only the Asian market but also the European market through the Suez Canal or the Cape of Good Hope. Backed by the abovementioned projects, global natural gas production will steadily increase.

Figure 3-7 | Major interregional natural gas trade flows [2019]

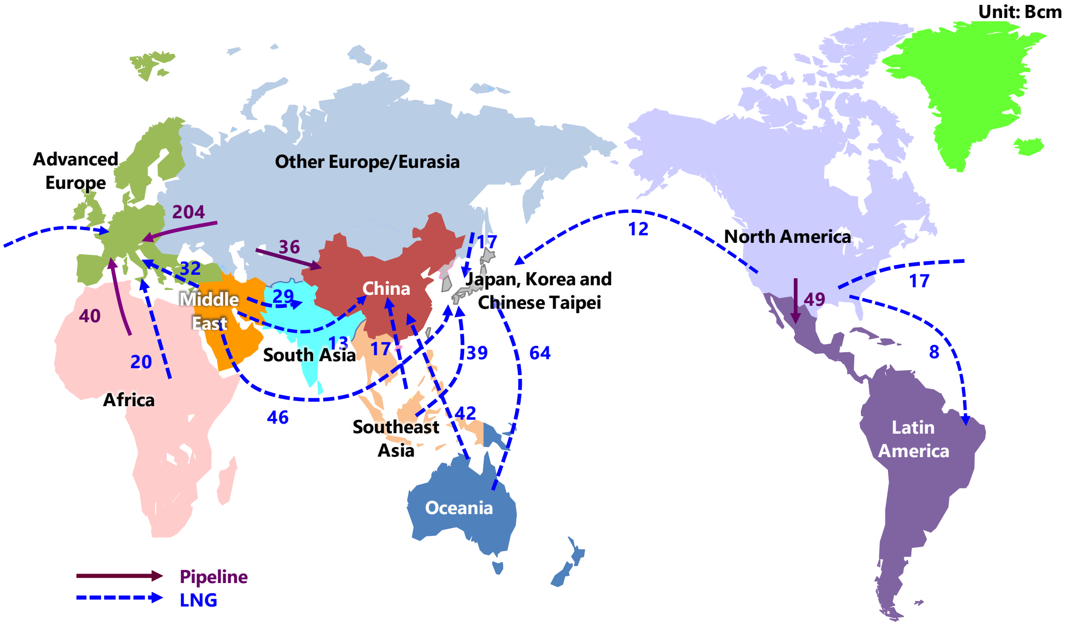
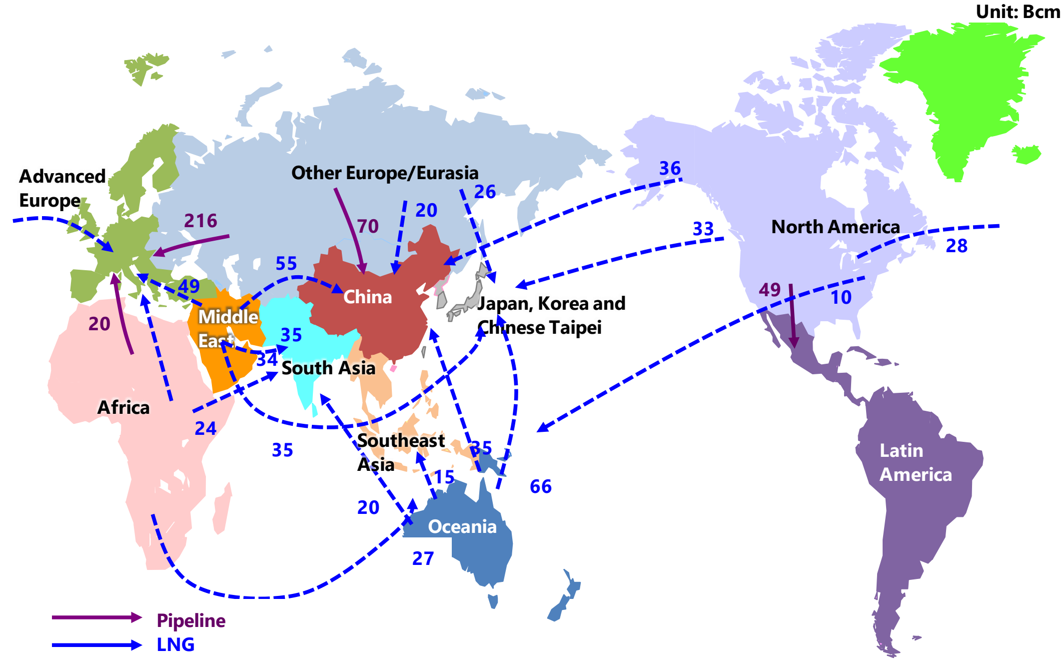
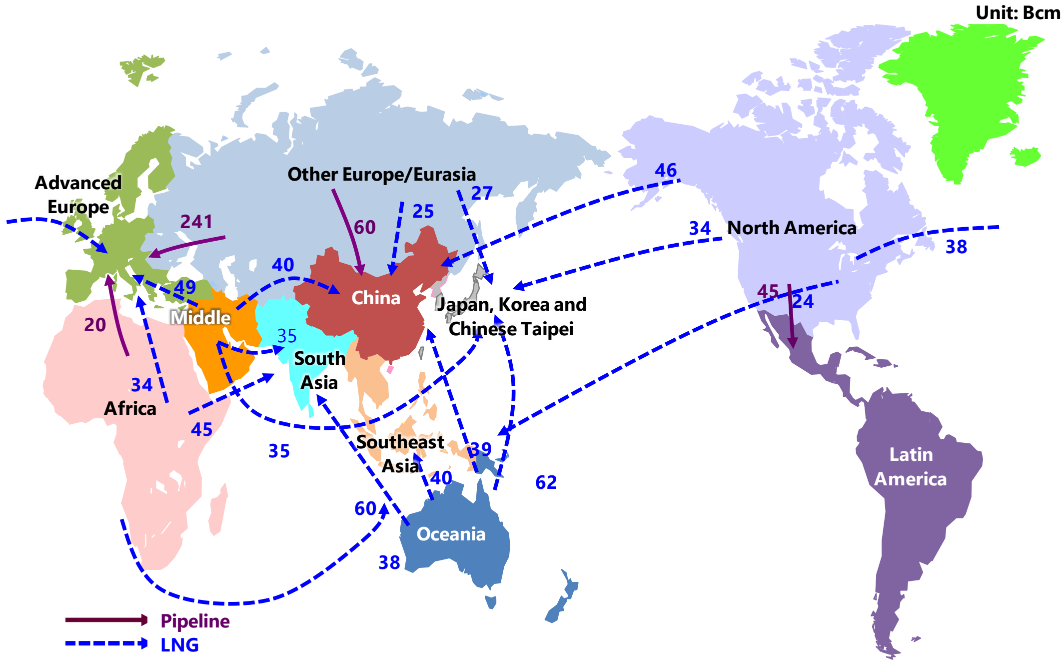


Figure 3-8 | Major interregional natural gas trade flows [Reference Scenario, 2030]



Note: Trade flows between major regions are covered. Some pipeline gas flows could be replaced with LNG flows.

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



Note: Trade flows between major regions are covered. Some pipeline gas flows could be replaced with LNG flows.

3.3 Coal

Uneven distribution of coal supply: Coal supply will rapidly decline in Western countries while remaining high in the Asia-Pacific region but could be affected by COVID-19

Coal's traditional economic advantage has been declining due to natural gas price drops and falling costs of renewable energy amid its rapid spread. At the same time, international arguments have grown for enhancing climate change countermeasures, leading to the shutdown or dismantlement of coal-fired power plants and pressuring investors' and financial institutions to divest or withdraw investment or loans from coal production and coal-fired power generation projects.

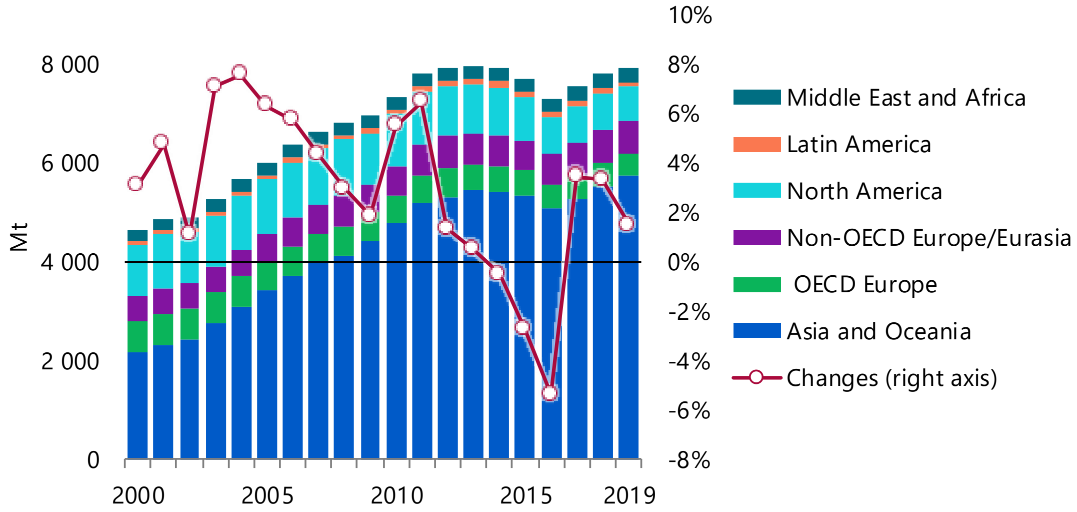
While global coal demand growth has been slowing down due to the abovementioned changes, global coal production increased by some 950 Mt in a decade from 6 968 Mt in 2009 to 7 921 Mt in 2019. Global coal production peaked at 7 976 Mt in 2013, fell to 7 299 Mt in 2016, and increased on a demand recovery for three consecutive years.

Coal production has been concentrating in the Asia-Pacific region, which accounts for 73% of global production. Production in the region hit a record high of 5 763 Mt in 2019. China, which accounts for nearly 50% of global coal production, boosted its annual production in 2019 by 4.1%, contributing much to the global production growth. Indonesia also increased coal production in 2019 by 12.4% and Viet Nam by 7.8%.

In contrast, the OECD Americas reduced coal production in 2019 to 711.1 Mt, the lowest since 1980. The United States experienced a steep decline of 6.7% and faster drops were observed in Europe. For example, coal production fell 22.3% in Germany, 8.2% in Poland, and 6.5% in the Czech Republic. OECD Europe which is promoting a coal phase-out posted a 12.2% decrease in coal production.

The global COVID-19 pandemic that emerged in early 2020 has affected coal demand and production is expected to weaken, with steam coal prices falling to lows for the next few years. The demand decline is feared to be prolonged and in some coal-producing countries, coalminers' infection with COVID-19 has led coal production to be suspended. Large coal producers are revising down their production plans.

Figure 3-10 | Global coal production



Note: Data for 2019 are provisional.
Source: IEA "World Energy Statistics and Balances 2020"

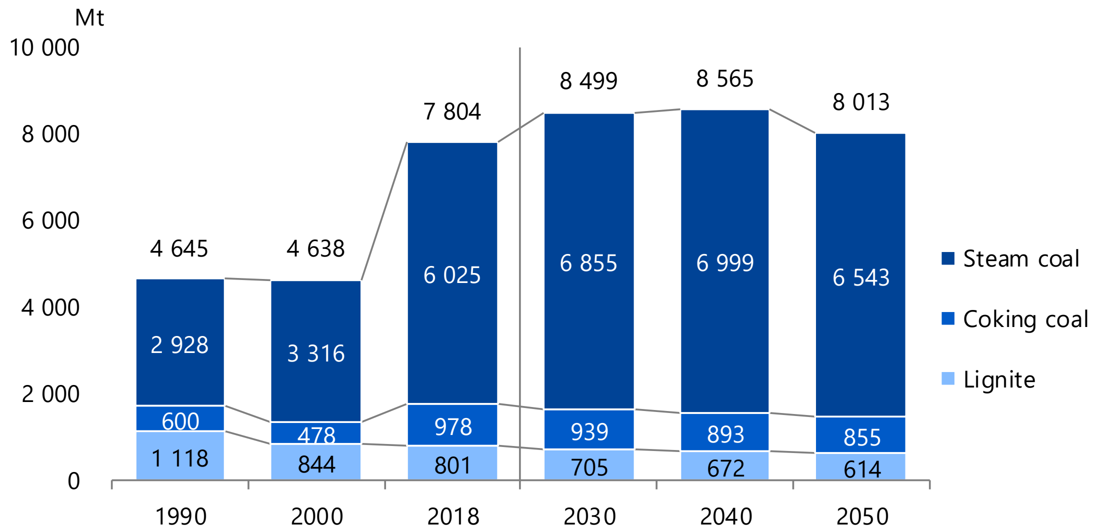
Coal production will remain high mainly in Emerging Market and Developing Economies until around 2040

Although the expansion of production at operating coalmines and the development of new coalmines are required for securing stable coal supply, Advanced Economies including Australia will continue to toughen regulations on coal production and consumption. Particularly, government approvals on and financing for steam coal production will become difficult under growing international arguments for enhancing climate change countermeasures. The European Union plans to enhance its coal phase-out measures while accelerating its low-carbonisation under a large-scale economic stimulus package to respond to economic deterioration through the COVID-19 spread. As no coal demand expansion is expected in North America, Europe and North America will thus continue to reduce coal production.

Meanwhile, steady demand for coal exists in Asian and other Emerging Market and Developing Economies. China is promoting the construction of new coal-fired power plants as part of economic stimulation measures to counter the COVID-19 pandemic. It is expected to maintain coal supply including domestically produced coal. India is promoting initiatives to expand coal production, while Indonesia has greatly increased domestic coal consumption. These major coal-producing and -consuming countries basically give priority to the utilisation of their respective domestic coal resources, indicating that their coal production will remain high until around 2040. Although these countries may try to import coal, growing moves to refrain from providing financing or public assistance for coalmine development indicate that coalmine development and coal production will concentrate in countries that have already been producing and exporting coal.

Global coal production will rise from 7 804 Mt in 2018 Mt to 8 499 Mt in 2030 (Figure 3-11). Later, it will slow down growth and level off until around 2040 before turning down.

Figure 3-11 | Global coal production [Reference Scenario]



Steam coal production will increase from 6 025 Mt in 2018 to a peak of 6 999 Mt in 2040, in line with coal demand for power generation. Meanwhile, coking coal production mainly for steelmaking will decline from 978 Mt in 2018 to 939 Mt in 2030. Demand for lignite that is produced and consumed within the same regions will decrease in countries such as Germany, Poland, and Thailand. Lignite production will gradually decrease from 801 Mt in 2018 to 614 Mt in 2050, in line with the dismantlement of existing lignite-fired power plants.

Among major coal exporters, Australia, Russia, and Africa will expand coal production in response to growth mainly in Asia, with coal trade increasing until 2040. Russia, while losing the European market, will give priority to exports to Asia. In line with the development of coal transportation infrastructure, Russia will expand exports while boosting coal production from 339 Mt in 2018 to 372 Mt in 2050.

Table 3-2 | Steam coal production [Reference Scenario]

(Mt)

	2018	2030	2040	2050	2018-2050	
					Changes	CAGR
World	6 025	6 855	6 999	6 543	518	0.3%
North America	582	455	391	292	-289	-2.1%
United States	562	450	388	289	-273	-2.1%
Latin America	92	97	101	97	5	0.2%
Colombia	79	84	87	83	4	0.2%
OECD Europe	63	50	44	37	-26	-1.7%
Non-OECD Europe/Eurasia	369	372	413	426	57	0.5%
Russia	247	260	284	290	43	0.5%
Middle East	0	0	0	0	0	0.0%
Africa	265	293	320	323	59	0.6%
South Africa	252	273	292	291	39	0.5%
Asia	4 394	5 288	5 399	5 038	644	0.4%
China	3 065	3 343	3 101	2 604	-462	-0.5%
India	694	1 184	1 490	1 625	931	2.7%
Indonesia	543	646	687	684	141	0.7%
Oceania	262	300	330	330	68	0.7%
Australia	260	299	328	328	69	0.7%

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

(Mt)

	2018	2030	2040	2050	2018-2050	
					Changes	CAGR
World	978	939	893	855	-123	-0.4%
North America	104	90	86	80	-24	-0.8%
United States	72	64	61	57	-15	-0.7%
Latin America	10	10	10	11	0	0.1%
Colombia	6	5	6	6	0	0.2%
OECD Europe	16	15	15	14	-2	-0.4%
Non-OECD Europe/Eurasia	101	98	95	91	-10	-0.3%
Russia	92	89	87	82	-9	-0.3%
Middle East	1	2	2	2	0	0.1%
Africa	11	24	30	36	25	3.7%
Mozambique	7	19	25	31	24	4.8%
Asia	553	516	446	399	-154	-1.0%
China	484	416	323	247	-237	-2.1%
India	37	66	92	119	81	3.7%
Mongolia	27	27	22	23	-4	-0.4%
Oceania	181	184	210	222	42	0.7%
Australia	179	183	209	221	42	0.7%

Figure 3-12 | Global coal trade (import volume) [Reference Scenario]

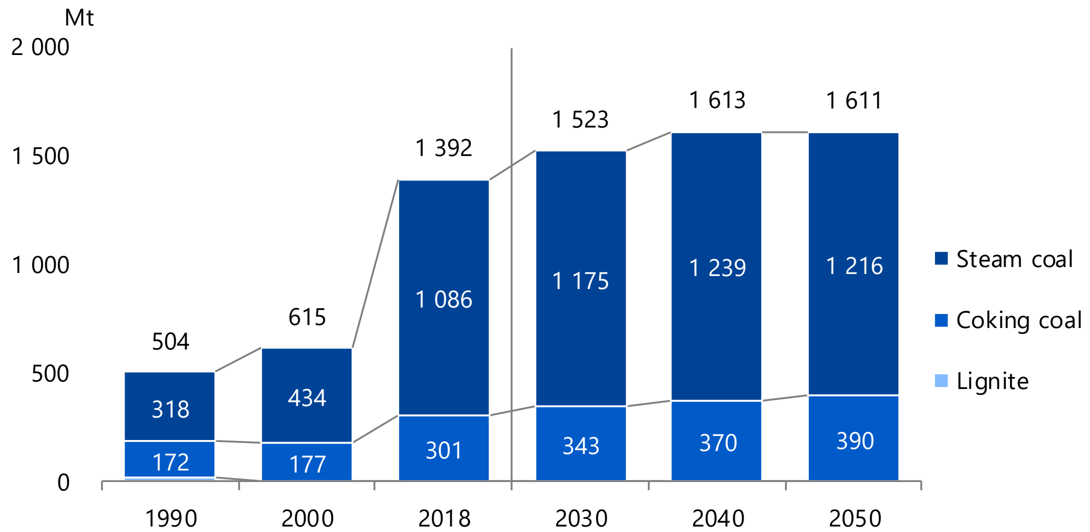
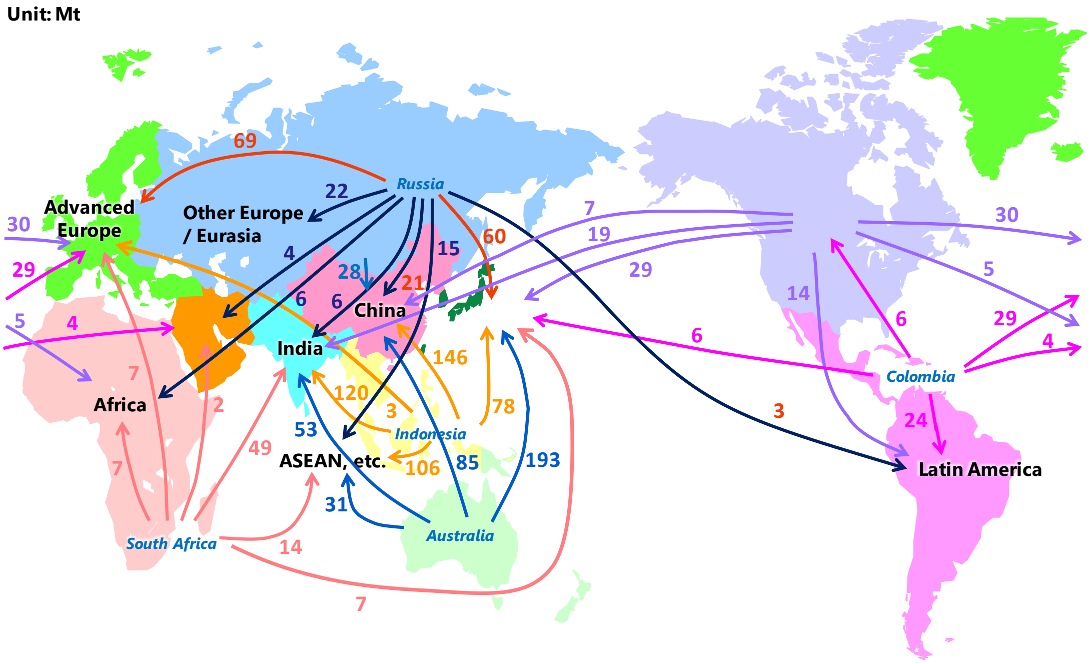


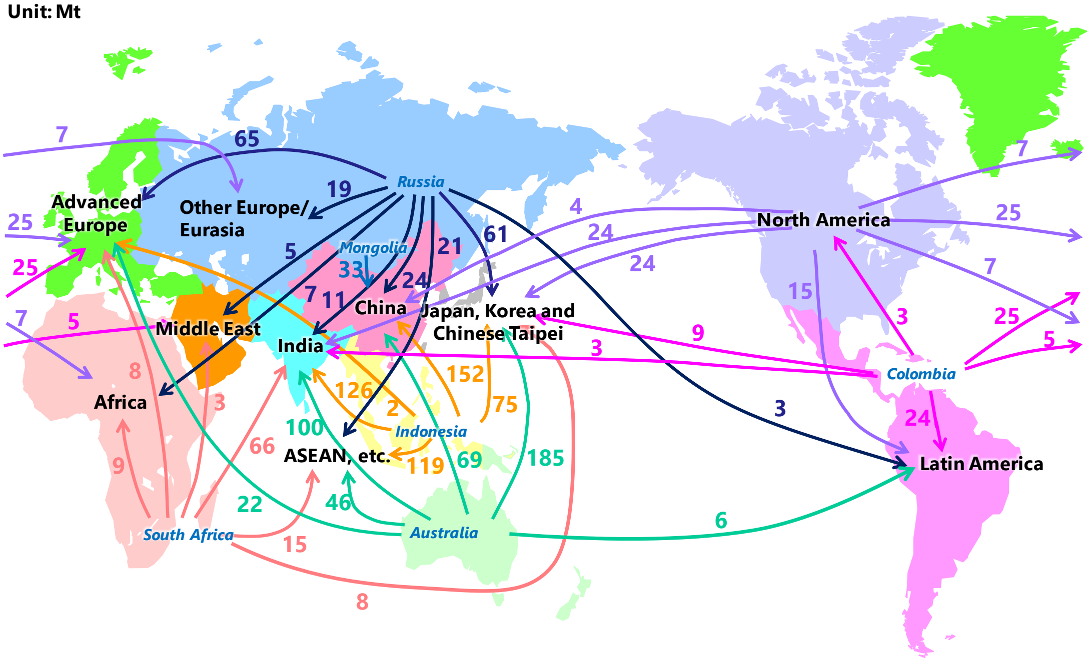
Figure 3-13 | Major interregional coal trade flows [2019]



Note: Trade volume covers steam and coking coal. Estimated imports totalling 2 Mt or more are specified. Mozambique is included into South Africa.
Sources: Estimated based on IEA "Coal Information 2020", TEX Report, etc.

Figure 3-14 | Major interregional coal trade flows [Reference Scenario, 2030]

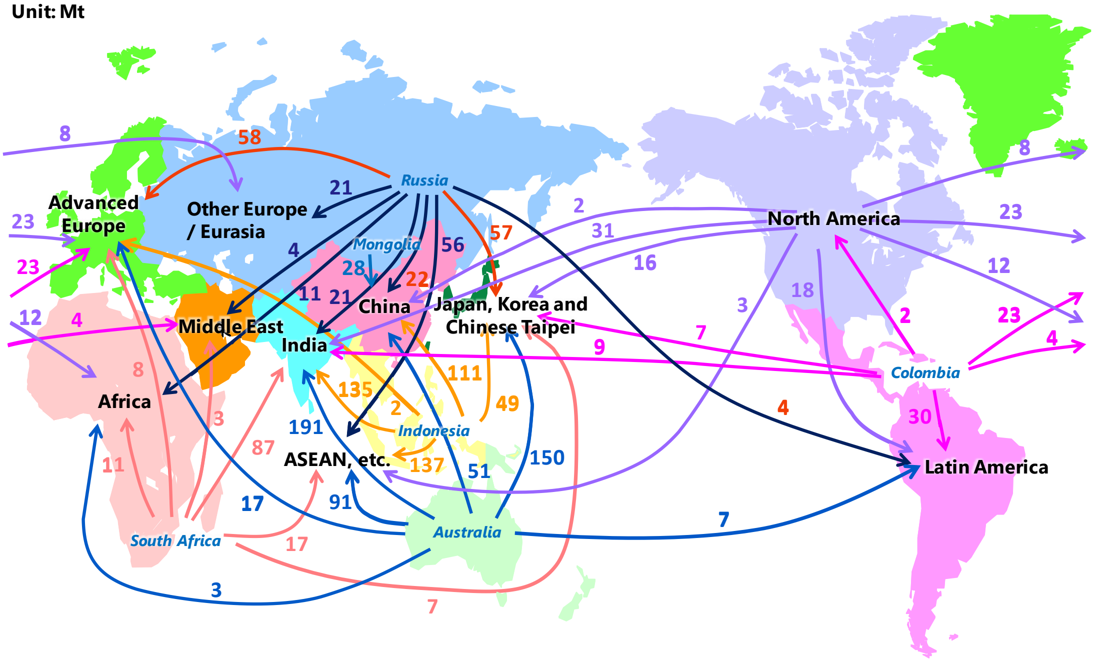
Unit: Mt



Note: Trade volume covers steam and coking coal. Estimated imports totalling 2 Mt or more are specified. Mozambique is included into South Africa.

Figure 3-15 | Major interregional coal trade flows [Reference Scenario, 2050]

Unit: Mt



Note: Trade volume covers steam and coking coal. Estimated imports totalling 2 Mt or more are specified. Mozambique is included into South Africa.

3.4 Power generation

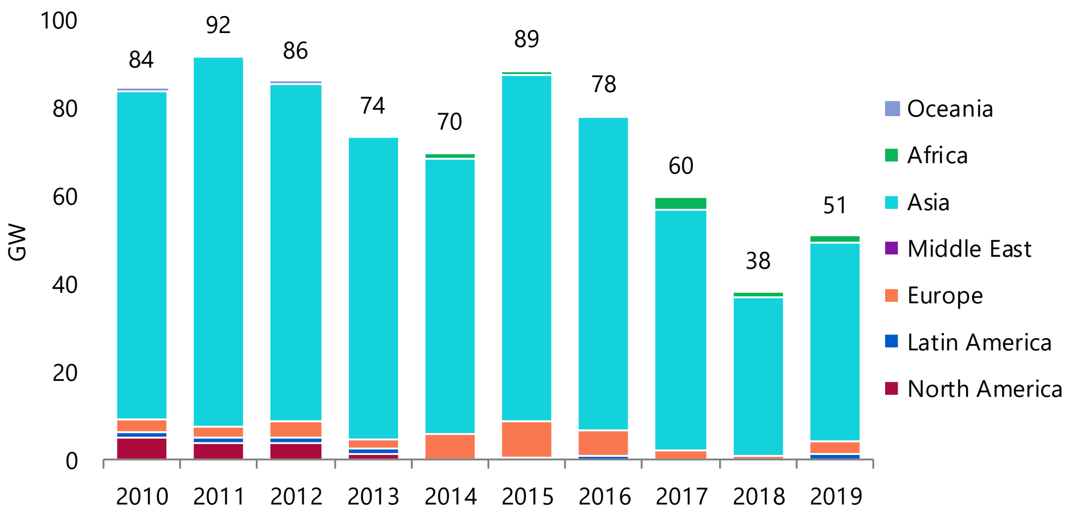
Recent trends

Investment in coal-fired power plants will continue declining

In recent years, governments, financial institutions, and environmental non-government organisations have increasingly sought to cancel coal-fired power generation development and to close existing coal-fired power plants prematurely. Such trends have been particularly remarkable in Europe. For example, Germany passed a long-pending bill to phase out coal-fired power plants by 2038 and Italian, French, U.K., (and Canadian) governments have announced coal phase-out policies and are initiating relevant procedures. With the World Bank restricting loans for new coal-fired power plants since 2013, some public and private financial institutions have also refrained from investing in such plants. In 2019, the European Investment Bank decided to end investment in not only coal but also oil and natural gas (all fossil fuels) related projects by 2021.

In response to such trends, newly completed coal-fired power plant capacity in the world has declined by a half to two-thirds of the past levels since around 2016 (Figure 3-16). Factors behind the decline may include not only economic deceleration in China as the world's largest coal consumer and shale gas development in North America, but also the abovementioned actions of governments and financial institutions.

Figure 3-16 | Newly completed coal-fired power plant capacity in the world



Source: Platt's

Electricity demand decline caused by COVID-19

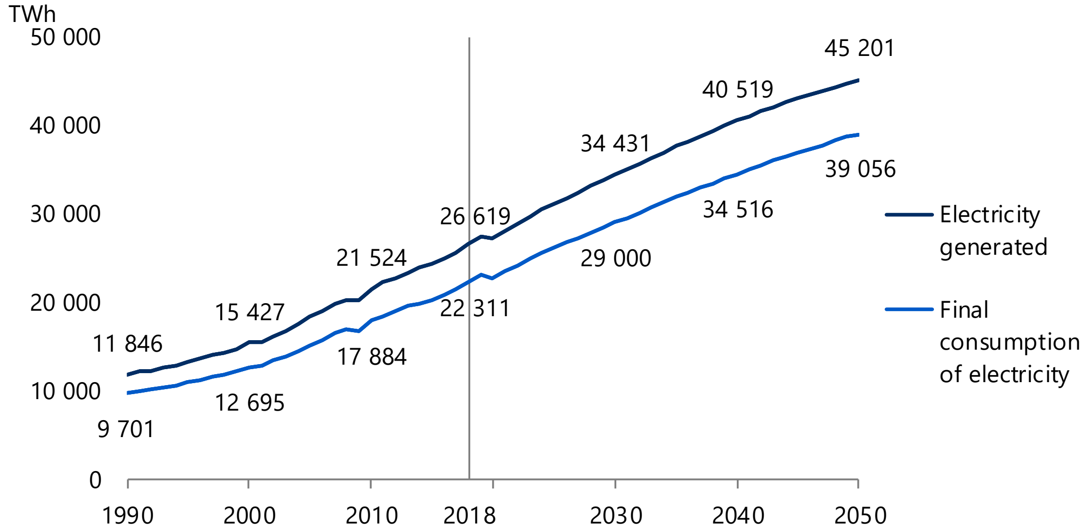
Between March and June 2020, electricity demand declined 5%-20% from past average levels in Europe, the United States, and Japan due to the COVID-19 pandemic and subsequent lockdowns. Even after the lockdowns, electricity demand failed to restore its past levels in multiple regions[12]. Such electricity demand decline led wholesale electricity prices to fall, affecting power generators' profitability and the adverse effects were particularly remarkable on fossil fuel-fired power plants with higher marginal costs, leading their capacity factor to sharply decrease.

Outlook

Power generation will rapidly increase in Asia

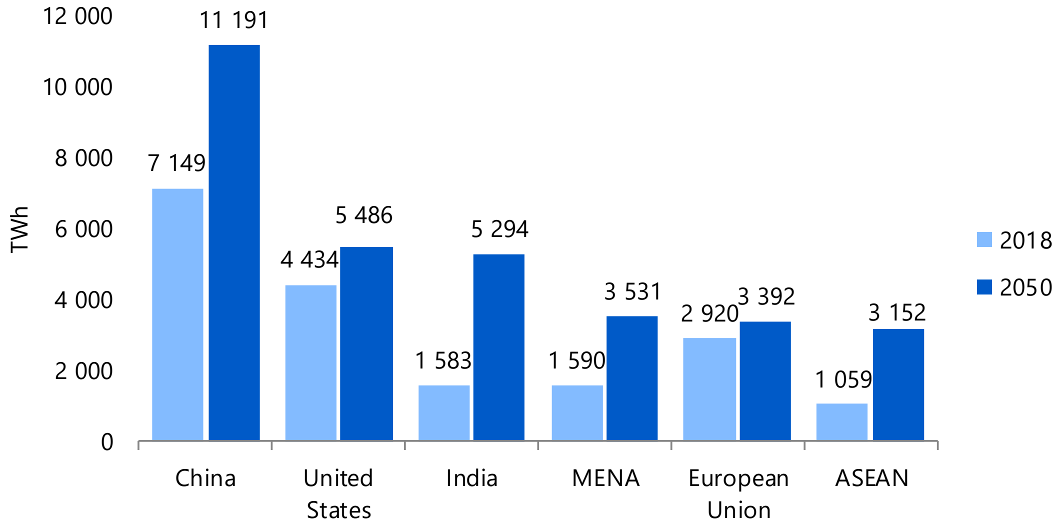
Over the long term and as the global economy recovers from the COVID-19 damages, electricity consumption will restore its uptrend. Global power generation will increase at an annual rate of 1.7% to 45 201 terawatt-hours (TWh) in 2050, a 1.7-fold rise from the current level (Figure 3-17). The growth of 18 582 TWh through 2050 is 2.6 times as much as the current power generation level in China, the largest power generator in the world. The Emerging Market and Developing Economies will capture 89% of the growth. Power generation in rapidly growing Asia will expand at an annual rate of 2.0% from 12 069 TWh in 2018 to 22 749 TWh in 2050, accounting for more than a half of the global total (Figure 3-18).

Figure 3-17 | Global power generation and final consumption [Reference Scenario]



[12] Ogasawara, et al "COVID-19 countermeasures' impacts on electricity demand and wholesale prices" Institute of Energy Economics, Japan (2020)

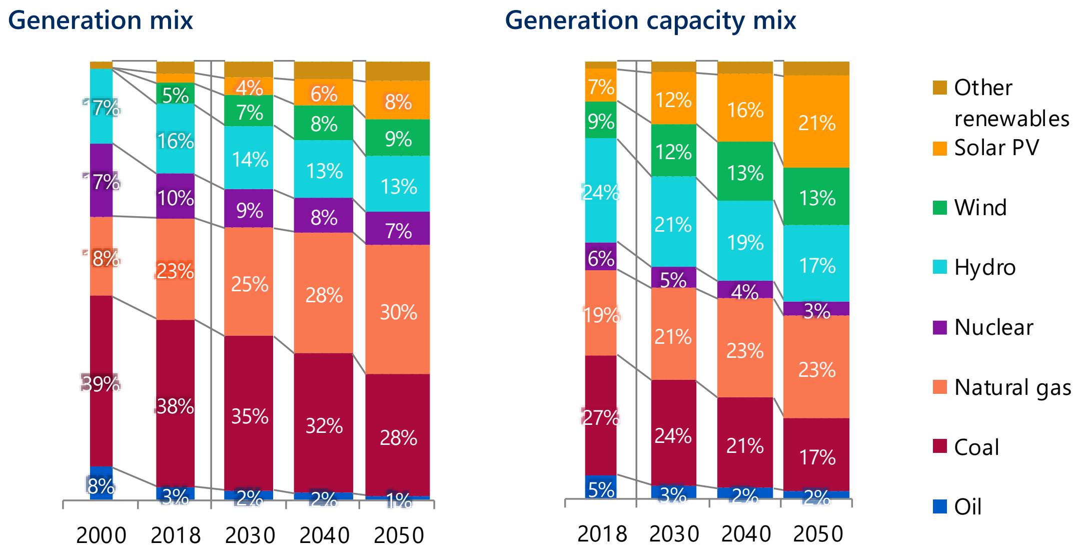
Figure 3-18 | Power generation in selected countries/regions [Reference Scenario]



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

Coal accounted for the largest share of global power generation in 2018, followed by natural gas, hydro, and nuclear (Figure 3-19). Natural gas, however, will expand its share from 23% in 2018 to 30% in 2050, becoming the largest electricity source surpassing coal. In 2050, generation from natural gas will be followed by coal, hydro, solar photovoltaics (PV), wind, and nuclear. The natural gas expansion results from technological development in combined cycle gas turbines (CCGTs) coupled with natural gas's growing role in adjusting for intermittent renewables power generation. Despite its share's decline, coal will continue to serve as a baseload electricity source mainly in Asia. The share for oil will trend down in the Advanced Economies as well as in the oil-rich Middle East. Nuclear power plant construction will make progress mainly in Asia as a measure to ensure energy security and mitigate climate change. However, the growth in nuclear power generation will not exceed the growth in electricity demand through 2050, leading the nuclear share to fall to 7% in 2050. Wind, solar PV and other renewable energy generation, excluding hydropower generation, will expand at the rapid annual rate of 5.7% on the strength of policy support and cost reduction, boosting its electricity mix share to about 20% in 2050.

Figure 3-19 | Global power generation mix [Reference Scenario]

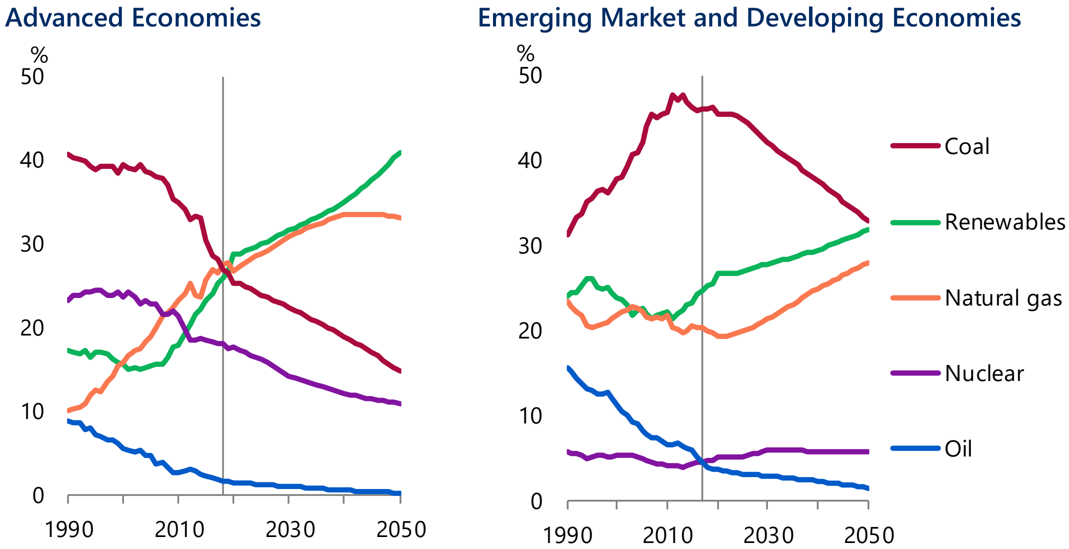


Note: Bar widths are proportionate to total power generation.

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

In the Advanced Economies, renewable energy will raise its share of total power generation to 30% in 2030 and exceed 40% in 2050, replacing natural gas as the largest electricity source for those economies (Figure 3-20). Solar PV and wind, among renewables, will account for 23% of total power generation, requiring each economy to promote adjustments for output fluctuations. Coal's share, now the largest, will substantially decline to 15% in 2050 under shifting away from coal-fired power generation policies in countries such as Canada and Italy and adhering to financial institutions' policies of restricting investments in coal-fired power generation projects. In the Emerging Market and Developing Economies, coal's share of total power generation will remain the largest even in 2050, while falling from the current level. As coal-fired power plants play a great role in meeting a robust electricity demand, it will urgently be required to develop a highly predictable environment for investments and to solve air pollution and related problems. Natural gas and renewable energy will expand their respective shares to around 30% in 2050, becoming major electricity sources.

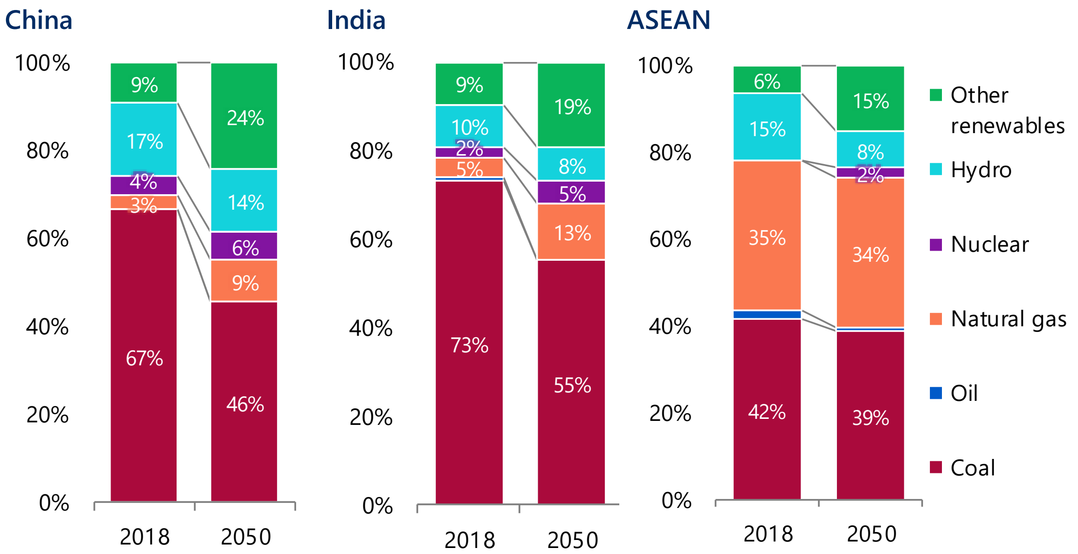
Figure 3-20 | Power generation mix in Advanced Economies and in Emerging Market and Developing Economies [Reference Scenario]



Fossil fuels will remain a dominant electricity source in Asia

In Asia including China and India, coal will remain a mainstay electricity source in response to the rapid electricity demand growth. But its currently high share of the power generation mix will fall gradually against the backdrop of air pollution and climate change countermeasures. Instead, renewable energy and natural gas will expand their shares (Figure 3-21). In ASEAN, the natural gas's share of the power generation mix will remain unchanged despite an increase in power generation from natural gas. Coal-fired power generation trends will differ by country. In the Philippines, coal-fired power plant construction will be promoted in response to growing electricity demand while in Thailand natural gas and renewable energy will cover the rise in electricity demand given the strong public support for coal phase-out and the absence of firm projects for new coal-fired power plants.

Figure 3-21 | Chinese, Indian, and ASEAN power generation mix [Reference Scenario]



Nuclear

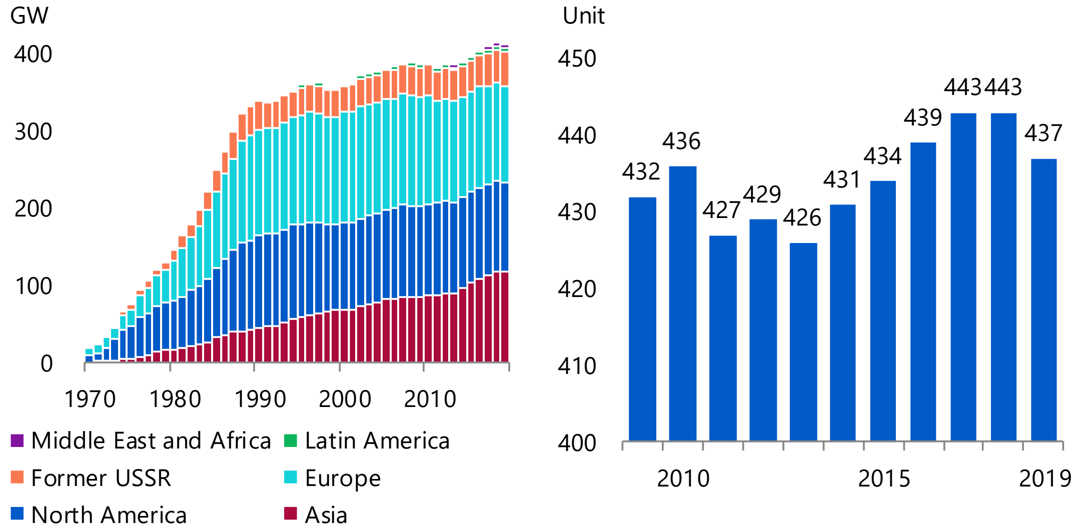
Nuclear capacity posted a slight fall in 2019: Will hopes on new technologies lead to a greater nuclear market?

Global installed nuclear power generation capacity rapidly expanded in Europe and the United States in the 1970s and 1980s before increasing moderately mainly in Asia. Nuclear power generation capacity and the number of nuclear reactors continuously increased between 2014 and 2018 before turning down in 2019 for the first time in six years (Figure 3-22). The downturn is attributable primarily to the closure of five reactors (with capacity totalling about 5 GW) in Japan. In China and Russia, meanwhile, new nuclear power plant construction projects have made relatively smooth progress. In 2019, three nuclear reactors in China and one in Russia reached commercial operation. As new nuclear power plant construction projects have been postponed or frozen in Europe and the United States, China and Russia have increased their presence in the global nuclear power generation market and Russia has expanded its nuclear power plant exports.

As a result of COVID-19 spreading globally from late 2019 to 2020 and electricity demand falling over the short term, nuclear power generation will decrease, and new nuclear power plant construction projects are being postponed.

Given that climate change countermeasures are globally growing important even in the absence of progress in new nuclear reactor construction projects in the world other than some countries, measures to better use existing nuclear reactors have been spreading. In the United States, particularly, it is worth noting that second license renewal was approved in December 2019 for Units 3 and 4 of the Turkey Point Nuclear Generating Station and in March 2020 for Units 2 and 3 of the Peach Bottom Nuclear Generating Station. These units are now allowed to operate for up to 80 years.

Figure 3-22 | Capacity and number of nuclear reactors

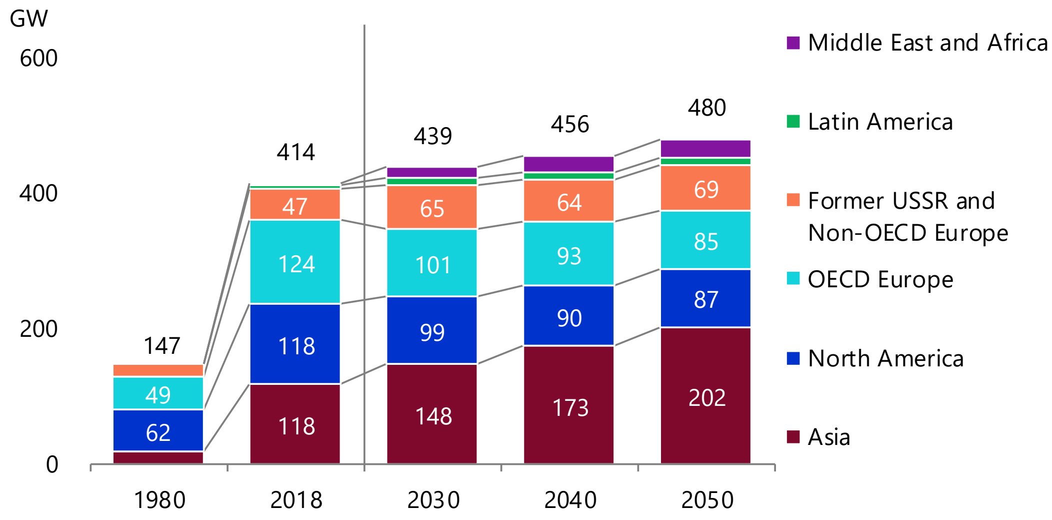


Measures to develop more competitive nuclear reactors such as small modular Reactors (SMRs) and Generation IV reactors have been activated. In such countries as the United States, the United Kingdom, and Canada, private companies have proactively promoted research, development, and demonstration projects using government-provided funds, sites, and equipment. The key question is whether these new reactors would end up as practical and attractive technologies for investors.

Future outlook: Nuclear reactors will decline in Europe and the United States but increase mainly in Asia

As the Fukushima Daiichi nuclear power plant accident triggered changes in public opinion about nuclear power plants causing rises in nuclear reactor construction costs, it has become difficult for Japan, Korea, the United States, and some European countries to construct new nuclear reactors as earlier planned. With existing reactors built in the 1970s or 1980s soon closing, nuclear power generation may decrease in many countries. These countries, however, may continue to use nuclear energy to address issues of stability in energy supply and climate change while maintaining and enhancing international competitiveness through the promotion of the nuclear industry. In contrast, multiple countries including China are planning to further promote nuclear energy. Middle Eastern and some other countries may expand the introduction of nuclear power generation in the future. Therefore, global installed nuclear power generation capacity will gradually increase through 2050 (Figure 3-23).

Figure 3-23 | Nuclear power generation capacity by region [Reference Scenario]



In the United States, the world's largest nuclear power generating country with 96 reactors, new nuclear power plant construction has slowed down as the economic advantages of natural gas-fired power generation have increased, thanks to shale gas development, and as power generation from low-cost renewable energy expanded. The country is even shutting down some existing reactors for economic reasons. Through 2050, its installed nuclear power generation capacity will decrease. Nevertheless, no change will be made to its policy of positioning nuclear as an important energy source and in fact, efforts will be made to avoid the early decommissioning or extend the operating period of existing reactors, while measures will promote building new ones.

In France, known as the largest nuclear energy promoter in Europe, the Energy Transition Law enacted in July 2015, limits the installed nuclear power generation capacity to the present 66 GW (63.2 GW in net power output) and reduces the nuclear share of power generation to 50% by 2025 (from around 75% in 2015). In view of a greenhouse gas emission reduction target, however, France has concluded the attainment of the target as difficult and decided to extend the target year to 2035. Therefore, France may maintain the present nuclear power generation capacity or slightly reduce the capacity for the immediate future as some reactors' closures are replaced by new ones. From 2040, however, the decommissioning of existing reactors will accelerate, reducing the total nuclear capacity substantially.

In the United Kingdom, installed nuclear power generation capacity will decrease due to the decommissioning of outdated reactors until around 2030. However, its government has given a policy of maintaining some nuclear power generation capacity, with multiple new reactor construction plans having been launched. Although these plans could be delayed due to difficulties in attracting investments, as seen in recent years, U.K. nuclear power generation capacity will rise back close to the current level around 2040.

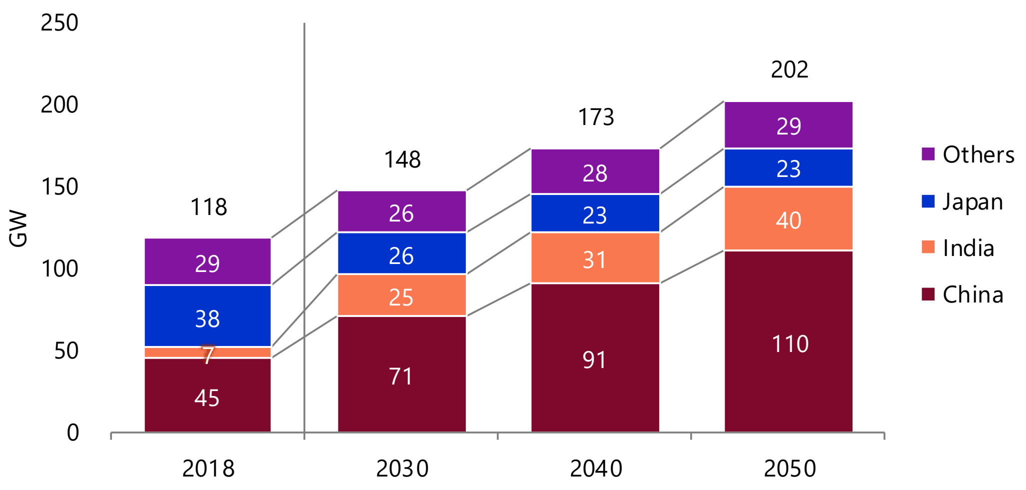
Germany, Switzerland, and Belgium have made clear their government plans for the nuclear phase-out plans in response to the Fukushima Daiichi accident and will eliminate nuclear power generation between 2025 and 2035. Despite some attempts to construct new plant, as outdated reactors are decommissioned, other OECD European countries will reduce their capacity through 2050.

Russia has vowed to proactively use nuclear energy at home and abroad. Its domestic installed nuclear power generation capacity will increase from 28 GW in 2017 to 38 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. For example, Russia launched the commercial operation of the world's first floating nuclear power station (comprising two 35 MW reactors) in May 2020. In the future, it may take advantage of the floating nuclear power plant technology to explore new market needs, including the introduction of such plants in remote regions.

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

Asia, including China and India, will ever more increase its presence in nuclear power generation. China will boost its installed nuclear power generation capacity to 91 GW in 2040, replacing the United States as the largest nuclear power generator in the world (Figure 3-24). Asian installed nuclear power generation capacity will surpass the combined OECD Europe and North American capacity in 2045, reaching 202 GW in 2050. China and India will account for more than 70% of the Asian capacity.

Figure 3-24 | Asian nuclear power generation capacity [Reference Scenario]

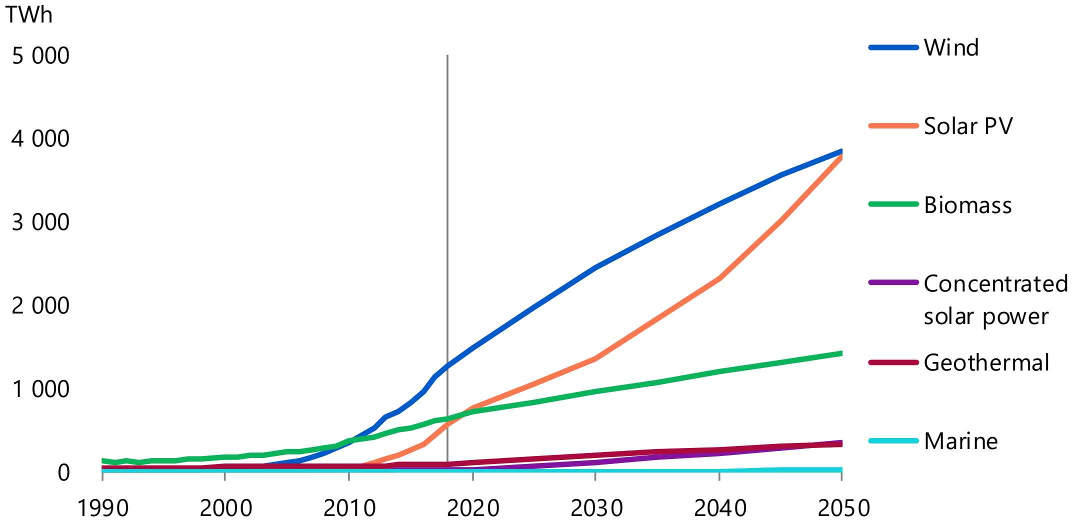


Renewables

Great expectations have been placed on the future of renewable energy. Since the mid-2000s, variable renewable energy power sources such as solar PV and wind 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 are now modifying or scaling down their incentive policies for wind and solar PV power generation. The United States is planning to phase out or terminate investment and production tax credits. In Europe, successful bids have been made for unsubsidised projects without any premium. China publicly invited bids for unsubsidised wind and solar PV power generation projects in 2019, and more than 20 GW of projects were scheduled to be constructed. In line with the fundamental modification of the Feed-in Tariff Scheme for renewable energy, Japan is considering developing new institutions to encourage independent wind and solar PV power generation. Even with reduced government subsidies, variable renewables power generation are becoming cost competitive to thermal power generation, paving the way for further diffusion.

As the pandemic affected supply chains, construction, and fundraising for renewable energy projects, the growth in renewables power generation capacity in 2020 is lower than in the previous year. Nevertheless, the decarbonisation trend will remain unchanged after the pandemic, leading investment in environmental technologies, including renewable energy, to further increase over the long term. Generation from variable renewables will increase from 1 840 TWh in 2018 to 7 992 TWh in 2050. Variable renewables will boost their share of global power generation from only 7% in 2018 to 18% in 2050, increasing their presence in the electricity system (Figure 3-25).

Figure 3-25 | Global renewables power generation except hydro [Reference Scenario]



Europe, China, and North America are currently major wind power generation markets and will continuously drive growth in global wind power generation (Figure 3-26). While growth for onshore wind power generation capacity decelerates, due to transmission line constraints and a decline in suitable onshore locations for development, offshore wind power generation will take advantage of its increasing economic efficiency to expand overall wind power generation in these regions. Installed offshore wind power generation capacity in the world increased from 3 GW in 2010 to 23 GW in 2018[13]. Europe is the world's largest offshore wind power generation market, with supply chains developed for offshore wind power generation. In recent years, bids have been invited for unsubsidised offshore wind power generation projects and bidders' electricity sales prices have fallen close to $50/MWh (for projects with power generation in or after 2025). Among other regions, Chinese Taipei, China, and the United States have attracted attention as emerging markets for offshore wind power generation. In Japan, the development of offshore projects has been activated following the enactment of the maritime renewable energy resources act[14]. Given an increasing number of offshore wind farms, global installed wind power generation capacity will more than triple from 564 GW in 2018 to 1 850 GW in 2050.

Figure 3-26 | Global wind power generation capacity [Reference Scenario]

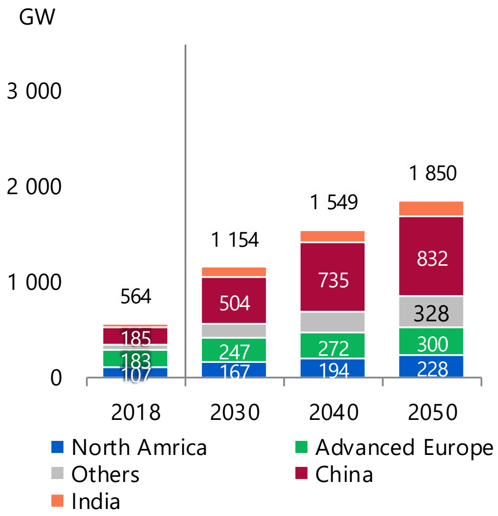
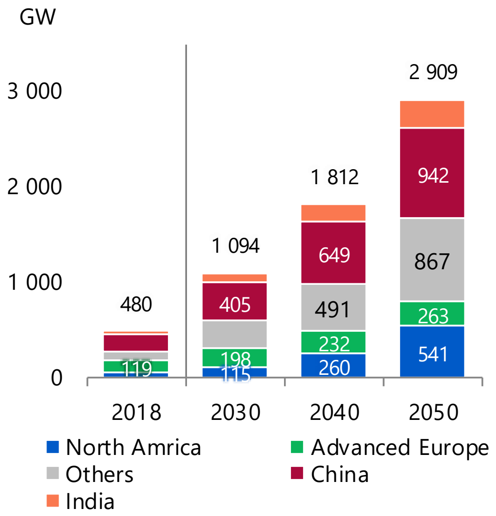


Figure 3-27 | Global solar PV power generation capacity [Reference Scenario]



Thanks to substantial cost drops, solar PV power generation has spread from Europe, the United States, China, and Japan, where subsidisation policies are well developed, to the rest of the world (Figure 3-27). In solar PV auctions in Chile, the United Arab Emirates, Saudi Arabia, and other countries rich with solar radiation, bid prices lower then $30/MWh have been recorded. Costs for self-consumption solar PV power generation systems have fallen to grid parity levels, competing with electricity retail prices and solar PV power generation is expected to grow even more competitive. Global installed solar PV generation capacity will expand more than six-fold from 480 GW in 2018 to 2 909 GW in 2050. As costs are expected to continue

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

[14] Act of Promoting Utilization of Sea Areas in Development of Power Generation Facilities Using Maritime Renewable Energy Resources

to fall over the long term, net capacity growth will accelerate in the second half of the outlook period, reaching 1 097 GW between 2040 and 2050.

An analysis of detailed power mix models[15] for China, India, Japan, the United States, ASEAN, and the European Union indicates that the expansion of onshore wind power generation capacity will be limited due to the uneven distribution of resources in the United States and China, while solar PV power generation is more competitive thanks to remarkable cost drops and more abundant suitable sites for such power generation.

Renewable energy will contribute to reducing carbon emissions from power supply and dependence on foreign energy sources and improve the resilience of energy systems, leading renewable energy power generation capacity to increase robustly. Given that the electrification of final energy demand will make further progress towards realising long-term climate change targets, the low-carbonisation of electricity sources will grow even more important, requiring renewable energy power generation to diffuse far more than as assumed in the Reference Scenario. To meet the requirement, research and development efforts to further cut costs and increase efficiency will have to be stepped up along with investment promotion policies, enhanced environmental regulations and policy incentives for power sources plagued with slow diffusion. Renewables' harmony with energy and social systems will also become a key challenge. For such harmony, variable renewables should be coupled with technologies and institutions for integrating them into the electricity system. Biomass-fired power generation should be supported by a sustainable biomass supply chain giving considerations to land use. Offshore wind and geothermal power generation should be associated with environmental protection and foster mutual understanding with existing industries.

3.5 Biofuels

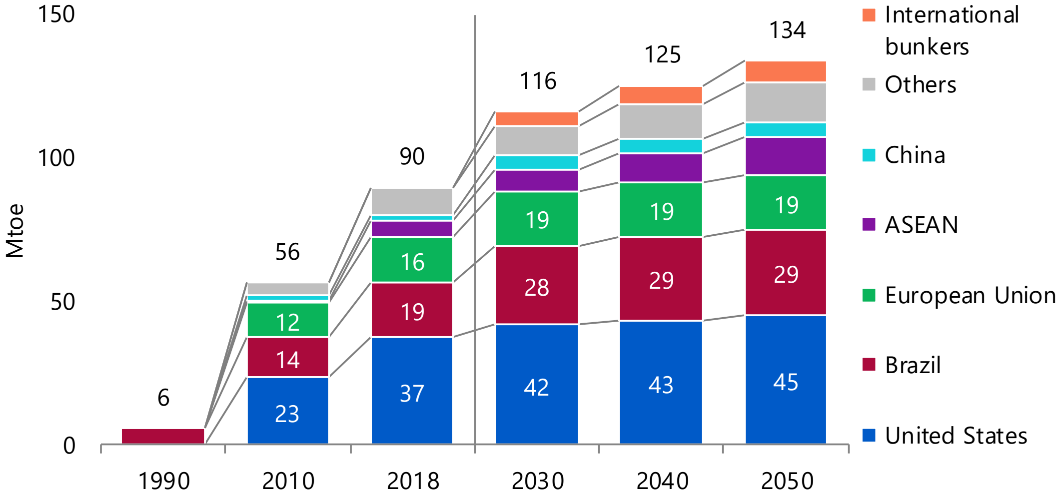
The penetration of liquid biofuels including bioethanol and biodiesel has made progress as part of measures on climate change, energy security, and agriculture promotion. However, biofuel consumption for automobiles remains concentrated in the United States, Brazil, and the European Union, which accounted for 80% of global biofuel consumption at 90 Mtoe in 2018.

While biofuel consumption has substantially increased since the 1990s, biofuel investment has remained stagnant since 2010. Due to a plunge in automobile fuel consumption under the impact of the COVID-19 pandemic, biofuel consumption in 2020 will decline from the previous year. Over the long term, biofuel consumption will recover as climate change countermeasures are enhanced, however, as vehicles are electrified further, biofuel demand growth will decelerate. Despite the consumption growth deceleration, biofuel consumption for vehicles will increase to 134 Mtoe in 2050 and consumption will remain concentrated in the United States, Brazil, and the European Union (Figure 3-28). In the United States and Brazil, biofuel consumption will slightly increase on the penetration of vehicles that can run on fuels with high bioethanol contents. In the European Union, biofuel consumption growth will level off from 2030 as liquid fuel demand growth slows down and concerns over first-generation biofuels' environmental impact grow. Although ASEAN, China, and some other Asian

[15] The models considered the uneven distribution of wind and solar PV resources, hourly fluctuations, and constraints and costs regarding storage, transmission, and output restrictions.

countries will sharply boost biofuel demand, Asian biofuel consumption will fall short of rivalling European, U.S., or Brazilian levels. Biofuel consumption for international aviation and shipping, which is very little at present, will expand in the future.

Figure 3-28 | Biofuel consumption [Reference Scenario]



4. Advanced Technologies Scenario

4.1 Major measures

In the Advanced Technologies Scenario, measures to maximise CO_2 emission reduction will be implemented with consideration given to their application opportunities and acceptability to society. Each country will strongly implement aggressive energy conservation and decarbonisation policies that contribute to securing stable energy supply and to enhancing climate change measures, 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 strongly diffuse energy efficient equipment and the supply side will further promote renewable and nuclear energies (Table 4-1).

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

2018 → 2050 (Reference Scenario, 2050)

	Advanced Economies	Emerging Market and Developing Economies
Fossil fuel-fired power generation	Developing an initial investment finance scheme	
	Installing CCS from 2030 (Countries with carbon storage potential excluding aquifers)	
[IGCC share of newly installed plants]	0% → 60% (20%)	
[Coal thermal efficiency (stock basis)]	37.9% → 42.9% (44.9%)	35.2% → 40.5% (40.4%)
[Natural gas thermal efficiency (stock basis)]	49.3% → 60.4% (59.9%)	37.5% → 55.1% (47.7%)
Nuclear power generation	Maintaining appropriate wholesale power prices	Developing an initial investment finance framework
[Capacity]	312 GW → 292 (204)	104 GW → 433 (276)
Renewables power generation	System cost reduction	System cost reduction
	Grid stabilisation technology cost reduction	Low-cost finance
	Efficient grid operation	Advancing power systems
[Wind capacity]	302 GW → 1 011 (608)	261 GW → 2 614 (1 242)
[Solar PV capacity]	248 GW → 1 793 (1 019)	232 GW → 2 943 (1 889)

2018 → 2050 (Reference Scenario, 2050)

	Advanced Economies	Emerging Market and Developing Economies
Biofuels	Developing next-generation biofuels	Biofuel cost reduction
	Diffusing FFVs further	Agricultural policy position
[Consumption]	58 Mtoe → 108 (70)	32 Mtoe → 83 (57)
Industry	Full diffusion of best available technologies in 2050	
Transportation	Reducing fuel-efficient vehicle costs. Doubling ZEV travel distances	
[New car fuel efficiency]	15.6 km/L → 41.1 (29.1)	13.5 km/L → 31.8 (22.1)
[ZEV share of new passenger vehicle sales]	2.2% → 66% (41%)	1.3% → 50% (25%)
Buildings	Doubling the pace of improving new electrical appliance and insulation efficiency (an improvement of about 15% from the Reference Scenario in 2050)	
	Electrifying space/water heating and cooking equipment, clean cooking	

Energy efficiency

Final energy consumption in 2050 in the Advanced Technologies Scenario will be 1 766 Mtoe less than in the Reference Scenario. The energy savings amount to 18% of global final energy consumption in 2018. Of the energy savings, the transport sector will account for 756 Mtoe, the buildings sector for 579 Mtoe, and the industry sector for 429 Mtoe (Figure 4-1). The road sector will be responsible for 548 Mtoe in the transport sector and the residential sector for 412 Mtoe in the buildings sector. This is because vehicles and home appliances offer huge potential to improve energy efficiency. The Emerging Market and Developing Economies will capture more than 50% of energy savings in all final energy consumption sectors, including the industry sector where they will account for 80% of energy savings. Whether or not the Emerging Market and Developing Economies would realise potential energy savings mainly in the industry sector is key to global energy savings progress.

By using already available high-efficiency technologies for steel, chemical, pulp and paper, and other energy-intensive industries, these industries will improve their energy intensity in 2050 by 11%-12% from the Reference Scenario (Table 4-2). Through energy intensity improvements, the Emerging Market and Developing Economies' industry sector will reduce consumption by 346 Mtoe from the Reference Scenario. Asia, where basic materials industries account for a large share of production, will command 58% of the global energy savings. Transfer of Advanced Economies' highly efficient technologies to the Emerging Market and Developing Economies will make great contributions to improving the overall energy efficiency. It is hoped that the Advanced Economies would develop energy conservation technologies and proactively diffuse them in the Emerging Market and Developing Economies.

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

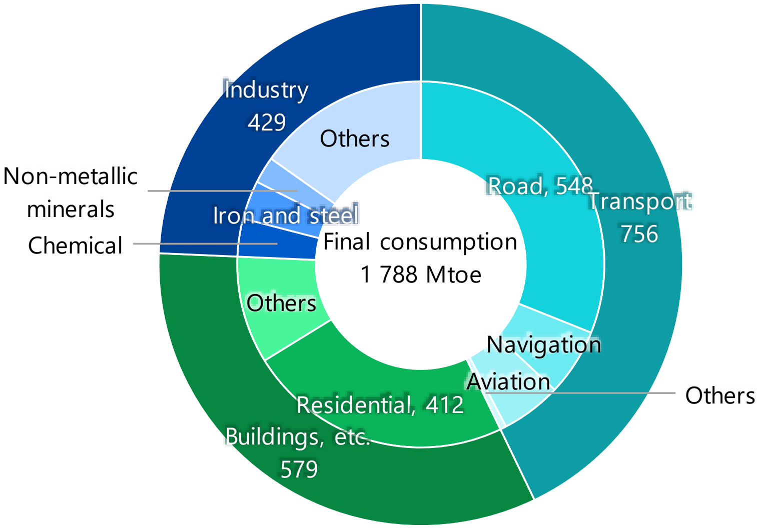


Table 4-2 | Global energy indicators

		2018	2050 Reference	2050 Advanced Technologies
Industry	Intensities (2018 = 100)			
	Iron and steel	100	75.6	66.6
	Non-metallic minerals	100	79.9	70.6
	Chemical	100	82.8	73.5
	Paper and pulp	100	88.7	78.9
	Other industries	100	67.4	59.7
Transport	New passenger vehicle fuel efficiency (km/L)	14.3	23.9	33.8
	ZEVs' share of vehicle sales	1.4%	27%	48%
	Natural gas's share in intl. marine bunkers	0.0%	21%	41%
	Biofuel's share of intl. aviation bunkers	0.0%	2.1%	19%
Buildings	Overall energy efficiency (2018 = 100)			
	Residential	100	66.7	55.4
	Commercial	100	37.8	32.2
	Electrification rate			
	Residential	24%	38%	42%
	Commercial	53%	65%	65%

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

In the transport sector, fuel efficiency and vehicle fleet mix improvements will make further progress. In addition to hybrid vehicles, electric, plug-in hybrid and fuel cell vehicles will diffuse further. Zero emission vehicles (ZEVs) will expand their share of vehicle sales in 2050 by 20 percentage points 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

9.3 km/L from the Reference Scenario to 33.0 km/L (3.0 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. Given their great potential to switch fuels, natural gas will account for 41% of international marine bunkers and biofuels for 19% of international aviation bunkers.

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 save energy consumption. The overall global energy efficiency will improve by some 17% from the Reference Scenario in the residential sector and by some 15% in the commercial sector. 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 kerosene, liquefied petroleum gas, city gas, and other fuels are used for water and space heating in various ways depending on national conditions, fuel consumption for water and space heating will be greatly reduced. Particularly, traditional biomass consumption including inefficient fuel wood and manure will be 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, powering, and lighting more than offset the effect of the electrification of appliances.

Renewables

In the Advanced Technologies Scenario, renewables (including hydro) will increase their share of primary energy consumption from 14% in 2018 to 25% in 2050, 9 percentage points higher than in the Reference Scenario. Particularly, variable renewable power sources (wind and solar PV power generation) will boost their combined share from 1.4% in 2018 to 9.0% in 2050. Factors supporting the spread of renewables in the Advanced Technologies Scenario will include enhanced decarbonisation policy initiatives and technological development, growing environmental consciousness among business operators, investors, and consumers, and the improved social acceptability of renewable energy facility and power transmission infrastructure construction. Playing major roles in integrating variable renewable power sources into the grid system will be power generation prediction technologies, output control, energy storage technologies, power supply/demand adjustment technologies using electric vehicles, and smart grid systems combining these and information technologies.

Installed capacity for onshore and offshore wind power generation will spread in all regions faster than in the Reference Scenario, reaching 3 625 GW in 2050 (Figure 4-2), twice as much as in the Reference Scenario. 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 distribution of wind resources. The United States will continue to spread wind power generation by extending policy incentives and enhancing grid systems in the Advanced Technologies Scenario, despite the termination of power-generation tax credits and the concentration of wind resources in the centre of the North American continent which work to hold down the spread in the Reference Scenario.

Offshore wind power generation will spread in Asia (including China, Chinese Taipei, and Japan) 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 including enhanced economic assistance, national institution-building efforts for ocean development, and the promotion of understanding by fishery business operators and other traditional ocean users about wind power generation will help to spread offshore wind power generation in these regions. China will keep the largest share of global onshore and offshore wind power generation capacity, remaining a major wind power generation market. It will capture 48% of global wind power generation capacity in 2030 and 44% in 2050.

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

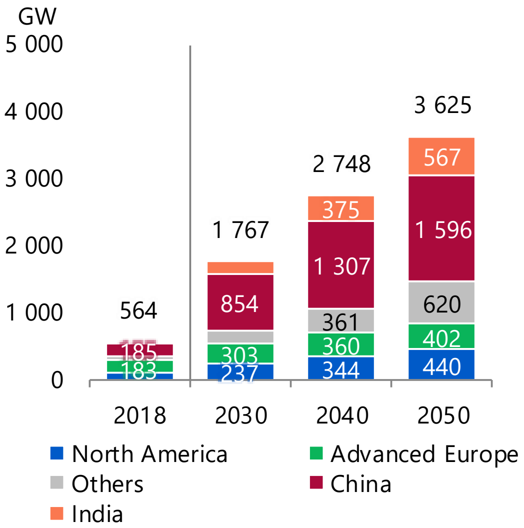
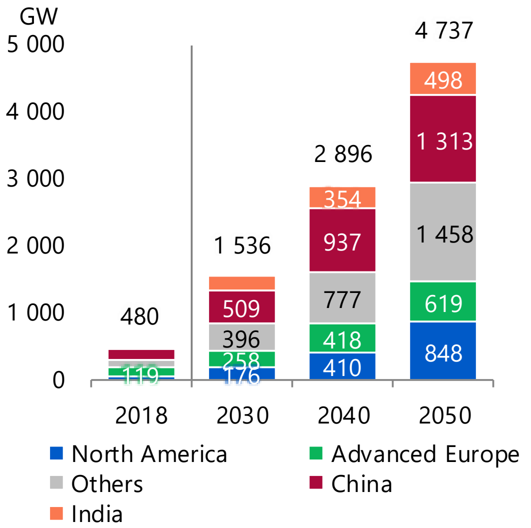


Figure 4-3 | Global installed solar PV power generation capacity [Advanced Technologies Scenario]



Solar PV power generation will also accelerate its expansion globally, boosting its global installed capacity in 2050 to 4 737 GW (Figure 4-3), 1.6 times as large as in the Reference Scenario. 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, solar PV power generation will accelerate its growth in the Sun Belt rich with 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 2 639 GW in 2050, accounting for 56% of the global total. The Middle East, Africa, and Latin America will expand their combined solar PV power generation capacity in 2050 to 486 GW, 1.7 times as much as in the Reference Scenario and 32 times as large as in 2018, becoming major solar PV power generation markets.

In addition to short-term energy storage technologies such as batteries, long-term energy storage technologies to adjust for seasonal output fluctuations could be required to realise the massive expansion of variable renewable power sources. Such technologies include hydrogen production. Europe and other regions have recently conducted conceptual design studies and demonstration tests for power-to-gas systems to use renewables electricity for producing hydrogen. Water electrolysis devices required for power-to-gas systems feature high load responsivity and are expected to become useful for adjusting electricity supply and demand and give flexibility to the grid system. They can also use “surplus” electricity to produce hydrogen, which can be used as fuel for power generation, transportation, and heat supply in the industrial and buildings sectors and as feedstock for industrial processes. The Circular Carbon Economy initiative (Chapter 7) to synthesise hydrogen from renewable energy and CO_2 into fuel or feedstock has also attracted attention recently. For example, synthetic fuel could result from methanation processes or liquid fuel synthesis (Fischer-Tropsch) processes. They would allow surplus electricity from renewables to be utilised across multiple sectors while methane and liquid hydrocarbon fuels are used through existing energy supply infrastructure. If system integration technologies to combine the electric grid with other sectors to stimulate decarbonisation are diffused over the long term, renewables power generation could be further promoted.

Nuclear

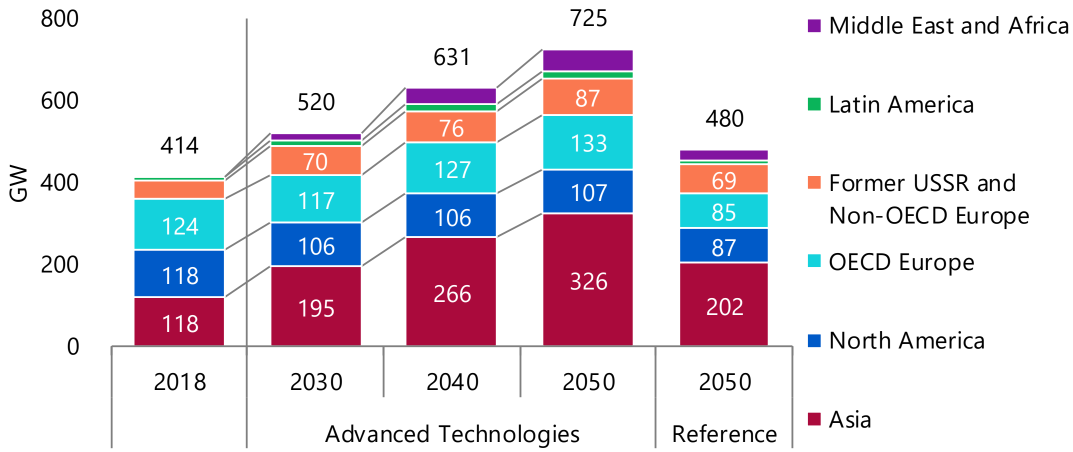
Nuclear power generation fulfils multiple policy objectives including stability in energy supply, climate change mitigation and air pollution controls. Therefore, nuclear power generation in the Advanced Technologies Scenario will spread more than in the Reference Scenario. Powerful policy measures will be implemented to commercialise new nuclear reactors such as small modular reactors (SMRs) and Generation IV reactors that are still under development as of 2020. It should be mentioned that the impact of SMR diffusion would be limited because of these reactors’ small capacity.

Nuclear energy initiatives in non-power sectors will also be important to achieve substantial decarbonisation in the whole of society. Therefore, nuclear energy will be used not only for power generation but could also be used for multiple other purposes such as residential and industrial heat supply, hydrogen production, and seawater desalination.

Among countries that have proactively promoted nuclear power generation, the United States and France will reduce their nuclear power generation capacity. In the Advanced Technologies Scenario, however, more new nuclear power plant construction projects will be realised in these countries than in the Reference Scenario, reducing the capacity drops from present levels. On the other hand, the United Kingdom and Russia will build new nuclear power plants and increase their capacity. Even countries that have clarified their nuclear phase-out policies in response to the Fukushima accident will change those policies to put off their nuclear power plant shutdown or replace decommissioned capacity to promote decarbonisation and maintain their industrial competitiveness. As well as Advanced Economies that have offered ambitious decarbonisation initiatives, some emerging economies will expand nuclear power generation to promote decarbonisation while meeting a rapidly growing electricity demand.

In the Advanced Technologies Scenario under these assumptions, global installed nuclear power generation capacity will increase from 414 GW in 2018 to 725 GW in 2050 (Figure 4-4), about 1.5 times as much as in the Reference Scenario.

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



North America will reduce installed nuclear power generation capacity to 107 GW in 2050 due primarily to a decrease in the United States. Factors behind the U.S. capacity decrease include the shutdown of plants with deteriorated economic efficiency and outdated ones, a slowdown in electricity demand growth, and cheap natural gas and renewable energy prices. However, the U.S. federal government and some state governments are increasingly giving higher ratings to nuclear energy's low-carbon value and the reliability of nuclear energy supply. In the Advanced Technologies Scenario in which such trend will be maximised, support for innovative nuclear technology development and the extension of lifespans for existing nuclear power plants will be greater than in the Reference Scenario. Particularly, the United States and Canada are proactively promoting the development of SMRs and Generation IV reactors to be commercialised in or after 2030.

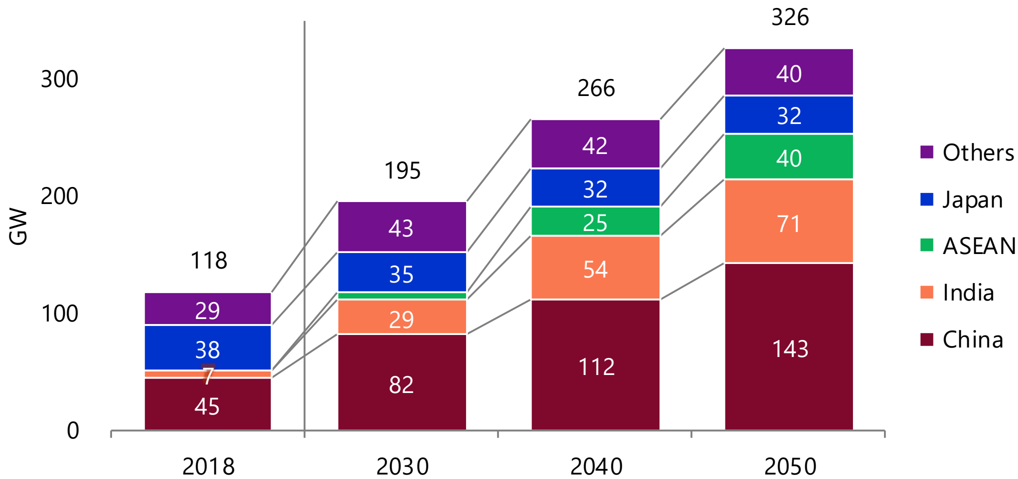
In OECD Europe that has offered ambitious greenhouse gas (GHG) emission reduction targets, the construction of additional nuclear power plants and the replacement of outdated reactors will be politically promoted, leading installed nuclear power generation capacity to rise from 124 GW in 2018 to 133 GW in 2050. In France known as the largest nuclear power generator in Europe, installed nuclear power generation capacity will decline more slowly than in the Reference Scenario, with more nuclear power plant construction projects implemented. The United Kingdom will promote the construction of sophisticated large light-water reactors, boosting its installed nuclear power generation capacity from the current level to 17 GW. As the United Kingdom, along with the United States and Canada, is advocating new reactor development, the promotion of large light-water (Generation III plus) reactors and the commercialisation and diffusion of new reactors from the 2030s will strongly drive its nuclear power generation capacity expansion.

Russia will accelerate new nuclear power plant construction, expanding its installed nuclear power generation capacity from 29 GW in 2018 to 38 GW around 2035. While the Russian capacity levels off later, Russia will proactively export nuclear power plants on the strength of economic and energy demand growth in emerging economies. Russia has already been promoting cooperative relations with many of those economies to support their development of nuclear, other industrial infrastructure and human resources, paving the way for its future nuclear power plant exports.

The Middle East, Africa, and Latin America, known as emerging nuclear energy markets, will launch the 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 that has already launched nuclear power plant construction and in Saudi Arabia that has announced nuclear power plant construction plans.

As in the Reference Scenario, Asia will have the world's largest installed nuclear power generation capacity in the Advanced Technologies Scenario (Figure 4-5). The Asian capacity will top the combined capacity of OECD Europe and North America (at 231 GW) in 2035 and reach 326 GW in 2050. As in the Reference Scenario, China and India will drive capacity growth in Asia. Southeast Asian countries, now planning to introduce nuclear power generation, will introduce low-carbon power sources that are stable and economically rational to meet its growing power demand. ASEAN's installed nuclear power generation capacity, though currently at zero, will start commercial nuclear power generation around 2030 and by 2050 will surpass Japan's 32 GW by about 8 GW (40 GW).

Figure 4-5 | Asian installed nuclear power generation capacity [Advanced Technologies Scenario]

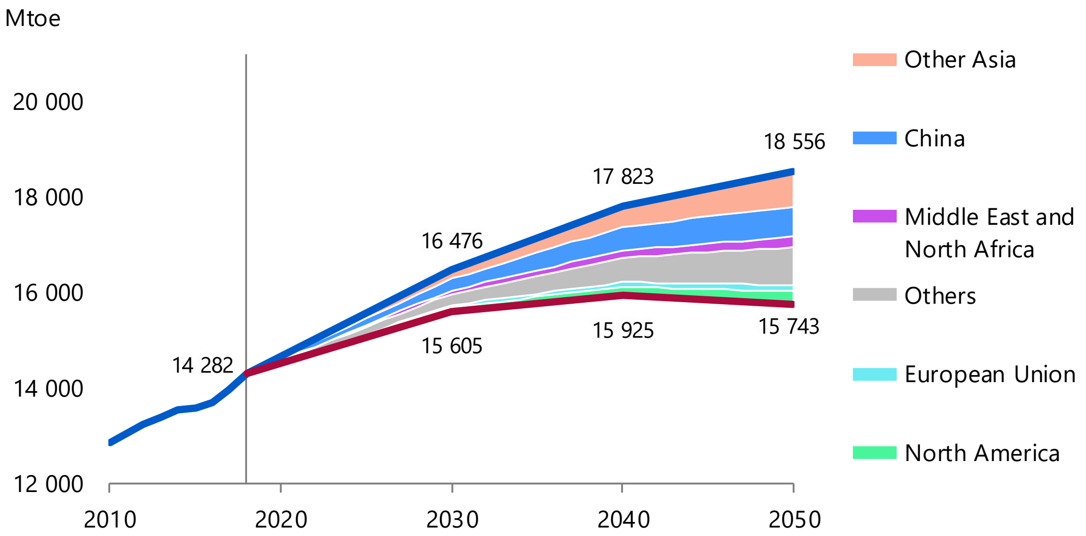


4.2 Energy supply and demand

Primary energy consumption will decline by 15% through a substantial cut in fossil fuel consumption in Emerging Market and Developing Economies

The strong implementation of energy efficiency improvement and climate change measures will substantially reduce primary energy consumption (Figure 4-6). Primary energy consumption in 2050 in the Advanced Technologies Scenario will be 15.2% less than in the Reference Scenario, with accumulated energy savings totalling 45.3 Gtoe. Particularly, fossil fuel consumption including oil, natural gas, and coal will be 65.1 Gtoe less, with accumulated CO_2 emission cuts reaching 225.7 Gt. This will be desirable from the viewpoint of climate change mitigation and contribute to each country's energy security.

Figure 4-6 | Global primary energy consumption and savings (from Reference Scenario) by region

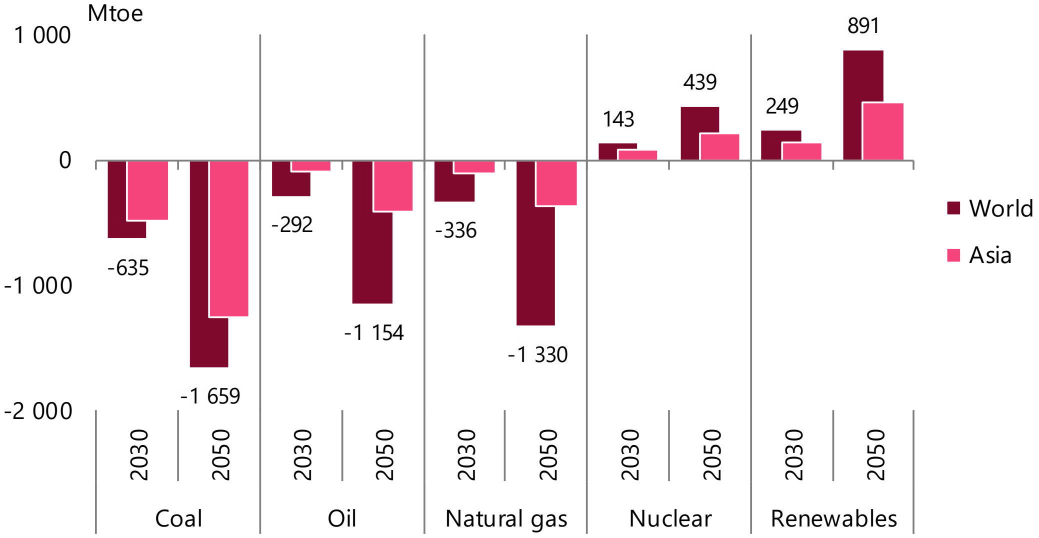


The Asian and other Emerging Market and Developing Economies that are projected to expand energy demand will play a great role in realising the Advanced Technologies Scenario as they offer great energy conservation potential. The Emerging Market and Developing Economies will account for 73.8% of global energy savings from the Reference Scenario in 2050 and those in Asia for 47.3%. Energy consumption in the Emerging Market and Developing Economies holds the key to reforming the broadly defined global energy system, including consumption and production patterns for energy sources required by the world. Their energy consumption influences the global environment.

Among energy sources, fossil fuels will post great primary energy consumption savings, while non-fossil fuel consumption increases (Figure 4-7). Of a decline of 4 143 Mtoe in primary fossil fuel consumption from the Reference Scenario in 2050, coal will account for 40.1%, oil for 27.9%, and natural gas for 32.1%. Meanwhile, non-fossil energy consumption will record an increase of 1 330 Mtoe. Consumption will rise by 67.0% for renewables and by 33.0% for nuclear. As a result, fossil fuels' share of primary energy consumption in the Advanced Technologies

Scenario will fall from 81.2% in 2018 to 66.6% in 2050. Notably, the world will remain heavily dependent on fossil fuels even in the Advanced Technologies Scenario.

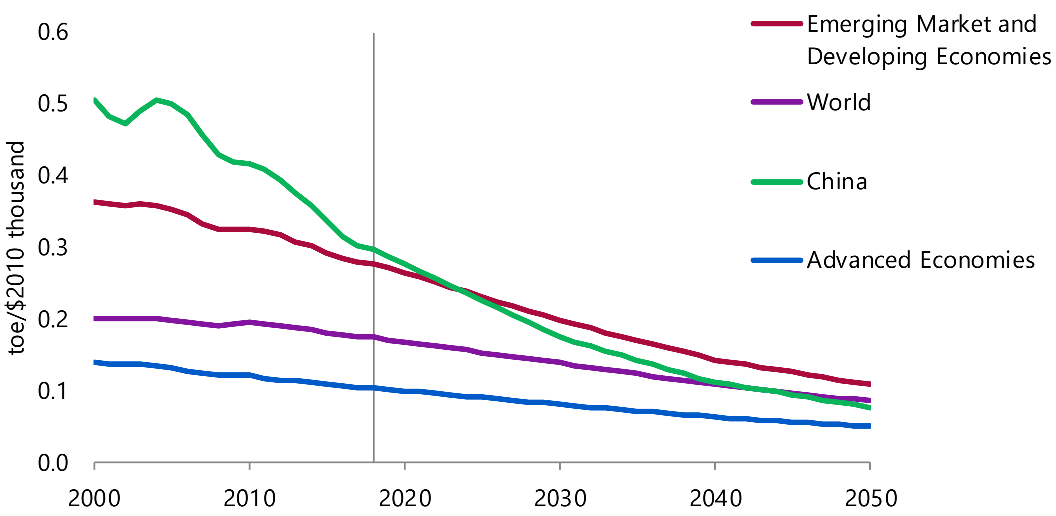
Figure 4-7 | Final energy consumption changes from Reference Scenario [Advanced Technologies Scenario]



The Emerging Market and Developing Economies will account for 68.5% of the fossil fuel consumption savings in 2050. Those in Asia, including China, India, and ASEAN, will capture 46.7%. The Emerging Market and Developing Economies will account for 82.8% and Asia for 73.3% of the coal consumption savings. The Emerging Market and Developing Economies will command 20.8% of nuclear consumption growth and 35.9% of renewable energy consumption growth. Those in Asia will account for 14.1% of nuclear consumption growth and 31.6% of renewable energy consumption growth. These percentage shares are too big to be ignored.

The world's GDP energy intensity will plunge by 51.2% from 2018 to 2050 (Figure 4-8). The Advanced Economies will post a decline of 52.2% against 61.1% for the Emerging Market and Developing Economies, which have greater potential to improve energy efficiency. China's GDP energy intensity will continue declining due mainly to industrial structure changes, slipping below the average for the Emerging Market and Developing Economies in the first half of the 2020s and catching up with the global average by around 2040. GDP energy intensity in 2050 will plunge by 63.0% in India and by 46.3% in ASEAN. The Asian Emerging Market and Developing Economies will reduce GDP energy intensity by 66.4%.

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



To promote the introduction and penetration of energy efficient technologies towards realising the Advanced Technologies Scenario, the Emerging Market and Developing Economies, particularly those in Asia, will have to eliminate energy efficiency improvement barriers including the lack of fundraising capacity and lack of consciousness that blocks the penetration of such technologies. They should spread energy-efficient equipment by offering them at reasonable prices to low-income individuals and provide energy efficiency improvement technologies that take into consideration differences between urban and suburban lifestyles. Each country and region should implement education programs to enhance energy efficiency consciousness. Advanced Economies' bilateral cooperation with Emerging Market and Developing Economies, as well as multilateral cooperation frameworks such as the ASEAN+3 and Asia Pacific Economic Cooperation forums, will help promote such education.

Final oil consumption in the road sector will substantially decline

The abovementioned powerful measures to improve energy efficiency and counter climate change will greatly affect final energy consumption. Final energy consumption in 2050 in the Advanced Technologies Scenario will total 11 107 Mtoe, down 1 766 Mtoe or 14% from the Reference Scenario. Global final energy consumption per capita that increased from 1.31 toe/person in 2018 to 1.33 toe/person in 2050 in the Reference Scenario will decrease in the Advanced Technologies Scenario by about 12% from 2018 to 1.15 toe/person (Figure 4-9). The steady implementation of the abovementioned measures will produce great effects.

Figure 4-9 | Global energy consumption per capita [Advanced Technologies Scenario]

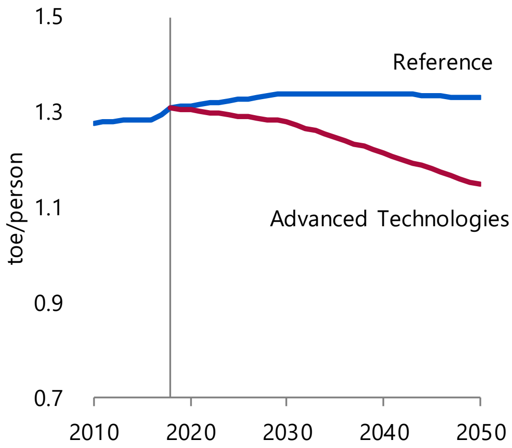
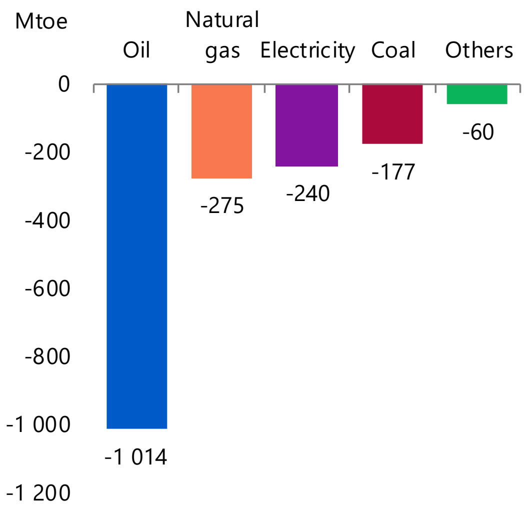


Figure 4-10 | Global final energy consumption changes (from Reference Scenario) [Advanced Technologies Scenario, 2050]



Among major energy sources, oil will post the largest final consumption decline from the Reference Scenario in 2050, followed by natural gas and electricity (Figure 4-10). Final oil consumption in the Advanced Technologies Scenario will be 1 014 Mtoe or 19% less than in the Reference Scenario, accounting for 57% of total final energy consumption savings. Almost all oil consumption savings will occur in the transport sector, and particularly in the road sector which will record remarkable savings against the backdrop of vehicle fuel efficiency improvements and electric vehicle penetration (Figure 4-11). Electrified vehicles' share of vehicle ownership in 2050 will be 78% in the Advanced Technologies Scenario against 57% in the Reference Scenario. To achieve such rapid penetration of electrified vehicles, efforts will have to be made to accelerate product development including high-performance storage battery technologies, vehicle production cost reduction, and product line-up expansion. Policies meeting regional market development phases, tax incentives, electric vehicle charging infrastructure development, and other measures will have to be promoted comprehensively and powerfully.

Final natural gas consumption in 2050 will be 275 Mtoe less than in the Reference Scenario. The savings include 39 Mtoe in buildings sector consumption in Europe and 36 Mtoe in North America. Contributing to the savings will be improvements in gas equipment efficiency and buildings insulation efficiency.

Final electricity consumption will decline by 202 Mtoe from the Reference Scenario in the buildings sector and by 151 Mtoe in the industry sector, offsetting a consumption increase in the transport sector. Asia, including China and India, will account for nearly half of the global electricity consumption declines in the buildings and industry sectors, indicating that the expansion of high energy efficiency technologies in the region will be effective for climate change measures and energy savings.

While final energy consumption in the Advanced Technologies Scenario substantially declines from the Reference Scenario, the differences in the energy mix between the two scenarios will be limited (Figure 4-12). Even in the Advanced Technologies Scenario, it will be important to provide a wide variety of energy sources in a stable manner.

Figure 4-11 | Global road sector energy consumption changes (from Reference Scenario) [Advanced Technologies Scenario, 2050]

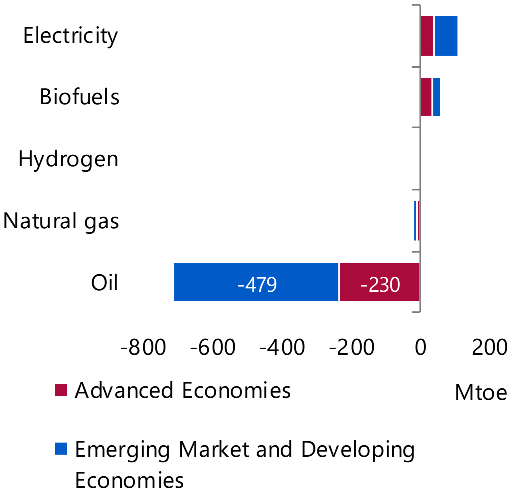
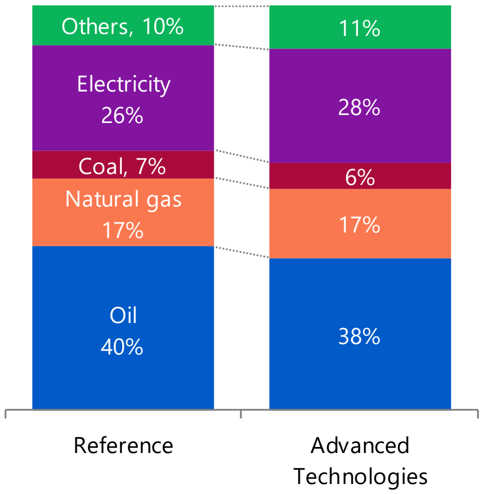


Figure 4-12 | Global final energy consumption mix [2050]

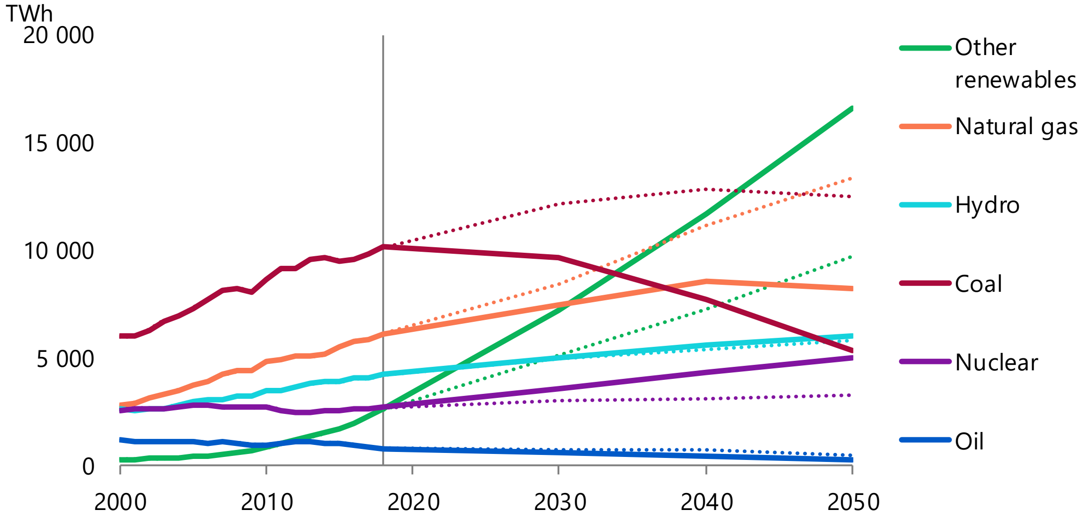


Power generation mix

In the Advanced Technologies Scenario, final electricity consumption savings will reduce the need for power generation by 3 711 TWh, equivalent to the U.S. power generation in 2018. The use of integrated gasification combined cycle (IGCC) plants for mixing biomass with coal, and other technologies for fuel transition from coal will contribute to halving coal-fired power generation in 2050 from the current level (Figure 4-13). In contrast to coal, non-hydro renewables including solar PV, wind, and biomass will become the largest power source. Nuclear power generation will gradually increase.

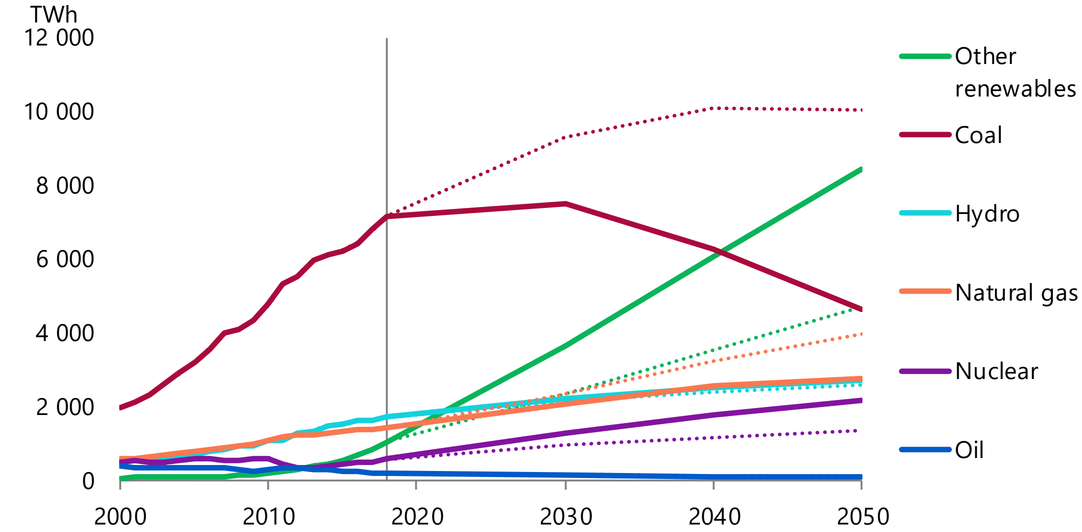
Although coal-fired power generation in Asia could be reduced substantially (Figure 4-14), coal will remain one of the major power sources, still accounting for a quarter of the power generation in 2050. China and India should particularly continue to expand renewable energy to reduce CO_2 emissions.

Figure 4-13 | Global power generation mix [Advanced Technologies Scenario]



Note: Dashed lines represent the Reference Scenario.

Figure 4-14 | Asian power generation [Advanced Technologies Scenario]



Note: Dashed lines represent the Reference Scenario.

Crude oil production

In the Advanced Technologies Scenario, progress in energy efficiency improvement and fuel switching will limit growth in oil consumption leading consumption to peak around 2030 before entering a downtrend. As a result, oil supply in all regions will decrease from the Reference Scenario, falling back to the 2017 level in 2050 (Table 4-3).

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

(Mb/d)

	2018	2030	2040	2050	2018-2050	
					Changes	CAGR
Crude oil production	95.3	96.5	95.7	92.4	-2.9	-0.1%
OPEC	37.0	38.3	40.9	41.3	4.3	0.3%
Middle East	28.7	29.7	31.4	31.4	2.8	0.3%
Others	8.4	8.7	9.6	9.9	1.5	0.5%
Non-OPEC	58.2	58.2	54.8	51.0	-7.2	-0.4%
North America	20.9	22.2	20.1	17.0	-3.8	-0.6%
Latin America	7.1	8.4	9.2	10.0	2.9	1.1%
Europe and Eurasia	18.1	16.1	14.4	13.3	-4.8	-1.0%
Middle East	3.2	3.3	3.3	3.4	0.2	0.2%
Africa	1.4	1.4	1.4	1.4	0.0	0.0%
Asia and Oceania	7.6	6.9	6.4	6.0	-1.6	-0.7%
Processing gains	2.3	2.5	2.7	2.8	0.5	0.6%
Oil supply	97.6	99.1	98.4	95.1	-2.4	-0.1%

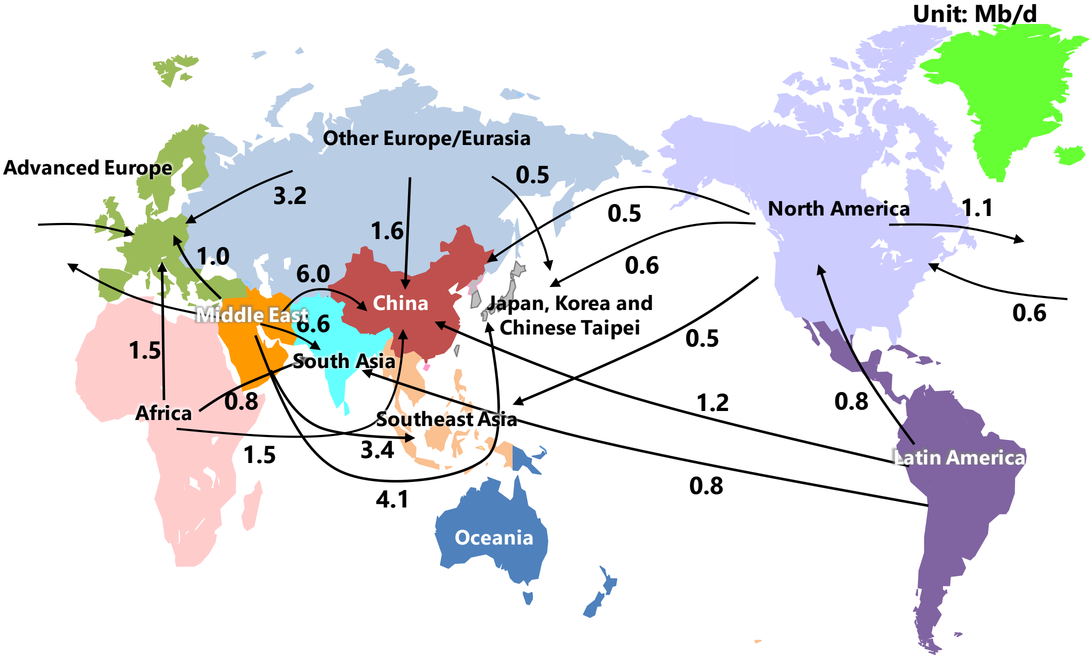
Note: Crude oil includes natural gas liquid.

Amid an intensifying competition among oil-producing countries through 2050, Middle Eastern member countries of Organization of the Petroleum Exporting Countries (OPEC) will increase oil production most and its share of production will be slightly higher than in the Reference Scenario taking advantage of its relatively lower production costs. Oil production will be far less than in the Reference Scenario for the less cost competitive North America that is posting the fastest demand decline of 7.4 Mb/d from 2018 to 2050. It is the same for Russia (representing Europe and Eurasia) supplying oil mainly to Europe that will record the second fastest demand fall of 5.4 Mb/d. Although Latin America also features rather high oil production costs, oil supply will increase as oil development is promoted in Guyana and other countries that have discovered new oil resources in recent years and are proactively attracting foreign investment. Unlike North America, Latin America will maintain its oil demand unchanged even in the Advanced Technologies Scenario, contributing to expanding local production.

Asia, where oil production has been moderately falling, will reduce production faster than in the Reference Scenario. Given that Asia is dominated by net oil-importing countries, the state-run oil companies of the many oil-producing countries will try to prevent production from falling from the viewpoint of supply security, even if production costs are higher. Consequently, Asia's oil self-sufficiency will be higher than in the Reference Scenario.

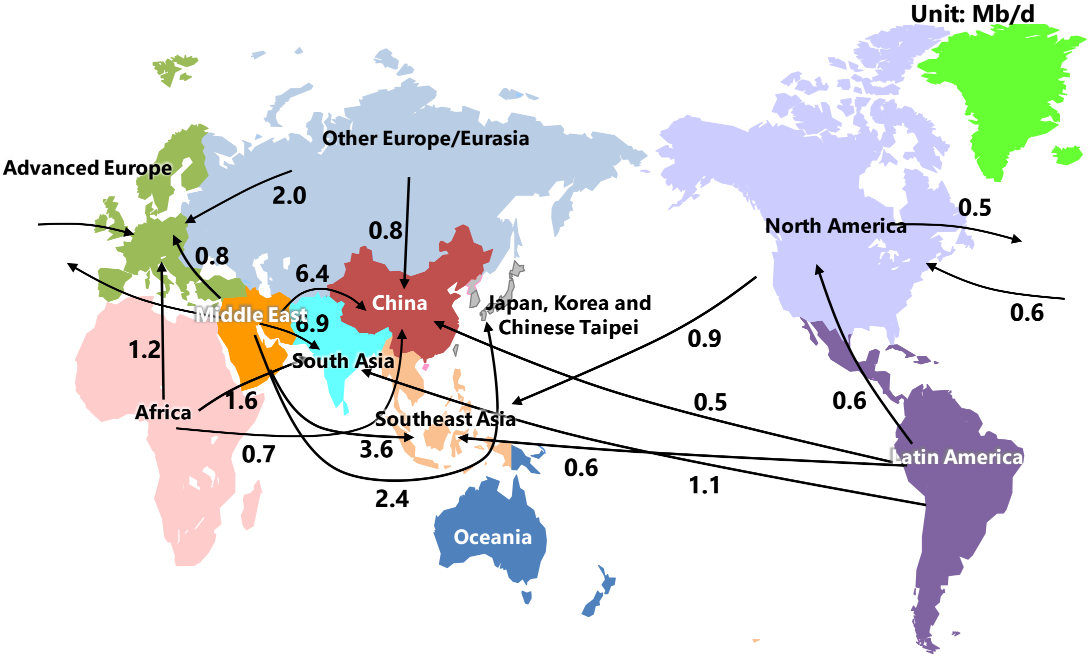
As oil demand peaks out, global crude oil trade will decrease. Crude oil trade between major regions in 2050 will decline from about 43 Mb/d in 2019 to about 35 Mb/d. In 2050, Asia will be a major oil-importing region, buying crude oil mainly from the Middle East that will maintain firm production.

Figure 4-15 | Major interregional crude oil trade flows [Advanced Technologies Scenario, 2030]



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

Figure 4-16 | Major interregional crude oil trade flows [Advanced Technologies Scenario, 2050]



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

However, future crude oil trade flows are uncertain because of the fierce competition in the oil-refining sector. Oil demand will peak out and fall back to the level seen around 2017 in 2050. Given the long service life of more than 50 years for oil refineries, however, the world will see a glut in petroleum products unless oil refineries are retired earlier than scheduled. As competition intensifies, refinery capacity utilisation rates will vary by region. Regions with cost-competitive oil refineries will try to prevent their crude oil procurement from declining and in the face of falling local oil demand they will increase petroleum products exports to secure economic growth. Depending on oil refining competition trends, crude oil trade flows may change.

Natural gas supply

As progress in energy utilisation and efficiency technologies suppresses consumption in the Advanced Technologies Scenario, natural gas production will be 17% less than in the Reference Scenario in 2040 and 27% less by 2050. However, better management of greenhouse gas (GHG) emissions through technological advances may lead to a greater share of 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 less than 40% of the Reference Scenario level. U.S and Canadian production will peak around 2040 while the Middle East and non-OECD Europe including Russia will expand natural gas production steadily, though more slowly than in the Reference Scenario. In the Middle East, particularly Iran, Qatar, and Saudi Arabia will sharply increase production even in the Advanced Technologies Scenario.

In the Advanced Technologies Scenario, production changes will depend on progress in the development of CO_2 and CH_4 emission monitoring/cutting technologies in natural gas production and transportation, and progress in policies or regulations to support them.

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

(Bcm)

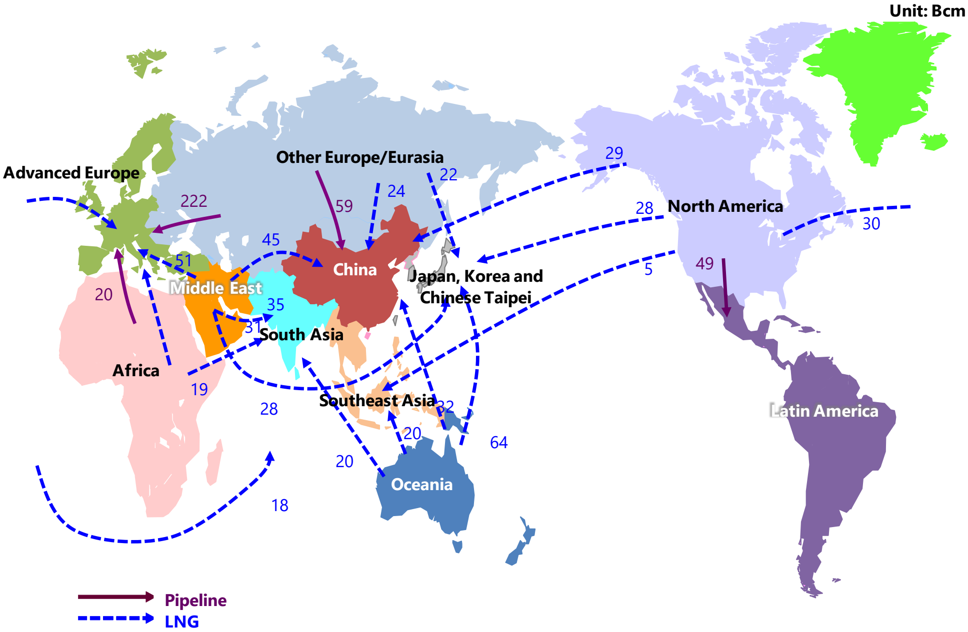
	2018	2030	2040	2050	2018-2050	
					Changes	CAGR
World	3 937	4 442	4 677	4 543	606	0.4%
North America	1 052	1 146	1 041	892	-160	-0.5%
Latin America	208	254	328	348	140	1.6%
OECD Europe	234	100	55	30	-204	-6.3%
Non-OECD Europe/Eurasia	951	970	935	929	-22	-0.1%
Russia	715	725	721	724	9	0.0%
Middle East	655	832	875	857	202	0.8%
Africa	240	337	462	507	268	2.4%
Asia	476	611	749	752	276	1.4%
China	160	240	361	367	207	2.6%
India	32	57	72	71	39	2.5%
ASEAN	208	226	220	221	13	0.2%
Oceania	122	192	231	229	107	2.0%

Natural gas trade flows in the Advanced Technologies Scenario indicate that net natural gas-importing regions will reduce imports by 10%-30% compared to the Reference Scenario in 2050. Among net natural gas-exporting regions, the Middle East and non-OECD Europe including Russia will export 20%-40% less natural gas than in the Reference Scenario in 2050. In North America, demand will decline from the Reference Scenario faster than production and its net exports in 2050 will slightly decrease, affected by international price falls.

In the Advanced Technologies Scenario, the changes in natural gas trade will depend on progress in relevant companies' cooperation and efforts to rationalise and optimise natural gas and LNG trade. It will also depend on the countries' cooperation and supportive policies and regulations on fuel efficiency and emissions for marine transportation. Regarding LNG transportation in particular, relevant parties will be able to increase transportation through cooperation in changing destinations and swapping cargoes.

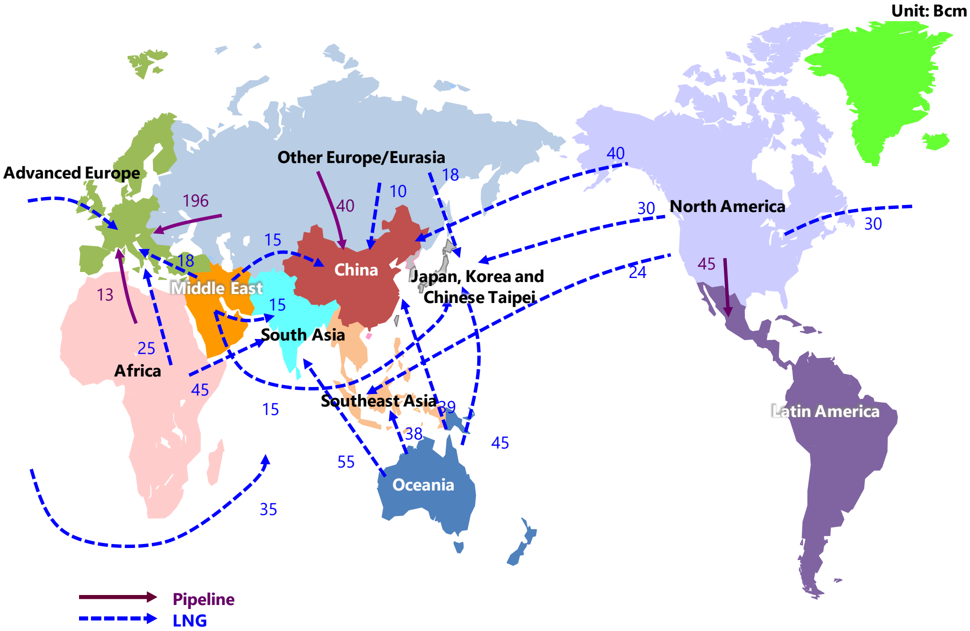
The development of a sustainable natural gas trade will necessitate progress in marine transportation technologies for LNG carriers and compressed natural gas carriers and support for relevant policy on pipeline gas trade. Examples of technologies include compressor efficiency improvements, leak detection and surveillance.

Figure 4-17 | Major interregional natural gas trade flows [Advanced Technologies Scenario, 2030]



Note: Trade flows between major regions are covered. Some pipeline gas flows could be replaced with LNG flows.

Figure 4-18 | Major interregional natural gas trade flows [Advanced Technologies Scenario, 2050]



Note: Trade flows between major regions are covered. Some pipeline gas flows could be replaced with LNG flows.

Coal supply

Coal's share of the power generation mix will decline in line with progress in renewable energy and other low-carbon technologies. Although coal-fired power plants will be used for adjusting the intermittency of renewables power generation, incentives to maintain coal-fired power plants will decline due to such factors as a fall in costs for energy storage technologies. Furthermore, coal demand will decrease as progress in coal utilisation technologies improves thermal efficiency in power generation, steelmaking, and other coal-using sectors.

Regarding coal-fired power generation, Emerging Market and Developing Economies will promote initiatives to replace outdated inefficient plants with highly efficient ones. In those economies, governments will give priority to supporting low-carbon power sources, replacing existing coal-fired power plants with highly efficient ones and limiting additional ones to highly efficient plants using IGCC and ammonia co-firing technologies.

Some Advanced Economies will promote low-carbonisation technologies such as IGCC and carbon capture and storage (CCS) systems for coal-fired power plants. In Europe, however, coal-using technologies will fail to diffuse. Coal demand growth stemming from advanced technologies will be limited even in 2050.

Consequently, coal production will decrease from 7 804 Mt in 2018 to 4 413 Mt in 2050 (Figure 4-19). Steam coal production will decline from 6 025 Mt in 2018 to 3 458 Mt in 2050, coking coal production from 978 Mt to 743 Mt, and lignite production from 801 Mt to 212 Mt. From the Reference Scenario, coal production in 2050 will decrease by 3 601 Mt with production plunging by 3 038 Mt for steam coal and by 402 Mt for lignite. Coking coal production will fall by 112 Mt. As coal demand declines generally, steam coal production will turn downward in all regions from 2030 and coking coal's share of overall coal production will rise.

Figure 4-19 | Global Coal production [Advanced Technologies Scenario]

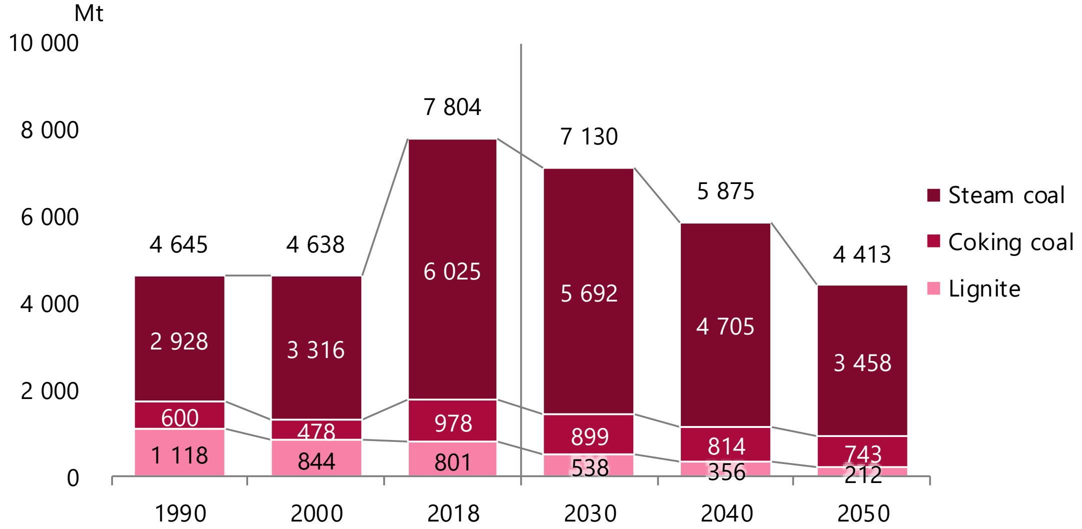
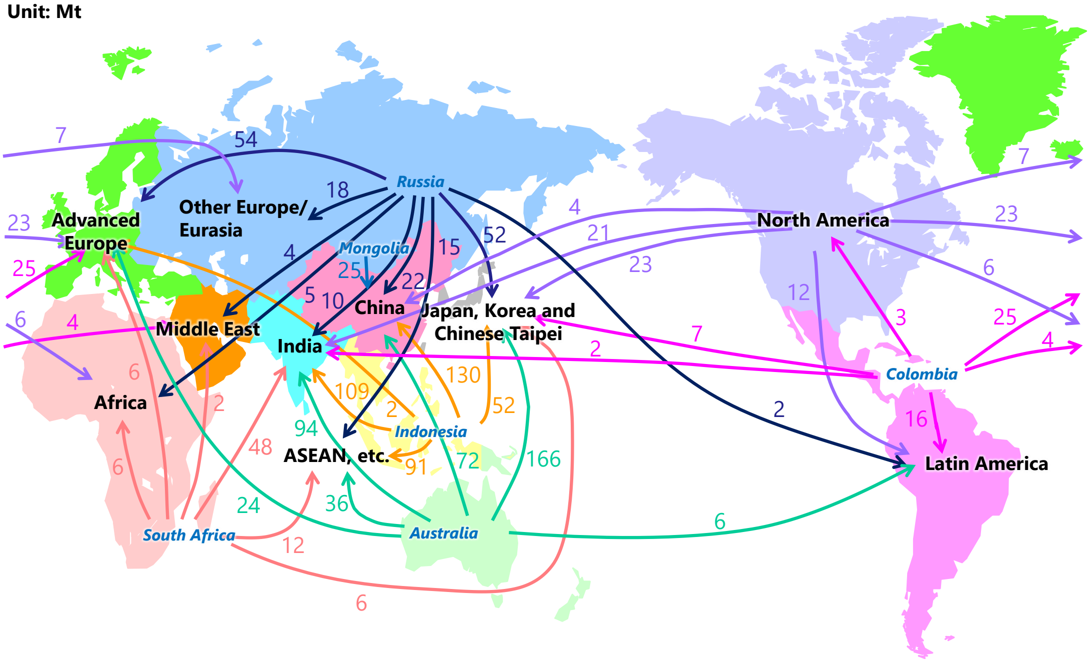


Figure 4-20 | Major interregional coal trade flows [Advanced Technologies Scenario, 2030]

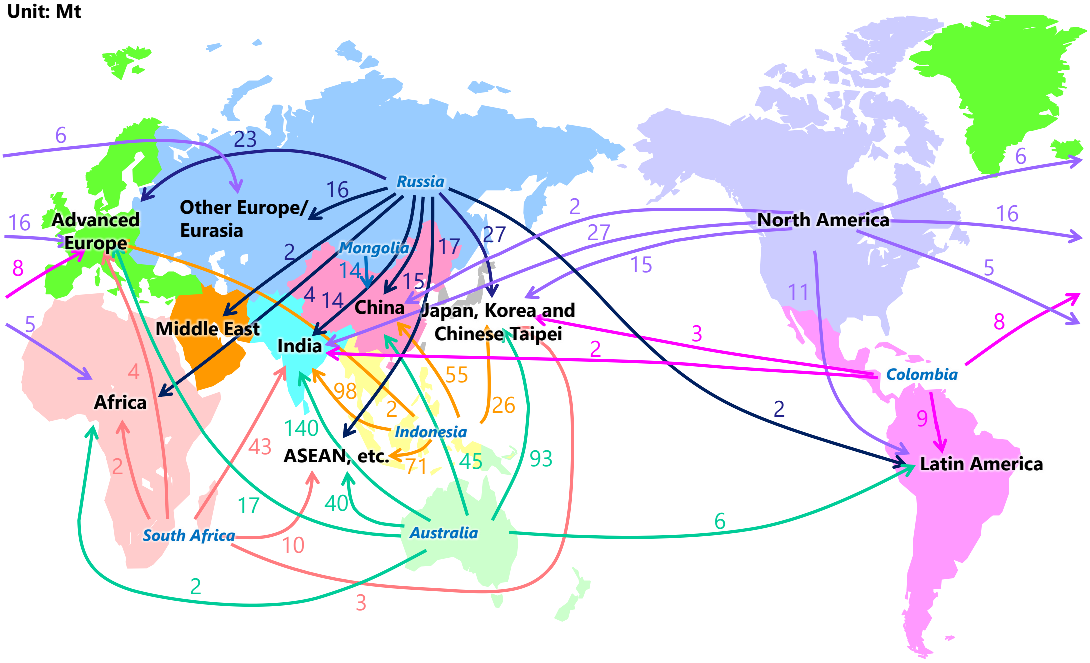
Unit: Mt



Notes: Steam coal and coking coal are combined. Estimates totalling 2 Mt or more are specified. Mozambique is included in South Africa.

Figure 4-21 | Major interregional coal trade flows [Advanced Technologies Scenario, 2050]

Unit: Mt



Notes: Steam coal and coking coal are combined. Estimates totalling 2 Mt or more are specified. Mozambique is included in South Africa.

Table 4-5 | Steam coal production [Advanced Technologies Scenario]

(Mt)

	2018	2030	2040	2050	2018-2050	
					Changes	CAGR
World	6 025	5 692	4 705	3 458	-2 567	-1.7%
North America	582	355	218	89	-493	-5.7%
United States	562	351	216	87	-475	-5.7%
Latin America	92	71	51	34	-58	-3.0%
Colombia	79	60	43	28	-51	-3.2%
OECD Europe	63	36	25	13	-50	-4.7%
Non-OECD Europe/Eurasia	369	306	274	232	-136	-1.4%
Russia	247	210	180	148	-99	-1.6%
Middle East	0	0	0	0	0	0.0%
Africa	265	243	206	146	-119	-1.8%
South Africa	252	229	192	134	-117	-1.9%
Asia	4 394	4 425	3 714	2 782	-1 612	-1.4%
China	3 065	2 858	2 223	1 469	-1 596	-2.3%
India	694	919	870	781	86	0.4%
Indonesia	543	530	500	414	-129	-0.8%
Oceania	262	256	216	162	-100	-1.5%
Australia	260	255	215	161	-99	-1.5%

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

(Mt)

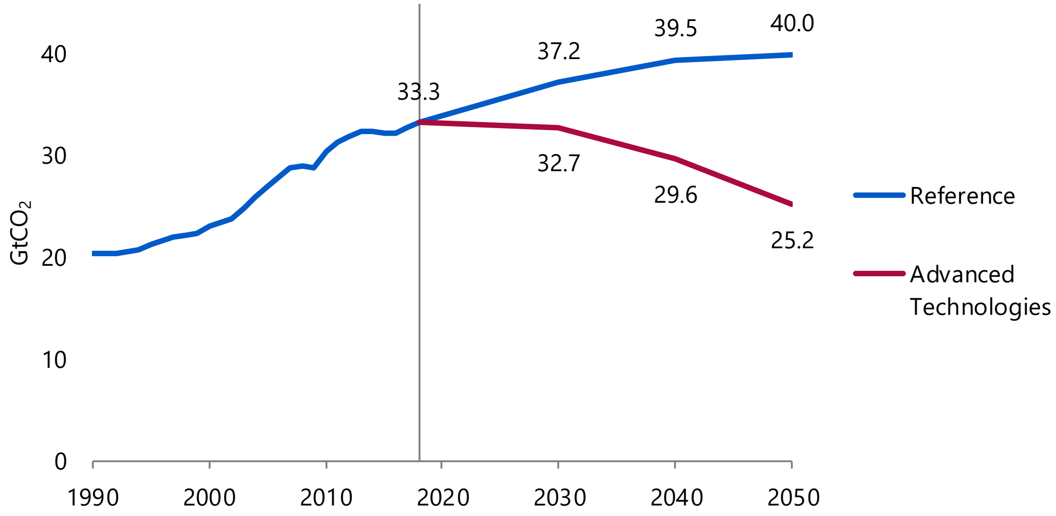
	2018	2030	2040	2050	2018-2050	
					Changes	CAGR
World	978	899	814	743	-235	-0.9%
North America	104	81	76	69	-35	-1.3%
United States	72	54	52	49	-23	-1.2%
Latin America	10	10	10	9	-1	-0.3%
Colombia	6	5	5	5	0	-0.2%
OECD Europe	16	14	14	13	-3	-0.6%
Non-OECD Europe/Eurasia	101	95	88	79	-21	-0.7%
Russia	92	87	80	71	-20	-0.8%
Middle East	1	2	2	1	0	0.0%
Africa	11	18	24	30	19	3.1%
Mozambique	7	14	20	25	18	4.1%
Asia	553	490	406	342	-212	-1.5%
China	484	404	307	228	-255	-2.3%
India	37	60	77	95	58	3.0%
Mongolia	27	21	16	12	-16	-2.6%
Oceania	181	189	194	199	19	0.3%
Australia	179	188	193	198	19	0.3%

4.3 CO_2 emissions

Global CO_2 emissions will decrease from the mid-2020s, emission growth in India will decelerate, low-carbonisation will make progress

Global energy-related CO_2 emissions will rise from 33.3 Gt in 2018 to a peak of nearly 34 Gt in the middle of the 2020s and plunge to 25.2 Gt in 2050 (Figure 4-22).

Figure 4-22 | Global energy-related CO_2 emissions



Global CO_2 emissions will decrease by 8.1 Gt from 2018 to 2050, with a drop of 4.3 Gt in China, 2.8 Gt in the United States, and 1.6 Gt in the European Union (Figure 4-23). India will boost emissions by 1.8 Gt from 2018 to 2050, but the increase will slow down from 1.1 Gt for 12 years between 2018 and 2030 to 0.7 Gt for 20 years between 2030 and 2050.

From the Reference Scenario, global energy-related CO_2 emissions will decline by 37.0% in 2050 (Figure 4-24). The United States will post the largest decline, followed by China, ASEAN, and the European Union in that order. The low-carbonisation of primary energy consumption will make a greater contribution to the fall in CO_2 emissions than the decline in primary energy consumption per GDP (energy efficiency improvement). Specifically, as the United States, China, ASEAN, and the European Union each will transition from natural gas and coal to solar PV and wind, from coal to geothermal energy, and from natural gas to nuclear. With such transition, the decarbonisation of fossil fuels is conceivable (Chapter 7). The promotion of low-carbonisation will hold the key to realising the Advanced Technologies Scenario.

Figure 4-23 | Changes in energy-related CO_2 emissions [Advanced Technologies Scenario]

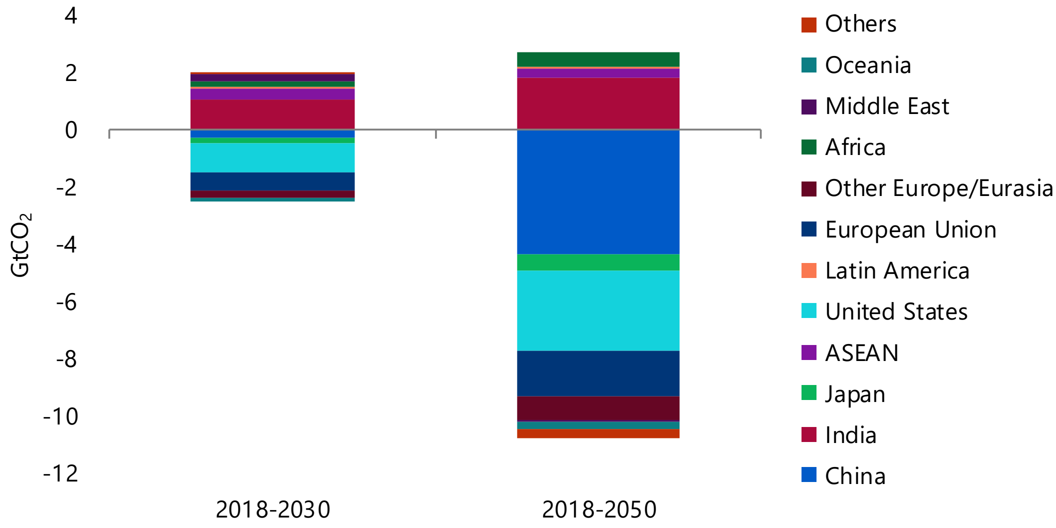
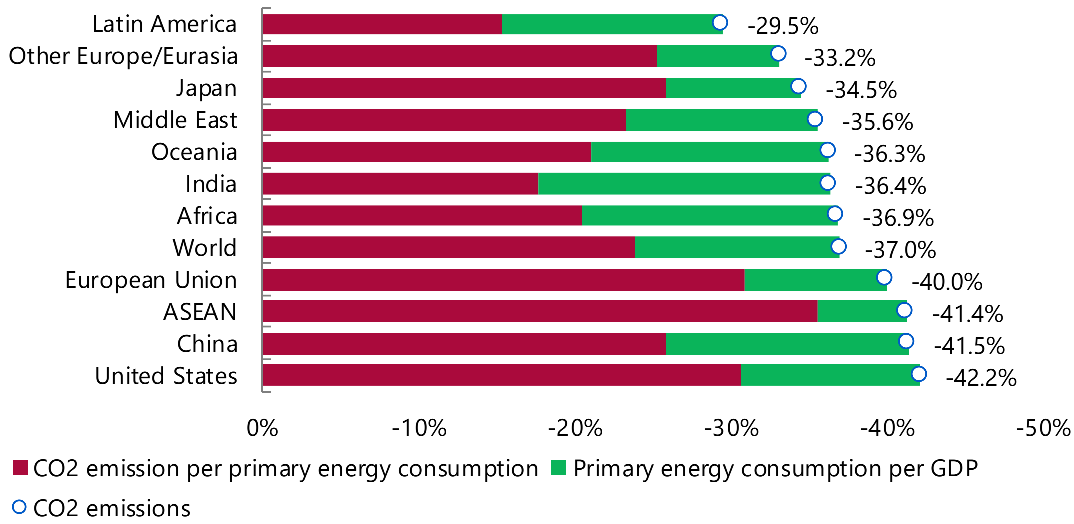


Figure 4-24 | CO_2 emission drops (from Reference Scenario) and their breakdown by factor [Advanced Technologies Scenario, 2050]



5. Energy-related Investment

5.1 Recent trends

Expanded investment in natural gas

Although the United States achieved record high natural gas exports, the increase in global natural gas demand in 2019 has been met with boosted production mainly from Australia and Russia. With trade expanding, global liquefied natural gas (LNG) transactions grew by 12% from 2018 to 348 million tonnes (Mt). As a result, final investment decisions were made for LNG projects adding capacity hitting a record high of 71 Mt/year.

COVID-19 impacts and "Green Recovery"

The COVID-19 pandemic grew serious in 2020 and triggered a historic crash of crude oil futures prices, dampening resources development investments. The resources oversupply and subsequent price crashes led international energy majors such as Chevron and Exxon, and state-run oil and gas companies such as Saudi Aramco to consider reducing their investments for the immediate future. With a break-even oil price estimated at $50/bbl, the weakness in oil prices has had fatal impacts on U.S. shale oil companies, prompting small and large companies to go bankrupt, one after another.

The pandemic's economic impacts, if prolonged, could cause a drop of capital investments in resources and all other industries. It is believed that such financial conditions could cause shortages in resources development investment, destabilising the fuel supply-demand balance over the medium term. Over the medium to long term, such investment shortages could impede the energy transition and delay improvements in the efficiency of energy-consuming appliances, affecting energy efficiency improvement and low-carbonisation.

On the other hand, Europe has taken leadership in spreading "Green Recovery" initiatives to take advantage of environmental investments for economic recovery from the COVID-19 crisis. In May 2020, the European Commission proposed the "NextGenerationEU" (NGEU) recovery fund of up to 7.5 billion euros. The fund covers not only healthcare and employment measures but also investment in renewable energy, electric vehicles, and other environmental and energy areas, seeking to balance economic recovery with environmental protection.

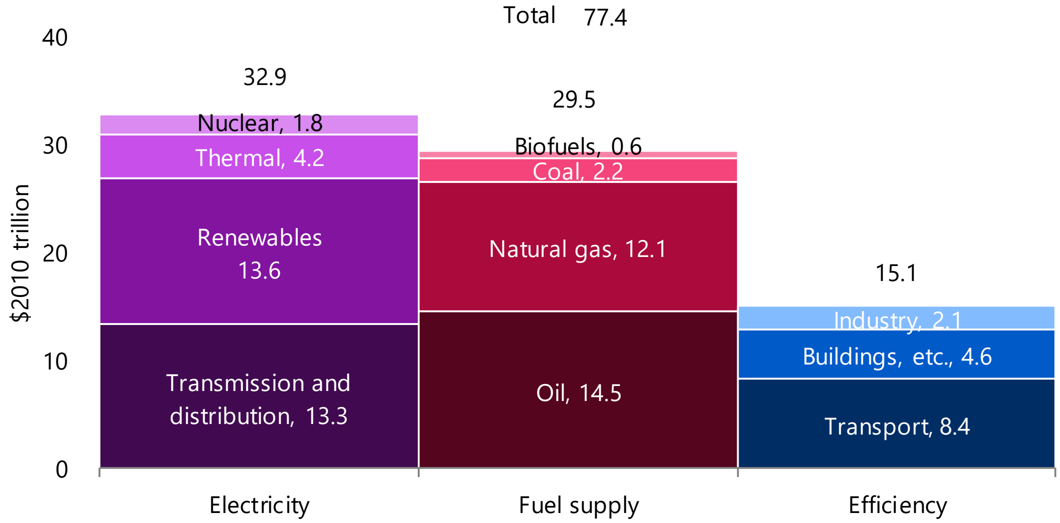
5.2 Reference Scenario

Investment equivalent to 2% of GDP would be required in electricity and other energy-related areas

As the world economy gradually recovers from the COVID-19 disaster, global primary energy consumption will resume growth, increasing from 14.0 Gtoe in 2018 to 18.5 Gtoe in 2050. Massive investments will be required to accommodate the remarkable increase in energy consumption in Emerging Market and Developing Economies. The investments would cover resources development, fuel transportation, and power generation, transmission and distribution capacity. Regions with sufficient capacity will have to replace existing capacity and invest in energy efficiency improvement.

In the Reference Scenario, $77.4 trillion (in 2010 dollars, the same hereinafter) in energy-related investment[16] will be required over the 32 years from 2019 to 2050 (Figure 5-1). The sum will be equivalent to some 2% of global GDP over the period.

Figure 5-1 | Global energy-related investment [Reference Scenario, 2019-2050]



Investment in the electricity sector will account for $32.9 trillion or 40% of the total. As final electricity consumption in 2050 totals 39 056 TWh, up 1.8-fold from 2018, intensive capital investment will be required mainly in Emerging Market and Developing Economies where electricity demand will increase more rapidly. Investment will total $11.5 trillion in renewables power generation and $4.2 trillion in fossil fuel-fired power generation. Investment in coal-fired power generation will progressively decrease year by year, while that in natural gas-fired power generation increases in a manner to cover the fall in coal-fired power generation investment. Investment in power transmission and distribution facilities will expand, in line with electricity demand growth, accounting for 17% of the total energy-related investment.

Investment in fuel supply (oil, natural gas, coal and biofuels) will total $29.5 trillion as much as investment in the electricity sector. Most of the fuel supply investment will be used for production and the remainder for refining, transportation and natural gas liquefaction. Fossil fuel-related investment will retain a major share of the fuel supply investment, indicating that any excessive fossil fuel divestment may threaten stable energy supply. An environment for providing sufficient funds for necessary resource development should be developed and maintained.

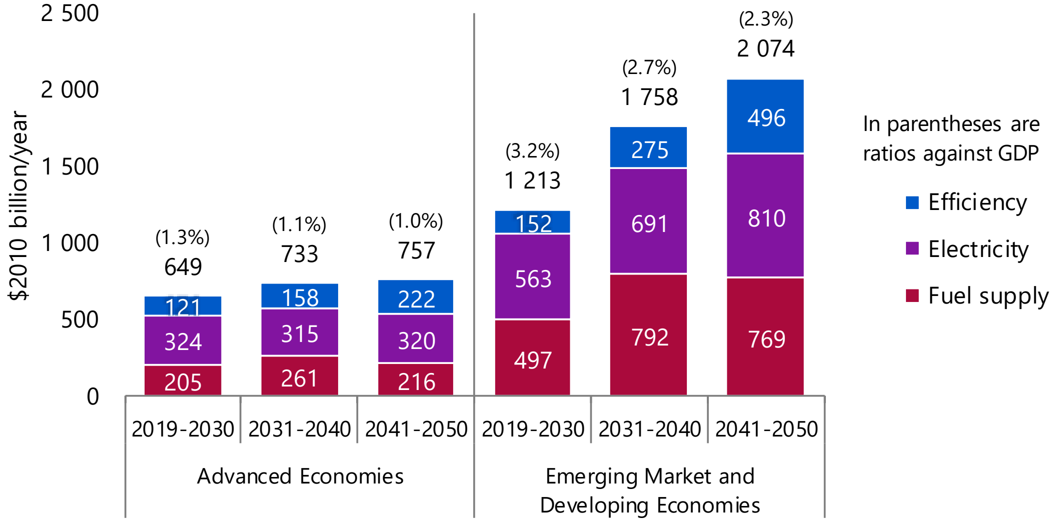
On the demand side, $15.1 trillion will be invested in energy efficiency improvement by 2050, accounting for 19% of the total energy-related investment. The sum includes $8.4 trillion (11%

[16] Energy-related investment in this chapter covers resources (oil, natural gas and coal) development, oil refining, fuel transport (oil, natural gas and coal), natural gas liquefaction, biofuels, fossil fuel-fired power generation (coal, natural gas and oil), nuclear power generation, renewables (solar photovoltaics, wind, hydro, geothermal, biomass, solar heat and marine energy), carbon capture and storage, power transmission, power distribution, and energy-efficient equipment or products (transport, buildings and industry sectors).

of the total energy-related investment) for the transport sector, $4.6 trillion (6%) for the buildings sector, and $2.1 trillion (3%) for the industry sector.

Energy-related investment trends in the Advanced Economies and the Emerging Market and Development Economies will differ from each other. While investment in both continue to increase, the Emerging Market and Developing Economies will post a much faster growth (Figure 5-2). Energy-related investment's share of GDP will be limited to around 1% in the Advanced Economies against around 2.7% in the Emerging Market and Developing Economies. The investment share of GDP for the Emerging Market and Developing Economies will top 3% for more than the next decade.

Figure 5-2 | Energy-related Investment [Reference Scenario]



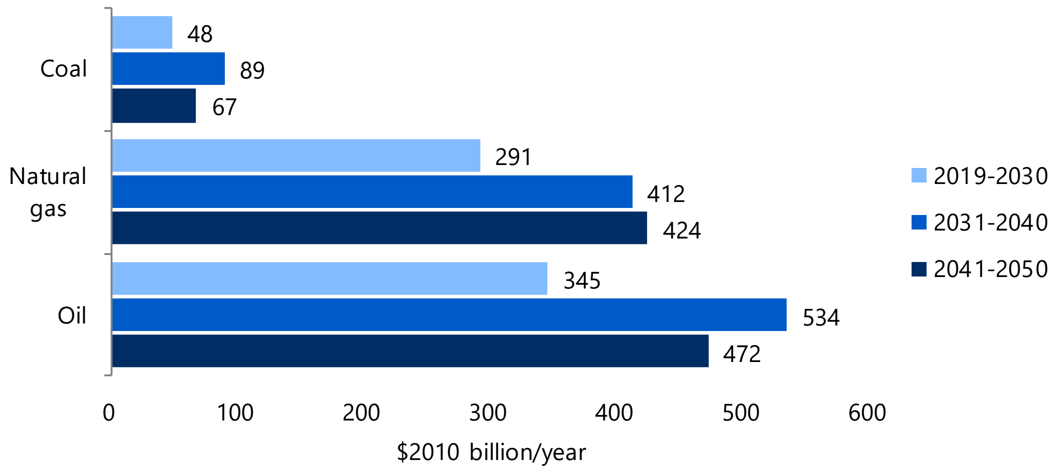
In the Advanced Economies that will implement ambitious climate change countermeasures, zero-emission power sources, such as nuclear and renewables, and the demand side's energy efficiency improvement will account for most of the total energy-related investment. In the Emerging Market and Developing Economies, including those with underdeveloped electricity infrastructure, massive investment will be required in the supply side to meet the rapid growth in energy demand.

Investment in fuel supply will peak in the 2030s for both the Advanced Economies and the Emerging Market and Developing Economies. Meanwhile, investment in power generation and transmission capacity will increase year by year, emphasising the significance of shifting investment to electricity-related capacity. The demand side's investment in energy efficiency improvement will also rise year by year, accounting for about 25% of the total investment in the 2040s.

Fossil fuel investment

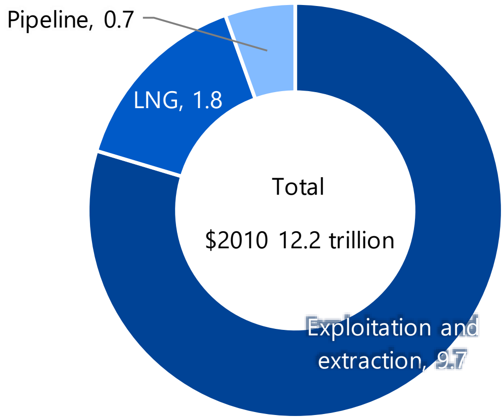
Fossil fuel investment will rapidly expand against the backdrop of growing oil and natural gas demand in the Emerging Market and Developing Economies until the 2030s but will decrease moderately thereafter. Even in the 2040s, however, investment as high as $1 trillion per year will be required to meet demand, indicating that investment in fossil fuels will remain essential for stable energy supply. As primary coal consumption turns downward in the 2040s, coal investment will begin to decline (Figure 5-3). Oil production growth will continue but slow down, resulting in a fall in investment in new capacity. In line with the fall in new capacity, the overall oil investment will turn downward in the 2040s. On the other hand, natural gas investment will continue increasing until 2050 as natural gas demand expands remarkably, mainly in Asia.

Figure 5-3 | Global fossil fuel investment [Reference Scenario]



Natural gas investment will maintain its recent expansion, leading production, transport and liquefaction capacity to increase at the same pace as at present. Resources development will account for $9.7 trillion or 80% of the total natural gas investment of $12.2 trillion through 2050 (Figure 5-4). In addition, $1.8 trillion will be required in LNG-related equipment including cooling facilities and tankers.

Figure 5-4 | Global natural gas investment [Reference Scenario, 2019-2050]



Power generation equipment: While renewable energy investment increases, fossil fuel-fired power plant investment will be required to maintain the current level

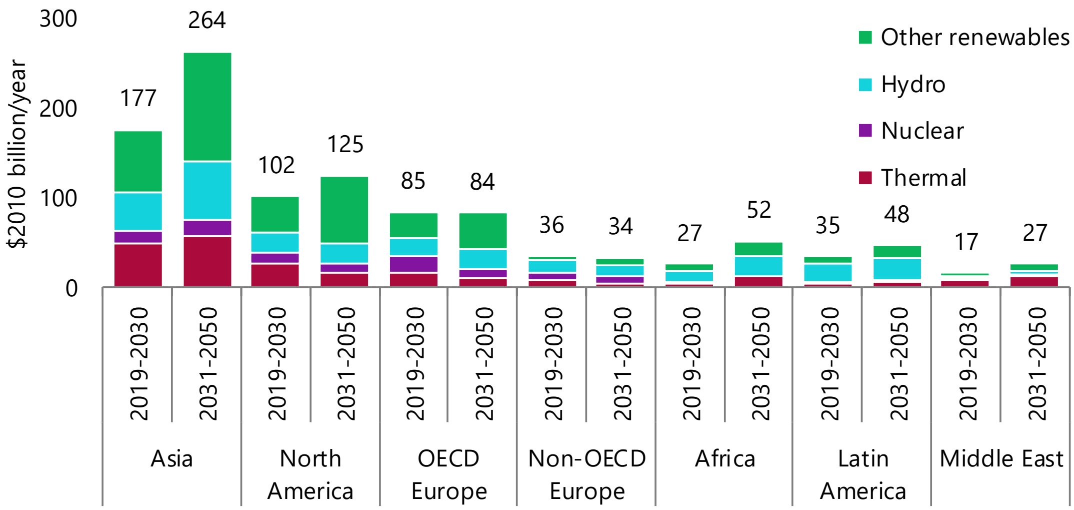
Investment in power generation equipment will continue expanding, totalling $19.5 trillion through 2050. In both the Advanced Economies and the Emerging Market and Developing Economies, investment in natural gas-fired power generation will expand each year at a faster pace than at present, making natural gas the largest electricity source by 2050. In contrast, coal-fired power generation investment will be halved from the present level by 2050. The Advanced Economies' investment in coal-fired power generation will decline sharply due to the United States' switching to natural gas-fired power generation and a coal phase-out policy in Europe. The capacity of nuclear power plants will increase year by year, but the construction of new plants will slow down after 2030. This, combined with reductions in equipment costs due to technological progress, will result in increased investment only in Asia and flat or declining investment in other regions.

Investment in renewables power generation will substantially expand through 2050. Annual investment required in the 2040s will reach $200 billion for hydro, $130 billion for solar photovoltaics (PV), and $120 billion for wind. Overall annual investment in renewable energy power generation in the decade (2040s) will increase 1.5-fold from the 2019-2030 level.

Power generation equipment investment strongly reflects regional differences (Figure 5-5). In Europe and North America, such investment will follow a downtrend with investment in fossil fuel-fired power generation that will particularly post a significant decline. In contrast, renewables power generation investment will continue to increase through 2050. These regions, though with moderate power demand growth, will become a key market for renewables power generation equipment.

In Asia, Africa, and the Middle East including the Emerging Market and Developing Economies, rapid growth in investment in power generation equipment will be required to meet power demand expansion. Through 2050, these regions will increase their annual power generation investment for fossil fuel-fired power generation facilities as well as for other power generation equipment. How to raise funds to cover such investment and how to address environmental problems accompanying fossil fuel-fired power generation will become key challenges.

Figure 5-5 | Power generation equipment investment in selected regions [Reference Scenario]

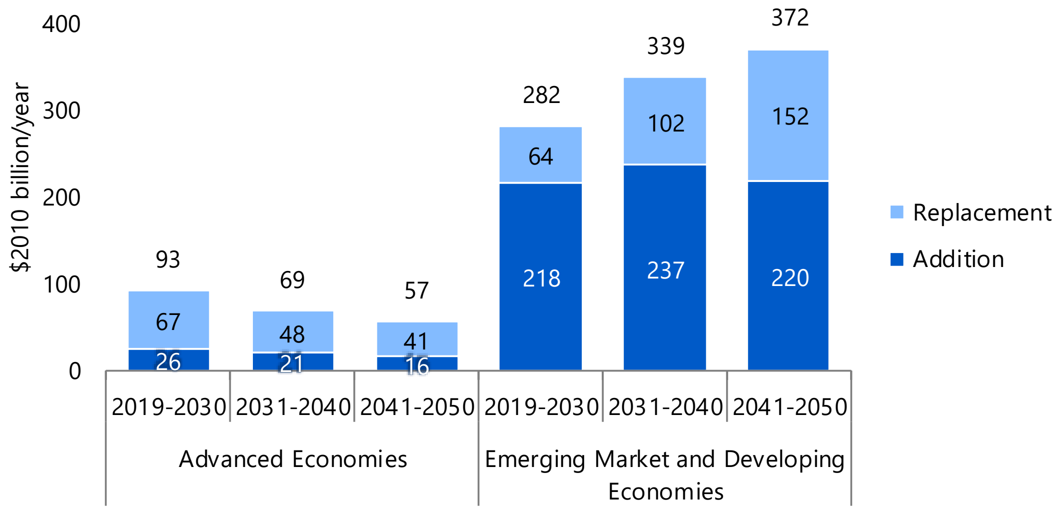


Power transmission/distribution equipment: Intensive investment will be required in the Emerging Market and Developing Economies

In response to the rapid electricity demand growth, priority should be given not only to the development of power generation equipment but also to the development of transmission and distribution equipment. Investment required in power transmission and distribution equipment through 2050 will total $13.3 trillion, equivalent to three quarters of the power generation equipment investment.

The trend of power transmission and distribution equipment investment in the Advanced Economies will contrast with that in the Emerging Market and Developing Economies (Figure 5-6). In the Advanced Economies, where power transmission and distribution networks have already been sufficiently developed to meet power demand, such investment will decrease year by year, mainly covering the cost of replacing outdated equipment. In the Emerging Market and Developing economies, where final electricity consumption will grow at an annual rate of 2%, power transmission and distribution equipment investment will expand year by year, focusing on additional equipment to meet the growing demand. Power transmission and distribution equipment investment will account for only 11% of the total energy-related investment in the Advanced Economies, against 20% in the Emerging Market and Developing Economies. The prompt development of power transmission and distribution networks is a key challenge for the Emerging Market Economies over the next several decades. Those economies will be required to smoothly raise funds, secure lands, and create legal systems to realise the development.

Figure 5-6 | Investment in power transmission and distribution equipment [Reference Scenario]



Demand-side investment in energy efficiency improvement

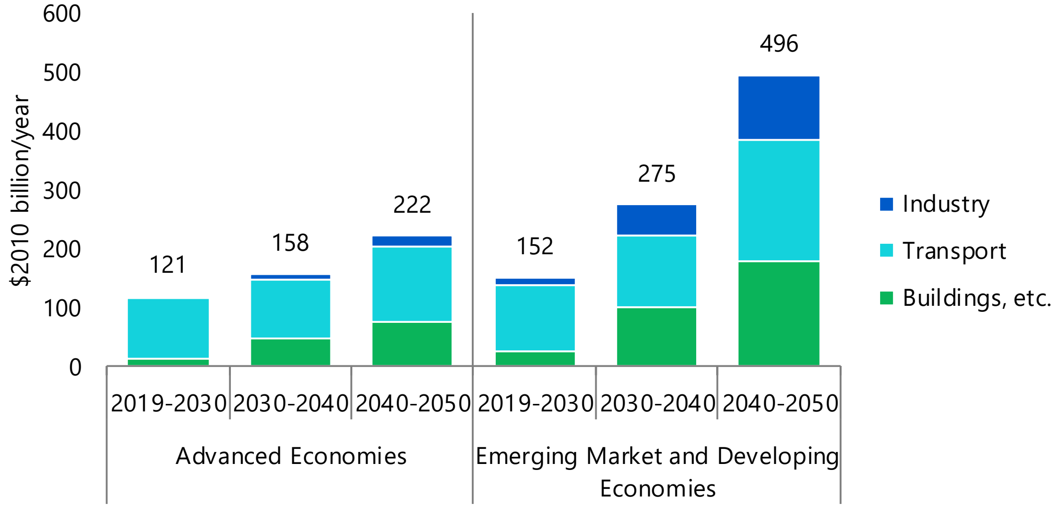
Demand-side investment in energy efficiency improvement[17] will increase year by year, totalling $15.1 trillion through 2050 (Figure 5-7).

The buildings sector will invest $4.7 trillion in energy efficiency improvement in the next 32 years. The sum includes $2.9 trillion for the residential sector and $1.7 trillion for the commercial sector. In both the residential and commercial sectors, investment in energy efficiency improvement will increase year by year as more efficient equipment diffuse. Of such investment, air-conditioning and insulation efficiency improvement will account for about 50% in the residential sector and for more than 80% in the commercial sector. Technological development and cost reduction for air-conditioning and insulation equipment will hold the key to energy efficiency improvement in the buildings sector.

The road sector will have to invest $8.4 trillion in energy efficiency improvement, of which most will be for passenger cars. In 2050, hybrid vehicles will account for 25% of passenger cars in the world and electric vehicles (including plug-in hybrid vehicles) also for 25%. Including fuel efficiency gains for internal combustion vehicles, the sector’s fuel efficiency improvement will make great progress. The vehicle stock fuel efficiency in 2050 will increase 1.7-fold from the present level.

[17] Investment in energy efficiency improvement is defined as the gap between prices paid for a traditional product and a more efficient one. Investment defined in this way fails to explicitly include technological development investment costs but some of such costs are considered passed on to prices for more efficient products.

Figure 5-7 | Investment in energy efficiency improvement [Reference Scenario]



Investment in energy efficiency improvement will be given priority mainly in the Advanced Economies, continuing an uptrend through 2050. The European Union that has set ambitious targets for the introduction of electric vehicles and fuel efficiency improvement will be required to intensify investment in energy efficiency improvement over the next several decades.

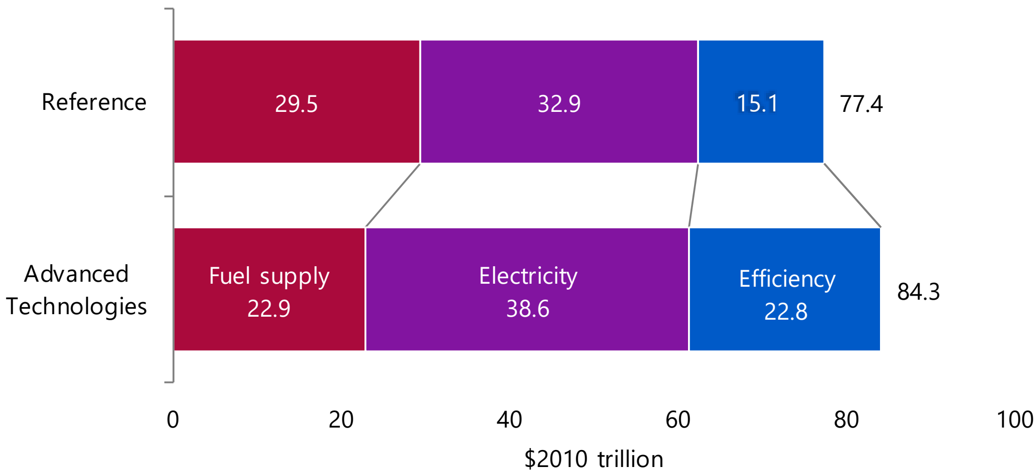
5.3 Advanced Technologies Scenario: Climate change countermeasures — investment and its effects

Overall investment required for climate change countermeasures

Accumulated energy-related CO_2 emissions through 2050 in the Advanced Technologies Scenario will be 235 Gt less than in the Reference Scenario (Figure 5-8). Additional investment to achieve the emission cut from the Reference Scenario will total $6.7 trillion, bringing accumulated investment in climate change countermeasures in the Advanced Technologies Scenario to $82 trillion. The additional investment divided by the CO_2 emission cut comes to $28.8 per tonne, indicating an average investment amount to realise the Advanced Technologies Scenario.

Fossil fuel investment in the Advanced Technologies Scenario will be equivalent to some 80% of the Reference Scenario level. Of particular interest would be the coal investment decreasing by 40% from the Reference Scenario to $140 million. Despite the coal investment plunge, overall fossil fuel investment in the 2040s will be close to the current level. If fossil fuel development investment declines for environmental conservation and other reasons, energy supply stability may be affected. Financial institutions and other investors, as well as policymakers, will need to make wise decisions for the so-called 3Es + S (energy security, environmental conservation, and economic efficiency plus safety).

Figure 5-8 | Global energy-related investment [2019-2050]

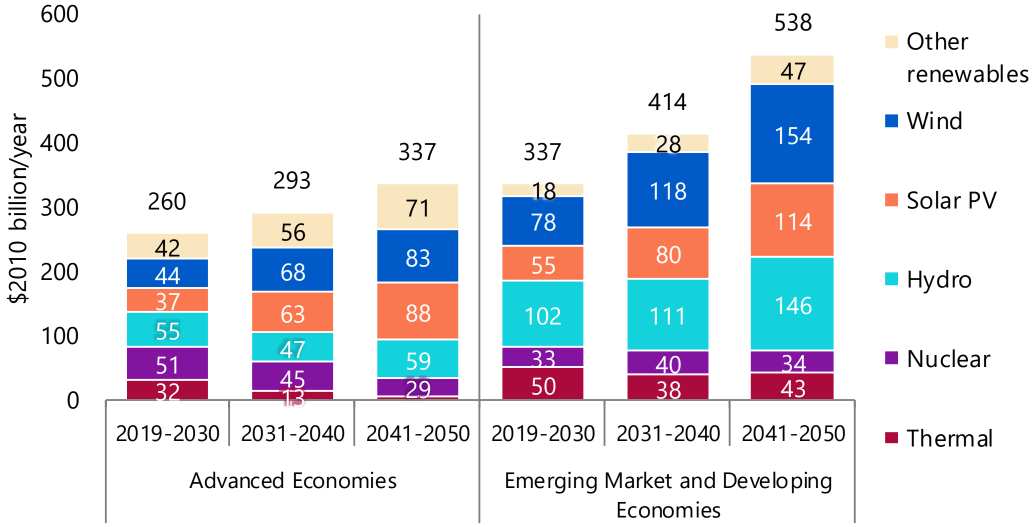


Power generation equipment: An increase in renewable energy equipment will lead power generation costs for equipment to rise

Electricity generated in 2050 in the Advanced Technologies Scenario will be 3 900 TWh less than in the Reference Scenario. Despite the drop in generation, investment in power generation, transmission and distribution facilities will increase by 16% from the Reference Scenario to $38.1 trillion. This is because renewables and nuclear power generation requires higher initial investment costs than fossil fuel-fired power generation (mainly coal-fired generation) that they will replace. Such transition in power source, though indispensable for climate change countermeasures, will be accompanied by greater initial investment costs (and far less fuel costs), by longer payback periods and by changes in the pricing mechanism for the electricity market. Relevant institutions should be designed to secure sufficient earnings for the power generation operators and make their earnings more predictable.

Renewable energy investment will account for most of the power generation equipment investment in both the Advanced Economies and the Emerging Market and Developing Economies (Figure 5-9). Investment in wind and solar PV power generation will expand year after year. In the Emerging Market Economies, the investment in fossil fuel-fired power generation will remain almost unchanged from the present level while it will be shrinking each year in the Advanced Economies. Although the expansion of zero-emission power sources will be important, investment in more efficient and lower environmental load technologies for fossil fuel-fired power generation should also be selected. In line with growth in intermittent renewables power generation, power transmission and transmission equipment will need enhancement. While electricity demand in 2050 in the Advanced Technologies Scenario is about 10% less than in the Reference Scenario, investment in power transmission and distribution equipment will be as much as in the Reference Scenario at $13.3 trillion. This is because power transmission and distribution cables and storage batteries will have to be increased to cope with the uneven endowment and intermittency of renewable energy.

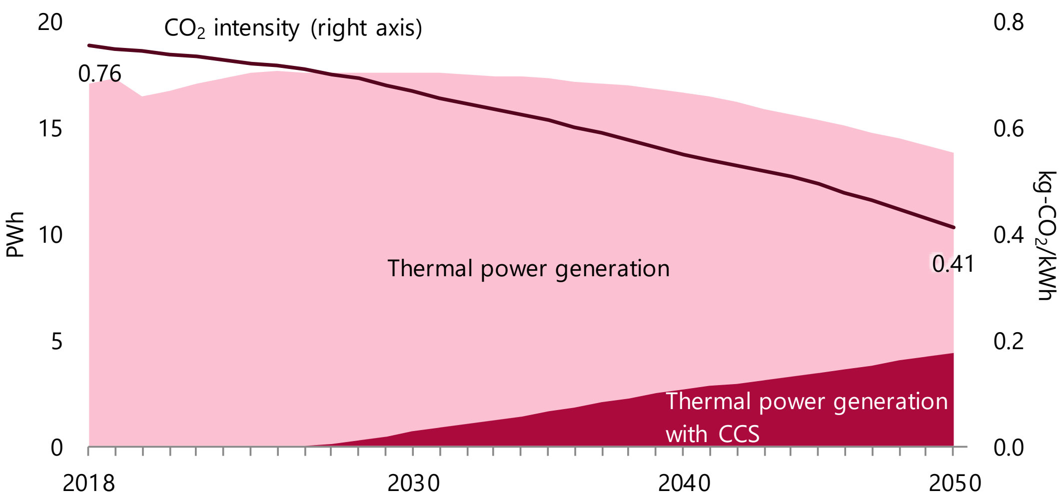
Figure 5-9 | Power generation equipment investment [Advanced Technologies Scenario]



For as long as some constraints on the expansion of renewable energy and nuclear power generation exist, even in the Advanced Technologies Scenario, the need for fossil fuel-fired power generation will remain high, making carbon capture and storage (CCS) technologies an effective option for reducing CO_2 emissions in the sector. CCS investment will total $200 billion between 2019 and 2050. Investment will be required not only for CO_2 separation and capture equipment at power plants but also for additional power generation to cover the electricity required for CCS and in equipment for transporting and injecting the captured CO_2.

The CCS investment will allow CCS-equipped power plants to cover 40% of fossil fuel-fired power generation in 2050, halving fossil fuel-fired power generation's CO_2 emission intensity from the present level (Figure 5-10).

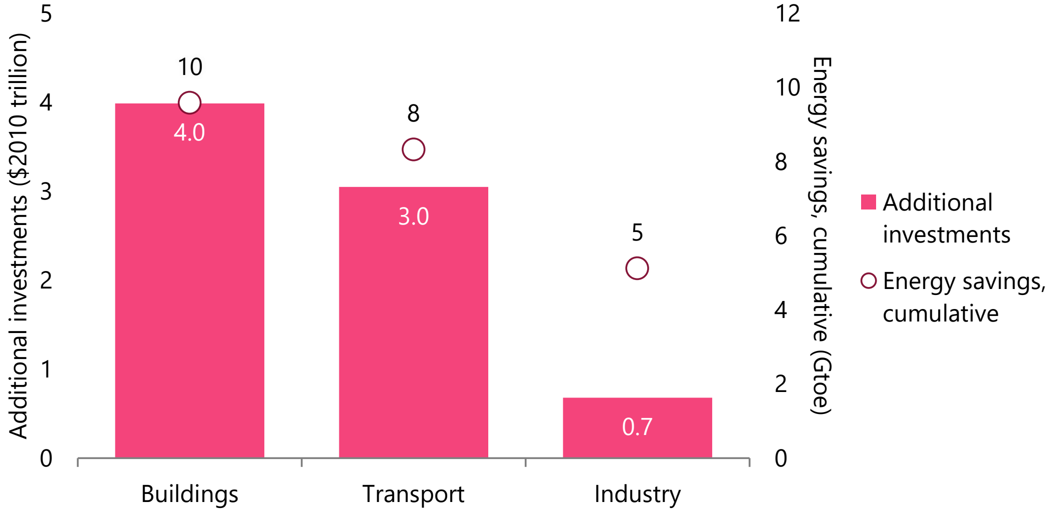
Figure 5-10 | Global fossil fuel-fired power generation and emission intensity [Advanced Technologies Scenario]



Energy efficiency investment: Relatively higher investment costs in buildings and transport sectors

Demand-side investment in energy efficiency improvement through 2050 will total $20 trillion, up $8.1 trillion from the Reference Scenario. The buildings sector will account for $4.1 trillion or the largest share of the increase from the Reference Scenario (Figure 5-11). Meanwhile, the buildings, transport, and industry sectors' total energy consumption through 2050 will decrease by 27 Gtoe from the Reference Scenario. Investment per toe in additional energy savings will differ from sector to sector, standing at about $450/toe in the buildings sector, at about $400/toe in the transport sector and at $150/toe in the industry sector. Given that energy prices in the buildings and transport sectors are relatively higher, higher investment in energy efficiency improvement in the sectors will be economically acceptable to some extent.

Figure 5-11 | Additional investment in energy efficiency improvement and cumulative energy savings (from Reference Scenario) [Advanced Technologies Scenario, 2019-2050]



Part II

Energy landscape transformation and innovation

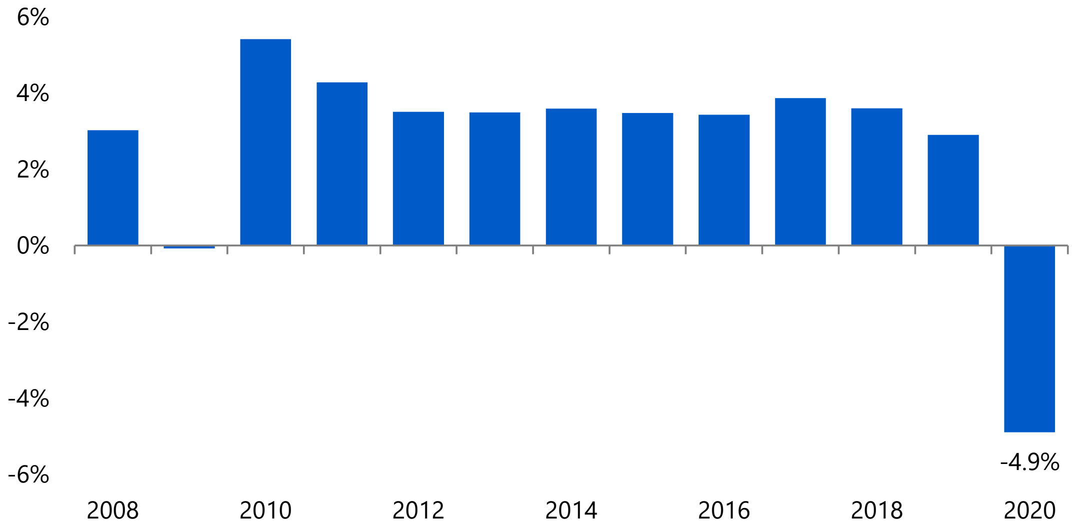
6. Post Corona World Transformation Scenario

6.1 COVID-19's impacts on the international energy landscape

Since early 2020, COVID-19 that broke out first in the southern Chinese city of Wuhan has explosively spread throughout the world, developing into a global pandemic. By 29 September 2020, the number of COVID-19 infections topped 33 million with more than one million deaths. The pandemic is still spreading, with no sign of its end in sight.

To prevent COVID-19 infections from spreading, countries have had no choice but to implement lockdown restrictions on the movement of people and goods and other measures to limit social interactions. Consequently, economic and industrial activities declined, leading to a substantial economic contraction. The International Monetary Fund (IMF) in its World Economic Outlook released in June 2020 projected that the world economy in 2020 would contract by 4.9% from the previous year (Figure 6-1). Under the COVID-19 disaster, the world economy has plunged into its worst situation since the Great Depression from the late 1920s.

Figure 6-1 | Global economic growth



Note: On a purchasing parity basis
Source: IMF "World Economic Outlook" (April 2020, June 2020)

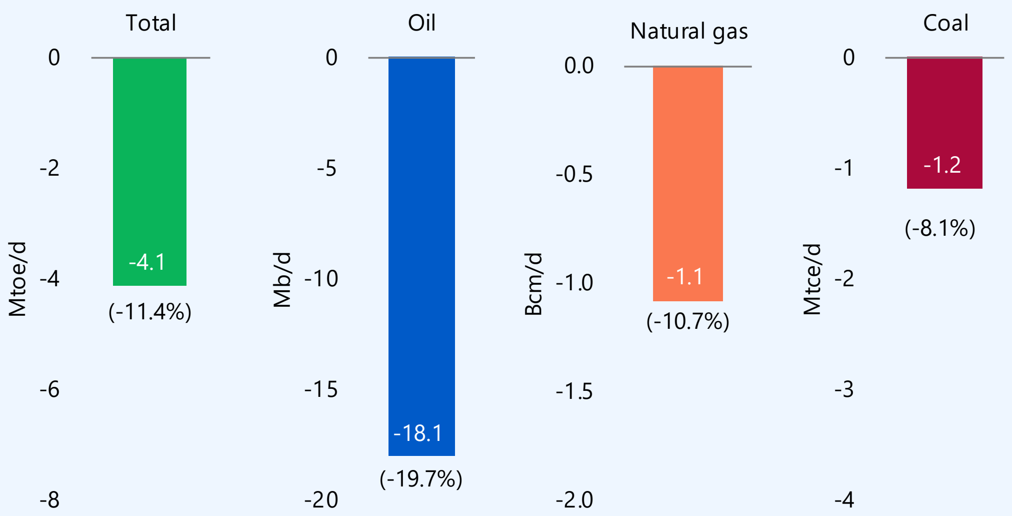
As lockdowns and other measures to restrict the movement of people and goods have been taken, civic life and social activities have been dramatically transformed. Given the limits on physical human movement, face-to-face meetings, and crowding to prevent COVID-19 from spreading, teleworking and web conferencing using information, communications, and digital technologies have rapidly become frequent and widespread throughout the world. International human travel has also been restricted, leading to a steep decline in air transport demand. Human behaviour and social and economic activities have been transformed because of the worst economic conditions since the Great Depression, dramatically reducing global energy consumption.

With demand for global travel substantially declining, the consumption of oil and other transport energy has remarkably decreased throughout the world. Energy consumption plunged mainly during the period of March to May 2020, when strict lockdowns affecting economic activities were implemented. As lockdowns phased out and economic activities picked up in May, global energy demand gradually rebounded, but falling far short of recovering to the levels before the COVID-19 disaster. The return to higher energy demand will depend on the future course of the disaster. If a second or third wave of the pandemic comes, the world economy and global energy demand would be seriously affected.

Box 6-1 | COVID-19's short-term impacts on energy consumption

In March and April 2020 when COVID-19 rapidly spread, many countries implemented lockdowns to restrict people movement to prevent further spreading. As of 9 April, more than 120 countries were implementing some forms of outing restrictions, according to media reports. This indicates that about 4.1 billion people, accounting for more than a half of the global population, were then subjected to lockdowns that differed in strength from country to country. Due to such lockdowns, daily global energy consumption is estimated to have decreased by 4.1 million tonnes of oil equivalent (Mtoe) or 11.4% from the expected level for the same period. Oil consumption, including transport fuel use which was affected the most, might have temporarily declined by 18.1 million barrels per day (Mb/d) or 19.7%. The impact on oil consumption was particularly huge in the Western countries that implemented strong lockdowns and feature large vehicle ownership.

Figure 6-2 | Lockdowns' impacts on global primary energy consumption

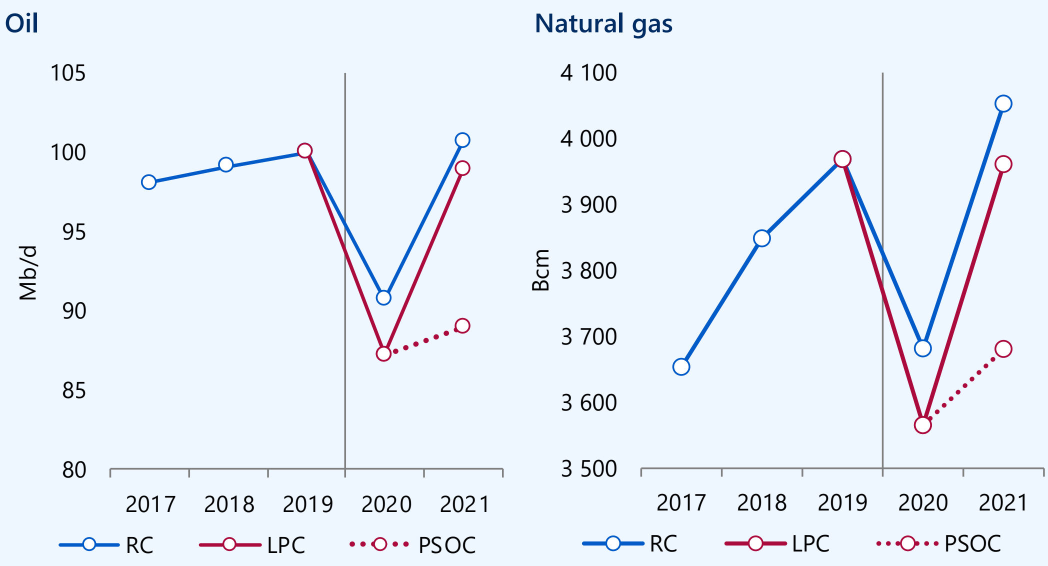


Note: In parentheses are percentage changes from normal levels (daily average consumption levels in 2017). Traditional biomass consumption is excluded.

Due mainly to lockdowns, declines in industrial activities and restrictions on international transportation, global oil consumption in 2020 will decrease by 9.3 Mb/d from the previous year to 90.7 Mb/d in the Reference Case (RC). In the second quarter of 2020, when lockdowns were implemented, oil consumption might have fallen to as low as 83.0 Mb/d before rebounding later in the RC. In the Longer Pandemic Case (LPC), however, oil consumption will remain low for a lengthier period. In both cases, oil consumption will restore to pre-pandemic level in 2021. In the Pandemic Second Outbreak Case (PSOC) where a second outbreak of the pandemic will come in 2021, however, oil consumption will remain sluggish.

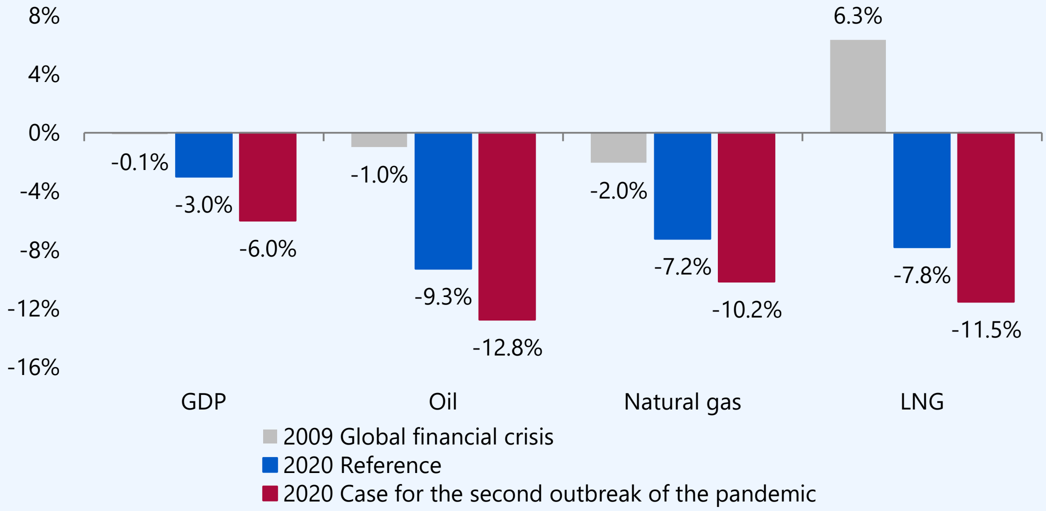
Natural gas consumption in 2020 will decline by 7.2% to 3 682 billion cubic metres (Bcm) and LNG consumption will fall by 28 Mt to 325 Mt (Reference Case). Like for oil consumption, natural gas consumption will return to pre-pandemic level in 2021. If the pandemic's second outbreak comes, however, it will stay stagnant.

Figure 6-3 | Global oil and natural gas consumption



The drops for the economy and energy demand under the COVID-19 pandemic will be far greater than during the 2008-2009 global financial crisis. The lower oil demand is attributable to a sharp fall in transportation fuel demand that is categorically different from a simple economic slump. The unprecedented demand destruction has brough about a massive oversupply in international oil, natural gas, and LNG markets, exerting downward pressures on international energy prices.

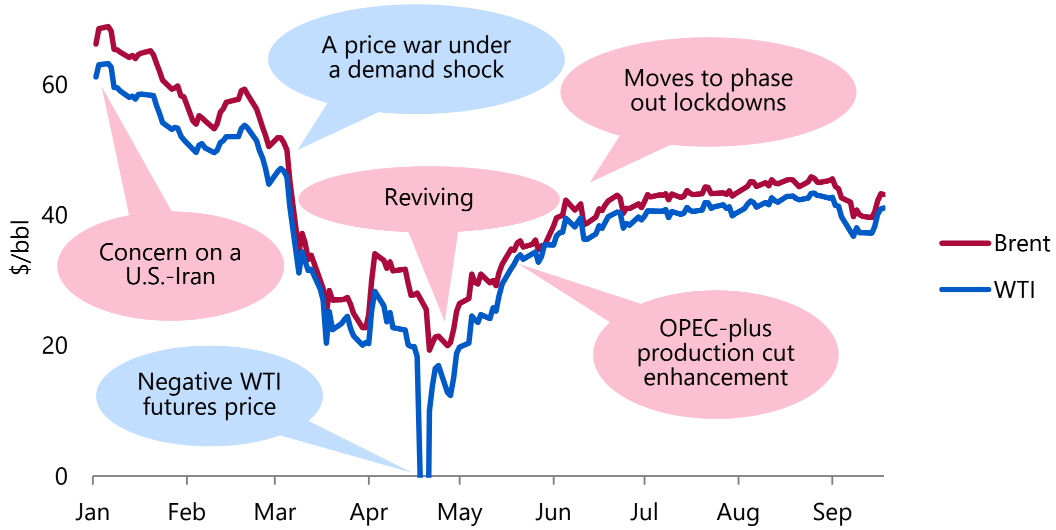
Figure 6-4 | Global GDP and energy demand falls from the previous year [2020]



Reference: Suehiro and Koyama "An Estimate on the Impact of a 'City Lockdown' on the Global Energy Demand" (IEEJ, 9 April 2020), Koyama and Suehiro "Demand for Oil, Natural Gas, and LNG Facing the Worst Global Economic Conditions since the Great Depression" (IEEJ, 17 April 2020), Koyama and Suehiro "COVID-19 and the Outlook for Oil, Natural Gas, and LNG Demand in 2021" (IEEJ, 1 May 2020)

The decrease in global energy consumption triggered an oversupply in international energy markets. Prices for oil, natural gas, liquefied natural gas (LNG), coal and electricity have declined substantially or crashed as lower demand tilted the supply-demand balance. In a most symbolic event, the futures price for the U.S. West Texas Intermediate (WTI) crude oil fell into negative territory for the first time in history (Figure 6-5). Oil futures sellers had no choice but to pay anyone to take their oil because of special conditions regarding the expiration of the front-month futures contract. Such special conditions combined with an unprecedented oil demand decline brought extremely low prices.

Figure 6-5 | Oil prices [2020]



Sources: Prepared from NYMEX and other data

In response to lower energy prices, the OPEC-plus group, which is comprised of the Organization of the Petroleum Exporting Countries (OPEC) and some non-OPEC oil-producing countries including Russia, implemented its largest ever production cut totalling 9.7 Mb/d, starting from May 2000. Under the price weakness, high-cost oil fields became unprofitable and production reduced for economic reasons. A typical example is the U.S. shale oil production decline in 2020 which is expected to exceed 1 Mb/d compared to the previous year.

Lower crude oil and other energy prices have greatly affected the international energy industries and companies. As their earnings deteriorated, energy companies have had no choice but to cut costs, make streamlining efforts and reduce investment. Representative international oil companies are cutting their investment by some 30% from the previous year, leading to concerns that their investment reduction would affect future supply expansion and cause a tighter oil supply-demand balance amid a future demand pickup. Oil-producing countries that depend heavily on oil revenue for economic growth have been seriously affected by the weakness in oil prices and lower demand. Many of them are plagued with the spread of COVID-19, causing economic losses and difficult social situations that could trigger destabilisation.

People are increasingly concerned that the COVID-19 disaster would structurally transform the world over the long term. In addition to the abovementioned impacts on the international energy situation, such structural transformation could exert widespread and deep impacts on international relations, the world economy, geopolitics, and social life. If those unprecedented negative impacts are prolonged or deepened, the future picture of the world or society would widely differ from past assumptions. When the future is uncertain because of difficulties in predicting forthcoming developments, people are looking for what to do in response to any dramatic change in the world. It is extremely important for governments and energy industry stakeholders to see the international energy situation from the long-term perspective and work out and implement suitable energy policies and strategies.

6.2 Basic scenario concept

Based on the abovementioned awareness, we provide an overview of a scenario on the global energy situation after the COVID-19 pandemic and quantitatively compare it with the Reference Scenario. To this end, we organised a workshop and used a "scenario planning approach" to describe an uncertain future and develop a scenario on the post corona global energy situation. The results were for a future world that differs far from that in the Reference Scenario and we named this scenario, the "Post Corona World Transformation Scenario"[18]. In this scenario, global primary energy consumption, oil consumption, electricity consumption, and primary energy mixes of major economies in 2050 were estimated quantitatively and compared to the Reference Scenario.

Basic policy for scenario planning

The Post Corona World Transformation Scenario depicts a world in which political, economic, and social changes, triggered by the ongoing COVID-19 pandemic will be maintained or enhanced. It is structurally different from the Reference Scenario world in which past trends will be sustained. The Post Corona World Transformation Scenario depicts a world into which the Reference Scenario world will be transformed under the COVID-19 disaster. The Post Corona World Transformation Scenario is not a world in which energy demand's recovery after the global economic slowdown will simply be further delayed.

When considering the future energy situation, we must ponder the possibility that the pandemic's impacts on climate change countermeasures may change the future course of the world. In the Post Corona World Transformation Scenario, global decarbonisation will make progress even under the impacts of the pandemic, meaning that the COVID-19 disaster will not become a strong impediment to decarbonisation. However, as the importance of human survival, health, and safety has been re-examined as urgent issues, and economic recovery has become extremely important, the issue of climate change will be seen as a relativisation even though it is important.

In the Post Corona World Transformation Scenario, countries will give greater priority to their energy security and pursue decarbonisation policies that are adapted to their respective conditions, as detailed later. For example, Europe will maintain its current initiative that strongly promote decarbonisation policies as the centre of its recovery plan from the COVID-19 disaster. Meanwhile, some developing economies will promote decarbonisation initiatives in their own ways and at their own pace. Decarbonisation measures in the world will thus be promoted in a patchy manner.

[18] It is called the "Post Corona Scenario" for short.

6.3 Post Corona World Transformation Scenario's characteristic points: Priority given to security

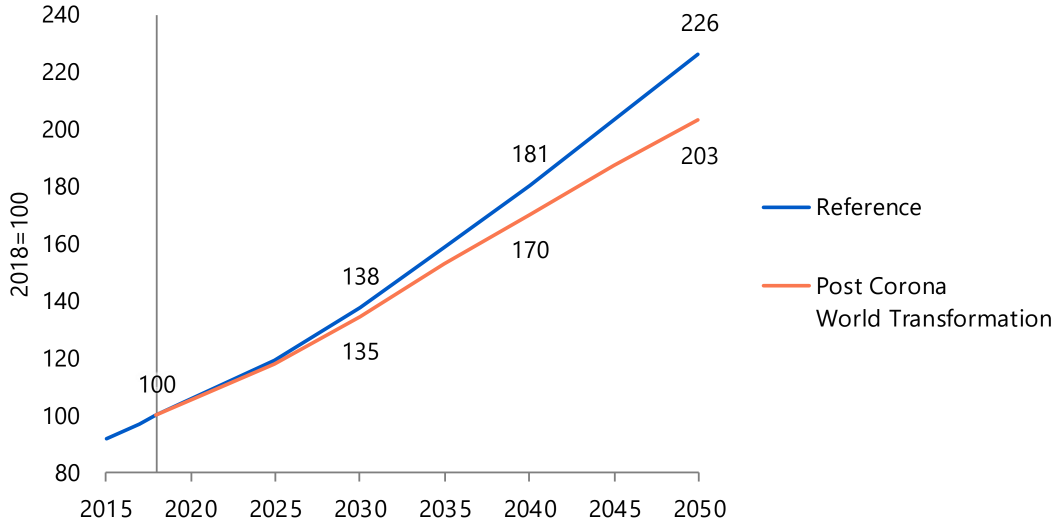
Downside pressure on world economy

Each country will recognise the significance and give greater priority to its national security through the enhancement and expansion of its crisis management for the prevention of COVID-19 infections for its people. This may lead to prioritising and expanding spending on national security rather than pursuing maximum economic efficiency through market forces. Such security cost expansion and increased burdens on citizens will be socially tolerated.

The recent intensification of the U.S.-China confrontation is adding fuel to national security consciousness in each country. The Post Corona World Transformation Scenario world will feature relatively higher international political and geopolitical tensions, and higher potential for regional conflicts.

Interest will also grow in the so-called economic security. The spread of COVID-19 has shed light on problems regarding supply chains that depend on foreign countries and rely on overseas strategic materials. Industries in each country will be encouraged by their government to revise the international division of labour and global supply chains and develop self-sufficiency. Revising traditional global supply chains designed to maximise cost efficiency will lead to higher costs and lower efficiency, having negative impacts on the global economy (Figure 6-6).

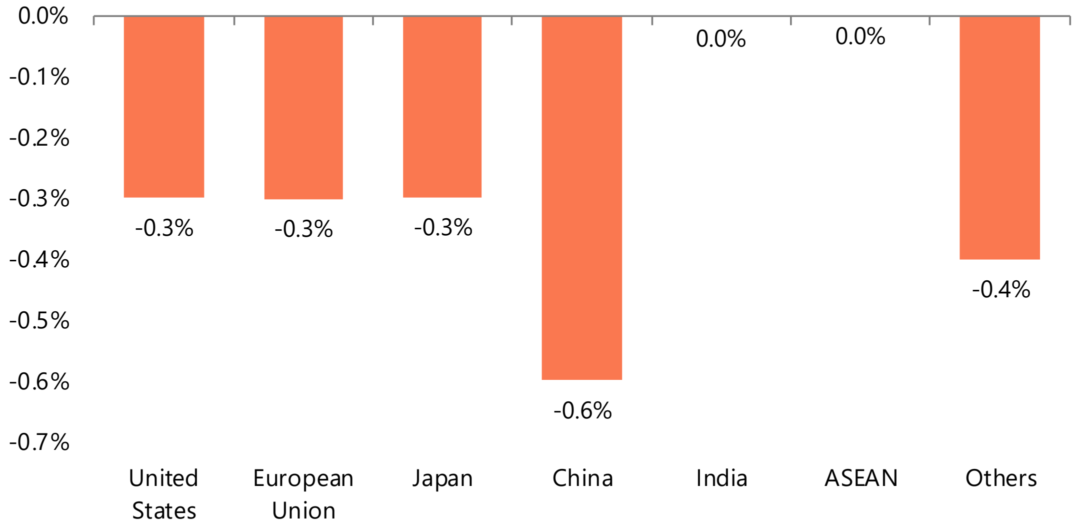
Figure 6-6 | Global economy size [Post Corona World Transformation Scenario]



The revision of global supply chains will lead countries to give priority to self-sufficiency and secure alliance with economic cooperation partners. The partners could be geographically close countries or countries within their respective spheres of influence. As such, revising the global supply chain will exert influence on regional economic growth patterns; growth will decline in economies from which manufacturing and other industries relocate but will rise in those into which industries will relocate.

Towards 2050, the global annual economic growth rate will fall on average by 0.3 percentage points from the Reference Scenario, in which priority is placed on economic efficiency. Growth will decline by 0.3 points in the OECD member economies and by 0.6 points in China from which global supply chains will relocate (Figure 6-7). Economic growth will remain unchanged from the Reference Scenario in India and ASEAN into which global supply chains will relocate. The global economic growth deceleration will result from the world's deviation from free trade and global supply chain arrangements that pursue optimum cost efficiency. That has the same characteristics as the negative effects on the world economy brought about by the formation of the world economic bloc after the Great Depression from the latter half of the 1920s.

Figure 6-7 | Changes in annual economic growth rates from Reference Scenario [Post Corona World Transformation Scenario, 2018-2050]

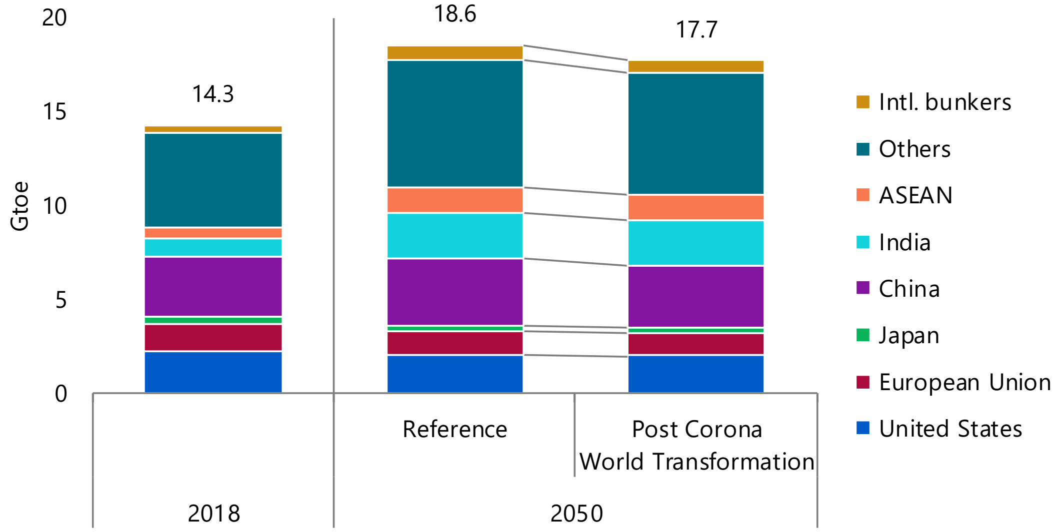


Falling energy consumption and rising interest in security

Reflecting the decelerating global economic growth, global primary energy consumption growth will also slow down totalling 17.7 gigatonnes of oil equivalent (Gtoe) in 2050, down 4% from the Reference Scenario (Figure 6-8). Energy consumption changes from the Reference Scenario will differ from economy to economy. It will decrease by 3% from the Reference Scenario in the United States, by 4% in Japan, and by 5% in the European Union. China will feature a larger decline at 7%. In contrast, energy consumption will remain unchanged in India and rise by 2% in ASEAN and these economies will increase their shares of energy demand growth and consumption.

As interest grows in national security and energy security, as noted above, energy self-sufficiency rates and diversified energy supply sources will become key energy policy indicators. National governments will grow interested in using domestic energy sources, renewable energy, nuclear, and hydrogen. Measures to enhance supply security for imported oil and natural gas will also become important.

Figure 6-8 | Global primary energy consumption [Post Corona World Transformation Scenario]



Enhanced non-fossil energy and innovative technology development

Momentum for decarbonisation initiatives will be maintained, although these initiatives will be promoted in a patchy manner. Therefore, renewable energy and nuclear will be promoted as contributors to decarbonisation as well as contributors to enhancing energy self-sufficiency. As competition for global supremacy intensifies amid high geopolitical tensions, priority will be given to the development of innovative technologies that enhance energy security and contribute to decarbonisation, prompting competition to be heightened for energy technology supremacy.

In this respect, innovative energy development initiatives will be enhanced to accelerate the advancement and diffusion of relevant individual technologies. Given that "green" hydrogen produced from renewable energy is used basically as domestic or local energy, green hydrogen initiatives will make progress mainly in Europe in the Post Corona World Transformation Scenario. The spread in global renewable energy will contribute to the use of green hydrogen. Initiatives will also promote "blue" hydrogen produced from fossil fuels with carbon capture and storage (CCS) technologies being used. Although imported blue hydrogen will fail to improve energy self-sufficiency, the blue hydrogen initiatives will be positioned to diversify energy supply sources, contribute to decarbonisation, and win technological supremacy. If blue hydrogen is produced in Middle Eastern and other oil-producing countries for exports to others, it will lead to the diversification, advancement, and stabilisation of oil-producing economies. This will contribute to stabilising international energy markets and to maintaining and enhancing energy security. The enhancement of strategic cooperative relations between relevant countries through innovative energy and supply chain development will also contribute to their energy security. Green and blue hydrogen initiatives will make gradual progress while reflecting national or regional conditions. The full-fledged diffusion of hydrogen and other innovative energy sources will begin to diffuse around 2050, after this outlook period.

The abovementioned measures and options in the Post Corona World Transformation Scenario will lead to higher overall costs than in the business-as-usual Reference Scenario. Although some cost hikes are expected and will be tolerated, as noted in the basic concept of the Post Corona World Transformation Scenario, cost cuts will become extremely important and the options will differ by region. In accordance with their respective national conditions, countries will promote higher energy self-sufficiency with the improvement of energy efficiency and the diffusion of renewable energy, nuclear, and innovative energy sources, such as hydrogen.

6.4 Post Corona World Transformation Scenario's characteristic points: Digitalisation and its impacts

Oil demand will peak around 2040

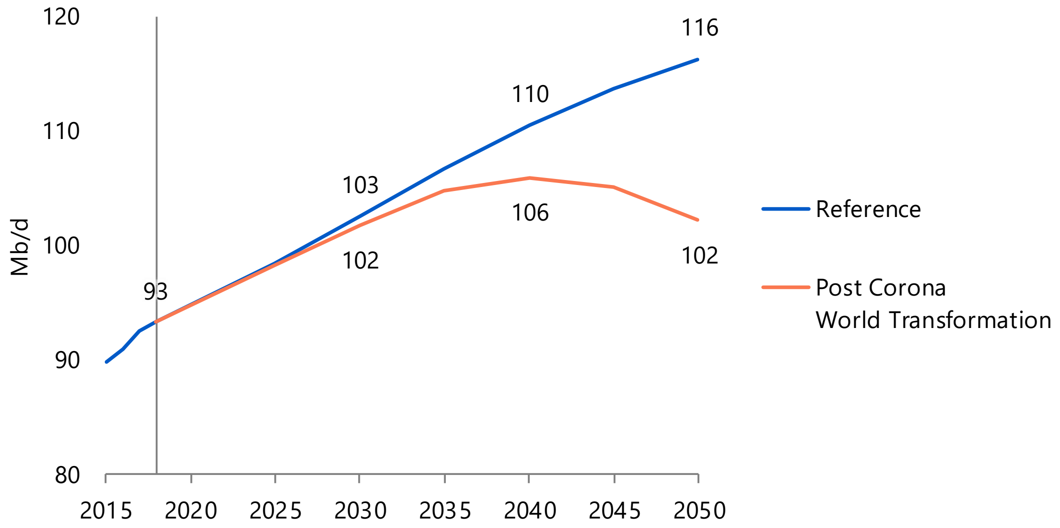
Key points of the Post Corona World Transformation Scenario include progress in digitalisation as well as growing national security consciousness. Digitalisation plays a key role in the economic, social and lifestyle transformation. Information and communications, and digital technologies have enabled telework, new workstyle and communications changes, and rapidly suppressed travel demand in response to the COVID-19 disaster. Their further development and diffusion will support the social transformation triggered by the disaster. The digitalisation of energy supply and demand systems and the subsequent world transformation will make progress.

With digitalisation, an oil demand peak will emerge as a major phenomenon in the energy field. Reflecting the further diffusion of vehicles, growing air transport demand and rising demand in the petrochemical sector, global oil demand is expected to moderately increase over the long term. For the last several years, however, an oil peak theory has been attracting interest. According to the theory, oil demand would peak and turn down due to powertrain and mobility changes including the replacement of internal combustion engine vehicles by electric and fuel cell vehicles.

The COVID-19 disaster, through lockdowns and travel restrictions, demonstrated how quickly oil demand could be suppressed. It has also demonstrated that telework and web conferencing can work as means to physically restrict human travel. Oil demand will peak because the social transformation, after the disaster, structurally suppresses travel demand. It will also peak because of the deceleration in growth for the global economy.

Global oil demand will peak around 2040 and fall to 102 Mb/d in 2050 (Figure 6-9), a decrease of about 14 Mb/d from the Reference Scenario. As noted above, the global annual economic growth rate will fall by 0.3 percentage points from the Reference Scenario, leading the overall oil demand to shrink, in part because of the substantial decline in travel demand.

Figure 6-9 | Global oil consumption [Post Corona World Transformation Scenario]



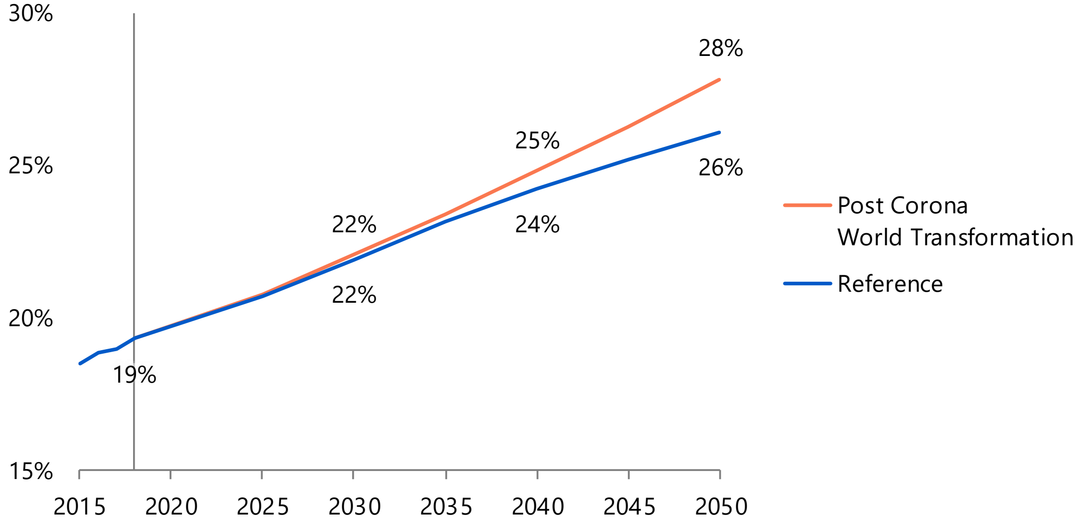
The peaking of global oil demand will exert great influence on the international oil situation. Most world energy outlooks project that oil prices will keep an uptrend over the long term, as high-cost oil supply will be required to meet oil demand's long-term expansion. If global oil demand peaks, however, such projection may be overturned, leading oil prices to lose the upward momentum.

The IEEJ Outlook 2018 analysed the possibility of oil demand peaking due to the electrification of vehicles and the diffusion of zero-emission vehicles and projection that oil prices would be limited to around $50/bbl in 2050. As a result, the Middle East's oil exports in the year would decrease by $1.6 trillion (equivalent to 13% of nominal GDP) from the Reference Scenario. The peaking of oil demand, even if being triggered by different factors, may have similar impacts on the oil supply-demand balance and oil prices, bringing about extremely negative economic effects on Middle Eastern and other major oil-producing countries. In this sense, it may become significant for oil-producing countries to sustain and enhance their ongoing efforts to structurally diversify and advance their economies. Even if oil demand peaks, however, global oil demand in 2050 may surpass the current level of 103 Mb/d. Given the depletion of producing oil fields, considerable investment may be required in the upstream oil sector to maintain the present production level. Securing adequate or sufficient investment may be indispensable for stabilising the oil market.

Progressing electrification and digitalisation

Like the peaking of oil demand, progress in electrification is attracting attention. The development of information and communications technologies and digitalisation to support the social, economic and lifestyle transformation, combined with the peaking of oil demand, will enhance the importance of electricity. In the Post Corona World Transformation Scenario, the global electrification rate (electricity's share of final energy consumption) will rise from 19% in 2018 to 28% in 2050 (Figure 6-10), 2 percentage points higher than in the Reference Scenario, indicating the world's greater dependence on electricity.

Figure 6-10 | Global electrification rate [Post Corona World Transformation Scenario]



As electricity becomes more important, it will become more significant to provide electricity stably, in an environment-friendly manner and at affordable prices. In this sense, each country will be required to implement energy policies to address the abovementioned three challenges in a well-balanced manner and develop optimum solutions to simultaneously resolve the challenges. Then, each country will have to respond to issues of growing importance such as cybersecurity, adequate measures for the expansion of intermittent renewable energy sources, and electricity investment required amid power market reform. How to cut costs for introducing advanced or innovative electricity-related technologies will be important for addressing these challenges or issues.

In a world where information and communications technologies play greater roles and digitalisation makes progress, how can we best manage those technologies and the growing importance of digitalisation? This is becoming a global matter of interest. In this respect, the various degrees of governments' collection and management of personal information and of privacy protection will attract attention in the future. Countries will decide whether to promote digitalisation in a centralised manner under strong government control or give priority to privacy protection and citizens' voluntary initiatives under their respective political regimes and industrial and social systems. Digitalisation will thus make progress in a variety of ways.

Under different patterns of digitalisation, energy infrastructure and supply chains will be developed in a centralised top-down manner in some economies and in a decentralised bottom-up manner in others. In a country featuring centralised control, its government will easily promote large-scale infrastructure development and support other projects in a top-down manner while taking leadership in the energy transition. In a society featuring privacy protection and decentralised control that gives priority to citizens' voluntary initiatives, business corporations and citizens will implement various initiatives in a bottom-up manner to take advantage of private-sector and market forces for energy transition. Economies will build on their energy resource endowment conditions, economic conditions, income levels, industrial and technological development conditions, government policies and systems, social systems, and human lifestyles to make optimum energy choices. In consideration of a growing national security consciousness, the need for decarbonisation initiatives and desire for energy-related technological supremacy, economies will make effective energy choices for improving energy self-sufficiency, diversifying energy supply sources, and reducing greenhouse gas emissions, based on their respective conditions.

Competition for technological supremacy will include a race to take leadership in digitalisation. If the abovementioned different patterns of digitalisation make progress, a key point of competition will be what pattern would form the mainstream or take a leading position in the world.

6.5 Primary energy consumption and power generation mix

With travel demand falling due to social transformation and global economic growth slowing down, relative to the Reference Scenario, countries will seek to improve energy self-sufficiency and diversify energy supply sources to enhance energy security. As explained earlier, decarbonisation initiatives will be implemented in a patchy manner in the world. In pursuit of technological supremacy, countries will strive to develop and introduce advanced and innovative energy sources. Consequently, energy supply in the Post Corona World Transformation Scenario will structurally differ from that in the Reference Scenario.

Global primary energy consumption will increase by 24% from 14.3 Gtoe in 2018 to 17.7 Gtoe in 2050 (Figure 6-11). However, the consumption in 2050 will be 4% lower than the 18.6 Gtoe in the Reference Scenario. Particularly, oil consumption will decline substantially due to the peaking of oil demand, reducing its share of primary energy consumption by 2% points from 30% in the Reference Scenario to 28%. Natural gas and coal will also cut their respective shares. Fossil fuels' combined share of primary energy consumption will fall from 81% in the Reference Scenario to 79%. In place, renewable energy and nuclear consumption will increase from the Reference Scenario. Renewable energy's share will rise from 17% in the Reference Scenario to 18%. Nuclear energy's share will remain unchanged at 5%.

As in the Reference Scenario, natural gas will post the largest consumption increase from 2018 to 2050, followed by renewables (Figure 6-12). In the Post Corona World Transformation Scenario, however, the natural gas consumption increase will be smaller than in the Reference Scenario and in contrast, the renewables consumption rise will be greater. Oil consumption will decrease substantially from the Reference Scenario.

Figure 6-11 | Global primary energy consumption mix [Post Corona World Transformation Scenario]

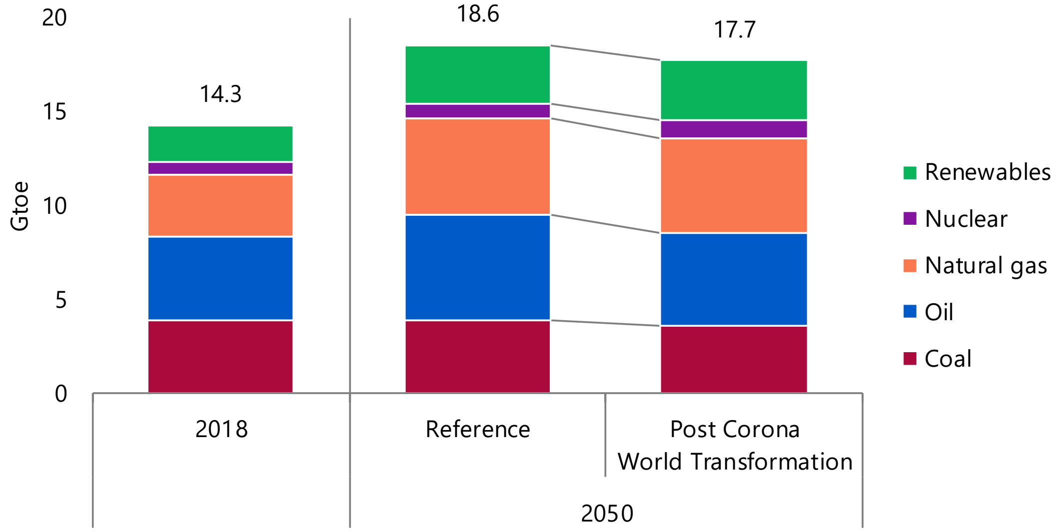
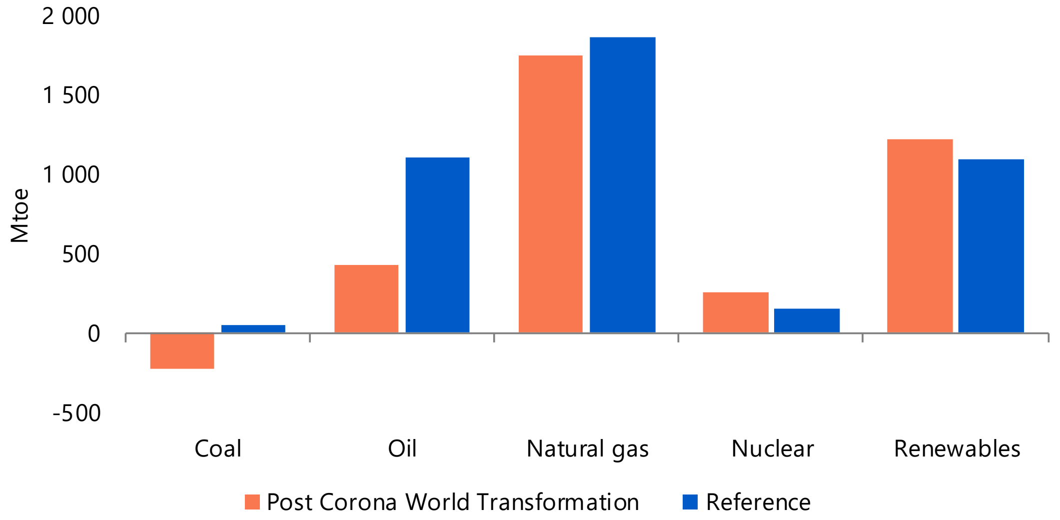


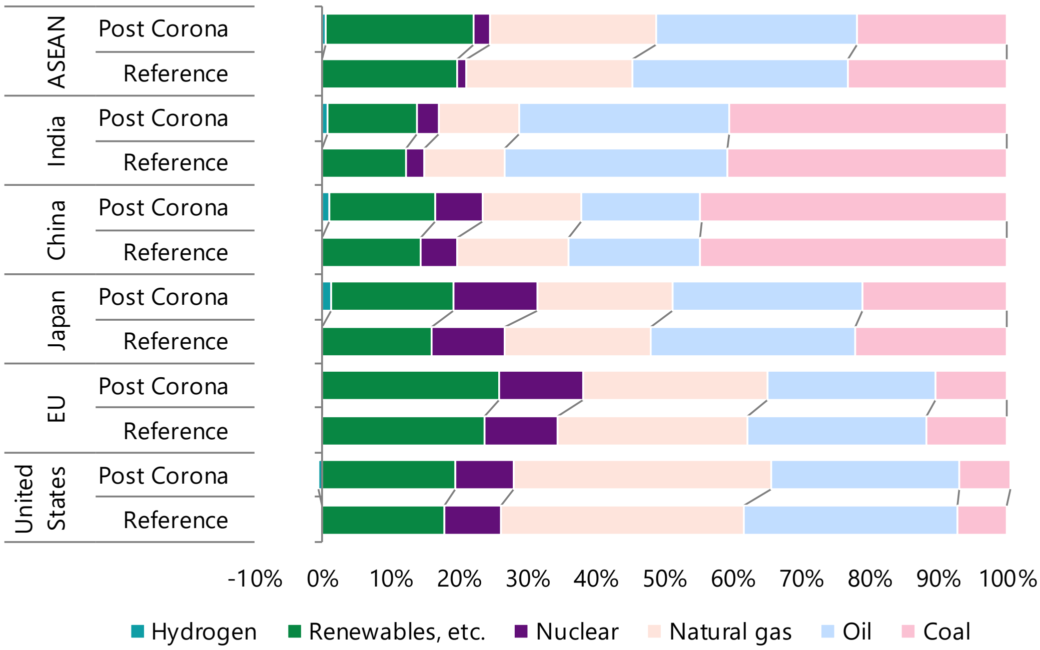
Figure 6-12 | Global primary energy consumption changes [2018-2050]



Non-fossil energy consumption and share of primary energy consumption will increase from Although non-fossil energy sources' share of primary energy consumption will expand from the Reference Scenario due to greater renewables and nuclear consumption, fossil fuels will still account for most of the energy consumption, even in the Post Corona World Transformation Scenario. In this sense, stable fossil fuel supply will be a key target even in the Post Corona World Transformation Scenario, in which priority will be given to energy security.

the Reference Scenario in all major regions of the world in 2050 but the energy consumption mixes will differ by region depending on energy resource endowments and the state of technology introduction (Figure 6-13).

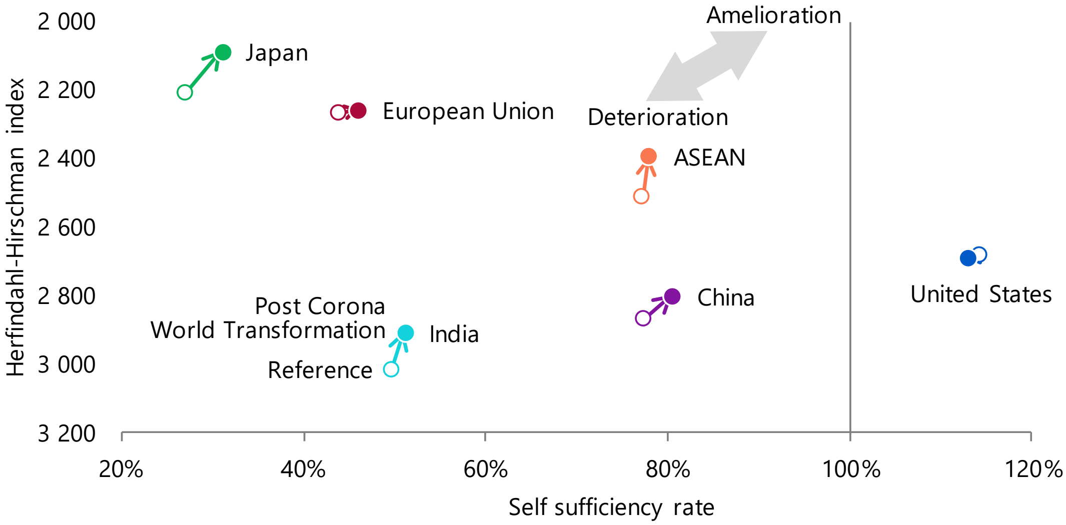
Figure 6-13 | Primary energy consumption mixes in selected countries/regions [2050]



Non-fossil energy sources' expansion will allow each region to raise energy self-sufficiency and diversify energy sources. The Herfindahl-Hirschman Index (HHI)[19] indicating the diversification and the energy self-sufficiency rate in the Post Corona World Transformation Scenario will improve from the Reference Scenario in all regions except for the United States where these indicators will remain unchanged, signalling the enhancement of energy security (Figure 6-14).

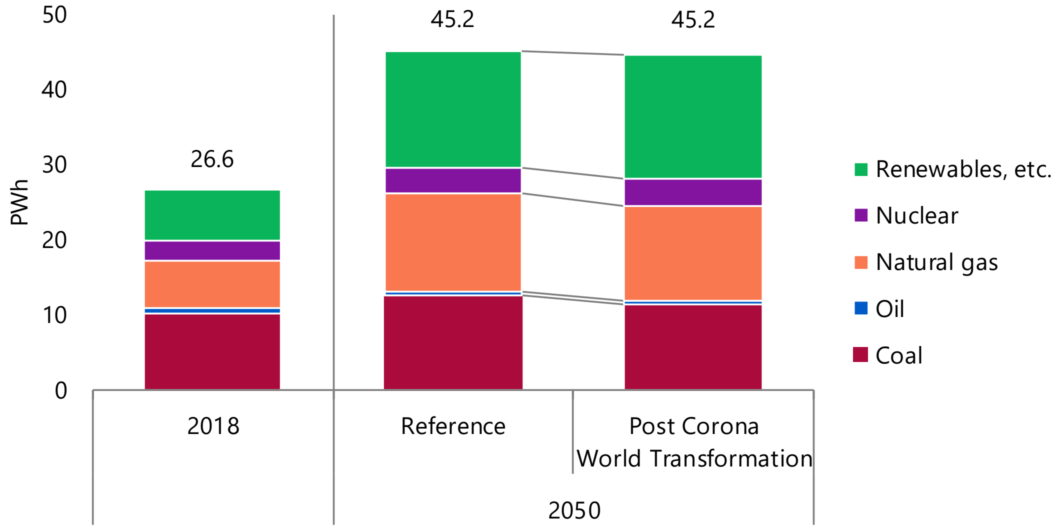
[19] The HHI is the sum of squared shares for energy sources.

Figure 6-14 | Energy self-sufficiency and primary energy consumption HHI levels [2050]



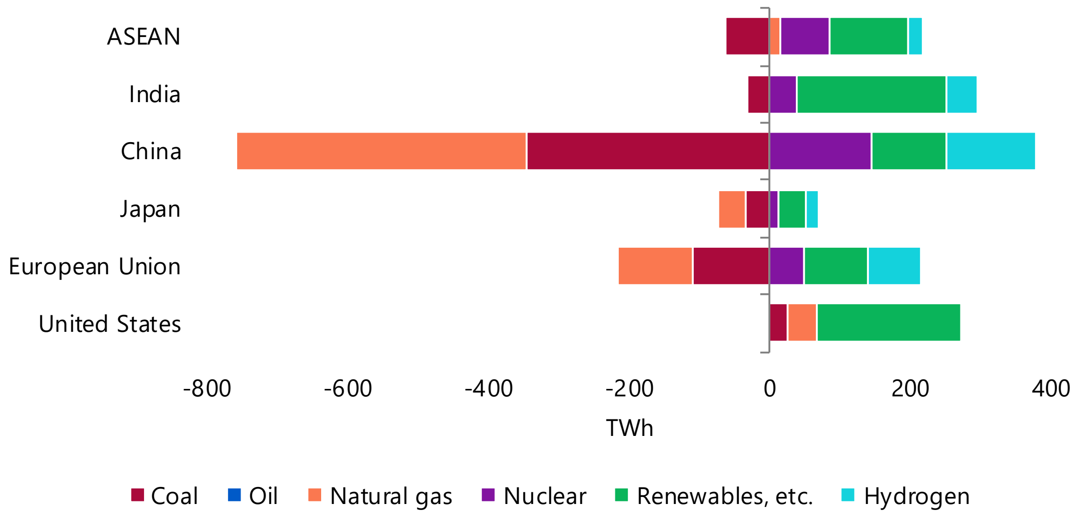
Power generation mix changes indicates a similar trend (Figure 6-15). While global power consumption increases sharply from 26.6 petawatt hours (PWh) in 2018 to 45.2 PWh in 2050, fossil fuels which account for more than a half of the generation in the Reference Scenario will be for less than 50% in the Post Corona World Transformation Scenario.

Figure 6-15 | Global power generation mix [Post Corona World Transformation Scenario]



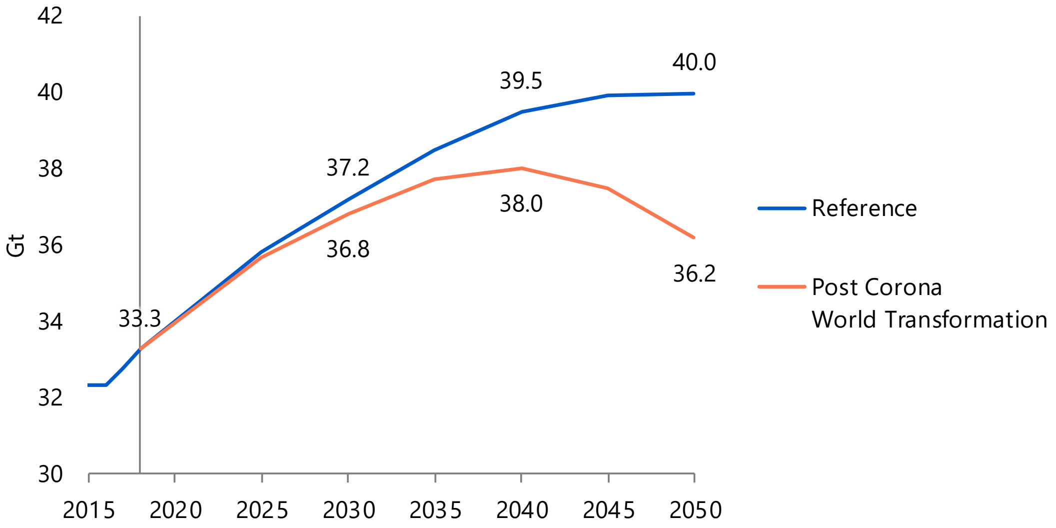
Hydrogen-fired power generation will begin to make progress in 2050 (Figure 6-16). The expansion of non-fossil power sources' share and hydrogen-fired power generation will make progress in the low-carbonisation of power sources.

Figure 6-16 | Global power generation changes (from Reference Scenario) [Post Corona World Transformation Scenario, 2050]



Energy-related CO_2 emissions will be less than in the Reference Scenario because of the economic growth deceleration, the drop in travel demand and the promotion of renewables and nuclear. As shown in Figure 6-17, global energy-related CO_2 emissions will increase from 33.3 Gt in 2018 to 36.2 Gt in 2050 in the Post Corona World Transformation Scenario, down 3.8 Gt or 10% from 40.0 Gt in the Reference Scenario.

Figure 6-17 | Global energy-related CO_2 emissions [Post Corona World Transformation Scenario]



6.6 Implications

The COVID-19 pandemic forced the global energy markets to face an oversupply through demand evaporation and subsequent energy price drops. Given that low energy prices have stimulated demand and reduced supply, how the supply-demand balance and prices in global energy markets would move has become a matter of global concern.

At the same time, structural and long-term changes triggered by the pandemic in global energy markets have also attracted interest. The Post Corona World Transformation Scenario used the scenario planning approach to depict how the world will transform because of the pandemic. The approach considered changes in international politics, the global economy, society and lifestyles, and provided for a quantitative comparison with the Reference Scenario.

If the world transitions from maximising economic efficiency (minimising costs) to emphasising national security, the growth in global economy will decelerate as it deviates from the optimisation of economic efficiency. This will lead energy demand growth to decelerate. If global supply chains are revised with priority given to national security, the change in economic growth patterns will differ by region and will naturally bring about changes in regional energy demand growth patterns. While the gravity centre of global energy demand shifts to Asia, energy stakeholders in the world will pay attention to changes in Asian countries' shares of the Asian growth pie.

The peaking of oil demand will bring about new challenges in the international oil market. If the peaking triggers oil price stagnation, oil-producing countries' stabilisation and their relevant economic diversification and advancement will grow even more important. If oil demand remains at the present level despite its peaking, it will be important to secure adequate investment to meet the demand.

As information and communications technologies and digitalisation become even more important, the world will see an acceleration in electrification and will be required to provide electricity stably, in an environment-friendly manner, and at affordable prices. To this end, policy initiatives and support will be needed along with the energy industry's efforts such as investment and the development and diffusion of advanced and innovative technologies.

The enhancement of energy security and decarbonisation initiatives and competition for developing relevant advanced and innovative technologies will work to promote non-fossil energy sources, including hydrogen. The promotion will lead these energy sources to increase their shares of the energy mix. At the same time, however, fossil fuels will still account for a major share of the energy mix, indicating that it will remain important to secure stable fossil fuel supply and promote the clean, environment-friendly use of fossil fuels.

The Post Corona World Transformation Scenario indicates how the world will transform based on changes caused by the COVID-19 pandemic. Whether or how the transformation will be realised is uncertain. We must remain conscious of the great potential changes and work out energy policies and strategies that will flexibly respond to such changes.

7. Circular Carbon Economy/4Rs Scenario

7.1 Circular carbon economy

Concept and importance

The ambitious reductions in greenhouse gas (GHG) emissions reinforce the growing importance of developing and diffusing a wider range of technologies than the ones that traditionally attracted interests, such as energy efficiency, renewable and nuclear energies. To further reduce emissions in the future, the world must adopt a more comprehensive approach and make maximum use of all available options and technologies to reduce emissions. Among such technologies, those for decarbonising and utilising fossil fuels are essential.

Even with the assumed diffusion of cutting-edge energy technologies of the Advanced Technologies Scenario, the world will depend on fossil fuels for nearly 70% of its energy needs in 2050. As the world will rely heavily on fossil fuels over the long term, the big challenge to be tackled in the medium to long-term perspective will be the development and introduction of technologies that cleanly use fossil fuels and promote future emission cuts. In addition to improving energy efficiency and diffusing renewable energy, the world must also consider and make use of technologies to decarbonise fossil fuels as much as possible. Otherwise, the realisation of ambitious emission cuts will be difficult.

Many countries in the world are already showing an interest in decarbonising fossil fuels. At a Group of 20 summit to be hosted by Saudi Arabia in 2020, the importance of the so-called Circular Carbon Economy (CCE) concept for tackling climate change, while using fossil fuels sustainably was advocated. The CCE concept considers atmospheric CO_2 as a cycle and seeks to reduce it from a comprehensive perspective covering the whole of economy. The traditional circular economy concept has been developed into the CCE concept. While the circular economy concept seeks to hold down the use of resources or the generation of waste through three Rs – Reduce, Reuse and Recycle, the CCE concept calls for reducing emissions of (see comments) atmospheric CO_2, through four Rs – the 3Rs and Remove[20].

4Rs technologies

The first of the 4Rs is Reduce, meaning reducing fossil fuel consumption to cut CO_2 emissions into the atmosphere. Reduce measures not only include promoting energy efficiency and substituting the use of fossil fuels with renewables or nuclear, but they also include decarbonising fossil fuels. Important for decarbonised use of fossil fuels is the use of *blue hydrogen* produced from fossil fuels with carbon capture and storage (CCS) technologies. Blue

[20] American architect William McDonough advocated the idea of conceiving atmospheric carbon as a cycle or a usable resource, on which the CCE concept is based. For details, see William McDonough, “Carbon Is Not the Enemy”, *Nature News* 539 (2016), 349-351. Based on the idea, the CCE concept was developed by Eric Williams, “Achieving Climate Goals by Closing the Loop in a Circular Carbon Economy”, *Instant Insight* KS-2019-II10 (2019), 1-12; Ahmad O. Al Khowaiter and Yasser M. Mufti, “An Alternative Energy Transition Pathway Enabled by the Oil and Gas Industry”, *Oxford Energy Forum* Issue 121 (2020), 14-19; etc.

hydrogen may be used in place of fossil fuels for power generation, transportation, industrial and other sectors, contributing to cutting CO_2 emissions.

The second R is Reuse. After lowering fossil fuel consumption through the above reduce measures, any remaining CO_2 emitted into the atmosphere through fossil fuel consumption could be captured and reused for some purposes to help cut emissions. More specifically, captured CO_2 may be used for enhancing oil recovery at oil fields or concentrated for expanding food or algae biofuel production.

The third R is Recycle. This means that CO_2 is captured and used (recycled) for some purposes as in the case with reuse. The recycle measures chemically transform the captured CO_2 into other materials. Representative recycle technologies include the use of special admixtures to allow the captured CO_2 to be absorbed into concrete. Other technologies synthesise the captured CO_2 with hydrogen to produce methane (to replace natural gas), produce liquid fuels, or transform it into methanol and other petrochemical materials.

The fourth and last R is Remove. This means that CO_2 emissions left after reduce and recycle measures can be directly captured and removed. Remove technologies include CCS technologies for collecting CO_2 from fossil fuel-fired power plants as well as direct air capture (DAC) technologies for capturing CO_2 directly from the atmosphere and injecting it into underground formations. The representative 4Rs technologies are compiled in Table 7-1.

The CCE concept provides two new viewpoints compared with the current mainstream approach on climate change countermeasures.

The First viewpoint calls for a holistic approach of using all energy sources, countermeasures and technologies available for reducing GHG emissions. The CCE concept seeks to promote not only zero-emission energy sources such as renewables but also advocates the decarbonisation of fossil fuels to cut emissions. The holistic approach allows complementary fossil fuel decarbonisation measures to provide effective emission cuts even if renewable energy diffusion fails to make progress on schedule. For example, some Asian countries where energy demand will increase substantially, already face difficulties in securing renewable energy in a stable manner. By pursuing additional or complementary options to renewable energy and other green technologies, the CCE concept is a more comprehensive system of measures for achieving emission reduction targets.

The other new viewpoint of the CCE concept regards CO_2 as a resource available for *reusing* or *recycling* to effectively cut emissions. The conventional wisdom for discussions on emission cuts has been that emissions left after the maximum use of energy efficiency measures and renewable energy should be captured and stored underground with CCS technologies. As described above, these energy efficiency, renewables and CCS technologies are among the core 4Rs technologies. In addition, capturing, reusing and recycling CO_2 as a resource can be the third or fourth option to cut emissions. This is the other new viewpoint of the CCE concept. In fact, emission cuts through reusing and recycling among the 4Rs technologies may be limited, as discussed later. To cut emissions further, however, all available technologies should be mobilised to the maximum extent. In this sense, the idea of viewing CO_2 emissions in society as a cycle and reusing or recycling them as much as possible is necessary. The CCE concept advocates emission reduction measures based on the wider perspective that the world will continue to depend on fossil fuels for some part of its overall energy supply.

Table 7-1 | 4Rs technologies for circular carbon economy

	Overview	Major technologies
Reduce	Reducing fossil fuel consumption volume to cut CO_2 emissions into the atmosphere	Promoting energy efficiency Promoting renewables diffusion Promoting nuclear diffusion Using advanced ultra-supercritical coal-fired power plants Promoting fuel cell vehicle diffusion Hydrogen-fired power generation Using ammonia as fuel for power generation and ships Using coal ash and other admixtures to reduce cement production Hydrogen-reduction ironmaking process
Reuse	Using CO_2 captured from the atmosphere for some purposes without transforming it chemically	Enhanced oil recovery using captured CO_2 at oil fields Concentrating captured CO_2 in greenhouses for agricultural production Using captured CO_2 for increasing algae biofuel feedstock production Producing reed-based jet fuel
Recycle	Transforming captured CO_2 chemically for some purposes	Allowing captured CO_2 to be absorbed into concrete Fixing captured CO_2 as carbonate Producing synthetic liquid fuels from captured CO_2 and hydrogen Producing synthetic methane from captured CO_2 and hydrogen Producing chemical materials from captured CO_2 and hydrogen
Remove	Capturing and removing atmospheric CO_2	Carbon capture and storage (CCS) Direct air capture (DAC) of CO_2

Source: Mansouri, N. Y. *et al.* (2020) "A Carbon Management System of Innovation: Towards a Circular Carbon Economy"

Most of the 4Rs technologies, reuse and recycle technologies in particular, are viewed as still under development and requiring more time for commercialisation, but this view is not necessarily correct. Some of these technologies have been commercialised or are close to commercialisation. For example, Kajima Corp., Chugoku Electric Power Co., and Denka Co. have developed and commercialised the CO_2-SUICOM (CO_2 Storage under Infrastructure by Concrete Materials) technology for concrete absorbing CO_2. Concrete produced with this technology is used for paving blocks and fence beds at Chugoku Electric Power's Fukuyama power plant. As for ammonia using blue hydrogen, Japan imported ammonia produced in

Saudi Arabia in 2020 and mix it with coal in demonstration tests at a coal-fired power plant. The presence of such technology close to commercialisation would help to realise the CCE.

7.2 Overview of Circular Carbon Economy/4Rs Scenario

Various technologies are assumed for realising the CCE. Based on these technologies' emission reduction impacts and development phases, we have developed the Circular Carbon Economy/4Rs Scenario in which some representative technologies among them will have been diffused to the maximum extent in 2050. Then, we have estimated global CO_2 emissions and energy supply and demand in the scenario. The assumed technologies for the scenario are specified in Table 7-2. Other assumptions for the scenario are the same as for the Advanced Technologies Scenario.

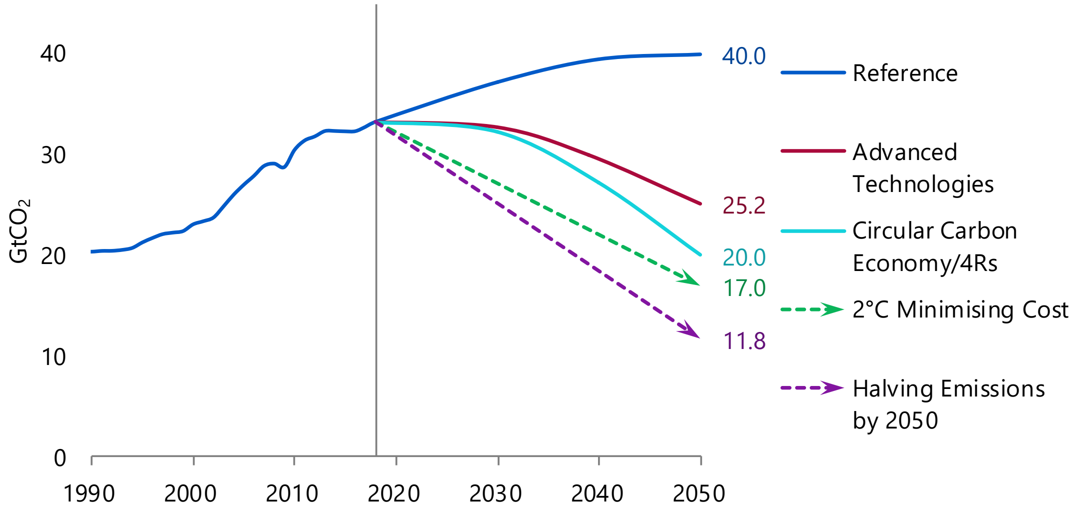
Table 7-2 | Technology assumptions [Circular Carbon Economy/4R Scenario]

4Rs	Technologies assumed for the scenario	Assumptions
Reduce	Using blue hydrogen for power generation	Blue hydrogen (including ammonia produced from blue hydrogen) will be introduced for 50% of non-CCS coal-fired power plants in 2050 in the Advanced Technologies Scenario
	Using blue hydrogen for transport	Blue hydrogen will cover 20% of fuel demand in the road transport sector in 2050 in the Advanced Technology Scenario.
	Using blue hydrogen for hydrogen-reduction ironmaking	Hydrogen-reduction ironmaking technology using blue hydrogen will be used for 25% of crude steel production in the Advanced Economies, China and India in 2050.
	Reducing cement production	Coal ash, limestone calcined clay and other admixtures will be used to cut global cement production in 2050 by 25%
Reuse	Concentrating CO_2 to increase algae biofuel production	Biodiesel production in 2050 in the Advanced Technologies Scenario will be increased by 50%
Recycle	CO_2-absorbing concrete	CO_2 absorption technology will be used for 50% of global concrete production in 2050
	Synthetic methane	Synthetic methane will cover 50% of fuel for non-CCS gas-fired power plants in 2050 in the Advanced Technologies Scenario
Remove	Carbon capture and storage	Additional CCS will be implemented for blue hydrogen production

7.3 Analysis results

CO_2 emissions in 2050 in the Carbon Circular Economy/4Rs Scenario will fall by 20% from 25.2 Gt in the Advanced Technologies Scenario to 20.0 Gt (Figure 7-1), covering more than 60% of the gap between the 2°C Minimising Cost Path (Chapter 8) and the Advanced Technologies Scenario.

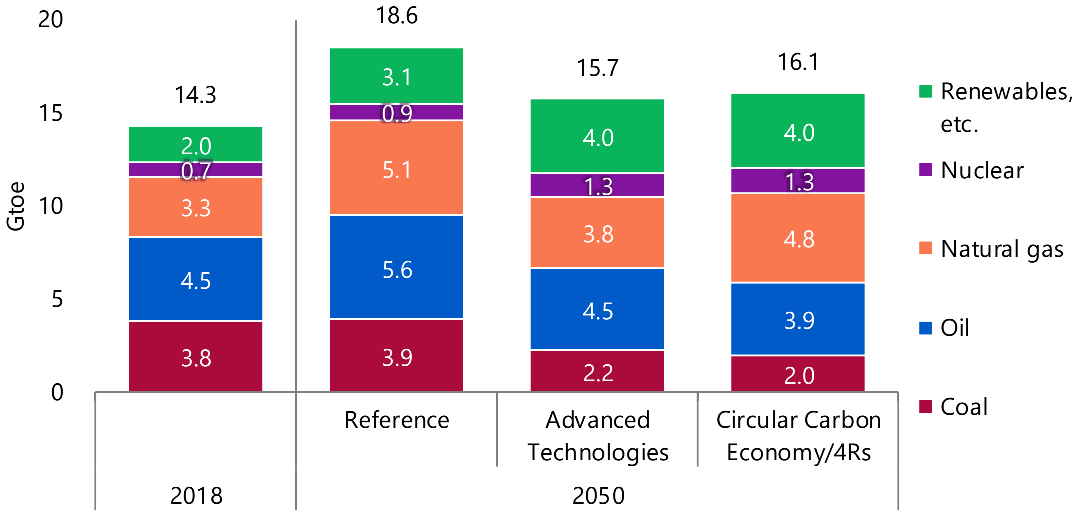
Figure 7-1 | Global CO_2 emissions



Primary energy consumption will increase slightly from the Advanced Technologies Scenario (Figure 7-2). This is because additional energy transformation demand will arise due to the introduction of the 4Rs technologies[21]. Fossil fuels' share of primary energy consumption in 2050 will remain unchanged from the Advanced Technologies Scenario at 67%, while falling substantially from 79% in the Reference Scenario. Among fossil fuels, the share for oil and coal will fall while natural gas' share will expand. This is because blue hydrogen, produced mainly from natural gas, will replace part of the coal and oil consumption in the power generation and transport sectors. The coal's share will not decline as much as oil's because the coal demand decline in the power generation sector will be partially offset by an increase in demand for coal for blue hydrogen production. These results indicate that the diffusion of technologies for decarbonising fossil fuel consumption could substantially reduce CO_2 emissions while fossil fuel consumption remains almost unchanged.

[21] However, primary energy consumption could be higher than this estimate because the Circular Carbon Economy/4Rs Scenario does not consider all additional energy consumption for the introduction of the assumed 4Rs technologies.

Figure 7-2 | Global primary energy consumption [2050]

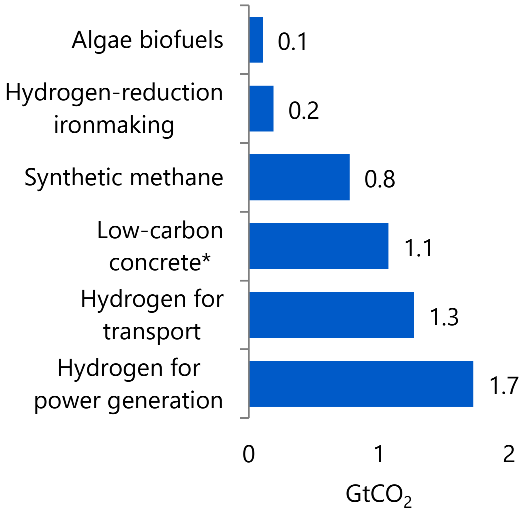


Note: Natural gas includes synthetic methane.

Among the 4Rs technologies to be introduced, the largest contributor to emission cuts will be blue hydrogen for coal-fired power plants, followed by blue hydrogen for transport (road sector) (Figure 7-3). In the industry sector in which it is generally difficult to cut emissions, low-carbon concrete and hydrogen-reduction ironmaking technologies will contribute to emission cuts. In the Circular Carbon Economy/4Rs Scenario, synthetic methane will be produced from both green and blue hydrogen and its introduction will make great contributions to decarbonising the power generation sector. Among the 4Rs technologies in the Circular Carbon Economy/4Rs Scenario, reduce and recycle technologies using blue hydrogen will make particularly great contributions to emission cuts.

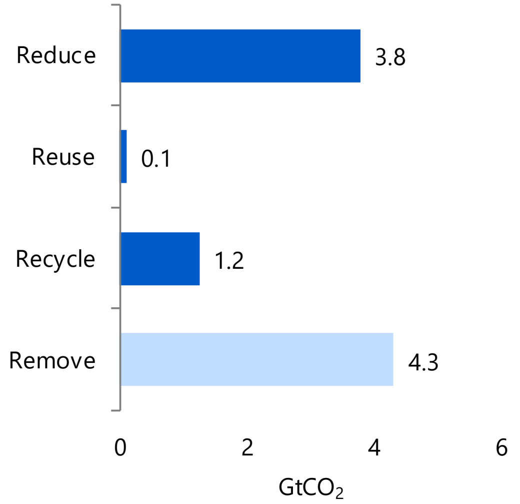
Coal's share of the power generation mix will decline while the share for hydrogen (including ammonia) increases (Figure 7-6). Fossil fuels' share of the power generation mix in 2050 will decrease from 34% in the Advanced Technologies Scenario to 27%. In contrast, hydrogen will account for 5% of electricity generated, replacing part of fossil fuels for power generation.

Figure 7-3 | Global CO_2 emission cuts (by technology, compared with Advanced Technologies Scenario) [Circular Carbon Economy/4Rs Scenario, 2050]



Note: Emission cuts through low-carbon concrete cover those through the reduction of cement production and the introduction of CO_2-absorbing concrete.

Figure 7-4 | Global CO_2 emission cuts (by 4R, compared with Advanced Technologies Scenario) [Circular Carbon Economy/4Rs Scenario, 2050]



Note: Emission cuts through remove (CCS) technologies are light-coloured because they are counted as cuts through blue hydrogen technologies.

Figure 7-5 | Global power generation [2050]

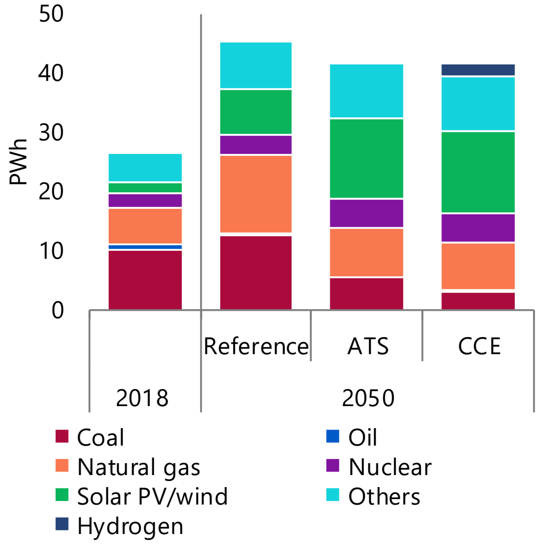
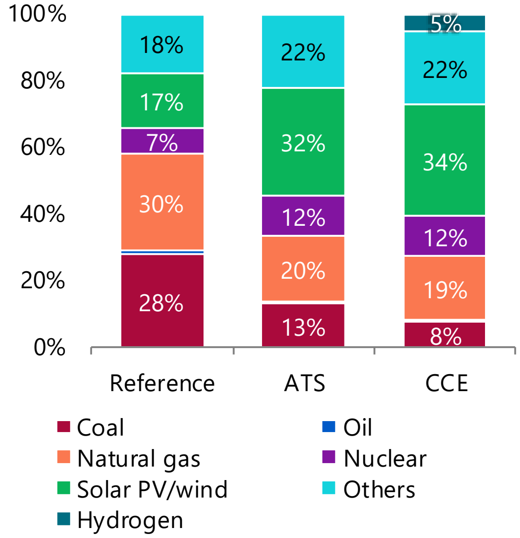


Figure 7-6 | Global power generation mix [2050]



Notes: ATS stands for Advanced Technologies Scenario. CCE stands for Circular Carbon Economy/4Rs Scenario. Natural gas includes synthetic methane.

Figure 7-7 shows region-by-region demand for blue and green hydrogen that will play great roles in the Circular Carbon Economy/4Rs Scenario. Global demand for hydrogen will total 1 164 Mtoe in 2050, arising mainly in Asia where energy demand will expand greatly. To allow emissions to be substantially reduced through fossil fuel decarbonisation, massive hydrogen will have to be provided stably at affordable prices everywhere in the world. Blue hydrogen will be produced and exported mainly from regions rich with cheap natural gas and coal resources (Figure 7-8). The development of infrastructure and markets for international hydrogen supply and trade will be a major challenge for realising the circular carbon economy.

Figure 7-7 | Global hydrogen demand [Circular Carbon Economy/4Rs Scenario]

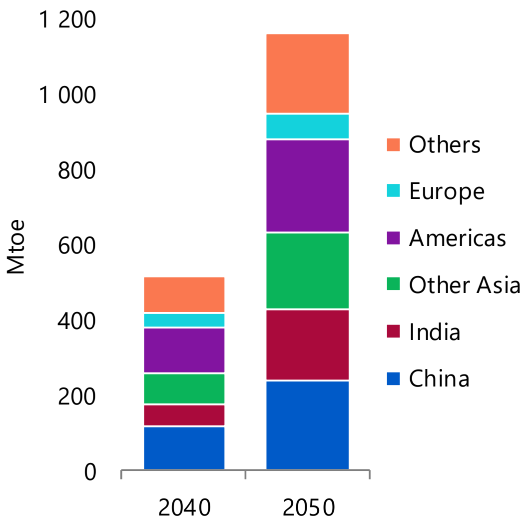
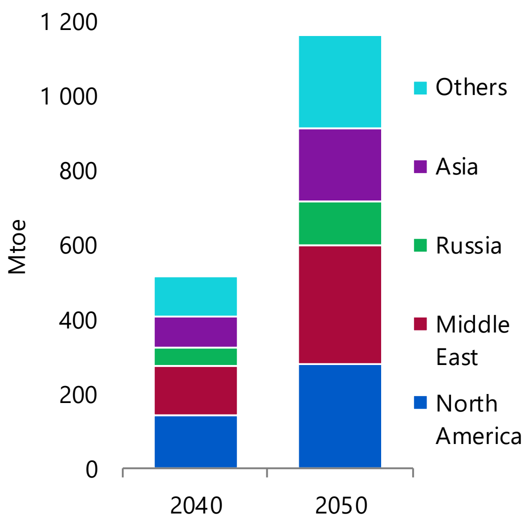


Figure 7-8 | Global hydrogen supply [Circular Carbon Economy/4Rs Scenario]



In the Circular Carbon Economy/4Rs Scenario where 80% of the blue hydrogen for consumption is assumed to be produced from natural gas, natural gas consumption will increase substantially along with blue hydrogen consumption (Figure 7-9). Other fossil fuels could also be used for hydrogen production. Global natural gas consumption (including synthetic methane) will increase by 27% from the Advanced Technologies Scenario as natural gas consumption for hydrogen production expands. Such natural gas demand growth will require major natural gas producers to expand from current production, although production in 2050 will fall short of the Reference Scenario level. There are sufficient natural gas resources for expanding blue hydrogen consumption (Figure 7-10).

Figure 7-9 | Global natural gas consumption [2050]

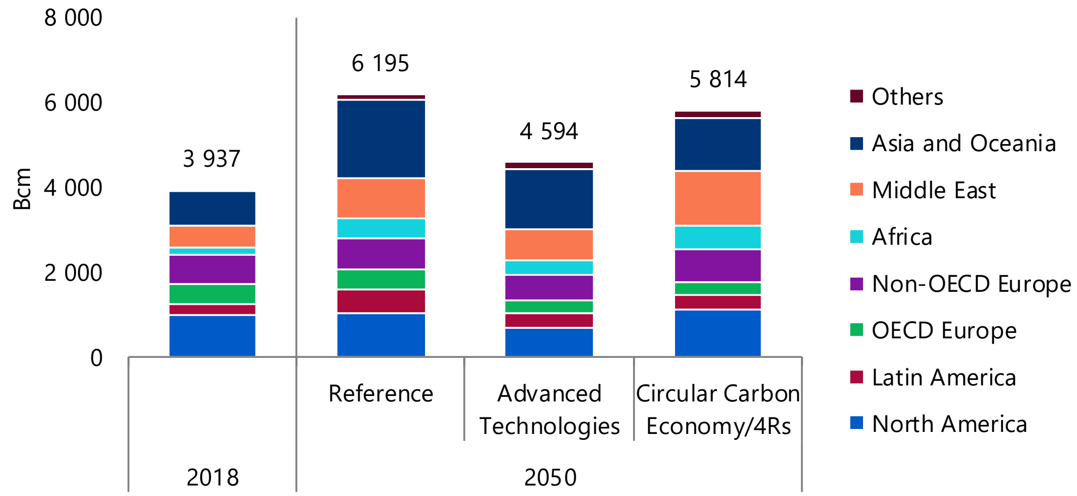
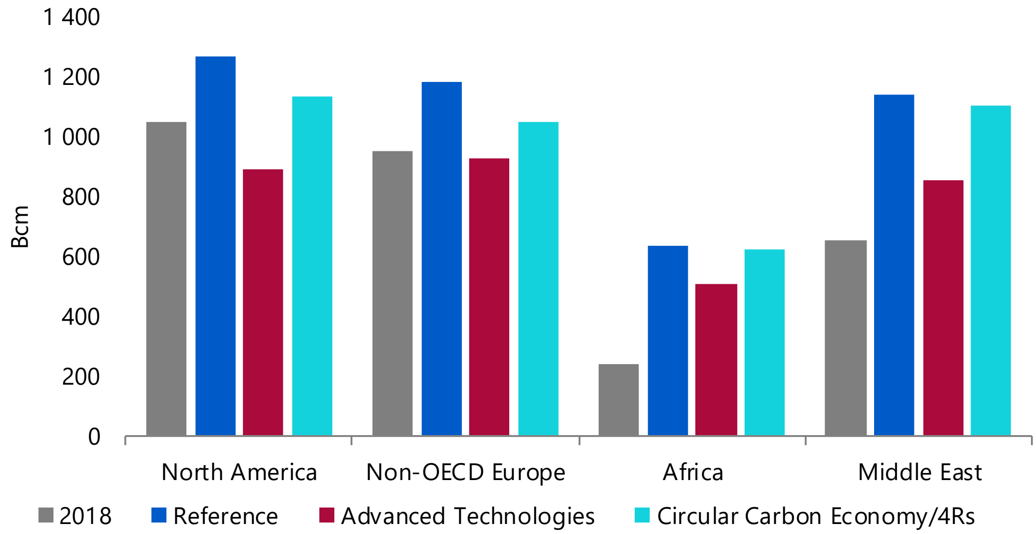


Figure 7-10 | Natural gas production in selected gas-producing regions [2050]



7.4 Summary and implications

The Circular Carbon Economy/4Rs Scenario has the following four implications.

The first and most important implication is that the potential combination of fossil fuel use and substantial CO_2 emission cuts. The maximum diffusion of the 4Rs technologies could substantially reduce CO_2 emissions without any major change in fossil fuels' share of energy consumption. Although the promotion of emission reduction measures is expected to centre on the diffusion of renewable energy, the continued use of fossil fuels would not necessarily conflict and could be combined with the other measures through the proactive promotion and introduction of the 4Rs decarbonisation technologies.

The second implication shows the importance of developing supply arrangements for blue hydrogen expected to play a great role in decarbonisation. The decarbonisation of fossil fuel can substantially reduce CO_2 emissions, depending on massive, cheap and stable supply of blue hydrogen. To this end, numerous challenges including how to cut hydrogen production costs, how to develop hydrogen supply infrastructure, and how to unify technology standards must be resolved. Much time and investment will be required for resolving these challenges, indicating that it will be important for governments and business corporations to implement initiatives based on a long-term perspective.

The third implication is the importance of technological development. As noted above, technologies assumed in the Circular Carbon Economy/4Rs Scenario include some commercialised ones and many under development. The Circular Carbon Economy/4Rs Scenario does not strictly consider technical constraints or economic efficiency for introducing 4Rs technologies. For these technologies to be launched, their costs will have to be comparable to existing technologies. Among the 4Rs technologies, reduce and remove technologies will make greater contributions to cutting emissions than reuse and recycle technologies. In Japan that has less potential to implement CCS, however, it is important to promote the development of reuse and recycle technologies to domestically decarbonise fossil fuel use. Given that continuous efforts are required to develop technologies for decarbonising fossil fuels, it is important to provide in a stable manner policy and financial support for technological development and to promote international cooperation in sharing information.

The last implication is the significance of public relations initiatives. Depending on the future development and application of relevant technologies, the sustained use of fossil fuels should not be in conflict with reductions in CO_2 emissions. So far, however, fossil fuel use has been associated with CO_2 emissions. It is important to inform a wide range of people that 4Rs technology development and diffusion will allow fossil fuel use to be combined with emission cuts.

8. Pragmatic approach to climate change

8.1 Climate change cost-benefit analysis

Climate change has increasingly attracted great interests in recent years. The Special Report on Global Warming of 1.5°C, published by the Intergovernmental Panel on Climate Change (IPCC) in 2018, stated that the earth has warmed by 1°C since pre-industrial times and that global anthropogenic greenhouse gas (GHG) emissions would have be net zero by around 2050 or 2075 to limit global warming to 1.5°C or 2.0°C. However, current target GHG emission cuts submitted by countries would fall short of achieving the goals and far more ambitious initiatives are required.

Given that the earth has already warmed by 1°C and is destined to warm further in the future, a key point for climate change policies is to appraise how much more human beings should tolerate before limiting global warming. To assess the extent, cost-benefit analyses have been conducted. To mitigate climate change, GHG emissions must first be lowered and the cost of reducing emissions is called "mitigation cost". If emissions are not reduced sufficiently, the planet will continue to warm-up and adaptation measures, such as the construction of seawalls in response to sea level rises, will be required. When such adaptation measures are insufficient, others to limit the mounting damages to humans would be necessary. Conceptually, an emission reduction path to minimise the total cost of mitigation, adaptation, and damage, maximising the utility for human beings, would be most desirable. Models to conduct cost-benefit analyses to find such emission path are called integrated assessment models and have been developed by numerous researchers since the 1990s.

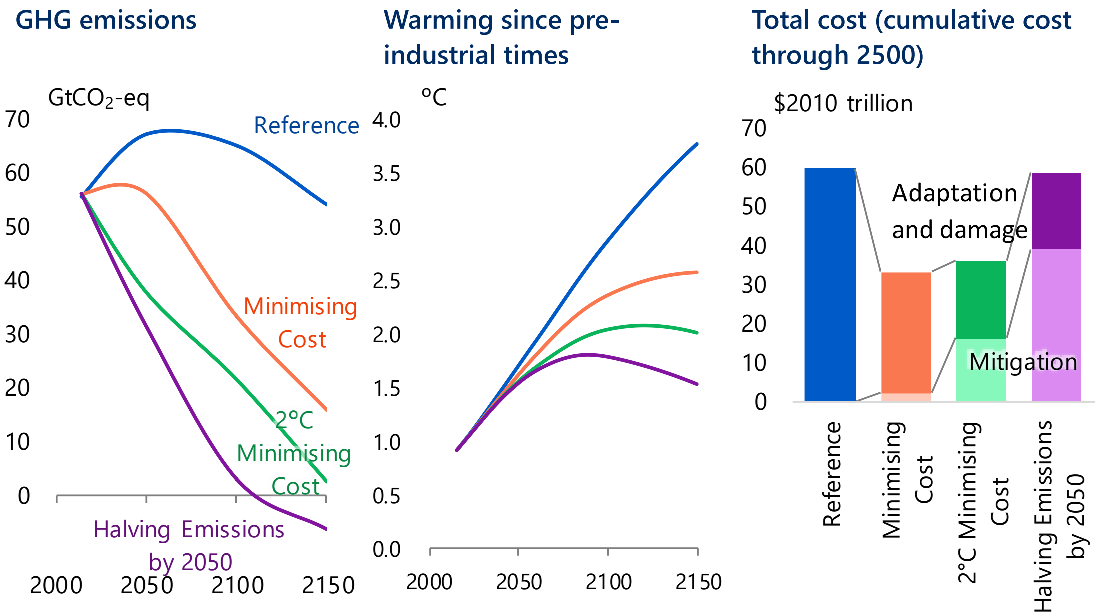
Figure 8-1 shows ultra-long-term paths[22] found through cost-benefit analysis using our integrated assessment model. In the Minimising Cost Path, the earth would warm by around 2.6°C by 2150. In a scenario where the warming by 2150 is limited to 2°C, however, the total cost will be lower than scenarios where GHG emission cuts are not implemented or where global GHG emission will be more than halved by 2050. It may be pragmatic to explore adequate emission levels based on not only a single set of assessment results but also uncertainties of assessments and potential cost cuts through technological development.

While numerous studies on cost-benefit analyses have been done, analytical approaches and assumptions are based on a number of uncertainties, causing controversy among researchers. Although the abovementioned IPCC Special Report on Global Warming of 1.5°C generally uses both cost-benefit and cost-efficiency analyses[23] as assessment methods, cost-benefit analysis assessments reportedly contain far more uncertainties than cost-efficiency analysis assessments. In principle, however, cost-benefit analysis is in reality the only method to assess adequately the strengths of climate change countermeasures. When we assume a global warming of 2°C for cost-efficiency analyses, there is an underlying judgment that policies leading to global warming above 2°C would be unjustifiable as such warming is likely to deal severe damage to human beings. In this sense, cost-efficiency analyses are a kind of cost-benefit

[22] For details, see the IEEJ Outlook 2018, 2019 and 2020.
[23] For example, the cost-efficiency analysis assesses the most efficient emission path to achieve the specific global warming target of 2°C.

analysis. While cost-benefit analyses face various challenges, it is important to continue efforts to resolve those challenges.

Figure 8-1 | Ultra-long-term paths found through cost-benefit analysis



Note: The Halving Emissions by 2050 Path roughly corresponds to IPCC's Representative Concentration Pathway 2.6.

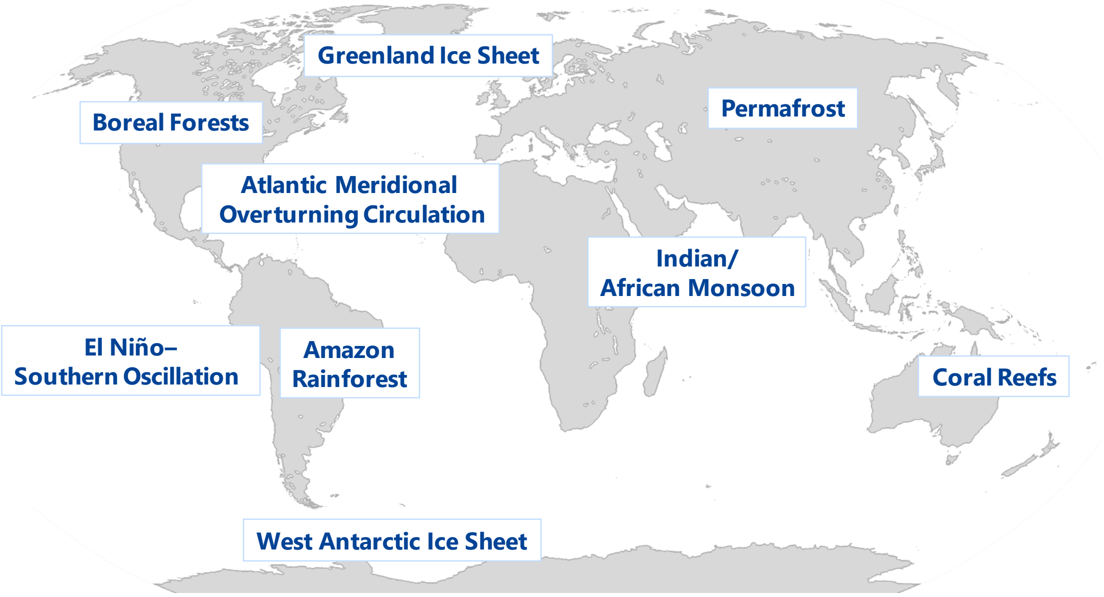
The IEEJ Outlook 2021 focuses its analysis on the so-called tipping elements, discount rate assumptions, and potential long-term technological development as major factors that could have great impacts on cost-benefit analyses.

8.2 Irreversible changes in earth system

Tipping elements: Key elements bringing about earth system transitions

The earth's climate has been in a kind of "equilibrium state". Disturbances beyond a certain level are most often offset by negative feedbacks preventing the earth from deviating too far from the equilibrium state. For example, an increase in the atmospheric CO_2 concentration could cause a rise in CO_2 absorptions into the earth surface or sea water. If the disturbance exceed certain levels, however, the earth system could go in the direction of accelerating the disturbance in a positive feedback loop, instead of restricting it. This may shift the earth irreversibly into a different equilibrium state (e.g., a state with higher temperatures). A saddle point or a tipping point is assumed between the two different equilibrium states and if some disturbance surpasses such point, the earth is acceleratingly shifting into a different (undesirable) equilibrium state. Tipping point events are called tipping elements and as shown in Figure 8-2, there are numerous potential tipping elements on the earth[24, 25, 26].

Figure 8-2 | Tipping elements



Sources: Lenton et al. 2008; Kopp et al. 2016; Stfefen et al. 2018

In the IEEJ Outlook 2020, we built on existing literature[27, 28] to model the release of methane from the Greenland ice sheet and the permafrost and incorporate them into a cost-benefit analysis. As a result, we found that these elements would have limited impacts on the cost-benefit analysis, falling short of changing the Minimising Cost Path or the social carbon cost. However, not all tipping elements have extremely limited impacts, some could be quite significant. For example, the collapse of the Antarctic ice sheet and the disappearance of coral reefs are expected to have relatively greater impacts than other tipping elements.

Specific tipping element (1): Antarctic ice sheet collapse

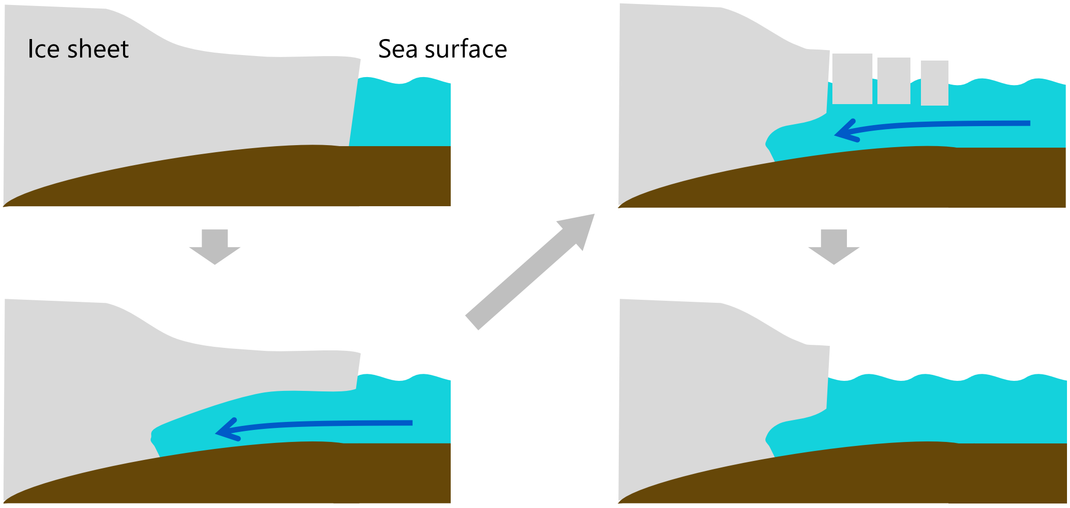
The Antarctic Continent is a vast area measuring about 14 million square kilometres and an ice sheet estimated at 27 million cubic kilometres. If the pure water ice sheet melts completely, sea levels are expected to rise by some 60 metres. The eastern side of the Transantarctic Mountains is called the Eastern Antarctic ice sheet (EAIS) and the western side the Western Antarctic ice sheet (WAIS). While the EAIS is physically bigger than the WAIS, the latter attracts greater attention regarding climate change because most of the WAIS bottom is below sea level and is

[24] T. M. Lenton et al. (2008). Tipping elements in the Earth's climate system. *PNAS*, 105(6), 1786-1793.
[25] R. E. Kopp et al. (2016). Tipping elements and climate–economic shocks: Pathways toward integrated assessment. *Earth's Future*, 4(8), 346-372.
[26] W. Steffen et al. (2018). Trajectories of the Earth System in the Anthropocene. *PNAS*, 115(33), 8252-8259.
[27] W. Nordhaus (2019). Economics of the disintegration of the Greenland ice sheet. *PNAS*, 116(25), 12261-12269
[28] D. Yumashev et al. (2019). Climate policy implications of nonlinear decline of Arctic land permafrost and other cryosphere elements. *Nature Communications*, 10, 1900.

expected to melt faster in response to seawater intrusion. DeConto and Pollard[29] pointed out the potential marine ice cliff instability (MICI) for the WAIS. This means that the underwater portion of the WAIS could melt due to a seawater temperature rise under global warming to destabilise and collapse the ice sheet, triggering a rapid global sea level rise.

However, Edwards et al.[30] noted that the past Antarctic ice sheet dynamics can be explained without any rapid marine ice cliff collapse being assumed and that DeConto and Pollard (2016) could represent an overestimate. Furthermore, Golledge et al.[31] used a climate model considering Antarctic and Greenland ice sheet melting and the oceanic and atmospheric feedback to estimate a sea level rise that is smaller than the DeConto and Pollard (2016) estimate but larger than an estimate given in the IPCC Fifth Assessment Report (AR5) (IPCC 2014). The IPCC's Special Report on the Ocean and Cryosphere in 2019 noted that any accurate MICI mechanism or whether it could occur is not necessarily certain at present, falling short of considering the MICI in predicting future sea level rises.

Figure 8-3 | Conceptual diagram of MICI



Here, we set parameters for an Antarctic ice sheet collapse without the MICI assumption according to Golledge et al. (2019) and those for the collapse with the MICI assumption according to DeConto and Pollard (2016). Their specific formulation is given in an annex.

The characteristic time for the case without the MICI assumption is 1 900 years against 700 years for the case with the MICI assumption. Anyway, the characteristic time of the Antarctic ice sheet collapse is far shorter than 9 000 years for the Greenland ice sheet collapse, indicating that the Antarctic ice sheet collapse is significant for climate change.

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[29] R. M. DeConto, and D. Pollard (2016). Contribution of Antarctica to past and future sea-level rise. *Nature*, 531, 591-597.

[30] T. L. Edwards et al. (2019). Revisiting Antarctic ice loss due to marine ice-cliff instability. *Nature*, 566, 58-64

[31] N. R. Golledge et al. (2019). Global environmental consequences of twenty-first-century ice-sheet melt. *Nature*, 566, 65-72.

Specific tipping element (2): Coral reef disappearance

Coral reefs, though accounting for only 0.1% of the earth's surface area, accommodate 90 000 kinds of creatures, providing human beings with fishing and tourism resources. They also serve as natural seawalls, contributing to preventing tidal waves. Coral reefs are roughly divided into two groups – warm coral reefs with seawater temperatures ranging from 20°C to 29°C and cold ones in deep or colder waters. Warm coral reefs are particularly vulnerable to climate change. Coral reef bleaching has already made considerable progress. More than 99% of warm coral reefs would be in danger of disappearance if the earth warms by 2°C, according to the IPCC. Even if the global warming is limited to 1.5°C, 70-90% would be threatened with disappearance. As shown in the annex, we used the arctangent function to model coral reef disappearance.

Minimising Cost Path changes through tipping elements

Figure 8-4 shows minimising cost paths for cases including the Greenland ice sheet collapse and the Antarctic ice sheet collapse (with the MICI). The inclusion of the Antarctic ice sheet collapse (with the MICI) as a tipping element greatly changes the path. Meanwhile, the impact of the Greenland ice sheet collapse is small, falling short of changing the Minimising Cost Path. As shown in Figure 8-5, permafrost melting, coral reef collapse, and the Antarctic ice sheet collapse (without the MICI) would have little impact, falling short of resulting in any major change in CO_2 emissions in 2050 for the Minimising Cost Path.

Figure 8-4 | GHG emission changes through tipping elements

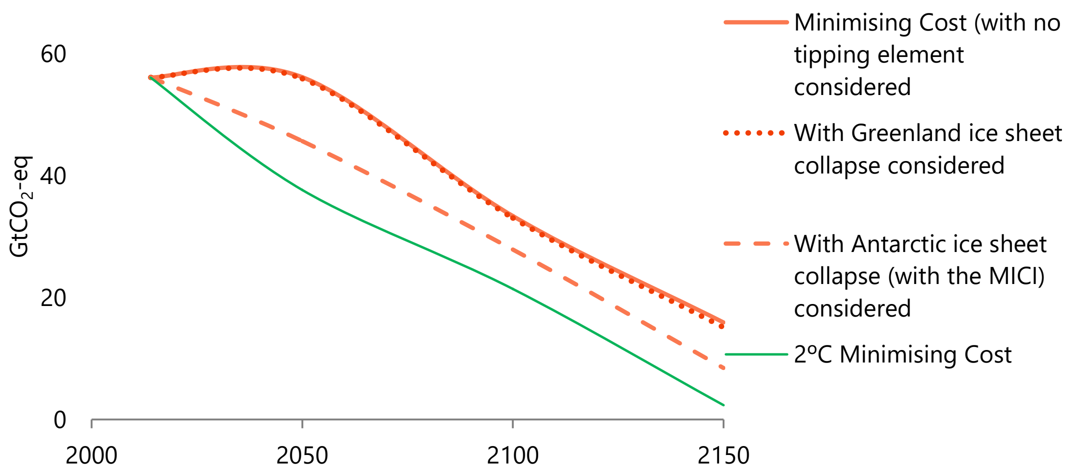
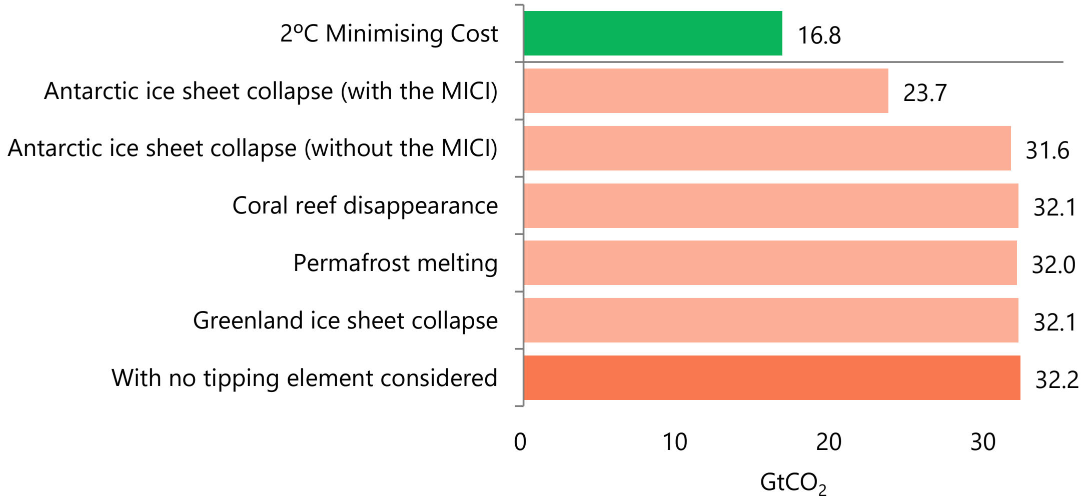


Figure 8-5 | Energy-related CO_2 emission changes through tipping elements [2050]

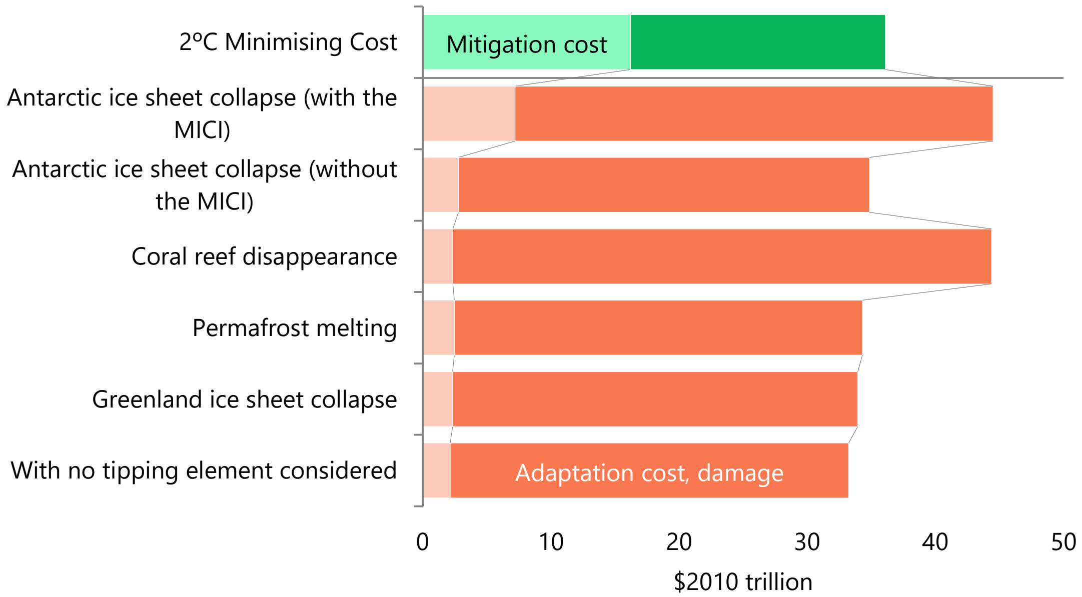


If the MICI works to substantially shorten the characteristic time of the Antarctic ice sheet collapse, it would exert impacts on the cost-benefit analysis that cannot be ignored. As far as ice sheet melting is concerned, a tipping element's impacts depend heavily on their characteristic timescale. The Greenland ice sheet collapse has a far longer characteristic time than the Antarctic ice sheet collapse accompanied by the MICI and would have far less impacts. For adequate responses to climate change, therefore, it is extremely important to deepen scientific understanding about whether there would be any phenomenon like the MICI that would shorten the characteristic time. Even if the MICI is considered, however, CO_2 emissions in the Minimising Cost Path would not be lower than in the conventional 2°C Minimising Cost Path.

Figure 8-6 shows a total cost change for each case. Like the emissions path, the total cost would be affected little by the Greenland ice sheet collapse, the permafrost melting or the Antarctic ice sheet collapse (without the MICI) but greatly pushed up by the Antarctic ice sheet collapse with the MICI.

Attention should be paid to a substantial cost hike through coral reef disappearance. This means that the coral reefs' disappearance could bring about great damage. Nevertheless, it would have little impact on the Minimising Cost Path. This is because coral reefs are assumed to disappear considerably due to the global warming of 1.5 °C and almost completely due to the warming of 2°C. Earth system changes through warming in the Minimising Cost Path or the 2°C Minimising Cost Path will not mean the end of the world. However, coral reefs as part of the world will be lost. Therefore, climate change will cause far more damage to people related deeply to coral reefs than to others. Any deep investigation into the issue of unequitable damage may go beyond a simple cost-benefit analysis but may be a viewpoint that should not be forgotten when future climate change policies are considered.

Figure 8-6 | Total cost changes through tipping elements



Note: If the Antarctic ice sheet collapse (with the MICI) is considered, the adaptation cost and damage in the 2°C Minimising Cost Path will increase by $9.6 trillion.

8.3 Long-term discount rate and technological development

How to assume the discount rate

As described above, tipping elements could exert great damage on human beings over the long term. However, their impacts may vary depending not only on the abovementioned characteristic timescale but also many other factors. In the following, we focus on the long-term discount rate and potential long-term technological development and assess how they could change the impacts of tipping elements.

The discount rate is an important concept for considering not only climate change but also many economic issues related to energy and the environment. Here, the real interest rate is assumed at 3%. In this case, $1 000 at present will be valued at $1 340 in real terms a decade later. Conversely, $1 000 at the end of the next decade is only worth $740 at present. The rate for converting monetary values at different points in time is called the discount rate and in the above case, the real interest rate of 3% corresponds to the discount rate.

The discount rate assumption is always important for assessing economic issues over time. For short to medium-term issues, real or nominal interest rates can be considered real or nominal discount rates, as described above. Meanwhile, there is no current consensus among researchers about an appropriate discount rate for climate change and other long-term issues. Usually, the social discount rate ϱ is described by the following formula called "Ramsey rule".

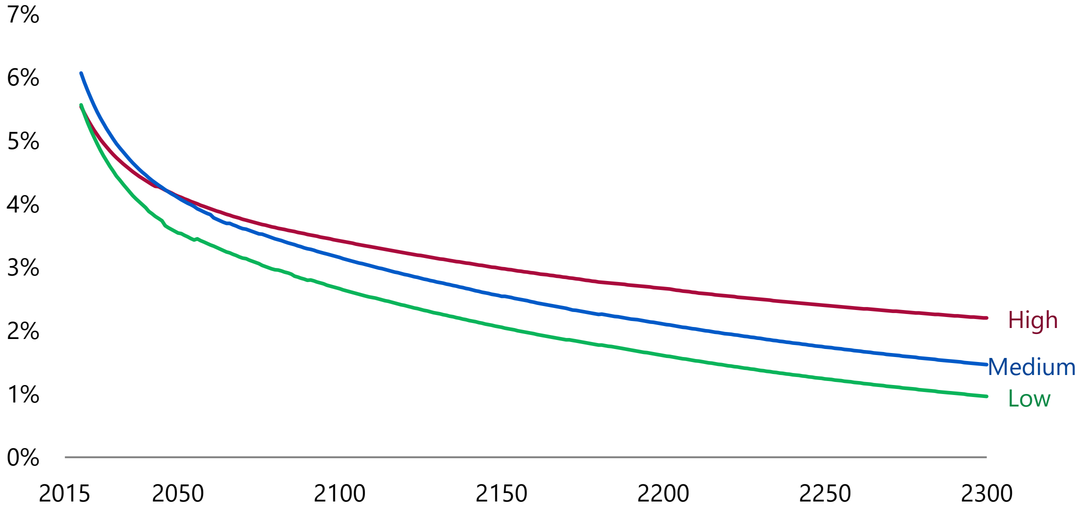
$$\rho = \delta + \eta g \quad (1)$$

δ is the pure time preference rate. The larger the rate is, the lower the future value should be assessed than the present value. g represents the consumption growth rate. Generally, consumption grows along with the economic size. η is the marginal utility's elasticity to consumption, indicating a percentage decline in value of a good in response to a 1% increase in per capita consumption.

Regarding an optimum solution in the integrated assessment model, Figure 8-7 indicates real discount rates for three different parameter sets: high (δ = 1.5%, η = 1.45), medium (δ = 0.5%, η = 2.0), and low (δ = 0.05%, η = 2.0). High and low assumptions are roughly based on Nordhaus's DICE-2016R model and Gollier[32], respectively. Computation in the previous section has been conducted according to the medium discount rate parameter assumption. Given that a higher discount rate generally leads future damage to be converted into a lower level in present value, the optimum solution moves in the direction of reducing the present mitigation cost and increasing future damage. In this way, cost-benefit analysis results differ depending on discount rate assumptions.

The long-term discount rate is controversial. From the viewpoint of model analysis, discount rate assumptions can be interpreted as reflecting our views on the future world. Assuming the discount rate at higher levels amounts to giving greater priority to present mitigation measures' economic impacts than to future climate change damage. At the same time, this may mean a greater belief in potential adaptation through future technological advancement. Assumptions for an adequate discount rate should continue to be studied and debated as they are indispensable in our efforts to make fairer and more objective policy decisions. At the same time, it is important to assess how different discount rate assumptions or different views about the future, within a scope that can be considered as reasonable at present, would influence our optimum choices.

Figure 8-7 | Discount rate assumptions



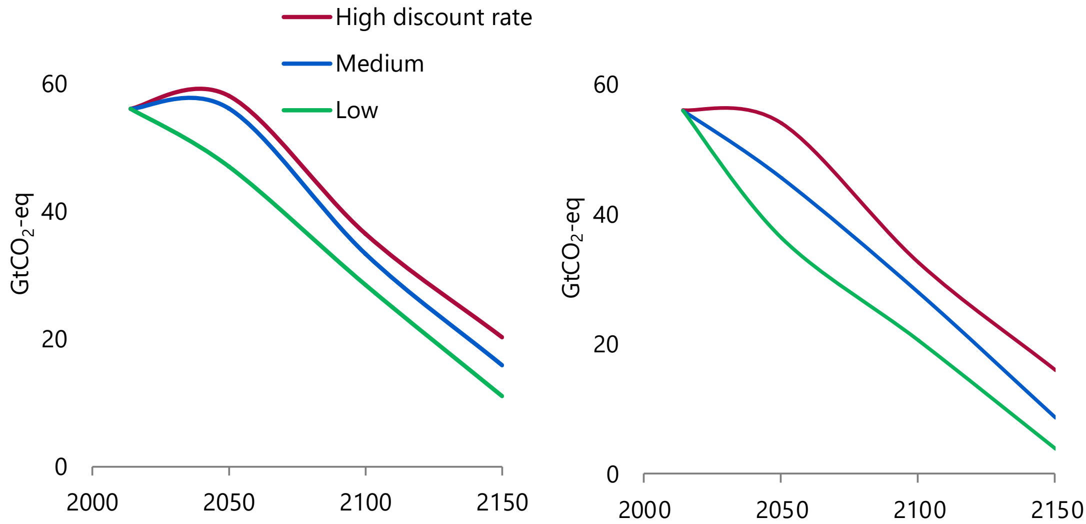
[32] C. Gollier (2013). *Pricing the Planet's Future: The Economics of Discounting in an Uncertain World.* Princeton University Press, Princeton, USA.

Minimising Cost Path and changes in impacts of tipping elements

As indicated by Figure 8-8, the Minimising Cost Path depends heavily on discount rate assumptions. If a low discount rate assumption is used, the optimum path may give greater priority to future damage from climate change and reduce GHG emissions more strongly. Likewise, the current value of the Minimising Cost Path including a tipping element (the Antarctic ice sheet's collapse accompanied by the MICI) would be more expensive for a lower discount rate assumption.

Figure 8-8 | GHG emission changes by discount rate assumption

With no tipping element considered **With the Antarctic ice sheet's collapse (accompanied by the MICI) considered**



Long-term technological development

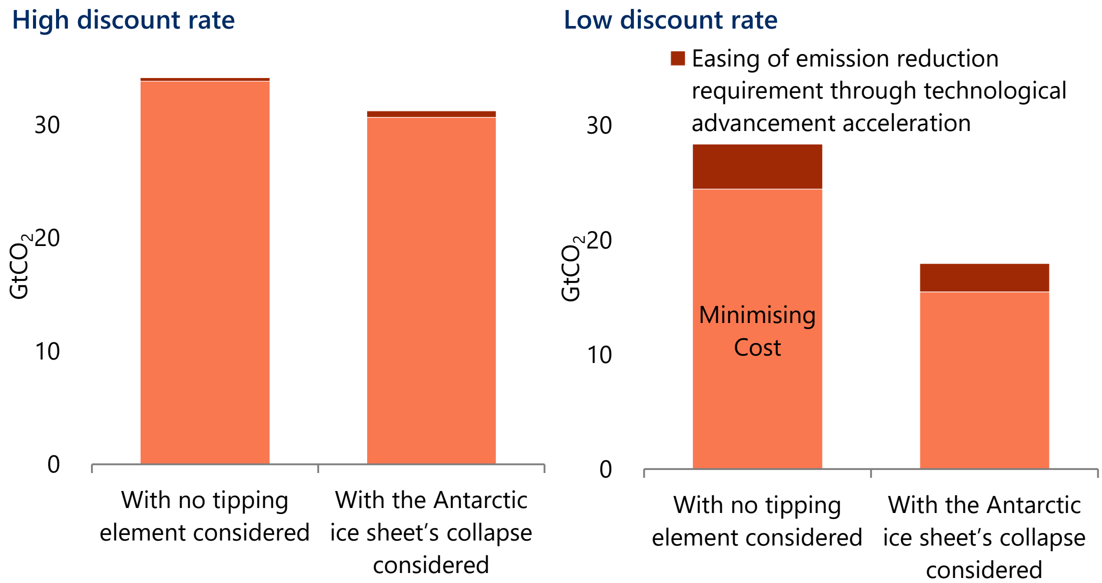
Potential technological development in the future may be significant for resolving the long-term climate change issue. To simply indicate the significance, we assumed that combining a higher mitigation cost cut rate of 0.5% per year with technological advancement acceleration would allow negative emission technologies to be introduced to cover 20% of energy-related CO_2 emissions in the Reference Case from 2100. Negative emission technologies capture atmospheric CO_2 for underground storage, including bioenergy with carbon capture and storage (BECCS) and direct air capture (DAC) of CO_2. Climeworks opened the world's first commercial DAC plant in 2017. Its cost has declined to \$600/tCO_2, according to the company. Keith et al.[33] estimated the cost for directly capturing atmospheric CO_2 at \$94-232/tCO_2 (depending on various conditions). These cost estimates are not necessarily low but close to carbon prices assumed in cost-benefit analyses over the long term, indicating that assuming the massive diffusion of DAC technologies is not necessarily unrealistic.

Figure 8-9 shows CO_2 emissions in 2050 for the cases in which the abovementioned technological advancement acceleration is considered for the original Minimising Cost Path

[33] D. W. Keith et al. (2018). A Process for Capturing CO_2 from the Atmosphere. *Joule*, 2(8), 1573-1594.

and the Minimising Cost Path including the Antarctic ice sheet's collapse for high and low discount rate assumptions. Under the high discount rate assumption, the technological advancement acceleration falls short of changing CO_2 emissions. Under the low discount rate assumption, however, the technological advancement acceleration eases an emission reduction requirement by several gigatons. This means that the acceleration of technological advancement could ease the emission reduction requirement by some extent even if tipping elements exert great impacts on climate change. It also indicates that the world is urgently required to scientifically clarify the MICI and other factors that would greatly affect the future of human kind.

Figure 8-9 | CO_2 emission changes through technological advancement acceleration [Minimising Cost Path, 2050]



It may be needless to note that various technological innovations will be required to dramatically reduce the anthropogenic load on the environment. Our model analysis suggests that the significance of technological development over the long term increases when potentially great environmental damages, including tipping elements, are considered and combined with intergenerational equity implied by low discount rate assumptions. Policies to support the steady development and commercialisation of technologies over the long term will be increasingly required to overcome the unprecedented challenge facing human kind with climate change.

[Annex] Formulating tipping elements

Antarctic ice sheet collapse

The Antarctic ice sheet collapse is formulated in the following way before being incorporated into the model.

Definitional equation of equilibrium

$$X^*(t) = \max(X_0(T(t) - 1.35), 0) \quad \text{(A1)}$$

Motion equation

$$\frac{\Delta X(t)}{\Delta t} = \frac{1}{t_0}\left(X^*(t) - X(t)\right) \quad \text{(A2)}$$

t stands for time (year), T for global warming since pre-industrial times, X for melted Antarctic ice sheet represented by the global average sea level rise, X^* for its potential volume, t_0 for the characteristic time indicating a melting speed, and X_0 for the characteristic scale reflecting the maximum sea level rise.

Coral reef disappearance

The potential coral reef disappearance rate X^* is assumed to increase in response to warming according to the following equation. The present state is assumed to shift to X^* over the timescale of 20 years.

$$X^*(t) = \frac{\mathrm{Arctan}\left(10.17(T(t) - 1.23)\right)}{\pi} - 0.5 \quad \text{(A3)}$$

Economic losses on coral reef disappearance are set in line with an assessment by the United Nations Environment Programme (UNEP). Here, annual economic losses are estimated at $375 billion, equivalent to nearly 0.5% of global GDP.

Annex

Table A8-1 | 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, 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 Turkey
	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, Ethiopia, Gabon, Ghana, Kenya, Mauritius, Mozambique, Namibia, Niger, Nigeria, Senegal, South Sudan, Sudan, Togo, United Republic of Tanzania, 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

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

Table A8-2 | Major energy and economic indicators

				Reference		Advanced Technologies		CAGR (%)		
								1990/	2018/2050	
		1990	2018	2030	2050	2030	2050	2018	Reference	Adv. Tech.
Total primary energy consumption (Mtoe)	**World**	**8 767**	**14 282**	**16 476**	**18 556**	**15 605**	**15 743**	**1.8**	**0.8**	**0.3**
	AEs*1	4 467	5 290	5 152	4 726	4 954	4 126	0.6	-0.4	-0.8
	EMDEs*2	4 097	8 570	10 797	13 076	10 160	10 991	2.7	1.3	0.8
	Asia	2 110	5 844	7 363	8 490	6 934	7 105	3.7	1.2	0.6
	Non-Asia	6 454	8 016	8 586	9 312	8 179	8 012	0.8	0.5	0.0
Oil consumption (Mtoe)	**World**	**3 233**	**4 497**	**4 946**	**5 608**	**4 654**	**4 454**	**1.2**	**0.7**	**0.0**
	AEs	1 826	1 870	1 698	1 423	1 598	1 121	0.1	-0.9	-1.6
	EMDEs	1 205	2 205	2 739	3 527	2 594	2 907	2.2	1.5	0.9
	Asia	618	1 464	1 808	2 269	1 720	1 863	3.1	1.4	0.8
	Non-Asia	2 413	2 612	2 629	2 680	2 471	2 165	0.3	0.1	-0.6
Natural gas consumption (Mtoe)	**World**	**1 662**	**3 262**	**4 059**	**5 132**	**3 723**	**3 802**	**2.4**	**1.4**	**0.5**
	AEs	827	1 452	1 565	1 513	1 419	982	2.0	0.1	-1.2
	EMDEs	835	1 809	2 481	3 530	2 282	2 683	2.8	2.1	1.2
	Asia	116	641	1 037	1 512	945	1 132	6.3	2.7	1.8
	Non-Asia	1 546	2 620	3 009	3 531	2 757	2 533	1.9	0.9	-0.1
Coal consumption (Mtoe)	**World**	**2 221**	**3 838**	**4 176**	**3 884**	**3 541**	**2 225**	**2.0**	**0.0**	**-1.7**
	AEs	1 088	877	732	516	587	231	-0.8	-1.6	-4.1
	EMDEs	1 133	2 962	3 444	3 368	2 953	1 994	3.5	0.4	-1.2
	Asia	788	2 821	3 290	3 133	2 817	1 857	4.7	0.3	-1.3
	Non-Asia	1 432	1 018	886	751	724	368	-1.2	-0.9	-3.1
Power generation (TWh)	**World**	**11 846**	**26 619**	**34 431**	**45 201**	**33 525**	**41 490**	**2.9**	**1.7**	**1.4**
	AEs	7 668	11 048	12 019	13 172	11 753	12 253	1.3	0.6	0.3
	EMDEs	4 178	15 571	22 412	32 028	21 772	29 237	4.8	2.3	2.0
	Asia	2 238	12 069	17 248	22 749	16 784	20 808	6.2	2.0	1.7
	Non-Asia	9 608	14 550	17 183	22 452	16 742	20 682	1.5	1.4	1.1
Energy-related carbon dioxide emissions (Mt)	**World**	**20 324**	**33 258**	**37 205**	**39 975**	**32 750**	**25 167**	**1.8**	**0.6**	**-0.9**
	AEs	10 827	11 407	10 520	8 717	9 250	5 392	0.2	-0.8	-2.3
	EMDEs	8 867	20 538	25 074	29 026	22 018	18 166	3.0	1.1	-0.4
	Asia	4 639	15 495	18 941	20 546	16 526	12 653	4.4	0.9	-0.6
	Non-Asia	15 055	16 449	16 653	17 198	14 742	10 905	0.3	0.1	-1.3
GDP ($2010 billion)	**World**	**37 880**	**82 365**	**113 405**	**186 235**	**113 405**	**186 235**	**2.8**	**2.6**	**2.6**
	AEs	28 740	51 436	61 870	83 921	61 870	83 921	2.1	1.5	1.5
	EMDEs	9 140	30 929	51 535	102 314	51 535	102 314	4.4	3.8	3.8
	Asia	7 629	25 670	42 014	78 948	42 014	78 948	4.4	3.6	3.6
	Non-Asia	30 251	56 695	71 392	107 287	71 392	107 287	2.3	2.0	2.0
Population (Million)	**World**	**5 278**	**7 591**	**8 497**	**9 682**	**8 497**	**9 682**	**1.3**	**0.8**	**0.8**
	AEs	998	1 186	1 222	1 238	1 222	1 238	0.6	0.1	0.1
	EMDEs	4 280	6 405	7 275	8 444	7 275	8 444	1.5	0.9	0.9
	Asia	2 939	4 118	4 454	4 687	4 454	4 687	1.2	0.4	0.4
	Non-Asia	2 339	3 473	4 043	4 995	4 043	4 995	1.4	1.1	1.1

*1 Advanced Economies *2 Emerging Market and Developing Economies

Table A8-3 | Population

(Million)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	5 278 (100)	6 111 (100)	7 591 (100)	8 497 (100)	9 146 (100)	9 682 (100)	1.3	0.9	0.7	0.6	0.8
Asia	2 939 (55.7)	3 420 (56.0)	4 118 (54.3)	4 454 (52.4)	4 623 (50.5)	4 687 (48.4)	1.2	0.7	0.4	0.1	0.4
China	1 135 (21.5)	1 263 (20.7)	1 393 (18.3)	1 429 (16.8)	1 414 (15.5)	1 368 (14.1)	0.7	0.2	-0.1	-0.3	-0.1
India	873 (16.5)	1 057 (17.3)	1 353 (17.8)	1 504 (17.7)	1 593 (17.4)	1 639 (16.9)	1.6	0.9	0.6	0.3	0.6
Japan	124 (2.3)	127 (2.1)	127 (1.7)	120 (1.4)	113 (1.2)	105 (1.1)	0.1	-0.4	-0.6	-0.7	-0.6
Korea	43 (0.8)	47 (0.8)	52 (0.7)	51 (0.6)	50 (0.5)	47 (0.5)	0.7	0.0	-0.3	-0.6	-0.3
Chinese Taipei	20 (0.4)	22 (0.4)	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)	507 (8.3)	631 (8.3)	699 (8.2)	738 (8.1)	761 (7.9)	1.4	0.9	0.5	0.3	0.6
Indonesia	181 (3.4)	212 (3.5)	268 (3.5)	299 (3.5)	319 (3.5)	331 (3.4)	1.4	0.9	0.6	0.4	0.7
Malaysia	18 (0.3)	23 (0.4)	32 (0.4)	36 (0.4)	39 (0.4)	41 (0.4)	2.0	1.1	0.7	0.5	0.8
Myanmar	41 (0.8)	47 (0.8)	54 (0.7)	58 (0.7)	61 (0.7)	62 (0.6)	0.9	0.7	0.5	0.2	0.5
Philippines	62 (1.2)	78 (1.3)	107 (1.4)	124 (1.5)	136 (1.5)	144 (1.5)	2.0	1.2	0.9	0.6	1.0
Singapore	3 (0.1)	4 (0.1)	6 (0.1)	6 (0.1)	6 (0.1)	6 (0.1)	2.2	0.7	0.3	-0.1	0.3
Thailand	57 (1.1)	63 (1.0)	69 (0.9)	70 (0.8)	69 (0.8)	66 (0.7)	0.7	0.1	-0.2	-0.5	-0.2
Viet Nam	68 (1.3)	80 (1.3)	96 (1.3)	104 (1.2)	108 (1.2)	110 (1.1)	1.2	0.7	0.3	0.2	0.4
North America	277 (5.3)	313 (5.1)	364 (4.8)	390 (4.6)	410 (4.5)	425 (4.4)	1.0	0.6	0.5	0.4	0.5
United States	250 (4.7)	282 (4.6)	327 (4.3)	350 (4.1)	366 (4.0)	379 (3.9)	1.0	0.6	0.5	0.3	0.5
Latin America	438 (8.3)	517 (8.5)	638 (8.4)	702 (8.3)	738 (8.1)	758 (7.8)	1.3	0.8	0.5	0.3	0.5
Advanced Europe	505 (9.6)	527 (8.6)	577 (7.6)	588 (6.9)	590 (6.5)	586 (6.0)	0.5	0.2	0.0	-0.1	0.0
European Union	420 (8.0)	429 (7.0)	447 (5.9)	447 (5.3)	445 (4.9)	437 (4.5)	0.2	0.0	-0.1	-0.2	-0.1
Other Europe/Eurasia	337 (6.4)	334 (5.5)	340 (4.5)	344 (4.0)	342 (3.7)	340 (3.5)	0.0	0.1	-0.1	-0.1	0.0
Africa	630 (11.9)	810 (13.3)	1 275 (16.8)	1 686 (19.8)	2 074 (22.7)	2 486 (25.7)	2.6	2.4	2.1	1.8	2.1
Middle East	132 (2.5)	168 (2.7)	248 (3.3)	299 (3.5)	333 (3.6)	362 (3.7)	2.3	1.6	1.1	0.8	1.2
Oceania	20 (0.4)	23 (0.4)	30 (0.4)	33 (0.4)	36 (0.4)	39 (0.4)	1.4	1.0	0.8	0.7	0.8
Advanced Economies	998 (18.9)	1 070 (17.5)	1 186 (15.6)	1 222 (14.4)	1 237 (13.5)	1 238 (12.8)	0.6	0.2	0.1	0.0	0.1
Emerging Market and Developing Economies	4 280 (81.1)	5 042 (82.5)	6 405 (84.4)	7 275 (85.6)	7 909 (86.5)	8 444 (87.2)	1.5	1.1	0.8	0.7	0.9

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

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

Table A8-4 | GDP

($2010 billion)

							CAGR (%)				
	1990	2000	2018	2030	2040	2050	1990/2018	2018/2030	2030/2040	2040/2050	2018/2050
World	37 880 (100)	49 899 (100)	82 365 (100)	113 405 (100)	148 705 (100)	186 235 (100)	2.8	2.7	2.7	2.3	2.6
Asia	7 629 (20.1)	11 103 (22.3)	25 670 (31.2)	42 014 (37.0)	59 911 (40.3)	78 948 (42.4)	4.4	4.2	3.6	2.8	3.6
China	828 (2.2)	2 232 (4.5)	10 797 (13.1)	20 026 (17.7)	29 506 (19.8)	37 968 (20.4)	9.6	5.3	4.0	2.6	4.0
India	506 (1.3)	870 (1.7)	2 831 (3.4)	6 146 (5.4)	10 304 (6.9)	15 988 (8.6)	6.3	6.7	5.3	4.5	5.6
Japan	4 704 (12.4)	5 349 (10.7)	6 190 (7.5)	6 693 (5.9)	7 234 (4.9)	7 744 (4.2)	1.0	0.7	0.8	0.7	0.7
Korea	363 (1.0)	710 (1.4)	1 382 (1.7)	1 859 (1.6)	2 275 (1.5)	2 626 (1.4)	4.9	2.5	2.0	1.4	2.0
Chinese Taipei	155 (0.4)	297 (0.6)	544 (0.7)	687 (0.6)	827 (0.6)	953 (0.5)	4.6	2.0	1.9	1.4	1.8
ASEAN	742 (2.0)	1 182 (2.4)	2 893 (3.5)	4 968 (4.4)	7 422 (5.0)	10 452 (5.6)	5.0	4.6	4.1	3.5	4.1
Indonesia	310 (0.8)	453 (0.9)	1 147 (1.4)	2 089 (1.8)	3 278 (2.2)	4 753 (2.6)	4.8	5.1	4.6	3.8	4.5
Malaysia	82 (0.2)	163 (0.3)	382 (0.5)	640 (0.6)	912 (0.6)	1 229 (0.7)	5.7	4.4	3.6	3.0	3.7
Myanmar	7 (0.0)	13 (0.0)	71 (0.1)	143 (0.1)	238 (0.2)	369 (0.2)	8.8	6.0	5.3	4.5	5.3
Philippines	95 (0.2)	125 (0.3)	322 (0.4)	613 (0.5)	907 (0.6)	1 290 (0.7)	4.5	5.5	4.0	3.6	4.4
Singapore	69 (0.2)	136 (0.3)	328 (0.4)	431 (0.4)	530 (0.4)	606 (0.3)	5.7	2.3	2.1	1.4	1.9
Thailand	142 (0.4)	218 (0.4)	442 (0.5)	656 (0.6)	907 (0.6)	1 191 (0.6)	4.1	3.3	3.3	2.8	3.1
Viet Nam	29 (0.1)	61 (0.1)	188 (0.2)	375 (0.3)	624 (0.4)	985 (0.5)	6.8	5.9	5.2	4.7	5.3
North America	9 935 (26.2)	13 827 (27.7)	19 761 (24.0)	24 631 (21.7)	30 511 (20.5)	36 654 (19.7)	2.5	1.9	2.2	1.9	1.9
United States	9 001 (23.8)	12 620 (25.3)	17 856 (21.7)	22 303 (19.7)	27 700 (18.6)	33 351 (17.9)	2.5	1.9	2.2	1.9	2.0
Latin America	2 834 (7.5)	3 819 (7.7)	5 833 (7.1)	8 064 (7.1)	11 058 (7.4)	14 073 (7.6)	2.6	2.7	3.2	2.4	2.8
Advanced Europe	12 689 (33.5)	15 969 (32.0)	21 276 (25.8)	25 015 (22.1)	28 501 (19.2)	31 766 (17.1)	1.9	1.4	1.3	1.1	1.3
European Union	10 234 (27.0)	12 698 (25.4)	16 365 (19.9)	19 171 (16.9)	21 845 (14.7)	24 303 (13.0)	1.7	1.3	1.3	1.1	1.2
Other Europe/Eurasia	2 146 (5.7)	1 478 (3.0)	2 857 (3.5)	3 740 (3.3)	4 733 (3.2)	5 916 (3.2)	1.0	2.3	2.4	2.3	2.3
Africa	895 (2.4)	1 171 (2.3)	2 474 (3.0)	4 015 (3.5)	6 457 (4.3)	9 559 (5.1)	3.7	4.1	4.9	4.0	4.3
Middle East	1 031 (2.7)	1 533 (3.1)	2 829 (3.4)	3 760 (3.3)	4 922 (3.3)	6 263 (3.4)	3.7	2.4	2.7	2.4	2.5
Oceania	722 (1.9)	998 (2.0)	1 665 (2.0)	2 166 (1.9)	2 612 (1.8)	3 057 (1.6)	3.0	2.2	1.9	1.6	1.9
Advanced Economies	28 740 (75.9)	37 440 (75.0)	51 436 (62.4)	61 870 (54.6)	72 952 (49.1)	83 921 (45.1)	2.1	1.6	1.7	1.4	1.5
Emerging Market and Developing Economies	9 140 (24.1)	12 459 (25.0)	30 929 (37.6)	51 535 (45.4)	75 753 (50.9)	102 314 (54.9)	4.4	4.3	3.9	3.1	3.8

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

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

Table A8-5 | GDP per capita

($2010 thousand/person)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	7.2	8.2	10.9	13.3	16.3	19.2	1.5	1.7	2.0	1.7	1.8
Asia	2.6	3.2	6.2	9.4	13.0	16.8	3.2	3.5	3.2	2.7	3.2
China	0.7	1.8	7.8	14.0	20.9	27.7	8.8	5.1	4.1	2.9	4.1
India	0.6	0.8	2.1	4.1	6.5	9.8	4.7	5.7	4.7	4.2	4.9
Japan	38.1	42.2	48.9	55.7	64.2	73.6	0.9	1.1	1.4	1.4	1.3
Korea	8.5	15.1	26.8	36.2	45.5	55.8	4.2	2.5	2.3	2.1	2.3
Chinese Taipei	7.6	13.3	23.1	28.7	35.2	42.7	4.0	1.8	2.1	1.9	1.9
ASEAN	1.7	2.3	4.6	7.1	10.1	13.7	3.6	3.7	3.5	3.2	3.5
Indonesia	1.7	2.1	4.3	7.0	10.3	14.3	3.3	4.1	3.9	3.4	3.8
Malaysia	4.5	7.0	12.1	17.7	23.5	30.3	3.6	3.2	2.9	2.6	2.9
Myanmar	0.2	0.3	1.3	2.4	3.9	5.9	7.8	5.3	4.8	4.3	4.8
Philippines	1.5	1.6	3.0	5.0	6.7	8.9	2.5	4.2	3.0	2.9	3.4
Singapore	22.6	33.9	58.2	70.0	83.6	96.2	3.4	1.5	1.8	1.4	1.6
Thailand	2.5	3.5	6.4	9.3	13.1	18.1	3.4	3.2	3.5	3.2	3.3
Viet Nam	0.4	0.8	2.0	3.6	5.8	9.0	5.5	5.2	4.9	4.5	4.9
North America	35.8	44.2	54.3	63.1	74.5	86.3	1.5	1.3	1.7	1.5	1.5
United States	36.1	44.7	54.7	63.8	75.6	87.9	1.5	1.3	1.7	1.5	1.5
Latin America	6.5	7.4	9.1	11.5	15.0	18.6	1.2	1.9	2.7	2.2	2.2
Advanced Europe	25.1	30.3	36.8	42.5	48.3	54.2	1.4	1.2	1.3	1.2	1.2
European Union	24.3	29.6	36.6	42.9	49.1	55.6	1.5	1.3	1.4	1.2	1.3
Other Europe/Eurasia	6.4	4.4	8.4	10.9	13.8	17.4	1.0	2.2	2.4	2.3	2.3
Africa	1.4	1.4	1.9	2.4	3.1	3.8	1.1	1.7	2.7	2.1	2.2
Middle East	7.8	9.2	11.4	12.6	14.8	17.3	1.4	0.8	1.6	1.6	1.3
Oceania	35.4	43.4	55.8	64.7	72.3	79.3	1.6	1.2	1.1	0.9	1.1
Advanced Economies	28.8	35.0	43.4	50.6	59.0	67.8	1.5	1.3	1.5	1.4	1.4
Emerging Market and Developing Economies	2.1	2.5	4.8	7.1	9.6	12.1	3.0	3.2	3.1	2.4	2.9

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

Table A8-6 | International energy prices

Real prices			Reference			Advanced Technologies		
		2019	2030	2040	2050	2030	2040	2050
Oil	$2019/bbl	64	87	102	107	71	66	56
Natural gas								
Japan	$2019/MBtu	9.9	8.2	8.2	8.0	7.7	7.0	5.8
Europe (UK)	$2019/MBtu	4.8	7.8	7.9	7.9	7.4	6.7	5.6
United States	$2019/MBtu	2.5	3.4	3.9	3.9	3.0	3.6	3.6
Steam coal	$2019/t	109	100	104	107	83	80	74

Nominal prices			Reference			Advanced Technologies		
		2019	2030	2040	2050	2030	2040	2050
Oil	$/bbl	64	108	155	198	89	100	104
Natural gas								
Japan	$/MBtu	9.9	10.2	12.4	14.8	9.5	10.6	10.6
Europe (UK)	$/MBtu	4.8	9.6	11.9	14.5	9.2	10.2	10.4
United States	$/MBtu	2.5	4.2	5.9	7.2	3.8	5.4	6.6
Steam coal	$/t	109	124	158	198	103	121	138

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

Table A8-7 | Primary energy consumption [Reference Scenario]

(Mtoe)

							CAGR (%)				
	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	8 767 (100)	10 034 (100)	14 282 (100)	16 476 (100)	17 823 (100)	18 556 (100)	1.8	1.2	0.8	0.4	0.8
Asia	2 110 (24.1)	2 887 (28.8)	5 844 (40.9)	7 363 (44.7)	8 101 (45.5)	8 490 (45.8)	3.7	1.9	1.0	0.5	1.2
China	874 (10.0)	1 130 (11.3)	3 196 (22.4)	3 719 (22.6)	3 756 (21.1)	3 532 (19.0)	4.7	1.3	0.1	-0.6	0.3
India	306 (3.5)	441 (4.4)	919 (6.4)	1 542 (9.4)	2 003 (11.2)	2 425 (13.1)	4.0	4.4	2.7	1.9	3.1
Japan	439 (5.0)	518 (5.2)	426 (3.0)	406 (2.5)	377 (2.1)	347 (1.9)	-0.1	-0.4	-0.7	-0.8	-0.6
Korea	93 (1.1)	188 (1.9)	282 (2.0)	299 (1.8)	290 (1.6)	268 (1.4)	4.0	0.5	-0.3	-0.8	-0.2
Chinese Taipei	48 (0.5)	85 (0.8)	110 (0.8)	111 (0.7)	109 (0.6)	102 (0.6)	3.0	0.0	-0.2	-0.6	-0.2
ASEAN	233 (2.7)	379 (3.8)	669 (4.7)	969 (5.9)	1 192 (6.7)	1 399 (7.5)	3.8	3.1	2.1	1.6	2.3
Indonesia	99 (1.1)	156 (1.6)	231 (1.6)	346 (2.1)	447 (2.5)	541 (2.9)	3.1	3.4	2.6	1.9	2.7
Malaysia	21 (0.2)	48 (0.5)	93 (0.7)	131 (0.8)	148 (0.8)	158 (0.8)	5.4	2.9	1.2	0.6	1.6
Myanmar	11 (0.1)	13 (0.1)	24 (0.2)	39 (0.2)	51 (0.3)	62 (0.3)	2.9	4.1	2.8	2.0	3.0
Philippines	29 (0.3)	40 (0.4)	60 (0.4)	94 (0.6)	119 (0.7)	146 (0.8)	2.7	3.8	2.4	2.0	2.8
Singapore	12 (0.1)	19 (0.2)	38 (0.3)	43 (0.3)	46 (0.3)	47 (0.3)	4.3	1.1	0.6	0.3	0.7
Thailand	42 (0.5)	72 (0.7)	136 (1.0)	172 (1.0)	193 (1.1)	209 (1.1)	4.3	2.0	1.1	0.8	1.4
Viet Nam	18 (0.2)	29 (0.3)	83 (0.6)	140 (0.8)	184 (1.0)	233 (1.3)	5.7	4.4	2.8	2.4	3.3
North America	2 126 (24.3)	2 527 (25.2)	2 528 (17.7)	2 472 (15.0)	2 423 (13.6)	2 333 (12.6)	0.6	-0.2	-0.2	-0.4	-0.3
United States	1 915 (21.8)	2 274 (22.7)	2 231 (15.6)	2 179 (13.2)	2 137 (12.0)	2 057 (11.1)	0.5	-0.2	-0.2	-0.4	-0.3
Latin America	463 (5.3)	607 (6.0)	819 (5.7)	1 003 (6.1)	1 175 (6.6)	1 271 (6.9)	2.1	1.7	1.6	0.8	1.4
Advanced Europe	1 643 (18.7)	1 759 (17.5)	1 742 (12.2)	1 653 (10.0)	1 567 (8.8)	1 467 (7.9)	0.2	-0.4	-0.5	-0.7	-0.5
European Union	1 439 (16.4)	1 471 (14.7)	1 428 (10.0)	1 364 (8.3)	1 288 (7.2)	1 202 (6.5)	0.0	-0.4	-0.6	-0.7	-0.5
Other Europe/Eurasia	1 514 (17.3)	993 (9.9)	1 159 (8.1)	1 207 (7.3)	1 252 (7.0)	1 290 (7.0)	-0.9	0.3	0.4	0.3	0.3
Africa	386 (4.4)	491 (4.9)	837 (5.9)	1 080 (6.6)	1 331 (7.5)	1 528 (8.2)	2.8	2.2	2.1	1.4	1.9
Middle East	222 (2.5)	371 (3.7)	782 (5.5)	1 019 (6.2)	1 178 (6.6)	1 276 (6.9)	4.6	2.2	1.5	0.8	1.5
Oceania	99 (1.1)	125 (1.2)	149 (1.0)	152 (0.9)	152 (0.9)	148 (0.8)	1.5	0.2	0.0	-0.3	0.0
Advanced Economies	4 467 (51.0)	5 235 (52.2)	5 290 (37.0)	5 152 (31.3)	4 981 (27.9)	4 726 (25.5)	0.6	-0.2	-0.3	-0.5	-0.4
Emerging Market and Developing Economies	4 097 (46.7)	4 526 (45.1)	8 570 (60.0)	10 797 (65.5)	12 198 (68.4)	13 076 (70.5)	2.7	1.9	1.2	0.7	1.3

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

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

Table A8-8 | Primary energy consumption, coal [Reference Scenario]

(Mtoe)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/2018	2018/2030	2030/2040	2040/2050	2018/2050
World	2 221 (100)	2 317 (100)	3 838 (100)	4 176 (100)	4 174 (100)	3 884 (100)	2.0	0.7	0.0	-0.7	0.0
Asia	788 (35.5)	1 037 (44.7)	2 821 (73.5)	3 290 (78.8)	3 332 (79.8)	3 133 (80.7)	4.7	1.3	0.1	-0.6	0.3
China	531 (23.9)	665 (28.7)	1 980 (51.6)	2 096 (50.2)	1 902 (45.6)	1 578 (40.6)	4.8	0.5	-1.0	-1.9	-0.7
India	93 (4.2)	146 (6.3)	414 (10.8)	697 (16.7)	883 (21.2)	990 (25.5)	5.5	4.4	2.4	1.2	2.8
Japan	77 (3.5)	97 (4.2)	114 (3.0)	98 (2.4)	90 (2.2)	76 (2.0)	1.4	-1.3	-0.9	-1.6	-1.3
Korea	25 (1.1)	42 (1.8)	81 (2.1)	82 (2.0)	76 (1.8)	64 (1.7)	4.2	0.1	-0.7	-1.7	-0.7
Chinese Taipei	11 (0.5)	30 (1.3)	40 (1.0)	41 (1.0)	37 (0.9)	32 (0.8)	4.5	0.3	-0.9	-1.4	-0.6
ASEAN	13 (0.6)	32 (1.4)	150 (3.9)	226 (5.4)	284 (6.8)	324 (8.3)	9.3	3.5	2.3	1.3	2.4
Indonesia	4 (0.2)	12 (0.5)	55 (1.4)	90 (2.2)	121 (2.9)	137 (3.5)	10.3	4.2	2.9	1.3	2.9
Malaysia	1 (0.1)	2 (0.1)	23 (0.6)	28 (0.7)	30 (0.7)	28 (0.7)	10.6	1.8	0.5	-0.6	0.6
Myanmar	0 (0.0)	0 (0.0)	1 (0.0)	3 (0.1)	5 (0.1)	8 (0.2)	9.6	10.9	5.7	4.5	7.2
Philippines	2 (0.1)	5 (0.2)	18 (0.5)	24 (0.6)	30 (0.7)	34 (0.9)	9.2	2.6	2.0	1.4	2.0
Singapore	0 (0.0)	- (-)	0 (0.0)	1 (0.0)	0 (0.0)	0 (0.0)	11.7	0.4	-0.1	-1.1	-0.2
Thailand	4 (0.2)	8 (0.3)	16 (0.4)	17 (0.4)	17 (0.4)	16 (0.4)	5.2	0.7	0.0	-1.0	0.0
Viet Nam	2 (0.1)	4 (0.2)	37 (1.0)	62 (1.5)	80 (1.9)	100 (2.6)	10.5	4.5	2.6	2.2	3.2
North America	484 (21.8)	566 (24.4)	336 (8.8)	250 (6.0)	208 (5.0)	149 (3.8)	-1.3	-2.4	-1.8	-3.3	-2.5
United States	460 (20.7)	534 (23.0)	321 (8.4)	245 (5.9)	204 (4.9)	145 (3.7)	-1.3	-2.2	-1.8	-3.3	-2.4
Latin America	21 (1.0)	27 (1.2)	44 (1.1)	46 (1.1)	54 (1.3)	55 (1.4)	2.6	0.5	1.5	0.3	0.8
Advanced Europe	448 (20.2)	331 (14.3)	255 (6.7)	218 (5.2)	191 (4.6)	162 (4.2)	-2.0	-1.3	-1.3	-1.7	-1.4
European Union	391 (17.6)	285 (12.3)	216 (5.6)	188 (4.5)	165 (4.0)	140 (3.6)	-2.1	-1.2	-1.3	-1.6	-1.4
Other Europe/Eurasia	365 (16.4)	209 (9.0)	217 (5.6)	201 (4.8)	210 (5.0)	208 (5.4)	-1.9	-0.6	0.4	-0.1	-0.1
Africa	74 (3.3)	90 (3.9)	114 (3.0)	123 (3.0)	138 (3.3)	142 (3.7)	1.5	0.7	1.1	0.3	0.7
Middle East	3 (0.1)	8 (0.3)	8 (0.2)	11 (0.3)	10 (0.2)	9 (0.2)	3.8	1.9	-0.6	-1.6	0.0
Oceania	36 (1.6)	49 (2.1)	44 (1.1)	36 (0.9)	32 (0.8)	26 (0.7)	0.7	-1.7	-1.4	-1.8	-1.6
Advanced Economies	1 088 (49.0)	1 119 (48.3)	877 (22.8)	732 (17.5)	641 (15.4)	516 (13.3)	-0.8	-1.5	-1.3	-2.1	-1.6
Emerging Market and Developing Economies	1 133 (51.0)	1 198 (51.7)	2 962 (77.2)	3 444 (82.5)	3 533 (84.6)	3 368 (86.7)	3.5	1.3	0.3	-0.5	0.4

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

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

Table A8-9 | Primary energy consumption, oil [Reference Scenario]

(Mtoe)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	3 233 (100)	3 669 (100)	4 497 (100)	4 946 (100)	5 328 (100)	5 608 (100)	1.2	0.8	0.7	0.5	0.7
Asia	618 (19.1)	916 (25.0)	1 464 (32.5)	1 808 (36.5)	2 048 (38.4)	2 269 (40.5)	3.1	1.8	1.3	1.0	1.4
China	119 (3.7)	221 (6.0)	610 (13.6)	713 (14.4)	731 (13.7)	679 (12.1)	6.0	1.3	0.3	-0.7	0.3
India	61 (1.9)	112 (3.1)	235 (5.2)	401 (8.1)	569 (10.7)	790 (14.1)	4.9	4.6	3.5	3.3	3.9
Japan	250 (7.7)	255 (6.9)	166 (3.7)	137 (2.8)	118 (2.2)	104 (1.9)	-1.5	-1.6	-1.5	-1.2	-1.5
Korea	50 (1.5)	99 (2.7)	110 (2.5)	111 (2.2)	106 (2.0)	99 (1.8)	2.9	0.1	-0.4	-0.8	-0.3
Chinese Taipei	26 (0.8)	38 (1.0)	43 (1.0)	42 (0.9)	40 (0.8)	37 (0.7)	1.9	-0.2	-0.5	-0.9	-0.5
ASEAN	89 (2.7)	153 (4.2)	239 (5.3)	319 (6.5)	381 (7.2)	442 (7.9)	3.6	2.4	1.8	1.5	1.9
Indonesia	33 (1.0)	58 (1.6)	77 (1.7)	105 (2.1)	129 (2.4)	151 (2.7)	3.0	2.6	2.1	1.6	2.1
Malaysia	11 (0.4)	19 (0.5)	29 (0.6)	35 (0.7)	35 (0.7)	34 (0.6)	3.4	1.6	0.1	-0.3	0.5
Myanmar	1 (0.0)	2 (0.1)	7 (0.2)	13 (0.3)	19 (0.4)	24 (0.4)	8.3	5.5	3.7	2.6	4.0
Philippines	11 (0.3)	16 (0.4)	20 (0.4)	35 (0.7)	49 (0.9)	65 (1.2)	2.2	4.7	3.4	3.0	3.8
Singapore	11 (0.4)	17 (0.5)	28 (0.6)	31 (0.6)	33 (0.6)	34 (0.6)	3.2	0.9	0.7	0.4	0.7
Thailand	18 (0.6)	32 (0.9)	55 (1.2)	64 (1.3)	69 (1.3)	72 (1.3)	4.1	1.2	0.8	0.4	0.8
Viet Nam	3 (0.1)	8 (0.2)	22 (0.5)	36 (0.7)	47 (0.9)	60 (1.1)	7.9	3.9	2.7	2.6	3.1
North America	833 (25.8)	958 (26.1)	905 (20.1)	834 (16.9)	777 (14.6)	719 (12.8)	0.3	-0.7	-0.7	-0.8	-0.7
United States	757 (23.4)	871 (23.7)	802 (17.8)	744 (15.0)	694 (13.0)	646 (11.5)	0.2	-0.6	-0.7	-0.7	-0.7
Latin America	237 (7.3)	310 (8.4)	336 (7.5)	376 (7.6)	409 (7.7)	411 (7.3)	1.3	0.9	0.8	0.0	0.6
Advanced Europe	617 (19.1)	654 (17.8)	563 (12.5)	492 (9.9)	435 (8.2)	386 (6.9)	-0.3	-1.1	-1.2	-1.2	-1.2
European Union	531 (16.4)	550 (15.0)	462 (10.3)	405 (8.2)	357 (6.7)	315 (5.6)	-0.5	-1.1	-1.3	-1.3	-1.2
Other Europe/Eurasia	459 (14.2)	200 (5.4)	238 (5.3)	233 (4.7)	230 (4.3)	228 (4.1)	-2.3	-0.2	-0.2	-0.1	-0.1
Africa	85 (2.6)	101 (2.8)	190 (4.2)	253 (5.1)	359 (6.7)	465 (8.3)	2.9	2.4	3.6	2.6	2.8
Middle East	146 (4.5)	216 (5.9)	330 (7.3)	394 (8.0)	431 (8.1)	431 (7.7)	3.0	1.5	0.9	0.0	0.8
Oceania	35 (1.1)	40 (1.1)	50 (1.1)	47 (0.9)	44 (0.8)	40 (0.7)	1.3	-0.6	-0.6	-0.8	-0.7
Advanced Economies	1 826 (56.5)	2 068 (56.4)	1 870 (41.6)	1 698 (34.3)	1 557 (29.2)	1 423 (25.4)	0.1	-0.8	-0.9	-0.9	-0.9
Emerging Market and Developing Economies	1 205 (37.3)	1 327 (36.2)	2 205 (49.0)	2 739 (55.4)	3 176 (59.6)	3 527 (62.9)	2.2	1.8	1.5	1.1	1.5

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

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

Table A8-10 | Primary energy consumption, natural gas [Reference Scenario]

(Mtoe)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	1 662 (100)	2 071 (100)	3 262 (100)	4 059 (100)	4 690 (100)	5 132 (100)	2.4	1.8	1.5	0.9	1.4
Asia	116 (7.0)	233 (11.2)	641 (19.7)	1 037 (25.5)	1 316 (28.1)	1 512 (29.5)	6.3	4.1	2.4	1.4	2.7
China	13 (0.8)	21 (1.0)	230 (7.1)	417 (10.3)	525 (11.2)	582 (11.3)	10.9	5.1	2.3	1.0	2.9
India	11 (0.6)	23 (1.1)	52 (1.6)	135 (3.3)	216 (4.6)	283 (5.5)	5.9	8.2	4.8	2.7	5.4
Japan	44 (2.7)	66 (3.2)	97 (3.0)	89 (2.2)	85 (1.8)	74 (1.4)	2.9	-0.7	-0.4	-1.4	-0.9
Korea	3 (0.2)	17 (0.8)	48 (1.5)	62 (1.5)	69 (1.5)	73 (1.4)	10.8	2.2	1.1	0.5	1.3
Chinese Taipei	1 (0.1)	6 (0.3)	18 (0.6)	23 (0.6)	25 (0.5)	26 (0.5)	9.6	2.1	0.9	0.4	1.2
ASEAN	30 (1.8)	74 (3.6)	141 (4.3)	229 (5.6)	287 (6.1)	341 (6.6)	5.7	4.1	2.3	1.7	2.8
Indonesia	16 (1.0)	27 (1.3)	39 (1.2)	70 (1.7)	98 (2.1)	126 (2.5)	3.3	5.0	3.4	2.6	3.7
Malaysia	7 (0.4)	25 (1.2)	39 (1.2)	64 (1.6)	74 (1.6)	83 (1.6)	6.4	4.2	1.6	1.1	2.4
Myanmar	1 (0.0)	1 (0.1)	4 (0.1)	12 (0.3)	18 (0.4)	23 (0.5)	6.2	9.4	3.9	2.8	5.6
Philippines	- (-)	0 (0.0)	4 (0.1)	6 (0.2)	9 (0.2)	12 (0.2)	-	4.7	3.7	2.7	3.8
Singapore	- (-)	1 (0.1)	9 (0.3)	10 (0.3)	11 (0.2)	10 (0.2)	-	1.1	0.4	-0.4	0.4
Thailand	5 (0.3)	17 (0.8)	36 (1.1)	44 (1.1)	47 (1.0)	47 (0.9)	7.3	1.8	0.7	-0.1	0.9
Viet Nam	0 (0.0)	1 (0.1)	8 (0.2)	20 (0.5)	28 (0.6)	37 (0.7)	33.0	8.0	3.2	3.0	4.9
North America	493 (29.7)	622 (30.0)	815 (25.0)	896 (22.1)	907 (19.3)	868 (16.9)	1.8	0.8	0.1	-0.4	0.2
United States	438 (26.4)	548 (26.4)	709 (21.7)	769 (18.9)	773 (16.5)	732 (14.3)	1.7	0.7	0.1	-0.5	0.1
Latin America	71 (4.3)	118 (5.7)	203 (6.2)	268 (6.6)	364 (7.8)	437 (8.5)	3.8	2.3	3.1	1.9	2.4
Advanced Europe	267 (16.1)	396 (19.1)	426 (13.1)	438 (10.8)	433 (9.2)	412 (8.0)	1.7	0.2	-0.1	-0.5	-0.1
European Union	250 (15.0)	309 (14.9)	324 (9.9)	341 (8.4)	347 (7.4)	333 (6.5)	0.9	0.4	0.2	-0.4	0.1
Other Europe/Eurasia	596 (35.8)	486 (23.4)	569 (17.5)	576 (14.2)	598 (12.7)	606 (11.8)	-0.2	0.1	0.4	0.1	0.2
Africa	30 (1.8)	47 (2.3)	133 (4.1)	207 (5.1)	296 (6.3)	391 (7.6)	5.5	3.7	3.6	2.8	3.4
Middle East	72 (4.3)	145 (7.0)	437 (13.4)	582 (14.3)	687 (14.6)	771 (15.0)	6.7	2.4	1.7	1.2	1.8
Oceania	19 (1.1)	24 (1.2)	36 (1.1)	43 (1.1)	47 (1.0)	47 (0.9)	2.4	1.5	0.8	0.0	0.8
Advanced Economies	827 (49.8)	1 134 (54.8)	1 452 (44.5)	1 565 (38.6)	1 581 (33.7)	1 513 (29.5)	2.0	0.6	0.1	-0.4	0.1
Emerging Market and Developing Economies	835 (50.2)	937 (45.2)	1 809 (55.5)	2 481 (61.1)	3 067 (65.4)	3 530 (68.8)	2.8	2.7	2.1	1.4	2.1

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

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

Table A8-11 | Final energy consumption [Reference Scenario]

(Mtoe)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	6 267 (100)	7 032 (100)	9 938 (100)	11 375 (100)	12 251 (100)	12 872 (100)	1.7	1.1	0.7	0.5	0.8
Asia	1 558 (24.9)	1 999 (28.4)	3 847 (38.7)	4 748 (41.7)	5 232 (42.7)	5 593 (43.5)	3.3	1.8	1.0	0.7	1.2
China	658 (10.5)	781 (11.1)	2 058 (20.7)	2 333 (20.5)	2 353 (19.2)	2 259 (17.6)	4.2	1.1	0.1	-0.4	0.3
India	243 (3.9)	315 (4.5)	607 (6.1)	1 002 (8.8)	1 305 (10.7)	1 621 (12.6)	3.3	4.3	2.7	2.2	3.1
Japan	292 (4.7)	337 (4.8)	283 (2.8)	263 (2.3)	244 (2.0)	224 (1.7)	-0.1	-0.6	-0.8	-0.8	-0.7
Korea	65 (1.0)	127 (1.8)	182 (1.8)	201 (1.8)	200 (1.6)	189 (1.5)	3.8	0.8	-0.1	-0.5	0.1
Chinese Taipei	29 (0.5)	49 (0.7)	72 (0.7)	73 (0.6)	73 (0.6)	70 (0.5)	3.2	0.2	0.0	-0.4	-0.1
ASEAN	172 (2.7)	269 (3.8)	454 (4.6)	635 (5.6)	778 (6.3)	917 (7.1)	3.5	2.8	2.0	1.7	2.2
Indonesia	79 (1.3)	120 (1.7)	156 (1.6)	214 (1.9)	271 (2.2)	326 (2.5)	2.5	2.7	2.4	1.9	2.3
Malaysia	13 (0.2)	29 (0.4)	63 (0.6)	88 (0.8)	99 (0.8)	108 (0.8)	5.7	2.9	1.2	0.9	1.7
Myanmar	9 (0.2)	11 (0.2)	20 (0.2)	29 (0.3)	36 (0.3)	43 (0.3)	2.8	3.0	2.4	1.7	2.4
Philippines	20 (0.3)	24 (0.3)	34 (0.3)	55 (0.5)	74 (0.6)	96 (0.7)	2.0	4.1	3.0	2.6	3.3
Singapore	5 (0.1)	8 (0.1)	20 (0.2)	23 (0.2)	25 (0.2)	25 (0.2)	5.1	1.2	0.7	0.3	0.8
Thailand	29 (0.5)	51 (0.7)	100 (1.0)	121 (1.1)	136 (1.1)	147 (1.1)	4.5	1.6	1.2	0.8	1.2
Viet Nam	16 (0.3)	25 (0.4)	60 (0.6)	103 (0.9)	135 (1.1)	170 (1.3)	4.8	4.6	2.7	2.4	3.3
North America	1 452 (23.2)	1 734 (24.7)	1 800 (18.1)	1 780 (15.7)	1 742 (14.2)	1 689 (13.1)	0.8	-0.1	-0.2	-0.3	-0.2
United States	1 294 (20.6)	1 546 (22.0)	1 594 (16.0)	1 575 (13.9)	1 543 (12.6)	1 497 (11.6)	0.7	-0.1	-0.2	-0.3	-0.2
Latin America	344 (5.5)	442 (6.3)	606 (6.1)	728 (6.4)	832 (6.8)	897 (7.0)	2.0	1.5	1.3	0.8	1.2
Advanced Europe	1 142 (18.2)	1 235 (17.6)	1 253 (12.6)	1 210 (10.6)	1 141 (9.3)	1 073 (8.3)	0.3	-0.3	-0.6	-0.6	-0.5
European Union	995 (15.9)	1 028 (14.6)	1 023 (10.3)	994 (8.7)	937 (7.6)	879 (6.8)	0.1	-0.2	-0.6	-0.6	-0.5
Other Europe/Eurasia	1 058 (16.9)	648 (9.2)	765 (7.7)	790 (6.9)	795 (6.5)	804 (6.2)	-1.1	0.3	0.1	0.1	0.2
Africa	287 (4.6)	365 (5.2)	612 (6.2)	801 (7.0)	969 (7.9)	1 096 (8.5)	2.7	2.3	1.9	1.2	1.8
Middle East	157 (2.5)	253 (3.6)	535 (5.4)	688 (6.0)	791 (6.5)	865 (6.7)	4.5	2.1	1.4	0.9	1.5
Oceania	66 (1.1)	83 (1.2)	98 (1.0)	104 (0.9)	104 (0.9)	103 (0.8)	1.4	0.5	0.1	-0.2	0.2
Advanced Economies	3 058 (48.8)	3 582 (50.9)	3 717 (37.4)	3 664 (32.2)	3 538 (28.9)	3 382 (26.3)	0.7	-0.1	-0.4	-0.4	-0.3
Emerging Market and Developing Economies	3 007 (48.0)	3 176 (45.2)	5 799 (58.4)	7 185 (63.2)	8 068 (65.9)	8 736 (67.9)	2.4	1.8	1.2	0.8	1.3

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

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

Table A8-12 | Final energy consumption, industry [Reference Scenario]

(Mtoe)

							CAGR (%)				
	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	1 803 (100)	1 871 (100)	2 839 (100)	3 264 (100)	3 463 (100)	3 518 (100)	1.6	1.2	0.6	0.2	0.7
Asia	515 (28.6)	655 (35.0)	1 556 (54.8)	1 828 (56.0)	1 911 (55.2)	1 921 (54.6)	4.0	1.4	0.4	0.0	0.7
China	234 (13.0)	302 (16.1)	996 (35.1)	988 (30.3)	900 (26.0)	803 (22.8)	5.3	-0.1	-0.9	-1.1	-0.7
India	67 (3.7)	85 (4.6)	206 (7.3)	391 (12.0)	499 (14.4)	559 (15.9)	4.1	5.5	2.5	1.1	3.2
Japan	108 (6.0)	104 (5.5)	82 (2.9)	77 (2.3)	71 (2.0)	64 (1.8)	-1.0	-0.6	-0.8	-1.1	-0.8
Korea	19 (1.1)	38 (2.1)	49 (1.7)	56 (1.7)	56 (1.6)	52 (1.5)	3.4	1.1	-0.1	-0.8	0.2
Chinese Taipei	12 (0.7)	19 (1.0)	24 (0.8)	25 (0.8)	24 (0.7)	23 (0.7)	2.4	0.3	0.0	-0.5	-0.1
ASEAN	42 (2.3)	75 (4.0)	151 (5.3)	228 (7.0)	281 (8.1)	327 (9.3)	4.7	3.5	2.1	1.5	2.4
Indonesia	17 (1.0)	30 (1.6)	50 (1.8)	74 (2.3)	93 (2.7)	109 (3.1)	3.8	3.3	2.3	1.6	2.5
Malaysia	6 (0.3)	12 (0.6)	20 (0.7)	25 (0.8)	29 (0.8)	32 (0.9)	4.6	2.2	1.4	0.9	1.5
Myanmar	0 (0.0)	1 (0.1)	4 (0.1)	7 (0.2)	10 (0.3)	13 (0.4)	8.3	5.3	4.3	2.6	4.1
Philippines	5 (0.3)	5 (0.3)	8 (0.3)	11 (0.3)	14 (0.4)	17 (0.5)	1.8	3.4	2.1	1.8	2.5
Singapore	1 (0.0)	2 (0.1)	7 (0.2)	8 (0.3)	9 (0.3)	9 (0.2)	9.2	1.4	0.6	-0.1	0.7
Thailand	9 (0.5)	17 (0.9)	30 (1.1)	39 (1.2)	46 (1.3)	49 (1.4)	4.6	2.2	1.4	0.7	1.5
Viet Nam	5 (0.3)	8 (0.4)	33 (1.1)	62 (1.9)	80 (2.3)	97 (2.8)	7.3	5.5	2.5	2.0	3.5
North America	331 (18.4)	388 (20.7)	322 (11.4)	329 (10.1)	330 (9.5)	323 (9.2)	-0.1	0.2	0.0	-0.2	0.0
United States	284 (15.7)	332 (17.8)	277 (9.7)	282 (8.7)	283 (8.2)	278 (7.9)	-0.1	0.2	0.0	-0.2	0.0
Latin America	113 (6.3)	143 (7.6)	179 (6.3)	223 (6.8)	265 (7.6)	285 (8.1)	1.6	1.8	1.8	0.7	1.5
Advanced Europe	330 (18.3)	325 (17.4)	299 (10.5)	301 (9.2)	296 (8.5)	282 (8.0)	-0.4	0.0	-0.2	-0.5	-0.2
European Union	313 (17.4)	274 (14.7)	244 (8.6)	247 (7.6)	244 (7.0)	233 (6.6)	-0.9	0.1	-0.1	-0.5	-0.1
Other Europe/Eurasia	391 (21.7)	205 (10.9)	202 (7.1)	216 (6.6)	227 (6.6)	231 (6.6)	-2.3	0.5	0.5	0.1	0.4
Africa	53 (2.9)	57 (3.0)	91 (3.2)	129 (4.0)	170 (4.9)	206 (5.9)	1.9	3.0	2.8	1.9	2.6
Middle East	47 (2.6)	71 (3.8)	163 (5.7)	209 (6.4)	234 (6.8)	241 (6.9)	4.5	2.1	1.1	0.3	1.2
Oceania	23 (1.3)	28 (1.5)	27 (0.9)	30 (0.9)	30 (0.9)	29 (0.8)	0.5	0.9	0.2	-0.3	0.3
Advanced Economies	826 (45.8)	906 (48.4)	813 (28.6)	827 (25.3)	818 (23.6)	784 (22.3)	-0.1	0.1	-0.1	-0.4	-0.1
Emerging Market and Developing Economies	977 (54.2)	965 (51.6)	2 027 (71.4)	2 437 (74.7)	2 645 (76.4)	2 734 (77.7)	2.6	1.5	0.8	0.3	0.9

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

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

Table A8-13 | Final energy consumption, transport [Reference Scenario]

(Mtoe)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/2018	2018/2030	2030/2040	2040/2050	2018/2050
World	1 575 (100)	1 963 (100)	2 891 (100)	3 222 (100)	3 556 (100)	3 898 (100)	2.2	0.9	1.0	0.9	0.9
Asia	187 (11.9)	321 (16.4)	717 (24.8)	935 (29.0)	1 121 (31.5)	1 322 (33.9)	4.9	2.2	1.8	1.7	1.9
China	30 (1.9)	84 (4.3)	325 (11.2)	415 (12.9)	445 (12.5)	416 (10.7)	8.9	2.1	0.7	-0.7	0.8
India	21 (1.3)	32 (1.6)	104 (3.6)	183 (5.7)	292 (8.2)	469 (12.0)	5.9	4.9	4.8	4.9	4.8
Japan	72 (4.6)	89 (4.5)	71 (2.4)	60 (1.8)	52 (1.5)	46 (1.2)	-0.1	-1.4	-1.4	-1.2	-1.3
Korea	15 (0.9)	26 (1.3)	35 (1.2)	35 (1.1)	33 (0.9)	29 (0.7)	3.2	0.1	-0.6	-1.3	-0.6
Chinese Taipei	7 (0.4)	11 (0.6)	12 (0.4)	11 (0.4)	10 (0.3)	8 (0.2)	2.2	-0.6	-1.4	-2.1	-1.3
ASEAN	32 (2.1)	61 (3.1)	132 (4.6)	176 (5.5)	218 (6.1)	264 (6.8)	5.1	2.4	2.2	1.9	2.2
Indonesia	11 (0.7)	21 (1.1)	54 (1.9)	76 (2.4)	97 (2.7)	119 (3.1)	6.0	2.8	2.4	2.1	2.5
Malaysia	5 (0.3)	11 (0.6)	21 (0.7)	22 (0.7)	22 (0.6)	21 (0.5)	5.3	0.5	-0.1	-0.5	0.0
Myanmar	0 (0.0)	1 (0.1)	2 (0.1)	4 (0.1)	6 (0.2)	9 (0.2)	5.7	5.6	4.7	3.6	4.7
Philippines	5 (0.3)	8 (0.4)	12 (0.4)	24 (0.7)	35 (1.0)	49 (1.2)	3.6	5.7	3.9	3.4	4.4
Singapore	1 (0.1)	2 (0.1)	3 (0.1)	2 (0.1)	2 (0.1)	2 (0.1)	2.3	-0.2	-0.5	-1.1	-0.6
Thailand	9 (0.6)	15 (0.7)	28 (1.0)	29 (0.9)	32 (0.9)	33 (0.9)	4.1	0.5	0.8	0.6	0.6
Viet Nam	1 (0.1)	3 (0.2)	12 (0.4)	18 (0.6)	24 (0.7)	31 (0.8)	8.0	3.5	2.8	2.6	3.0
North America	531 (33.7)	640 (32.6)	706 (24.4)	651 (20.2)	615 (17.3)	585 (15.0)	1.0	-0.7	-0.6	-0.5	-0.6
United States	488 (31.0)	588 (30.0)	638 (22.1)	585 (18.1)	553 (15.6)	527 (13.5)	1.0	-0.7	-0.5	-0.5	-0.6
Latin America	103 (6.5)	140 (7.1)	225 (7.8)	266 (8.3)	294 (8.3)	309 (7.9)	2.8	1.4	1.0	0.5	1.0
Advanced Europe	269 (17.1)	318 (16.2)	354 (12.3)	313 (9.7)	279 (7.9)	253 (6.5)	1.0	-1.0	-1.1	-1.0	-1.1
European Union	220 (14.0)	262 (13.3)	287 (9.9)	253 (7.9)	225 (6.3)	202 (5.2)	1.0	-1.0	-1.2	-1.1	-1.1
Other Europe/Eurasia	170 (10.8)	109 (5.6)	156 (5.4)	152 (4.7)	147 (4.1)	143 (3.7)	-0.3	-0.2	-0.3	-0.2	-0.3
Africa	38 (2.4)	55 (2.8)	124 (4.3)	165 (5.1)	224 (6.3)	287 (7.4)	4.3	2.5	3.1	2.5	2.7
Middle East	51 (3.2)	75 (3.8)	147 (5.1)	175 (5.4)	193 (5.4)	208 (5.3)	3.9	1.4	1.0	0.7	1.1
Oceania	24 (1.5)	30 (1.5)	39 (1.4)	39 (1.2)	38 (1.1)	37 (0.9)	1.8	-0.1	-0.2	-0.3	-0.2
Advanced Economies	920 (58.4)	1 120 (57.1)	1 223 (42.3)	1 114 (34.6)	1 032 (29.0)	961 (24.7)	1.0	-0.8	-0.8	-0.7	-0.7
Emerging Market and Developing Economies	453 (28.8)	569 (29.0)	1 246 (43.1)	1 582 (49.1)	1 879 (52.8)	2 183 (56.0)	3.7	2.0	1.7	1.5	1.8

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

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

Table A8-14 | Final energy consumption, buildings, etc. [Reference Scenario]

(Mtoe)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/2018	2018/2030	2030/2040	2040/2050	2018/2050
World	2 411 (100)	2 592 (100)	3 291 (100)	3 772 (100)	3 986 (100)	4 111 (100)	1.1	1.1	0.6	0.3	0.7
Asia	740 (30.7)	842 (32.5)	1 172 (35.6)	1 456 (38.6)	1 602 (40.2)	1 701 (41.4)	1.7	1.8	1.0	0.6	1.2
China	351 (14.5)	338 (13.1)	559 (17.0)	704 (18.7)	764 (19.2)	793 (19.3)	1.7	1.9	0.8	0.4	1.1
India	142 (5.9)	171 (6.6)	246 (7.5)	339 (9.0)	394 (9.9)	443 (10.8)	2.0	2.7	1.5	1.2	1.9
Japan	78 (3.2)	108 (4.2)	96 (2.9)	94 (2.5)	89 (2.2)	84 (2.0)	0.7	-0.2	-0.5	-0.6	-0.4
Korea	24 (1.0)	37 (1.4)	47 (1.4)	49 (1.3)	48 (1.2)	46 (1.1)	2.4	0.4	-0.2	-0.5	0.0
Chinese Taipei	6 (0.3)	10 (0.4)	12 (0.4)	12 (0.3)	13 (0.3)	13 (0.3)	2.2	0.3	0.4	0.1	0.3
ASEAN	87 (3.6)	112 (4.3)	113 (3.4)	141 (3.7)	170 (4.3)	200 (4.9)	1.0	1.8	1.9	1.6	1.8
Indonesia	44 (1.8)	59 (2.3)	43 (1.3)	49 (1.3)	61 (1.5)	74 (1.8)	-0.1	1.0	2.3	1.9	1.7
Malaysia	2 (0.1)	4 (0.2)	9 (0.3)	12 (0.3)	15 (0.4)	17 (0.4)	5.2	2.8	1.8	1.3	2.0
Myanmar	8 (0.4)	9 (0.4)	14 (0.4)	17 (0.5)	19 (0.5)	19 (0.5)	1.8	1.8	0.8	0.4	1.0
Philippines	10 (0.4)	10 (0.4)	13 (0.4)	18 (0.5)	21 (0.5)	24 (0.6)	0.8	2.8	2.0	1.3	2.1
Singapore	1 (0.0)	2 (0.1)	3 (0.1)	3 (0.1)	3 (0.1)	3 (0.1)	3.0	1.1	0.4	0.0	0.5
Thailand	11 (0.4)	14 (0.5)	18 (0.5)	21 (0.6)	23 (0.6)	24 (0.6)	1.8	1.5	0.8	0.5	1.0
Viet Nam	10 (0.4)	14 (0.5)	14 (0.4)	20 (0.5)	28 (0.7)	38 (0.9)	1.2	3.1	3.2	3.0	3.1
North America	456 (18.9)	533 (20.6)	600 (18.2)	607 (16.1)	597 (15.0)	577 (14.0)	1.0	0.1	-0.2	-0.3	-0.1
United States	403 (16.7)	473 (18.2)	530 (16.1)	539 (14.3)	531 (13.3)	514 (12.5)	1.0	0.1	-0.2	-0.3	-0.1
Latin America	101 (4.2)	121 (4.7)	166 (5.0)	197 (5.2)	223 (5.6)	247 (6.0)	1.8	1.4	1.3	1.0	1.3
Advanced Europe	442 (18.3)	477 (18.4)	495 (15.0)	491 (13.0)	460 (11.5)	434 (10.6)	0.4	-0.1	-0.7	-0.6	-0.4
European Union	374 (15.5)	391 (15.1)	400 (12.2)	403 (10.7)	377 (9.5)	354 (8.6)	0.2	0.1	-0.7	-0.6	-0.4
Other Europe/Eurasia	432 (17.9)	287 (11.1)	316 (9.6)	326 (8.7)	315 (7.9)	313 (7.6)	-1.1	0.3	-0.4	0.0	0.0
Africa	185 (7.7)	238 (9.2)	374 (11.4)	473 (12.5)	535 (13.4)	557 (13.5)	2.5	2.0	1.2	0.4	1.2
Middle East	40 (1.7)	75 (2.9)	143 (4.3)	192 (5.1)	225 (5.6)	253 (6.1)	4.7	2.5	1.6	1.2	1.8
Oceania	15 (0.6)	19 (0.7)	25 (0.8)	28 (0.7)	29 (0.7)	30 (0.7)	1.9	1.0	0.4	0.2	0.6
Advanced Economies	1 025 (42.5)	1 189 (45.9)	1 281 (38.9)	1 290 (34.2)	1 244 (31.2)	1 191 (29.0)	0.8	0.1	-0.4	-0.4	-0.2
Emerging Market and Developing Economies	1 386 (57.5)	1 403 (54.1)	2 009 (61.1)	2 482 (65.8)	2 742 (68.8)	2 920 (71.0)	1.3	1.8	1.0	0.6	1.2

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

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

Table A8-15 | Final energy consumption, electricity [Reference Scenario]

(TWh)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	9 701 (100)	12 695 (100)	22 311 (100)	29 000 (100)	34 516 (100)	39 056 (100)	3.0	2.2	1.8	1.2	1.8
Asia	1 822 (18.8)	3 251 (25.6)	10 190 (45.7)	14 609 (50.4)	17 556 (50.9)	19 772 (50.6)	6.3	3.0	1.9	1.2	2.1
China	454 (4.7)	1 036 (8.2)	6 010 (26.9)	8 245 (28.4)	9 309 (27.0)	9 708 (24.9)	9.7	2.7	1.2	0.4	1.5
India	212 (2.2)	369 (2.9)	1 201 (5.4)	2 441 (8.4)	3 471 (10.1)	4 454 (11.4)	6.4	6.1	3.6	2.5	4.2
Japan	765 (7.9)	973 (7.7)	945 (4.2)	973 (3.4)	989 (2.9)	982 (2.5)	0.8	0.2	0.2	-0.1	0.1
Korea	94 (1.0)	263 (2.1)	531 (2.4)	623 (2.1)	664 (1.9)	668 (1.7)	6.4	1.3	0.6	0.1	0.7
Chinese Taipei	77 (0.8)	160 (1.3)	247 (1.1)	274 (0.9)	294 (0.9)	304 (0.8)	4.3	0.9	0.7	0.3	0.6
ASEAN	130 (1.3)	320 (2.5)	941 (4.2)	1 583 (5.5)	2 192 (6.3)	2 844 (7.3)	7.3	4.4	3.3	2.6	3.5
Indonesia	28 (0.3)	79 (0.6)	256 (1.1)	460 (1.6)	700 (2.0)	955 (2.4)	8.2	5.0	4.3	3.1	4.2
Malaysia	20 (0.2)	61 (0.5)	153 (0.7)	221 (0.8)	277 (0.8)	329 (0.8)	7.5	3.1	2.3	1.7	2.4
Myanmar	2 (0.0)	3 (0.0)	19 (0.1)	47 (0.2)	77 (0.2)	116 (0.3)	8.8	8.1	5.1	4.1	5.9
Philippines	21 (0.2)	37 (0.3)	83 (0.4)	138 (0.5)	193 (0.6)	251 (0.6)	5.0	4.4	3.4	2.7	3.5
Singapore	13 (0.1)	27 (0.2)	50 (0.2)	62 (0.2)	68 (0.2)	70 (0.2)	5.0	1.7	0.9	0.2	1.0
Thailand	38 (0.4)	88 (0.7)	188 (0.8)	272 (0.9)	337 (1.0)	390 (1.0)	5.8	3.1	2.2	1.4	2.3
Viet Nam	6 (0.1)	22 (0.2)	189 (0.8)	378 (1.3)	535 (1.5)	730 (1.9)	13.0	5.9	3.5	3.2	4.3
North America	3 051 (31.5)	3 980 (31.4)	4 424 (19.8)	4 802 (16.6)	5 265 (15.3)	5 580 (14.3)	1.3	0.7	0.9	0.6	0.7
United States	2 633 (27.1)	3 499 (27.6)	3 900 (17.5)	4 213 (14.5)	4 623 (13.4)	4 895 (12.5)	1.4	0.6	0.9	0.6	0.7
Latin America	518 (5.3)	797 (6.3)	1 327 (5.9)	1 825 (6.3)	2 382 (6.9)	2 863 (7.3)	3.4	2.7	2.7	1.9	2.4
Advanced Europe	2 248 (23.2)	2 717 (21.4)	3 159 (14.2)	3 460 (11.9)	3 642 (10.6)	3 700 (9.5)	1.2	0.8	0.5	0.2	0.5
European Union	1 887 (19.4)	2 198 (17.3)	2 511 (11.3)	2 773 (9.6)	2 933 (8.5)	2 992 (7.7)	1.0	0.8	0.6	0.2	0.5
Other Europe/Eurasia	1 449 (14.9)	1 001 (7.9)	1 279 (5.7)	1 506 (5.2)	1 783 (5.2)	2 013 (5.2)	-0.4	1.4	1.7	1.2	1.4
Africa	256 (2.6)	363 (2.9)	680 (3.0)	1 096 (3.8)	1 744 (5.1)	2 580 (6.6)	3.6	4.1	4.8	4.0	4.3
Middle East	199 (2.0)	379 (3.0)	999 (4.5)	1 402 (4.8)	1 816 (5.3)	2 198 (5.6)	5.9	2.9	2.6	1.9	2.5
Oceania	158 (1.6)	207 (1.6)	252 (1.1)	299 (1.0)	329 (1.0)	349 (0.9)	1.7	1.4	1.0	0.6	1.0
Advanced Economies	6 429 (66.3)	8 363 (65.9)	9 655 (43.3)	10 545 (36.4)	11 303 (32.7)	11 703 (30.0)	1.5	0.7	0.7	0.3	0.6
Emerging Market and Developing Economies	3 272 (33.7)	4 332 (34.1)	12 657 (56.7)	18 456 (63.6)	23 213 (67.3)	27 353 (70.0)	5.0	3.2	2.3	1.7	2.4

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

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

Table A8-16 | Electricity generated [Reference Scenario]

(TWh)

	1990	2000	2018	2030	2040	2050	CAGR (%)				
							1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	11 846 (100)	15 427 (100)	26 619 (100)	34 431 (100)	40 519 (100)	45 201 (100)	2.9	2.2	1.6	1.1	1.7
Asia	2 238 (18.9)	3 971 (25.7)	12 069 (45.3)	17 248 (50.1)	20 488 (50.6)	22 749 (50.3)	6.2	3.0	1.7	1.1	2.0
China	621 (5.2)	1 356 (8.8)	7 149 (26.9)	9 723 (28.2)	10 858 (26.8)	11 191 (24.8)	9.1	2.6	1.1	0.3	1.4
India	289 (2.4)	562 (3.6)	1 583 (5.9)	3 128 (9.1)	4 284 (10.6)	5 294 (11.7)	6.3	5.8	3.2	2.1	3.8
Japan	862 (7.3)	1 055 (6.8)	1 050 (3.9)	1 079 (3.1)	1 093 (2.7)	1 082 (2.4)	0.7	0.2	0.1	-0.1	0.1
Korea	105 (0.9)	289 (1.9)	586 (2.2)	687 (2.0)	731 (1.8)	734 (1.6)	6.3	1.3	0.6	0.0	0.7
Chinese Taipei	88 (0.7)	181 (1.2)	272 (1.0)	302 (0.9)	323 (0.8)	333 (0.7)	4.1	0.9	0.7	0.3	0.6
ASEAN	154 (1.3)	370 (2.4)	1 059 (4.0)	1 763 (5.1)	2 435 (6.0)	3 152 (7.0)	7.1	4.3	3.3	2.6	3.5
Indonesia	33 (0.3)	93 (0.6)	284 (1.1)	513 (1.5)	782 (1.9)	1 065 (2.4)	8.0	5.1	4.3	3.1	4.2
Malaysia	23 (0.2)	69 (0.4)	170 (0.6)	247 (0.7)	309 (0.8)	366 (0.8)	7.4	3.1	2.3	1.7	2.4
Myanmar	2 (0.0)	5 (0.0)	25 (0.1)	78 (0.2)	122 (0.3)	175 (0.4)	8.5	10.1	4.6	3.7	6.3
Philippines	26 (0.2)	45 (0.3)	99 (0.4)	165 (0.5)	227 (0.6)	291 (0.6)	4.9	4.3	3.2	2.5	3.4
Singapore	16 (0.1)	32 (0.2)	53 (0.2)	65 (0.2)	72 (0.2)	73 (0.2)	4.4	1.7	0.9	0.2	1.0
Thailand	44 (0.4)	96 (0.6)	182 (0.7)	249 (0.7)	307 (0.8)	350 (0.8)	5.2	2.6	2.1	1.3	2.1
Viet Nam	9 (0.1)	27 (0.2)	241 (0.9)	441 (1.3)	612 (1.5)	826 (1.8)	12.6	5.2	3.3	3.0	3.9
North America	3 685 (31.1)	4 631 (30.0)	5 088 (19.1)	5 500 (16.0)	5 993 (14.8)	6 309 (14.0)	1.2	0.6	0.9	0.5	0.7
United States	3 203 (27.0)	4 026 (26.1)	4 434 (16.7)	4 774 (13.9)	5 212 (12.9)	5 486 (12.1)	1.2	0.6	0.9	0.5	0.7
Latin America	623 (5.3)	1 009 (6.5)	1 637 (6.2)	2 224 (6.5)	2 851 (7.0)	3 356 (7.4)	3.5	2.6	2.5	1.6	2.3
Advanced Europe	2 697 (22.8)	3 238 (21.0)	3 656 (13.7)	3 984 (11.6)	4 161 (10.3)	4 191 (9.3)	1.1	0.7	0.4	0.1	0.4
European Union	2 259 (19.1)	2 631 (17.1)	2 920 (11.0)	3 206 (9.3)	3 361 (8.3)	3 392 (7.5)	0.9	0.8	0.5	0.1	0.5
Other Europe/Eurasia	1 857 (15.7)	1 415 (9.2)	1 801 (6.8)	2 049 (6.0)	2 326 (5.7)	2 516 (5.6)	-0.1	1.1	1.3	0.8	1.1
Africa	315 (2.7)	442 (2.9)	835 (3.1)	1 336 (3.9)	2 092 (5.2)	3 031 (6.7)	3.5	4.0	4.6	3.8	4.1
Middle East	244 (2.1)	472 (3.1)	1 228 (4.6)	1 733 (5.0)	2 218 (5.5)	2 643 (5.8)	5.9	2.9	2.5	1.8	2.4
Oceania	187 (1.6)	249 (1.6)	305 (1.1)	359 (1.0)	389 (1.0)	406 (0.9)	1.8	1.4	0.8	0.4	0.9
Advanced Economies	7 668 (64.7)	9 706 (62.9)	11 048 (41.5)	12 019 (34.9)	12 808 (31.6)	13 172 (29.1)	1.3	0.7	0.6	0.3	0.6
Emerging Market and Developing Economies	4 178 (35.3)	5 721 (37.1)	15 571 (58.5)	22 412 (65.1)	27 711 (68.4)	32 028 (70.9)	4.8	3.1	2.1	1.5	2.3

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

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

Table A8-17 | Primary energy consumption per capita [Reference Scenario]

(toe/person)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	1.66	1.64	1.88	1.94	1.95	1.92	0.4	0.3	0.0	-0.2	0.1
Asia	0.72	0.84	1.42	1.65	1.75	1.81	2.5	1.3	0.6	0.3	0.8
China	0.77	0.89	2.30	2.60	2.66	2.58	4.0	1.1	0.2	-0.3	0.4
India	0.35	0.42	0.68	1.03	1.26	1.48	2.4	3.5	2.1	1.6	2.5
Japan	3.55	4.09	3.37	3.38	3.35	3.29	-0.2	0.0	-0.1	-0.2	-0.1
Korea	2.17	4.00	5.47	5.81	5.80	5.70	3.4	0.5	0.0	-0.2	0.1
Chinese Taipei	2.33	3.81	4.67	4.64	4.63	4.58	2.5	-0.1	0.0	-0.1	-0.1
ASEAN	0.54	0.75	1.06	1.39	1.62	1.84	2.4	2.3	1.5	1.3	1.7
Indonesia	0.54	0.74	0.86	1.16	1.40	1.63	1.7	2.5	1.9	1.5	2.0
Malaysia	1.18	2.08	2.96	3.64	3.83	3.88	3.4	1.7	0.5	0.1	0.8
Myanmar	0.26	0.27	0.44	0.66	0.83	1.00	1.9	3.4	2.3	1.9	2.6
Philippines	0.46	0.51	0.56	0.76	0.88	1.01	0.7	2.5	1.5	1.4	1.8
Singapore	3.78	4.63	6.70	7.00	7.26	7.48	2.1	0.4	0.4	0.3	0.3
Thailand	0.75	1.15	1.96	2.45	2.80	3.17	3.5	1.9	1.3	1.2	1.5
Viet Nam	0.26	0.36	0.87	1.34	1.71	2.13	4.4	3.6	2.4	2.2	2.8
North America	7.67	8.08	6.95	6.34	5.91	5.49	-0.3	-0.8	-0.7	-0.7	-0.7
United States	7.67	8.06	6.83	6.23	5.83	5.42	-0.4	-0.8	-0.7	-0.7	-0.7
Latin America	1.06	1.17	1.28	1.43	1.59	1.68	0.7	0.9	1.1	0.5	0.8
Advanced Europe	3.25	3.34	3.02	2.81	2.66	2.51	-0.3	-0.6	-0.6	-0.6	-0.6
European Union	3.42	3.43	3.20	3.05	2.90	2.75	-0.2	-0.4	-0.5	-0.5	-0.5
Other Europe/Eurasia	4.50	2.97	3.41	3.51	3.66	3.79	-1.0	0.2	0.4	0.4	0.3
Africa	0.61	0.61	0.66	0.64	0.64	0.61	0.2	-0.2	0.0	-0.4	-0.2
Middle East	1.69	2.22	3.15	3.40	3.54	3.53	2.3	0.6	0.4	0.0	0.4
Oceania	4.85	5.44	4.98	4.54	4.22	3.83	0.1	-0.8	-0.7	-1.0	-0.8
Advanced Economies	4.47	4.89	4.46	4.22	4.03	3.82	0.0	-0.5	-0.5	-0.5	-0.5
Emerging Market and Developing Economies	0.96	0.90	1.34	1.48	1.54	1.55	1.2	0.9	0.4	0.0	0.5

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

Note: World includes international bunkers.

Table A8-18 | Primary energy consumption per GDP [Reference Scenario]

(toe/$2010 million)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/ 2018	2018/ 2030	2030/ 2040	2040/ 2050	2018/ 2050
World	231	201	173	145	120	100	-1.0	-1.5	-1.9	-1.8	-1.7
Asia	277	260	228	175	135	108	-0.7	-2.2	-2.6	-2.3	-2.3
China	1 055	506	296	186	127	93	-4.4	-3.8	-3.7	-3.1	-3.6
India	605	507	325	251	194	152	-2.2	-2.1	-2.5	-2.5	-2.4
Japan	93	97	69	61	52	45	-1.1	-1.0	-1.5	-1.5	-1.3
Korea	256	265	204	161	128	102	-0.8	-2.0	-2.3	-2.2	-2.1
Chinese Taipei	307	286	203	161	131	107	-1.5	-1.9	-2.0	-2.0	-2.0
ASEAN	313	321	231	195	161	134	-1.1	-1.4	-1.9	-1.8	-1.7
Indonesia	318	343	202	166	136	114	-1.6	-1.6	-1.9	-1.8	-1.8
Malaysia	259	297	245	205	163	128	-0.2	-1.5	-2.3	-2.4	-2.0
Myanmar	1 594	960	337	271	213	169	-5.4	-1.8	-2.4	-2.3	-2.1
Philippines	304	319	186	154	132	113	-1.7	-1.6	-1.5	-1.5	-1.5
Singapore	168	137	115	100	87	78	-1.3	-1.2	-1.4	-1.1	-1.2
Thailand	298	332	307	263	213	175	0.1	-1.3	-2.1	-1.9	-1.7
Viet Nam	607	470	445	372	295	237	-1.1	-1.5	-2.3	-2.2	-2.0
North America	214	183	128	100	79	64	-1.8	-2.0	-2.3	-2.2	-2.2
United States	213	180	125	98	77	62	-1.9	-2.0	-2.3	-2.2	-2.2
Latin America	163	159	140	124	106	90	-0.5	-1.0	-1.6	-1.6	-1.4
Advanced Europe	129	110	82	66	55	46	-1.6	-1.8	-1.8	-1.7	-1.8
European Union	141	116	87	71	59	49	-1.7	-1.7	-1.9	-1.7	-1.8
Other Europe/Eurasia	706	672	406	323	265	218	-2.0	-1.9	-2.0	-1.9	-1.9
Africa	432	419	338	269	206	160	-0.9	-1.9	-2.6	-2.5	-2.3
Middle East	216	242	277	271	239	204	0.9	-0.2	-1.2	-1.6	-1.0
Oceania	137	126	89	70	58	48	-1.5	-2.0	-1.8	-1.9	-1.9
Advanced Economies	155	140	103	83	68	56	-1.5	-1.7	-2.0	-1.9	-1.9
Emerging Market and Developing Economies	448	363	277	210	161	128	-1.7	-2.3	-2.6	-2.3	-2.4

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

Note: World includes international bunkers.

Table A8-19 | Energy-related carbon dioxide emissions [Reference Scenario]

(Mt)

	1990	2000	2018	2030	2040	2050	CAGR (%) 1990/2018	2018/2030	2030/2040	2040/2050	2018/2050
World	20 324 (100)	23 046 (100)	33 258 (100)	37 205 (100)	39 486 (100)	39 975 (100)	1.8	0.9	0.6	0.1	0.6
Asia	4 639 (22.8)	6 729 (29.2)	15 495 (46.6)	18 941 (50.9)	20 310 (51.4)	20 546 (51.4)	4.4	1.7	0.7	0.1	0.9
China	2 146 (10.6)	3 140 (13.6)	9 348 (28.1)	10 360 (27.8)	9 853 (25.0)	8 562 (21.4)	5.4	0.9	-0.5	-1.4	-0.3
India	530 (2.6)	890 (3.9)	2 324 (7.0)	4 033 (10.8)	5 384 (13.6)	6 557 (16.4)	5.4	4.7	2.9	2.0	3.3
Japan	1 058 (5.2)	1 161 (5.0)	1 081 (3.2)	940 (2.5)	852 (2.2)	738 (1.8)	0.1	-1.2	-1.0	-1.4	-1.2
Korea	209 (1.0)	404 (1.8)	602 (1.8)	629 (1.7)	608 (1.5)	550 (1.4)	3.8	0.4	-0.3	-1.0	-0.3
Chinese Taipei	105 (0.5)	203 (0.9)	255 (0.8)	266 (0.7)	250 (0.6)	223 (0.6)	3.2	0.4	-0.6	-1.1	-0.4
ASEAN	341 (1.7)	669 (2.9)	1 444 (4.3)	2 106 (5.7)	2 608 (6.6)	3 026 (7.6)	5.3	3.2	2.2	1.5	2.3
Indonesia	130 (0.6)	254 (1.1)	539 (1.6)	817 (2.2)	1 062 (2.7)	1 248 (3.1)	5.2	3.5	2.7	1.6	2.7
Malaysia	51 (0.3)	111 (0.5)	222 (0.7)	280 (0.8)	298 (0.8)	296 (0.7)	5.4	2.0	0.6	-0.1	0.9
Myanmar	4 (0.0)	10 (0.0)	31 (0.1)	77 (0.2)	116 (0.3)	157 (0.4)	7.6	7.8	4.2	3.0	5.2
Philippines	36 (0.2)	67 (0.3)	133 (0.4)	206 (0.6)	271 (0.7)	337 (0.8)	4.8	3.7	2.8	2.2	3.0
Singapore	21 (0.1)	33 (0.1)	47 (0.1)	53 (0.1)	56 (0.1)	56 (0.1)	2.9	1.0	0.6	0.0	0.6
Thailand	77 (0.4)	147 (0.6)	238 (0.7)	272 (0.7)	281 (0.7)	271 (0.7)	4.1	1.1	0.3	-0.4	0.4
Viet Nam	17 (0.1)	43 (0.2)	227 (0.7)	396 (1.1)	517 (1.3)	655 (1.6)	9.7	4.7	2.7	2.4	3.4
North America	5 184 (25.5)	6 154 (26.7)	5 501 (16.5)	5 046 (13.6)	4 719 (12.0)	4 215 (10.5)	0.2	-0.7	-0.7	-1.1	-0.8
United States	4 783 (23.5)	5 661 (24.6)	4 929 (14.8)	4 499 (12.1)	4 186 (10.6)	3 704 (9.3)	0.1	-0.8	-0.7	-1.2	-0.9
Latin America	866 (4.3)	1 193 (5.2)	1 574 (4.7)	1 838 (4.9)	2 171 (5.5)	2 339 (5.9)	2.2	1.3	1.7	0.7	1.2
Advanced Europe	3 935 (19.4)	3 910 (17.0)	3 456 (10.4)	3 140 (8.4)	2 855 (7.2)	2 547 (6.4)	-0.5	-0.8	-0.9	-1.1	-1.0
European Union	3 422 (16.8)	3 248 (14.1)	2 781 (8.4)	2 478 (6.7)	2 262 (5.7)	2 008 (5.0)	-0.7	-1.0	-0.9	-1.2	-1.0
Other Europe/Eurasia	3 680 (18.1)	2 233 (9.7)	2 399 (7.2)	2 323 (6.2)	2 366 (6.0)	2 348 (5.9)	-1.5	-0.3	0.2	-0.1	-0.1
Africa	541 (2.7)	667 (2.9)	1 253 (3.8)	1 617 (4.3)	2 174 (5.5)	2 712 (6.8)	3.0	2.1	3.0	2.2	2.4
Middle East	568 (2.8)	943 (4.1)	1 844 (5.5)	2 291 (6.2)	2 567 (6.5)	2 689 (6.7)	4.3	1.8	1.1	0.5	1.2
Oceania	282 (1.4)	363 (1.6)	423 (1.3)	399 (1.1)	380 (1.0)	348 (0.9)	1.5	-0.5	-0.5	-0.9	-0.6
Advanced Economies	10 827 (53.3)	12 268 (53.2)	11 407 (34.3)	10 520 (28.3)	9 765 (24.7)	8 717 (21.8)	0.2	-0.7	-0.7	-1.1	-0.8
Emerging Market and Developing Economies	8 867 (43.6)	9 925 (43.1)	20 538 (61.8)	25 074 (67.4)	27 779 (70.4)	29 026 (72.6)	3.0	1.7	1.0	0.4	1.1

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

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

Table A8-20 | World [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	7 203	8 767	10 034	14 282	16 476	17 823	18 556	100	100	100	1.8	1.2	0.6	0.8
Coal	1 783	2 221	2 317	3 838	4 176	4 174	3 884	25	27	21	2.0	0.7	-0.4	0.0
Oil	3 105	3 233	3 669	4 497	4 946	5 328	5 608	37	31	30	1.2	0.8	0.6	0.7
Natural gas	1 231	1 662	2 071	3 262	4 059	4 690	5 132	19	23	28	2.4	1.8	1.2	1.4
Nuclear	185	526	675	707	786	819	858	6.0	4.9	4.6	1.1	0.9	0.4	0.6
Hydro	148	184	225	362	424	464	502	2.1	2.5	2.7	2.4	1.3	0.8	1.0
Geothermal	12	34	52	92	185	243	292	0.4	0.6	1.6	3.6	6.0	2.3	3.7
Solar, wind, etc.	0.1	2.5	8.0	194	403	583	803	0.0	1.4	4.3	16.8	6.3	3.5	4.5
Biomass and waste	738	904	1 015	1 327	1 494	1 520	1 475	10	9.3	8.0	1.4	1.0	-0.1	0.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	5 370	6 267	7 032	9 938	11 375	12 251	12 872	100	100	100	1.7	1.1	0.6	0.8
Industry	1 767	1 803	1 871	2 839	3 264	3 463	3 518	29	29	27	1.6	1.2	0.4	0.7
Transport	1 245	1 575	1 963	2 891	3 222	3 556	3 898	25	29	30	2.2	0.9	1.0	0.9
Buildings, etc.	2 000	2 411	2 592	3 291	3 772	3 986	4 111	38	33	32	1.1	1.1	0.4	0.7
Non-energy use	358	477	606	917	1 117	1 245	1 345	7.6	9.2	10	2.4	1.7	0.9	1.2
Coal	703	752	542	994	995	943	875	12	10	6.8	1.0	0.0	-0.6	-0.4
Oil	2 449	2 606	3 119	4 051	4 516	4 892	5 211	42	41	40	1.6	0.9	0.7	0.8
Natural gas	815	944	1 119	1 611	1 928	2 065	2 175	15	16	17	1.9	1.5	0.6	0.9
Electricity	586	834	1 092	1 919	2 494	2 968	3 359	13	19	26	3.0	2.2	1.5	1.8
Heat	121	336	248	301	311	298	283	5.4	3.0	2.2	-0.4	0.3	-0.5	-0.2
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-1.5	n.a.
Renewables	697	794	911	1 061	1 132	1 083	969	13	11	7.5	1.0	0.5	-0.8	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	8 282	11 846	15 427	26 619	34 431	40 519	45 201	100	100	100	2.9	2.2	1.4	1.7
Coal	3 137	4 430	5 994	10 160	12 146	12 846	12 477	37	38	28	3.0	1.5	0.1	0.6
Oil	1 659	1 323	1 184	784	754	694	494	11	2.9	1.1	-1.9	-0.3	-2.1	-1.4
Natural gas	998	1 749	2 775	6 150	8 477	11 198	13 344	15	23	30	4.6	2.7	2.3	2.5
Nuclear	713	2 013	2 591	2 710	3 018	3 142	3 294	17	10	7.3	1.1	0.9	0.4	0.6
Hydro	1 717	2 141	2 613	4 214	4 936	5 398	5 835	18	16	13	2.4	1.3	0.8	1.0
Geothermal	14	36	52	89	191	264	319	0.3	0.3	0.7	3.2	6.6	2.6	4.1
Solar PV	-	0.1	0.8	554	1 357	2 311	3 785	0.0	2.1	8.4	36.5	7.7	5.3	6.2
Wind	0.0	3.9	31	1 273	2 441	3 224	3 856	0.0	4.8	8.5	23.0	5.6	2.3	3.5
CSP and marine	0.5	1.2	1.1	12	119	214	351	0.0	0.0	0.8	8.7	20.8	5.6	11.0
Biomass and waste	44	130	163	637	957	1 195	1 412	1.1	2.4	3.1	5.9	3.4	2.0	2.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	35	35	35	35	0.2	0.1	0.1	2.0	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	28 022	37 880	49 899	82 365	113 405	148 705	186 235	2.8	2.7	2.5	2.6
Population (million)	4 434	5 278	6 111	7 591	8 497	9 146	9 682	1.3	0.9	0.7	0.8
CO_2 emissions (Mt)	17 774	20 324	23 046	33 258	37 205	39 486	39 975	1.8	0.9	0.4	0.6
GDP per capita ($2010 thousand)	6.3	7.2	8.2	11	13	16	19	1.5	1.7	1.8	1.8
Primary energy consump. per capita (toe)	1.6	1.7	1.6	1.9	1.9	1.9	1.9	0.4	0.3	-0.1	0.1
Primary energy consumption per GDP[*2]	257	231	201	173	145	120	100	-1.0	-1.5	-1.9	-1.7
CO_2 emissions per GDP[*3]	634	537	462	404	328	266	215	-1.0	-1.7	-2.1	-2.0
CO_2 per primary energy consumption[*4]	2.5	2.3	2.3	2.3	2.3	2.2	2.2	0.0	-0.3	-0.2	-0.2

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-21 | Asia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	1 439	2 110	2 887	5 844	7 363	8 101	8 490	100	100	100	3.7	1.9	0.7	1.2
Coal	466	788	1 037	2 821	3 290	3 332	3 133	37	48	37	4.7	1.3	-0.2	0.3
Oil	477	618	916	1 464	1 808	2 048	2 269	29	25	27	3.1	1.8	1.1	1.4
Natural gas	51	116	233	641	1 037	1 316	1 512	5.5	11	18	6.3	4.1	1.9	2.7
Nuclear	25	77	132	148	250	295	345	3.6	2.5	4.1	2.4	4.5	1.6	2.7
Hydro	20	32	41	146	183	205	222	1.5	2.5	2.6	5.6	1.9	1.0	1.3
Geothermal	2.6	8.2	23	47	96	121	147	0.4	0.8	1.7	6.4	6.1	2.1	3.6
Solar, wind, etc.	-	1.2	2.1	89	200	296	393	0.1	1.5	4.6	16.5	7.0	3.4	4.7
Biomass and waste	396	471	503	487	498	486	469	22	8.3	5.5	0.1	0.2	-0.3	-0.1

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	1 133	1 558	1 999	3 847	4 748	5 232	5 593	100	100	100	3.3	1.8	0.8	1.2
Industry	384	515	655	1 556	1 828	1 911	1 921	33	40	34	4.0	1.4	0.2	0.7
Transport	124	187	321	717	935	1 121	1 322	12	19	24	4.9	2.2	1.7	1.9
Buildings, etc.	568	740	842	1 172	1 456	1 602	1 701	48	30	30	1.7	1.8	0.8	1.2
Non-energy use	58	116	180	401	528	598	650	7.4	10	12	4.5	2.3	1.0	1.5
Coal	301	423	372	834	835	789	731	27	22	13	2.5	0.0	-0.7	-0.4
Oil	331	464	740	1 288	1 622	1 853	2 070	30	33	37	3.7	1.9	1.2	1.5
Natural gas	21	46	89	318	511	602	664	3.0	8.3	12	7.1	4.0	1.3	2.3
Electricity	88	157	280	876	1 256	1 510	1 700	10	23	30	6.3	3.0	1.5	2.1
Heat	7.5	14	30	112	126	127	122	0.9	2.9	2.2	7.7	1.0	-0.1	0.3
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-11.7	n.a.
Renewables	385	455	488	418	397	352	306	29	11	5.5	-0.3	-0.4	-1.3	-1.0

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	1 195	2 238	3 971	12 069	17 248	20 488	22 749	100	100	100	6.2	3.0	1.4	2.0
Coal	298	868	1 983	7 172	9 327	10 096	10 060	39	59	44	7.8	2.2	0.4	1.1
Oil	475	432	376	170	151	125	95	19	1.4	0.4	-3.3	-1.0	-2.3	-1.8
Natural gas	90	237	570	1 416	2 324	3 215	3 979	11	12	17	6.6	4.2	2.7	3.3
Nuclear	97	294	505	569	960	1 134	1 323	13	4.7	5.8	2.4	4.5	1.6	2.7
Hydro	232	368	477	1 703	2 133	2 389	2 582	16	14	11	5.6	1.9	1.0	1.3
Geothermal	3.0	8.4	20	27	61	78	95	0.4	0.2	0.4	4.3	6.9	2.2	4.0
Solar PV	-	0.1	0.4	299	782	1 308	2 069	0.0	2.5	9.1	34.8	8.3	5.0	6.2
Wind	-	0.0	2.4	449	1 126	1 639	1 928	0.0	3.7	8.5	40.3	8.0	2.7	4.7
CSP and marine	-	0.0	0.0	0.8	7.5	14	26	0.0	0.0	0.1	18.4	20.6	6.4	11.5
Biomass and waste	0.0	9.4	16	241	355	469	573	0.4	2.0	2.5	12.3	3.3	2.4	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	21	21	21	21	0.9	0.2	0.1	0.3	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	4 510	7 629	11 103	25 670	42 014	59 911	78 948	4.4	4.2	3.2	3.6
Population (million)	2 445	2 939	3 420	4 118	4 454	4 623	4 687	1.2	0.7	0.3	0.4
CO_2 emissions (Mt)	3 102	4 639	6 729	15 495	18 941	20 310	20 546	4.4	1.7	0.4	0.9
GDP per capita ($2010 thousand)	1.8	2.6	3.2	6.2	9.4	13	17	3.2	3.5	2.9	3.2
Primary energy consump. per capita (toe)	0.6	0.7	0.8	1.4	1.7	1.8	1.8	2.5	1.3	0.5	0.8
Primary energy consumption per GDP*2	319	277	260	228	175	135	108	-0.7	-2.2	-2.4	-2.3
CO_2 emissions per GDP*3	688	608	606	604	451	339	260	0.0	-2.4	-2.7	-2.6
CO_2 per primary energy consumption*4	2.2	2.2	2.3	2.7	2.6	2.5	2.4	0.7	-0.3	-0.3	-0.3

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-22 | China [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	598	874	1 130	3 196	3 719	3 756	3 532	100	100	100	4.7	1.3	-0.3	0.3
Coal	313	531	665	1 980	2 096	1 902	1 578	61	62	45	4.8	0.5	-1.4	-0.7
Oil	89	119	221	610	713	731	679	14	19	19	6.0	1.3	-0.2	0.3
Natural gas	12	13	21	230	417	525	582	1.5	7.2	16	10.9	5.1	1.7	2.9
Nuclear	-	-	4.4	77	121	156	189	-	2.4	5.4	n.a.	3.9	2.2	2.9
Hydro	5.0	11	19	103	124	134	138	1.2	3.2	3.9	8.4	1.6	0.5	0.9
Geothermal	-	-	1.7	11	15	16	17	-	0.4	0.5	n.a.	2.3	0.8	1.3
Solar, wind, etc.	-	0.0	1.0	70	145	207	252	0.0	2.2	7.1	31.4	6.3	2.8	4.1
Biomass and waste	180	200	198	117	89	86	98	23	3.7	2.8	-1.9	-2.2	0.5	-0.5

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	487	658	781	2 058	2 333	2 353	2 259	100	100	100	4.2	1.1	-0.2	0.3
Industry	181	234	302	996	988	900	803	36	48	36	5.3	-0.1	-1.0	-0.7
Transport	22	30	84	325	415	445	416	4.6	16	18	8.9	2.1	0.0	0.8
Buildings, etc.	274	351	338	559	704	764	793	53	27	35	1.7	1.9	0.6	1.1
Non-energy use	10	43	57	179	225	243	246	6.5	8.7	11	5.2	2.0	0.4	1.0
Coal	214	311	274	635	541	437	345	47	31	15	2.6	-1.3	-2.2	-1.9
Oil	59	85	180	535	637	655	608	13	26	27	6.8	1.5	-0.2	0.4
Natural gas	6.4	8.9	12	153	241	268	281	1.3	7.4	12	10.7	3.8	0.8	1.9
Electricity	21	39	89	517	709	801	835	5.9	25	37	9.7	2.7	0.8	1.5
Heat	7.4	13	26	103	116	118	113	2.0	5.0	5.0	7.6	1.0	-0.1	0.3
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	180	200	199	114	88	74	77	30	5.5	3.4	-2.0	-2.1	-0.7	-1.2

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	301	621	1 356	7 149	9 723	10 858	11 191	100	100	100	9.1	2.6	0.7	1.4
Coal	159	441	1 060	4 773	5 768	5 680	5 126	71	67	46	8.9	1.6	-0.6	0.2
Oil	82	50	47	11	10	7.4	4.2	8.1	0.2	0.0	-5.4	-0.5	-4.3	-2.9
Natural gas	0.7	2.8	5.8	224	578	845	1 034	0.4	3.1	9.2	17.0	8.2	3.0	4.9
Nuclear	-	-	17	295	466	597	725	-	4.1	6.5	n.a.	3.9	2.2	2.9
Hydro	58	127	222	1 199	1 445	1 553	1 600	20	17	14	8.4	1.6	0.5	0.9
Geothermal	-	0.1	0.1	0.1	0.3	0.5	0.5	0.0	0.0	0.0	2.9	8.6	2.2	4.5
Solar PV	-	0.0	0.0	177	409	656	952	0.0	2.5	8.5	50.2	7.2	4.3	5.4
Wind	-	0.0	0.6	366	907	1 321	1 497	0.0	5.1	13	54.1	7.9	2.5	4.5
CSP and marine	-	0.0	0.0	0.3	1.0	3.7	8.0	0.0	0.0	0.1	14.5	10.6	10.7	10.7
Biomass and waste	-	-	2.4	104	139	195	244	-	1.5	2.2	n.a.	2.5	2.8	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	341	828	2 232	10 797	20 026	29 506	37 968	9.6	5.3	3.3	4.0
Population (million)	981	1 135	1 263	1 393	1 429	1 414	1 368	0.7	0.2	-0.2	-0.1
CO_2 emissions (Mt)	1 399	2 146	3 140	9 348	10 360	9 853	8 562	5.4	0.9	-0.9	-0.3
GDP per capita ($2010 thousand)	0.3	0.7	1.8	7.8	14	21	28	8.8	5.1	3.5	4.1
Primary energy consump. per capita (toe)	0.6	0.8	0.9	2.3	2.6	2.7	2.6	4.0	1.1	0.0	0.4
Primary energy consumption per GDP*2	1 756	1 055	506	296	186	127	93	-4.4	-3.8	-3.4	-3.6
CO_2 emissions per GDP*3	4 106	2 593	1 407	866	517	334	226	-3.8	-4.2	-4.1	-4.1
CO_2 per primary energy consumption*4	2.3	2.5	2.8	2.9	2.8	2.6	2.4	0.6	-0.4	-0.7	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-23 | India [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	200	306	441	919	1 542	2 003	2 425	100	100	100	4.0	4.4	2.3	3.1
Coal	44	93	146	414	697	883	990	30	45	41	5.5	4.4	1.8	2.8
Oil	33	61	112	235	401	569	790	20	26	33	4.9	4.6	3.4	3.9
Natural gas	1.3	11	23	52	135	216	283	3.5	5.7	12	5.9	8.2	3.8	5.4
Nuclear	0.8	1.6	4.4	9.9	43	54	68	0.5	1.1	2.8	6.7	13.1	2.3	6.2
Hydro	4.0	6.2	6.4	13	21	28	35	2.0	1.4	1.4	2.7	4.1	2.5	3.1
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	0.0	0.2	9.9	34	55	81	0.0	1.1	3.3	27.8	10.9	4.4	6.8
Biomass and waste	116	133	149	185	211	200	178	44	20	7.4	1.2	1.1	-0.8	-0.1

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	174	243	315	607	1 002	1 305	1 621	100	100	100	3.3	4.3	2.4	3.1
Industry	42	67	85	206	391	499	559	28	34	34	4.1	5.5	1.8	3.2
Transport	17	21	32	104	183	292	469	8.5	17	29	5.9	4.9	4.8	4.8
Buildings, etc.	110	142	171	246	339	394	443	58	41	27	2.0	2.7	1.3	1.9
Non-energy use	5.7	13	27	51	89	120	151	5.5	8.4	9.3	4.9	4.7	2.7	3.5
Coal	25	38	33	107	186	233	261	16	18	16	3.7	4.7	1.7	2.8
Oil	27	50	94	208	364	520	727	21	34	45	5.2	4.8	3.5	4.0
Natural gas	0.7	6.1	12	32	80	116	146	2.5	5.3	9.0	6.2	7.8	3.1	4.8
Electricity	7.7	18	32	103	210	298	383	7.5	17	24	6.4	6.1	3.1	4.2
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	114	130	144	157	162	138	103	54	26	6.4	0.7	0.3	-2.2	-1.3

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	119	289	562	1 583	3 128	4 284	5 294	100	100	100	6.3	5.8	2.7	3.8
Coal	61	192	390	1 163	2 014	2 598	2 937	66	73	55	6.7	4.7	1.9	2.9
Oil	7.6	10	22	7.8	10	9.0	5.2	3.5	0.5	0.1	-0.9	2.2	-3.3	-1.3
Natural gas	0.6	10.0	56	74	242	447	672	3.4	4.6	13	7.4	10.4	5.2	7.2
Nuclear	3.0	6.1	17	38	165	206	262	2.1	2.4	4.9	6.7	13.1	2.3	6.2
Hydro	47	72	74	151	244	322	401	25	9.5	7.6	2.7	4.1	2.5	3.1
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	0.0	40	200	359	591	-	2.5	11	n.a.	14.4	5.6	8.8
Wind	-	0.0	1.7	64	162	221	270	0.0	4.1	5.1	31.2	8.0	2.6	4.6
CSP and marine	-	-	-	-	3.2	5.9	9.5	-	-	0.2	n.a.	n.a.	5.6	n.a.
Biomass and waste	-	-	1.3	45	87	116	146	-	2.9	2.8	n.a.	5.6	2.6	3.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	295	506	870	2 831	6 146	10 304	15 988	6.3	6.7	4.9	5.6
Population (million)	699	873	1 057	1 353	1 504	1 593	1 639	1.6	0.9	0.4	0.6
CO_2 emissions (Mt)	258	530	890	2 324	4 033	5 384	6 557	5.4	4.7	2.5	3.3
GDP per capita ($2010 thousand)	0.4	0.6	0.8	2.1	4.1	6.5	9.8	4.7	5.7	4.4	4.9
Primary energy consump. per capita (toe)	0.3	0.4	0.4	0.7	1.0	1.3	1.5	2.4	3.5	1.8	2.5
Primary energy consumption per GDP*2	679	605	507	325	251	194	152	-2.2	-2.1	-2.5	-2.4
CO_2 emissions per GDP*3	876	1 048	1 023	821	656	523	410	-0.9	-1.8	-2.3	-2.1
CO_2 per primary energy consumption*4	1.3	1.7	2.0	2.5	2.6	2.7	2.7	1.4	0.3	0.2	0.2

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-24 | Japan [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	345	439	518	426	406	377	347	100	100	100	-0.1	-0.4	-0.8	-0.6
Coal	60	77	97	114	98	90	76	17	27	22	1.4	-1.3	-1.2	-1.3
Oil	234	250	255	166	137	118	104	57	39	30	-1.5	-1.6	-1.4	-1.5
Natural gas	21	44	66	97	89	85	74	10	23	21	2.9	-0.7	-0.9	-0.9
Nuclear	22	53	84	17	41	37	37	12	4.0	11	-4.0	7.6	-0.6	2.4
Hydro	7.6	7.6	7.2	7.0	7.8	8.1	8.1	1.7	1.6	2.3	-0.3	1.0	0.2	0.5
Geothermal	0.8	1.6	3.1	2.3	5.3	8.4	11	0.4	0.5	3.1	1.4	7.2	3.7	5.0
Solar, wind, etc.	-	1.2	0.8	6.3	9.2	12	16	0.3	1.5	4.7	6.2	3.2	2.9	3.0
Biomass and waste	-	4.6	5.4	16	19	20	20	1.0	3.7	5.9	4.6	1.3	0.5	0.8

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	236	292	337	283	263	244	224	100	100	100	-0.1	-0.6	-0.8	-0.7
Industry	91	108	104	82	77	71	64	37	29	28	-1.0	-0.6	-0.9	-0.8
Transport	54	72	89	71	60	52	46	25	25	20	-0.1	-1.4	-1.3	-1.3
Buildings, etc.	58	78	108	96	94	89	84	27	34	37	0.7	-0.2	-0.6	-0.4
Non-energy use	32	34	37	34	33	32	31	12	12	14	0.0	-0.3	-0.4	-0.3
Coal	25	27	21	21	19	16	14	9.3	7.5	6.1	-0.9	-1.0	-1.5	-1.3
Oil	160	182	207	144	123	107	95	62	51	42	-0.8	-1.3	-1.3	-1.3
Natural gas	5.8	14	21	29	31	29	26	4.7	10	11	2.7	0.4	-0.9	-0.4
Electricity	44	66	84	81	84	85	84	22	29	38	0.8	0.2	0.0	0.1
Heat	0.1	0.2	0.5	0.5	0.5	0.4	0.3	0.1	0.2	0.1	3.6	-1.3	-1.8	-1.6
Hydrogen	-	-	-	-	0.0	0.0	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	-	3.9	4.3	6.6	6.5	6.0	5.5	1.3	2.3	2.4	1.9	-0.2	-0.8	-0.6

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	573	862	1 055	1 050	1 079	1 093	1 082	100	100	100	0.7	0.2	0.0	0.1
Coal	55	123	223	339	291	289	262	14	32	24	3.7	-1.3	-0.5	-0.8
Oil	265	250	134	52	21	2.0	-	29	4.9	-	-5.5	-7.3	-100	-100
Natural gas	81	168	258	378	329	330	288	20	36	27	2.9	-1.1	-0.7	-0.8
Nuclear	83	202	322	65	157	141	141	23	6.2	13	-4.0	7.6	-0.6	2.4
Hydro	88	88	84	81	91	94	94	10	7.7	8.7	-0.3	1.0	0.2	0.5
Geothermal	0.9	1.7	3.3	2.5	6.0	9.7	13	0.2	0.2	1.2	1.3	7.5	3.7	5.1
Solar PV	-	0.1	0.4	63	87	106	123	0.0	6.0	11	27.7	2.8	1.7	2.1
Wind	-	-	0.1	7.5	18	32	64	-	0.7	5.9	n.a.	7.5	6.6	6.9
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	8.7	9.9	44	60	70	78	1.0	4.2	7.2	6.0	2.6	1.3	1.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	19	19	19	19	2.3	1.8	1.8	-0.1	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	3 019	4 704	5 349	6 190	6 693	7 234	7 744	1.0	0.7	0.7	0.7
Population (million)	117	124	127	127	120	113	105	0.1	-0.4	-0.7	-0.6
CO_2 emissions (Mt)	904	1 058	1 161	1 081	940	852	738	0.1	-1.2	-1.2	-1.2
GDP per capita ($2010 thousand)	26	38	42	49	56	64	74	0.9	1.1	1.4	1.3
Primary energy consump. per capita (toe)	3.0	3.6	4.1	3.4	3.4	3.3	3.3	-0.2	0.0	-0.1	-0.1
Primary energy consumption per GDP[*2]	114	93	97	69	61	52	45	-1.1	-1.0	-1.5	-1.3
CO_2 emissions per GDP[*3]	299	225	217	175	140	118	95	-0.9	-1.8	-1.9	-1.9
CO_2 per primary energy consumption[*4]	2.6	2.4	2.2	2.5	2.3	2.3	2.1	0.2	-0.8	-0.4	-0.5

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-25 | Korea [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	41	93	188	282	299	290	268	100	100	100	4.0	0.5	-0.5	-0.2
Coal	14	25	42	81	82	76	64	27	29	24	4.2	0.1	-1.2	-0.7
Oil	27	50	99	110	111	106	99	54	39	37	2.9	0.1	-0.6	-0.3
Natural gas	-	2.7	17	48	62	69	73	2.9	17	27	10.8	2.2	0.8	1.3
Nuclear	0.9	14	28	35	32	25	17	15	12	6.4	3.4	-0.8	-3.0	-2.2
Hydro	0.2	0.5	0.3	0.3	0.3	0.3	0.3	0.6	0.1	0.1	-2.3	0.5	0.0	0.2
Geothermal	-	-	-	0.2	0.2	0.2	0.2	-	0.1	0.1	n.a.	1.1	-0.2	0.3
Solar, wind, etc.	-	0.0	0.0	1.2	2.8	4.3	6.3	0.0	0.4	2.3	18.8	7.1	4.1	5.2
Biomass and waste	-	0.7	1.4	7.1	9.0	9.1	8.4	0.8	2.5	3.1	8.4	2.0	-0.3	0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	31	65	127	182	201	200	189	100	100	100	3.8	0.8	-0.3	0.1
Industry	10	19	38	49	56	56	52	30	27	27	3.4	1.1	-0.4	0.2
Transport	4.8	15	26	35	35	33	29	22	19	15	3.2	0.1	-1.0	-0.6
Buildings, etc.	13	24	37	47	49	48	46	38	26	24	2.4	0.4	-0.3	0.0
Non-energy use	3.1	6.7	25	51	60	62	62	10	28	33	7.5	1.4	0.2	0.6
Coal	9.7	12	9.1	9.4	8.7	7.5	6.0	18	5.2	3.2	-0.8	-0.7	-1.8	-1.4
Oil	19	44	80	95	100	97	89	67	52	47	2.8	0.5	-0.6	-0.2
Natural gas	-	0.7	11	22	27	27	26	1.0	12	14	13.3	1.6	-0.2	0.5
Electricity	2.8	8.1	23	46	54	57	57	13	25	30	6.4	1.3	0.3	0.7
Heat	-	-	3.3	5.5	5.9	5.7	5.3	-	3.0	2.8	n.a.	0.5	-0.5	-0.1
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	-	0.7	1.3	4.5	5.7	5.4	4.7	1.1	2.5	2.5	6.7	1.9	-0.9	0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	37	105	289	586	687	731	734	100	100	100	6.3	1.3	0.3	0.7
Coal	2.5	18	111	258	283	285	258	17	44	35	10.1	0.8	-0.5	0.0
Oil	29	19	35	13	8.5	2.6	-	18	2.2	-	-1.3	-3.5	-100	-100
Natural gas	-	9.6	29	156	224	280	318	9.1	27	43	10.5	3.1	1.8	2.3
Nuclear	3.5	53	109	134	122	94	66	50	23	9.0	3.4	-0.8	-3.0	-2.2
Hydro	2.0	6.4	4.0	3.4	3.6	3.6	3.6	6.0	0.6	0.5	-2.3	0.5	0.0	0.2
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	0.0	0.0	9.2	24	35	49	0.0	1.6	6.7	38.5	8.2	3.7	5.4
Wind	-	-	0.0	2.5	5.7	9.6	16	-	0.4	2.1	n.a.	7.2	5.2	6.0
CSP and marine	-	-	-	0.5	3.2	4.7	8.0	-	0.1	1.1	n.a.	17.0	4.7	9.2
Biomass and waste	-	-	0.1	8.4	12	13	14	-	1.4	1.9	n.a.	2.8	0.9	1.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	1.9	1.9	1.9	1.9	-	0.3	0.3	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	141	363	710	1 382	1 859	2 275	2 626	4.9	2.5	1.7	2.0
Population (million)	38	43	47	52	51	50	47	0.7	0.0	-0.4	-0.3
CO_2 emissions (Mt)	109	209	404	602	629	608	550	3.8	0.4	-0.7	-0.3
GDP per capita ($2010 thousand)	3.7	8.5	15	27	36	45	56	4.2	2.5	2.2	2.3
Primary energy consump. per capita (toe)	1.1	2.2	4.0	5.5	5.8	5.8	5.7	3.4	0.5	-0.1	0.1
Primary energy consumption per GDP[*2]	292	256	265	204	161	128	102	-0.8	-2.0	-2.2	-2.1
CO_2 emissions per GDP[*3]	772	577	568	436	338	267	210	-1.0	-2.1	-2.4	-2.3
CO_2 per primary energy consumption[*4]	2.6	2.3	2.1	2.1	2.1	2.1	2.0	-0.2	-0.1	-0.1	-0.1

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-26 | Chinese Taipei [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	28	48	85	110	111	109	102	100	100	100	3.0	0.0	-0.4	-0.2
Coal	3.9	11	30	40	41	37	32	24	36	32	4.5	0.3	-1.2	-0.6
Oil	20	26	38	43	42	40	37	54	39	36	1.9	-0.2	-0.7	-0.5
Natural gas	1.6	1.4	5.6	18	23	25	26	2.9	16	26	9.6	2.1	0.6	1.2
Nuclear	2.1	8.6	10	7.2	-	-	-	18	6.5	-	-0.6	-100	n.a.	-100
Hydro	0.3	0.5	0.4	0.4	0.5	0.5	0.5	1.2	0.3	0.5	-1.3	1.7	0.1	0.7
Geothermal	-	0.0	-	-	-	-	-	0.0	-	-	-100	n.a.	n.a.	n.a.
Solar, wind, etc.	-	0.0	0.1	0.5	1.5	2.3	3.3	0.0	0.4	3.2	12.4	9.8	4.1	6.2
Biomass and waste	-	-	0.6	1.5	2.6	2.8	2.8	-	1.4	2.8	n.a.	4.4	0.5	2.0

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	19	29	49	72	73	73	70	100	100	100	3.2	0.2	-0.2	-0.1
Industry	10	12	19	24	25	24	23	42	33	33	2.4	0.3	-0.3	-0.1
Transport	2.8	6.6	11	12	11	9.8	8.0	23	17	11	2.2	-0.6	-1.7	-1.3
Buildings, etc.	3.5	6.5	10	12	12	13	13	22	17	19	2.2	0.3	0.2	0.3
Non-energy use	2.0	4.0	7.8	24	25	26	26	14	33	37	6.6	0.5	0.2	0.3
Coal	2.2	3.5	4.9	5.3	5.6	5.3	4.8	12	7.4	6.8	1.5	0.5	-0.8	-0.3
Oil	12	18	28	39	38	37	34	63	55	48	2.7	-0.2	-0.6	-0.4
Natural gas	1.4	0.9	1.6	3.5	3.9	3.8	3.6	3.0	4.9	5.1	5.1	1.0	-0.5	0.1
Electricity	3.2	6.6	14	21	24	25	26	22	30	37	4.3	0.9	0.5	0.6
Heat	-	-	-	1.8	1.4	1.4	1.3	-	2.5	1.8	n.a.	-1.9	-0.6	-1.1
Hydrogen	-	-	-	-	0.0	0.0	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	-	0.0	0.1	0.5	0.6	0.6	0.5	0.1	0.7	0.8	12.5	1.0	0.0	0.4

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	43	88	181	272	302	323	333	100	100	100	4.1	0.9	0.5	0.6
Coal	6.0	24	89	131	137	126	110	28	48	33	6.2	0.3	-1.1	-0.5
Oil	26	23	30	8.2	7.1	5.1	2.8	26	3.0	0.9	-3.7	-1.2	-4.5	-3.3
Natural gas	-	1.2	17	92	129	152	169	1.4	34	51	16.6	2.8	1.3	1.9
Nuclear	8.2	33	39	28	-	-	-	37	10	-	-0.6	-100	n.a.	-100
Hydro	2.9	6.4	4.6	4.5	5.4	5.5	5.5	7.2	1.6	1.7	-1.3	1.7	0.1	0.7
Geothermal	-	0.0	-	-	-	-	-	0.0	-	-	-100	n.a.	n.a.	n.a.
Solar PV	-	-	-	2.7	6.5	10	14	-	1.0	4.3	n.a.	7.5	4.1	5.3
Wind	-	-	0.0	1.7	9.6	16	23	-	0.6	7.0	n.a.	15.6	4.5	8.5
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	1.7	3.7	7.2	8.3	8.7	-	1.4	2.6	n.a.	5.7	0.9	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	70	155	297	544	687	827	953	4.6	2.0	1.7	1.8
Population (million)	18	20	22	24	24	23	22	0.5	0.1	-0.3	-0.2
CO_2 emissions (Mt)	70	105	203	255	266	250	223	3.2	0.4	-0.9	-0.4
GDP per capita ($2010 thousand)	3.9	7.6	13	23	29	35	43	4.0	1.8	2.0	1.9
Primary energy consump. per capita (toe)	1.6	2.3	3.8	4.7	4.6	4.6	4.6	2.5	-0.1	-0.1	-0.1
Primary energy consumption per GDP[*2]	396	307	286	203	161	131	107	-1.5	-1.9	-2.0	-2.0
CO_2 emissions per GDP[*3]	993	679	684	468	388	303	234	-1.3	-1.6	-2.5	-2.1
CO_2 per primary energy consumption[*4]	2.5	2.2	2.4	2.3	2.4	2.3	2.2	0.2	0.3	-0.5	-0.2

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-27 | ASEAN [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	142	233	379	669	969	1 192	1 399	100	100	100	3.8	3.1	1.9	2.3
Coal	3.6	13	32	150	226	284	324	5.4	22	23	9.3	3.5	1.8	2.4
Oil	58	89	153	239	319	381	442	38	36	32	3.6	2.4	1.6	1.9
Natural gas	8.6	30	74	141	229	287	341	13	21	24	5.7	4.1	2.0	2.8
Nuclear	-	-	-	-	-	9.7	18	-	-	1.3	n.a.	n.a.	n.a.	n.a.
Hydro	0.8	2.3	4.1	14	18	21	23	1.0	2.1	1.6	6.6	2.3	1.0	1.5
Geothermal	1.8	6.6	18	33	75	96	117	2.9	4.9	8.4	5.9	7.1	2.3	4.0
Solar, wind, etc.	-	-	-	0.9	5.3	12	28	-	0.1	2.0	n.a.	16.1	8.6	11.3
Biomass and waste	69	92	98	89	93	98	102	40	13	7.3	-0.1	0.3	0.5	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	112	172	269	454	635	778	917	100	100	100	3.5	2.8	1.9	2.2
Industry	22	42	75	151	228	281	327	24	33	36	4.7	3.5	1.8	2.4
Transport	17	32	61	132	176	218	264	19	29	29	5.1	2.4	2.0	2.2
Buildings, etc.	70	87	112	113	141	170	200	50	25	22	1.0	1.8	1.8	1.8
Non-energy use	2.4	11	21	58	90	108	126	6.3	13	14	6.1	3.7	1.7	2.5
Coal	2.1	5.4	13	40	57	68	76	3.1	8.9	8.2	7.5	2.9	1.4	2.0
Oil	41	67	123	219	292	351	410	39	48	45	4.3	2.4	1.7	2.0
Natural gas	2.5	7.5	17	46	87	109	127	4.4	10	14	6.7	5.4	1.9	3.2
Electricity	4.7	11	28	81	136	188	245	6.5	18	27	7.3	4.4	3.0	3.5
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-7.8	n.a.
Renewables	61	81	89	68	63	62	59	47	15	6.5	-0.7	-0.6	-0.3	-0.4

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	62	154	370	1 059	1 763	2 435	3 152	100	100	100	7.1	4.3	2.9	3.5
Coal	3.0	28	79	442	744	1 002	1 226	18	42	39	10.4	4.4	2.5	3.2
Oil	47	66	72	20	28	32	28	43	1.9	0.9	-4.2	2.8	0.0	1.1
Natural gas	0.7	26	154	366	614	853	1 085	17	35	34	9.9	4.4	2.9	3.5
Nuclear	-	-	-	-	-	37	71	-	-	2.2	n.a.	n.a.	n.a.	n.a.
Hydro	9.8	27	47	163	215	243	262	18	15	8.3	6.6	2.3	1.0	1.5
Geothermal	2.1	6.6	16	24	54	67	81	4.3	2.3	2.6	4.8	6.8	2.1	3.8
Solar PV	-	-	-	6.7	45	112	278	-	0.6	8.8	n.a.	17.2	9.5	12.3
Wind	-	-	-	3.5	17	27	42	-	0.3	1.3	n.a.	13.8	4.8	8.1
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	33	47	63	78	0.4	3.1	2.5	15.4	3.0	2.5	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	441	742	1 182	2 893	4 968	7 422	10 452	5.0	4.6	3.8	4.1
Population (million)	347	431	507	631	699	738	761	1.4	0.9	0.4	0.6
CO_2 emissions (Mt)	185	341	669	1 444	2 106	2 608	3 026	5.3	3.2	1.8	2.3
GDP per capita ($2010 thousand)	1.3	1.7	2.3	4.6	7.1	10	14	3.6	3.7	3.3	3.5
Primary energy consump. per capita (toe)	0.4	0.5	0.7	1.1	1.4	1.6	1.8	2.4	2.3	1.4	1.7
Primary energy consumption per GDP[*2]	322	313	321	231	195	161	134	-1.1	-1.4	-1.9	-1.7
CO_2 emissions per GDP[*3]	420	459	566	499	424	351	289	0.3	-1.3	-1.9	-1.7
CO_2 per primary energy consumption[*4]	1.3	1.5	1.8	2.2	2.2	2.2	2.2	1.4	0.1	0.0	0.0

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-28 | Indonesia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	56	99	156	231	346	447	541	100	100	100	3.1	3.4	2.3	2.7
Coal	0.2	3.5	12	55	90	121	137	3.6	24	25	10.3	4.2	2.1	2.9
Oil	20	33	58	77	105	129	151	34	33	28	3.0	2.6	1.9	2.1
Natural gas	5.0	16	27	39	70	98	126	16	17	23	3.3	5.0	3.0	3.7
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.5	0.9	1.9	2.2	2.7	3.1	0.5	0.8	0.6	4.9	1.4	1.8	1.6
Geothermal	-	1.9	8.4	24	58	76	96	2.0	10	18	9.4	7.6	2.6	4.4
Solar, wind, etc.	-	-	-	0.0	0.3	2.6	11	-	0.0	2.0	n.a.	23.3	19.6	21.0
Biomass and waste	30	44	50	34	20	18	17	44	15	3.1	-0.9	-4.0	-1.0	-2.1

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	50	79	120	156	214	271	326	100	100	100	2.5	2.7	2.1	2.3
Industry	6.7	17	30	50	74	93	109	22	32	34	3.8	3.3	1.9	2.5
Transport	6.0	11	21	54	76	97	119	14	35	37	6.0	2.8	2.3	2.5
Buildings, etc.	36	44	59	43	49	61	74	55	28	23	-0.1	1.0	2.1	1.7
Non-energy use	1.2	7.4	9.8	8.5	15	20	24	9.3	5.4	7.3	0.5	5.0	2.3	3.3
Coal	0.1	1.5	4.6	15	22	27	32	1.9	9.4	9.7	8.4	3.3	1.9	2.4
Oil	17	27	48	76	102	124	146	34	48	45	3.7	2.5	1.8	2.1
Natural gas	2.4	6.0	12	17	33	44	53	7.6	11	16	3.7	5.8	2.4	3.7
Electricity	0.6	2.4	6.8	22	40	60	82	3.1	14	25	8.2	5.0	3.7	4.2
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	29	42	49	27	18	15	14	53	17	4.2	-1.6	-3.3	-1.4	-2.1

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	7.5	33	93	284	513	782	1 065	100	100	100	8.0	5.1	3.7	4.2
Coal	-	9.8	34	160	287	408	482	30	56	45	10.5	5.0	2.6	3.5
Oil	6.2	15	18	15	23	28	27	47	5.2	2.5	-0.1	3.7	0.7	1.8
Natural gas	-	0.7	26	59	137	236	334	2.2	21	31	17.0	7.2	4.5	5.5
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	1.3	5.7	10	22	25	31	36	17	7.6	3.4	4.9	1.4	1.8	1.6
Geothermal	-	1.1	4.9	14	34	44	56	3.4	4.9	5.3	9.4	7.6	2.6	4.4
Solar PV	-	-	-	0.1	2.1	27	119	-	0.0	11	n.a.	30.2	22.2	25.1
Wind	-	-	-	0.2	1.3	2.7	5.6	-	0.1	0.5	n.a.	17.6	7.4	11.1
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	0.0	14	3.4	4.6	5.8	-	4.8	0.5	n.a.	-10.8	2.6	-2.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	182	310	453	1 147	2 089	3 278	4 753	4.8	5.1	4.2	4.5
Population (million)	147	181	212	268	299	319	331	1.4	0.9	0.5	0.7
CO_2 emissions (Mt)	64	130	254	539	817	1 062	1 248	5.2	3.5	2.1	2.7
GDP per capita ($2010 thousand)	1.2	1.7	2.1	4.3	7.0	10	14	3.3	4.1	3.7	3.8
Primary energy consump. per capita (toe)	0.4	0.5	0.7	0.9	1.2	1.4	1.6	1.7	2.5	1.7	2.0
Primary energy consumption per GDP[*2]	307	318	343	202	166	136	114	-1.6	-1.6	-1.9	-1.8
CO_2 emissions per GDP[*3]	351	420	561	470	391	324	263	0.4	-1.5	-2.0	-1.8
CO_2 per primary energy consumption[*4]	1.1	1.3	1.6	2.3	2.4	2.4	2.3	2.1	0.1	-0.1	0.0

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-29 | Malaysia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	11	21	48	93	131	148	158	100	100	100	5.4	2.9	0.9	1.6
Coal	0.1	1.4	2.3	23	28	30	28	6.4	24	18	10.6	1.8	-0.1	0.6
Oil	7.9	11	19	29	35	35	34	54	31	22	3.4	1.6	-0.1	0.5
Natural gas	2.2	6.8	25	39	64	74	83	32	42	53	6.4	4.2	1.4	2.4
Nuclear	-	-	-	-	-	3.7	3.7	-	-	2.3	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.3	0.6	2.3	3.0	3.3	3.4	1.6	2.4	2.2	7.0	2.4	0.7	1.3
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	0.0	0.2	0.4	2.8	-	0.1	1.8	n.a.	11.7	14.6	13.5
Biomass and waste	1.2	1.2	1.3	0.9	1.7	2.0	2.4	5.9	0.9	1.5	-1.2	5.5	1.9	3.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	6.9	13	29	63	88	99	108	100	100	100	5.7	2.9	1.0	1.7
Industry	3.1	5.6	12	20	25	29	32	41	31	29	4.6	2.2	1.1	1.5
Transport	2.1	4.9	11	21	22	22	21	36	34	19	5.3	0.5	-0.3	0.0
Buildings, etc.	1.4	2.1	4.3	8.8	12	15	17	16	14	15	5.2	2.8	1.5	2.0
Non-energy use	0.3	0.8	2.2	13	28	34	39	6.3	21	36	10.4	6.5	1.6	3.4
Coal	0.1	0.5	1.0	1.8	2.0	2.0	2.0	3.8	2.9	1.9	4.6	0.6	0.2	0.3
Oil	5.3	9.3	18	28	32	32	32	70	45	29	4.0	1.1	-0.1	0.3
Natural gas	0.0	1.1	3.9	19	34	41	46	8.2	30	42	10.7	5.1	1.4	2.8
Electricity	0.7	1.7	5.3	13	19	24	28	13	21	26	7.5	3.1	2.0	2.4
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	0.8	0.8	0.7	0.4	0.6	0.6	0.7	5.7	0.7	0.6	-2.0	2.0	1.2	1.5

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	10	23	69	170	247	309	366	100	100	100	7.4	3.1	2.0	2.4
Coal	-	2.9	7.7	77	102	113	113	13	45	31	12.4	2.4	0.5	1.2
Oil	8.5	11	3.6	1.0	0.8	0.3	-	46	0.6	-	-7.9	-1.9	-100	-100
Natural gas	0.1	5.5	51	64	103	134	160	24	37	44	9.1	4.1	2.2	2.9
Nuclear	-	-	-	-	-	14	14	-	-	3.8	n.a.	n.a.	n.a.	n.a.
Hydro	1.4	4.0	7.0	26	35	39	40	17	15	11	7.0	2.4	0.7	1.3
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	0.6	2.2	4.3	33	-	0.3	9.0	n.a.	11.7	14.6	13.5
Wind	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	-	1.4	3.4	4.5	5.7	-	0.8	1.6	n.a.	7.9	2.6	4.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	46	82	163	382	640	912	1 229	5.7	4.4	3.3	3.7
Population (million)	14	18	23	32	36	39	41	2.0	1.1	0.6	0.8
CO_2 emissions (Mt)	26	51	111	222	280	298	296	5.4	2.0	0.3	0.9
GDP per capita ($2010 thousand)	3.3	4.5	7.0	12	18	24	30	3.6	3.2	2.7	2.9
Primary energy consump. per capita (toe)	0.8	1.2	2.1	3.0	3.6	3.8	3.9	3.4	1.7	0.3	0.8
Primary energy consumption per GDP[*2]	251	259	297	245	205	163	128	-0.2	-1.5	-2.3	-2.0
CO_2 emissions per GDP[*3]	568	625	680	580	437	327	241	-0.3	-2.3	-2.9	-2.7
CO_2 per primary energy consumption[*4]	2.3	2.4	2.3	2.4	2.1	2.0	1.9	-0.1	-0.9	-0.6	-0.7

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-30 | Myanmar [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	9.4	11	13	24	39	51	62	100	100	100	2.9	4.1	2.4	3.0
Coal	0.2	0.1	0.3	0.9	3.0	5.3	8.2	0.6	3.7	13	9.6	10.9	5.1	7.2
Oil	1.3	0.7	2.0	6.9	13	19	24	6.8	29	39	8.3	5.5	3.1	4.0
Natural gas	0.3	0.8	1.2	4.1	12	18	23	7.1	17	37	6.2	9.4	3.3	5.6
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.1	0.2	1.2	1.5	1.8	2.0	1.0	5.1	3.2	9.2	1.7	1.5	1.6
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	0.0	0.1	0.2	0.5	-	0.0	0.7	n.a.	44.3	9.7	21.6
Biomass and waste	7.6	9.0	9.2	11	11	9.4	7.1	84	46	11	0.7	-0.3	-2.0	-1.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	8.4	9.4	11	20	29	36	43	100	100	100	2.8	3.0	2.0	2.4
Industry	0.6	0.4	1.1	3.7	6.8	10	13	4.2	18	31	8.3	5.3	3.4	4.1
Transport	0.6	0.4	1.2	2.1	4.0	6.4	9.1	4.7	10	21	5.7	5.6	4.1	4.7
Buildings, etc.	7.0	8.5	9.1	14	17	19	19	90	69	45	1.8	1.8	0.6	1.0
Non-energy use	0.1	0.1	0.1	0.5	0.7	0.9	1.1	1.0	2.4	2.6	6.0	3.2	2.4	2.7
Coal	0.1	0.1	0.3	0.3	0.4	0.5	0.6	0.5	1.3	1.3	6.0	3.3	1.9	2.4
Oil	1.2	0.6	1.5	6.8	13	19	24	6.2	34	56	9.2	5.5	3.2	4.0
Natural gas	0.1	0.2	0.3	0.6	0.8	1.0	1.2	2.4	2.8	2.9	3.4	2.5	2.4	2.4
Electricity	0.1	0.1	0.3	1.6	4.0	6.7	10.0	1.6	7.9	23	8.8	8.1	4.6	5.9
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-2.7	n.a.
Renewables	6.9	8.4	9.0	11	11	9.4	7.1	89	54	16	0.9	-0.3	-2.0	-1.3

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	1.5	2.5	5.1	25	78	122	175	100	100	100	8.5	10.1	4.1	6.3
Coal	0.0	0.0	-	1.5	11	22	37	1.6	6.3	21	13.9	18.0	6.2	10.5
Oil	0.5	0.3	0.7	0.1	0.3	0.2	-	11	0.3	-	-4.4	11.1	-100	-100
Natural gas	0.2	1.0	2.5	8.8	48	77	109	39	36	62	8.2	15.3	4.2	8.2
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.8	1.2	1.9	14	17	21	23	48	58	13	9.2	1.7	1.5	1.6
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	0.0	0.6	1.8	4.7	-	0.0	2.7	n.a.	39.5	11.3	21.1
Wind	-	-	-	0.0	0.3	0.4	0.7	-	0.0	0.4	n.a.	121	4.4	38.4
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	5.9	6.7	13	71	143	238	369	8.8	6.0	4.9	5.3
Population (million)	34	41	47	54	58	61	62	0.9	0.7	0.3	0.5
CO_2 emissions (Mt)	5.2	4.0	9.5	31	77	116	157	7.6	7.8	3.6	5.2
GDP per capita ($2010 thousand)	0.2	0.2	0.3	1.3	2.4	3.9	5.9	7.8	5.3	4.5	4.8
Primary energy consump. per capita (toe)	0.3	0.3	0.3	0.4	0.7	0.8	1.0	1.9	3.4	2.1	2.6
Primary energy consumption per GDP*2	1 597	1 594	960	337	271	213	169	-5.4	-1.8	-2.3	-2.1
CO_2 emissions per GDP*3	879	602	711	445	540	488	426	-1.1	1.6	-1.2	-0.1
CO_2 per primary energy consumption*4	0.6	0.4	0.7	1.3	2.0	2.3	2.5	4.6	3.5	1.2	2.0

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-31 | Philippines [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	22	29	40	60	94	119	146	100	100	100	2.7	3.8	2.2	2.8
Coal	0.5	1.5	5.2	18	24	30	34	5.3	30	23	9.2	2.6	1.7	2.0
Oil	10	11	16	20	35	49	65	38	33	45	2.2	4.7	3.2	3.8
Natural gas	-	-	0.0	3.6	6.3	9.1	12	-	6.0	8.1	n.a.	4.7	3.2	3.8
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.3	0.5	0.7	0.8	1.1	1.2	1.3	1.8	1.3	0.9	1.6	2.6	0.9	1.6
Geothermal	1.8	4.7	10	9.0	17	19	21	16	15	15	2.3	5.6	1.1	2.7
Solar, wind, etc.	-	-	-	0.2	0.8	1.6	2.8	-	0.3	1.9	n.a.	11.7	6.6	8.5
Biomass and waste	9.4	11	8.1	8.5	9.6	9.4	9.1	39	14	6.2	-1.0	1.0	-0.3	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	16	20	24	34	55	74	96	100	100	100	2.0	4.1	2.8	3.3
Industry	3.4	4.7	5.3	7.6	11	14	17	24	23	18	1.8	3.4	2.0	2.5
Transport	3.3	4.5	8.1	12	24	35	49	23	36	51	3.6	5.7	3.6	4.4
Buildings, etc.	9.4	10	10	13	18	21	24	52	37	26	0.8	2.8	1.7	2.1
Non-energy use	0.3	0.2	0.3	1.3	2.2	3.5	5.6	1.2	3.7	5.9	6.3	4.8	4.7	4.8
Coal	0.2	0.6	0.8	2.5	3.5	4.1	4.7	3.1	7.4	4.9	5.2	2.7	1.5	2.0
Oil	6.8	8.1	13	18	33	46	63	41	54	66	2.9	5.0	3.3	4.0
Natural gas	-	-	-	0.1	0.1	0.2	0.2	-	0.2	0.2	n.a.	7.0	2.8	4.4
Electricity	1.5	1.8	3.1	7.1	12	17	22	9.3	21	23	5.0	4.4	3.0	3.5
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	7.8	9.1	6.9	5.9	6.8	6.5	6.0	46	18	6.3	-1.5	1.1	-0.6	0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	18	26	45	99	165	227	291	100	100	100	4.9	4.3	2.9	3.4
Coal	0.2	1.9	17	52	80	109	134	7.3	52	46	12.5	3.7	2.6	3.0
Oil	12	12	9.2	3.2	3.4	2.8	1.2	47	3.2	0.4	-4.8	0.6	-5.2	-3.1
Natural gas	-	-	0.0	21	38	59	81	-	22	28	n.a.	5.0	3.8	4.2
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	3.5	6.1	7.8	9.4	13	14	15	23	9.5	5.3	1.6	2.6	0.9	1.6
Geothermal	2.1	5.5	12	10	20	23	25	21	11	8.5	2.3	5.6	1.1	2.7
Solar PV	-	-	-	1.2	4.9	12	20	-	1.3	7.0	n.a.	12.0	7.4	9.1
Wind	-	-	-	1.2	4.2	6.8	12	-	1.2	4.2	n.a.	11.3	5.5	7.7
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	0.4	-	0.5	1.3	1.8	2.2	1.6	0.5	0.8	0.8	7.9	2.6	4.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	80	95	125	322	613	907	1 290	4.5	5.5	3.8	4.4
Population (million)	47	62	78	107	124	136	144	2.0	1.2	0.8	1.0
CO_2 emissions (Mt)	31	36	67	133	206	271	337	4.8	3.7	2.5	3.0
GDP per capita ($2010 thousand)	1.7	1.5	1.6	3.0	5.0	6.7	8.9	2.5	4.2	3.0	3.4
Primary energy consump. per capita (toe)	0.5	0.5	0.5	0.6	0.8	0.9	1.0	0.7	2.5	1.4	1.8
Primary energy consumption per GDP[*2]	280	304	319	186	154	132	113	-1.7	-1.6	-1.5	-1.5
CO_2 emissions per GDP[*3]	392	382	532	411	335	299	262	0.3	-1.7	-1.2	-1.4
CO_2 per primary energy consumption[*4]	1.4	1.3	1.7	2.2	2.2	2.3	2.3	2.0	-0.1	0.3	0.1

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-32 | Thailand [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	22	42	72	136	172	193	209	100	100	100	4.3	2.0	1.0	1.4
Coal	0.5	3.8	7.7	16	17	17	16	9.1	12	7.5	5.2	0.7	-0.5	0.0
Oil	11	18	32	55	64	69	72	43	41	35	4.1	1.2	0.6	0.8
Natural gas	-	5.0	17	36	44	47	47	12	26	22	7.3	1.8	0.3	0.9
Nuclear	-	-	-	-	-	1.8	6.2	-	-	3.0	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.4	0.5	0.7	0.8	0.9	1.0	1.0	0.5	0.5	1.5	1.9	0.9	1.3
Geothermal	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	9.9	1.1	4.3
Solar, wind, etc.	-	-	-	0.5	2.3	4.3	6.6	-	0.4	3.2	n.a.	12.8	5.4	8.1
Biomass and waste	11	15	15	26	39	47	54	35	19	26	2.0	3.6	1.6	2.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	15	29	51	100	121	136	147	100	100	100	4.5	1.6	1.0	1.2
Industry	4.0	8.7	17	30	39	46	49	30	30	33	4.6	2.2	1.1	1.5
Transport	3.2	9.0	15	28	29	32	33	31	28	23	4.1	0.5	0.7	0.6
Buildings, etc.	7.8	11	14	18	21	23	24	37	18	17	1.8	1.5	0.7	1.0
Non-energy use	0.2	0.4	5.6	25	31	36	40	1.5	25	27	15.5	2.0	1.3	1.5
Coal	0.1	1.3	3.5	6.8	7.4	7.2	6.6	4.5	6.8	4.5	6.1	0.7	-0.6	-0.1
Oil	7.3	15	29	55	62	67	70	52	55	47	4.7	1.1	0.6	0.8
Natural gas	-	0.1	1.1	7.2	10	13	15	0.5	7.2	10	15.2	3.0	1.9	2.3
Electricity	1.1	3.3	7.6	16	23	29	33	11	16	23	5.8	3.1	1.8	2.3
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	6.7	9.3	9.4	15	18	20	22	32	15	15	1.8	1.3	1.0	1.1

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	14	44	96	182	249	307	350	100	100	100	5.2	2.6	1.7	2.1
Coal	1.4	11	18	36	43	47	44	25	20	13	4.3	1.4	0.1	0.6
Oil	12	10	10	0.2	-	-	-	23	0.1	-	-13.5	-100	n.a.	-100
Natural gas	-	18	62	116	134	145	135	40	63	39	6.9	1.3	0.0	0.5
Nuclear	-	-	-	-	-	7.0	24	-	-	6.8	n.a.	n.a.	n.a.	n.a.
Hydro	1.3	5.0	6.0	7.6	9.5	11	11	11	4.1	3.3	1.5	1.9	0.9	1.3
Geothermal	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	9.9	1.1	4.3
Solar PV	-	-	-	4.5	21	42	66	-	2.5	19	n.a.	13.8	5.8	8.7
Wind	-	-	-	1.6	4.9	7.4	9.7	-	0.9	2.8	n.a.	9.5	3.5	5.7
CSP and marine	-	-	-	-	0.1	0.2	0.3	-	-	0.1	n.a.	n.a.	8.3	n.a.
Biomass and waste	-	-	0.5	16	36	48	60	-	9.0	17	n.a.	6.8	2.6	4.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	67	142	218	442	656	907	1 191	4.1	3.3	3.0	3.1
Population (million)	47	57	63	69	70	69	66	0.7	0.1	-0.3	-0.2
CO_2 emissions (Mt)	31	77	147	238	272	281	271	4.1	1.1	0.0	0.4
GDP per capita ($2010 thousand)	1.4	2.5	3.5	6.4	9.3	13	18	3.4	3.2	3.4	3.3
Primary energy consump. per capita (toe)	0.5	0.7	1.1	2.0	2.4	2.8	3.2	3.5	1.9	1.3	1.5
Primary energy consumption per GDP*2	331	298	332	307	263	213	175	0.1	-1.3	-2.0	-1.7
CO_2 emissions per GDP*3	466	546	674	539	414	310	227	0.0	-2.2	-3.0	-2.7
CO_2 per primary energy consumption*4	1.4	1.8	2.0	1.8	1.6	1.5	1.3	-0.2	-0.9	-1.0	-0.9

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-33 | Viet Nam [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	14	18	29	83	140	184	233	100	100	100	5.7	4.4	2.6	3.3
Coal	2.3	2.2	4.4	37	62	80	100	12	44	43	10.5	4.5	2.4	3.2
Oil	1.8	2.7	7.8	22	36	47	60	15	27	26	7.9	3.9	2.6	3.1
Natural gas	-	0.0	1.1	7.9	20	28	37	0.0	9.5	16	33.0	8.0	3.1	4.9
Nuclear	-	-	-	-	-	4.2	8.6	-	-	3.7	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.5	1.3	7.2	9.9	11	12	2.6	8.7	5.0	10.3	2.6	0.8	1.5
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	0.0	1.6	2.7	4.0	-	0.1	1.7	n.a.	34.7	4.7	15.1
Biomass and waste	10	12	14	8.9	9.6	10	11	70	11	4.6	-1.2	0.6	0.6	0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	13	16	25	60	103	135	170	100	100	100	4.8	4.6	2.5	3.3
Industry	3.8	4.5	7.9	33	62	80	97	28	54	57	7.3	5.5	2.3	3.5
Transport	0.6	1.4	3.5	12	18	24	31	8.6	20	18	8.0	3.5	2.7	3.0
Buildings, etc.	8.6	10	14	14	20	28	38	63	24	22	1.2	3.1	3.1	3.1
Non-energy use	0.0	0.0	0.1	1.5	2.3	3.2	4.1	0.2	2.5	2.4	15.3	3.8	2.8	3.2
Coal	1.5	1.3	3.2	14	22	27	30	8.3	24	18	8.8	3.7	1.6	2.4
Oil	1.7	2.3	6.5	21	34	45	58	15	34	34	8.1	4.2	2.7	3.3
Natural gas	-	-	0.0	1.0	6.2	8.0	9.5	-	1.6	5.6	n.a.	16.6	2.2	7.3
Electricity	0.2	0.5	1.9	16	32	46	63	3.3	27	37	13.0	5.9	3.4	4.3
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-13.2	n.a.
Renewables	9.7	12	13	8.1	8.7	9.6	9.9	74	13	5.8	-1.4	0.6	0.6	0.6

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	3.6	8.7	27	241	441	612	826	100	100	100	12.6	5.2	3.2	3.9
Coal	1.4	2.0	3.1	114	219	303	415	23	47	50	15.5	5.6	3.2	4.1
Oil	0.7	1.3	4.5	0.3	-	-	-	15	0.1	-	-5.6	-100	n.a.	-100
Natural gas	-	0.0	4.4	42	88	133	196	0.1	17	24	37.2	6.5	4.1	5.0
Nuclear	-	-	-	-	-	16	33	-	-	4.0	n.a.	n.a.	n.a.	n.a.
Hydro	1.5	5.4	15	84	115	128	135	62	35	16	10.3	2.6	0.8	1.5
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	0.0	13	22	33	-	0.0	4.0	n.a.	69.4	4.8	25.5
Wind	-	-	-	0.5	5.8	9.6	14	-	0.2	1.7	n.a.	22.8	4.4	11.0
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	-	0.1	0.2	0.3	0.3	-	0.1	0.0	n.a.	4.2	2.6	3.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	17	29	61	188	375	624	985	6.8	5.9	4.9	5.3
Population (million)	54	68	80	96	104	108	110	1.2	0.7	0.3	0.4
CO_2 emissions (Mt)	15	17	43	227	396	517	655	9.7	4.7	2.5	3.4
GDP per capita ($2010 thousand)	0.3	0.4	0.8	2.0	3.6	5.8	9.0	5.5	5.2	4.7	4.9
Primary energy consump. per capita (toe)	0.3	0.3	0.4	0.9	1.3	1.7	2.1	4.4	3.6	2.3	2.8
Primary energy consumption per GDP[*2]	851	607	470	445	372	295	237	-1.1	-1.5	-2.2	-2.0
CO_2 emissions per GDP[*3]	859	572	699	1 210	1 055	828	665	2.7	-1.1	-2.3	-1.9
CO_2 per primary energy consumption[*4]	1.0	0.9	1.5	2.7	2.8	2.8	2.8	3.9	0.3	0.0	0.1

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-34 | North America [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	1 997	2 126	2 527	2 528	2 472	2 423	2 333	100	100	100	0.6	-0.2	-0.3	-0.3
Coal	397	484	566	336	250	208	149	23	13	6.4	-1.3	-2.4	-2.6	-2.5
Oil	885	833	958	905	834	777	719	39	36	31	0.3	-0.7	-0.7	-0.7
Natural gas	522	493	622	815	896	907	868	23	32	37	1.8	0.8	-0.2	0.2
Nuclear	80	179	227	245	201	185	177	8.4	9.7	7.6	1.1	-1.7	-0.6	-1.0
Hydro	46	49	53	59	61	63	64	2.3	2.3	2.7	0.6	0.4	0.2	0.3
Geothermal	4.6	14	13	10	18	31	38	0.7	0.4	1.6	-1.2	5.2	3.7	4.2
Solar, wind, etc.	-	0.3	2.1	37	72	108	170	0.0	1.5	7.3	18.5	5.6	4.4	4.9
Biomass and waste	62	73	87	121	141	145	149	3.4	4.8	6.4	1.8	1.3	0.3	0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	1 466	1 452	1 734	1 800	1 780	1 742	1 689	100	100	100	0.8	-0.1	-0.3	-0.2
Industry	437	331	388	322	329	330	323	23	18	19	-0.1	0.2	-0.1	0.0
Transport	470	531	640	706	651	615	585	37	39	35	1.0	-0.7	-0.5	-0.6
Buildings, etc.	446	456	533	600	607	597	577	31	33	34	1.0	0.1	-0.3	-0.1
Non-energy use	114	134	173	172	193	200	205	9.2	9.5	12	0.9	1.0	0.3	0.6
Coal	60	59	36	20	17	15	12	4.1	1.1	0.7	-3.9	-1.4	-1.5	-1.5
Oil	769	749	870	860	797	745	695	52	48	41	0.5	-0.6	-0.7	-0.7
Natural gas	374	346	413	432	445	424	400	24	24	24	0.8	0.2	-0.5	-0.2
Electricity	200	262	342	381	413	453	480	18	21	28	1.3	0.7	0.8	0.7
Heat	1.0	2.8	6.1	6.9	6.2	5.6	5.0	0.2	0.4	0.3	3.3	-0.9	-1.1	-1.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	62	33	66	101	103	100	97	2.3	5.6	5.7	4.1	0.1	-0.3	-0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	2 801	3 685	4 631	5 088	5 500	5 993	6 309	100	100	100	1.2	0.6	0.7	0.7
Coal	1 303	1 782	2 247	1 323	1 106	941	668	48	26	11	-1.1	-1.5	-2.5	-2.1
Oil	277	147	133	49	39	28	14	4.0	1.0	0.2	-3.8	-2.0	-4.8	-3.7
Natural gas	380	391	668	1 582	1 972	2 298	2 308	11	31	37	5.1	1.9	0.8	1.2
Nuclear	304	685	871	942	770	708	680	19	19	11	1.1	-1.7	-0.6	-1.0
Hydro	530	570	612	681	715	731	740	15	13	12	0.6	0.4	0.2	0.3
Geothermal	5.4	16	15	19	36	64	77	0.4	0.4	1.2	0.6	5.6	3.8	4.5
Solar PV	-	0.0	0.2	85	161	365	761	0.0	1.7	12	44.2	5.5	8.1	7.1
Wind	-	3.1	5.9	309	482	557	653	0.1	6.1	10	17.9	3.8	1.5	2.4
CSP and marine	-	0.7	0.6	4.0	52	100	174	0.0	0.1	2.8	6.4	23.9	6.3	12.5
Biomass and waste	1.8	90	80	88	162	197	228	2.5	1.7	3.6	-0.1	5.2	1.7	3.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	5.5	5.5	5.5	5.5	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	7 216	9 935	13 827	19 761	24 631	30 511	36 654	2.5	1.9	2.0	1.9
Population (million)	252	277	313	364	390	410	425	1.0	0.6	0.4	0.5
CO_2 emissions (Mt)	4 997	5 184	6 154	5 501	5 046	4 719	4 215	0.2	-0.7	-0.9	-0.8
GDP per capita ($2010 thousand)	29	36	44	54	63	74	86	1.5	1.3	1.6	1.5
Primary energy consump. per capita (toe)	7.9	7.7	8.1	7.0	6.3	5.9	5.5	-0.3	-0.8	-0.7	-0.7
Primary energy consumption per GDP[*2]	277	214	183	128	100	79	64	-1.8	-2.0	-2.3	-2.2
CO_2 emissions per GDP[*3]	692	522	445	278	205	155	115	-2.2	-2.5	-2.8	-2.7
CO_2 per primary energy consumption[*4]	2.5	2.4	2.4	2.2	2.0	1.9	1.8	-0.4	-0.5	-0.6	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-35 | United States [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	1 805	1 915	2 274	2 231	2 179	2 137	2 057	100	100	100	0.5	-0.2	-0.3	-0.3
Coal	376	460	534	321	245	204	145	24	14	7.1	-1.3	-2.2	-2.6	-2.4
Oil	797	757	871	802	744	694	646	40	36	31	0.2	-0.6	-0.7	-0.7
Natural gas	477	438	548	709	769	773	732	23	32	36	1.7	0.7	-0.2	0.1
Nuclear	69	159	208	219	180	171	170	8.3	9.8	8.2	1.1	-1.6	-0.3	-0.8
Hydro	24	23	22	25	26	27	27	1.2	1.1	1.3	0.3	0.3	0.2	0.2
Geothermal	4.6	14	13	10	18	31	38	0.7	0.4	1.8	-1.2	5.2	3.7	4.2
Solar, wind, etc.	-	0.3	2.1	34	66	100	159	0.0	1.5	7.7	18.1	5.6	4.5	4.9
Biomass and waste	54	62	73	107	128	132	136	3.3	4.8	6.6	2.0	1.4	0.3	0.8

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	1 311	1 294	1 546	1 594	1 575	1 543	1 497	100	100	100	0.7	-0.1	-0.3	-0.2
Industry	387	284	332	277	282	283	278	22	17	19	-0.1	0.2	-0.1	0.0
Transport	425	488	588	638	585	553	527	38	40	35	1.0	-0.7	-0.5	-0.6
Buildings, etc.	397	403	473	530	539	531	514	31	33	34	1.0	0.1	-0.2	-0.1
Non-energy use	102	119	153	149	169	176	179	9.2	9.4	12	0.8	1.0	0.3	0.6
Coal	56	56	33	17	14	12	10	4.3	1.1	0.7	-4.2	-1.4	-1.6	-1.5
Oil	689	683	793	765	704	658	614	53	48	41	0.4	-0.7	-0.7	-0.7
Natural gas	338	303	360	381	396	378	357	23	24	24	0.8	0.3	-0.5	-0.2
Electricity	174	226	301	335	362	398	421	18	21	28	1.4	0.6	0.8	0.7
Heat	-	2.2	5.3	6.2	5.5	5.0	4.4	0.2	0.4	0.3	3.9	-1.0	-1.2	-1.1
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	54	23	54	90	94	92	90	1.8	5.6	6.0	5.0	0.4	-0.2	0.0

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	2 427	3 203	4 026	4 434	4 774	5 212	5 486	100	100	100	1.2	0.6	0.7	0.7
Coal	1 243	1 700	2 129	1 272	1 101	940	667	53	29	12	-1.0	-1.2	-2.5	-2.0
Oil	263	131	118	43	33	25	13	4.1	1.0	0.2	-3.9	-2.1	-4.5	-3.6
Natural gas	370	382	634	1 519	1 834	2 108	2 087	12	34	38	5.1	1.6	0.6	1.0
Nuclear	266	612	798	841	690	655	651	19	19	12	1.1	-1.6	-0.3	-0.8
Hydro	279	273	253	296	305	312	316	8.5	6.7	5.8	0.3	0.3	0.2	0.2
Geothermal	5.4	16	15	19	36	64	77	0.5	0.4	1.4	0.6	5.6	3.8	4.5
Solar PV	-	0.0	0.2	81	153	354	744	0.0	1.8	14	44.0	5.4	8.2	7.2
Wind	-	3.1	5.7	276	420	475	548	0.1	6.2	10	17.4	3.6	1.3	2.2
CSP and marine	-	0.7	0.5	3.9	52	100	174	0.0	0.1	3.2	6.6	23.9	6.3	12.6
Biomass and waste	0.5	86	72	78	144	175	203	2.7	1.8	3.7	-0.4	5.3	1.7	3.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	5.3	5.3	5.3	5.3	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	6 496	9 001	12 620	17 856	22 303	27 700	33 351	2.5	1.9	2.0	2.0
Population (million)	227	250	282	327	350	366	379	1.0	0.6	0.4	0.5
CO_2 emissions (Mt)	4 582	4 783	5 661	4 929	4 499	4 186	3 704	0.1	-0.8	-1.0	-0.9
GDP per capita ($2010 thousand)	29	36	45	55	64	76	88	1.5	1.3	1.6	1.5
Primary energy consump. per capita (toe)	7.9	7.7	8.1	6.8	6.2	5.8	5.4	-0.4	-0.8	-0.7	-0.7
Primary energy consumption per GDP*2	278	213	180	125	98	77	62	-1.9	-2.0	-2.3	-2.2
CO_2 emissions per GDP*3	705	531	449	276	202	151	111	-2.3	-2.6	-2.9	-2.8
CO_2 per primary energy consumption*4	2.5	2.5	2.5	2.2	2.1	2.0	1.8	-0.4	-0.6	-0.7	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-36 | Latin America [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	381	463	607	819	1 003	1 175	1 271	100	100	100	2.1	1.7	1.2	1.4
Coal	13	21	27	44	46	54	55	4.6	5.3	4.4	2.6	0.5	0.9	0.8
Oil	222	237	310	336	376	409	411	51	41	32	1.3	0.9	0.4	0.6
Natural gas	47	71	118	203	268	364	437	15	25	34	3.8	2.3	2.5	2.4
Nuclear	0.6	3.2	5.3	9.4	18	19	16	0.7	1.2	1.3	3.9	5.6	-0.6	1.7
Hydro	19	33	50	64	75	82	88	7.2	7.8	6.9	2.4	1.3	0.8	1.0
Geothermal	1.2	5.1	6.5	6.3	22	30	37	1.1	0.8	2.9	0.7	10.9	2.7	5.7
Solar, wind, etc.	-	0.0	0.2	9.3	22	31	42	0.0	1.1	3.3	25.1	7.5	3.3	4.8
Biomass and waste	78	92	89	147	176	185	184	20	18	14	1.7	1.6	0.2	0.7

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	287	344	442	606	728	832	897	100	100	100	2.0	1.5	1.0	1.2
Industry	98	113	143	179	223	265	285	33	30	32	1.6	1.8	1.2	1.5
Transport	85	103	140	225	266	294	309	30	37	35	2.8	1.4	0.8	1.0
Buildings, etc.	88	101	121	166	197	223	247	29	27	28	1.8	1.4	1.1	1.3
Non-energy use	16	26	38	36	42	49	55	7.6	6.0	6.1	1.2	1.3	1.3	1.3
Coal	6.2	8.1	11	16	18	20	20	2.4	2.6	2.2	2.4	1.1	0.6	0.7
Oil	158	178	235	294	337	374	390	52	48	43	1.8	1.2	0.7	0.9
Natural gas	27	38	54	75	92	108	122	11	12	14	2.5	1.7	1.4	1.5
Electricity	27	45	69	114	157	205	246	13	19	27	3.4	2.7	2.3	2.4
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	69	75	74	107	124	125	119	22	18	13	1.3	1.2	-0.2	0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	380	623	1 009	1 637	2 224	2 851	3 356	100	100	100	3.5	2.6	2.1	2.3
Coal	8.2	24	43	96	104	139	152	3.8	5.9	4.5	5.1	0.6	1.9	1.4
Oil	112	129	198	133	121	96	26	21	8.1	0.8	0.1	-0.8	-7.5	-5.0
Natural gas	34	58	141	449	679	1 066	1 413	9.3	27	42	7.6	3.5	3.7	3.6
Nuclear	2.3	12	20	36	70	74	62	2.0	2.2	1.9	3.9	5.6	-0.6	1.7
Hydro	218	386	584	746	871	951	1 023	62	46	30	2.4	1.3	0.8	1.0
Geothermal	1.4	5.9	8.0	9.4	34	49	60	1.0	0.6	1.8	1.7	11.3	2.9	6.0
Solar PV	-	0.0	0.0	14	51	85	130	0.0	0.9	3.9	40.7	11.1	4.9	7.1
Wind	-	0.0	0.3	79	182	253	331	0.0	4.8	9.9	49.6	7.2	3.0	4.6
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	3.6	7.5	13	74	112	139	158	1.2	4.6	4.7	8.5	3.5	1.7	2.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.4	0.4	0.4	0.4	0.4	-	0.0	0.0	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	2 440	2 834	3 819	5 833	8 064	11 058	14 073	2.6	2.7	2.8	2.8
Population (million)	357	438	517	638	702	738	758	1.3	0.8	0.4	0.5
CO_2 emissions (Mt)	761	866	1 193	1 574	1 838	2 171	2 339	2.2	1.3	1.2	1.2
GDP per capita ($2010 thousand)	6.8	6.5	7.4	9.1	11	15	19	1.2	1.9	2.4	2.2
Primary energy consump. per capita (toe)	1.1	1.1	1.2	1.3	1.4	1.6	1.7	0.7	0.9	0.8	0.8
Primary energy consumption per GDP[*2]	156	163	159	140	124	106	90	-0.5	-1.0	-1.6	-1.4
CO_2 emissions per GDP[*3]	312	305	312	270	228	196	166	-0.4	-1.4	-1.6	-1.5
CO_2 per primary energy consumption[*4]	2.0	1.9	2.0	1.9	1.8	1.8	1.8	0.1	-0.4	0.0	-0.1

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-37 | Advanced Europe [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	1 494	1 643	1 759	1 742	1 653	1 567	1 467	100	100	100	0.2	-0.4	-0.6	-0.5
Coal	464	448	331	255	218	191	162	27	15	11	-2.0	-1.3	-1.5	-1.4
Oil	688	617	654	563	492	435	386	38	32	26	-0.3	-1.1	-1.2	-1.2
Natural gas	206	267	396	426	438	433	412	16	24	28	1.7	0.2	-0.3	-0.1
Nuclear	60	210	247	215	171	158	144	13	12	9.8	0.1	-1.9	-0.9	-1.3
Hydro	36	39	47	49	51	52	54	2.4	2.8	3.7	0.8	0.4	0.3	0.3
Geothermal	3.0	4.9	7.1	19	28	30	32	0.3	1.1	2.2	5.0	3.0	0.8	1.6
Solar, wind, etc.	0.1	0.4	2.7	51	77	89	102	0.0	2.9	6.9	19.4	3.6	1.4	2.2
Biomass and waste	36	56	72	161	175	176	174	3.4	9.2	12	3.9	0.7	0.0	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	1 081	1 142	1 235	1 253	1 210	1 141	1 073	100	100	100	0.3	-0.3	-0.6	-0.5
Industry	356	330	325	299	301	296	282	29	24	26	-0.4	0.0	-0.3	-0.2
Transport	209	269	318	354	313	279	253	24	28	24	1.0	-1.0	-1.1	-1.1
Buildings, etc.	425	442	477	495	491	460	434	39	39	40	0.4	-0.1	-0.6	-0.4
Non-energy use	90	101	115	105	105	105	104	8.9	8.4	9.7	0.1	0.0	-0.1	0.0
Coal	156	124	62	44	38	33	29	11	3.5	2.7	-3.6	-1.3	-1.4	-1.3
Oil	551	527	573	514	452	399	355	46	41	33	-0.1	-1.1	-1.2	-1.2
Natural gas	161	205	269	276	275	258	242	18	22	23	1.1	0.0	-0.6	-0.4
Electricity	147	193	234	272	298	313	318	17	22	30	1.2	0.8	0.3	0.5
Heat	35	45	42	48	45	40	35	3.9	3.8	3.3	0.3	-0.5	-1.3	-1.0
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	31	48	55	99	102	98	94	4.2	7.9	8.8	2.6	0.3	-0.4	-0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	2 049	2 697	3 238	3 656	3 984	4 161	4 191	100	100	100	1.1	0.7	0.3	0.4
Coal	887	1 030	968	738	701	625	514	38	20	12	-1.2	-0.4	-1.5	-1.1
Oil	364	210	180	51	37	26	10.0	7.8	1.4	0.2	-5.0	-2.5	-6.4	-5.0
Natural gas	138	176	514	702	902	1 063	1 124	6.5	19	27	5.1	2.1	1.1	1.5
Nuclear	230	804	948	825	656	607	551	30	23	13	0.1	-1.9	-0.9	-1.3
Hydro	416	451	549	567	592	608	624	17	16	15	0.8	0.4	0.3	0.3
Geothermal	2.7	3.6	6.2	20	30	34	36	0.1	0.5	0.9	6.3	3.5	0.9	1.9
Solar PV	-	0.0	0.1	129	214	251	284	0.0	3.5	6.8	37.8	4.3	1.4	2.5
Wind	0.0	0.8	22	392	535	588	651	0.0	11	16	24.9	2.6	1.0	1.6
CSP and marine	0.5	0.5	0.5	5.4	34	47	65	0.0	0.1	1.5	8.8	16.5	3.3	8.1
Biomass and waste	11	21	48	221	276	306	327	0.8	6.0	7.8	8.8	1.9	0.9	1.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	0.3	1.5	5.8	5.8	5.8	5.8	0.0	0.2	0.1	10.6	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	9 896	12 689	15 969	21 276	25 015	28 501	31 766	1.9	1.4	1.2	1.3
Population (million)	475	505	527	577	588	590	586	0.5	0.2	0.0	0.0
CO_2 emissions (Mt)	4 102	3 935	3 910	3 456	3 140	2 855	2 547	-0.5	-0.8	-1.0	-1.0
GDP per capita ($2010 thousand)	21	25	30	37	43	48	54	1.4	1.2	1.2	1.2
Primary energy consump. per capita (toe)	3.1	3.3	3.3	3.0	2.8	2.7	2.5	-0.3	-0.6	-0.6	-0.6
Primary energy consumption per GDP*2	151	129	110	82	66	55	46	-1.6	-1.8	-1.8	-1.8
CO_2 emissions per GDP*3	415	310	245	162	126	100	80	-2.3	-2.1	-2.2	-2.2
CO_2 per primary energy consumption*4	2.7	2.4	2.2	2.0	1.9	1.8	1.7	-0.7	-0.4	-0.4	-0.4

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-38 | Other Europe/Eurasia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	1 240	1 514	993	1 159	1 207	1 252	1 290	100	100	100	-0.9	0.3	0.3	0.3
Coal	362	365	209	217	201	210	208	24	19	16	-1.9	-0.6	0.2	-0.1
Oil	464	459	200	238	233	230	228	30	20	18	-2.3	-0.2	-0.1	-0.1
Natural gas	355	596	486	569	576	598	606	39	49	47	-0.2	0.1	0.3	0.2
Nuclear	20	55	61	83	117	116	125	3.6	7.2	9.7	1.5	2.8	0.3	1.3
Hydro	20	22	23	28	29	31	32	1.5	2.4	2.4	0.8	0.4	0.4	0.4
Geothermal	-	0.0	0.1	0.2	0.5	0.6	0.6	0.0	0.0	0.0	8.2	7.9	0.7	3.4
Solar, wind, etc.	-	-	0.0	1.7	4.4	6.7	9.5	-	0.1	0.7	n.a.	8.3	4.0	5.6
Biomass and waste	21	17	15	25	48	63	84	1.1	2.2	6.5	1.5	5.5	2.9	3.8

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	869	1 058	648	765	790	795	804	100	100	100	-1.1	0.3	0.1	0.2
Industry	395	391	205	202	216	227	231	37	26	29	-2.3	0.5	0.3	0.4
Transport	107	170	109	156	152	147	143	16	20	18	-0.3	-0.2	-0.3	-0.3
Buildings, etc.	301	432	287	316	326	315	313	41	41	39	-1.1	0.3	-0.2	0.0
Non-energy use	67	65	47	91	96	106	116	6.2	12	14	1.2	0.5	0.9	0.8
Coal	152	113	36	50	51	50	46	11	6.5	5.8	-2.9	0.3	-0.5	-0.2
Oil	310	275	144	197	199	197	196	26	26	24	-1.2	0.1	-0.1	0.0
Natural gas	215	258	200	257	258	255	256	24	34	32	0.0	0.1	0.0	0.0
Electricity	95	125	86	110	130	153	173	12	14	22	-0.4	1.4	1.5	1.4
Heat	78	274	170	134	134	126	121	26	18	15	-2.5	0.0	-0.5	-0.3
Hydrogen	-	-	-	-	0.0	0.0	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	21	13	11	18	18	15	11	1.2	2.3	1.4	1.2	0.2	-2.3	-1.4

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	1 461	1 857	1 415	1 801	2 049	2 326	2 516	100	100	100	-0.1	1.1	1.0	1.1
Coal	471	429	338	390	428	516	555	23	22	22	-0.3	0.8	1.3	1.1
Oil	357	252	69	16	13	11	7.5	14	0.9	0.3	-9.4	-1.6	-2.8	-2.3
Natural gas	295	707	504	726	734	860	903	38	40	36	0.1	0.1	1.0	0.7
Nuclear	79	209	234	319	449	445	479	11	18	19	1.5	2.9	0.3	1.3
Hydro	232	260	267	326	341	357	367	14	18	15	0.8	0.4	0.4	0.4
Geothermal	-	0.0	0.1	0.4	1.7	2.0	2.2	0.0	0.0	0.1	10.2	12.3	1.1	5.2
Solar PV	-	-	-	6.1	18	29	41	-	0.3	1.6	n.a.	9.4	4.2	6.1
Wind	-	-	0.0	12	31	47	68	-	0.7	2.7	n.a.	8.3	4.0	5.6
CSP and marine	-	-	-	-	0.0	0.1	0.2	-	-	0.0	n.a.	n.a.	12.7	n.a.
Biomass and waste	27	0.0	2.6	6.2	34	59	93	0.0	0.3	3.7	19.0	15.1	5.2	8.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	0.1	0.1	0.1	0.1	-	0.0	0.0	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	1 736	2 146	1 478	2 857	3 740	4 733	5 916	1.0	2.3	2.3	2.3
Population (million)	320	337	334	340	344	342	340	0.0	0.1	-0.1	0.0
CO_2 emissions (Mt)	3 319	3 680	2 233	2 399	2 323	2 366	2 348	-1.5	-0.3	0.1	-0.1
GDP per capita ($2010 thousand)	5.4	6.4	4.4	8.4	11	14	17	1.0	2.2	2.4	2.3
Primary energy consump. per capita (toe)	3.9	4.5	3.0	3.4	3.5	3.7	3.8	-1.0	0.2	0.4	0.3
Primary energy consumption per GDP[*2]	715	706	672	406	323	265	218	-2.0	-1.9	-1.9	-1.9
CO_2 emissions per GDP[*3]	1 912	1 715	1 511	840	621	500	397	-2.5	-2.5	-2.2	-2.3
CO_2 per primary energy consumption[*4]	2.7	2.4	2.2	2.1	1.9	1.9	1.8	-0.6	-0.6	-0.3	-0.4

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-39 | European Union [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	n.a.	1 439	1 471	1 428	1 364	1 288	1 202	100	100	100	0.0	-0.4	-0.6	-0.5
Coal	n.a.	391	285	216	188	165	140	27	15	12	-2.1	-1.2	-1.5	-1.4
Oil	n.a.	531	550	462	405	357	315	37	32	26	-0.5	-1.1	-1.3	-1.2
Natural gas	n.a.	250	309	324	341	347	333	17	23	28	0.9	0.4	-0.1	0.1
Nuclear	n.a.	190	224	199	165	142	128	13	14	11	0.2	-1.5	-1.2	-1.4
Hydro	n.a.	24	30	30	30	31	31	1.7	2.1	2.6	0.7	0.1	0.2	0.2
Geothermal	n.a.	3.2	4.6	6.8	8.8	9.6	10	0.2	0.5	0.9	2.8	2.2	0.8	1.3
Solar, wind, etc.	n.a.	0.3	2.4	41	65	75	87	0.0	2.9	7.2	19.1	3.8	1.5	2.3
Biomass and waste	n.a.	47	65	147	159	158	155	3.3	10	13	4.2	0.7	-0.1	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	n.a.	995	1 028	1 023	994	937	879	100	100	100	0.1	-0.2	-0.6	-0.5
Industry	n.a.	313	274	244	247	244	233	31	24	26	-0.9	0.1	-0.3	-0.1
Transport	n.a.	220	262	287	253	225	202	22	28	23	1.0	-1.0	-1.1	-1.1
Buildings, etc.	n.a.	374	391	400	403	377	354	38	39	40	0.2	0.1	-0.6	-0.4
Non-energy use	n.a.	88	101	91	91	91	89	8.9	8.9	10	0.1	0.0	-0.1	-0.1
Coal	n.a.	109	47	32	28	24	21	11	3.1	2.4	-4.3	-1.2	-1.4	-1.3
Oil	n.a.	444	479	420	370	326	288	45	41	33	-0.2	-1.1	-1.2	-1.2
Natural gas	n.a.	185	220	216	221	209	196	19	21	22	0.6	0.2	-0.6	-0.3
Electricity	n.a.	162	189	216	238	252	257	16	21	29	1.0	0.8	0.4	0.5
Heat	n.a.	55	43	46	44	38	34	5.5	4.5	3.8	-0.6	-0.5	-1.3	-1.0
Hydrogen	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	n.a.	39	50	92	93	88	83	4.0	9.0	9.4	3.1	0.1	-0.6	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	n.a.	2 259	2 631	2 920	3 206	3 361	3 392	100	100	100	0.9	0.8	0.3	0.5
Coal	n.a.	844	846	643	630	564	468	37	22	14	-1.0	-0.2	-1.5	-1.0
Oil	n.a.	190	173	55	41	29	12	8.4	1.9	0.3	-4.3	-2.4	-6.1	-4.7
Natural gas	n.a.	188	331	491	646	834	902	8.3	17	27	3.5	2.3	1.7	1.9
Nuclear	n.a.	729	860	762	633	547	493	32	26	15	0.2	-1.5	-1.2	-1.4
Hydro	n.a.	285	352	344	348	357	365	13	12	11	0.7	0.1	0.2	0.2
Geothermal	n.a.	3.2	4.8	6.7	10	11	12	0.1	0.2	0.4	2.6	3.5	0.9	1.9
Solar PV	n.a.	0.0	0.1	110	187	222	254	0.0	3.8	7.5	37.3	4.5	1.5	2.6
Wind	n.a.	0.8	21	321	445	490	543	0.0	11	16	24.0	2.8	1.0	1.7
CSP and marine	n.a.	0.5	0.5	5.3	34	47	65	0.0	0.2	1.9	8.8	16.5	3.3	8.1
Biomass and waste	n.a.	19	42	177	227	255	274	0.8	6.1	8.1	8.3	2.1	0.9	1.4
Hydrogen	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	n.a.	0.2	1.4	4.6	4.6	4.6	4.6	0.0	0.2	0.1	11.6	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	n.a.	10 234	12 698	16 365	19 171	21 845	24 303	1.7	1.3	1.2	1.2
Population (million)	n.a.	420	429	447	447	445	437	0.2	0.0	-0.1	-0.1
CO_2 emissions (Mt)	n.a.	3 422	3 248	2 781	2 478	2 262	2 008	-0.7	-1.0	-1.0	-1.0
GDP per capita ($2010 thousand)	n.a.	24	30	37	43	49	56	1.5	1.3	1.3	1.3
Primary energy consump. per capita (toe)	n.a.	3.4	3.4	3.2	3.0	2.9	2.7	-0.2	-0.4	-0.5	-0.5
Primary energy consumption per GDP[*2]	n.a.	141	116	87	71	59	49	-1.7	-1.7	-1.8	-1.8
CO_2 emissions per GDP[*3]	n.a.	334	256	170	129	104	83	-2.4	-2.3	-2.2	-2.2
CO_2 per primary energy consumption[*4]	n.a.	2.4	2.2	1.9	1.8	1.8	1.7	-0.7	-0.6	-0.4	-0.5

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-40 | Africa [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	273	386	491	837	1 080	1 331	1 528	100	100	100	2.8	2.2	1.7	1.9
Coal	52	74	90	114	123	138	142	19	14	9.3	1.5	0.7	0.7	0.7
Oil	65	85	101	190	253	359	465	22	23	30	2.9	2.4	3.1	2.8
Natural gas	12	30	47	133	207	296	391	7.6	16	26	5.5	3.7	3.2	3.4
Nuclear	-	2.2	3.4	3.0	7.6	12	12	0.6	0.4	0.8	1.1	8.0	2.5	4.5
Hydro	4.1	4.8	6.4	11	19	25	37	1.2	1.3	2.4	3.1	4.4	3.4	3.8
Geothermal	-	0.3	0.4	4.5	13	21	29	0.1	0.5	1.9	10.4	9.6	4.0	6.1
Solar, wind, etc.	-	0.0	0.0	2.4	13	29	52	0.0	0.3	3.4	35.3	15.5	7.0	10.1
Biomass and waste	140	190	241	379	443	450	398	49	45	26	2.5	1.3	-0.5	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	217	287	365	612	801	969	1 096	100	100	100	2.7	2.3	1.6	1.8
Industry	46	53	57	91	129	170	206	18	15	19	1.9	3.0	2.4	2.6
Transport	28	38	55	124	165	224	287	13	20	26	4.3	2.5	2.8	2.7
Buildings, etc.	138	185	238	374	473	535	557	64	61	51	2.5	2.0	0.8	1.2
Non-energy use	5.4	11	15	24	33	39	46	3.8	3.9	4.2	2.8	2.7	1.7	2.1
Coal	21	20	19	25	29	30	30	6.9	4.0	2.8	0.8	1.2	0.3	0.7
Oil	54	70	90	172	233	322	414	25	28	38	3.2	2.6	2.9	2.8
Natural gas	2.8	8.6	14	47	69	87	103	3.0	7.7	9.4	6.3	3.3	2.0	2.5
Electricity	14	22	31	59	94	150	222	7.7	9.6	20	3.6	4.1	4.4	4.3
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	3.3	n.a.
Renewables	125	166	211	310	375	380	327	58	51	30	2.3	1.6	-0.7	0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	184	315	442	835	1 336	2 092	3 031	100	100	100	3.5	4.0	4.2	4.1
Coal	100	164	209	260	300	363	391	52	31	13	1.7	1.2	1.3	1.3
Oil	22	41	37	67	96	161	210	13	8.0	6.9	1.8	3.0	4.0	3.6
Natural gas	14	45	106	334	554	938	1 432	14	40	47	7.4	4.3	4.9	4.7
Nuclear	-	8.4	13	12	29	46	48	2.7	1.4	1.6	1.1	8.0	2.5	4.5
Hydro	47	56	75	131	219	294	429	18	16	14	3.1	4.4	3.4	3.8
Geothermal	-	0.3	0.4	5.2	16	24	34	0.1	0.6	1.1	10.4	9.6	4.0	6.1
Solar PV	-	-	0.0	5.3	55	145	298	-	0.6	9.8	n.a.	21.5	8.8	13.4
Wind	-	-	0.2	14	37	61	103	-	1.7	3.4	n.a.	8.2	5.3	6.4
CSP and marine	-	-	-	2.0	20	42	66	-	0.2	2.2	n.a.	21.1	6.2	11.6
Biomass and waste	0.2	0.4	0.9	2.1	9.9	15	19	0.1	0.2	0.6	6.0	13.9	3.2	7.1
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.1	1.7	1.7	1.7	1.7	-	0.2	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	720	895	1 171	2 474	4 015	6 457	9 559	3.7	4.1	4.4	4.3
Population (million)	476	630	810	1 275	1 686	2 074	2 486	2.6	2.4	2.0	2.1
CO_2 emissions (Mt)	397	541	667	1 253	1 617	2 174	2 712	3.0	2.1	2.6	2.4
GDP per capita ($2010 thousand)	1.5	1.4	1.4	1.9	2.4	3.1	3.8	1.1	1.7	2.4	2.2
Primary energy consump. per capita (toe)	0.6	0.6	0.6	0.7	0.6	0.6	0.6	0.2	-0.2	-0.2	-0.2
Primary energy consumption per GDP*2	380	432	419	338	269	206	160	-0.9	-1.9	-2.6	-2.3
CO_2 emissions per GDP*3	552	604	570	506	403	337	284	-0.6	-1.9	-1.7	-1.8
CO_2 per primary energy consumption*4	1.5	1.4	1.4	1.5	1.5	1.6	1.8	0.2	0.0	0.9	0.5

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-41 | Middle East [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	121	222	371	782	1 019	1 178	1 276	100	100	100	4.6	2.2	1.1	1.5
Coal	1.2	3.0	8.1	8.5	11	10	8.5	1.3	1.1	0.7	3.8	1.9	-1.1	0.0
Oil	90	146	216	330	394	431	431	66	42	34	3.0	1.5	0.4	0.8
Natural gas	29	72	145	437	582	687	771	32	56	60	6.7	2.4	1.4	1.8
Nuclear	-	-	-	2.0	22	33	39	-	0.3	3.1	n.a.	22.1	3.0	9.8
Hydro	0.8	1.0	0.7	1.6	2.1	2.3	2.4	0.5	0.2	0.2	1.6	2.2	0.7	1.3
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	0.4	0.7	1.2	7.0	12	22	0.2	0.2	1.7	4.0	15.5	5.8	9.4
Biomass and waste	0.3	0.4	0.4	1.0	1.0	0.9	0.9	0.2	0.1	0.1	3.1	-0.3	-0.4	-0.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	84	157	253	535	688	791	865	100	100	100	4.5	2.1	1.1	1.5
Industry	30	47	71	163	209	234	241	30	30	28	4.5	2.1	0.7	1.2
Transport	26	51	75	147	175	193	208	32	28	24	3.9	1.4	0.9	1.1
Buildings, etc.	22	40	75	143	192	225	253	25	27	29	4.7	2.5	1.4	1.8
Non-energy use	5.6	20	32	81	112	139	163	12	15	19	5.2	2.7	1.9	2.2
Coal	0.3	0.2	0.5	3.1	3.4	3.4	3.1	0.1	0.6	0.4	10.5	0.8	-0.4	0.1
Oil	67	108	153	253	316	359	389	69	47	45	3.1	1.9	1.0	1.4
Natural gas	9.8	31	65	191	247	271	282	20	36	33	6.7	2.1	0.7	1.2
Electricity	6.5	17	33	86	121	156	189	11	16	22	5.9	2.9	2.3	2.5
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	2.5	n.a.
Renewables	0.2	0.7	1.0	1.5	1.7	1.7	1.8	0.5	0.3	0.2	2.6	0.8	0.4	0.5

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	95	244	472	1 228	1 733	2 218	2 643	100	100	100	5.9	2.9	2.1	2.4
Coal	0.1	11	30	21	30	28	23	4.3	1.7	0.9	2.5	3.0	-1.4	0.2
Oil	47	108	189	293	294	244	130	44	24	4.9	3.6	0.0	-4.0	-2.5
Natural gas	39	114	246	881	1 241	1 682	2 110	47	72	80	7.6	2.9	2.7	2.8
Nuclear	-	-	-	7.6	83	127	151	-	0.6	5.7	n.a.	22.1	3.0	9.8
Hydro	9.7	12	8.0	19	24	26	28	4.9	1.5	1.1	1.6	2.2	0.7	1.3
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	5.1	44	77	136	-	0.4	5.1	n.a.	19.7	5.8	10.8
Wind	-	0.0	0.0	1.3	9.5	22	44	0.0	0.1	1.7	29.2	18.1	7.9	11.6
CSP and marine	-	-	-	0.2	6.0	10	20	-	0.0	0.8	n.a.	31.1	6.2	14.9
Biomass and waste	-	-	0.0	0.0	0.3	0.4	0.6	-	0.0	0.0	n.a.	22.4	2.9	9.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	0.2	0.2	0.2	0.2	-	0.0	0.0	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	977	1 031	1 533	2 829	3 760	4 922	6 263	3.7	2.4	2.6	2.5
Population (million)	92	132	168	248	299	333	362	2.3	1.6	0.9	1.2
CO_2 emissions (Mt)	311	568	943	1 844	2 291	2 567	2 689	4.3	1.8	0.8	1.2
GDP per capita ($2010 thousand)	11	7.8	9.2	11	13	15	17	1.4	0.8	1.6	1.3
Primary energy consump. per capita (toe)	1.3	1.7	2.2	3.2	3.4	3.5	3.5	2.3	0.6	0.2	0.4
Primary energy consumption per GDP[*2]	124	216	242	277	271	239	204	0.9	-0.2	-1.4	-1.0
CO_2 emissions per GDP[*3]	318	550	615	652	609	522	429	0.6	-0.6	-1.7	-1.3
CO_2 per primary energy consumption[*4]	2.6	2.6	2.5	2.4	2.2	2.2	2.1	-0.3	-0.4	-0.3	-0.3

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-42 | Oceania [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	79	99	125	149	152	152	148	100	100	100	1.5	0.2	-0.1	0.0
Coal	28	36	49	44	36	32	26	36	30	18	0.7	-1.7	-1.6	-1.6
Oil	34	35	40	50	47	44	40	35	34	27	1.3	-0.6	-0.7	-0.7
Natural gas	8.3	19	24	36	43	47	47	19	25	32	2.4	1.5	0.4	0.8
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	2.7	3.2	3.5	3.6	3.6	3.5	3.5	3.2	2.4	2.4	0.4	-0.2	-0.1	-0.1
Geothermal	1.0	1.5	2.0	5.0	7.7	8.1	8.5	1.5	3.3	5.8	4.4	3.8	0.5	1.7
Solar, wind, etc.	0.0	0.1	0.1	2.8	6.8	10.0	13	0.1	1.9	9.0	11.7	7.7	3.4	5.0
Biomass and waste	4.1	4.7	6.2	6.5	7.7	8.4	9.0	4.8	4.3	6.1	1.1	1.5	0.8	1.0

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	54	66	83	98	104	104	103	100	100	100	1.4	0.5	0.0	0.2
Industry	20	23	28	27	30	30	29	35	27	29	0.5	0.9	-0.1	0.3
Transport	19	24	30	39	39	38	37	36	40	36	1.8	-0.1	-0.3	-0.2
Buildings, etc.	11	15	19	25	28	29	30	22	25	29	1.9	1.0	0.3	0.6
Non-energy use	3.1	4.6	6.1	6.8	7.0	7.0	6.9	6.9	7.0	6.7	1.4	0.2	-0.1	0.0
Coal	5.3	5.2	4.7	3.7	3.8	3.7	3.4	7.9	3.7	3.3	-1.3	0.4	-0.6	-0.3
Oil	31	33	40	51	51	49	46	50	53	45	1.6	-0.1	-0.5	-0.3
Natural gas	5.4	10	14	15	17	18	17	16	16	17	1.4	0.9	0.1	0.4
Electricity	8.5	14	18	22	26	28	30	20	22	29	1.7	1.4	0.8	1.0
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-11.1	n.a.
Renewables	4.0	4.1	5.6	5.7	6.2	6.2	6.0	6.2	5.9	5.9	1.2	0.6	-0.1	0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	118	187	249	305	359	389	406	100	100	100	1.8	1.4	0.6	0.9
Coal	70	122	176	159	151	137	115	65	52	28	1.0	-0.5	-1.3	-1.0
Oil	5.2	3.6	1.8	4.8	4.0	3.1	2.1	1.9	1.6	0.5	1.1	-1.6	-3.2	-2.6
Natural gas	8.7	20	26	60	71	76	74	11	20	18	4.0	1.4	0.2	0.7
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	32	37	41	42	41	41	40	20	14	10.0	0.4	-0.2	-0.1	-0.1
Geothermal	1.2	2.1	2.9	8.0	13	13	14	1.1	2.6	3.4	4.8	3.9	0.5	1.8
Solar PV	-	-	0.0	10	33	51	67	-	3.3	17	n.a.	10.5	3.6	6.1
Wind	-	-	0.2	17	39	58	80	-	5.6	20	n.a.	7.1	3.6	4.9
CSP and marine	-	-	-	0.0	0.0	0.1	0.2	-	0.0	0.0	n.a.	25.7	6.5	13.3
Biomass and waste	0.7	1.2	1.7	4.1	7.4	10	13	0.7	1.3	3.2	4.3	5.0	2.8	3.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	-0.9	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	527	722	998	1 665	2 166	2 612	3 057	3.0	2.2	1.7	1.9
Population (million)	18	20	23	30	33	36	39	1.4	1.0	0.7	0.8
CO_2 emissions (Mt)	230	282	363	423	399	380	348	1.5	-0.5	-0.7	-0.6
GDP per capita ($2010 thousand)	30	35	43	56	65	72	79	1.6	1.2	1.0	1.1
Primary energy consump. per capita (toe)	4.4	4.9	5.4	5.0	4.5	4.2	3.8	0.1	-0.8	-0.8	-0.8
Primary energy consumption per GDP*2	149	137	126	89	70	58	48	-1.5	-2.0	-1.8	-1.9
CO_2 emissions per GDP*3	436	390	364	254	184	146	114	-1.5	-2.6	-2.4	-2.5
CO_2 per primary energy consumption*4	2.9	2.8	2.9	2.8	2.6	2.5	2.4	0.0	-0.7	-0.5	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-43 | Advanced Economies [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	3 993	4 467	5 235	5 290	5 152	4 981	4 726	100	100	100	0.6	-0.2	-0.4	-0.4
Coal	966	1 088	1 119	877	732	641	516	24	17	11	-0.8	-1.5	-1.7	-1.6
Oil	1 898	1 826	2 068	1 870	1 698	1 557	1 423	41	35	30	0.1	-0.8	-0.9	-0.9
Natural gas	760	827	1 134	1 452	1 565	1 581	1 513	19	27	32	2.0	0.6	-0.2	0.1
Nuclear	164	463	596	519	444	404	375	10	9.8	7.9	0.4	-1.3	-0.9	-1.0
Hydro	92	100	111	119	124	127	130	2.2	2.2	2.7	0.6	0.4	0.2	0.3
Geothermal	9.4	22	25	37	59	78	89	0.5	0.7	1.9	1.8	4.0	2.1	2.8
Solar, wind, etc.	0.1	2.0	5.9	99	169	226	311	0.0	1.9	6.6	14.9	4.6	3.1	3.7
Biomass and waste	102	139	173	314	356	363	365	3.1	5.9	7.7	3.0	1.0	0.1	0.5

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	2 891	3 058	3 582	3 717	3 664	3 538	3 382	100	100	100	0.7	-0.1	-0.4	-0.3
Industry	927	826	906	813	827	818	784	27	22	23	-0.1	0.1	-0.3	-0.1
Transport	761	920	1 120	1 223	1 114	1 032	961	30	33	28	1.0	-0.8	-0.7	-0.7
Buildings, etc.	959	1 025	1 189	1 281	1 290	1 244	1 191	34	34	35	0.8	0.1	-0.4	-0.2
Non-energy use	245	287	367	400	433	443	445	9.4	11	13	1.2	0.7	0.1	0.3
Coal	259	231	137	104	93	82	70	7.5	2.8	2.1	-2.8	-1.0	-1.4	-1.3
Oil	1 545	1 559	1 809	1 722	1 580	1 454	1 334	51	46	39	0.4	-0.7	-0.8	-0.8
Natural gas	547	578	732	780	802	762	717	19	21	21	1.1	0.2	-0.6	-0.3
Electricity	407	553	719	830	907	972	1 006	18	22	30	1.5	0.7	0.5	0.6
Heat	36	48	52	63	59	53	47	1.6	1.7	1.4	1.0	-0.5	-1.1	-0.9
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-11.5	n.a.
Renewables	97	89	133	217	224	216	208	2.9	5.8	6.1	3.2	0.3	-0.4	-0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	5 639	7 668	9 706	11 048	12 019	12 808	13 172	100	100	100	1.3	0.7	0.5	0.6
Coal	2 323	3 127	3 833	2 972	2 695	2 430	1 951	41	27	15	-0.2	-0.8	-1.6	-1.3
Oil	985	669	539	178	117	68	30	8.7	1.6	0.2	-4.6	-3.5	-6.6	-5.4
Natural gas	607	767	1 531	3 033	3 704	4 283	4 367	10	27	33	5.0	1.7	0.8	1.1
Nuclear	629	1 776	2 288	1 993	1 705	1 551	1 438	23	18	11	0.4	-1.3	-0.9	-1.0
Hydro	1 071	1 159	1 294	1 379	1 448	1 482	1 508	15	12	11	0.6	0.4	0.2	0.3
Geothermal	10	23	27	49	85	120	140	0.3	0.4	1.1	2.7	4.7	2.5	3.3
Solar PV	-	0.1	0.7	299	526	821	1 300	0.0	2.7	9.9	33.7	4.8	4.6	4.7
Wind	0.0	3.8	29	730	1 089	1 260	1 487	0.1	6.6	11	20.6	3.4	1.6	2.2
CSP and marine	0.5	1.2	1.1	9.8	88	152	247	0.0	0.1	1.9	7.8	20.1	5.3	10.6
Biomass and waste	13	121	142	372	528	609	674	1.6	3.4	5.1	4.1	3.0	1.2	1.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	32	32	32	32	0.3	0.3	0.2	1.7	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	20 957	28 740	37 440	51 436	61 870	72 952	83 921	2.1	1.6	1.5	1.5
Population (million)	925	998	1 070	1 186	1 222	1 237	1 238	0.6	0.2	0.1	0.1
CO_2 emissions (Mt)	10 435	10 827	12 268	11 407	10 520	9 765	8 717	0.2	-0.7	-0.9	-0.8
GDP per capita ($2010 thousand)	23	29	35	43	51	59	68	1.5	1.3	1.5	1.4
Primary energy consump. per capita (toe)	4.3	4.5	4.9	4.5	4.2	4.0	3.8	0.0	-0.5	-0.5	-0.5
Primary energy consumption per GDP[*2]	191	155	140	103	83	68	56	-1.5	-1.7	-1.9	-1.9
CO_2 emissions per GDP[*3]	498	377	328	222	170	134	104	-1.9	-2.2	-2.4	-2.3
CO_2 per primary energy consumption[*4]	2.6	2.4	2.3	2.2	2.0	2.0	1.8	-0.4	-0.5	-0.5	-0.5

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-44 | Emerging Market and Developing Economies [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	3 031	4 097	4 526	8 570	10 797	12 198	13 076	100	100	100	2.7	1.9	1.0	1.3
Coal	817	1 133	1 198	2 962	3 444	3 533	3 368	28	35	26	3.5	1.3	-0.1	0.4
Oil	1 028	1 205	1 327	2 205	2 739	3 176	3 527	29	26	27	2.2	1.8	1.3	1.5
Natural gas	471	835	937	1 809	2 481	3 067	3 530	20	21	27	2.8	2.7	1.8	2.1
Nuclear	21	62	79	187	342	415	484	1.5	2.2	3.7	4.0	5.1	1.7	3.0
Hydro	56	84	113	244	300	337	372	2.1	2.8	2.8	3.9	1.7	1.1	1.3
Geothermal	3.0	12	27	55	126	165	202	0.3	0.6	1.5	5.6	7.1	2.4	4.1
Solar, wind, etc.	-	0.5	2.1	96	233	357	493	0.0	1.1	3.8	20.8	7.7	3.8	5.3
Biomass and waste	636	765	842	1 013	1 134	1 151	1 103	19	12	8.4	1.0	0.9	-0.1	0.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	2 300	3 007	3 176	5 799	7 185	8 068	8 736	100	100	100	2.4	1.8	1.0	1.3
Industry	839	977	965	2 027	2 437	2 645	2 734	32	35	31	2.6	1.5	0.6	0.9
Transport	306	453	569	1 246	1 582	1 879	2 183	15	21	25	3.7	2.0	1.6	1.8
Buildings, etc.	1 041	1 386	1 403	2 009	2 482	2 742	2 920	46	35	33	1.3	1.8	0.8	1.2
Non-energy use	113	191	239	517	684	802	900	6.3	8.9	10	3.6	2.4	1.4	1.7
Coal	444	521	404	890	902	862	806	17	15	9.2	1.9	0.1	-0.6	-0.3
Oil	726	844	1 036	1 907	2 427	2 844	3 220	28	33	37	3.0	2.0	1.4	1.6
Natural gas	268	367	388	831	1 113	1 260	1 369	12	14	16	3.0	2.5	1.0	1.6
Electricity	178	281	373	1 088	1 587	1 996	2 352	9.4	19	27	5.0	3.2	2.0	2.4
Heat	85	288	196	238	252	245	236	9.6	4.1	2.7	-0.7	0.5	-0.3	0.0
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	1.0	n.a.
Renewables	600	705	779	844	904	861	754	23	15	8.6	0.6	0.6	-0.9	-0.4

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	2 643	4 178	5 721	15 571	22 412	27 711	32 028	100	100	100	4.8	3.1	1.8	2.3
Coal	814	1 303	2 162	7 188	9 451	10 416	10 527	31	46	33	6.3	2.3	0.5	1.2
Oil	674	654	645	605	637	626	464	16	3.9	1.4	-0.3	0.4	-1.6	-0.8
Natural gas	391	982	1 243	3 117	4 773	6 915	8 977	24	20	28	4.2	3.6	3.2	3.4
Nuclear	85	236	303	717	1 313	1 591	1 856	5.7	4.6	5.8	4.0	5.2	1.7	3.0
Hydro	646	981	1 319	2 835	3 489	3 915	4 327	23	18	14	3.9	1.7	1.1	1.3
Geothermal	3.5	13	25	40	106	143	179	0.3	0.3	0.6	4.1	8.5	2.7	4.8
Solar PV	-	0.0	0.1	255	831	1 490	2 485	0.0	1.6	7.8	50.0	10.3	5.6	7.4
Wind	-	0.0	2.8	543	1 352	1 964	2 369	0.0	3.5	7.4	41.0	7.9	2.8	4.7
CSP and marine	-	0.0	0.0	2.5	30	63	104	0.0	0.0	0.3	23.4	23.0	6.4	12.3
Biomass and waste	31	8.4	21	266	429	586	738	0.2	1.7	2.3	13.1	4.1	2.8	3.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.5	2.3	2.3	2.3	2.3	-	0.0	0.0	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	7 065	9 140	12 459	30 929	51 535	75 753	102 314	4.4	4.3	3.5	3.8
Population (million)	3 510	4 280	5 042	6 405	7 275	7 909	8 444	1.5	1.1	0.7	0.9
CO_2 emissions (Mt)	6 784	8 867	9 925	20 538	25 074	27 779	29 026	3.0	1.7	0.7	1.1
GDP per capita ($2010 thousand)	2.0	2.1	2.5	4.8	7.1	9.6	12	3.0	3.2	2.7	2.9
Primary energy consump. per capita (toe)	0.9	1.0	0.9	1.3	1.5	1.5	1.5	1.2	0.9	0.2	0.5
Primary energy consumption per GDP*2	429	448	363	277	210	161	128	-1.7	-2.3	-2.4	-2.4
CO_2 emissions per GDP*3	960	970	797	664	487	367	284	-1.3	-2.6	-2.7	-2.6
CO_2 per primary energy consumption*4	2.2	2.2	2.2	2.4	2.3	2.3	2.2	0.4	-0.3	-0.2	-0.2

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-45 | World [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	7 203	8 767	10 034	14 282	15 605	15 925	15 743	100	100	100	1.8	0.7	0.0	0.3
Coal	1 783	2 221	2 317	3 838	3 541	2 939	2 225	25	27	14	2.0	-0.7	-2.3	-1.7
Oil	3 105	3 233	3 669	4 497	4 654	4 617	4 454	37	31	28	1.2	0.3	-0.2	0.0
Natural gas	1 231	1 662	2 071	3 262	3 723	3 918	3 802	19	23	24	2.4	1.1	0.1	0.5
Nuclear	185	526	675	707	929	1 134	1 297	6.0	4.9	8.2	1.1	2.3	1.7	1.9
Hydro	148	184	225	362	434	479	522	2.1	2.5	3.3	2.4	1.5	0.9	1.1
Geothermal	12	34	52	92	232	341	440	0.4	0.6	2.8	3.6	8.0	3.3	5.0
Solar, wind, etc.	0.1	2.5	8.0	194	573	964	1 420	0.0	1.4	9.0	16.8	9.4	4.6	6.4
Biomass and waste	738	904	1 015	1 327	1 517	1 530	1 581	10	9.3	10	1.4	1.1	0.2	0.5

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	5 370	6 267	7 032	9 938	10 878	11 102	11 107	100	100	100	1.7	0.8	0.1	0.3
Industry	1 767	1 803	1 871	2 839	3 200	3 237	3 089	29	29	28	1.6	1.0	-0.2	0.3
Transport	1 245	1 575	1 963	2 891	2 999	3 052	3 142	25	29	28	2.2	0.3	0.2	0.3
Buildings, etc.	2 000	2 411	2 592	3 291	3 562	3 570	3 532	38	33	32	1.1	0.7	0.0	0.2
Non-energy use	358	477	606	917	1 116	1 243	1 344	7.6	9.2	12	2.4	1.7	0.9	1.2
Coal	703	752	542	994	924	816	699	12	10	6.3	1.0	-0.6	-1.4	-1.1
Oil	2 449	2 606	3 119	4 051	4 282	4 297	4 198	42	41	38	1.6	0.5	-0.1	0.1
Natural gas	815	944	1 119	1 611	1 853	1 888	1 900	15	16	17	1.9	1.2	0.1	0.5
Electricity	586	834	1 092	1 919	2 444	2 836	3 118	13	19	28	3.0	2.0	1.2	1.5
Heat	121	336	248	301	300	276	250	5.4	3.0	2.3	-0.4	0.0	-0.9	-0.6
Hydrogen	-	-	-	-	0.3	0.8	1.7	-	-	0.0	n.a.	n.a.	9.2	n.a.
Renewables	697	794	911	1 061	1 075	988	940	13	11	8.5	1.0	0.1	-0.7	-0.4

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	8 282	11 846	15 427	26 619	33 525	38 288	41 490	100	100	100	2.9	1.9	1.1	1.4
Coal	3 137	4 430	5 994	10 160	9 632	7 712	5 369	37	38	13	3.0	-0.4	-2.9	-2.0
Oil	1 659	1 323	1 184	784	601	428	236	11	2.9	0.6	-1.9	-2.2	-4.6	-3.7
Natural gas	998	1 749	2 775	6 150	7 433	8 551	8 230	15	23	20	4.6	1.6	0.5	0.9
Nuclear	713	2 013	2 591	2 710	3 567	4 352	4 979	17	10	12	1.1	2.3	1.7	1.9
Hydro	1 717	2 141	2 613	4 214	5 043	5 574	6 070	18	16	15	2.4	1.5	0.9	1.1
Geothermal	14	36	52	89	248	369	481	0.3	0.3	1.2	3.2	8.9	3.4	5.4
Solar PV	-	0.1	0.8	554	1 969	3 751	6 177	0.0	2.1	15	36.5	11.1	5.9	7.8
Wind	0.0	3.9	31	1 273	3 665	5 626	7 330	0.0	4.8	18	23.0	9.2	3.5	5.6
CSP and marine	0.5	1.2	1.1	12	173	426	809	0.0	0.0	2.0	8.7	24.6	8.0	14.0
Biomass and waste	44	130	163	637	1 159	1 465	1 773	1.1	2.4	4.3	5.9	5.1	2.1	3.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	35	35	35	35	0.2	0.1	0.1	2.0	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	28 022	37 880	49 899	82 365	113 405	148 705	186 235	2.8	2.7	2.5	2.6
Population (million)	4 434	5 278	6 111	7 591	8 497	9 146	9 682	1.3	0.9	0.7	0.8
CO_2 emissions (Mt)	17 774	20 324	23 046	33 258	32 750	29 634	25 167	1.8	-0.1	-1.3	-0.9
GDP per capita ($2010 thousand)	6.3	7.2	8.2	11	13	16	19	1.5	1.7	1.8	1.8
Primary energy consump. per capita (toe)	1.6	1.7	1.6	1.9	1.8	1.7	1.6	0.4	-0.2	-0.6	-0.5
Primary energy consumption per GDP*2	257	231	201	173	138	107	85	-1.0	-1.9	-2.4	-2.2
CO_2 emissions per GDP*3	634	537	462	404	289	199	135	-1.0	-2.8	-3.7	-3.4
CO_2 per primary energy consumption*4	2.5	2.3	2.3	2.3	2.1	1.9	1.6	0.0	-0.9	-1.4	-1.2

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-46 | Asia [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	1 439	2 110	2 887	5 844	6 934	7 166	7 105	100	100	100	3.7	1.4	0.1	0.6
Coal	466	788	1 037	2 821	2 817	2 392	1 857	37	48	26	4.7	0.0	-2.1	-1.3
Oil	477	618	916	1 464	1 720	1 816	1 863	29	25	26	3.1	1.4	0.4	0.8
Natural gas	51	116	233	641	945	1 096	1 132	5.5	11	16	6.3	3.3	0.9	1.8
Nuclear	25	77	132	148	332	463	566	3.6	2.5	8.0	2.4	7.0	2.7	4.3
Hydro	20	32	41	146	190	215	234	1.5	2.5	3.3	5.6	2.2	1.1	1.5
Geothermal	2.6	8.2	23	47	119	181	233	0.4	0.8	3.3	6.4	8.0	3.4	5.1
Solar, wind, etc.	-	1.2	2.1	89	302	501	697	0.1	1.5	9.8	16.5	10.7	4.3	6.6
Biomass and waste	396	471	503	487	509	503	523	22	8.3	7.4	0.1	0.4	0.1	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	1 133	1 558	1 999	3 847	4 559	4 771	4 848	100	100	100	3.3	1.4	0.3	0.7
Industry	384	515	655	1 556	1 791	1 778	1 671	33	40	34	4.0	1.2	-0.3	0.2
Transport	124	187	321	717	861	942	1 035	12	19	21	4.9	1.5	0.9	1.2
Buildings, etc.	568	740	842	1 172	1 380	1 454	1 494	48	30	31	1.7	1.4	0.4	0.8
Non-energy use	58	116	180	401	527	597	649	7.4	10	13	4.5	2.3	1.0	1.5
Coal	301	423	372	834	786	693	593	27	22	12	2.5	-0.5	-1.4	-1.1
Oil	331	464	740	1 288	1 548	1 649	1 703	30	33	35	3.7	1.5	0.5	0.9
Natural gas	21	46	89	318	497	548	570	3.0	8.3	12	7.1	3.8	0.7	1.8
Electricity	88	157	280	876	1 231	1 436	1 573	10	23	32	6.3	2.9	1.2	1.8
Heat	7.5	14	30	112	122	118	109	0.9	2.9	2.2	7.7	0.7	-0.6	-0.1
Hydrogen	-	-	-	-	0.1	0.4	0.8	-	-	0.0	n.a.	n.a.	10.5	n.a.
Renewables	385	455	488	418	374	327	301	29	11	6.2	-0.3	-0.9	-1.1	-1.0

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	1 195	2 238	3 971	12 069	16 784	19 257	20 808	100	100	100	6.2	2.8	1.1	1.7
Coal	298	868	1 983	7 172	7 492	6 252	4 642	39	59	22	7.8	0.4	-2.4	-1.4
Oil	475	432	376	170	123	86	62	19	1.4	0.3	-3.3	-2.6	-3.4	-3.1
Natural gas	90	237	570	1 416	2 045	2 576	2 767	11	12	13	6.6	3.1	1.5	2.1
Nuclear	97	294	505	569	1 275	1 775	2 173	13	4.7	10	2.4	7.0	2.7	4.3
Hydro	232	368	477	1 703	2 205	2 501	2 722	16	14	13	5.6	2.2	1.1	1.5
Geothermal	3.0	8.4	20	27	76	116	151	0.4	0.2	0.7	4.3	9.0	3.5	5.5
Solar PV	-	0.1	0.4	299	1 157	2 117	3 210	0.0	2.5	15	34.8	11.9	5.2	7.7
Wind	-	0.0	2.4	449	1 933	3 205	4 268	0.0	3.7	21	40.3	12.9	4.0	7.3
CSP and marine	-	0.0	0.0	0.8	12	28	62	0.0	0.0	0.3	18.4	25.8	8.4	14.6
Biomass and waste	0.0	9.4	16	241	443	581	729	0.4	2.0	3.5	12.3	5.2	2.5	3.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	21	21	21	21	0.9	0.2	0.1	0.3	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	4 510	7 629	11 103	25 670	42 014	59 911	78 948	4.4	4.2	3.2	3.6
Population (million)	2 445	2 939	3 420	4 118	4 454	4 623	4 687	1.2	0.7	0.3	0.4
CO_2 emissions (Mt)	3 102	4 639	6 729	15 495	16 526	15 087	12 653	4.4	0.5	-1.3	-0.6
GDP per capita ($2010 thousand)	1.8	2.6	3.2	6.2	9.4	13	17	3.2	3.5	2.9	3.2
Primary energy consump. per capita (toe)	0.6	0.7	0.8	1.4	1.6	1.6	1.5	2.5	0.8	-0.1	0.2
Primary energy consumption per GDP[*2]	319	277	260	228	165	120	90	-0.7	-2.6	-3.0	-2.9
CO_2 emissions per GDP[*3]	688	608	606	604	393	252	160	0.0	-3.5	-4.4	-4.1
CO_2 per primary energy consumption[*4]	2.2	2.2	2.3	2.7	2.4	2.1	1.8	0.7	-0.9	-1.4	-1.2

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-47 | China [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	598	874	1 130	3 196	3 474	3 270	2 890	100	100	100	4.7	0.7	-0.9	-0.3
Coal	313	531	665	1 980	1 829	1 416	952	61	62	33	4.8	-0.7	-3.2	-2.3
Oil	89	119	221	610	676	633	544	14	19	19	6.0	0.9	-1.1	-0.4
Natural gas	12	13	21	230	376	443	452	1.5	7.2	16	10.9	4.2	0.9	2.1
Nuclear	-	-	4.4	77	140	193	244	-	2.4	8.4	n.a.	5.1	2.8	3.7
Hydro	5.0	11	19	103	128	139	144	1.2	3.2	5.0	8.4	1.8	0.6	1.1
Geothermal	-	-	1.7	11	15	16	16	-	0.4	0.5	n.a.	2.1	0.4	1.1
Solar, wind, etc.	-	0.0	1.0	70	208	320	404	0.0	2.2	14	31.4	9.5	3.4	5.6
Biomass and waste	180	200	198	117	103	111	135	23	3.7	4.7	-1.9	-1.0	1.3	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	487	658	781	2 058	2 251	2 159	1 983	100	100	100	4.2	0.8	-0.6	-0.1
Industry	181	234	302	996	972	849	716	36	48	36	5.3	-0.2	-1.5	-1.0
Transport	22	30	84	325	378	362	314	4.6	16	16	8.9	1.3	-0.9	-0.1
Buildings, etc.	274	351	338	559	677	705	708	53	27	36	1.7	1.6	0.2	0.7
Non-energy use	10	43	57	179	225	242	245	6.5	8.7	12	5.2	1.9	0.4	1.0
Coal	214	311	274	635	512	387	282	47	31	14	2.6	-1.8	-2.9	-2.5
Oil	59	85	180	535	604	567	488	13	26	25	6.8	1.0	-1.1	-0.3
Natural gas	6.4	8.9	12	153	231	239	237	1.3	7.4	12	10.7	3.5	0.1	1.4
Electricity	21	39	89	517	698	769	778	5.9	25	39	9.7	2.5	0.5	1.3
Heat	7.4	13	26	103	113	110	101	2.0	5.0	5.1	7.6	0.8	-0.6	-0.1
Hydrogen	-	-	-	-	0.1	0.2	0.5	-	-	0.0	n.a.	n.a.	11.2	n.a.
Renewables	180	200	199	114	92	87	97	30	5.5	4.9	-2.0	-1.8	0.3	-0.5

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	301	621	1 356	7 149	9 522	10 326	10 346	100	100	100	9.1	2.4	0.4	1.2
Coal	159	441	1 060	4 773	4 779	3 746	2 463	71	67	24	8.9	0.0	-3.3	-2.0
Oil	82	50	47	11	8.4	5.0	2.1	8.1	0.2	0.0	-5.4	-2.0	-6.6	-4.9
Natural gas	0.7	2.8	5.8	224	483	681	752	0.4	3.1	7.3	17.0	6.6	2.2	3.9
Nuclear	-	-	17	295	537	739	937	-	4.1	9.1	n.a.	5.1	2.8	3.7
Hydro	58	127	222	1 199	1 493	1 621	1 677	20	17	16	8.4	1.8	0.6	1.1
Geothermal	-	0.1	0.1	0.1	0.4	0.6	0.8	0.0	0.0	0.0	2.9	11.0	2.8	5.8
Solar PV	-	0.0	0.0	177	514	947	1 328	0.0	2.5	13	50.2	9.3	4.9	6.5
Wind	-	0.0	0.6	366	1 536	2 351	2 870	0.0	5.1	28	54.1	12.7	3.2	6.6
CSP and marine	-	0.0	0.0	0.3	3.5	11	29	0.0	0.0	0.3	14.5	22.3	11.2	15.2
Biomass and waste	-	-	2.4	104	168	225	288	-	1.5	2.8	n.a.	4.1	2.7	3.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	341	828	2 232	10 797	20 026	29 506	37 968	9.6	5.3	3.3	4.0
Population (million)	981	1 135	1 263	1 393	1 429	1 414	1 368	0.7	0.2	-0.2	-0.1
CO_2 emissions (Mt)	1 399	2 146	3 140	9 348	9 103	7 398	5 012	5.4	-0.2	-2.9	-1.9
GDP per capita ($2010 thousand)	0.3	0.7	1.8	7.8	14	21	28	8.8	5.1	3.5	4.1
Primary energy consump. per capita (toe)	0.6	0.8	0.9	2.3	2.4	2.3	2.1	4.0	0.5	-0.7	-0.3
Primary energy consumption per GDP*2	1 756	1 055	506	296	173	111	76	-4.4	-4.4	-4.0	-4.2
CO_2 emissions per GDP*3	4 106	2 593	1 407	866	455	251	132	-3.8	-5.2	-6.0	-5.7
CO_2 per primary energy consumption*4	2.3	2.5	2.8	2.9	2.6	2.3	1.7	0.6	-0.9	-2.0	-1.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-48 | India [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	200	306	441	919	1 418	1 689	1 921	100	100	100	4.0	3.7	1.5	2.3
Coal	44	93	146	414	563	569	558	30	45	29	5.5	2.6	-0.1	0.9
Oil	33	61	112	235	390	520	654	20	26	34	4.9	4.3	2.6	3.2
Natural gas	1.3	11	23	52	124	169	195	3.5	5.7	10	5.9	7.4	2.3	4.2
Nuclear	0.8	1.6	4.4	9.9	50	93	122	0.5	1.1	6.3	6.7	14.5	4.5	8.2
Hydro	4.0	6.2	6.4	13	22	30	38	2.0	1.4	2.0	2.7	4.6	2.7	3.4
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	0.0	0.2	9.9	64	121	177	0.0	1.1	9.2	27.8	16.7	5.2	9.4
Biomass and waste	116	133	149	185	205	188	178	44	20	9.3	1.2	0.8	-0.7	-0.1

Final energy consumption

	Mtoe							Shares (%)						
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total	174	243	315	607	949	1 166	1 357	100	100	100	3.3	3.8	1.8	2.5
Industry	42	67	85	206	377	445	454	28	34	33	4.1	5.2	0.9	2.5
Transport	17	21	32	104	171	251	369	8.5	17	27	5.9	4.3	3.9	4.0
Buildings, etc.	110	142	171	246	312	349	383	58	41	28	2.0	2.0	1.0	1.4
Non-energy use	5.7	13	27	51	89	120	151	5.5	8.4	11	4.9	4.7	2.7	3.5
Coal	25	38	33	107	174	202	209	16	18	15	3.7	4.2	0.9	2.1
Oil	27	50	94	208	355	477	603	21	34	44	5.2	4.6	2.7	3.4
Natural gas	0.7	6.1	12	32	76	103	120	2.5	5.3	8.8	6.2	7.4	2.3	4.2
Electricity	7.7	18	32	103	203	276	349	7.5	17	26	6.4	5.8	2.7	3.9
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.2	-	-	0.0	n.a.	n.a.	14.9	n.a.
Renewables	114	130	144	157	141	107	76	54	26	5.6	0.7	-0.9	-3.1	-2.2

Electricity generation

	(TWh)							Shares (%)						
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total	119	289	562	1 583	2 958	3 817	4 645	100	100	100	6.3	5.3	2.3	3.4
Coal	61	192	390	1 163	1 467	1 290	1 164	66	73	25	6.7	1.9	-1.1	0.0
Oil	7.6	10	22	7.8	7.5	4.7	2.2	3.5	0.5	0.0	-0.9	-0.3	-5.9	-3.9
Natural gas	0.6	10.0	56	74	213	316	398	3.4	4.6	8.6	7.4	9.3	3.2	5.4
Nuclear	3.0	6.1	17	38	192	357	467	2.1	2.4	10	6.7	14.5	4.5	8.2
Hydro	47	72	74	151	260	352	445	25	9.5	9.6	2.7	4.6	2.7	3.4
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	0.0	40	392	705	993	-	2.5	21	n.a.	21.0	4.8	10.6
Wind	-	0.0	1.7	64	306	627	949	0.0	4.1	20	31.2	13.9	5.8	8.8
CSP and marine	-	-	-	-	5.1	11	22	-	-	0.5	n.a.	n.a.	7.6	n.a.
Biomass and waste	-	-	1.3	45	116	155	206	-	2.9	4.4	n.a.	8.1	2.9	4.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	295	506	870	2 831	6 146	10 304	15 988	6.3	6.7	4.9	5.6
Population (million)	699	873	1 057	1 353	1 504	1 593	1 639	1.6	0.9	0.4	0.6
CO_2 emissions (Mt)	258	530	890	2 324	3 430	3 870	4 169	5.4	3.3	1.0	1.8
GDP per capita ($2010 thousand)	0.4	0.6	0.8	2.1	4.1	6.5	9.8	4.7	5.7	4.4	4.9
Primary energy consump. per capita (toe)	0.3	0.4	0.4	0.7	0.9	1.1	1.2	2.4	2.8	1.1	1.7
Primary energy consumption per GDP[*2]	679	605	507	325	231	164	120	-2.2	-2.8	-3.2	-3.1
CO_2 emissions per GDP[*3]	876	1 048	1 023	821	558	376	261	-0.9	-3.2	-3.7	-3.5
CO_2 per primary energy consumption[*4]	1.3	1.7	2.0	2.5	2.4	2.3	2.2	1.4	-0.4	-0.5	-0.5

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-49 | Japan [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	345	439	518	426	396	355	312	100	100	100	-0.1	-0.6	-1.2	-1.0
Coal	60	77	97	114	83	63	38	17	27	12	1.4	-2.7	-3.8	-3.4
Oil	234	250	255	166	132	107	91	57	39	29	-1.5	-1.9	-1.8	-1.9
Natural gas	21	44	66	97	78	62	41	10	23	13	2.9	-1.8	-3.1	-2.7
Nuclear	22	53	84	17	56	59	58	12	4.0	19	-4.0	10.6	0.2	4.0
Hydro	7.6	7.6	7.2	7.0	7.9	8.1	8.2	1.7	1.6	2.6	-0.3	1.0	0.2	0.5
Geothermal	0.8	1.6	3.1	2.3	6.5	11	16	0.4	0.5	5.0	1.4	9.1	4.5	6.2
Solar, wind, etc.	-	1.2	0.8	6.3	12	21	33	0.3	1.5	10	6.2	5.7	5.0	5.3
Biomass and waste	-	4.6	5.4	16	21	24	26	1.0	3.7	8.4	4.6	2.4	1.1	1.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	236	292	337	283	253	225	201	100	100	100	-0.1	-0.9	-1.1	-1.1
Industry	91	108	104	82	75	68	58	37	29	29	-1.0	-0.7	-1.3	-1.1
Transport	54	72	89	71	55	44	38	25	25	19	-0.1	-2.1	-1.9	-1.9
Buildings, etc.	58	78	108	96	90	82	74	27	34	37	0.7	-0.6	-1.0	-0.8
Non-energy use	32	34	37	34	33	32	31	12	12	15	0.0	-0.3	-0.4	-0.3
Coal	25	27	21	21	17	14	11	9.3	7.5	5.3	-0.9	-1.8	-2.3	-2.1
Oil	160	182	207	144	118	98	82	62	51	41	-0.8	-1.7	-1.8	-1.8
Natural gas	5.8	14	21	29	30	26	23	4.7	10	11	2.7	0.2	-1.3	-0.8
Electricity	44	66	84	81	82	81	78	22	29	39	0.8	0.0	-0.2	-0.1
Heat	0.1	0.2	0.5	0.5	0.4	0.4	0.3	0.1	0.2	0.1	3.6	-1.5	-2.0	-1.8
Hydrogen	-	-	-	-	0.0	0.1	0.1	-	-	0.0	n.a.	n.a.	5.5	n.a.
Renewables	-	3.9	4.3	6.6	6.2	5.9	6.8	1.3	2.3	3.4	1.9	-0.5	0.4	0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	573	862	1 055	1 050	1 053	1 042	1 003	100	100	100	0.7	0.0	-0.2	-0.1
Coal	55	123	223	339	219	156	63	14	32	6.3	3.7	-3.6	-6.1	-5.1
Oil	265	250	134	52	16	1.2	-	29	4.9	-	-5.5	-9.2	-100	-100
Natural gas	81	168	258	378	269	206	104	20	36	10	2.9	-2.8	-4.6	-4.0
Nuclear	83	202	322	65	217	225	224	23	6.2	22	-4.0	10.6	0.2	4.0
Hydro	88	88	84	81	91	94	95	10	7.7	9.5	-0.3	1.0	0.2	0.5
Geothermal	0.9	1.7	3.3	2.5	7.5	13	18	0.2	0.2	1.8	1.3	9.4	4.5	6.4
Solar PV	-	0.1	0.4	63	113	149	183	0.0	6.0	18	27.7	5.1	2.4	3.4
Wind	-	-	0.1	7.5	27	88	196	-	0.7	20	n.a.	11.3	10.4	10.7
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	8.7	9.9	44	75	91	101	1.0	4.2	10	6.0	4.5	1.5	2.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	19	19	19	19	2.3	1.8	1.9	-0.1	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	3 019	4 704	5 349	6 190	6 693	7 234	7 744	1.0	0.7	0.7	0.7
Population (million)	117	124	127	127	120	113	105	0.1	-0.4	-0.7	-0.6
CO_2 emissions (Mt)	904	1 058	1 161	1 081	837	669	483	0.1	-2.1	-2.7	-2.5
GDP per capita ($2010 thousand)	26	38	42	49	56	64	74	0.9	1.1	1.4	1.3
Primary energy consump. per capita (toe)	3.0	3.6	4.1	3.4	3.3	3.1	3.0	-0.2	-0.2	-0.5	-0.4
Primary energy consumption per GDP[*2]	114	93	97	69	59	49	40	-1.1	-1.3	-1.9	-1.7
CO_2 emissions per GDP[*3]	299	225	217	175	125	92	62	-0.9	-2.7	-3.4	-3.2
CO_2 per primary energy consumption[*4]	2.6	2.4	2.2	2.5	2.1	1.9	1.5	0.2	-1.5	-1.5	-1.5

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-50 | ASEAN [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total*1	142	233	379	669	945	1 147	1 299	100	100	100	3.8	2.9	1.6	2.1
Coal	3.6	13	32	150	192	206	194	5.4	22	15	9.3	2.1	0.1	0.8
Oil	58	89	153	239	303	340	367	38	36	28	3.6	2.0	0.9	1.3
Natural gas	8.6	30	74	141	211	244	259	13	21	20	5.7	3.4	1.0	1.9
Nuclear	-	-	-	-	12	46	73	-	-	5.7	n.a.	n.a.	9.6	n.a.
Hydro	0.8	2.3	4.1	14	19	22	24	1.0	2.1	1.9	6.6	2.6	1.2	1.7
Geothermal	1.8	6.6	18	33	97	153	200	2.9	4.9	15	5.9	9.3	3.7	5.8
Solar, wind, etc.	-	-	-	0.9	10	24	59	-	0.1	4.5	n.a.	22.5	9.2	14.0
Biomass and waste	69	92	98	89	98	107	119	40	13	9.2	-0.1	0.8	1.0	0.9

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	112	172	269	454	613	718	808	100	100	100	3.5	2.5	1.4	1.8
Industry	22	42	75	151	224	265	290	24	33	36	4.7	3.3	1.3	2.1
Transport	17	32	61	132	165	189	215	19	29	27	5.1	1.9	1.3	1.5
Buildings, etc.	70	87	112	113	134	156	177	50	25	22	1.0	1.4	1.4	1.4
Non-energy use	2.4	11	21	58	90	108	126	6.3	13	16	6.1	3.7	1.7	2.5
Coal	2.1	5.4	13	40	53	60	62	3.1	8.9	7.6	7.5	2.3	0.7	1.3
Oil	41	67	123	219	279	315	343	39	48	42	4.3	2.0	1.0	1.4
Natural gas	2.5	7.5	17	46	85	100	110	4.4	10	14	6.7	5.2	1.3	2.8
Electricity	4.7	11	28	81	133	179	225	6.5	18	28	7.3	4.2	2.7	3.2
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	7.5	n.a.
Renewables	61	81	89	68	63	64	69	47	15	8.5	-0.7	-0.6	0.4	0.0

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	62	154	370	1 059	1 731	2 345	2 947	100	100	100	7.1	4.2	2.7	3.3
Coal	3.0	28	79	442	615	681	645	18	42	22	10.4	2.8	0.2	1.2
Oil	47	66	72	20	24	25	19	43	1.9	0.6	-4.2	1.6	-1.2	-0.2
Natural gas	0.7	26	154	366	580	741	810	17	35	27	9.9	3.9	1.7	2.5
Nuclear	-	-	-	-	45	178	282	-	-	9.6	n.a.	n.a.	9.6	n.a.
Hydro	9.8	27	47	163	222	256	280	18	15	9.5	6.6	2.6	1.2	1.7
Geothermal	2.1	6.6	16	24	67	102	131	4.3	2.3	4.4	4.8	8.8	3.4	5.4
Solar PV	-	-	-	6.7	83	202	510	-	0.6	17	n.a.	23.3	9.5	14.5
Wind	-	-	-	3.5	34	82	169	-	0.3	5.7	n.a.	21.1	8.3	12.9
CSP and marine	-	-	-	-	0.1	0.2	0.5	-	-	0.0	n.a.	n.a.	8.8	n.a.
Biomass and waste	-	0.6	1.0	33	60	79	100	0.4	3.1	3.4	15.4	5.0	2.6	3.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	441	742	1 182	2 893	4 968	7 422	10 452	5.0	4.6	3.8	4.1
Population (million)	347	431	507	631	699	738	761	1.4	0.9	0.4	0.6
CO_2 emissions (Mt)	185	341	669	1 444	1 824	1 845	1 774	5.3	2.0	-0.1	0.6
GDP per capita ($2010 thousand)	1.3	1.7	2.3	4.6	7.1	10	14	3.6	3.7	3.3	3.5
Primary energy consump. per capita (toe)	0.4	0.5	0.7	1.1	1.4	1.6	1.7	2.4	2.0	1.2	1.5
Primary energy consumption per GDP*2	322	313	321	231	190	155	124	-1.1	-1.6	-2.1	-1.9
CO_2 emissions per GDP*3	420	459	566	499	367	249	170	0.3	-2.5	-3.8	-3.3
CO_2 per primary energy consumption*4	1.3	1.5	1.8	2.2	1.9	1.6	1.4	1.4	-0.9	-1.7	-1.4

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-51 | United States [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	1 805	1 915	2 274	2 231	2 093	1 942	1 772	100	100	100	0.5	-0.5	-0.8	-0.7
Coal	376	460	534	321	191	115	42	24	14	2.4	-1.3	-4.2	-7.3	-6.1
Oil	797	757	871	802	691	582	489	40	36	28	0.2	-1.2	-1.7	-1.5
Natural gas	477	438	548	709	714	631	470	23	32	27	1.7	0.1	-2.1	-1.3
Nuclear	69	159	208	219	195	195	197	8.3	9.8	11	1.1	-1.0	0.0	-0.3
Hydro	24	23	22	25	28	31	34	1.2	1.1	1.9	0.3	0.9	0.9	0.9
Geothermal	4.6	14	13	10	26	42	57	0.7	0.4	3.2	-1.2	8.1	4.1	5.6
Solar, wind, etc.	-	0.3	2.1	34	97	182	299	0.0	1.5	17	18.1	9.2	5.8	7.0
Biomass and waste	54	62	73	107	147	161	179	3.3	4.8	10	2.0	2.6	1.0	1.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	1 311	1 294	1 546	1 594	1 512	1 404	1 298	100	100	100	0.7	-0.4	-0.8	-0.6
Industry	387	284	332	277	277	266	248	22	17	19	-0.1	0.0	-0.6	-0.3
Transport	425	488	588	638	546	476	428	38	40	33	1.0	-1.3	-1.2	-1.2
Buildings, etc.	397	403	473	530	520	485	443	31	33	34	1.0	-0.2	-0.8	-0.6
Non-energy use	102	119	153	149	169	176	179	9.2	9.4	14	0.8	1.0	0.3	0.6
Coal	56	56	33	17	11	8.3	6.3	4.3	1.1	0.5	-4.2	-3.8	-2.5	-3.0
Oil	689	683	793	765	656	556	472	53	48	36	0.4	-1.3	-1.6	-1.5
Natural gas	338	303	360	381	376	335	294	23	24	23	0.8	-0.1	-1.2	-0.8
Electricity	174	226	301	335	356	383	393	18	21	30	1.4	0.5	0.5	0.5
Heat	-	2.2	5.3	6.2	5.4	4.6	3.8	0.2	0.4	0.3	3.9	-1.2	-1.7	-1.5
Hydrogen	-	-	-	-	0.1	0.2	0.4	-	-	0.0	n.a.	n.a.	9.6	n.a.
Renewables	54	23	54	90	109	117	129	1.8	5.6	9.9	5.0	1.6	0.8	1.1

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	2 427	3 203	4 026	4 434	4 684	5 011	5 102	100	100	100	1.2	0.5	0.4	0.4
Coal	1 243	1 700	2 129	1 272	838	496	155	53	29	3.0	-1.0	-3.4	-8.1	-6.4
Oil	263	131	118	43	28	15	4.2	4.1	1.0	0.1	-3.9	-3.6	-8.9	-7.0
Natural gas	370	382	634	1 519	1 596	1 442	760	12	34	15	5.1	0.4	-3.6	-2.1
Nuclear	266	612	798	841	748	750	755	19	19	15	1.1	-1.0	0.0	-0.3
Hydro	279	273	253	296	329	361	393	8.5	6.7	7.7	0.3	0.9	0.9	0.9
Geothermal	5.4	16	15	19	52	86	119	0.5	0.4	2.3	0.6	8.8	4.2	5.9
Solar PV	-	0.0	0.2	81	237	560	1 166	0.0	1.8	23	44.0	9.3	8.3	8.7
Wind	-	3.1	5.7	276	608	896	1 145	0.1	6.2	22	17.4	6.8	3.2	4.5
CSP and marine	-	0.7	0.5	3.9	84	208	376	0.0	0.1	7.4	6.6	29.1	7.8	15.3
Biomass and waste	0.5	86	72	78	158	192	224	2.7	1.8	4.4	-0.4	6.1	1.8	3.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	5.3	5.3	5.3	5.3	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	6 496	9 001	12 620	17 856	22 303	27 700	33 351	2.5	1.9	2.0	2.0
Population (million)	227	250	282	327	350	366	379	1.0	0.6	0.4	0.5
CO_2 emissions (Mt)	4 582	4 783	5 661	4 929	3 948	3 054	2 140	0.1	-1.8	-3.0	-2.6
GDP per capita ($2010 thousand)	29	36	45	55	64	76	88	1.5	1.3	1.6	1.5
Primary energy consump. per capita (toe)	7.9	7.7	8.1	6.8	6.0	5.3	4.7	-0.4	-1.1	-1.2	-1.2
Primary energy consumption per GDP[*2]	278	213	180	125	94	70	53	-1.9	-2.4	-2.8	-2.6
CO_2 emissions per GDP[*3]	705	531	449	276	177	110	64	-2.3	-3.6	-4.9	-4.5
CO_2 per primary energy consumption[*4]	2.5	2.5	2.5	2.2	1.9	1.6	1.2	-0.4	-1.3	-2.2	-1.9

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-52 | European Union [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	n.a.	1 439	1 471	1 428	1 316	1 188	1 070	100	100	100	0.0	-0.7	-1.0	-0.9
Coal	n.a.	391	285	216	144	92	55	27	15	5.2	-2.1	-3.3	-4.7	-4.2
Oil	n.a.	531	550	462	383	307	248	37	32	23	-0.5	-1.6	-2.1	-1.9
Natural gas	n.a.	250	309	324	303	263	208	17	23	19	0.9	-0.6	-1.9	-1.4
Nuclear	n.a.	190	224	199	192	195	196	13	14	18	0.2	-0.3	0.1	0.0
Hydro	n.a.	24	30	30	30	31	31	1.7	2.1	2.9	0.7	0.1	0.2	0.2
Geothermal	n.a.	3.2	4.6	6.8	10	12	13	0.2	0.5	1.2	2.8	3.4	1.1	1.9
Solar, wind, etc.	n.a.	0.3	2.4	41	80	109	140	0.0	2.9	13	19.1	5.6	2.8	3.9
Biomass and waste	n.a.	47	65	147	172	173	173	3.3	10	16	4.2	1.3	0.0	0.5

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	n.a.	995	1 028	1 023	958	857	765	100	100	100	0.1	-0.5	-1.1	-0.9
Industry	n.a.	313	274	244	243	231	209	31	24	27	-0.9	0.0	-0.8	-0.5
Transport	n.a.	220	262	287	236	190	160	22	28	21	1.0	-1.6	-1.9	-1.8
Buildings, etc.	n.a.	374	391	400	387	347	313	38	39	41	0.2	-0.3	-1.1	-0.8
Non-energy use	n.a.	88	101	91	91	89	84	8.9	8.9	11	0.1	0.0	-0.4	-0.3
Coal	n.a.	109	47	32	21	16	13	11	3.1	1.7	-4.3	-3.6	-2.2	-2.7
Oil	n.a.	444	479	420	352	284	230	45	41	30	-0.2	-1.5	-2.1	-1.9
Natural gas	n.a.	185	220	216	213	190	168	19	21	22	0.6	-0.1	-1.2	-0.8
Electricity	n.a.	162	189	216	234	243	243	16	21	32	1.0	0.7	0.2	0.4
Heat	n.a.	55	43	46	42	35	29	5.5	4.5	3.8	-0.6	-0.7	-1.8	-1.4
Hydrogen	n.a.	-	-	-	0.0	0.1	0.1	-	-	0.0	n.a.	n.a.	9.1	n.a.
Renewables	n.a.	39	50	92	96	89	81	4.0	9.0	11	3.1	0.4	-0.8	-0.4

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	n.a.	2 259	2 631	2 920	3 151	3 210	3 212	100	100	100	0.9	0.6	0.1	0.3
Coal	n.a.	844	846	643	445	224	68	37	22	2.1	-1.0	-3.0	-9.0	-6.8
Oil	n.a.	190	173	55	29	12	2.8	8.4	1.9	0.1	-4.3	-5.1	-11.0	-8.9
Natural gas	n.a.	188	331	491	482	430	246	8.3	17	7.7	3.5	-0.2	-3.3	-2.1
Nuclear	n.a.	729	860	762	739	748	753	32	26	23	0.2	-0.3	0.1	0.0
Hydro	n.a.	285	352	344	348	357	365	13	12	11	0.7	0.1	0.2	0.2
Geothermal	n.a.	3.2	4.8	6.7	11	14	16	0.1	0.2	0.5	2.6	4.5	1.6	2.7
Solar PV	n.a.	0.0	0.1	110	245	397	599	0.0	3.8	19	37.3	6.9	4.6	5.4
Wind	n.a.	0.8	21	321	546	649	724	0.0	11	23	24.0	4.5	1.4	2.6
CSP and marine	n.a.	0.5	0.5	5.3	38	70	99	0.0	0.2	3.1	8.8	17.6	5.0	9.6
Biomass and waste	n.a.	19	42	177	265	305	337	0.8	6.1	10	8.3	3.4	1.2	2.0
Hydrogen	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	n.a.	0.2	1.4	4.6	4.6	4.6	4.6	0.0	0.2	0.1	11.6	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	n.a.	10 234	12 698	16 365	19 171	21 845	24 303	1.7	1.3	1.2	1.2
Population (million)	n.a.	420	429	447	447	445	437	0.2	0.0	-0.1	-0.1
CO_2 emissions (Mt)	n.a.	3 422	3 248	2 781	2 153	1 638	1 204	-0.7	-2.1	-2.9	-2.6
GDP per capita ($2010 thousand)	n.a.	24	30	37	43	49	56	1.5	1.3	1.3	1.3
Primary energy consump. per capita (toe)	n.a.	3.4	3.4	3.2	2.9	2.7	2.4	-0.2	-0.7	-0.9	-0.8
Primary energy consumption per GDP[*2]	n.a.	141	116	87	69	54	44	-1.7	-2.0	-2.2	-2.1
CO_2 emissions per GDP[*3]	n.a.	334	256	170	112	75	50	-2.4	-3.4	-4.0	-3.8
CO_2 per primary energy consumption[*4]	n.a.	2.4	2.2	1.9	1.6	1.4	1.1	-0.7	-1.4	-1.9	-1.7

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A8-53 | World [Post Corona World Transformation Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total	7 203	8 767	10 034	14 282	16 389	17 494	17 724	100	100	100	1.8	1.2	0.4	0.7
Coal	1 783	2 221	2 317	3 838	4 129	4 042	3 614	25	27	20	2.0	0.6	-0.7	-0.2
Oil	3 105	3 233	3 669	4 497	4 907	5 109	4 929	37	31	28	1.2	0.7	0.0	0.3
Natural gas	1 231	1 662	2 071	3 262	4 025	4 611	5 019	19	23	28	2.4	1.8	1.1	1.4
Nuclear	185	526	675	707	800	866	966	6.0	4.9	5.4	1.1	1.0	0.9	1.0
Renewables, etc.	899	1 125	1 301	1 978	2 527	2 866	3 197	13	14	18	2.0	2.1	1.2	1.5

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	5 370	6 267	7 032	9 938	11 300	11 948	12 062	100	100	100	1.7	1.1	0.3	0.6
Coal	703	752	542	994	978	907	824	12	10	6.8	1.0	-0.1	-0.9	-0.6
Oil	2 449	2 606	3 119	4 051	4 479	4 675	4 536	42	41	38	1.6	0.8	0.1	0.4
Natural gas	815	944	1 119	1 611	1 908	2 008	2 064	15	16	17	1.9	1.4	0.4	0.8
Electricity	586	834	1 092	1 919	2 492	2 963	3 356	13	19	28	3.0	2.2	1.5	1.8
Hydrogen	-	-	-	-	4.4	21	43	-	-	0.4	n.a.	n.a.	12.1	n.a.
Heat and Renewables	817	1 131	1 160	1 362	1 440	1 374	1 239	18	14	10	0.7	0.5	-0.7	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	8 282	11 846	15 427	26 619	34 407	40 441	45 151	100	100	100	2.9	2.2	1.4	1.7
Coal	3 137	4 430	5 994	10 160	12 017	12 410	11 422	37	38	25	3.0	1.4	-0.3	0.4
Oil	1 659	1 323	1 184	784	749	684	479	11	2.9	1.1	-1.9	-0.4	-2.2	-1.5
Natural gas	998	1 749	2 775	6 150	8 359	10 838	12 551	15	23	28	4.6	2.6	2.1	2.3
Nuclear	713	2 013	2 591	2 710	3 072	3 323	3 707	17	10	8.2	1.1	1.0	0.9	1.0
Renewables	1 775	2 332	2 884	6 815	10 191	13 099	16 618	20	26	37	3.9	3.4	2.5	2.8
Hydrogen	-	-	-	-	19	86	373	-	-	0.8	n.a.	n.a.	16.1	n.a.

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	28 022	37 880	49 899	82 365	110 959	140 233	167 242	2.8	2.5	2.1	2.2
CO_2 emissions (Mt)	17 774	20 324	23 046	33 258	36 816	38 013	36 175	1.8	0.9	-0.1	0.3

Table A8-54 | World [Circular Carbon Economy/4Rs Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
Total[*1]	7 203	8 767	10 034	14 282	15 624	16 030	16 061	100	100	100	1.8	0.8	0.1	0.4
Coal	1 783	2 221	2 317	3 838	3 521	2 800	1 980	25	27	12	2.0	-0.7	-2.8	-2.0
Oil	3 105	3 233	3 669	4 497	4 605	4 350	3 922	37	31	24	1.2	0.2	-0.8	-0.4
Natural gas[*2]	1 231	1 662	2 071	3 262	3 812	4 397	4 816	19	23	30	2.4	1.3	1.2	1.2
Nuclear	185	526	675	707	929	1 134	1 297	6.0	4.9	8.1	1.1	2.3	1.7	1.9
Hydro	148	184	225	362	434	479	522	2.1	2.5	3.2	2.4	1.5	0.9	1.1
Geothermal	12	34	52	92	232	341	440	0.4	0.6	2.7	3.6	8.0	3.3	5.0
Solar, wind, etc.	0.1	2.5	8.0	194	573	978	1 468	0.0	1.4	9.1	16.8	9.4	4.8	6.5
Biomass and waste	738	904	1 015	1 327	1 517	1 548	1 613	10	9.3	10	1.4	1.1	0.3	0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	5 370	6 267	7 032	9 938	10 876	11 056	10 999	100	100	100	1.7	0.8	0.1	0.3
Industry	1 767	1 803	1 871	2 839	3 200	3 201	3 006	29	29	27	1.6	1.0	-0.3	0.2
Transport	1 245	1 575	1 963	2 891	2 999	3 052	3 142	25	29	29	2.2	0.3	0.2	0.3
Buildings, etc.	2 000	2 411	2 592	3 291	3 560	3 560	3 508	38	33	32	1.1	0.7	-0.1	0.2
Non-energy use	358	477	606	917	1 116	1 243	1 344	7.6	9.2	12	2.4	1.7	0.9	1.2
Coal	703	752	542	994	924	798	658	12	10	6.0	1.0	-0.6	-1.7	-1.3
Oil	2 449	2 606	3 119	4 051	4 238	4 058	3 714	42	41	34	1.6	0.4	-0.7	-0.3
Natural gas	815	944	1 119	1 611	1 853	1 880	1 882	15	16	17	1.9	1.2	0.1	0.5
Electricity	586	834	1 092	1 919	2 443	2 826	3 096	13	19	28	3.0	2.0	1.2	1.5
Heat	121	336	248	301	300	275	248	5.4	3.0	2.3	-0.4	0.0	-0.9	-0.6
Hydrogen	-	-	-	-	44	213	430	-	-	3.9	n.a.	n.a.	12.1	n.a.
Renewables	697	794	911	1 061	1 074	1 005	972	13	11	8.8	1.0	0.1	-0.5	-0.3

Electricity generation

	TWh							Shares (%)			1990/	2018/	2030/	2018/
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	2018	2030	2050	2050
Total	8 282	11 846	15 427	26 619	33 515	38 297	41 639	100	100	100	2.9	1.9	1.1	1.4
Coal	3 137	4 430	5 994	10 160	9 438	6 598	3 154	37	38	7.6	3.0	-0.6	-5.3	-3.6
Oil	1 659	1 323	1 184	784	592	387	185	11	2.9	0.4	-1.9	-2.3	-5.6	-4.4
Natural gas[*2]	998	1 749	2 775	6 150	7 435	8 489	7 977	15	23	19	4.6	1.6	0.4	0.8
Nuclear	713	2 013	2 591	2 710	3 567	4 352	4 979	17	10	12	1.1	2.3	1.7	1.9
Hydro	1 717	2 141	2 613	4 214	5 043	5 574	6 070	18	16	15	2.4	1.5	0.9	1.1
Geothermal	14	36	52	89	248	369	481	0.3	0.3	1.2	3.2	8.9	3.4	5.4
Solar PV	-	0.1	0.8	554	1 969	3 884	6 636	0.0	2.1	16	36.5	11.1	6.3	8.1
Wind	0.0	3.9	31	1 273	3 665	5 626	7 351	0.0	4.8	18	23.0	9.2	3.5	5.6
CSP and marine	0.5	1.2	1.1	12	173	426	809	0.0	0.0	1.9	8.7	24.6	8.0	14.0
Biomass and waste	44	130	163	637	1 159	1 465	1 773	1.1	2.4	4.3	5.9	5.1	2.1	3.2
Hydrogen	-	-	-	-	190	1 093	2 188	-	-	5.3	n.a.	n.a.	13.0	n.a.
Others	-	20	22	35	35	35	35	0.2	0.1	0.1	2.0	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2018	2030	2040	2050	1990/ 2018	2018/ 2030	2030/ 2050	2018/ 2050
GDP ($2010 billion)	28 022	37 880	49 899	82 365	113 405	148 705	186 235	2.8	2.7	2.5	2.6
Population (million)	4 434	5 278	6 111	7 591	8 497	9 146	9 682	1.3	0.9	0.7	0.8
CO_2 emissions (Mt)	17 774	20 324	23 046	33 258	32 316	27 435	20 025	1.8	-0.2	-2.4	-1.6
GDP per capita ($2010 thousand)	6.3	7.2	8.2	11	13	16	19	1.5	1.7	1.8	1.8
Primary energy consump. per capita (toe)	1.6	1.7	1.6	1.9	1.8	1.7	1.6	0.4	-0.2	-0.6	-0.4
Primary energy consumption per GDP[*3]	257	231	201	173	138	107	85	-1.0	-1.9	-2.4	-2.2
CO_2 emissions per GDP[*4]	634	537	462	404	285	184	109	-1.0	-2.8	-4.7	-4.0
CO_2 per primary energy consumption[*5]	2.5	2.3	2.3	2.3	2.1	1.7	1.3	0.0	-1.0	-2.4	-1.8

*1 Trade of electricity, heat and hydrogen are not shown, *2 Incudes synthetic methane, * toe/$2010 million,
*4 t/$2010 million, *5 t/toe

Slides

The 436th Forum on Research Work

IEEJ Outlook 2021

Energy transition in the post corona world

Energy, Environment and Economy

Tokyo, 16 October 2020

The Institute of Energy Economics, Japan

Energy Outlook toward 2050 and Post Corona Scenario

Reference

Summary of Reference Scenario

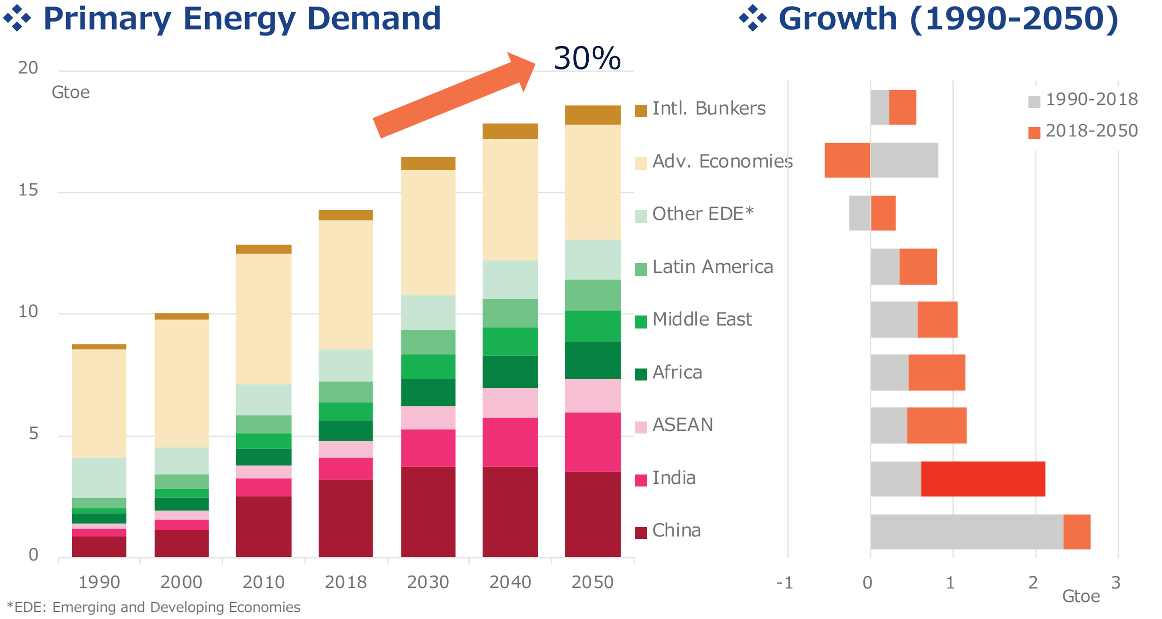
Reference Scenario

The scenario reflects past trends with technology progress and current energy policies.

- Global energy demand increases, especially in Asia. The center of global energy demand shifts to Asia.
- Within Asia, demand increases mainly in India and Southeast Asia.
- Natural gas increases significantly, oil increases moderately while coal peaks out. The overall share of fossil fuels stays at 80%, even in 2050.
- With an increase in energy demand centered on fossil fuels in Asia, energy security and environmental issues become more serious in the future.
- It is important to respond to the decline in self-sufficiency and the increase impact on the environment, especially in Asia.

Reference

Demand growth shifts from China to India



*EDE: Emerging and Developing Economies

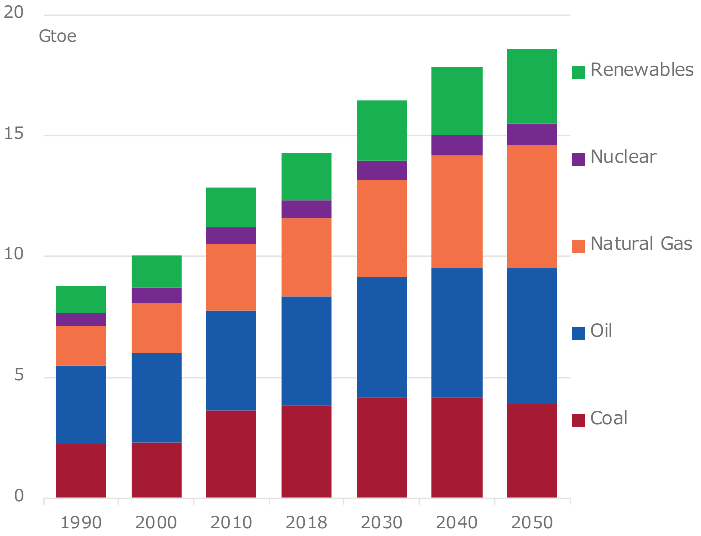
Energy demand in emerging and developing countries increases by more than 50%, while that in advanced economies decreases by about 10%.

The global energy demand growth changes from China to India. More than one-third of the global demand growth comes from India, while China's demand peaks in the late 2030s.

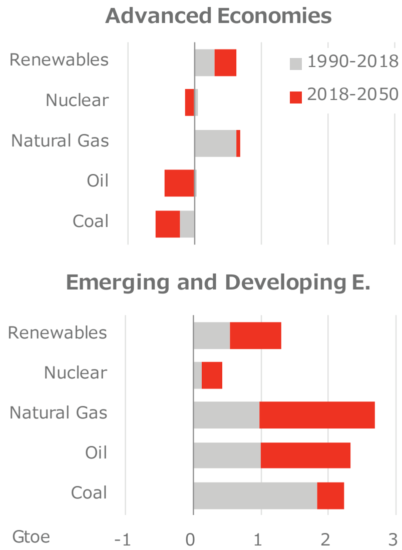
Reference

Coal peaks out, NG increases significantly, Oil continues to increase

❖ Primary Energy Demand



❖ Growth (1990-2050)



Natural gas increases the most, especially in the power generation sector, making it the second largest energy source after oil. The growth in oil consumption in emerging and developing countries by far counter-balances the decrease in advanced economies. Coal demand peaks in the mid-2030s due to a decline in advanced economies and China.

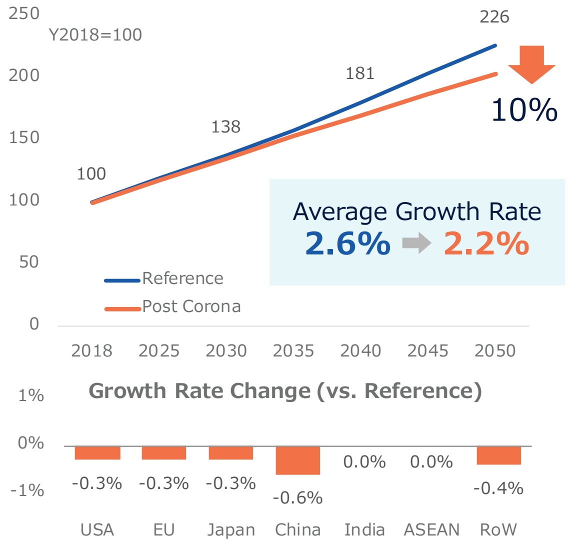
Analyzing "Post Corona World Transformation Scenario"

Reference Scenario	Reflects past trends with technology progress and current energy policies.	
Post Corona World Transformation Scenario	A world in which the coronavirus pandemic causes transformation and changes in politics, economy and society. Strengthening climate measures continues, but the extent of efforts differs in each country/region.	
	Emphasis on security	**Progress of digitization**
Changes in consciousness and behavior	・Ensuring the safety and health of people, including measures against infection. ・Reviewing supply chains, including the extent of self-sufficiency.	・Increasing remote activities by refraining people's movements and personal contacts. ・As society avoids denseness, migration from large cities to rural areas is emerging.
Changes are accelerating	・The worsening of US-China relations ignites relatively high political tensions between nations. ・Nationalism and alliedism leading to withdraws from the free trade system.	・Accelerating ICT to support and establish remote economic activities. ・Refraining from foreign travel, transportation demand stagnated.
Consequences of the changes	・Global economy slowing down. Manufacturing base shifts from China to India /ASEAN. ・Strengthening efforts to diversify energy supply and improve self-sufficiency. Competition for energy technology hegemony.	・As society becomes more digital, electricity demand increases. ・Significant drop in oil demand, especially for transportation fuels .

Post-Corona

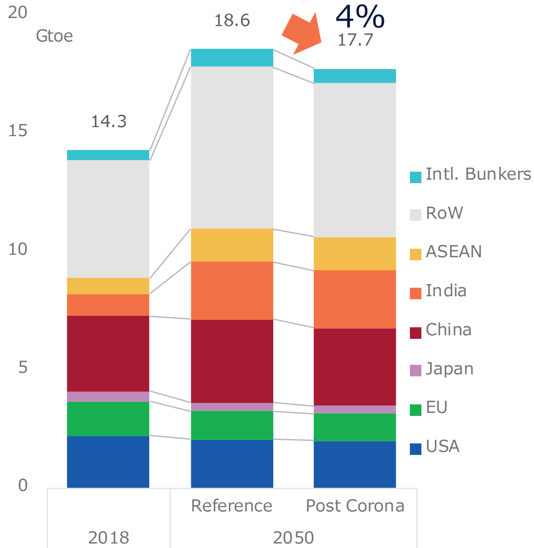
Economic growth slows and energy demand curtails

GDP



Ref.) During the Great Depression of 1929, about 10% of GDP was lost in three years.

Primary Energy Demand



Note) The EU (European Union) does not include the United Kingdom. The same shall apply hereafter. RoW: Rest of the world

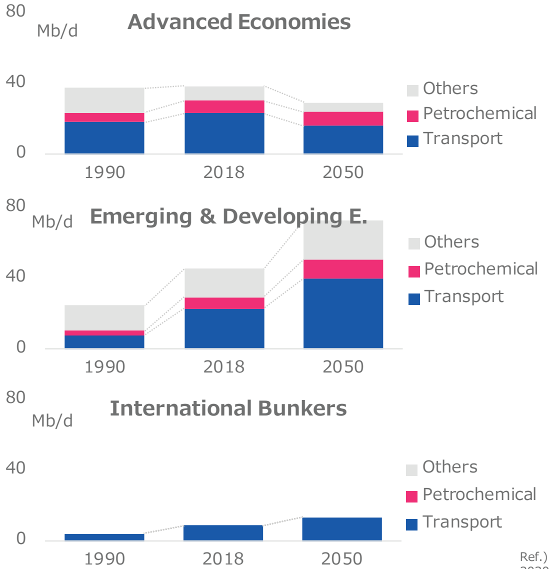
In the Reference scenario (RS), energy demand increases by 30%, with more than 60% of the increase coming from the Asian region.

In the Post Corona scenario (PCS), stagnation in free trade causes the world economy to shrink 10% by 2050. With leakages in production bases, China's economy significantly slows down. Global energy demand shrinks by 4%, but concentration in Asia remains unchanged.

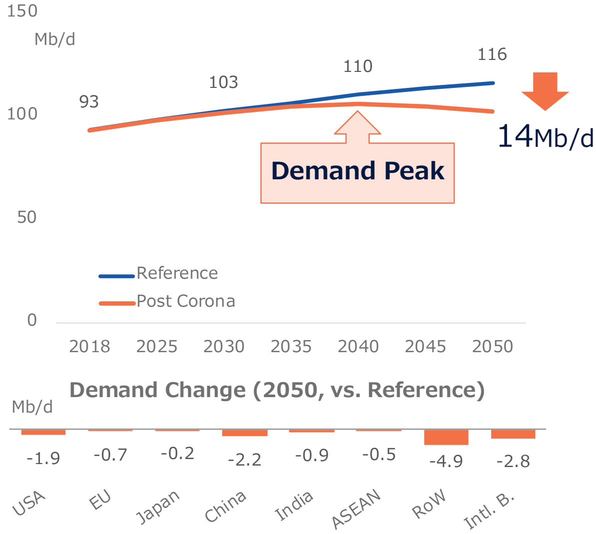
Post-Corona

Oil demand peaks due to stagnation in transportation

Oil Demand by Sector (Reference)



Oil Demand in Post-Corona



Ref.) It is estimated that if the electrification of automobiles progresses rapidly, it will reach its peak around 2030 (IEEJ Outlook 2018).

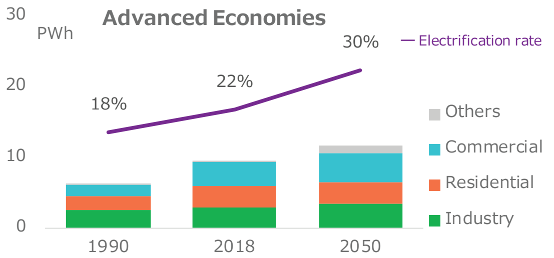
In the RS, global oil demand grows primarily because of transportation fuels and petrochemical feedstocks. In advanced economies, however, demand for transportation fuels is declining.

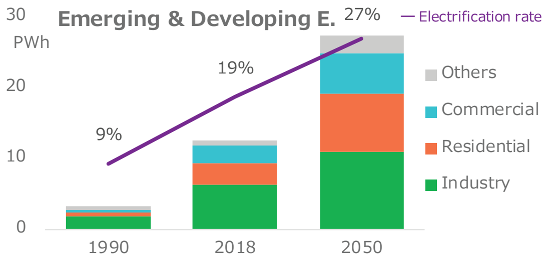
In the PCS, oil demand peaks around 2040. Fuel demand for automobiles, aviation, and ships declines due to economic slowdown and associated lower transportation requirements.

Post-Corona

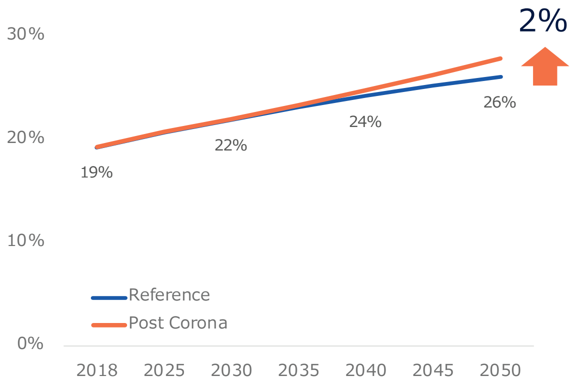
Digital transformation(DX) raises electrification rate

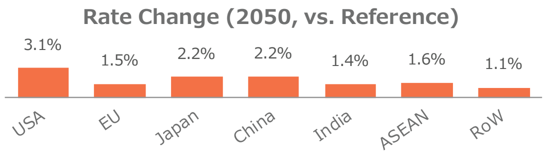
❖ Final Electricity Demand (Reference)





❖ Electrification Rate in Post-Corona





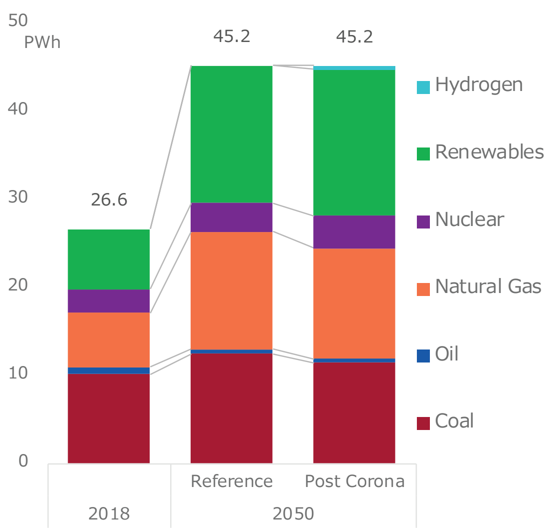
In the RS, electricity demand in the industry and building sectors surged along with the economic development of developing countries. Energy demand becomes more electrified.

In the PCS, digital transformation (DX) supports remote economic activities and further promotes electrification. The issue is the balance between privacy protection and information management by governments. There are two patterns, “centralized” and “distributed”, and there are various differences.

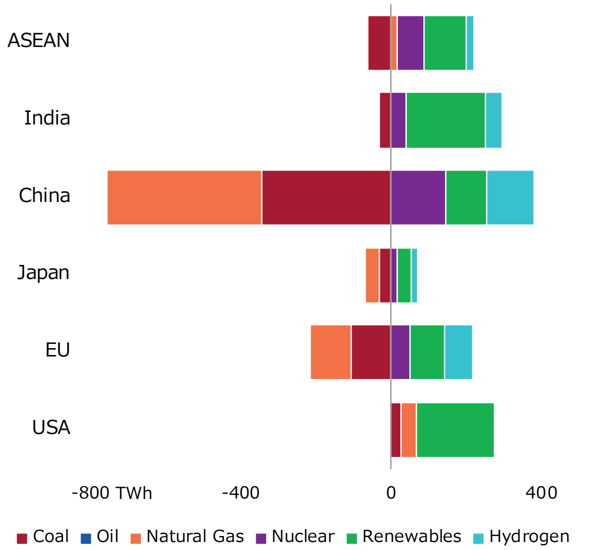
Post-Corona

Power generation shifts to non-fossil power sources, including hydrogen

❖ Power Generation Mix



❖ Generation Change (2050, vs. Reference)



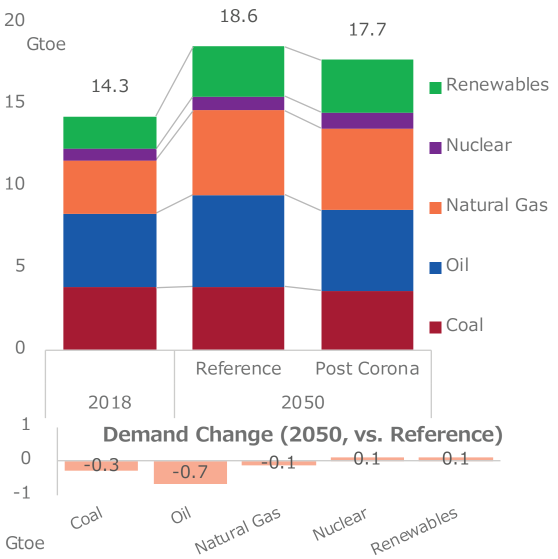
In the RS, gas-fired power and renewable energy support the rapidly increasing electricity demand. Coal-fired power is still needed in developing countries.

In the PCS, the shift to nuclear and renewable energy sources progresses, while the use of natural gas, which is highly dependent on imports, is curtailed. As competition for the development of innovative technologies progresses, hydrogen begins to be used for power generation. For more on hydrogen introduction, see “Circular Carbon Economy / 4R Scenario”.

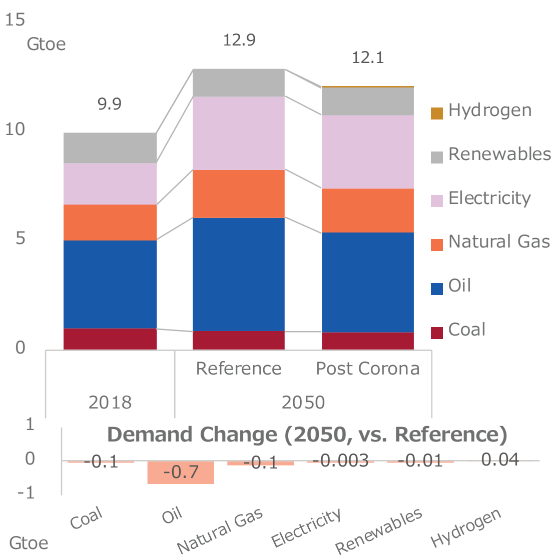
Post-Corona

Shift to non-fossil fuels but world still depends on fossil fuel

Primary Energy Demand



Final Energy Demand



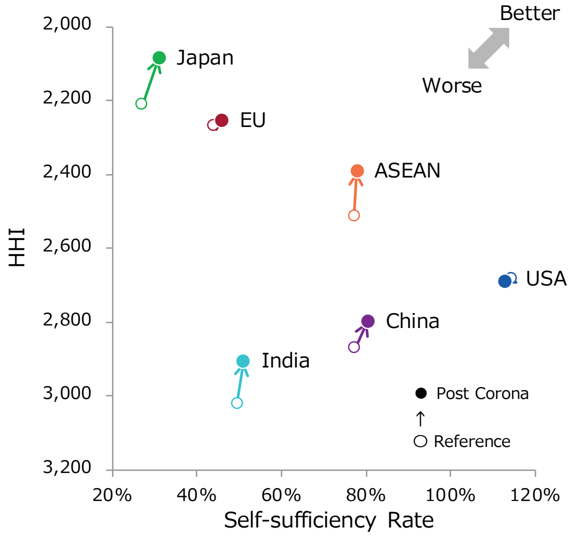
In the RS, primary energy reliance on fossil fuels drops slightly from 81% to 79%.

In the PCS, a shift to (semi-) domestic energy, such as nuclear power and renewable energy, occurs. Due to the stagnation in the transportation sector, oil demand decreases significantly and fossil fuel dependency declines slightly to 77%.

Post-Corona

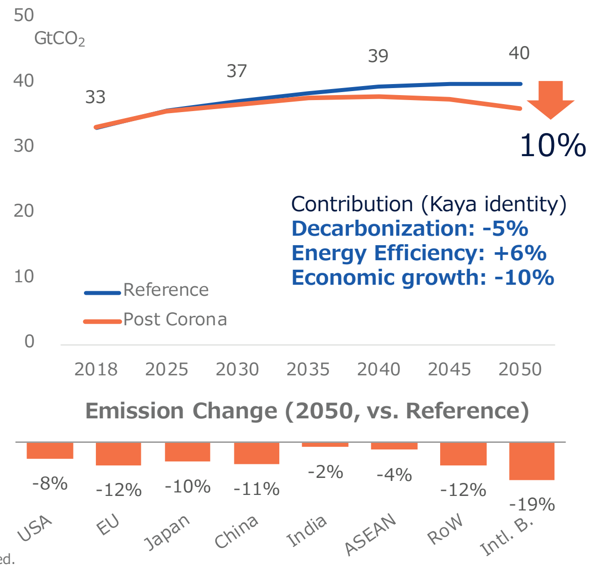
Self-sufficiency / diversity improves and CO_2 peaks earlier

Energy Self-sufficiency/Diversity (2050)



HHI (Herfindahl-Hirschman Index): An indicator of concentration. The higher the number, the higher the concentration, and the lower the number, the more diversified.

Energy-related CO_2 Emissions



In the RS, the energy self-sufficiency rate of ASEAN and India dropped significantly and CO_2 emissions peak in the late 2040s.

In the PCS, the self-sufficiency / diversity improve in importing countries. The peak of CO_2 emissions is accelerated by 10 years due to economic slowdown and decarbonization.

Reference Post-Corona

Summary

Reference

- Energy demand increases, especially in Asia, and the fossil fuel dependency remains unchanged even in 2050. Improving living standards in developing countries drives oil and electricity demand.
- CO_2 emissions peak in the late 2040s due to progress in energy saving and low carbonization of power supply.

Post Corona

- The global economy and energy demand are slowing down, due to divergent systems to pursue economic efficiency. The pattern of increase in energy demand by region also changes.
- An earlier peak in oil demand squeezes the oil-producing economies, making economic diversification more important. Meanwhile, appropriate upstream investment is essential because demand is maintained at a certain level.
- Efforts to strengthen energy security and decarbonize induces competition for the development of innovative technologies and promotes non-fossil energy and CO_2-free hydrogen.
- It is important to be aware of the possibility of a world in transformation and to formulate energy policies based on strategic thinking to respond to those changes.

ATS

Advanced Technologies Scenario (ATS)

ATS

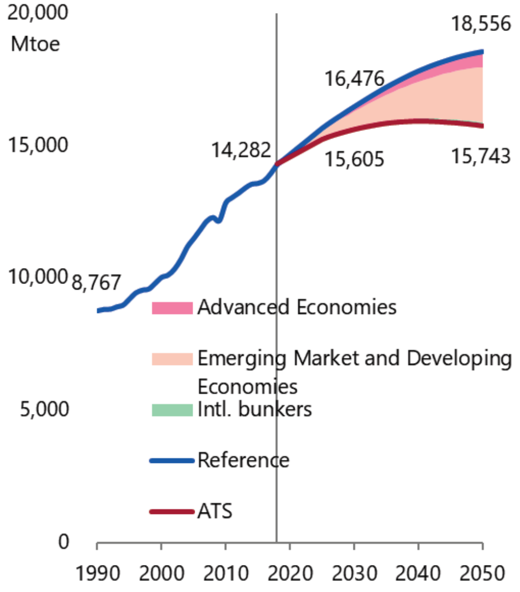
Base scenarios of IEEJ Outlook

	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.
Social-economy structure	Stable growth led by developing economies despite slower population growth. Rapid diffusion of energy consuming appliances and vehicles due to higher income.	
International energy price	**Oil** supply cost increases along with demand growth. **Gas** price convergences among Europe, N. America and Asia markets. **Coal** keeps unchanged with today’s level. [LNG in Asia] Higher/lower price cases	Slower price increase due to lower demand growth (coal price decreases).
Energy policies	Gradual reinforcement of low-carbon policies with past pace.	Further reinforcement of domestic policies along with international collaboration.
Energy technologies	Improving efficiency and declining cost of existing technology with past pace.	Further declining cost of existing and promising technology.

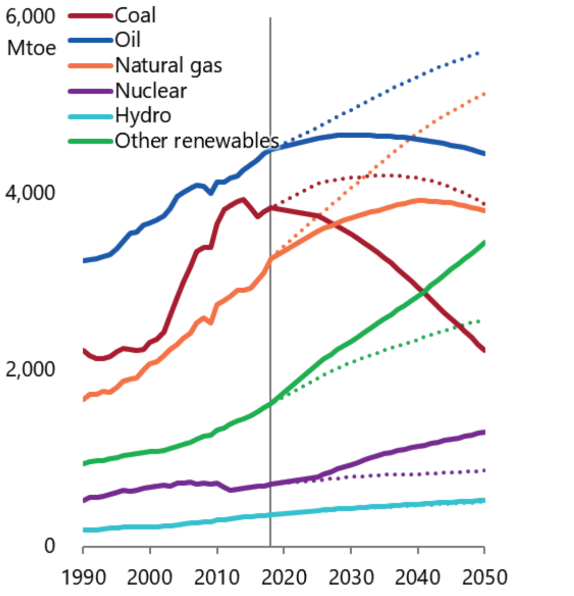
ATS

Total Primary Energy demand (World)

By Region



By Source

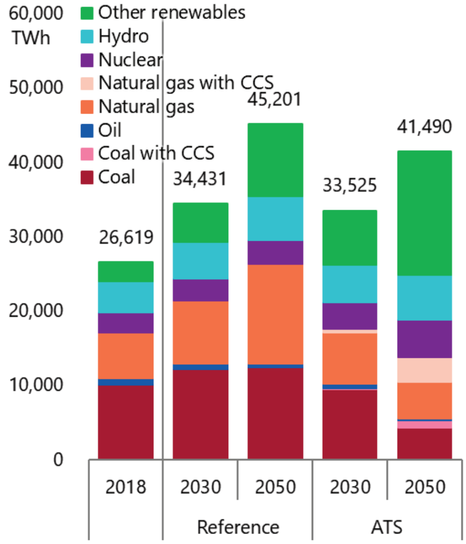


The world’s energy demand in ATS is lower by 15% compared to Reference largely because of the energy saving by emerging countries.
The world will remain dependent on fossil fuels for 67% of the total demand as of 2050.

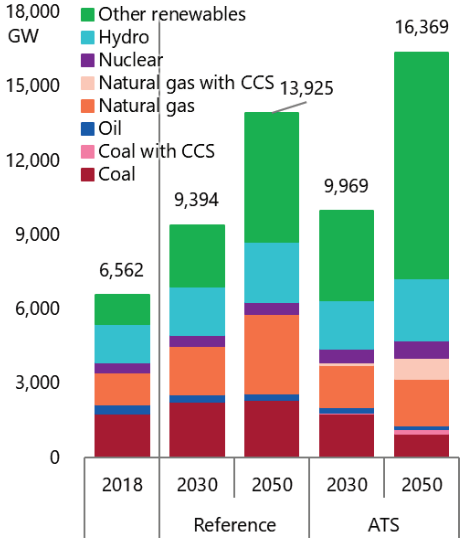
ATS

Electricity generation

Electricity generation



Generation capacity



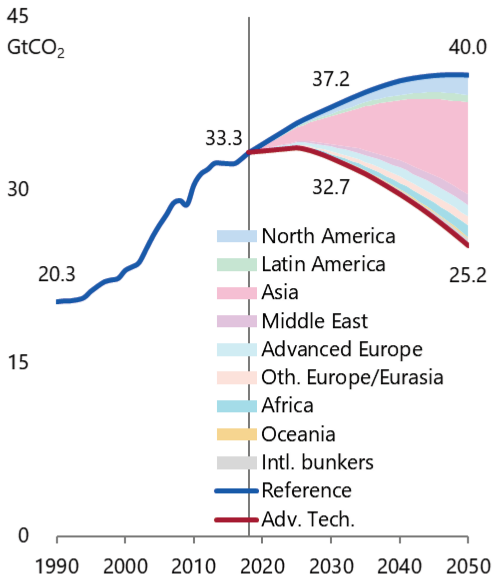
The total electricity generation will decline in ATS. Electricity demand of the transportation sector will grow in ATS, but the decline of the demand of the industrial, residential, and commercial sectors more than offset the growth.

The share of other renewable (solar, wind, etc.) will grow to the largest electricity generation source while the share of coal will decline.

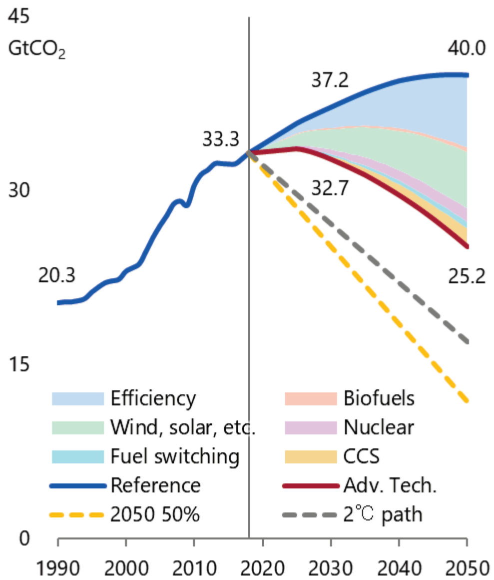
ATS

CO_2 Emissions

By country / region



By technology



The world CO_2 emissions in ATS are estimated to peak in around 2025.

The emissions of ATS asof 2050 will be lower by37% compared to Reference. Decarbonization of energy mix is a primary reason of the emissions reduction.

Circular Carbon Economy / 4R Scenario (CCE)

Significance of this scenario

- In order to achieve an ambitious emissions reduction target, a holistic approach to utilize all available emissions reduction technologies at the utmost is necessary.

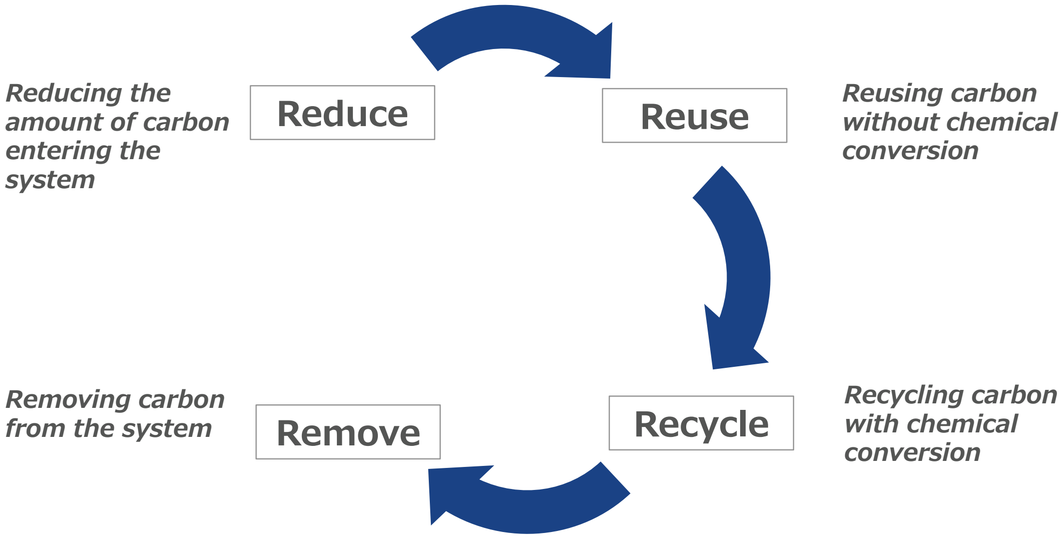
- In pursuing the emissions reduction, not only technologies of zero-carbon energy sources such as renewable and nuclear but also technologies of carbon-neutral (or decarbonized) use of fossil fuels have to be deployed.

- Global interests on the concept of Circular Carbon Economy (CCE) are growing as the concept will be a major agenda of G20 Summit 2020 hosted by Saudi Arabia.

- Circular Carbon Economy / 4R Scenario (CCE scenario, hereafter) provides a future scenario where technologies of carbon-neutral use of fossil fuels are assumed to be utilized at the utmost to show how the CO_2 emissions, energy mix, and the power generation will evolve.

CCE

Circular Carbon Economy: CCE



Circular Carbon Economy (CCE) is a holistic approach to manage carbon emissions as a closed circular system.

CCE aims to utilize all available emissions reduction technologies by the "4R" steps (Reduce, Reuse, Recycle, and Remove).

CCE

4R technologies to manage carbon

Major 4R technologies

Reduce	Reuse	Recycle	Remove
Reducing the amount of carbon entering the system	Reusing carbon without chemical conversion	Recycling carbon with chemical conversion	Removing carbon from the system
• Energy and materials efficiency • Renewable energy, including hybrid use with fossil fuel • Nuclear energy, including hybrid use with fossil fuel • Advanced ultra-super-critical technologies for coal power plants • Hydrogen (blue/green) fuel cells for long-distance heavy-duty vehicles • Ammonia produced from zero-carbon hydrogen (blue/green) for power generation and ships • Direct reduction in steel making by using CO_2 free hydrogen (blue/green)	• Carbon capture and utilization (CCU) • Use CO_2 at carbon utilization facilities, such as at greenhouses for enhancing crops • Bio-jet fuels with reed beds • Algal synthesis	• CCU • Artificial photosynthesis • Bioenergy recycle in the pulp and paper industry • Bioenergy with carbon capture and storage • Carbamide (urea production using CO_2 as feedstock) • Coal ash concrete curing with absorbing CO_2 • Electrochemical reduction of CO_2 • Fine chemicals with innovative manufacturing processes and carbon recycling • Fischer-Tropsch exothermic of carbon dioxide with hydrogen syngas • Hydrogenation to formic acid • Oil sludge pyrolysis • Sabatier synthesis (CO_2 methanation: exothermic of carbon dioxide with blue/green hydrogen) • Thermal pyrolysis	• CCS • Direct air capture (DAC) • Carbon dioxide removal • Fossil fuels-based blue hydrogen

Source : Mansouri, N. Y. *et al.*(2020) "A Carbon Management System of Innovation: Towards a Circular Carbon Economy"

The "4R" in CCE covers all available technology options to reduce CO_2 in a systematic manner.

The concept of 4R highlights the importance of Reuse and Recycle technologies that regard carbon as a resource.

CCE

Assumptions of CCE Scenario

Assumed adoptions of 4R technologies in CCE scenario

4R	Technology	Assumption
Reduce	Blue hydrogen* for power generation	Adopt blue hydrogen power generation (including ammonia produced from blue hydrogen) for 50% of coal-fired power plants without CCS facility as of 2050 in Advanced Technologies Scenario (ATS)
	Blue hydrogen for transportation	Adopt blue hydrogen (mainly as fuel cell vehicle) to 20% of road transportation demand as of 2050
	Direct reduction in steel making by blue hydrogen	Adopt direct reduction technology utilizing blue hydrogen to 25% of crude steel production in OECD, China, and India as of 2050
	Reduction of cement production	Reduction of cement production by 25% utilizing coal ash and limestone and calcined clay as of 2050
Reuse	Algae synthesis to produce biofuel	Increase algae-based bio-diesel by 50% from ATS
Recycle	Concrete curing capturing CO_2	Adopt concrete curing capturing CO_2 technology to 50% of the world concrete production as of 2050
	Synthetic methane	Replace natural gas with synthetic methane (produced from blue hydrogen and green hydrogen**) for 50% of gas-fired power plants without CCS facility as of 2050 in ATS
Remove	Carbon capture and storage	CCS for blue hydrogen production

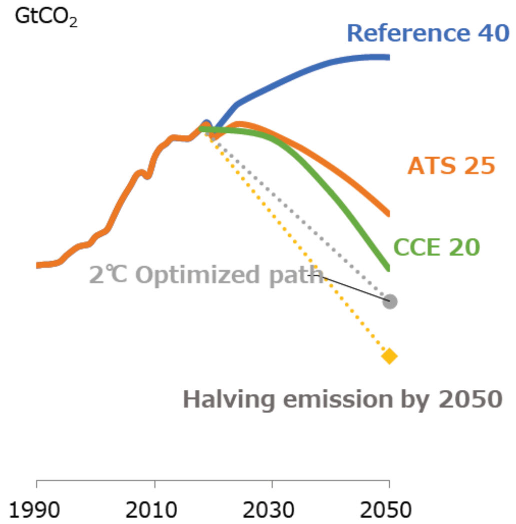
*Blue hydrogen : Hydrogen produced from fossil fuels with CCS
**Green hydrogen : Hydrogen produced by electrolysis utilizing electricity from renewable power generation

CCE scenario assumes the utmost adoptions of 4R technologies for carbon-neutral use of fossil fuels with all other assumptions based on the Advanced Technologies Scenario.

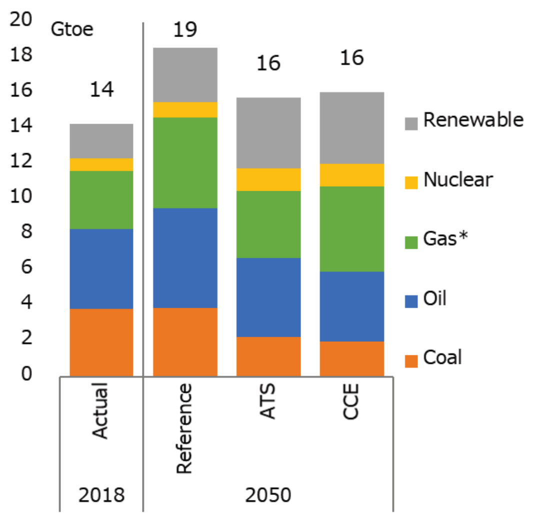
CCE

Emissions reduced while using fossil fuels

World CO_2 Emissions



Total Primary Energy Demand of the World



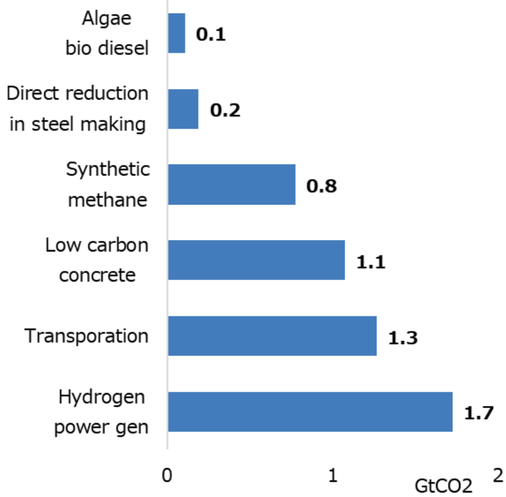
*Gas in CCE scenario includes synthetic methane

CO_2 emissions are reduced by 5Gt from ATS and approaches 2℃ optimized path.
While the share of fossil fuels of CCE scenario is almost same as ATS', the mix of fossil fuel shifts from coal and oil to natural gas as a primary feedstock of blue hydrogen.
CO_2 emissions significantly reduced while the consumption of fossil fuel unchanged.

CCE

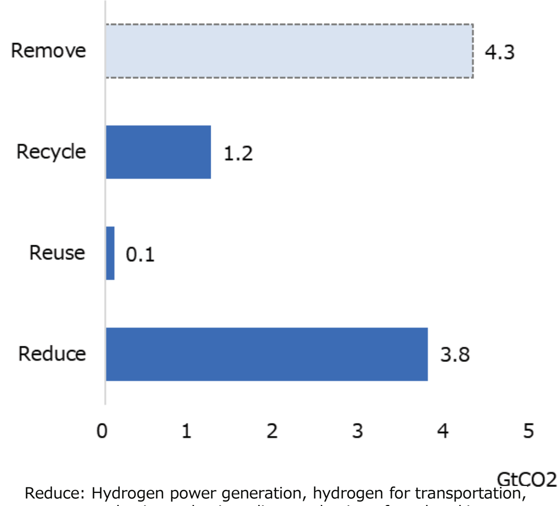
Power and transport have large reduction potential.

✣ CO_2 emissions reduction by technology



* The amount of Low carbon concrete is the sum of reduced volume of cement production reduction and concrete curing absorbing CO_2.

✣ CO_2 emissions reduction by 4R



Reduce: Hydrogen power generation, hydrogen for transportation, cement production reduction, direct reduction of steel making
Reuse : Algae biodiesel
Recycle : CO_2 absorbing concrete, synthetic methane
Remove: CCS（also counted in Reduce and Recycle technologies)

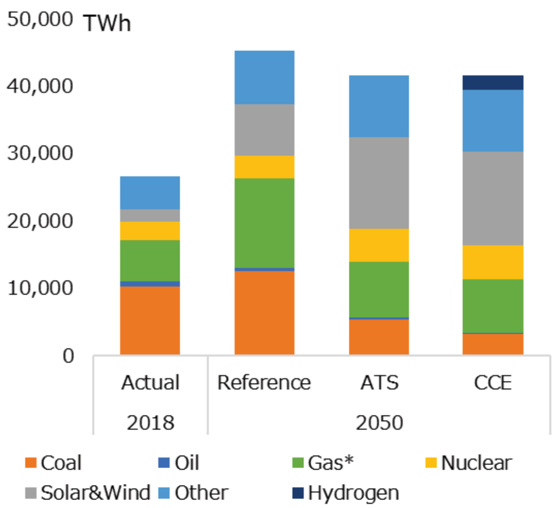
Power and Transportation sectors have high potential of emissions reduction in CCE scenario. Blue hydrogen plays a significant role in both sectors.

Reduce technologies contributes the reduction most while the Reuse and Recycle's contributions are relatively small.

CCE

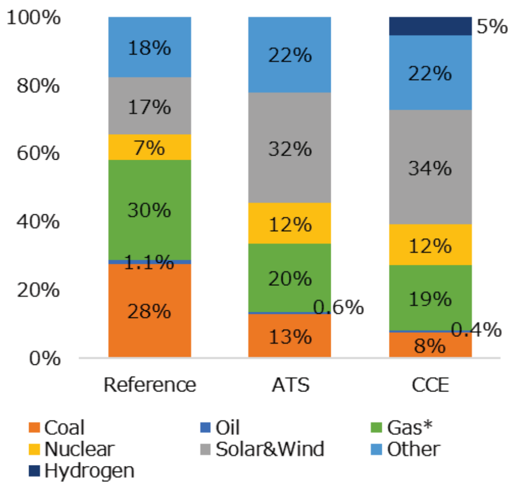
Coal power will be partially replaced with H_2.

✣ Electricity generation (World)



*CCE scenario includes synthetic methane.

✣ Power generation mix (World as of 2050)



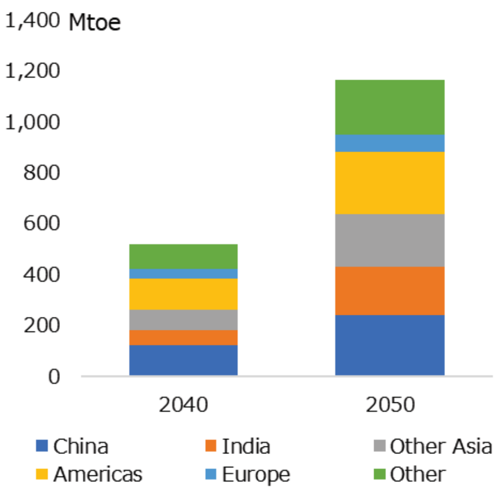
*CCE scenario includes synthetic methane.

Share of fossil fuels will decline from 34% to 27% in CCE scenario.
Share of hydrogen power will be 5% as of 2050.

CCE

Hydrogen demand will grow in Asia.

❖ World hydrogen demand



❖ Hydrogen balance (2050)

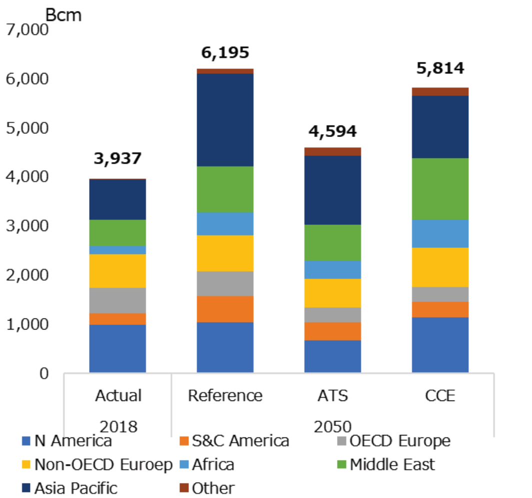
World hydrogen demand is expected to grow mainly in Asia in CCE scenario.

Countries without blue hydrogen production capability will need to import blue hydrogen from countries with low cost and abundant fossil fuel resources with CCS capability.

CCE

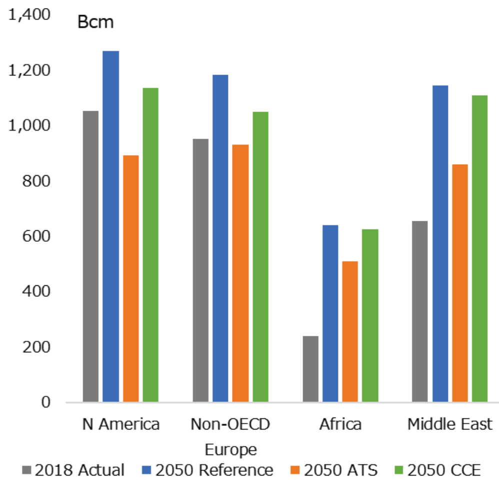
New natural gas demand will emerge.

❖ Natural gad demand* (World)



*Includes synthetic methane

❖ Natural gas production (as of 2050)



Natural gas demand will grow by 27% in CCE scenario as of 2050 because of the additional feedstock demand for blue hydrogen.*

Major gas producing countries are required to increase their production although the volume of production will not exceed the reference scenario.

***This scenario assumes a major feedstock of blue hydrogen will be natural gas.**

CCE

Implications

- Significant emissions reduction of CO_2 and the use of fossil fuels can be pursued simultaneously by utilizing 4R technologies for carbon-neutral use of fossil fuels.
- Blue hydrogen will play a key role. Reduction of its production cost and infrastructure developments will be necessary.
- Among 4R technologies, technologies of Reuse and Recycle need to be further developed. Policy and financial support for R&D as well as international collaboration are important.
- Significance and implications of the concept of Circular Carbon Economy need to be more publicized.

Climate change scenario analysis

— Towards a more robust estimation of costs and benefits —

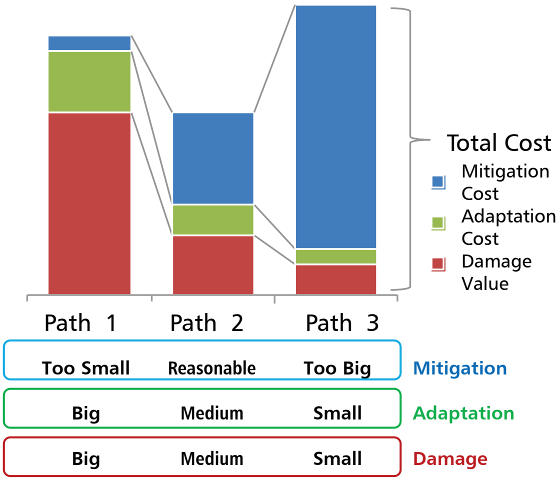
Cost-benefit analysis of climate change

Note: Exactly, the optimal path is calculated not by minimizing the cost, but by maximizing the utility.

❖ Mitigation+Adaptation+Damage=Total Cost

Mitigation	•Typical measures are GHG emissions reduction via energy efficiency and non-fossil energy use. • Includes reduction of GHG release to the atmosphere via CCS • These measures **mitigate** climate change.
Adaptation	•Temperature rise may cause sea-level rise, agricultural crop drought, disease pandemic, etc. • **Adaptation** includes counter measures such as building banks/reservoir, agricultural research and disease preventive actions.
Damage	If mitigation and adaptation cannot reduce the climate change effects enough to stop sea-level rise, draught and pandemics, **damage** will take place.

❖ Illustration of the Total Cost

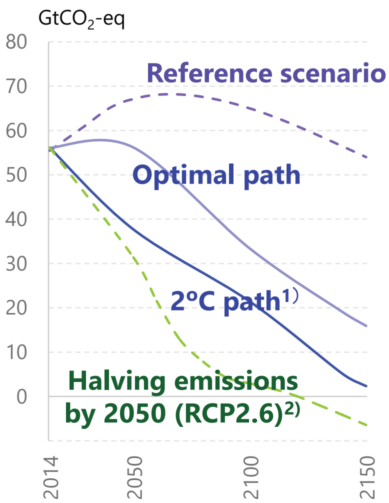


Without measures against climate change, the mitigation cost is small, while the adaptation and damage costs become substantial. Aggressive mitigation measures on the other hand, would reduce the adaptation and damage costs but the mitigation costs would be notably colossal.

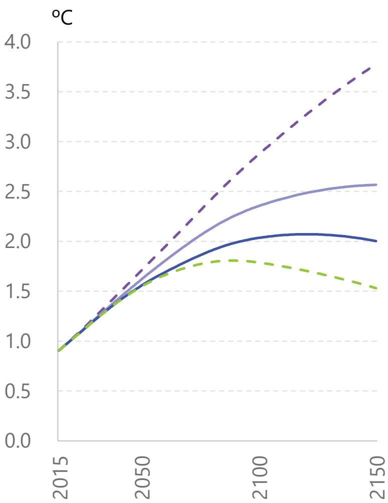
The climate change issue is a long-term challenge influencing vast areas over many generations. As such, and from a sustainability point of view, the combination (or the mix) of different approaches to reduce the total cost of mitigation, adaptation and damage is important.

Optimal and 2°C paths

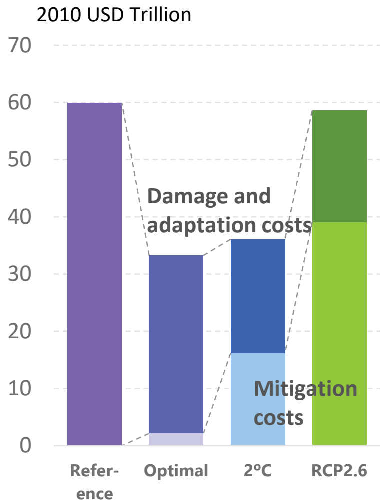
GHG emissions



Temperature rise from preindustrial levels



Total cost (Cumulative up to 2500)



1) A path in which the global mean temperature exceeds 2°C and the returns to 2°C by 21!

2) A path roughly equivalent to IPCC's RCP2.6.

- The temperature rise in the optimal path exceeds 2.5°C by 2150, although the results vary strongly depending on the assumptions.
- At the same time, an overshooting path, in which the temperature rise returns to 2.0°C by 2150, may also be achievable without large cost increases.

Challenges for cost-benefit analysis

Accuracy of the damage function

- Estimation of the damages caused by climate change involves great uncertainties. Although research is progressing around the world, sufficient knowledge has not been accumulated.
- It is important to refine the damage function (relationship between temperature rise and damage value) based on the latest scientific knowledge.

Effects of "tipping elements"

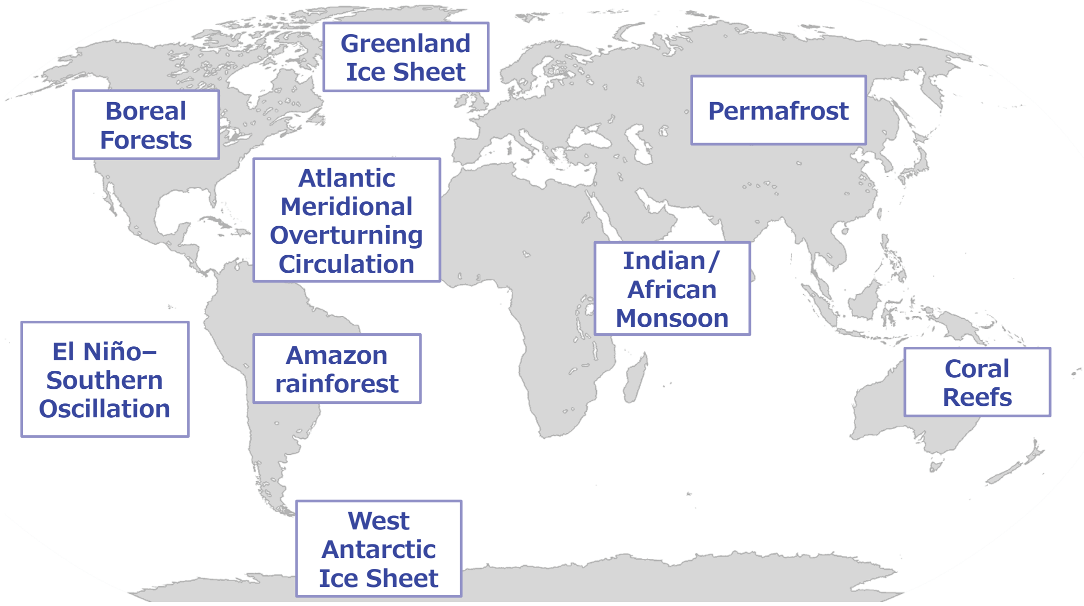
- If the progress of an event exceeds the critical point, negative feedbacks of the Earth system may stop functioning, and the change may be accelerated.
- For example, as Siberian permafrost melting progresses due to global warming, underground methane and CO_2 are released into the atmosphere. The release itself contributes to global warming, further thawing the frozen soil.
- They point out that there is a risk of shifting to a different equilibrium state, for example, "Hothouse Earth" where the temperature is higher by several degrees or more than before as a result.

Other theoretical issues

- Issues related long-term discount rates, "fat tails,"[1)] etc.
- Discussions continue, and no consensus has been found among researchers at present.

1):It has been pointed out that the tail of the probability distribution of the damage by climate change may be thick (i.e. higher probability of occurrence than the normal distribution).

Tipping points of the earth system



- The earth system is supposed to have been in a quasi equilibrium state; when the CO_2 concentration in the atmosphere increases to a certain extent, it is offset by negative feedbacks.
- In recent years, however, scientists have expressed concern that once the change in the Earth System surpasses a certain point, it may become irreversible, and the System may shift to another stable state with higher temperatures. Such critical points are known as "tipping points," and the events that cause the transition over a tipping point are called "tipping elements.

Example of tipping elements

Disintegration of the Greenland ice sheet (GIS)

The Greenland ice sheet has already been melting rapidly because of global warming. Its complete disintegration would raise the Global Mean Sea Level (GMSL) by approximately 7 m. The melting of the ice sheet may exhibit a hysteretic response, which may cause an irreversible transition to a catastrophic state.

Collapse of the West Antarctic ice sheet (WAIS)

Antarctica holds a huge ice sheet that can raise the GMSL by around 60 m. It is divided by the Transantarctic Mountains into two parts: East AIS (EAIS) and West AIS (WAIS). Although the WAIS contains less ice than the EAIS, it is considered to be more vulnerable to global warming, because it is grounded below sea level.

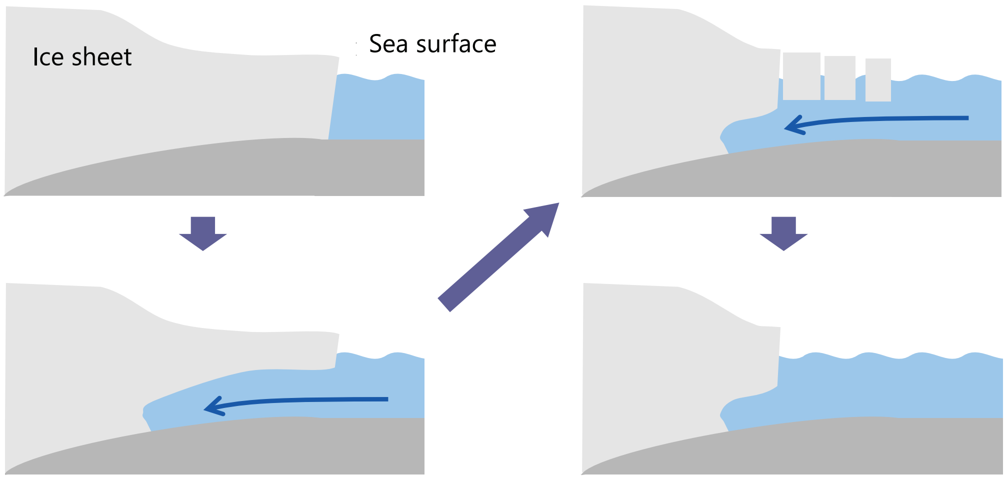
Permafrost carbon feedback (PCF)

Even a small part of the estimated 1.7 trillion tons of carbon contained in arctic permafrost could cause significant global warming, if it is released into the atmosphere. This is a typical example of the possible positive feedbacks of the Earth System, with rising surface temperatures promoting additional release of carbon.

Disappearance of coral reefs (CR)

Coral reefs are home to nearly one-quarter of all marine species, providing fishery and tourism resources to humankind. The economic damage caused by the disappearance of coral reefs was estimated at 0.5% of the global GDP. According to the IPCC, coral reefs will experience severe bleaching at 1.5°C, resulting in extensive damages, with the number reaching almost 100% at 2°C.

Marine Ice-Cliff Instability (MICI)



- In West Antarctica, a large part of ice sheet is grounded below sea level. DeConto and Pollard (2016) pointed out the risk of Marine Ice Cliff Instability (MICI) associated with the WAIS, in which coastal ice cliffs collapse rapidly after the disintegration of ice shelves caused by surface and sub-shelf melting.
- According to Edwards et al. (2019), however, the MICI is not required to reproduce historical GMSL changes due to the Antarctic ice loss. The IPCC's sea level rise projection in the Special Report on the Ocean and Cryosphere in a Changing Climate does not assume MICI, because the validity of MICI currently remains unproven.

Simple representation of tipping elements

Definition of the equilibrium state

$$X^*(t) = X_0 \frac{max(T(t) - T_C)}{T_0} = \alpha\, max(T(t) - T_C)$$

Equation of motion

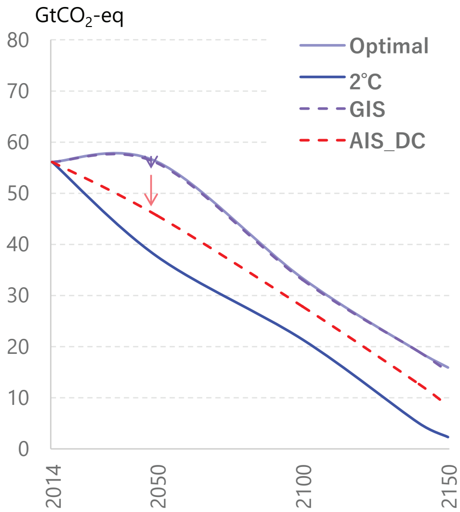
$$\frac{\Delta X(t)}{\Delta t} = \beta\, X_0 sign\left(X^*(t) - X(t)\right) \left|\frac{X^*(t) - X(t)}{X_0}\right|^{\gamma}$$

X : Variable that describes the event (e.g. relative volume of melted ice)
X^* : Equilibrium state of X
T : Global mean surface temperature
T_C : Critical temperature
X_0 : Characteristic scale of the event
T_0 : Characteristic temperature
$\alpha \cdot \beta \cdot \gamma$: Parameters

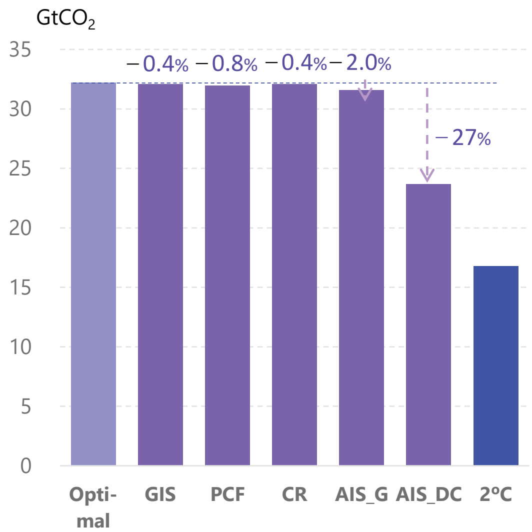
- The motion of tipping elements was modeled according to the simple equations described above. Here, for example, the "equilibrium state" (X^*) of the AIS, or the potential volume of melted ice is supposed to be determined by the temperature rise T, and the actual state X is supposed to move towards the equilibrium state with time delays.
- The parameters for the GIS are determined according to Nordhaus (2019), while those for the AIS are set according to DeConto and Pollard (2016), for a case with MICI, and according to Golledge et al. (2019) for the case without MICI. PCF is modeled according to Yumashev et al. (2019), and coral reefs are assumed to disappear according to the literature (50% at 1.2°C and almost 100% at 2°C), with a time delay of 20 years.

Changes in the optimal path by considering tipping elements

Changes in the optimal path



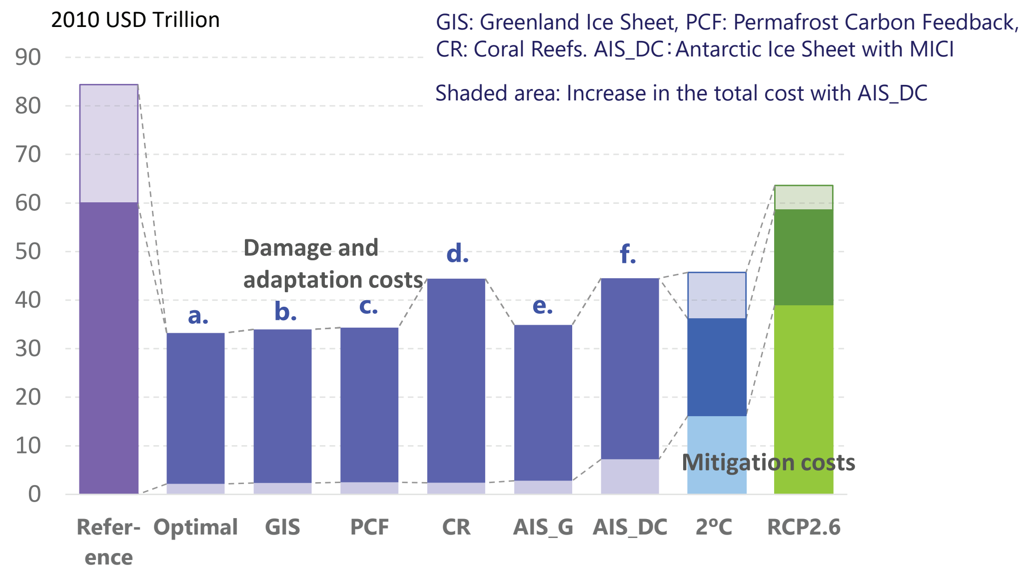
Optimal CO_2 emissions in 2050



GIS：Greenland Ice Sheet, PCF: Permafrost Carbon Feedback, CR: Coral Reefs, AIS_G: Antarctic Ice Sheet without MICI, AIS_DC: Antarctic Ice Sheet with MICI.

- The optimal path does not change greatly with consideration of GIS, PCF, CR, and AIS without MICI (AIS_G).
- On the other hand, if we assume the rapid collapse of AIS by MICI (AIS_DC), the optimal path changes largely to the red dotted path, and the optimal global CO_2 emission in 2050 declines by 27%, although still larger than that in the 2°C path.

Changes in the total cost by considering tipping elements

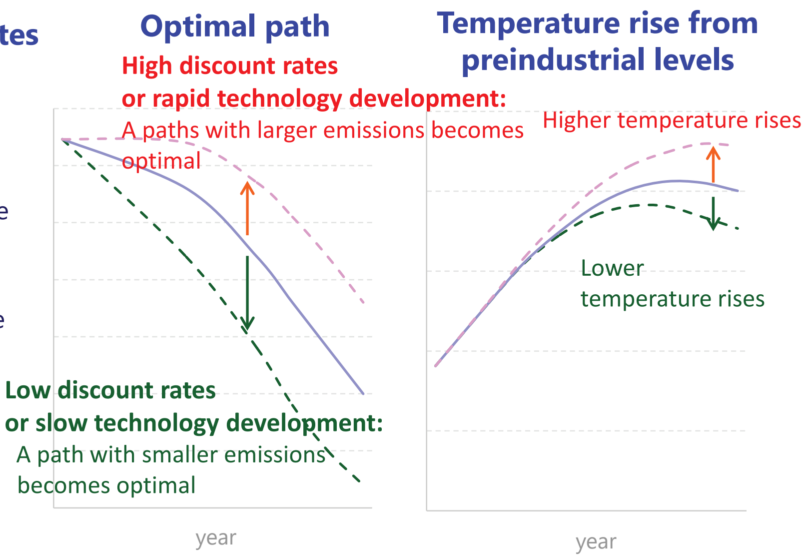


- Considering Greenland ice sheet, permafrost, or Antarctic ice sheet without MICI boosts the total cost only slightly (a. versus b., c., and e.)
- With explicit consideration of Antarctic ice sheet with MICI, or coral reefs, the total cost rises considerably (d. and f.) Although the economic damages related to the loss of coral reefs may be huge, it hardly affects the optimal path, because most part of coral reefs will be lost even with a temperature rise of 1.5°C.

Assumptions on discount rates and technology development

Assumptions on discount rates

- The discount rate is an annual ratio used to convert a future value to the present value.
- When a certain rate of interest is expected for sure, the interest rate can be regarded as the discount rate.
- With higher discount rates, future climate damages are valued less, resulting in smaller mitigation being optimal.
- Lower assumptions on discount rates can be seen to represent views that put more emphasis on intergenerational equity.

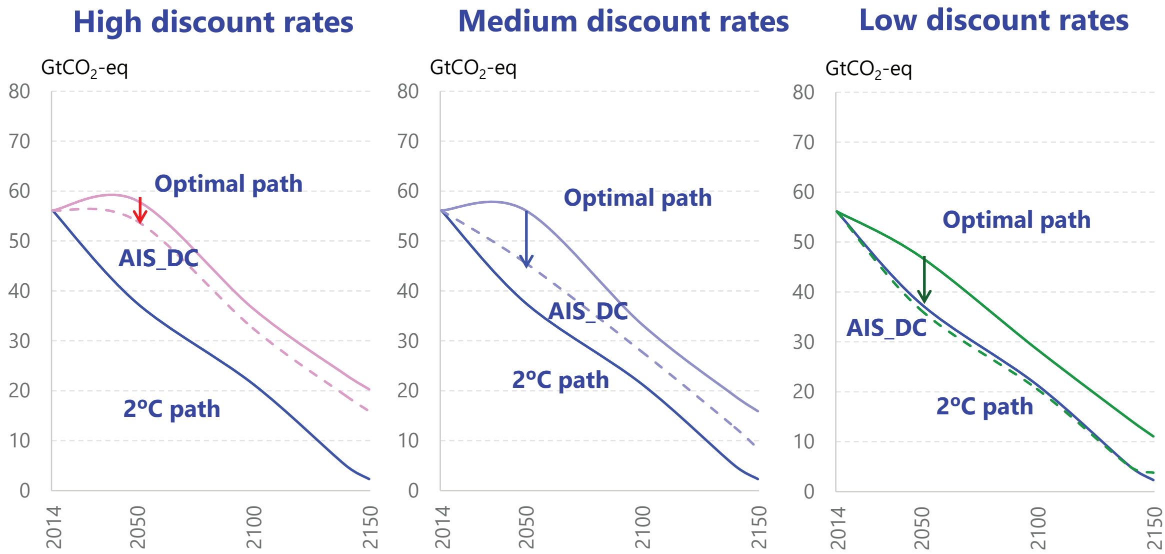


Assumptions on the speed of technology development

- Assumes more rapid declines in mitigation costs, as well as the future potentials of negative emission technologies.
- With slower technology development, the optimal path requires larger near-term mitigations.

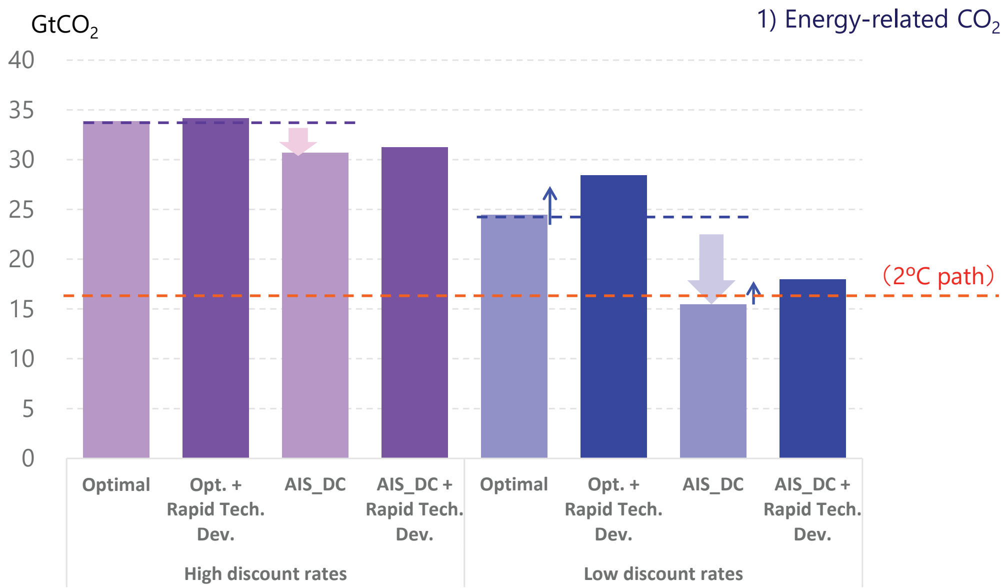
Simulation cases: “High”, “Medium”, and “Low” discounting assumptions
“Normal” and “Rapid” technology

Effect of tipping element with different discounting rates



- Assuming lower discount rates, the optimal path moves downwards, and becomes closer to the 2°C path.
- In addition, if the Antarctic Ice Sheet collapses rapidly with MICI (AIS_DC), the optimal path moves downwards further; we can observe larger change in the optimal path for the cases with lower discount rates.

Effect of technology development: CO_2 emission[1] in 2050



- With high discount rate assumptions, rapid technology development does not affect the optimal emissions in 2050 greatly, as high discount rates put more focus on the costs and damages in the near future.
- On the other hand, with low discount rate assumptions, rapid technology development boosts up the optimal emission in 2050, which implies that the low discount rates represent views that emphasizes the importance of long-term technology development.

Conclusions

・If we neglect to take strong actions to address climate change, future climate damages, and/or adaptation costs would be enormous. On the other hand, if we take very strong mitigation measures, the adaptation and damage costs are alleviated, but larger mitigation costs will be required.

・In this regard, many researchers have attempted to assess the "optimal" path considering the total cost including mitigation, adaptation, and damage costs, although with considerable discussion.

・In recent years, scientists have expressed concerns about so-called tipping elements, or the subsystem of the earth that may cause an irreversible transition of the earth system. In many cases, explicit consideration of these elements does not affect the optimal path greatly, partly because of the very long characteristic times of the events.

・However, if self-sustaining mechanisms, such as MICI for the collapse of Antarctic ice sheet, accelerate the occurrence of the events, the optimal path may be pushed downwards. Obtaining deeper scientific insights into these events are crucial for decent climate policies.

・The impacts of tipping elements are dependent on the assumptions on the discount rates: With lower discount rates, tipping elements exert larger influences on the optimal mitigation path, which can partly be mitigated by long-term technology development.

・At the same time, the explicit consideration of tipping elements, as well as lower discount rate assumptions, put more focus on the importance of long-term technology development. Thus, policy measures to promote technology development in long-term perspectives would be regarded as more and more important to address climate change issues.

Appendix: Specification of the assumptions

Assumptions on discount rates

- The social discount rate ρ is calculated by the following Ramsey formula:

$\rho = \delta + \eta g$

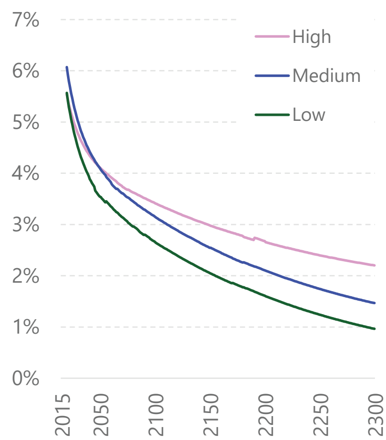
δ: Pure rate of time preference
g: Growth rate of per capita consumption
η: Elasticity of marginal utility with respect to consumption

- Three sets of parameters have been used:

High: $\delta = 1.5\%$, $\eta = 1.45$

Medium: $\delta = 0.5\%$, $\eta = 2.0$

Low: $\delta = 0.05\%$, $\eta = 2.0$



Assumptions on the speed of technology development

- Accelerating future technology development is supposed to contribute to declines in mitigation costs, as well as to larger reductions in GHG emissions.

- In the "rapid technology development" case, the annual reduction rate of mitigation costs are assumed to be 50% larger (0.75%/year compared to the default value of 0.5%/year), and negative emission technologies are assumed to be available after 2100, absorbing CO_2 equivalent to 20% of the baseline emissions.

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.

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.

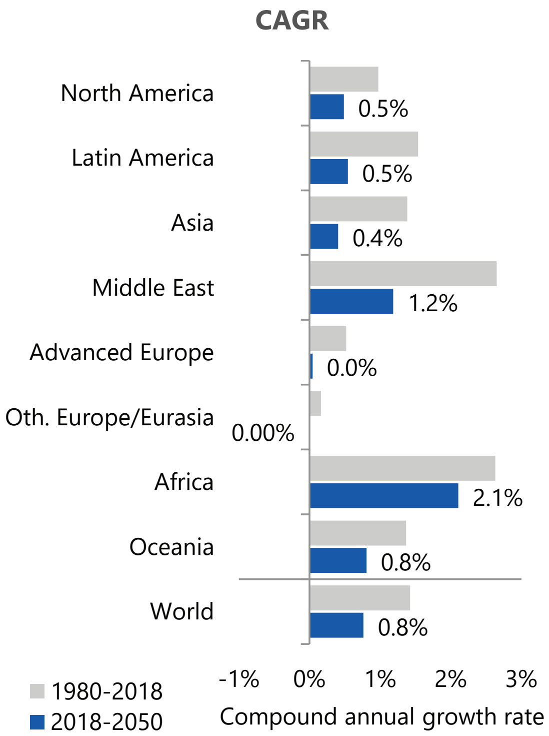
Climate change model
Calculate future GHG concentration in the atmosphere, temperature rise, damage caused by climate change, etc.

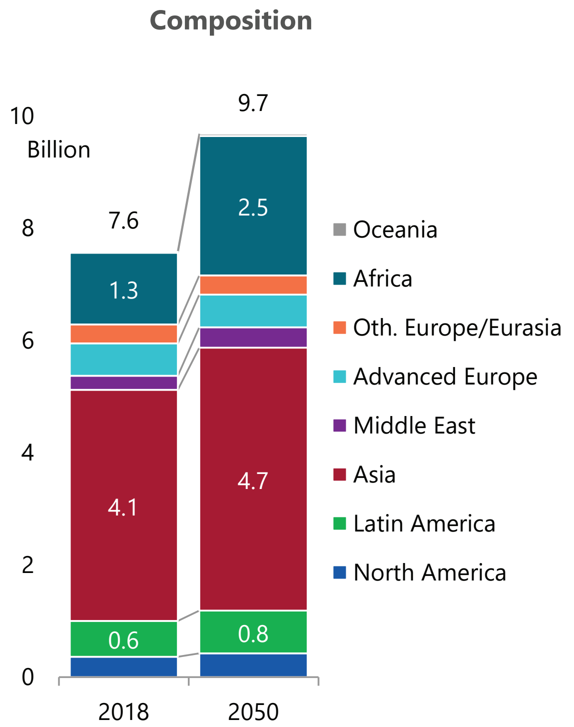
Basic scenarios in IEEJ Outlook

	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** keeps unchanged with today's level.	Slower price increase due to lower demand growth (coal price decreases)
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

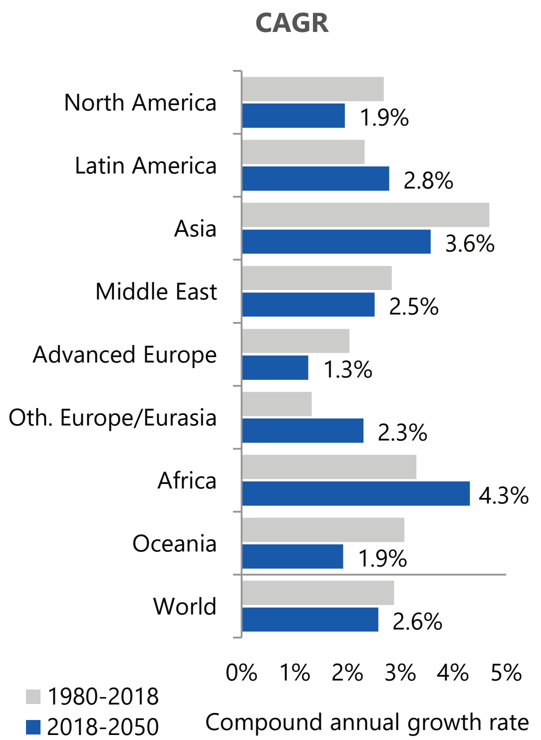
Population

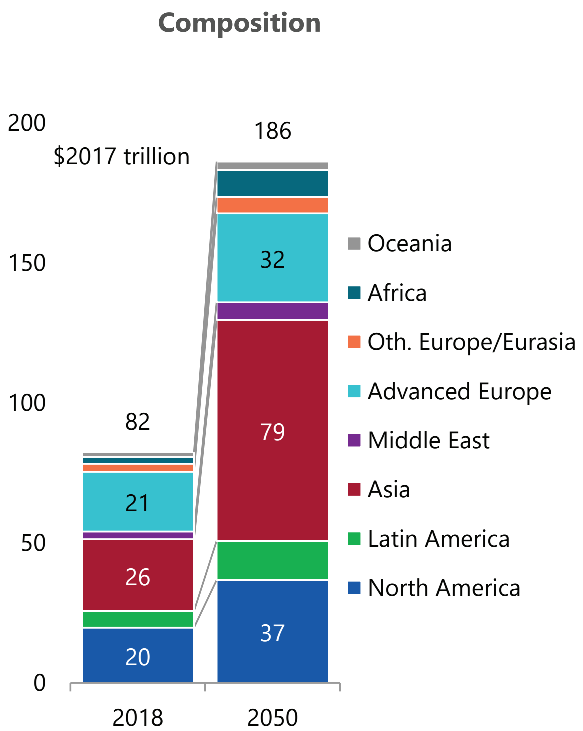




Assumptions

Real GDP

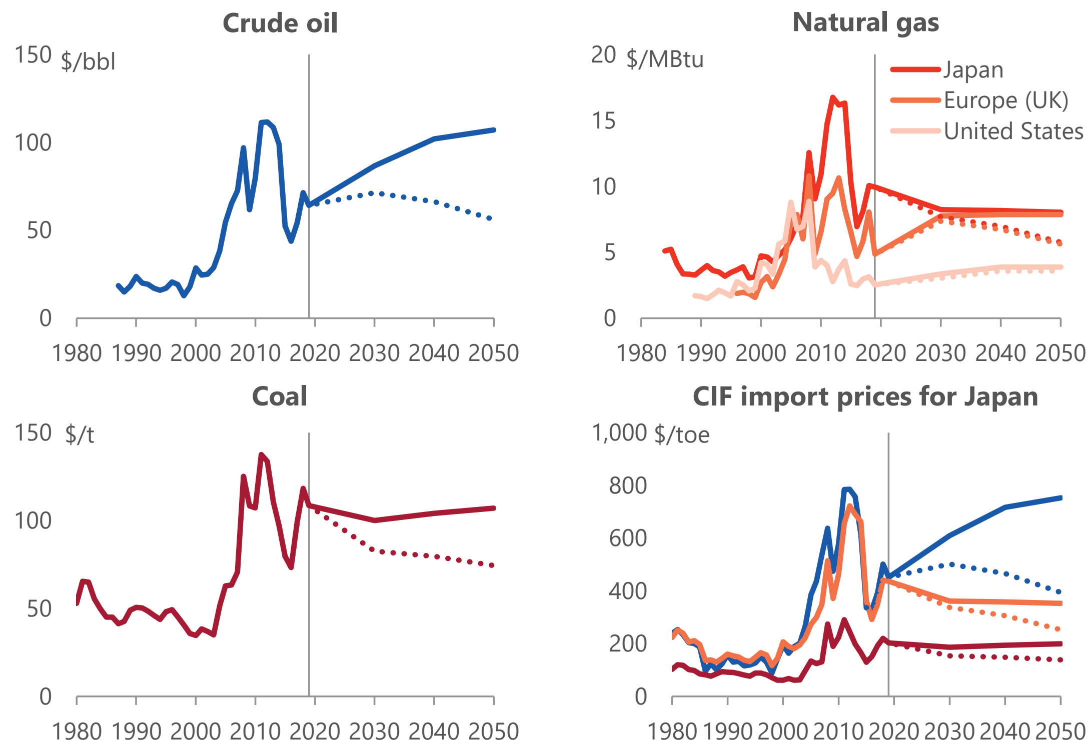




Assumptions

International energy prices

Reference : ———
Advanced Technologies : ••••••••••



Note: Historical prices are nominal. Assumed future prices as real in $2019.

Assumptions

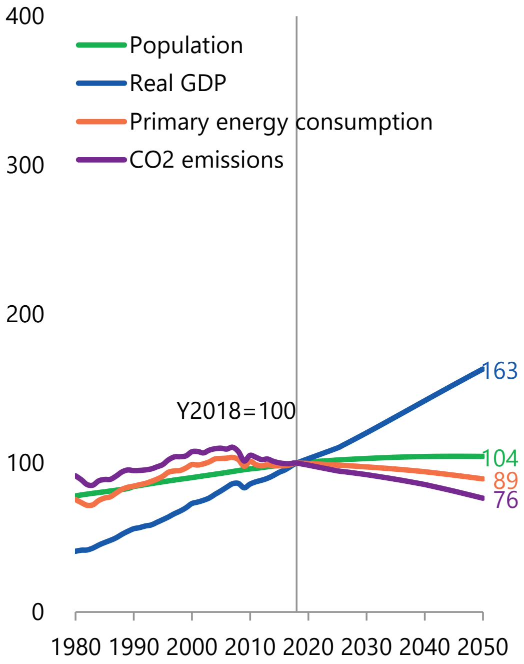
Energy and environmental technology

		2018	2050 Reference	2050 Advanced Technologies	Assumptions for Advanced Technologies Scenario
Improving energy efficiency					
Industry	Intensity in steel industry (ktoe/kt)	0.274	0.245	0.217	100% penetration of Best Available Technology by 2050.
	Intensity in non-metallic minerals industry	0.093	0.072	0.064	
Transport	Electrified vehicle share in passenger car sales	6%	55%	87%	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)	14.4	23.7	34.0	
Buildings	Residential total efficiency (Y2018=100)	100	150	181	Efficiency improvement at twice the speed for newly installed appliance, equipment and insulation.
	Commercial total efficiency	100	180	211	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)		90	134	254	Development of next generation biofuel with cost reduction. Relating to agricultural policy in developing regions.
Nuclear power generation capacity (GW)		416	480	725	Appropriate price in wholesale electricity market. Framework for financing initial investment in developing regions.
Wind power generation capacity (GW)		564	1,850	3,625	Further reduction of generation cost. Cost reduction of grid stabilization technology. Efficient operation of power system.
Solar PV power generation capacity		480	2,909	4,737	
Thermal power generation capacity with CCS (GW)		0	0	1,023	Installing CCS after 2030 (regions which have storage potential except for aquifer).
Zero-emission generation ratio (incl. CCS)		36%	42%	77%	Efficient operation of power system including international power grid.

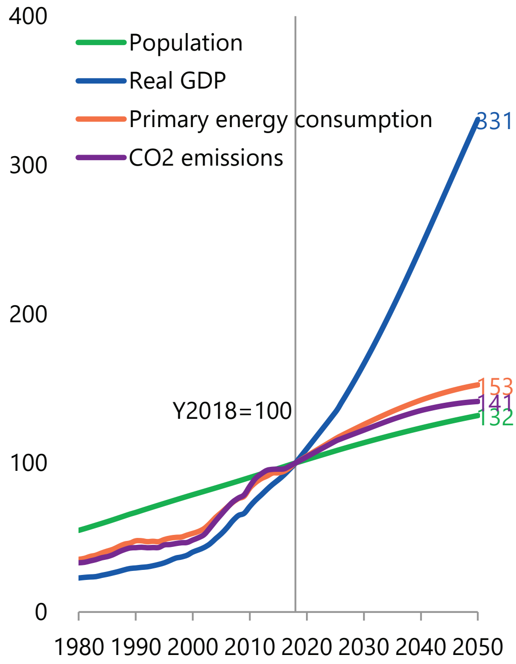
Reference Scenario

Population, GDP, energy and CO_2

Advanced Economies



Emerging Market and Developing Economies

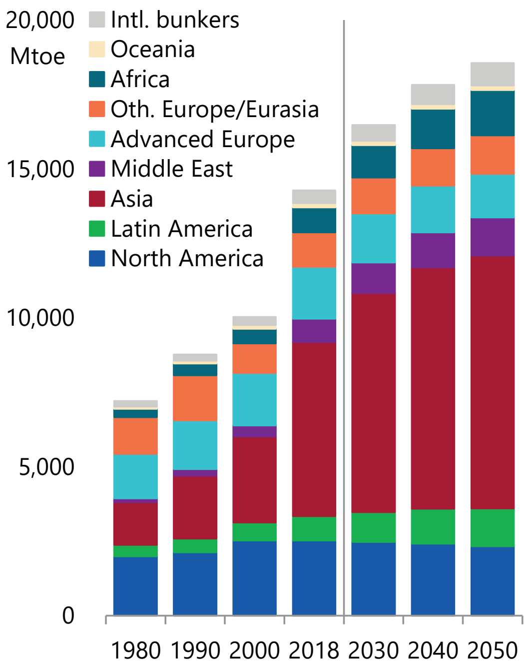


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

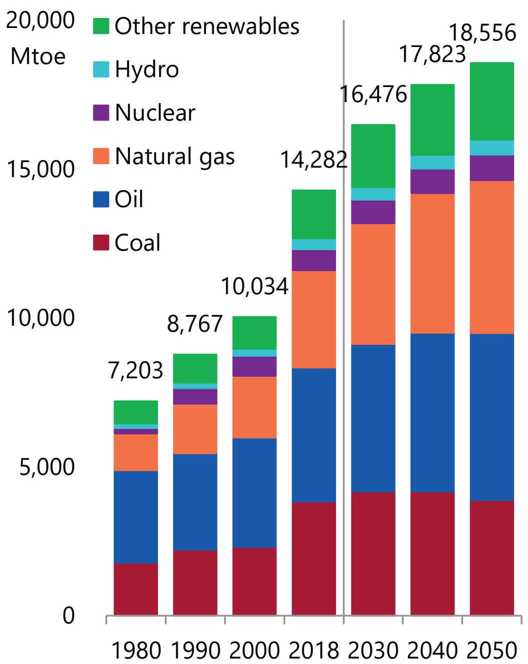
Reference Scenario

Primary energy consumption

By region

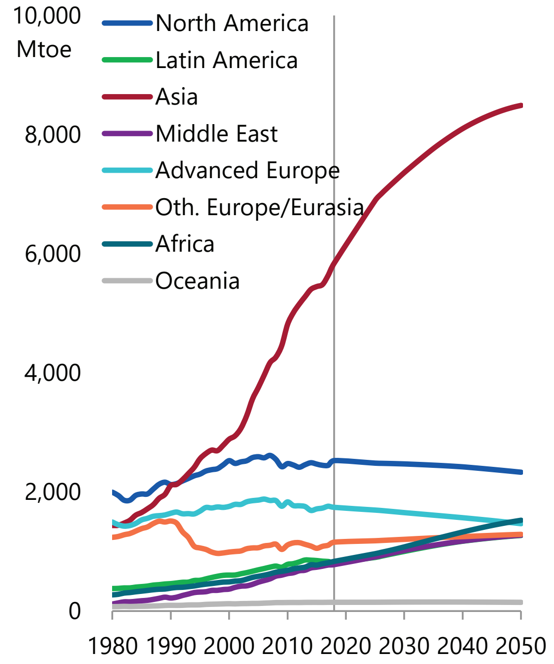


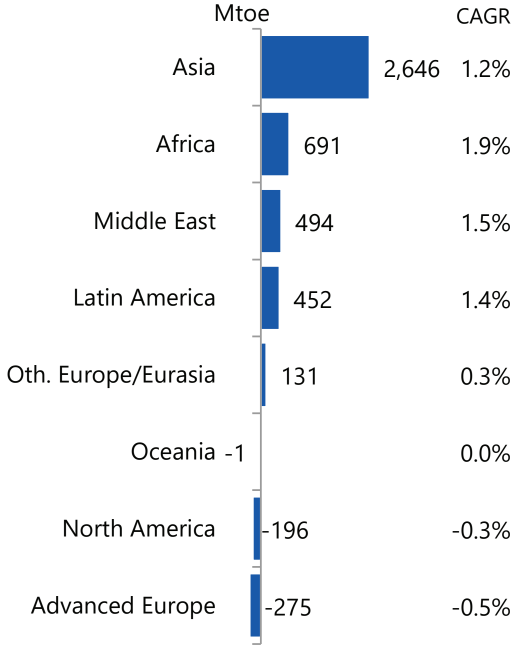
By energy source



Reference Scenario

Primary energy consumption (by region)

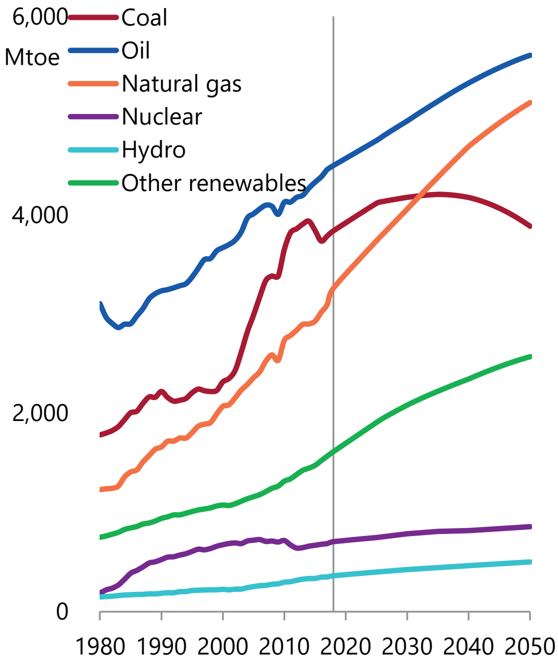


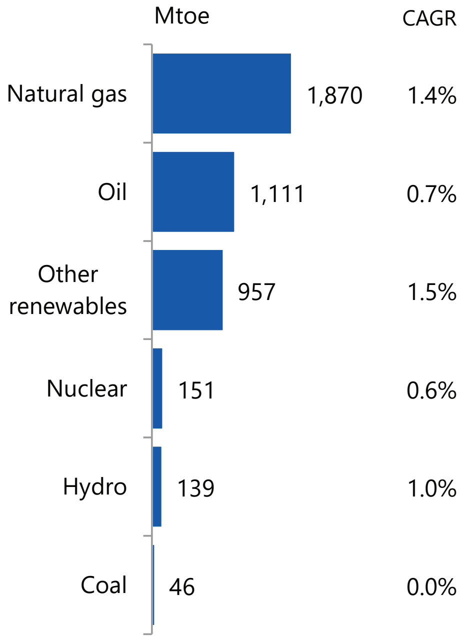


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

Reference Scenario

Primary energy consumption (by energy source)



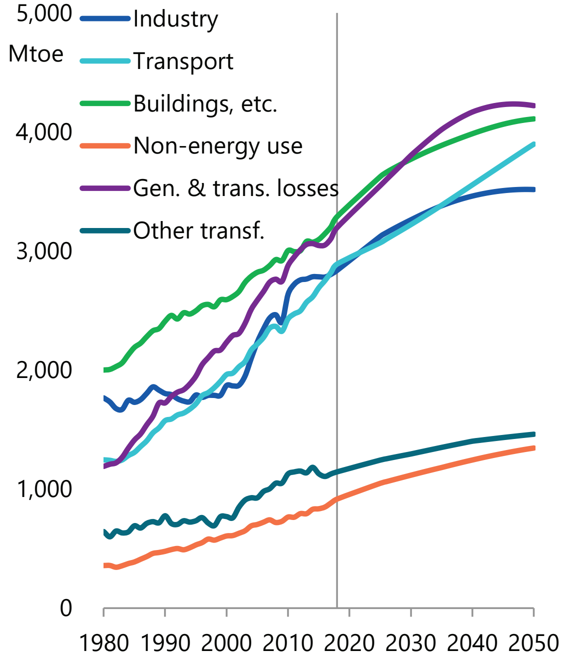


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

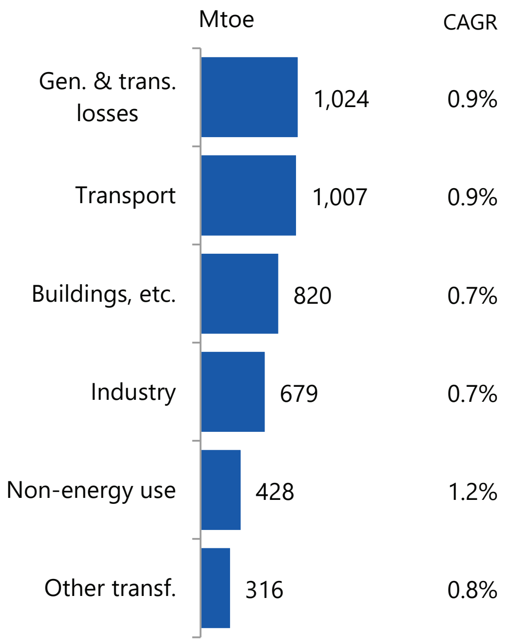
Reference Scenario

Primary energy consumption (by sector)

Energy consumption



Changes (2018-2050)

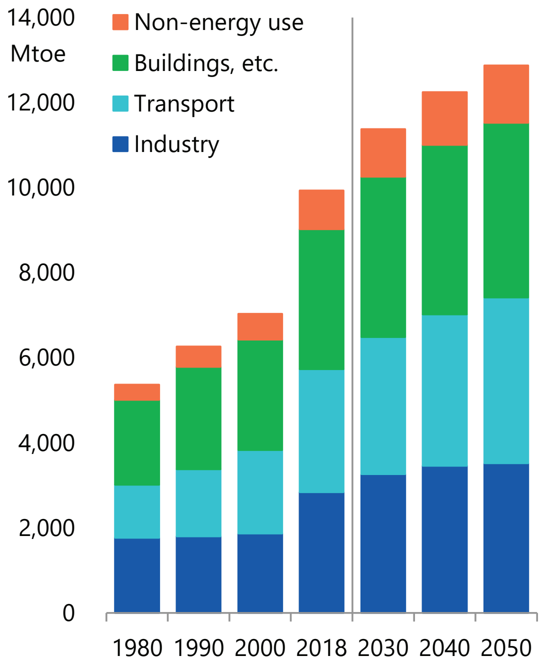


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

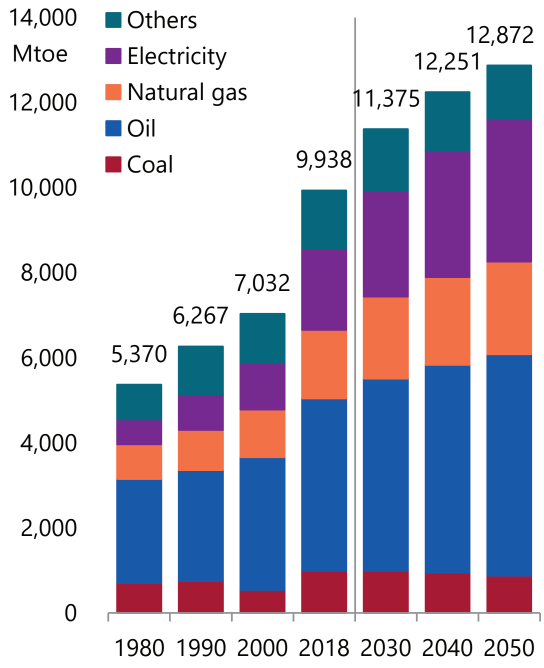
Reference Scenario

Final energy consumption

By sector

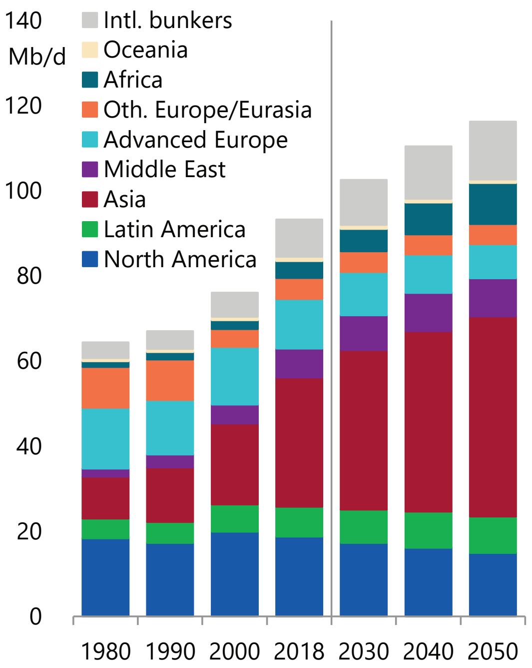


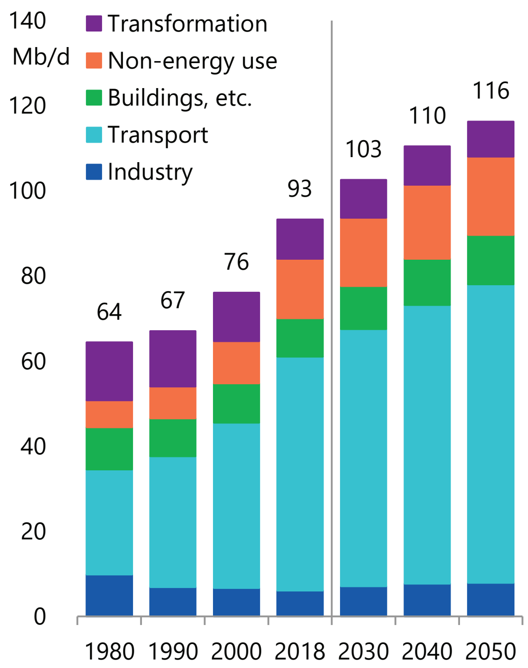
By energy source



Reference Scenario

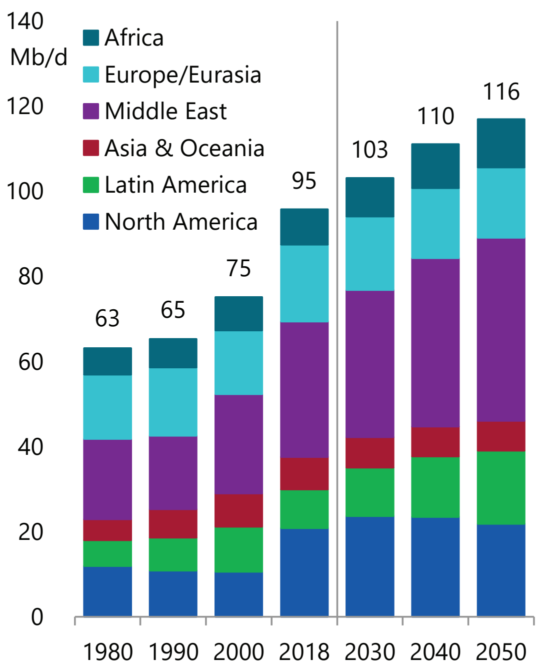
Oil consumption

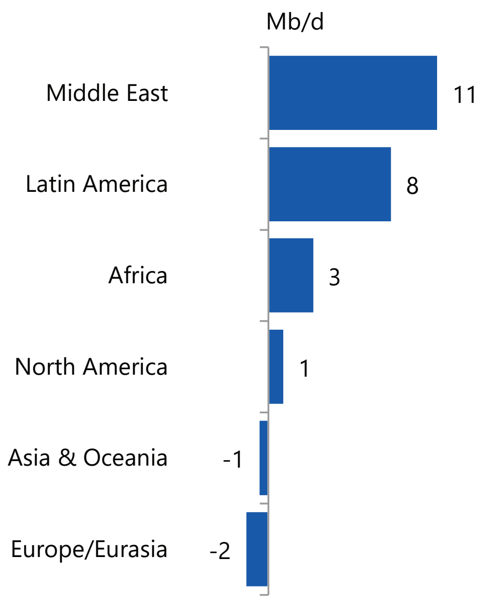




Reference Scenario

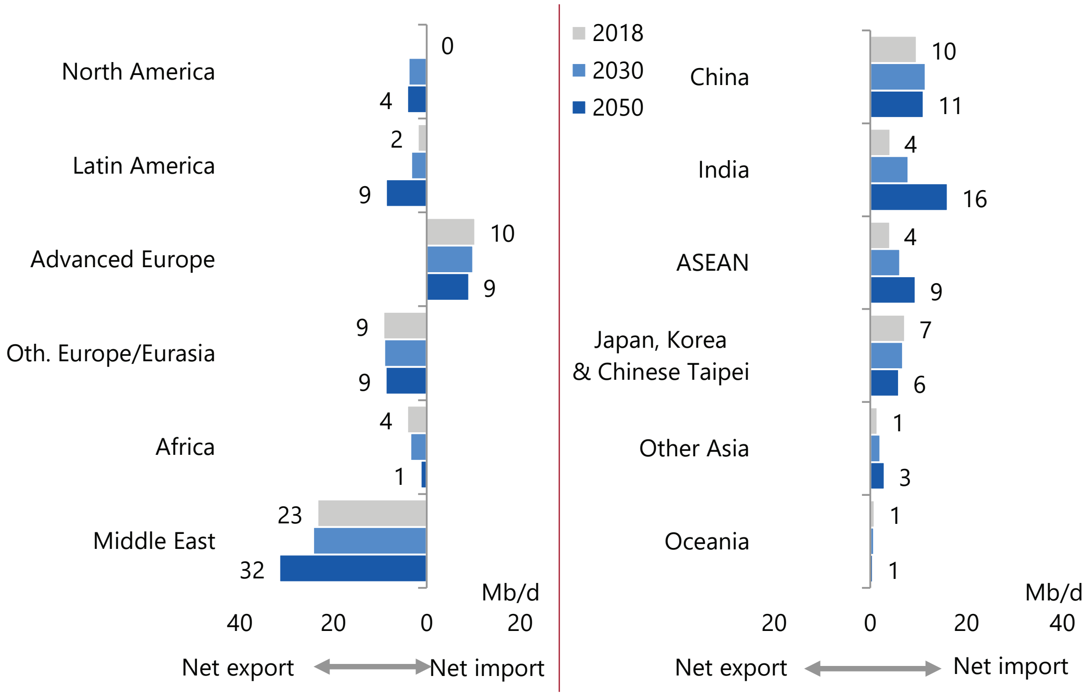
Crude oil production





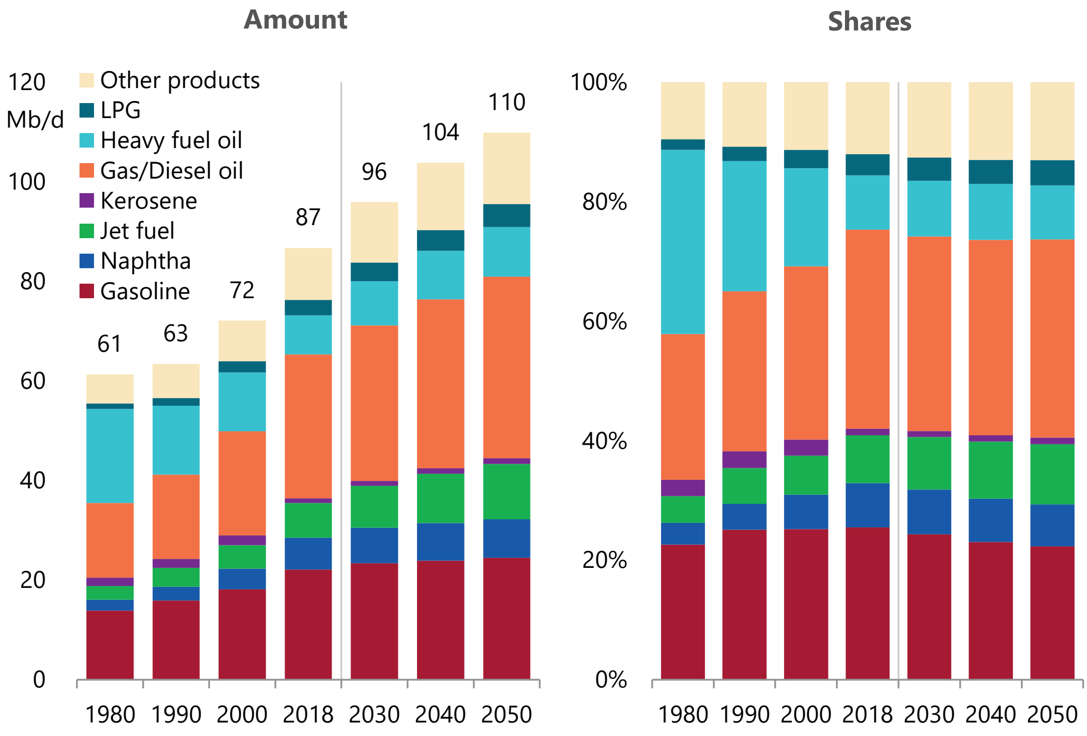
Reference Scenario

Net exports and imports of oil



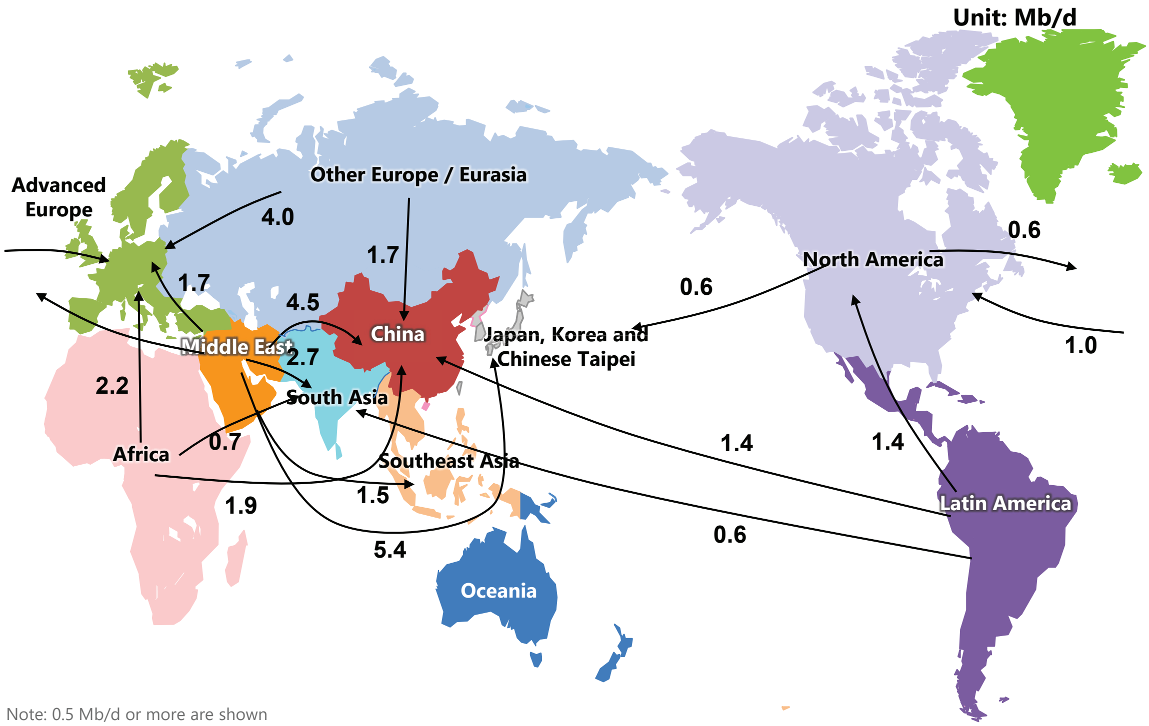
Reference Scenario

Petroleum product consumption



Reference Scenario

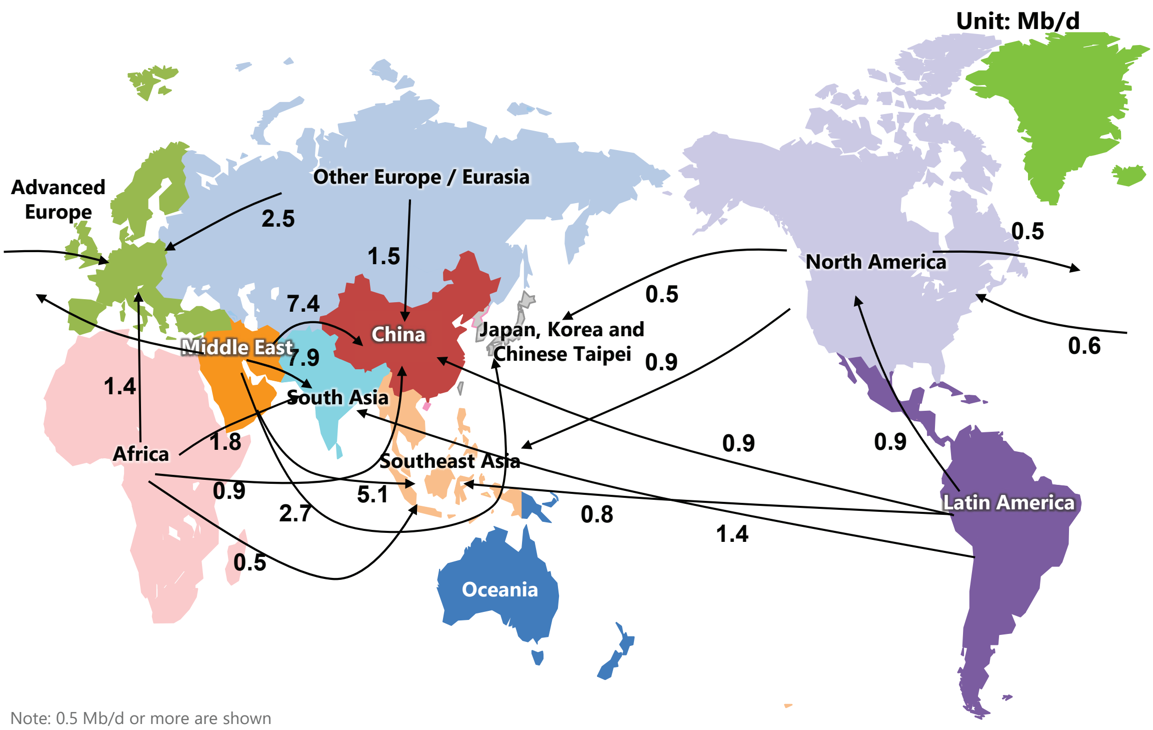
Major trade flows of crude oil (2019)



Note: 0.5 Mb/d or more are shown

Reference Scenario

Major trade flows of crude oil (2050)

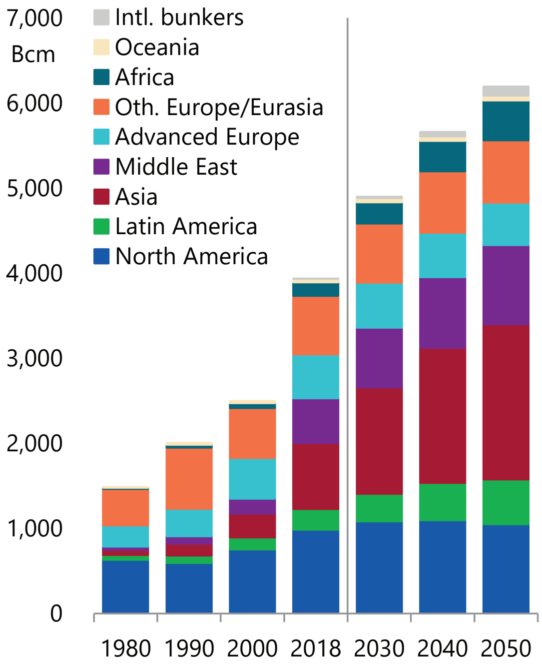


Note: 0.5 Mb/d or more are shown

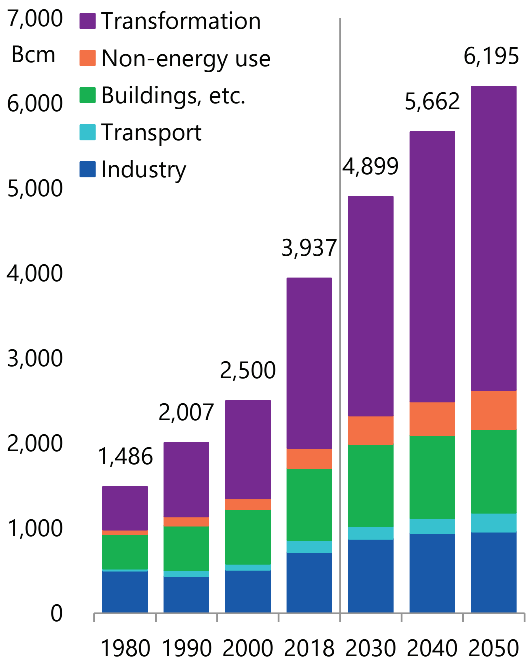
Reference Scenario

Natural gas consumption

By region



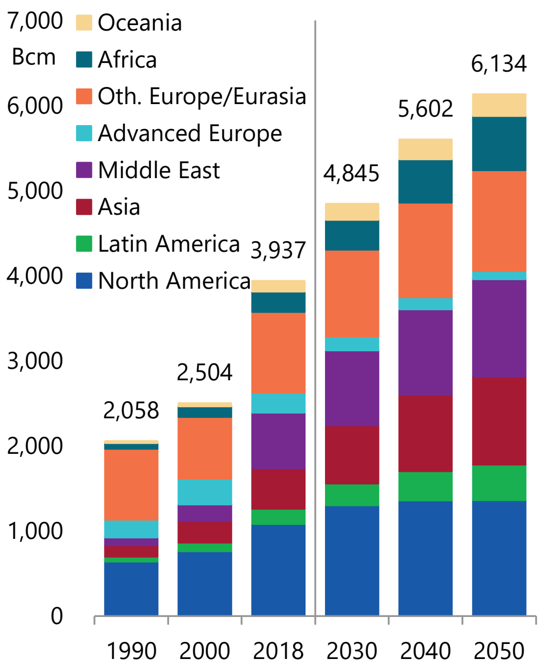
By sector



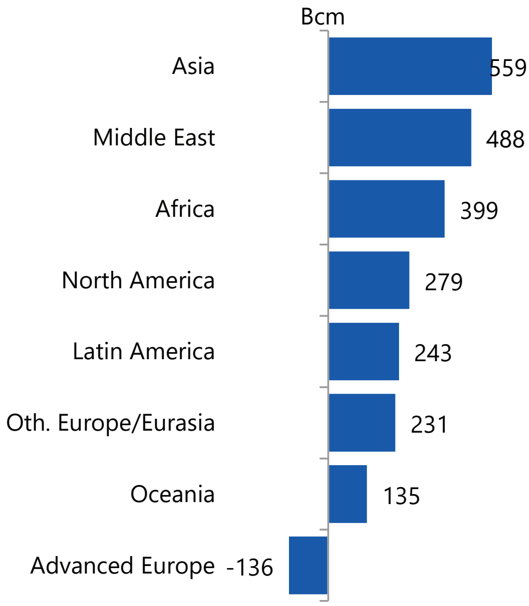
Reference Scenario

Natural gas production

By region

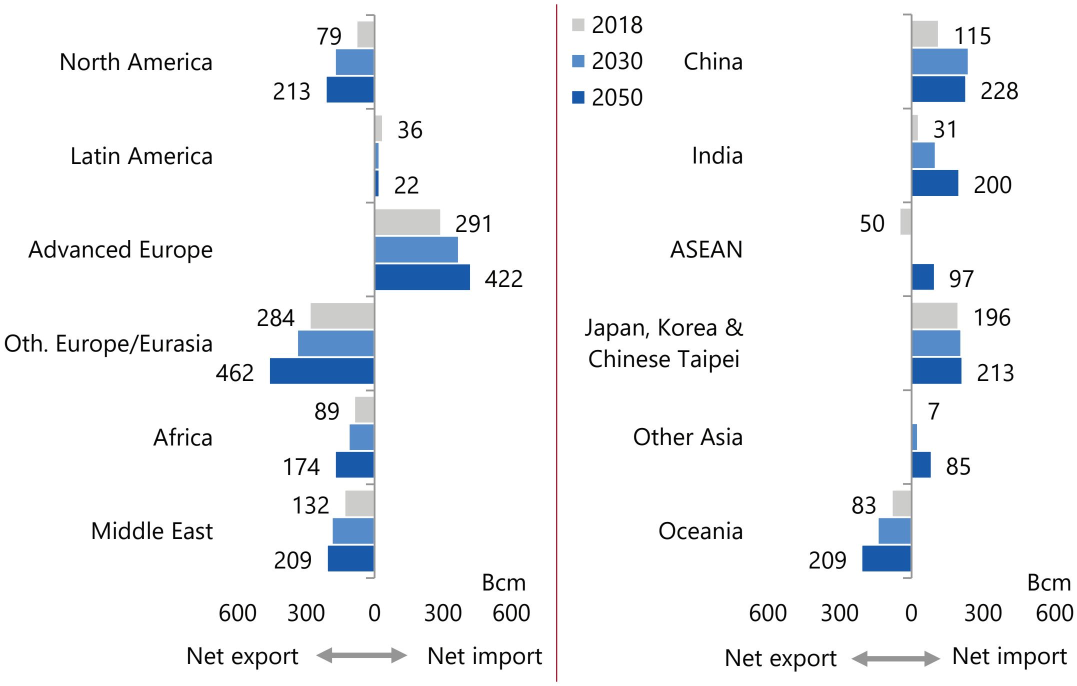


Changes (2018-2050)



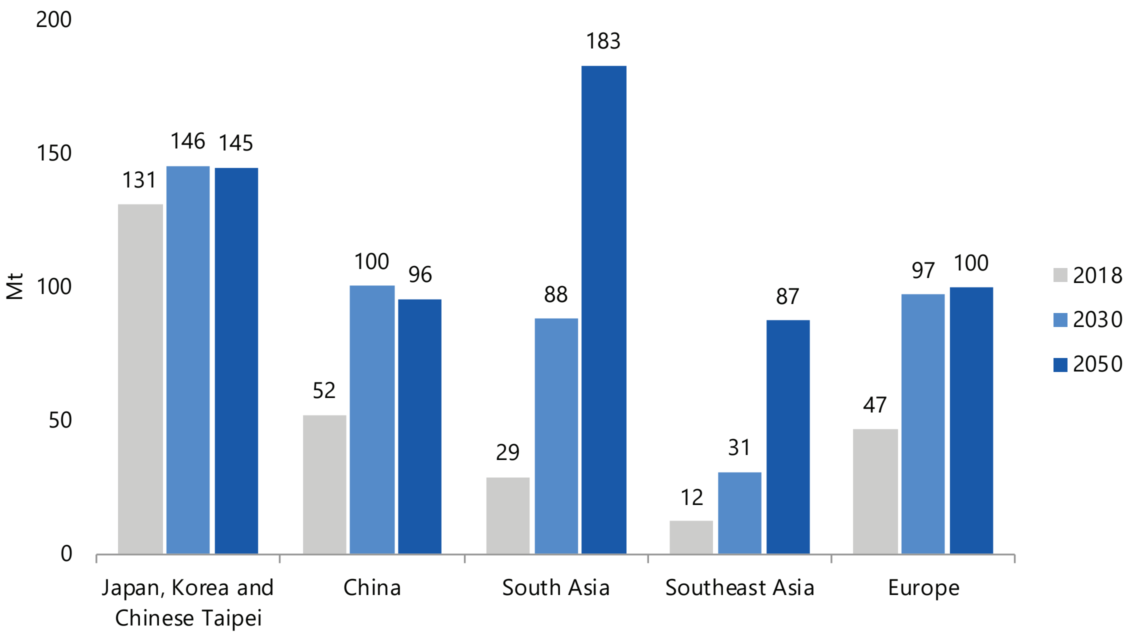
Reference Scenario

Net exports and imports of natural gas



Reference Scenario

Net LNG imports in selected regions

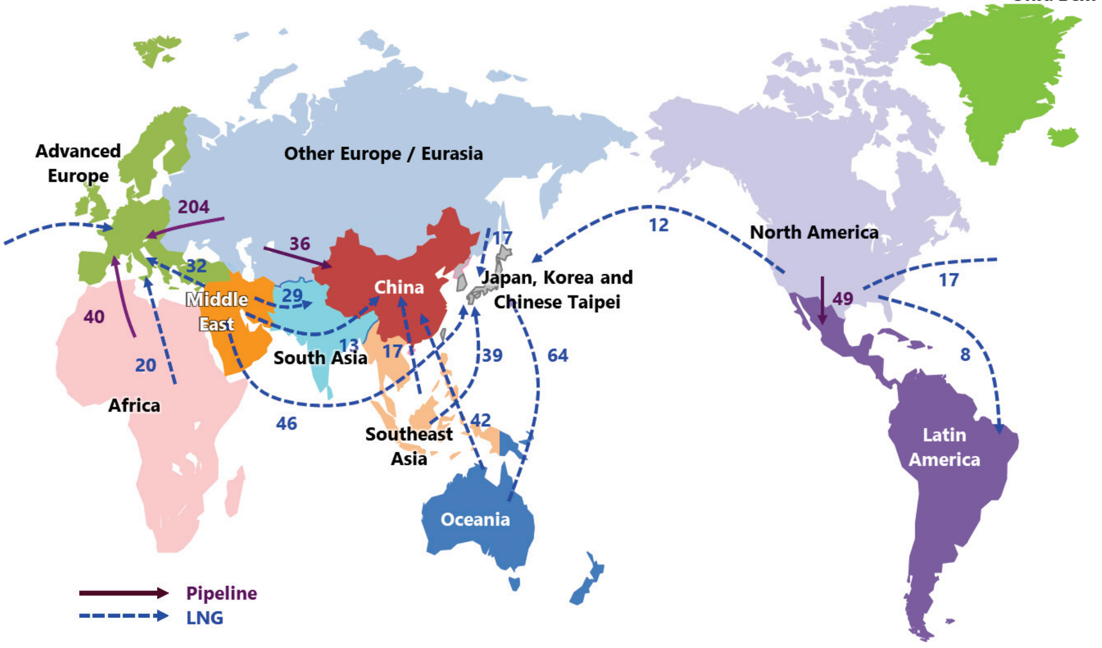


Note: does not include intra-regional trade

Reference Scenario

Major trade flows of natural gas (2019)

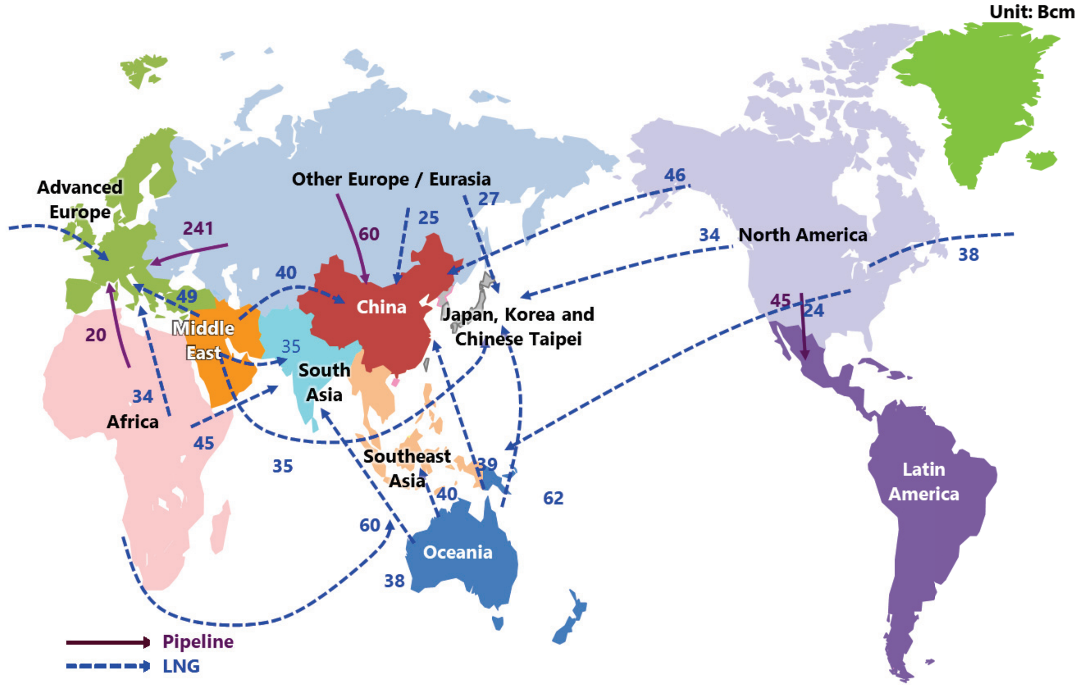
Unit: Bcm



Reference Scenario

Major trade flows of natural gas (2050)

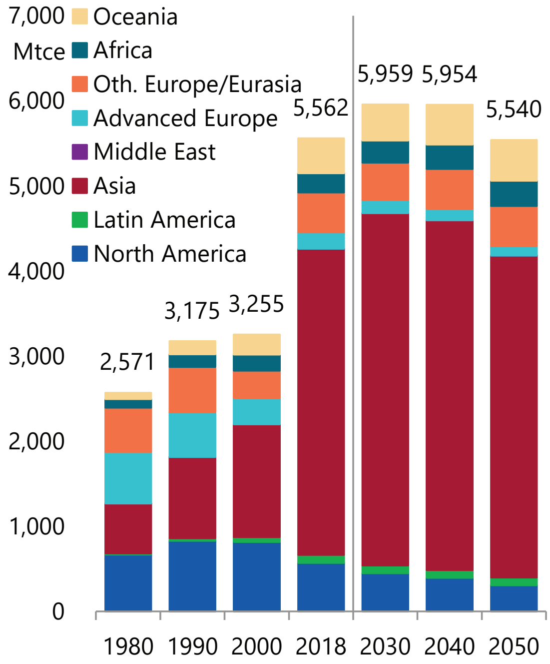
Unit: Bcm



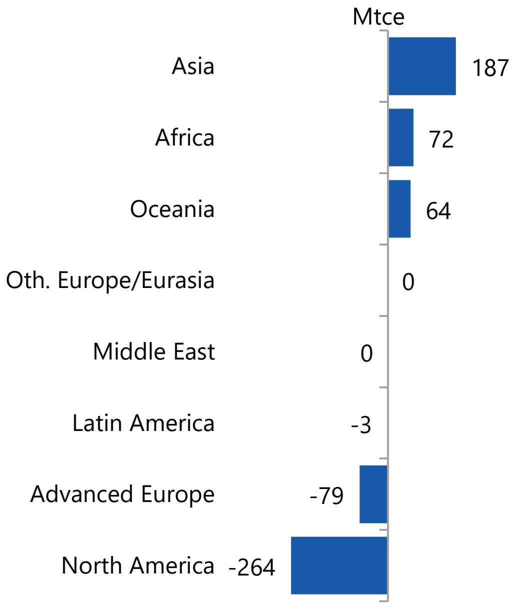
Reference Scenario

Coal production

By region



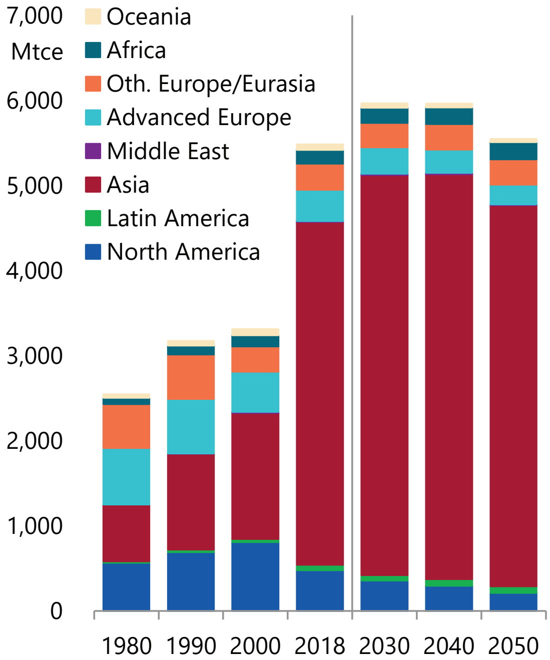
Changes (2018-2050)



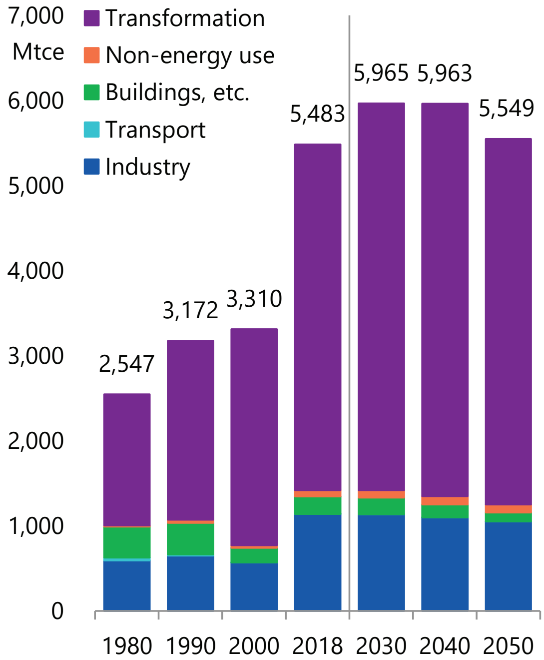
Reference Scenario

Coal consumption

By region

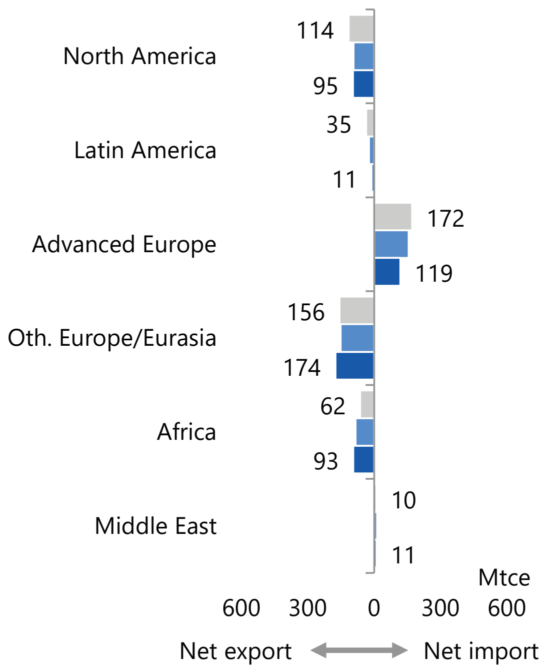


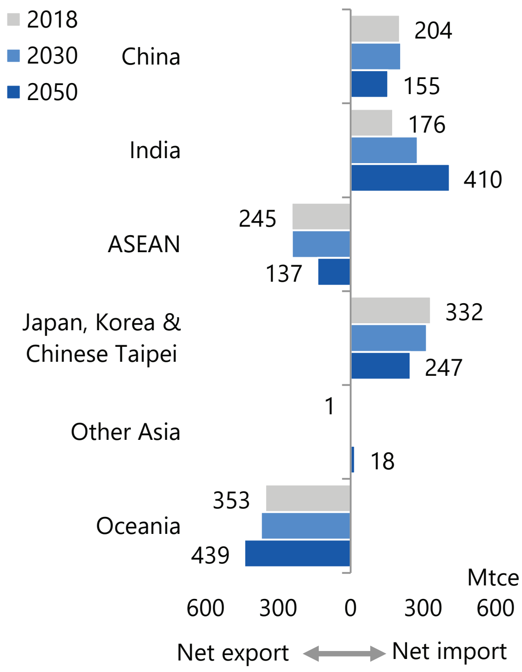
By sector



Reference Scenario

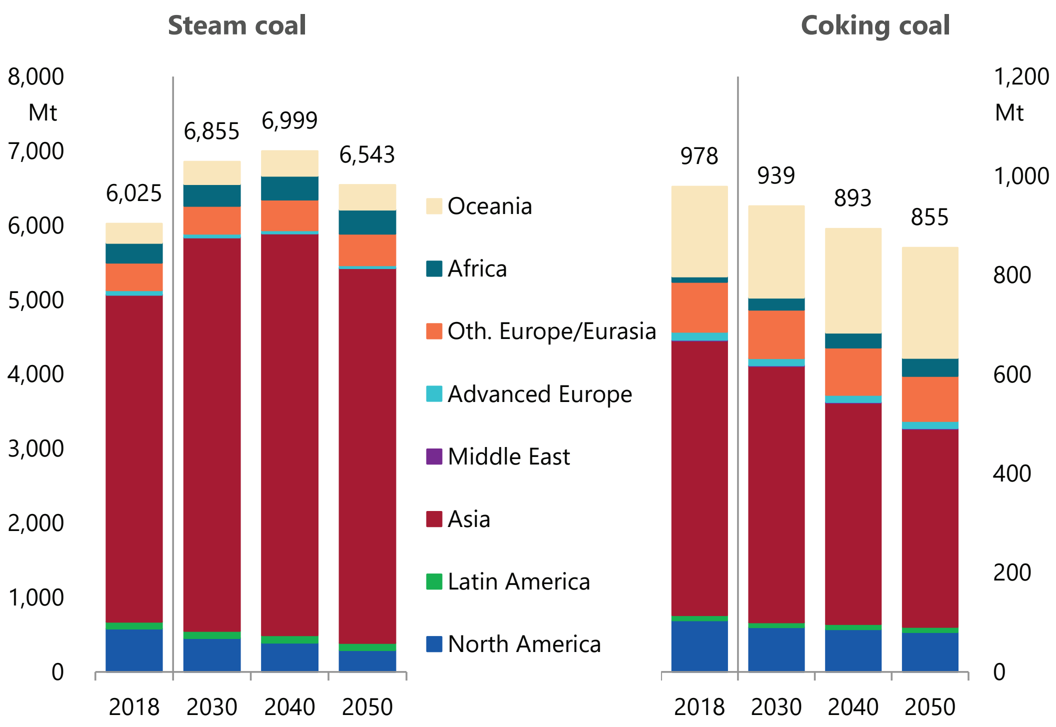
Net exports and imports of coal





Reference Scenario

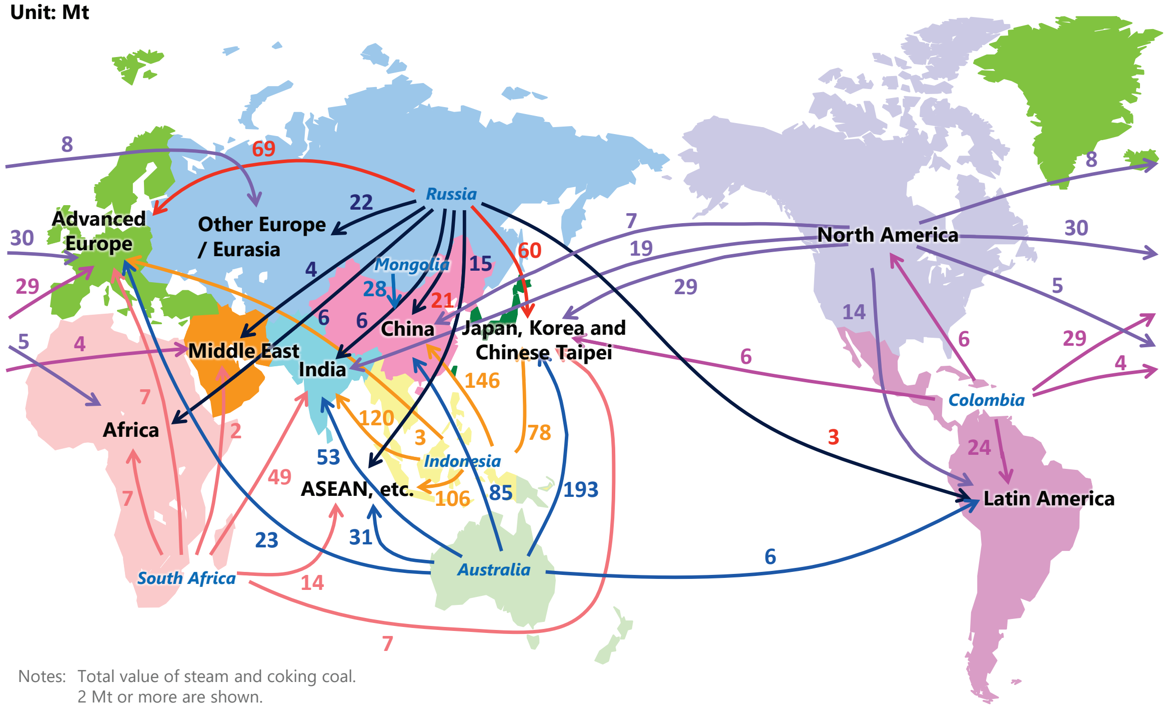
Coal production (steam and coking coal)



Reference Scenario

Major trade flows of steam and coking coal (2019)

Unit: Mt

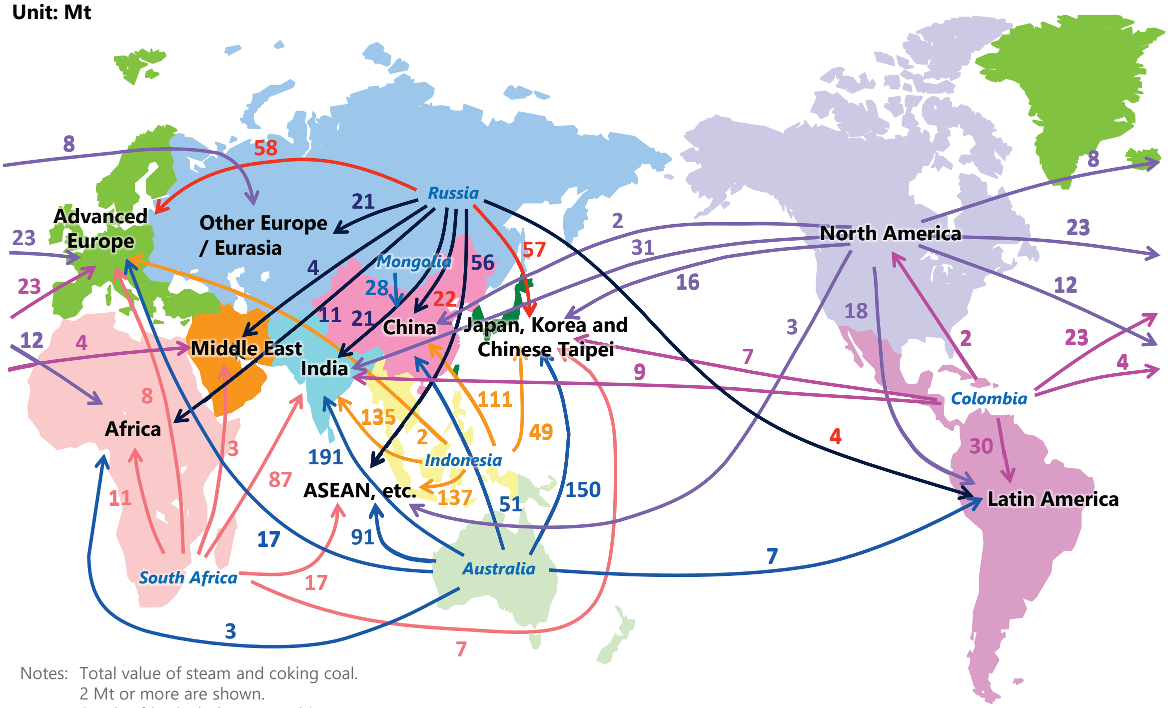


Notes: Total value of steam and coking coal.
2 Mt or more are shown.
South Africa includes Mozambique.

Reference Scenario

Major trade flows of steam and coking coal (2050)

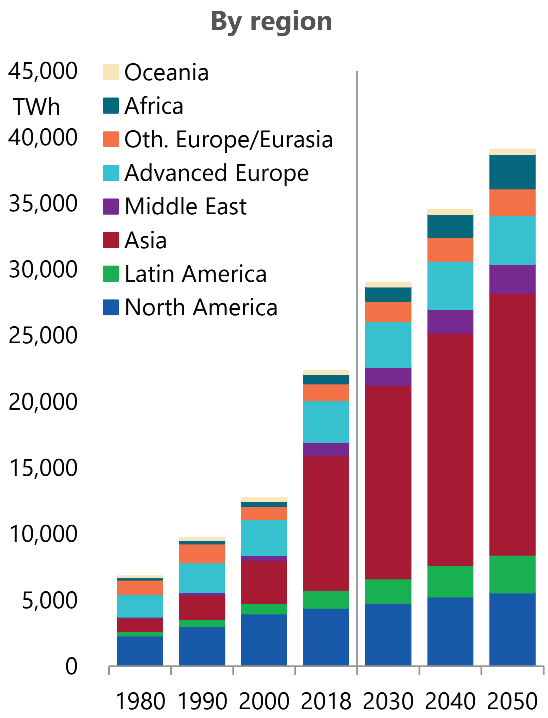
Unit: Mt

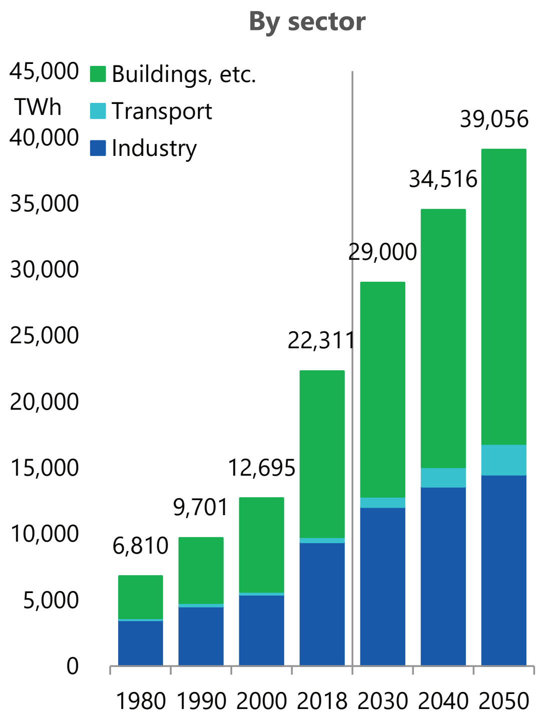


Notes: Total value of steam and coking coal.
2 Mt or more are shown.
South Africa includes Mozambique.

Reference Scenario

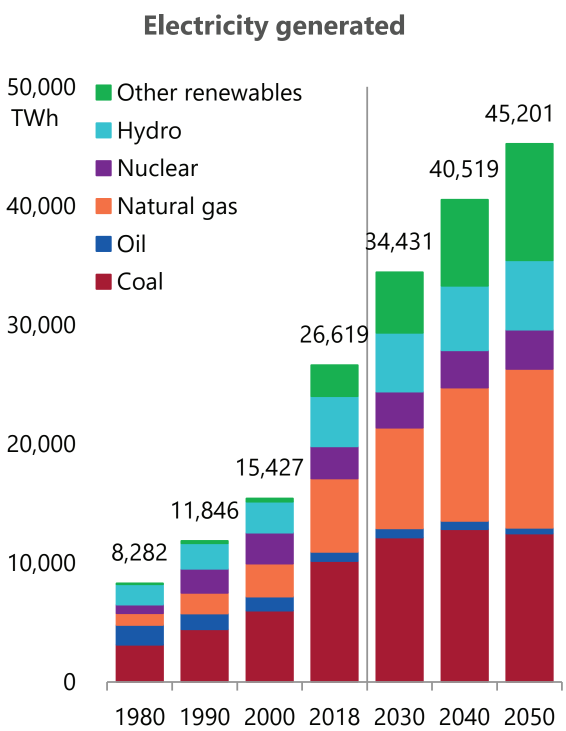
Final consumption of electricity

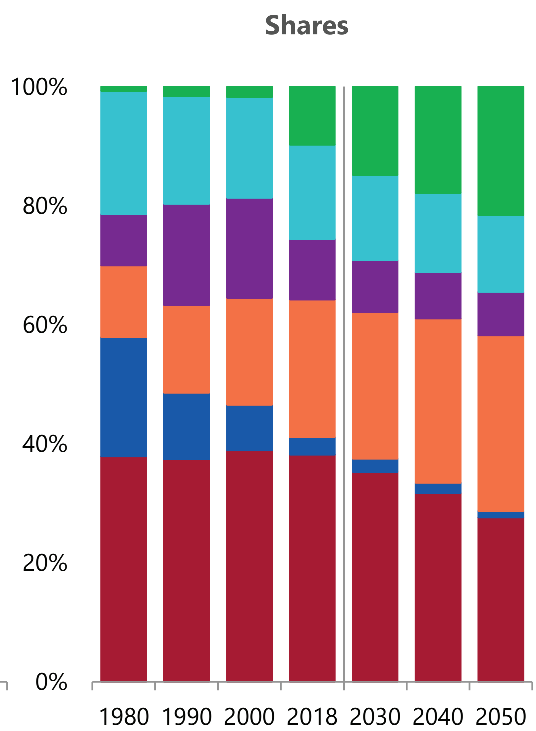




Reference Scenario

Power generation mix

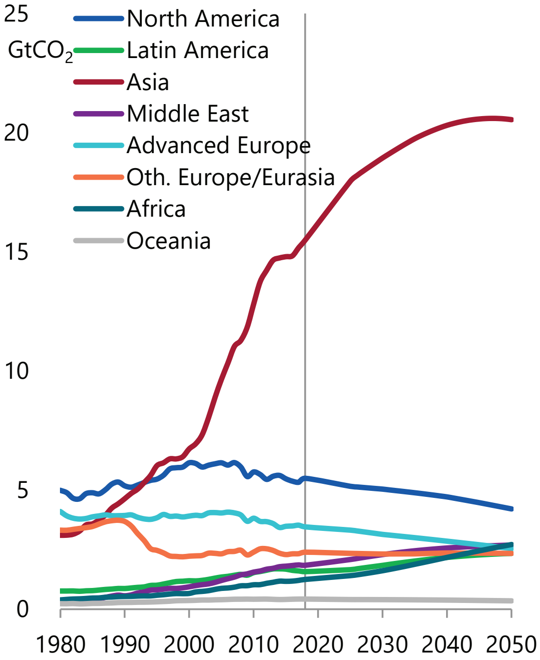




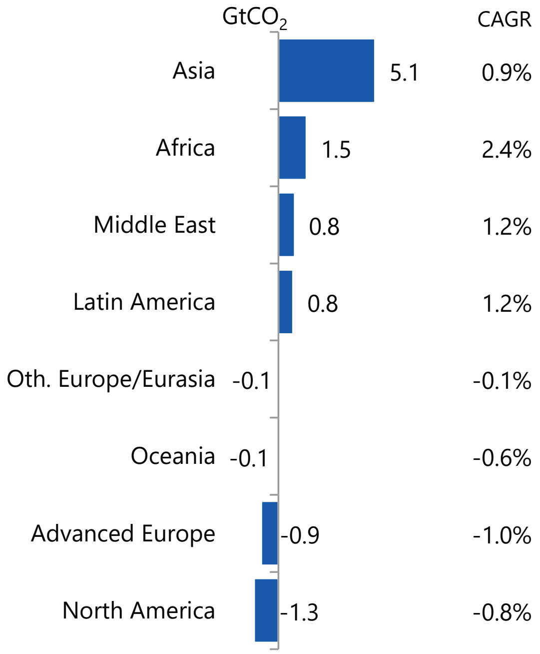
Reference Scenario

Energy-related CO_2 emissions

Emissions



Changes (2018-2050)

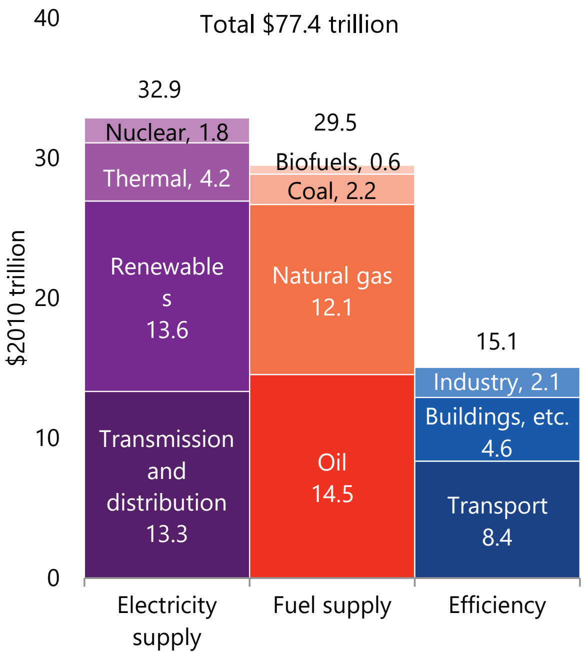


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

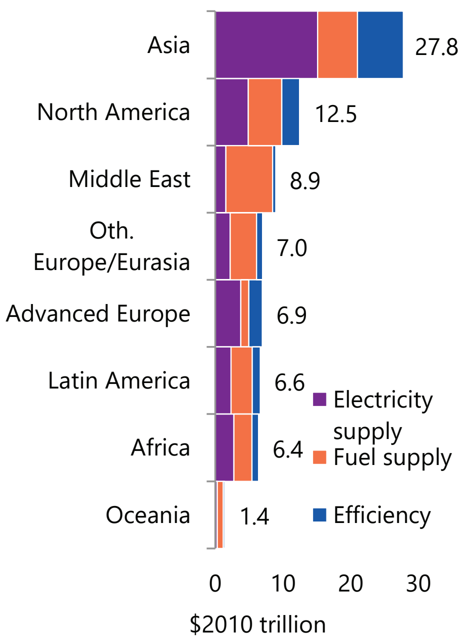
Reference Scenario

Energy-related investments (2019 – 2050)

By sector

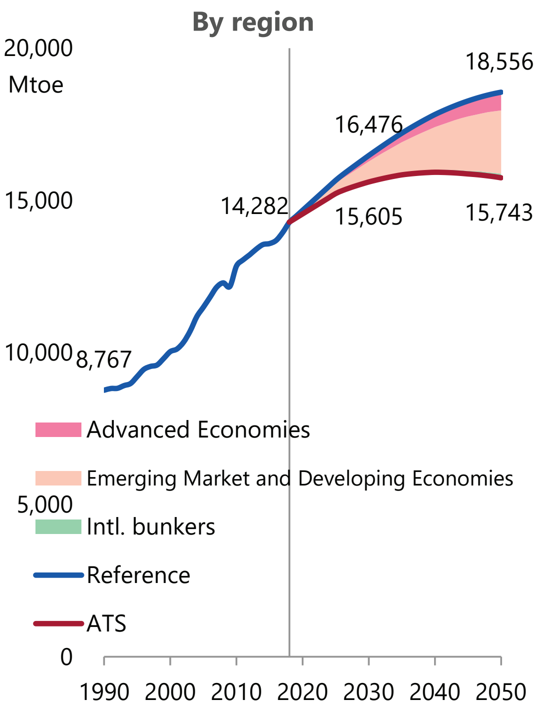


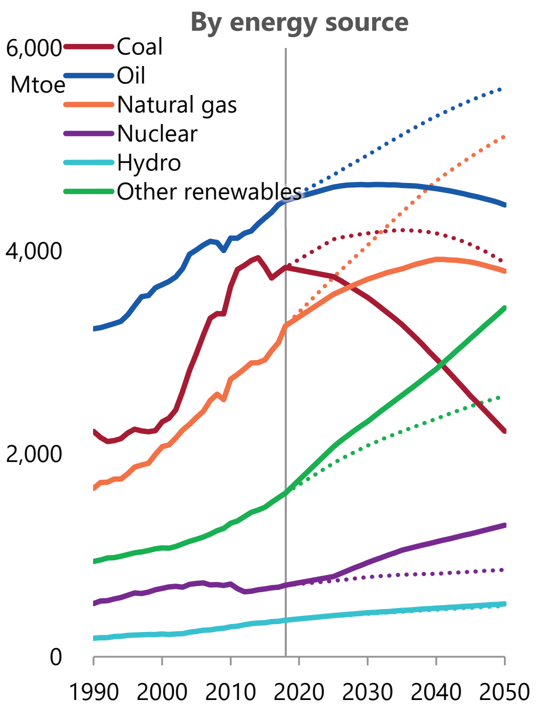
By region



Advanced Technologies Scenario

Primary energy consumption



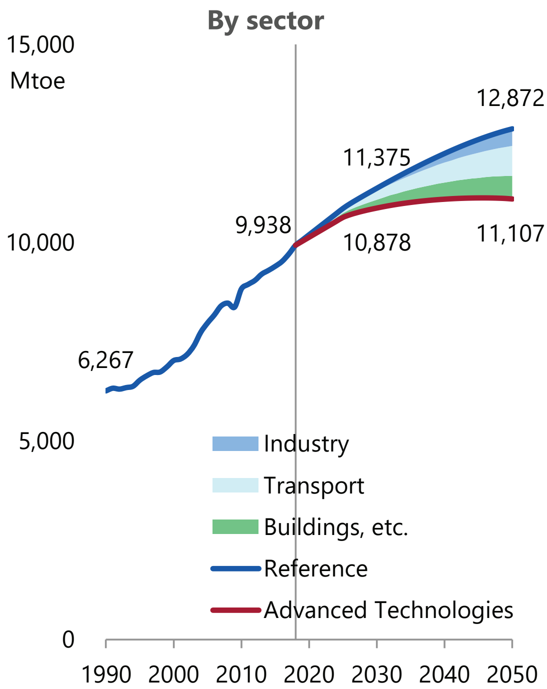


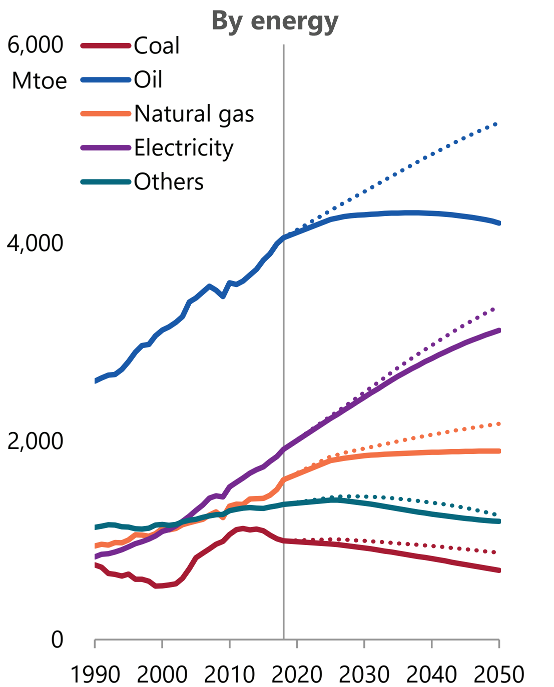
Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Advanced Technologies Scenario

Final energy consumption



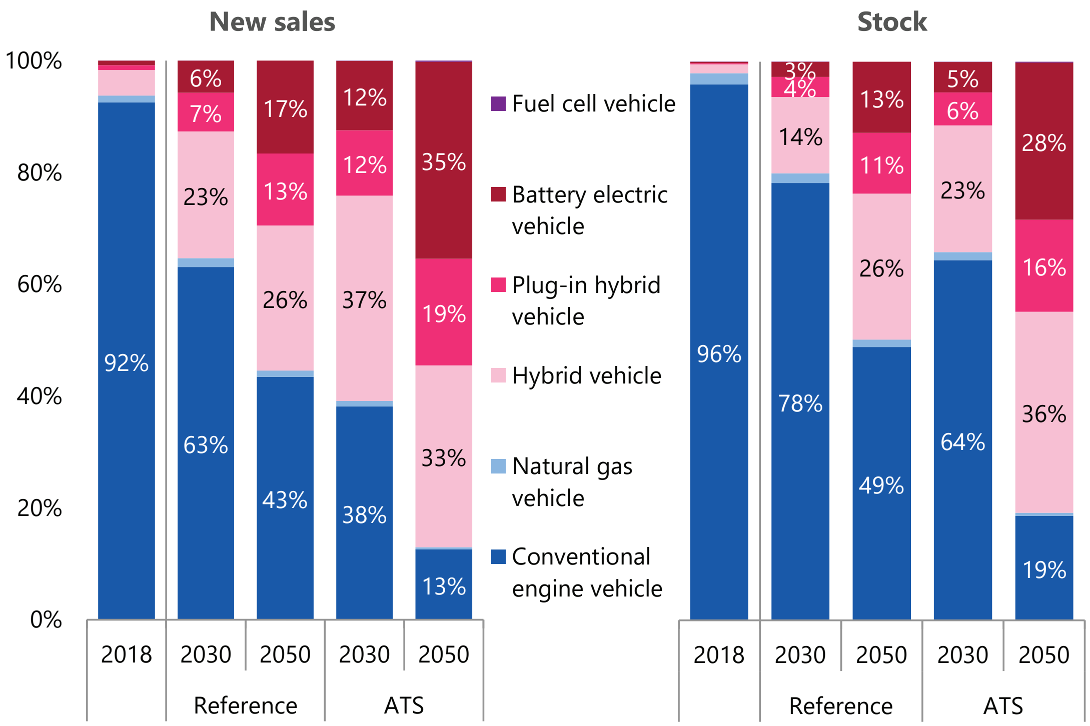


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

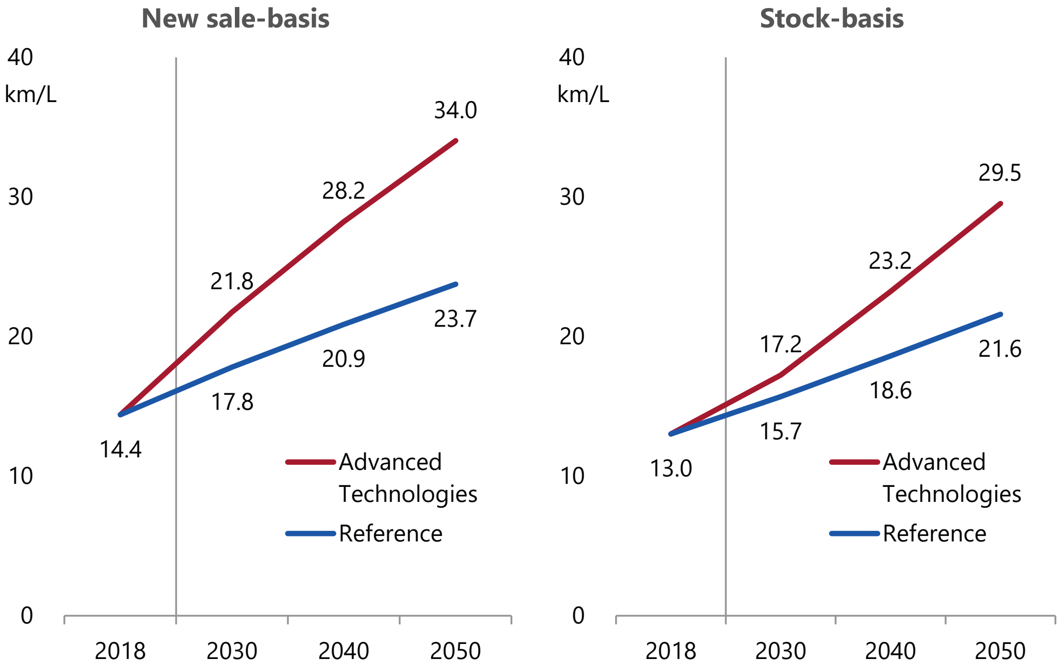
Advanced Technologies Scenario

Share of passenger vehicle



Advanced Technologies Scenario

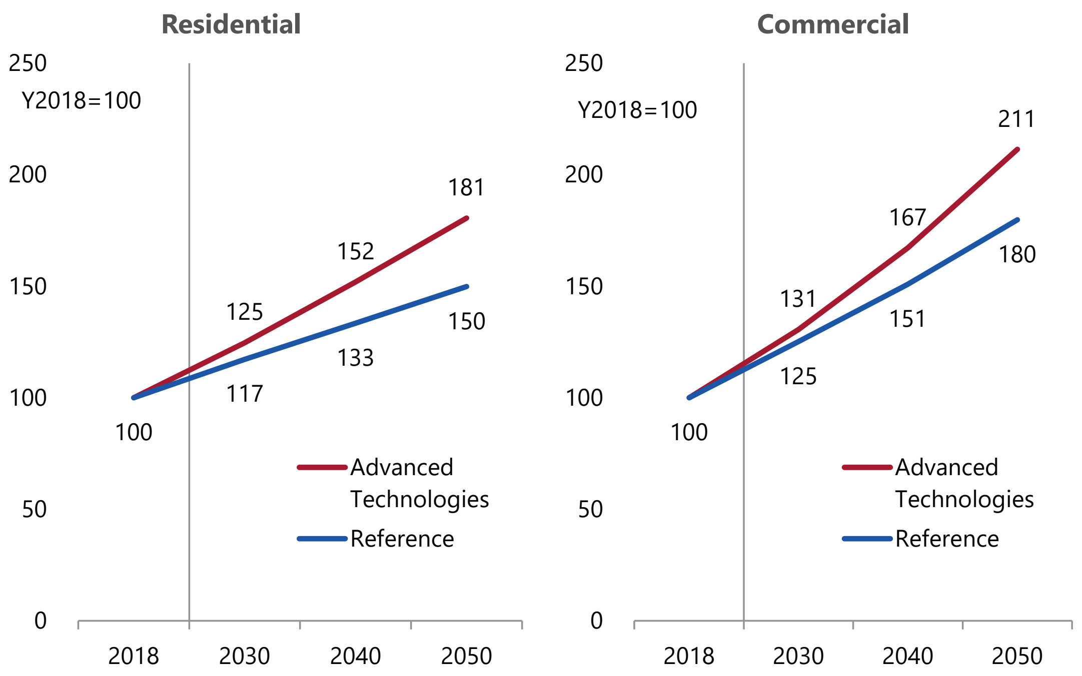
Fuel efficiency of passenger vehicle



Note: Litres of gasoline equivalent

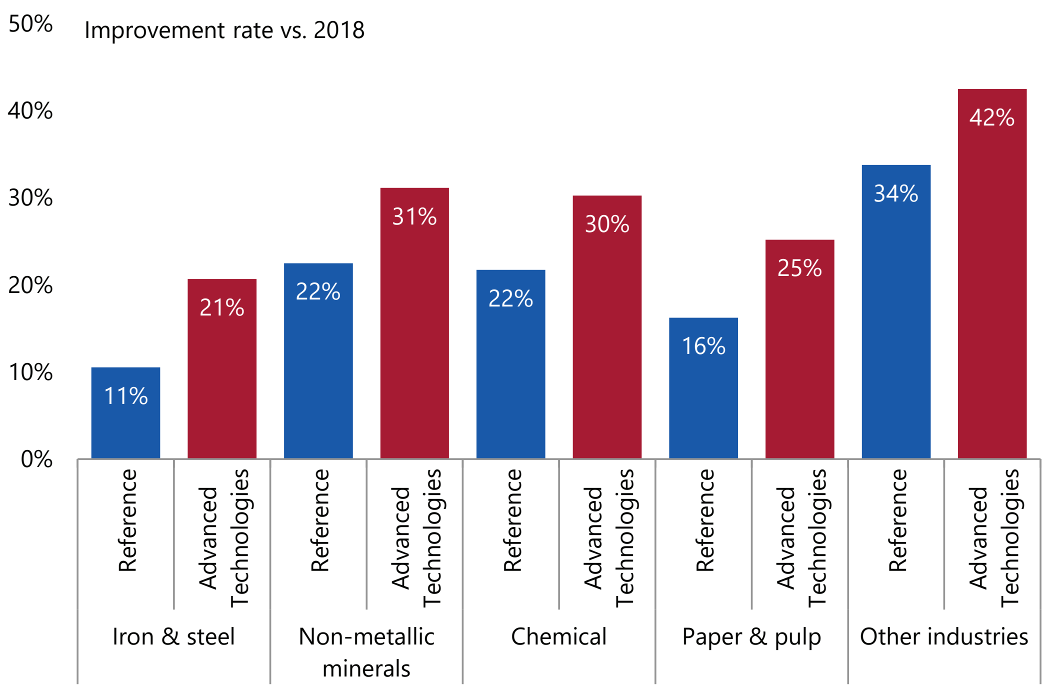
Advanced Technologies Scenario

Energy efficiency in buildings sector



Advanced Technologies Scenario

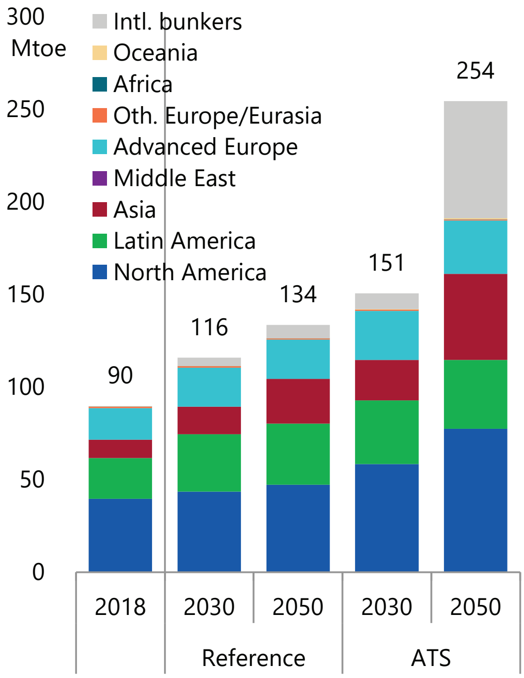
Energy intensity improvement in industry sector



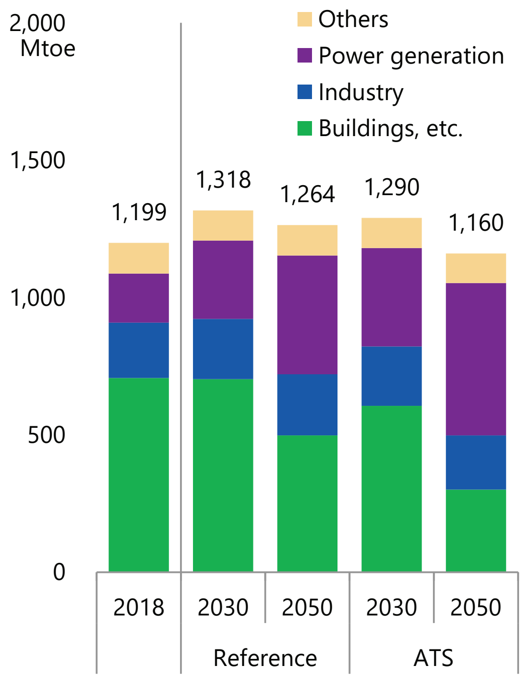
Advanced Technologies Scenario

Biomass

Biofuels for transport



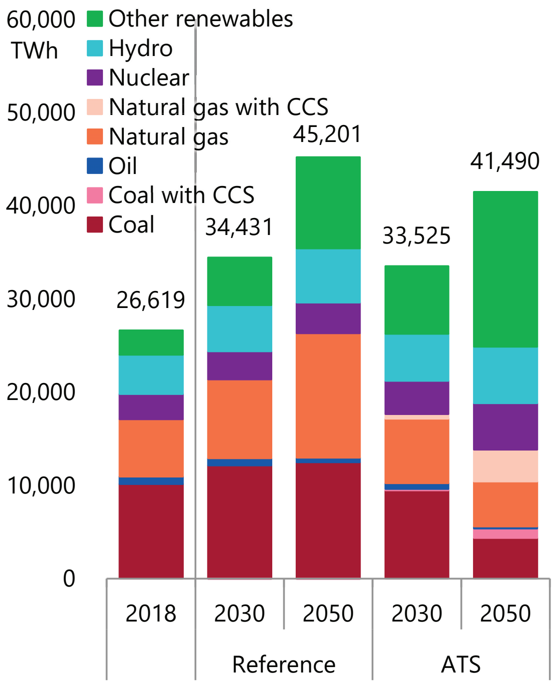
Solid biomass



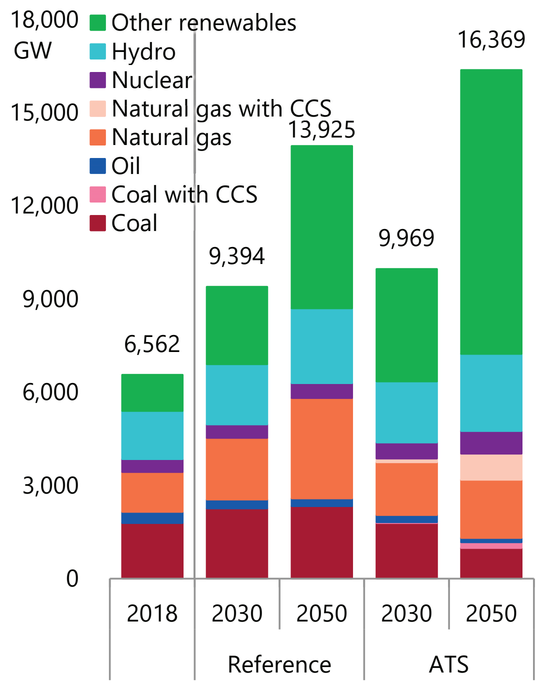
Advanced Technologies Scenario

Power generation mix

Electricity generated

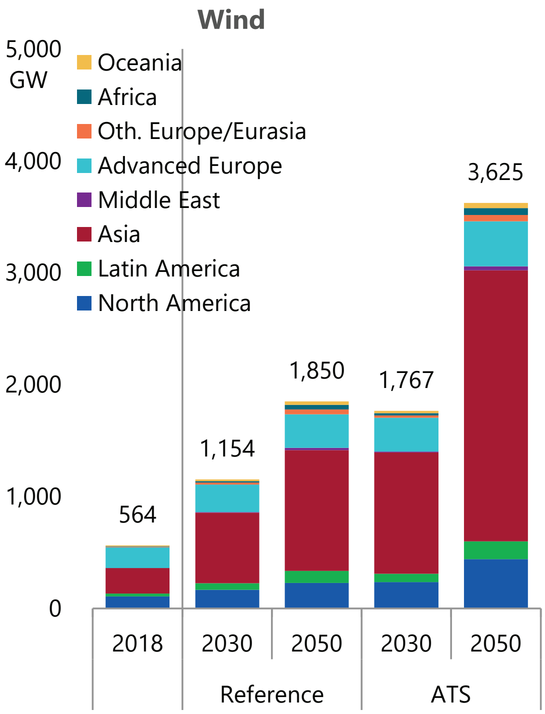


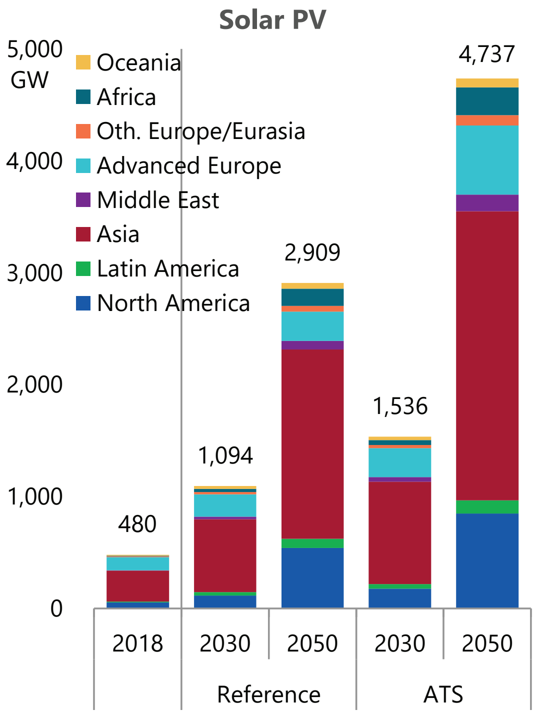
Power generation capacity



Advanced Technologies Scenario

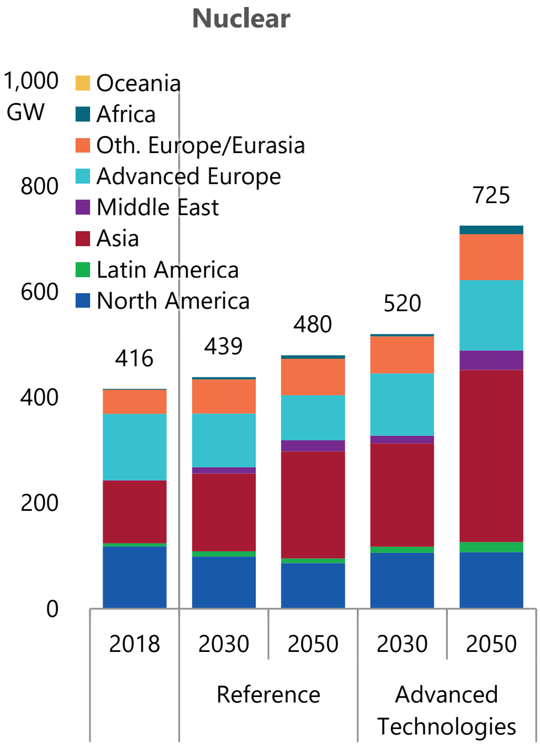
Wind and solar PV power generation capacity

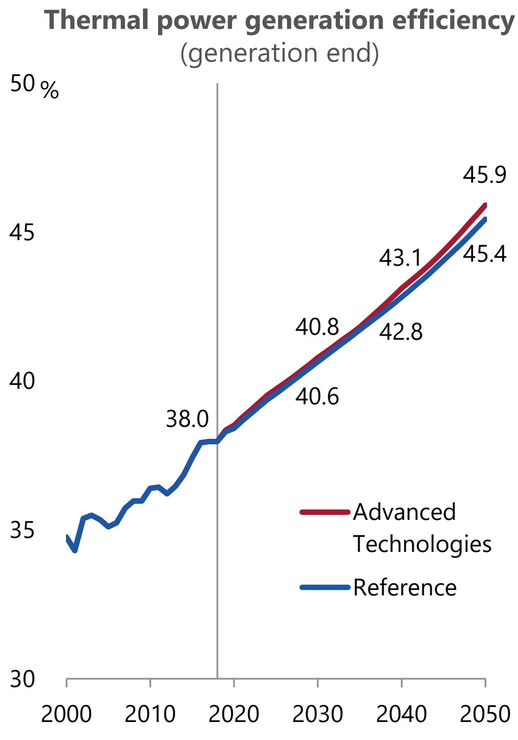




Advanced Technologies Scenario

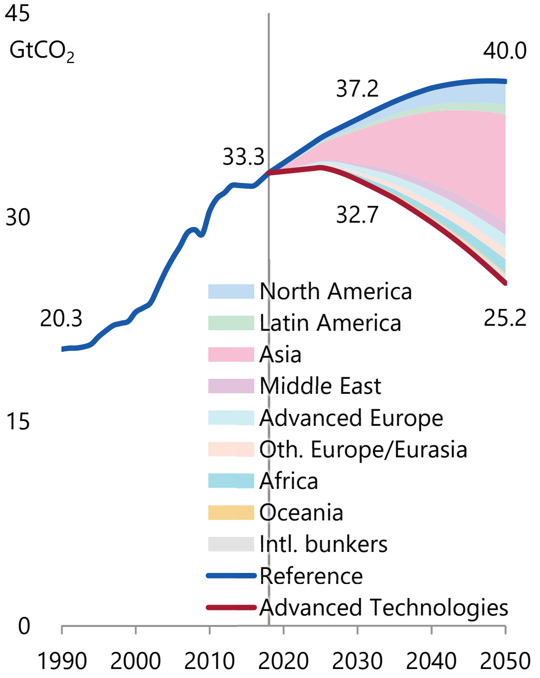
Nuclear power generation capacity and thermal power generation efficiency

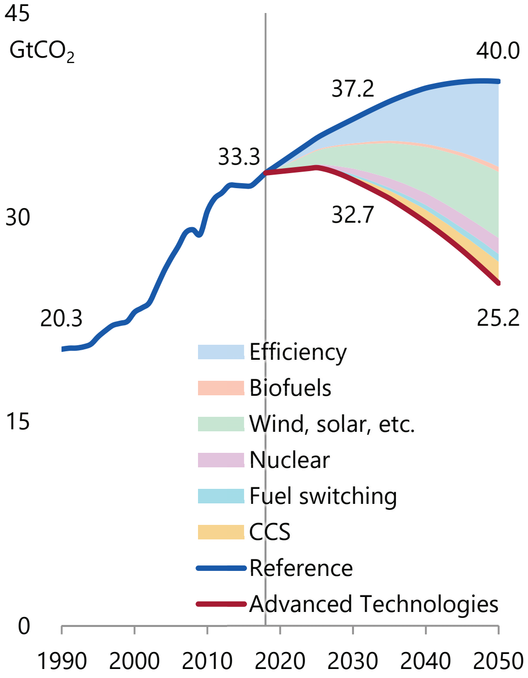




Advanced Technologies Scenario

Energy-related CO_2 emissions

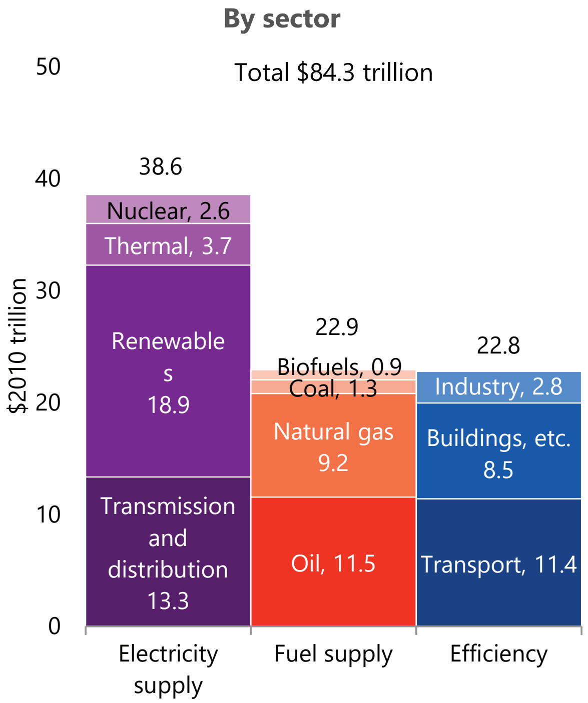


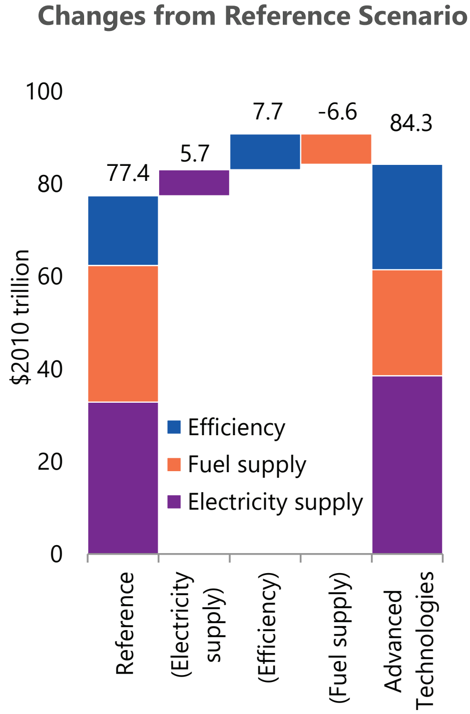


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

Advanced Technologies Scenario

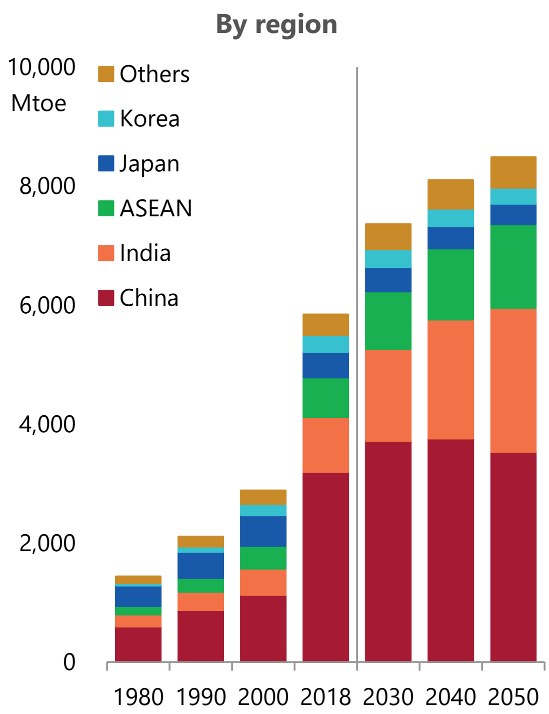
Energy-related investments (2019 – 2050)

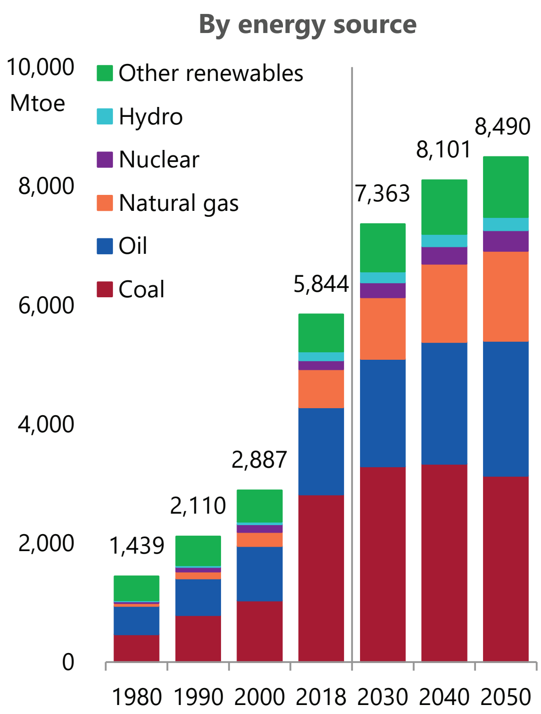




Asia | Reference Scenario

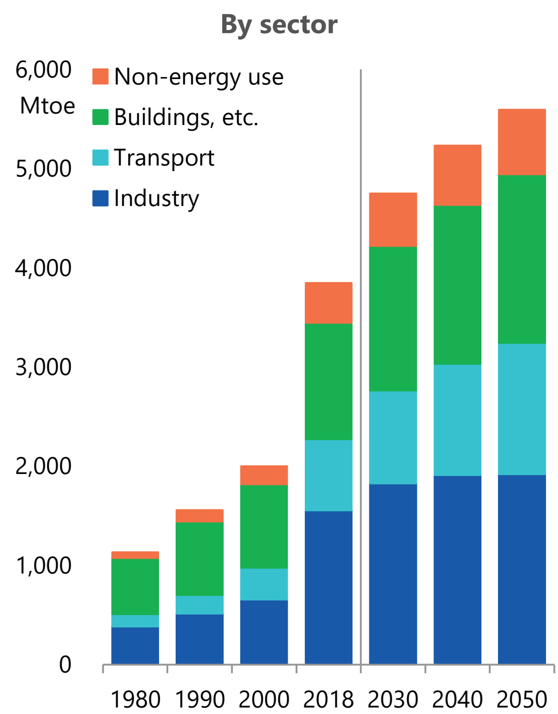
Primary energy consumption

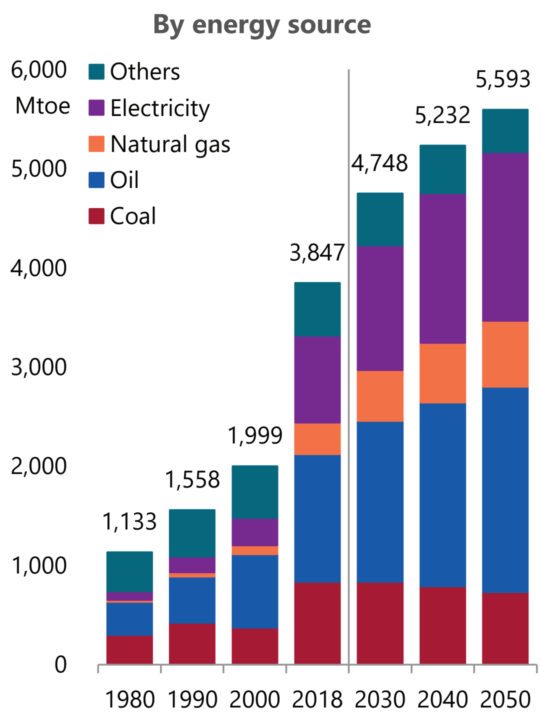




Asia | Reference Scenario

Final energy consumption

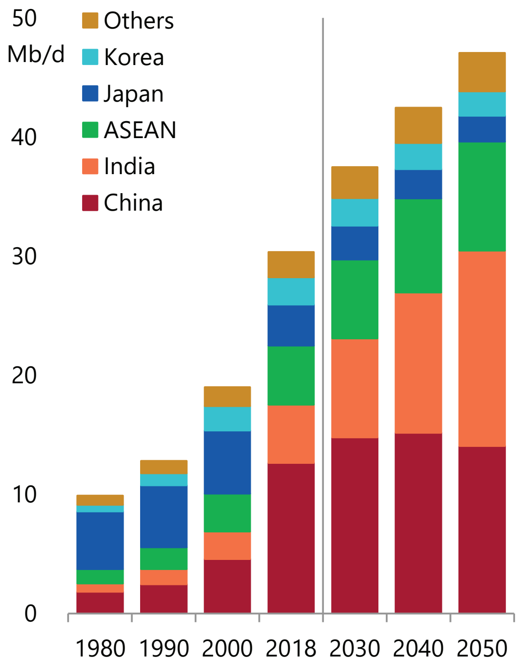




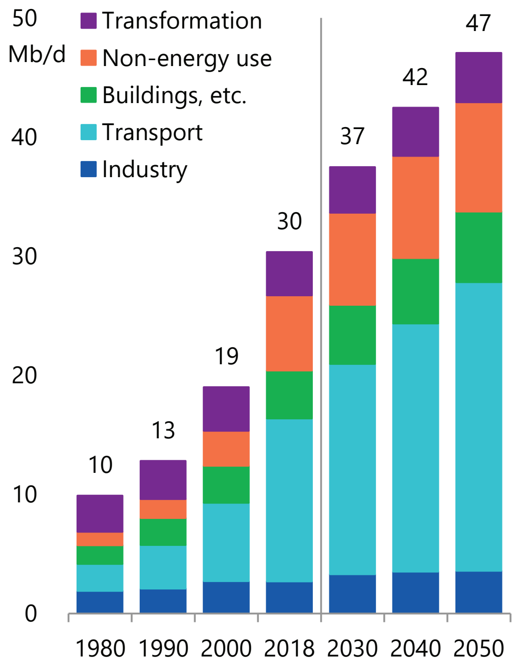
Asia | Reference Scenario

Oil consumption

By region



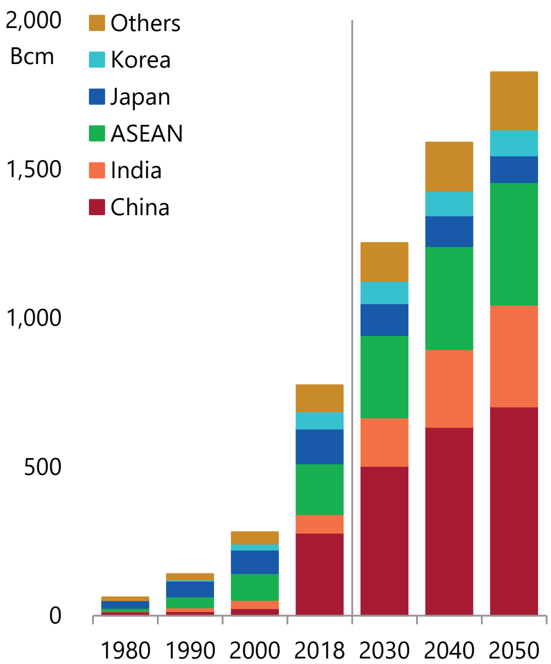
By sector



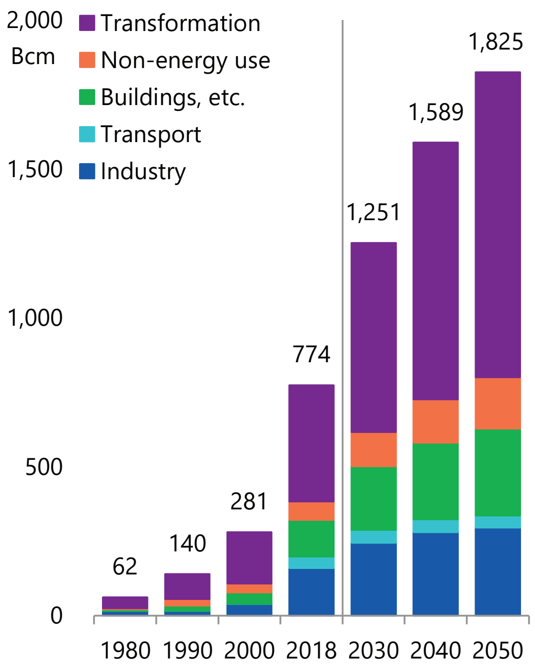
Asia | Reference Scenario

Natural gas consumption

By region



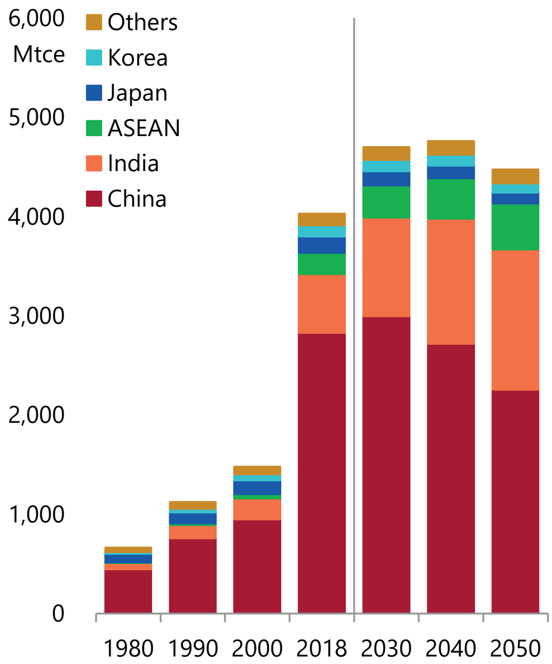
By sector



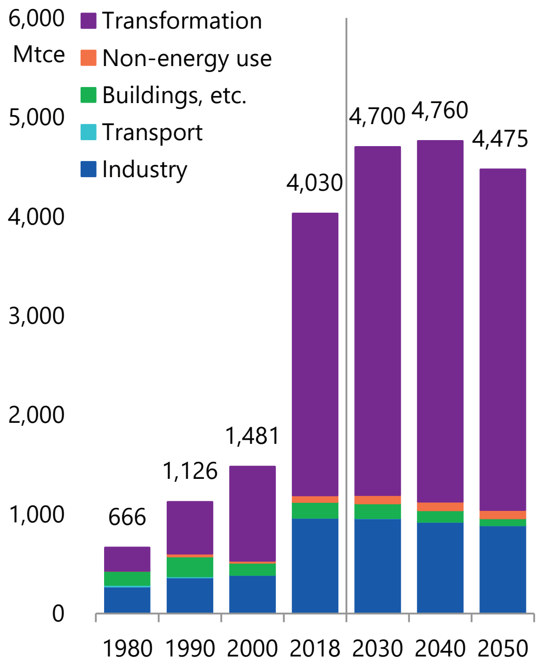
Asia | Reference Scenario

Coal consumption

By region



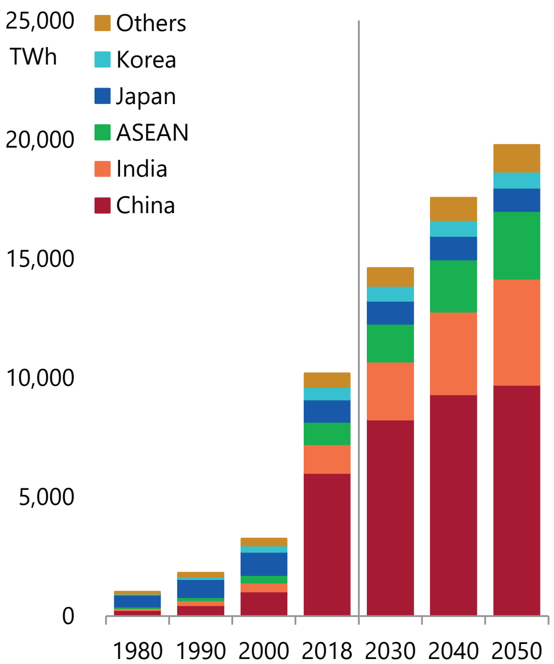
By sector



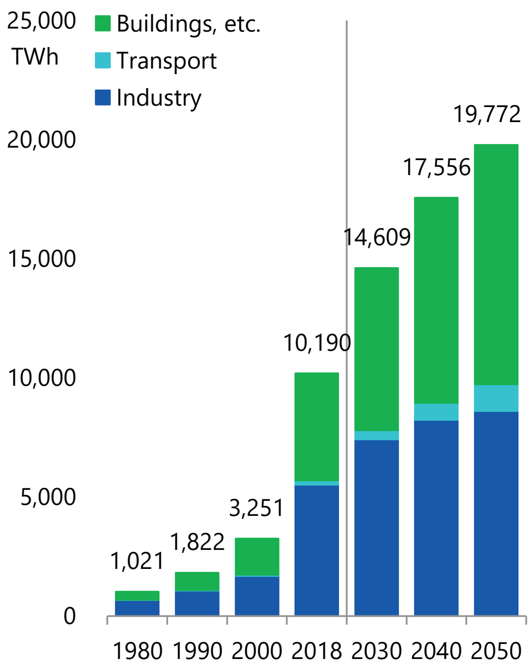
Asia | Reference Scenario

Final consumption of electricity

By region



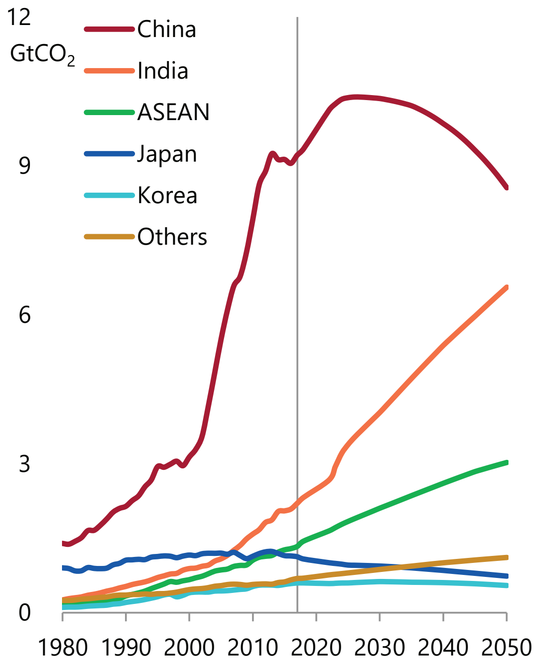
By sector



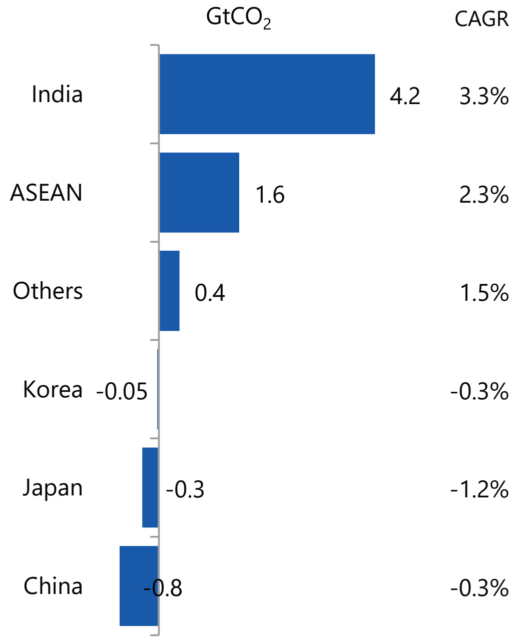
Asia | Reference Scenario

Energy-related CO_2 emissions

Emissions



Changes (2018-2050)

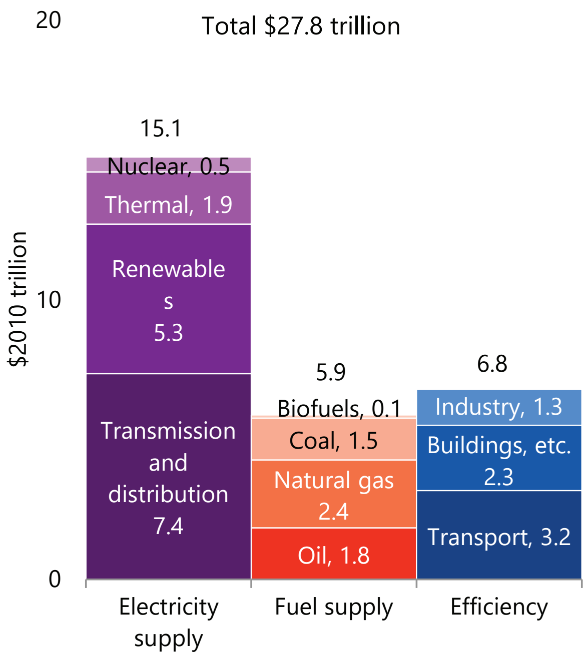


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

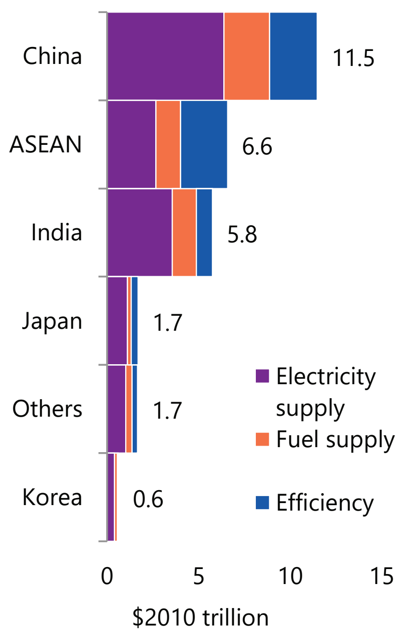
Asia | Reference Scenario

Energy-related investments (2019 – 2050)

By sector



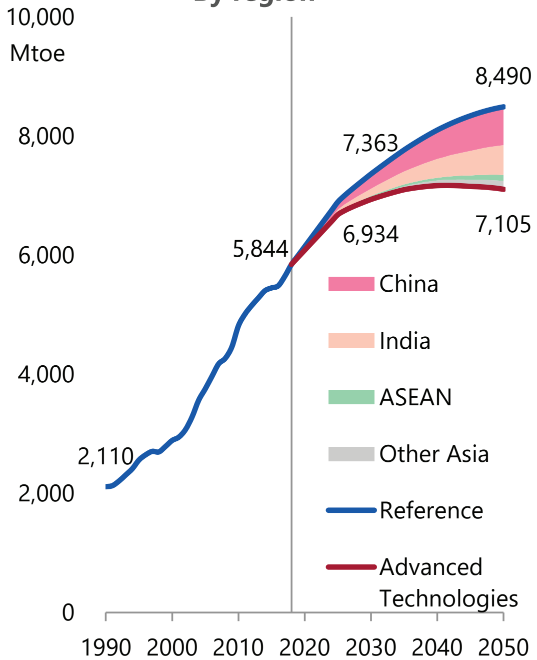
By region



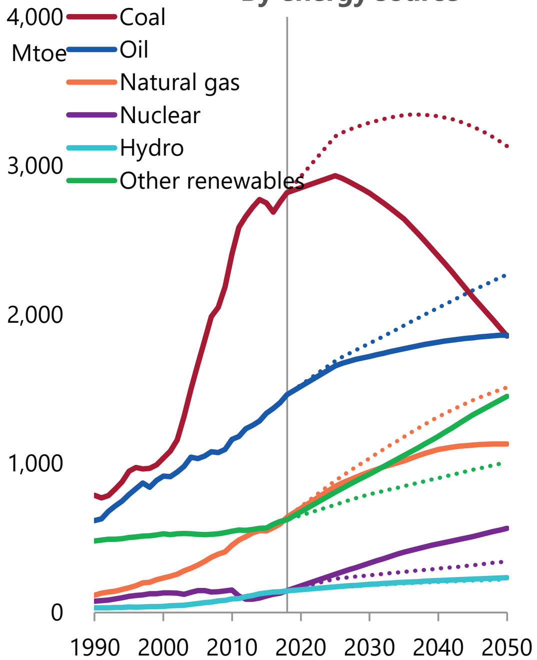
Asia | Advanced Technologies Scenario

Primary energy consumption

By region



By energy source



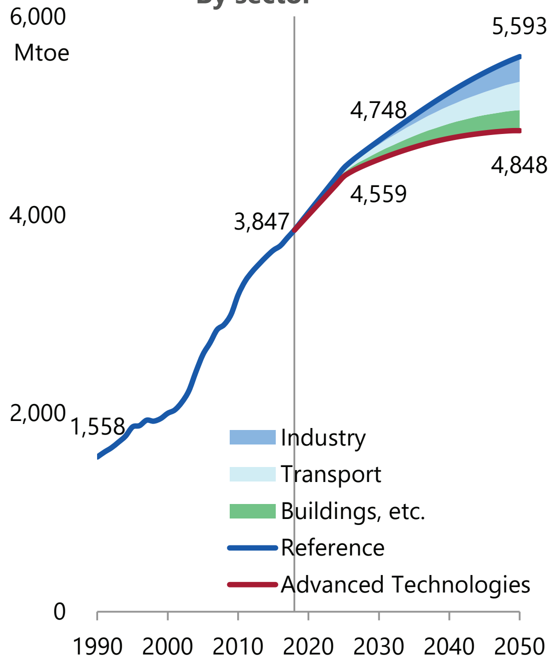
Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

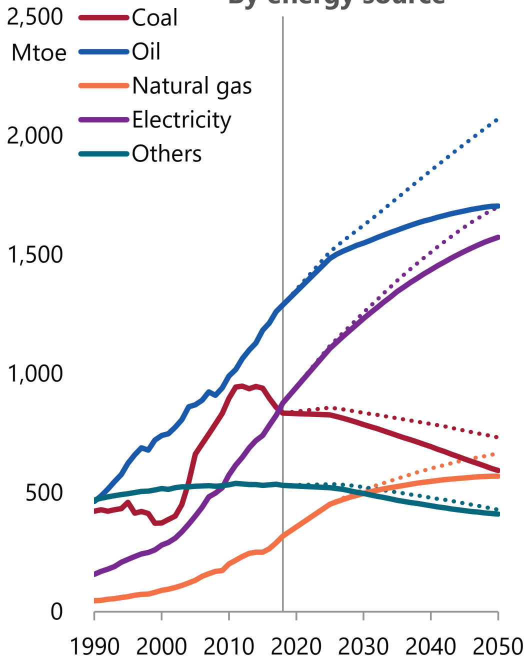
Asia | Advanced Technologies Scenario

Final energy consumption

By sector



By energy source

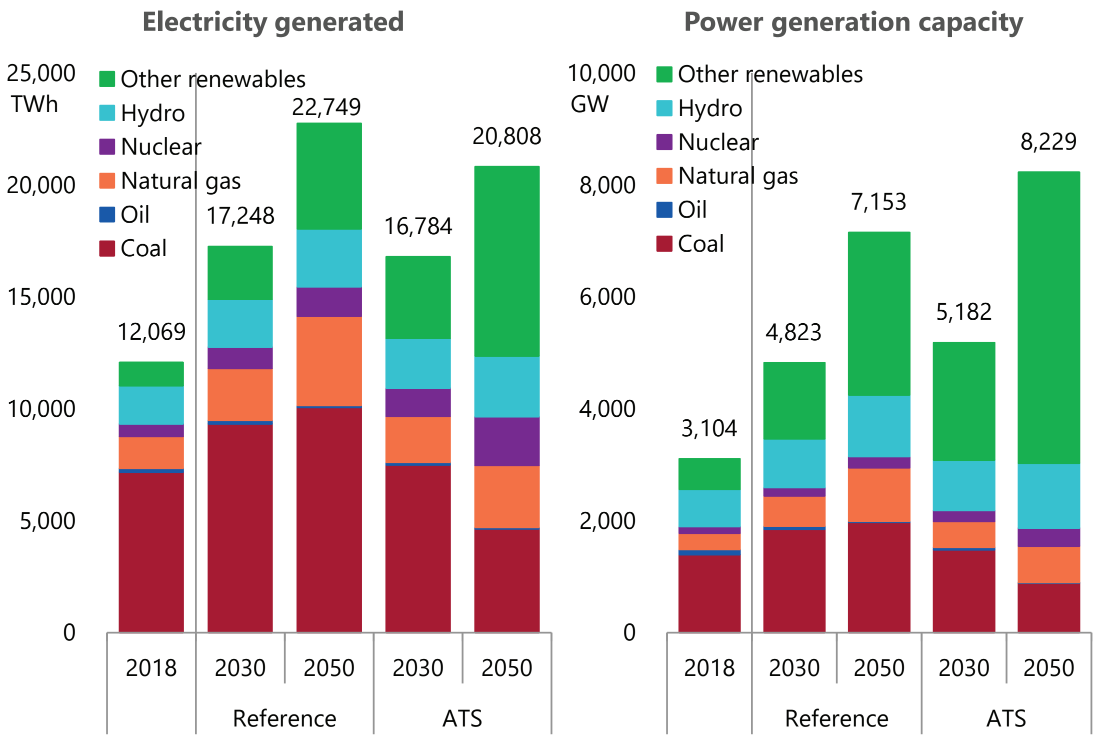


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

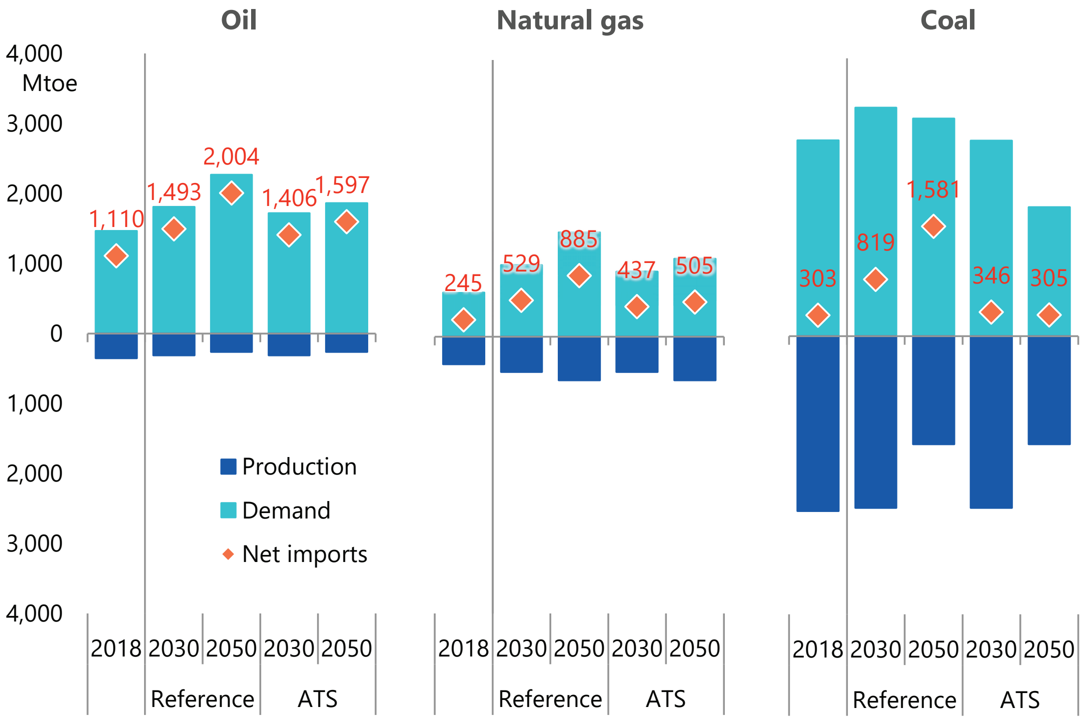
Asia | Advanced Technologies Scenario

Power generation mix



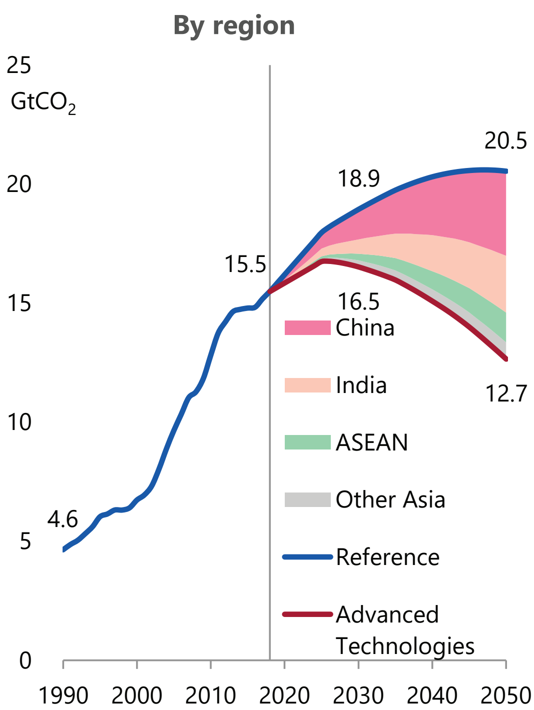
Asia | Advanced Technologies Scenario

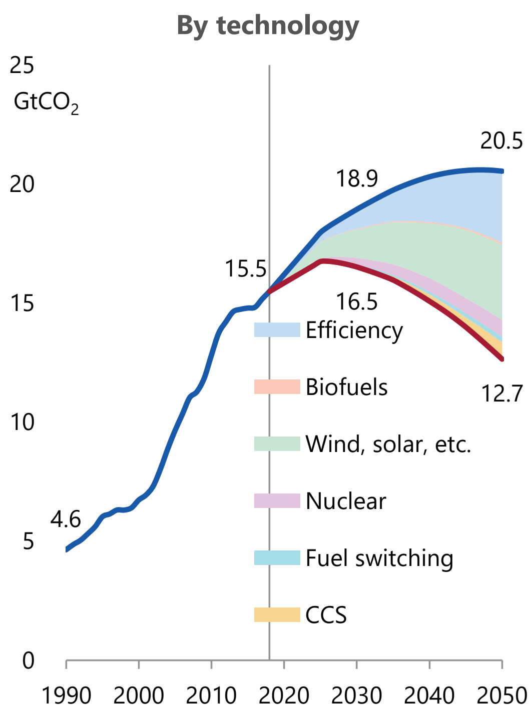
Supply and demand balance of fossil fuels



Asia | Advanced Technologies Scenario

Energy-related CO_2 emissions

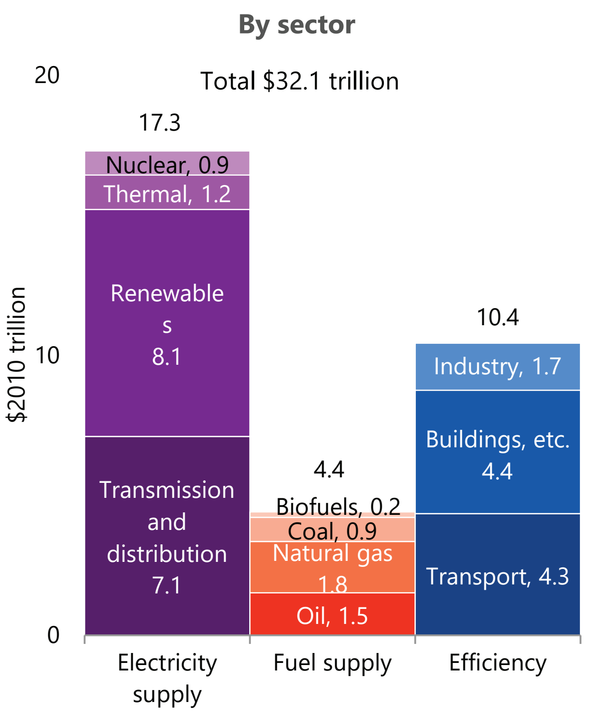


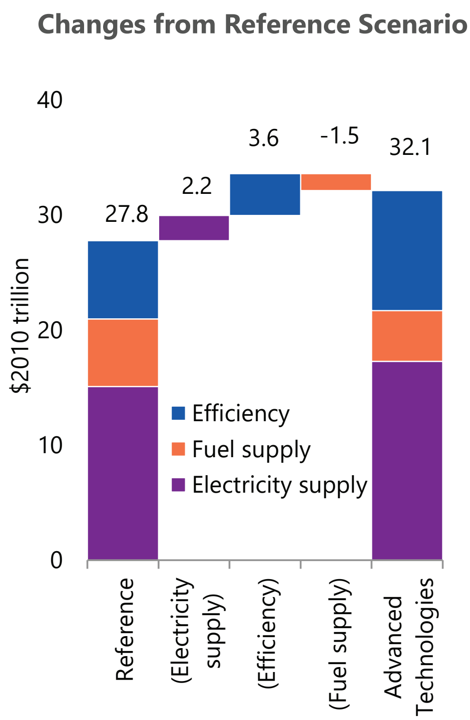


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

Asia | Advanced Technologies Scenario

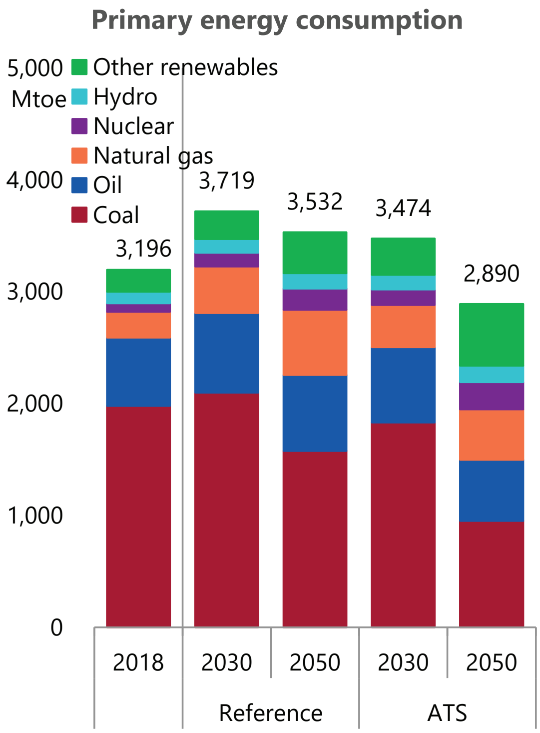
Energy-related investments (2019 – 2050)

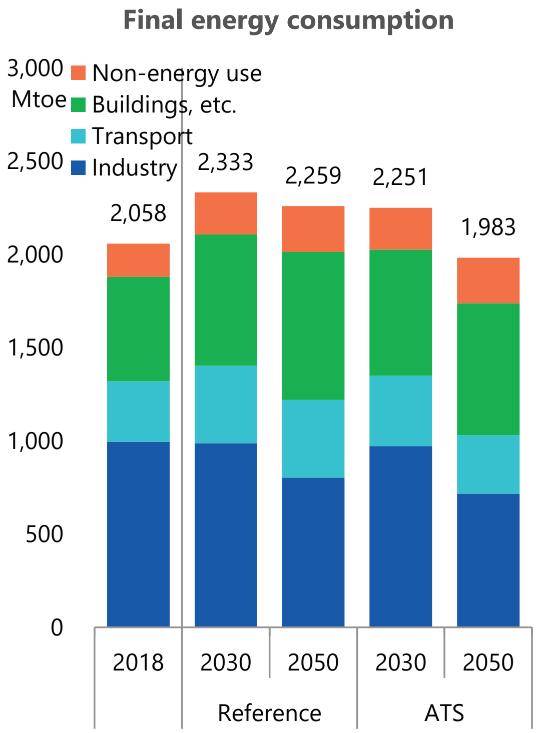




China

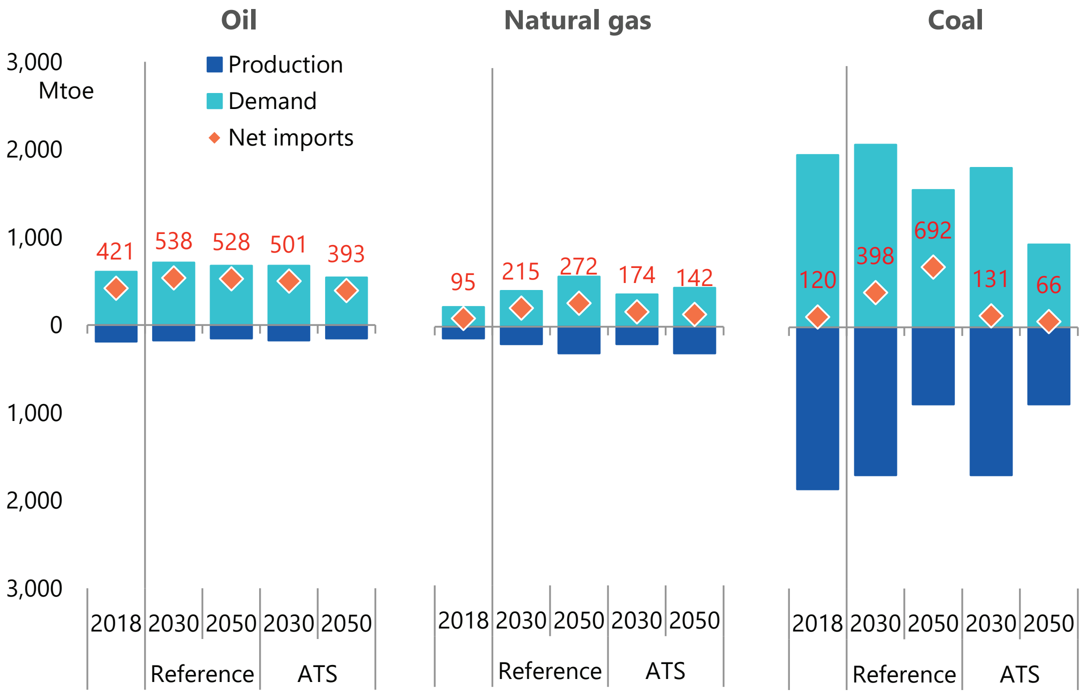
Energy consumption





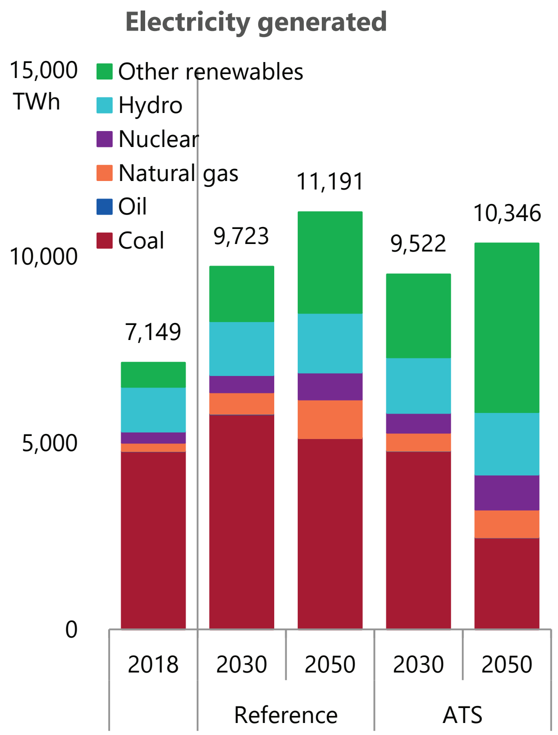
China

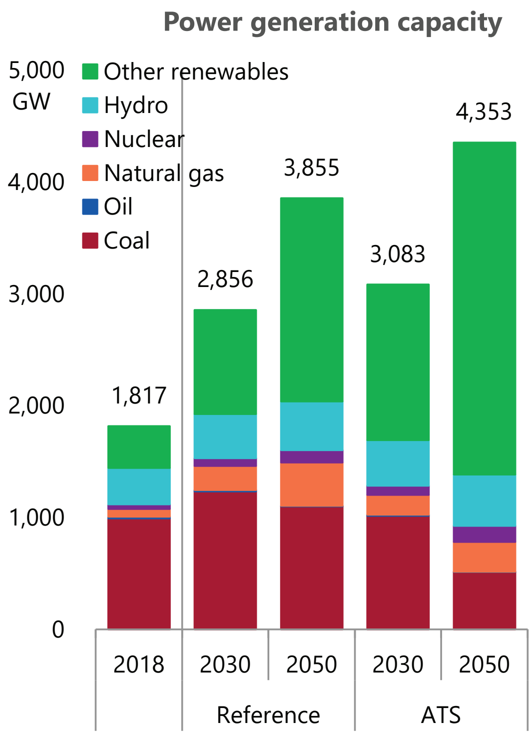
Supply and demand balance of fossil fuels



China

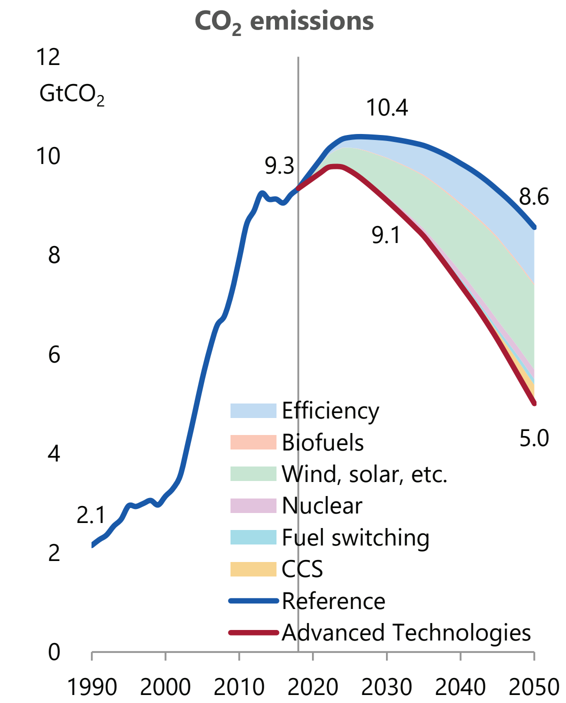
Power generation mix

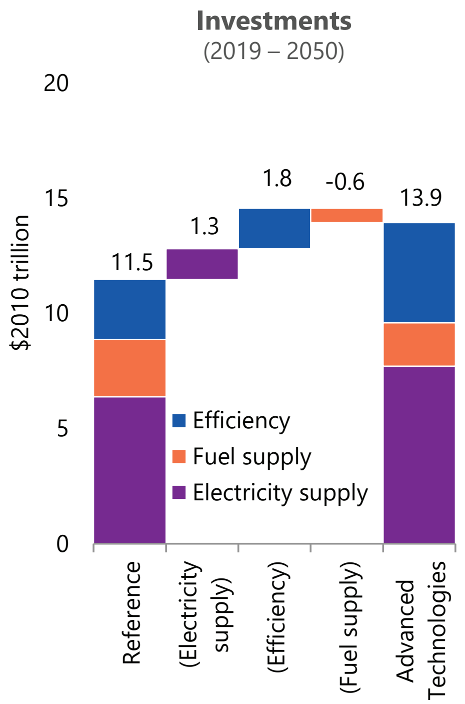




China

Energy-related CO_2 emissions and investments

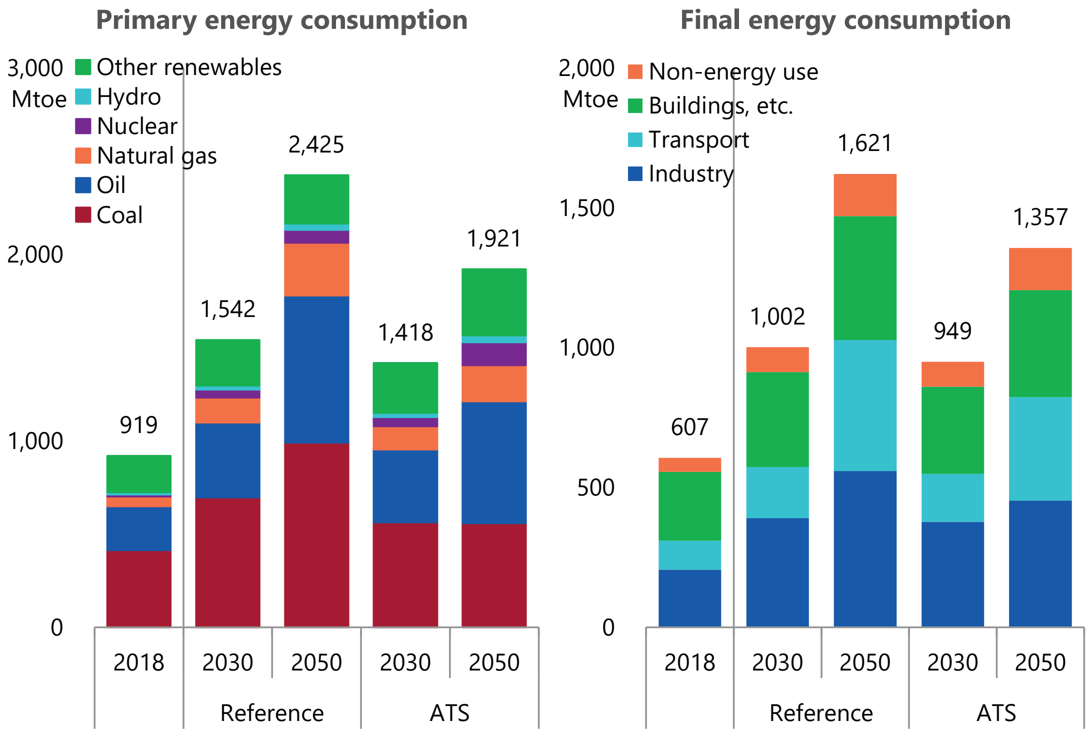




Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

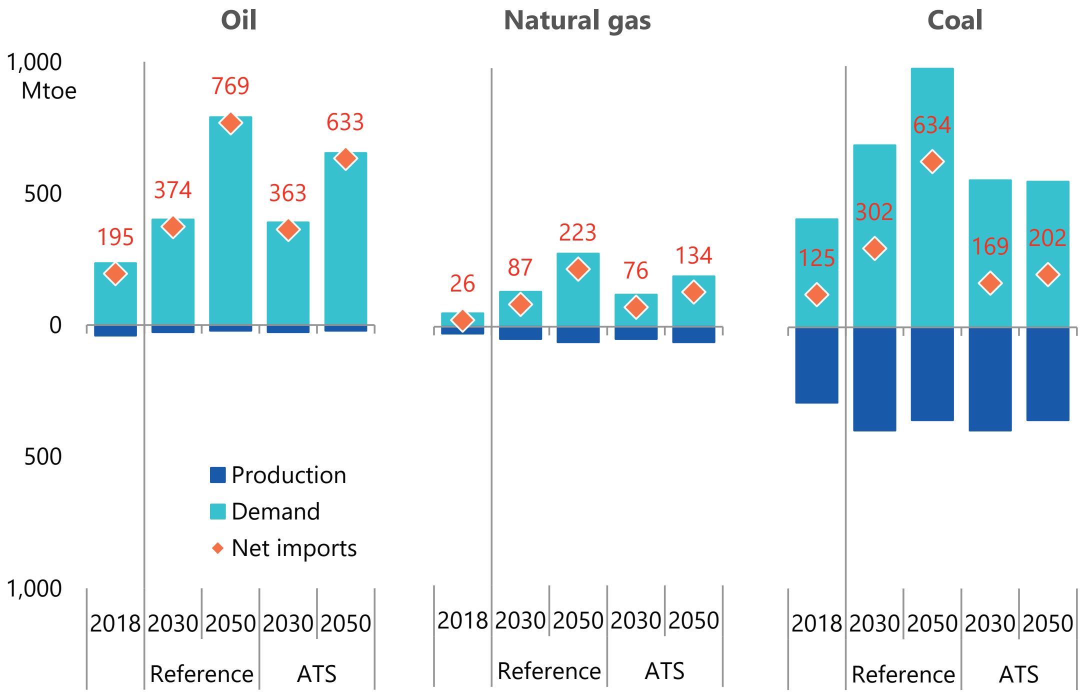
India

Energy consumption



India

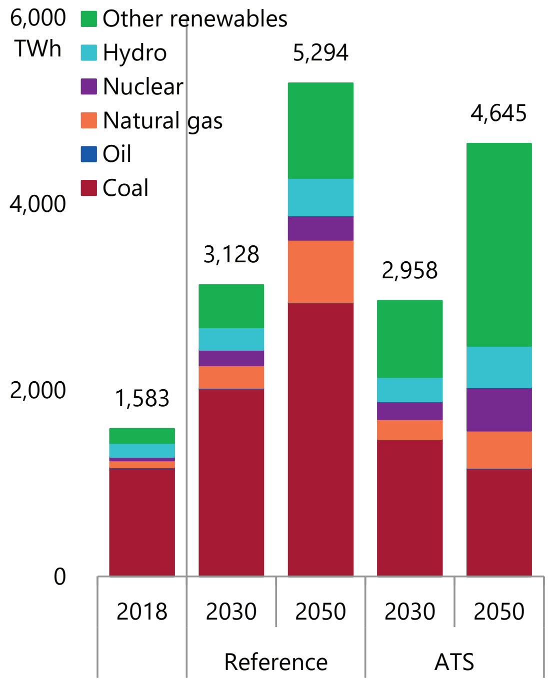
Supply and demand balance of fossil fuels



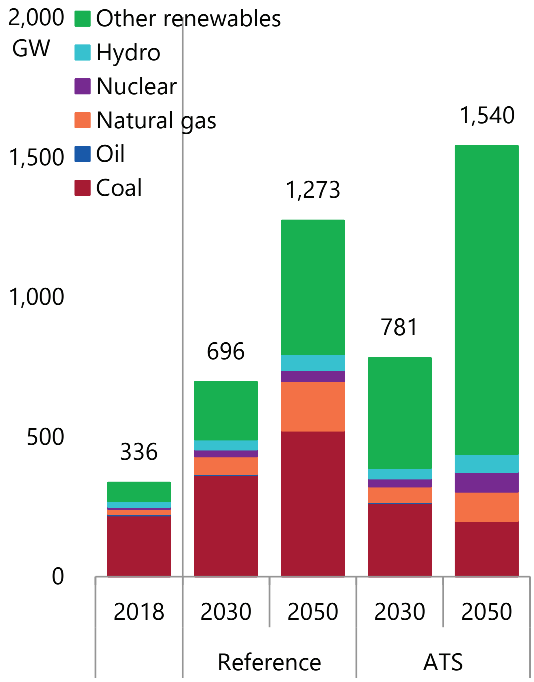
India

Power generation mix

Electricity generated



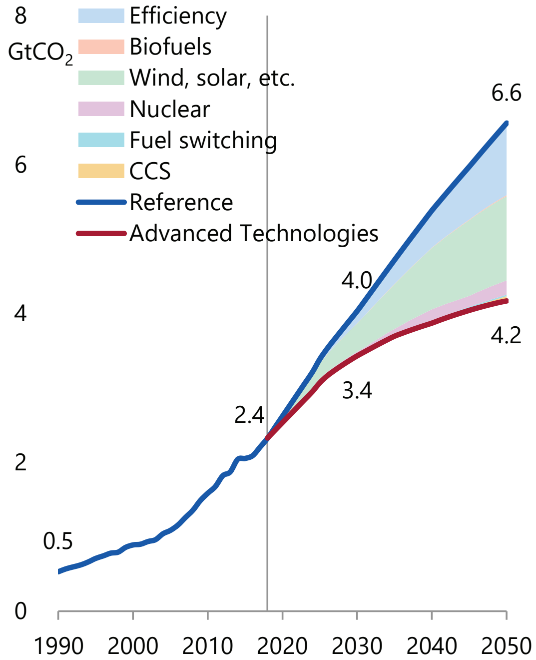
Power generation capacity



India

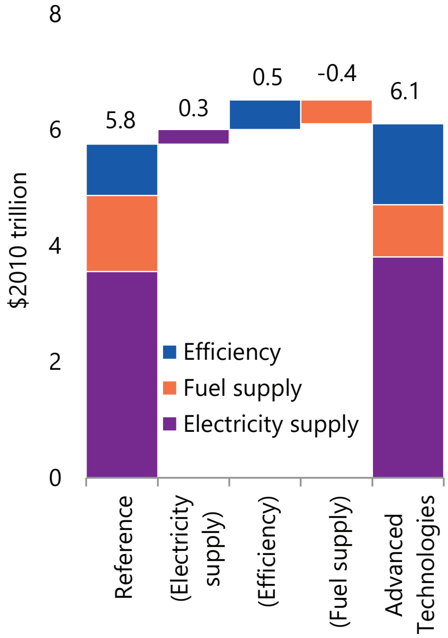
Energy-related CO_2 emissions and investments

CO_2 emissions



Investments

(2019 – 2050)

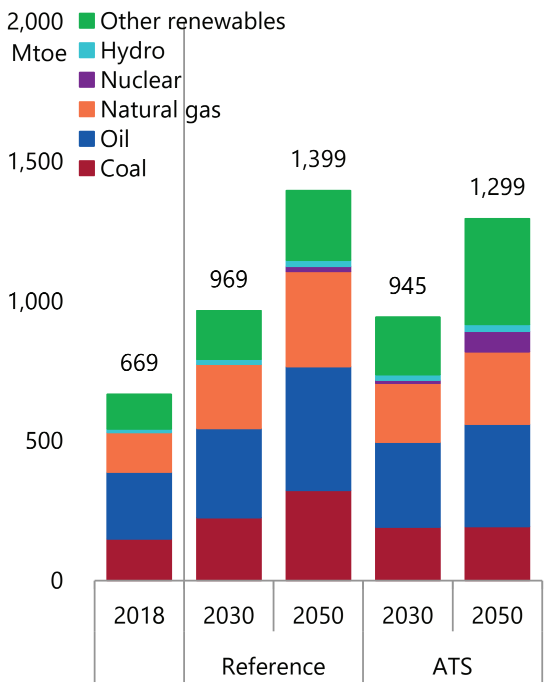


Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

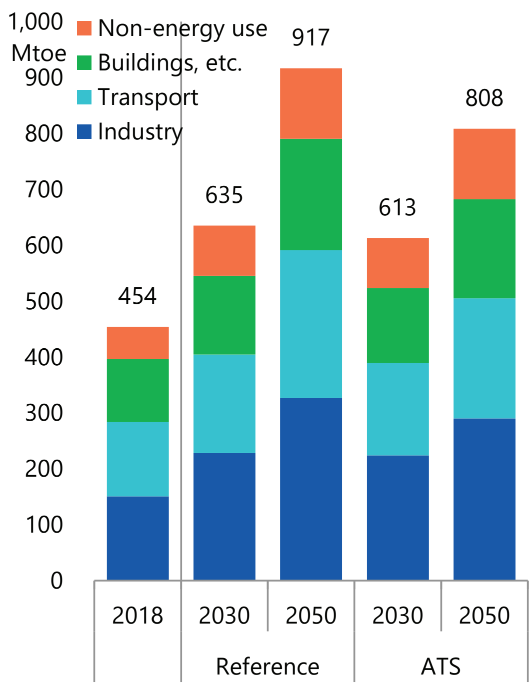
ASEAN

Energy consumption

Primary energy consumption

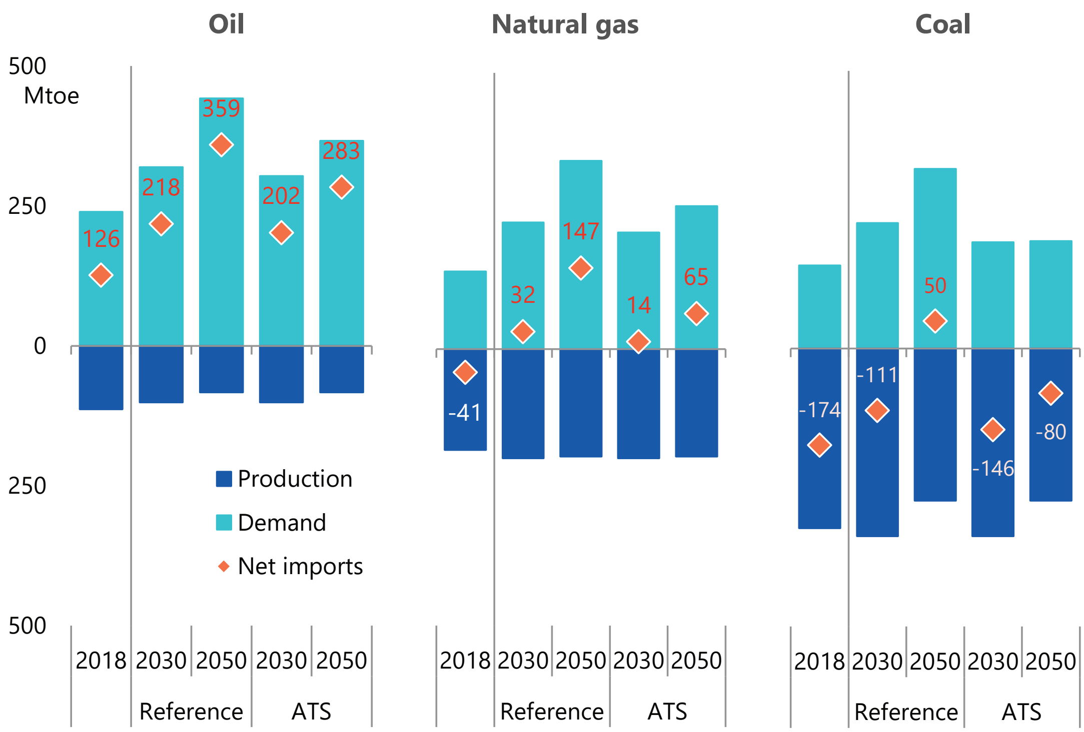


Final energy consumption



ASEAN

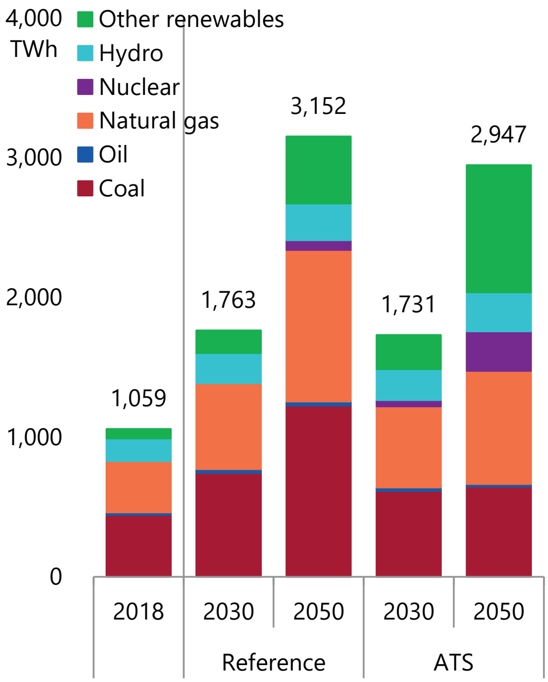
Supply and demand balance of fossil fuels



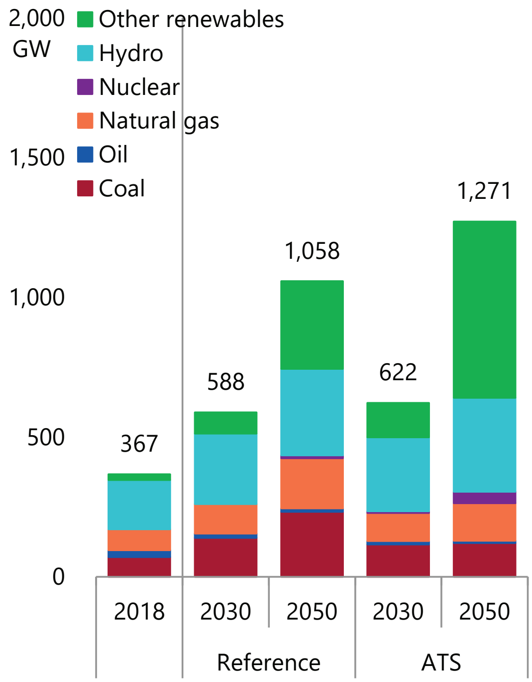
ASEAN

Power generation mix

Electricity generated



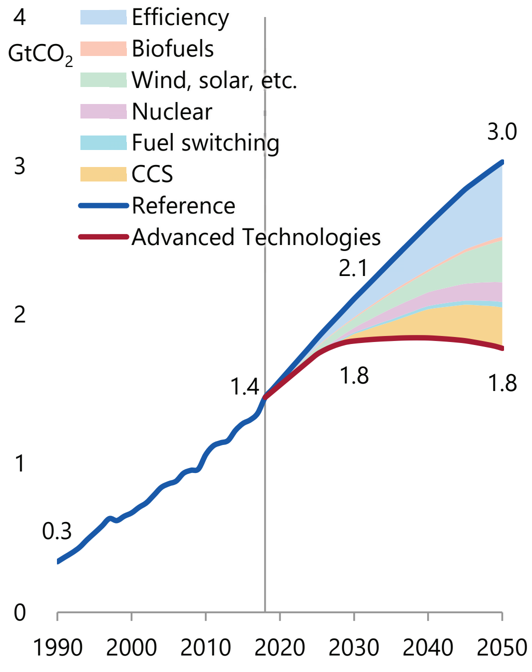
Power generation capacity



ASEAN

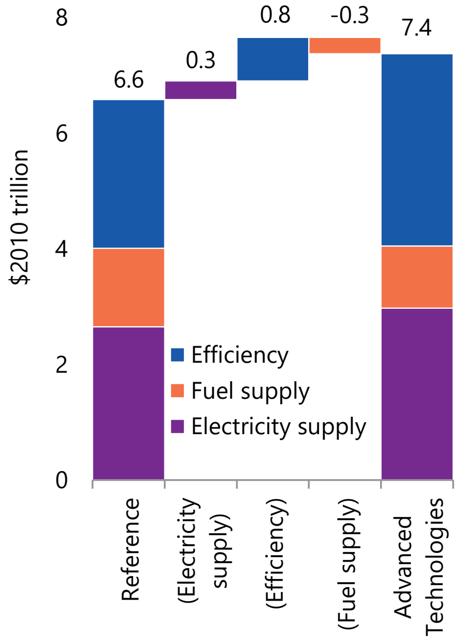
Energy-related CO_2 emissions and investments

CO_2 emissions



Investments

(2019 – 2050)



Note: See Figure 6-1 in Chapter 6 for the short-term impact of COVID-19.

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