IEEJ Outlook 2020

Coping with the increasingly challenging energy trilemma (3Es)

Energy, Environment and Economy

The Institute of Energy Economics, Japan

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In 1969, or a half century ago, liquefied natural gas was imported for the first time from the United States to Japan, paving the way for LNG use in Asia that has since evolved into the world's energy demand centre. The event came only a decade after the world developed a new energy supply means. In 1959, the tanker Methane Pioneer successfully transported supercool liquid from the United States to the United Kingdom and the 2 000 tonnes aboard the former wartime standard ship marked the beginning of international LNG trade. Over the last half century, trade has increased beyond 300 Mt a year and LNG now accounts for as much as one-third of global natural gas trade.

Solar photovoltaics, often seen as a representative of modern renewable energy, also has a history as long as that of LNG. The first practical crystal silicon solar cell was realised in the United States in 1954, five years before the first LNG transportation across the Atlantic. The solar cell, mounted on the U.S. Vanguard I satellite launched in 1958, symbolised its development potential despite its capacity of only 1 Watt. Wind power generation, another representative of modern renewable energy known for its rapid cost cuts in areas suitable for such power generation has a much longer history that goes back to the 19th century. In an experimental development, Danish inventor Poul la Cour used electricity from wind power generation to produce and store hydrogen, initiating what is now called an "RE-P2G" (Renewable Power-to-Gas) system. The full-blown development of solar PV and wind power generation, however, was only triggered by the oil crises of the 1970s and their widespread penetration has taken a long time.

During the 40 years following the world-shaking oil crisis in 1979, hopes have been placed on LNG, solar PV and wind power generation for not only energy security and air pollution prevention purposes but also for climate change mitigation purposes. Meanwhile, greenhouse gas emissions have continued increasing despite the 2016 Paris Agreement. Mankind must tackle climate change while continuing economic growth. What would a pragmatic approach to that end be?

The enhancement of LNG's price competitiveness is seen as key to LNG's further spread in Asian Emerging Market and Developing Economies. As for intermittent solar PV and wind power generation, how to rationally overcome the destabilisation of the power grid caused by their massive expansion has become an urgent challenge. Due to the advancement and informatisation of society, securing the supply of quality electricity has become significantly important. Regrettably, humankind has yet to acquire the perfect energy source, at least for the immediate future. In a bid to overcome the so-called energy trilemma, the IEEJ Outlook 2020 considers how best to make up for the disadvantages of renewable energy, LNG and other energy sources while utilising their advantages. As a matter of course, the outlook provides quantitative long-term estimates for energy supply and demand, and related areas reflecting improvements in analytical approaches, as did the earlier ones. We wish that this outlook would contribute to a better world.

Tokyo, October 2019

The Institute of Energy Economics, Japan

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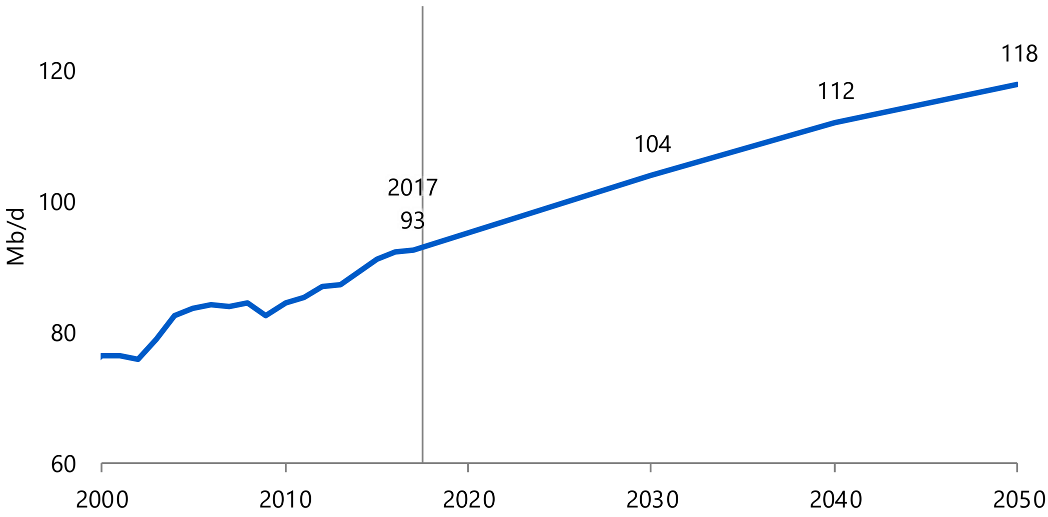
Supply

In the Reference Scenario, which reflects energy and environmental policies to date and continues to trend in the future, world crude oil production[1] increases in response to expanding demand, exceeding 100 million barrels per day (Mb/d) by the mid-2020s (Figure 1). Production will reach 104 Mb/d in 2030 and 118 Mb/d in 2050. The increases, however, gradually shrink as demand growth slowed. Production increased by 10 Mb/d in the last nine years, and a similar increase of 10 Mb/d towards the end of the projection period would be needed over 15 years.

Figure 1 | World crude oil production [Reference Scenario]

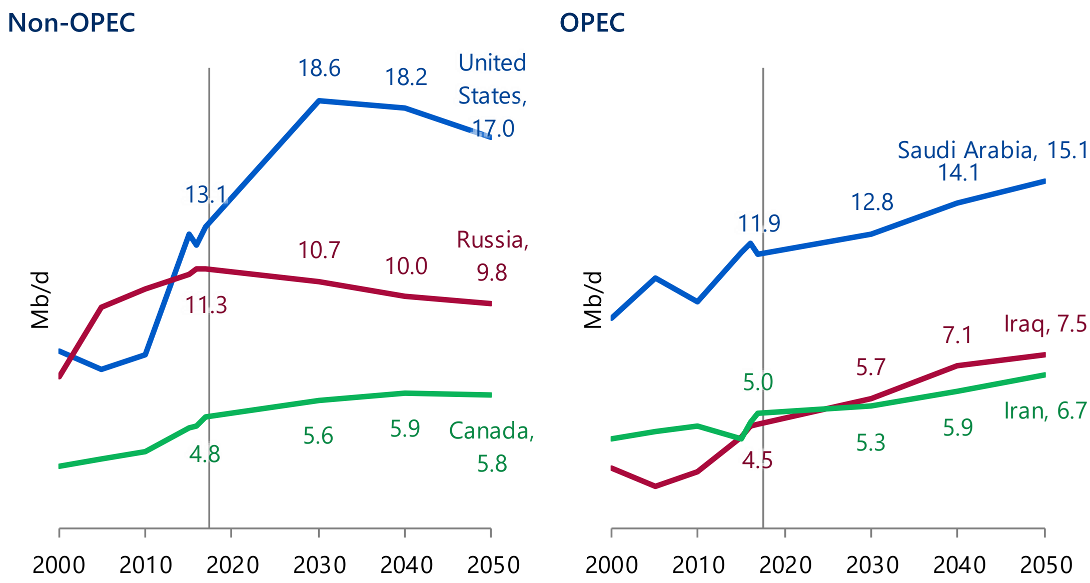


The increase in production of shale oil (light tight oil) over the past decade in the United States has been remarkable, making the country the world’s largest oil producer. This trend will continue for some time due to steady investments in exploration and development (Figure 2). The United States will further increase crude oil production by 5.5 Mb/d by 2030, the equivalent of nearly half of the world’s increase of 11.6 Mb/d. In the long run, on the other hand, it is the Organization of Petroleum Exporting Countries (OPEC), especially Middle Eastern member countries, that will meet the increase in global oil demand and offset the decline in existing oil fields. The United States will maintain its position as the largest oil producer after 2030, but its production volume will decline. By contrast, the giant cartel will have a market share of 44% in 2050, up four percentage points from today. OPEC’s quantitative superiority is even stronger in its power relationships

[1] Includes natural gas liquids (NGL) and does not include processing gains, biofuel, etc.

with Russia, which currently controls its production in a coordinated manner as OPEC-plus.

Figure 2 | Crude oil production in selected countries [Reference Scenario]



Crude oil trade between selected regions will increase only slightly from 43 Mb/d in 2018 to 44 Mb/d in 2030. Imports by the Advanced Economies will decrease as consumption shrinks and North American production increases. However, an increase in imports due to the expansion of consumption in the Emerging and Developing Asia will underpin the overall trade volume. On the export side, the Middle East is the largest crude oil hub, accounting for three fifths of all interregional trade in 2030 (Figure 3). The links between Asia and the Middle East in crude oil trade are disproportionate to those of other regions and are most important for both sides.

Figure 3 | Major crude oil trade between selected regions [Reference Scenario, 2030]

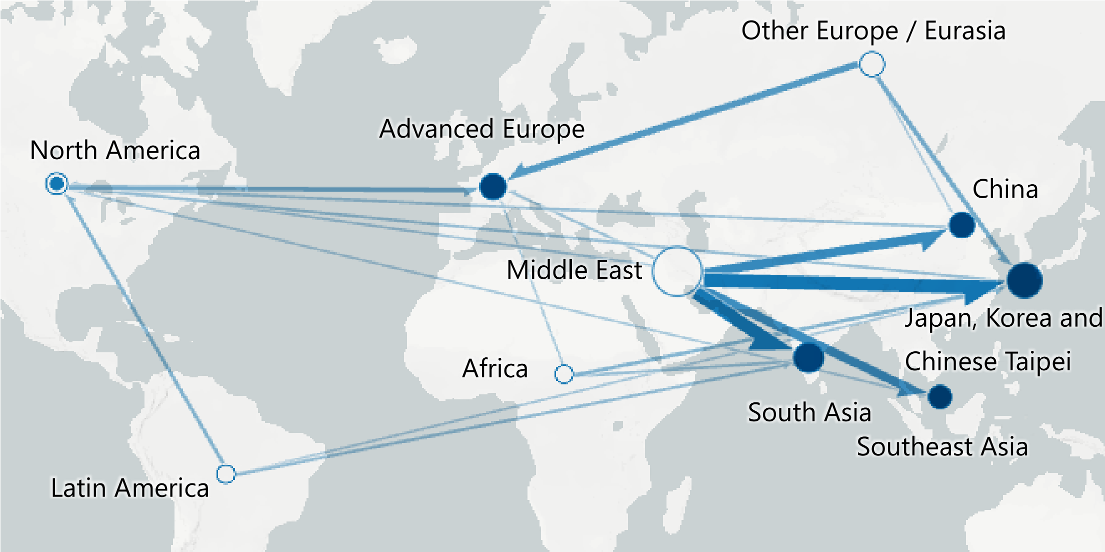


Diagram created using flowmap.blue. ©Mapboxs

Natural gas production has increased by an average of 74 billion m³ (Bcm) per year since 2000 and the rate of increase does not slow down significantly until 2040 (Figure 4). With some moderation thereafter, production still reaches 6.1 trillion m³ (Tcm) in 2050 from 3.8 Tcm in 2017.

Figure 4 | World natural gas production [Reference Scenario]

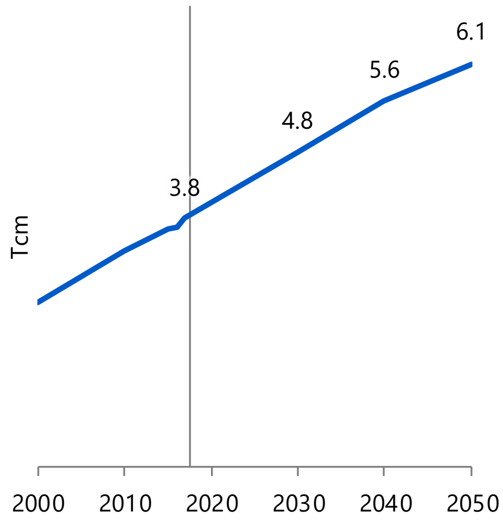
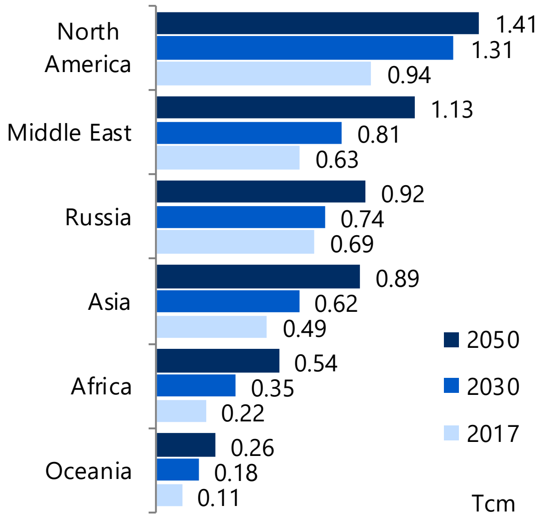


Figure 5 | Natural gas production in selected regions [Reference Scenario]



North America will show the largest increase in producing natural gas for some time, with 36% of the 1.0 Tcm global production increase by 2030 (Figure 5). In the long run, like for crude oil production, the rest of the world — the Middle East, Other Europe / Eurasia and Asia — will play a bigger role. The country with the largest increase in production between 2030 and 2050 is China. It is currently investing heavily in domestic natural gas development in response to growing demand.

- Major natural gas trade between selected regions will expand from 759 Bcm (637 Mtoe) in 2018 to 983 Bcm (825 Mtoe) in 2030 (Figure 6). This is in sharp contrast to the expectations that the export and import volume of crude oil, the largest trade commodity, increased from 1 891 Mtoe to only 1 993 Mtoe during the same period. North America will more than double its exports on the back of increased production, while China will almost double its imports.

- Pipeline gas currently account for 44% and liquefied natural gas (LNG) account for 56% of the natural gas trade between selected regions[2]. Until now, Japan and Korea played a leading role in importing LNG, however, due to a full-scale expansion of its utilisation in the future, LNG will eventually overwhelm the pipeline gas. The presence of China and other regions such as South Asia, India and Europe is increasing (Figure 7). China overtook Korea to become the world's second largest importer in 2017. The Association of Southeast Asian Nations (ASEAN), which had long been an exporter, will rapidly expand imports due to increased consumption and resource depletion. As a supply source, Oceania and North America, where many LNG projects are planned to start operation from 2020 to 2025, will greatly increase their presence.

Figure 6 | Major natural gas trade between selected regions [Reference Scenario, 2030]

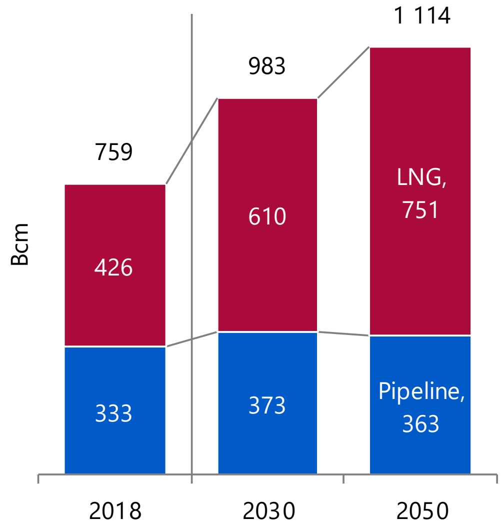
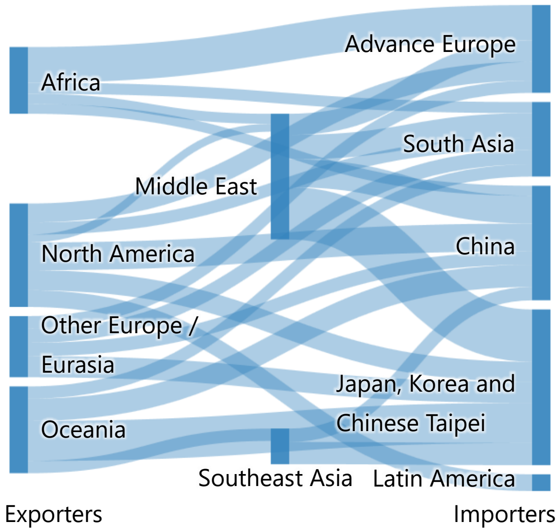


Figure 7 | Major LNG trade between selected regions [Reference Scenario, 2030]



Note: 3 Mt or more are shown.
Diagram created using SankeyMATIC

- Coal production will increase from 5.4 billion tonnes of coal equivalent (Gtce) in 2017 to 6.1 Gtce in 2040 (Figure 8). After that, production will decrease by 0.3 Gtce over the following 10 years; production in 2050 is still larger than at present. Steam coal, which is

[2] Pipeline gas accounts for about two thirds of the natural gas trade if intra-regional trade is included.

consumed in power generation boilers, represents a large proportion of the coal production.

Coal production in China, which currently mines about half of the world's coal, will peak in the first half of the 2020s and then decline (Figure 9). Its contribution rate to the reduction in global production after 2040 exceeds 100%. Nevertheless, China is still the largest coal producer in 2050, unsurpassed by any other country. Production in the United States, the second largest producer today, also trends downward, whilst production in India and Australia continues to grow as a result of increased domestic demand and calls for exports, respectively.

Figure 8 | World coal production [Reference Scenario]

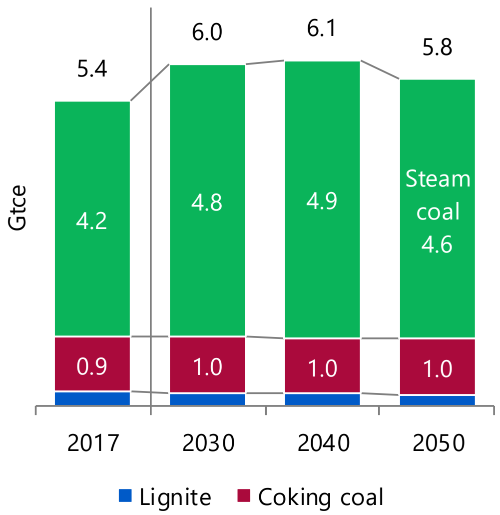
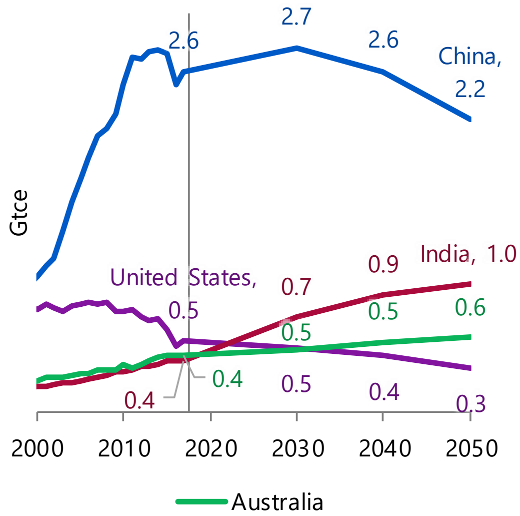


Figure 9 | Coal production in selected countries [Reference Scenario]



Changes in public opinion following the Fukushima Daiichi Nuclear Power Station accident and increased construction costs have made it difficult to build nuclear power plants as planned. In many countries, the use of nuclear shrinks as existing reactors are being shut down. However, even in these countries, efforts are being made to maintain the use of nuclear from the perspective of stable energy supply, addressing climate change issues, and maintaining and strengthening international competitiveness through fostering the nuclear industry. In addition, there are countries such as China that further promote the use of nuclear in the future. Global nuclear power generation capacity will expand from 409 GW in 2017 to 480 GW in 2050, and nuclear power generation will increase by 24% (Figure 10). However, it will not keep up with the rapid increase in total power generation, and its ratio to power generation will fall by three percentage points.

Renewable energies are responding to high expectations. The cost of solar photovoltaic (PV) and wind power generation has drastically reduced, particularly in suitable locations, and the installed amount of solar PV and wind power generation has increased significantly. Solar PV and wind power generation capacity will increase by 7.7 times and by 3.5 times in 2050, respectively. Each generation of 3.7 PWh is about 90% of the current scale of hydro, which is the largest primary electricity supplier.

- Nevertheless, there has been no change in the overall power generation mix in which thermal power generation is mainstream (Figure 11). Only natural gas, which has high power generation efficiency, low carbon dioxide (CO_2) emissions, and excellent load-following properties, will increase its share as thermal power generation. Coal, which is currently the largest power source, will continue to generate more electricity until the mid-2040s, to eventually be replaced by natural gas.

Figure 10 | World major primary electricity supply [Reference Scenario]

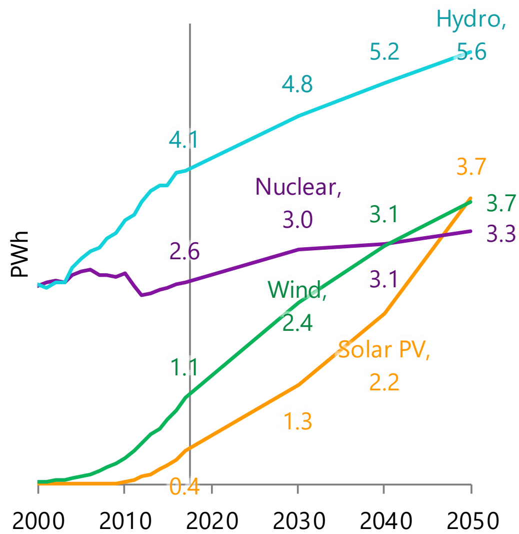
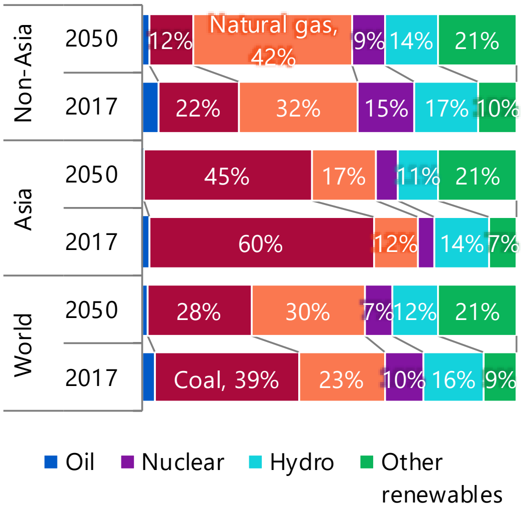


Figure 11 | Power generation mix [Reference Scenario]



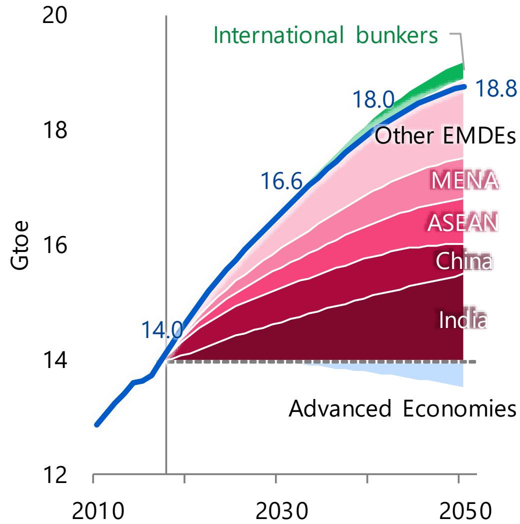
Demand

- The world's primary energy consumption will increase to 18.8 billion tonnes of oil equivalent (Gtoe) in 2050, due to expanding economy and population (Figure 12). The future direction of energy consumption, however, varies considerably among countries and regions. Despite economic growth, energy consumption in the Advanced Economies remains flat to declining. In other words, the net increase in energy consumption is entirely due to the Emerging Market and Developing Economies, and international bunkers. China will remain the world's largest consumer, with consumption reaching 3.8 Gtoe in 2040 and despite a subsequent decline, consumption in 2050 is 17% higher than current levels. China is followed by India and ASEAN, which are booming. Each increasing 2.9 times and 1.5 times is equivalent to that in China by 2050. In the Middle East and North Africa (MENA), economic growth and a rapidly growing population are boosting consumption.

- Although expectations for non-fossil energy are high, fossil fuels will continue to be the core of the energy required to meet the enormous demand (Figure 13). Because fossil fuels will account for three quarters of the increase in energy consumption to 2050, the current

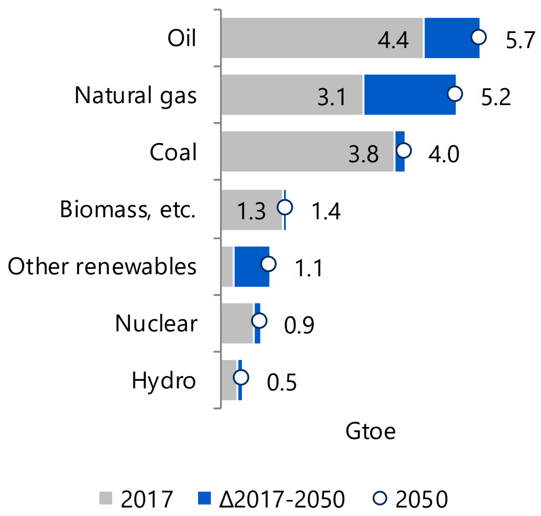
81% dependence on fossil fuels will decline slightly over the next 30 years to 79%. All non-fossil fuels combined still fall short of coal, the least of the fossil fuels in 2050. All the non-fossil energy increases combined barely match the oil increase.

Figure 12 | World primary energy consumption and contributions [Reference Scenario, compared to 2017]



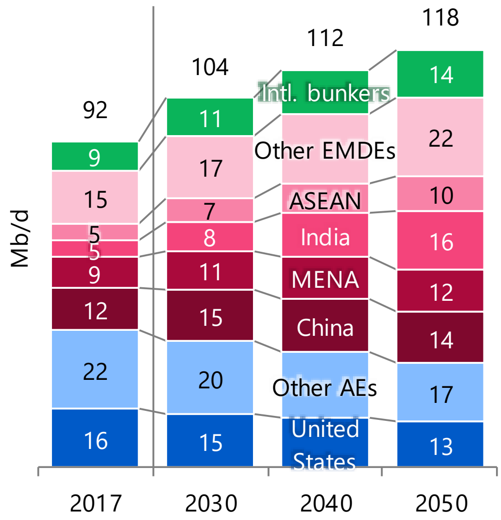
Note: EMDEs stand for Emerging Market and Developing Economies.

Figure 13 | World primary energy consumption [Reference Scenario]



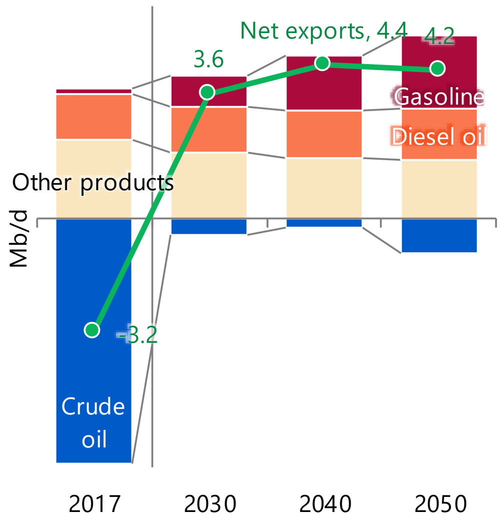
Oil will remain the largest energy source supporting 30% of global energy demand in 2050. Oil consumption at present 92 Mb/d will reach 118 Mb/d by 2050 (Figure 14). These increases are again driven by the Emerging Market and Developing Economies, and international bunkers. China overtakes the United States around 2030 to temporarily become the world's largest consumer. China's consumption will peak around 2040 and then decline to be replaced by India as the largest consumer in the late 2040s. The balance of oil supply and demand in the United States, currently the largest consumer and producer of oil, will shift to net exports on the back of a decline in crude oil imports and an increase in gasoline exports, with net exports expanding to 4.4 Mb/d in 2040 (Figure 15).

Figure 14 | Primary consumption of oil [Reference Scenario]



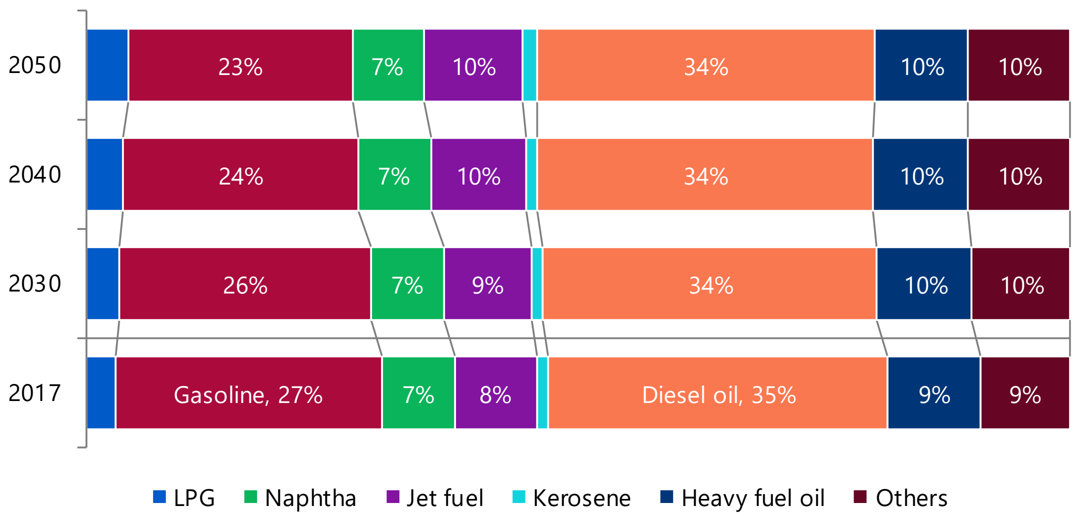
Note: AEs and EMDEs stand for Advanced Economies and Emerging Market and Developing Economies, respectively.

Figure 15 | Net oil exports of United States [Reference Scenario]



Gasoline and diesel oil, currently the most consumed petroleum products, will not be replaced by other fuels, but the share of gasoline, strongly affected by improvements in fuel efficiency and electrification of automobile, will gradually decrease (Figure 16). On the other hand, jet fuel oil for air transportation, benefits from globalisation, and will increase its share. Trends in the transport sector, including heavy fuel oil for ships, are important determinants of demand for petroleum products.

Figure 16 | World petroleum product consumption structure [Reference Scenario]



Note: Excludes own use at refineries

Increases in the consumption of natural gas will be larger than for any other energy source. Natural gas will surpass coal in the mid-2030s to become the second largest energy source after oil. However, the use of natural gas varies greatly among regions (Figure 17). It will become the largest energy source in the United States over the next 10 years, in the European Union (EU) by around 2040, and in countries outside of Asia in the coming years. Its consumption in the Advanced Economies — unlike up to IEEJ Outlook 2019 — follows a slow decreasing trend after 2040 (Figure 18).

Figure 17 | Primary consumption of natural gas and its share in primary energy consumption [Reference Scenario]

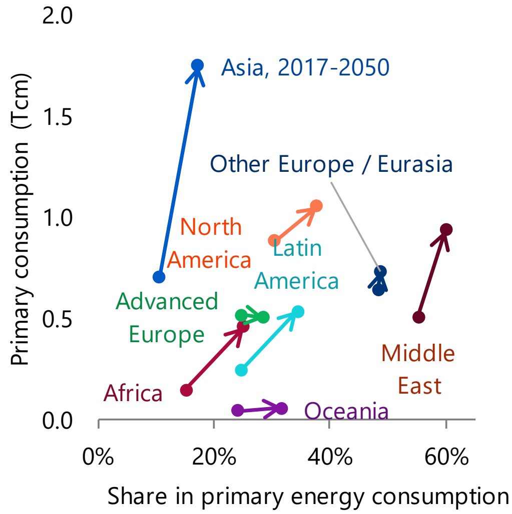
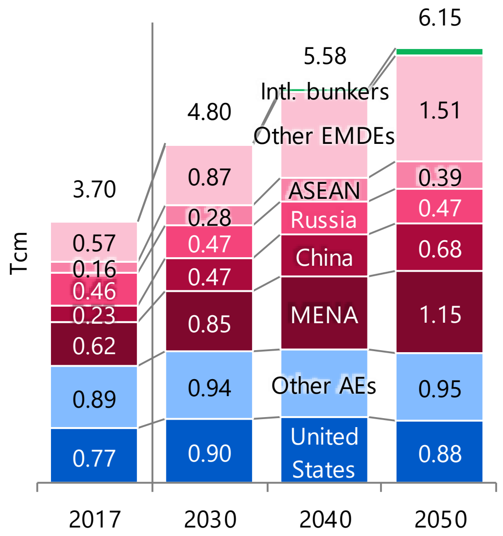


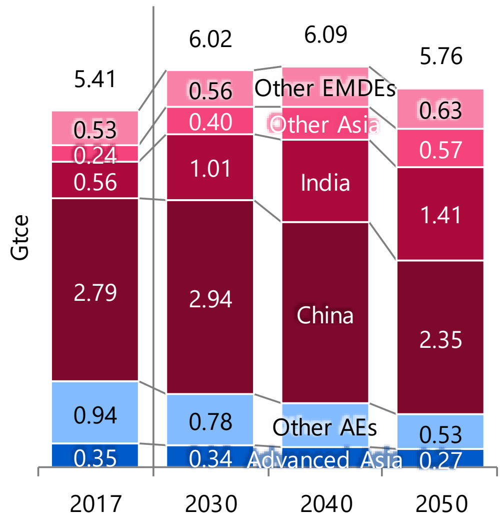
Figure 18 | Primary consumption of natural gas [Reference Scenario]



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

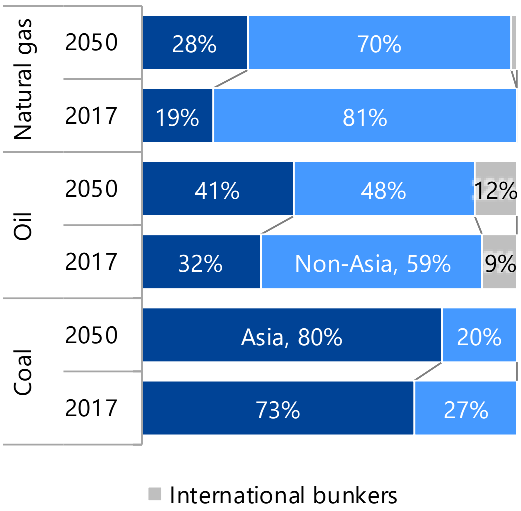
Coal consumption has been rather dull in recent years, but it will not continue to decline. Consumption will increase moderately to 6.0 Gtce in 2030 and 6.1 Gtce in 2040 (Figure 19). It is during the 2040s that a decreasing (slight decrease) trend is forming. The situation, however, varies considerably from region to region. In the Advanced Economies, coal consumption will continue to decline, whilst in China, the world's largest coal consumer, it will increase slightly until the mid-2020s before declining. On the other hand, in India and ASEAN, coal will meet much of their vigorous energy demand, and the dependence on coal in 2050 will be higher than at present in ASEAN. As a result, 80% of the world's coal will be consumed in Asia in 2050 (Figure 20).

Figure 19 | Primary consumption of coal [Reference Scenario]



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

Figure 20 | Share of primary consumption of fossil fuels [Reference Scenario]



Final energy consumption, which represents actual consumption by end users, will increase by 34% from the current 9.7 Gtoe to 13.0 Gtoe by 2050 (Figure 21). Oil will continue to be the largest energy source for final consumption, accounting for 41% of total final energy consumption in 2050, unchanged from today. In the road sector, which is the largest consumer of oil, the decline in oil consumption due to electric vehicles is attracting attention. However, even in 2050, six out of seven cars on the road will be equipped with oil tanks, namely, conventional internal-combustion vehicles, hybrid vehicles, and plug-in hybrid vehicles.

Electricity is preferred at all stages of economic development in each country and region, increasing more than any other energy source. Its share of final energy consumption will rise from 19% today to 26% in 2050. In the Emerging Market and Developing Economies, electricity consumption per capita increases due to improvements in the electricity infrastructure and higher incomes (Figure 22). Population growth accelerates the increase. Even in the Advanced Economies, total and per capita electricity consumption continue to increase and electrification continues despite a decrease in total final energy consumption. The share of electricity in final energy consumption will rise from the current 22% to 30%.

Figure 21 | World final energy consumption [Reference Scenario]

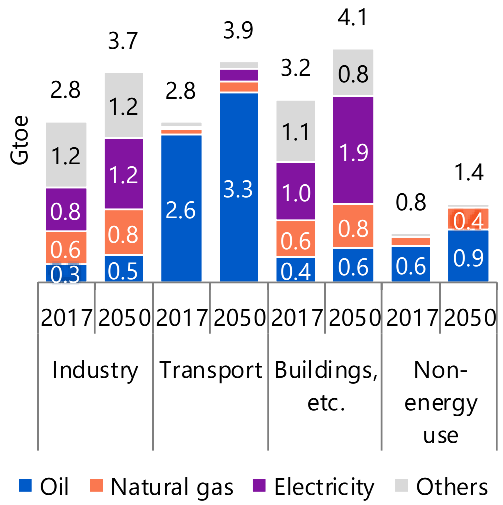
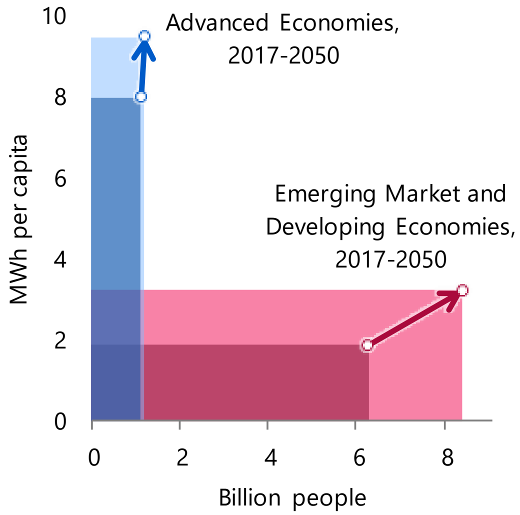


Figure 22 | Final consumption of electricity [Reference Scenario]



World electricity generated will increase substantially by 77% by 2050 along with the increase in electricity consumption (Figure 23). Consequently, more than half or most of the increase in primary consumption of non-oil energy sources by 2050 is attributable to power generation (Figure 24). In other words, what is used and how efficiently it is used in power plants will greatly influence the overall picture of energy consumption.

Figure 23 | Electricity generated [Reference Scenario]

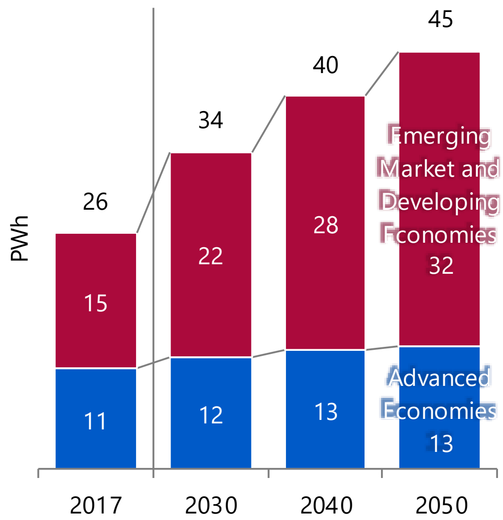
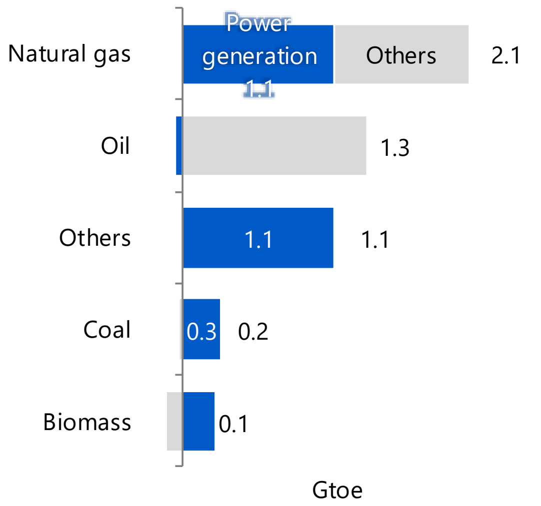


Figure 24 | Increase of world primary energy consumption [Reference Scenario, 2017-2050]

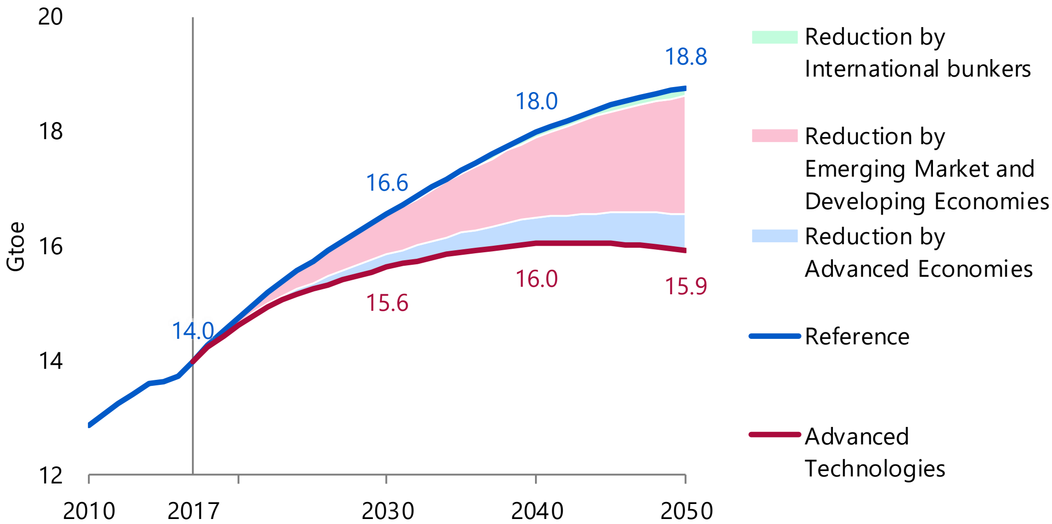


Advanced Technologies Scenario

- The Advanced Technologies Scenario assumes that energy conservation and low-carbon technologies will be deployed to the maximum extent in all countries of the world, taking into account the applicability and acceptability in the real world, in order to secure a stable energy supply, combat climate change and air pollution. In order to assume this maximum development, the possibility of introduction was examined for each technology, and a judgment was made from a professional viewpoint. Future consumption growth will be limited to 41% of the Reference Scenario, and energy savings in 2050 will be 2.8 Gtoe, equivalent to 20% of current consumption (Figure 25).

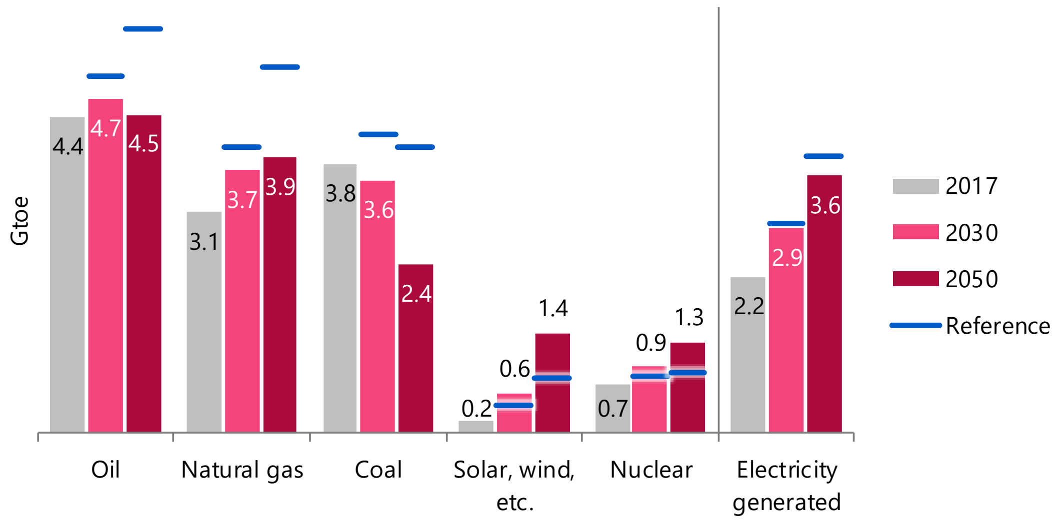
- It took 36 advanced economies to achieve 22% of the amount of energy savings realised in the scenario, in 2050. In contrast, China and India will each contribute near the same amount with 18% and 21%, respectively. The combined savings in the Emerging Market and Developing Economies will be 73%. Consequently, the future of the world consumption will largely depend on a wide range of energy conservation and low-carbonisation measures from the Emerging Market and Developing Economies. They have the potential to develop and introduce new technologies.

Figure 25 | World primary energy consumption



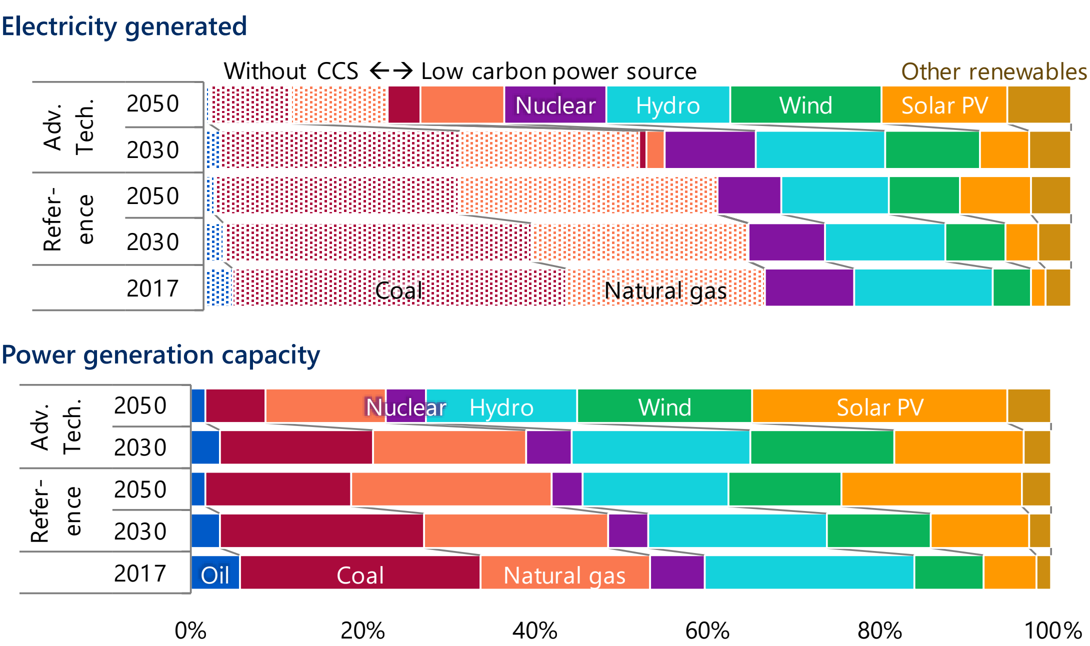
- All fossil fuels will decrease by 4.2 Gtoe from the Reference Scenario in 2050 (Figure 26). The most striking of these is coal, which is used mainly for power generation but is reduced due to the curtailment of power consumption and substitution to other energy sources. Natural gas peaks in the early 2040s and then declines slightly; this is different to IEEJ Outlook 2019, in which it would continue to grow even under the Advanced Technologies Scenario. Oil peaks after 2030 and falls by 25 Mb/d below the Reference Scenario in 2050.

Figure 26 | World primary energy consumption and electricity generated [Advanced Technologies Scenario]



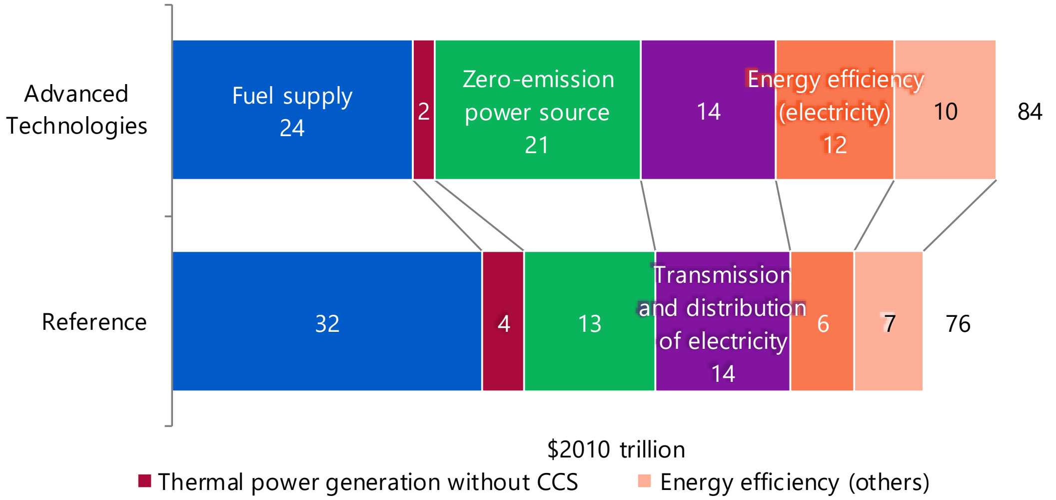
For non-fossil energy, solar and wind will increase by 0.6 Gtoe and nuclear by 0.4 Gtoe from the Reference Scenario. With the introduction of thermal power plants equipped with carbon capture and storage (CCS), the share of electricity generated from low-carbon power sources in 2050 is 79%, about twice as much as in the Reference Scenario (41%) (Figure 27).

Figure 27 | World power generation mix [Advanced Technologies Scenario]



To realise this energy supply and demand situation, it will be necessary to invest[3] a total of $84 trillion ($2010) by 2050 (Figure 28). Of this, $22 trillion will be spent on energy efficiency improvement. The transition to the Advanced Technologies Scenario requires higher capital cost (initial investments) for facilities and equipment used to supply or consume electricity. Achieving a low carbon society requires steady technological developments, cost reductions and appropriate long-term investments.

Figure 28 | World energy-related investments [cumulative from 2018 to 2050]



Global energy-related CO_2 emissions will peak in the mid-2020s and then begin to decline, reaching 25.3 Gt in 2050, a decrease of 17% compared to 2010 — a decrease of 54% in the Advanced Economies and an increase of 6% in the Emerging Market and Developing Economies. This is far from the target of halving greenhouse gas (GHG) emissions.

Challenges for energy transition

Possibilities and challenges of mass introduction of renewable energy

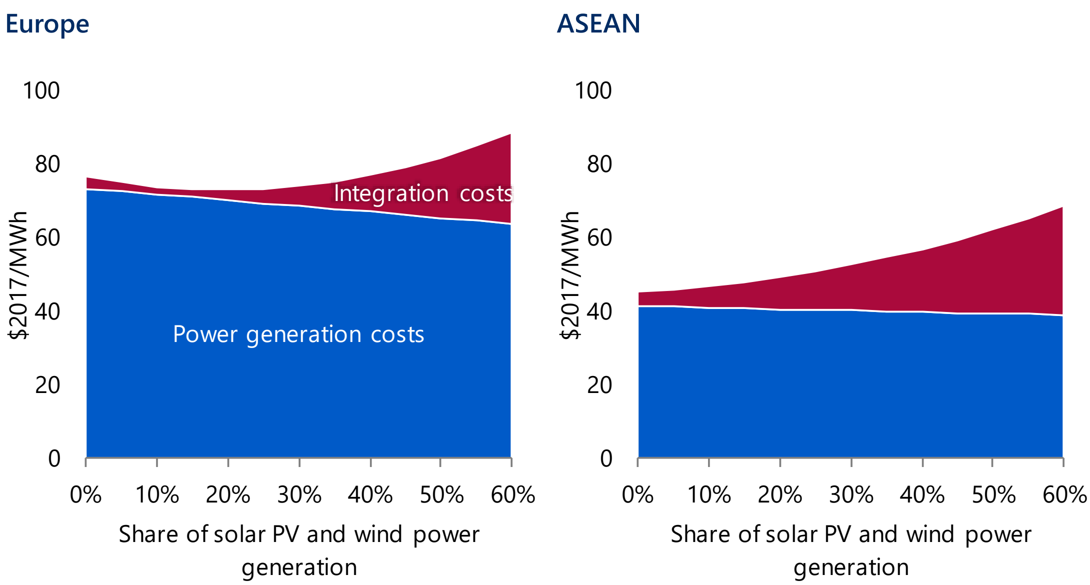
Solar PV and wind power generation is rapidly becoming widespread. With generating costs falling substantially in many countries, ambitious targets for the future have been set. However, sunshine and wind, as well as other renewable energy resources, are not globally evenly distributed. When considering the possibility of massive introduction, it is essential to take into account regional characteristics and regional differences — for instance, Europe is one of the best places for wind power generation while ASEAN is not suitable.

[3] It is an investment, not a non-revenue-generating expense or loss. Many of these investments are expected to be fully recovered if the market is functioning properly. However, if short-termism prevails in the market, energy investments that require a long return period without appropriate support will not attract sufficient funding, increasing the risk that necessary investments will not be made.

Another important aspect of the study of the feasibility of solar PV and wind power generation is the changes in economic efficiency associated with large-scale installations. Solar PV and wind power outputs are intermittent and cannot be controlled. Measures such as the introduction of batteries for storage, curtailment of excess output, and securing flexibility are required to maintain the stability of the power system. These additional costs will increase as the introduction of solar PV and wind power generation progresses. In other words, when evaluating the economic efficiency it is not enough to simply look at the levelised unit cost of generation, as has been done in the past, but other costs such as "integration costs" must be taken into account.

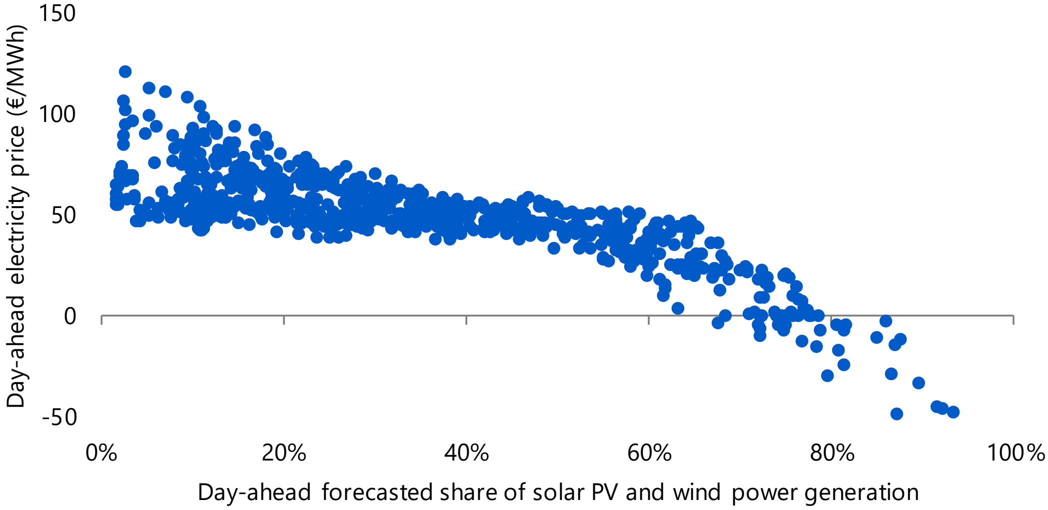
Regarding the relationship between the ratio of solar PV and wind power generation and the economic efficiency, in Europe and ASEAN in 2050, the unit power generation costs will decrease as the shares of these renewables increase (Figure 29) — this is because the unit cost of solar PV and wind power generation is assumed to be lower than that of conventional power generation. On the other hand, the integration costs increase "significantly" as the share of solar PV and wind power generation increases. Therefore, the total cost of electricity, which is the sum of the unit cost of power generation and the integration costs, is the smallest at relatively low shares of solar PV and wind power generation.

Figure 29 | Example of integration cost estimation [2050]



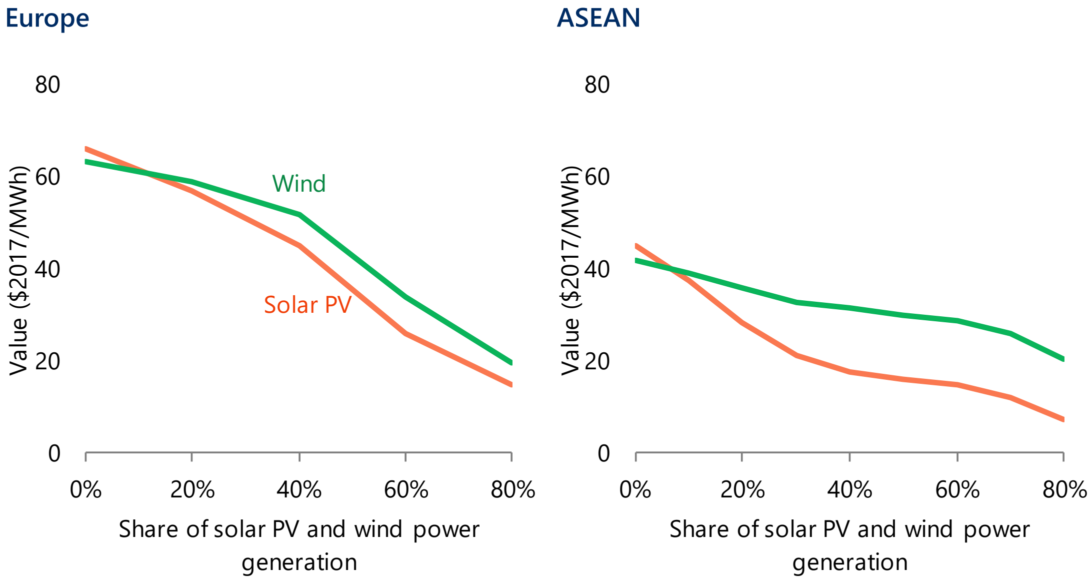
Solar PV and wind tend to generate regardless of the market price of electricity because fuel costs are irrelevant and maintenance costs are low. As the introduction of solar PV and wind power generation increases, wholesale electricity market prices decline and even become negative when the amount of electricity generated increases — for example, during the daytime on a sunny day or when the wind is favourable throughout the region (Figure 30).

Figure 30 | German solar PV and wind power generation share and electricity market price [January 2019 - July 2019]



Source: compiled from Entso-E data

Figure 31 | Estimation of the cannibalisation effect [2050]



If the installed capacity of solar PV is enormous, the market price of electricity during the daytime when solar PV generates electricity will be virtually zero, making it almost impossible for solar PV power generation facilities to be profitable. It is a form of the "cannibalisation" effect that solar PV power generation reduces the values[4] of other solar PV facilities (Figure 31). Not only an extreme drop in the price of electricity will impair

[4] Defined as revenue from sales of electricity divided by the amount of electricity generated.

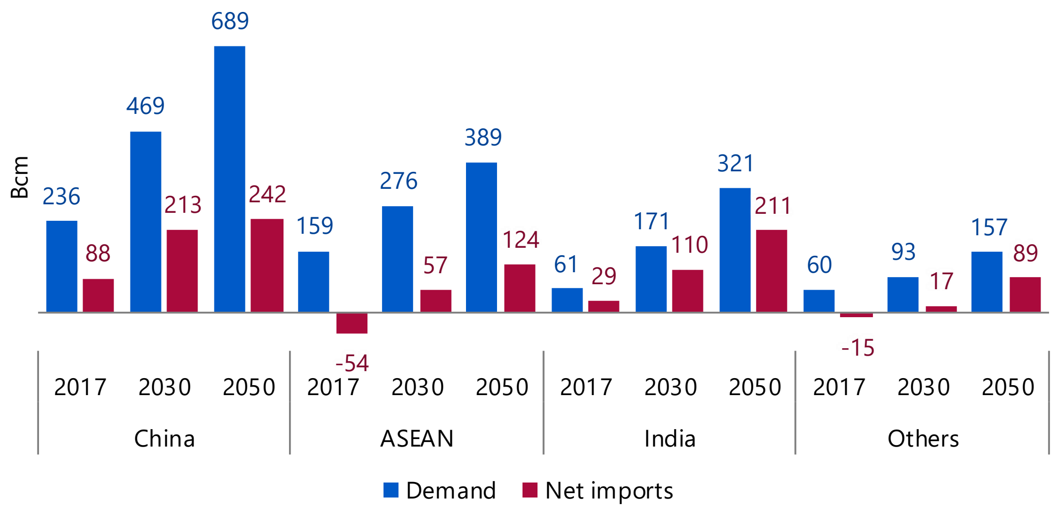
the profitability of other renewable power generation and thermal power generation, but it will result in underinvestment in the entire power supply. The introduction of solar PV and wind power generation must be promoted with sufficient policy measures while coping with the risk of power supply disruptions caused by natural variability.

Respice, adspice, prospice. (Examine the past, examine the present, examine the future)

LNG in Asia

In the Reference Scenario, natural gas demand in Asia will increase by 2.8% per year to 1 748 Bcm by 2050. Much will be met by imports, especially LNG, due to domestic resource constraints (Figure 32). However, because affordability of energy supply is critical part of energy policy in emerging LNG importers in Asia[5], LNG in the power generation sector in these countries will inevitably compete with inexpensive coal. LNG use in Asia is expected to be substantially lower than its potential demand.

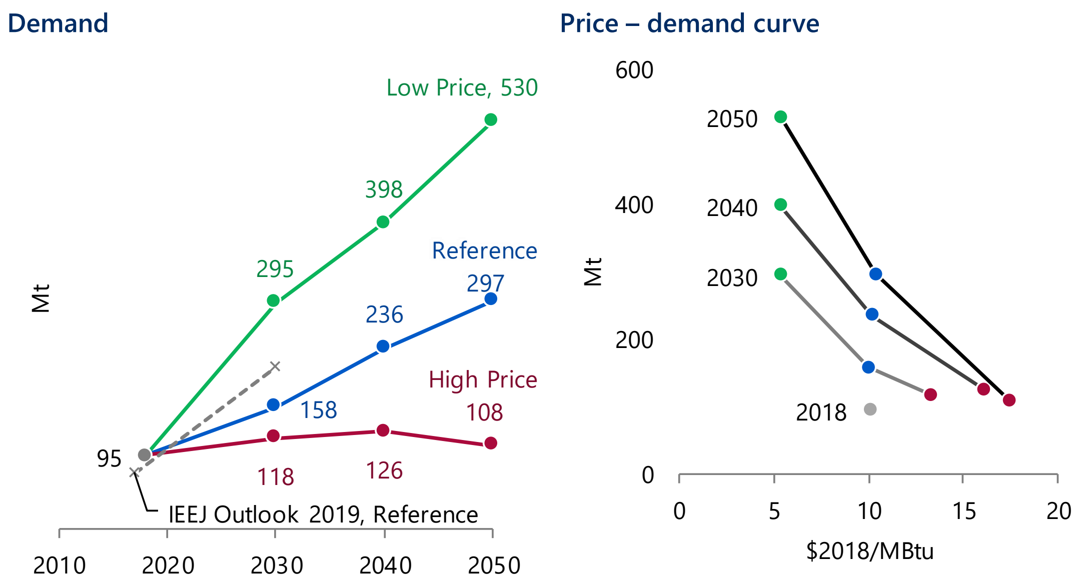
Figure 32 | Natural gas demand and net imports by emerging LNG importers in Asia [Reference Scenario]



In a High Price Case under which no new natural gas-fired power plants are assumed installed in Asia, LNG demand in emerging LNG importers in Asia will grow at an annual rate of only 0.4% through 2050 (Figure 33). Demand in 2050 is 108 Mt, 188 Mt or 63% less than in the Reference Scenario. On the other hand, in a Low Price Case where half of the increase in coal-fired power generation in Asia is assumed to be replaced by natural gas-fired power generation, the annual growth rate of LNG through 2050 is 5.5%, and the demand in 2050 is 530 Mt, which exceeds the current world LNG demand of 426 Mt. Above all, demand in ASEAN, India and other parts of South Asia will grow very rapidly. The difference in demand between the High and Low Price Cases in 2050 is 422 Mt.

[5] Emerging LNG importers in Asia include China, ASEAN, India, and other South Asian countries.

Figure 33 | LNG demand in emerging LNG importers in Asia



- It is necessary for LNG prices to remain low in order to enjoy the environmental and other benefits of an expanding LNG demand. It is crucial to ensure appropriate investments for supply side to meet the expanding demand, and it is important to achieve sound and sustainable market growth from both the supply and demand perspectives. For example, suppliers will need to reduce liquefaction and transportation costs while on the import side, it will be essential to promote measures such as infrastructure development, fuel switching to natural gas, reduction of subsidies for gas and electricity retail prices, and preferential treatment for natural gas-fired power generation, such as long-term power sales contracts are essential.

- As the importance of LNG in energy use increases in the future, interest in the security of LNG supply should intensify. Until now, the security of LNG supply to the traditional LNG importers of Asia has been mainly dependent on diversification of importing sources and routes and on the efficient use of natural gas. It has also been believed that long-term contracts themselves contribute to stable supply. In recent years, however, new factors and changes have emerged in the LNG market, such as the expansion of supply capacity and the increase in transactions that are quantitatively flexible. Under these circumstances, there are "deep" gas markets such as the United States, Europe, and China that have various means of supplying natural gas other than LNG, and there is the possibility of further enhancing the security of LNG supply in Asia through global coordination of flexibility in LNG with flexibility in natural gas market of these regions.

Table 1 | LNG supply security measures

Existing measures	**Diversification of importing sources and routes** Substitute imports from other countries when imports from one country cease
	Reducing demand through efficient use Reduce imports by improving efficiency, and reduce the scope of impact of disruptions and the amount of countermeasures taken
	Building stable relationships with sellers through long-term contracts Secure supply by establishing stable relationships with sellers through binding long-term contracts. Especially effective when demand is growing
New measures	**Creation and utilisation of a highly liquid Asian LNG market** Import as needed from highly liquid international markets
	Cooperation with other natural gas markets Establishing a system to adjust the supply-demand balance of LNG in coordination with these markets taking advantage of the characteristics of other natural gas markets such as Europe, China, and the United States

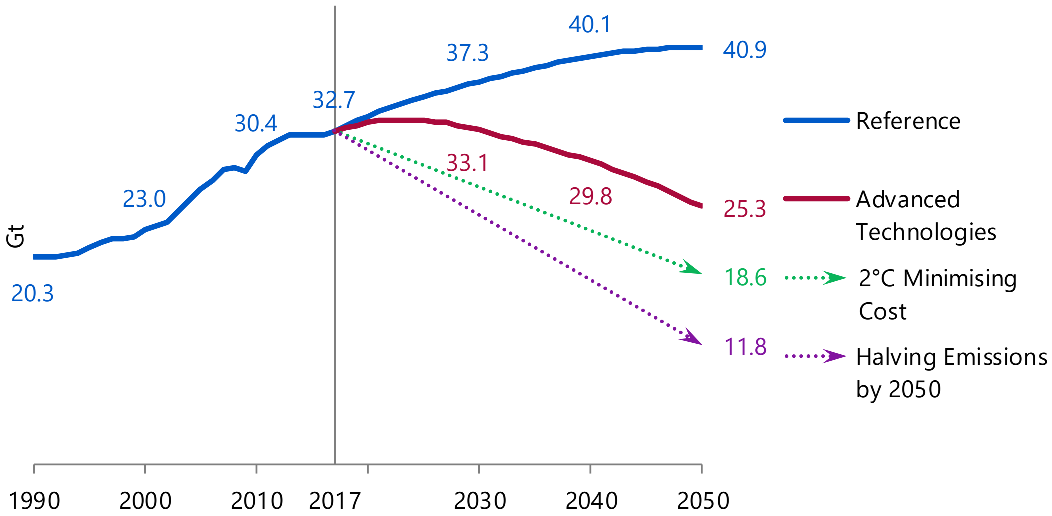
It is a common fault of men not to reckon on storms in fair weather. (Niccolò Machiavelli)

Pragmatic Approach to climate change issue

- Energy-related CO_2 emissions in the Advanced Technologies Scenario in 2050 are 25.3 Gt, down 17% from 2010 (Figure 34). However, in order to achieve the "2°C Minimising Cost Path[6]," in which the temperature rise from the latter half of the 19th century is held to 2°C in 2150, an additional 7 Gt reduction is required.
- In this context, "costs" (total costs) refer to not only payments for "mitigation" as typified by CO_2 reductions, but also to the total cost of "adaptation" to successfully address the impacts of climate change, plus "damage" (Figure 35). The "Pragmatic Approach" means taking the best possible measures to keep costs as low as possible while simultaneously coping with climate change and achieving economic growth in the future. Promoting the development and penetration of new and innovative technologies, such as zero-carbon hydrogen and carbon recycling technologies is essential.

[6] See IEEJ Outlook 2018

Figure 34 | World energy-related CO_2 emissions



Note: Halving Emissions by 2050 Path represents an emission path in the RCP2.6 scenario summarised in the fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC).

Figure 35 | "Costs" and their minimisation

Mitigation	Representative among mitigation measures is GHG emission reduction, including CCS to prevent GHG from being released into the atmosphere. Mitigation measures are designed to mitigate climate change.
Adaptation	An increase in temperature could cause a sea level rise, droughts, new disease epidemics, etc. Seawalls and reservoir construction, agricultural research, and disease prevention and treatment to respond to these problems are adaptation measures.
Damage	When mitigation and adaptation fail to sufficiently reduce the effects of climate change, damages from sea level rise, droughts or new disease epidemics may emerge

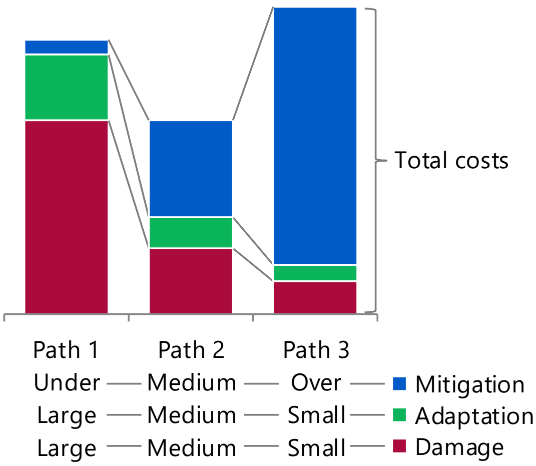


Table 2 | Technology development for ultra-long-term

Technologies		Description	Challenges
Technologies to reduce CO_2 emissions	Next generation nuclear reactors	Fourth-generation nuclear reactors such as ultra-high-temperature gas-cooled reactors (HTGR) and fast reactors, and small- and medium-sized reactors are now being developed internationally.	Expansion of R&D support for next generation reactors
	Nuclear fusion reactor	Technology to extract energy just like the sun by nuclear fusion of small mass number such as hydrogen. Deuterium as fuel exists abundantly and universally. Spent nuclear fuel as high-level radioactive waste is not produced.	Technologies for continuously nuclear fusion and confining them in a certain space, energy balance, cost reduction, financing for large-scale development and establishment of international cooperation system, etc.
	Space-based solar power (SBSP)	Technologies for solar PV power generation in space where sunlight rings abundantly above than on the ground and transmitting generated electricity to the earth wirelessly via microwave, etc.	Establishment of wireless energy transfer technology, reduction of cost of carrying construction materials to space, etc.
Technologies to sequestrate CO_2 or to remove CO_2 from the atmosphere	Hydrogen production and usage	Production of carbon-free hydrogen by steam reforming of fossil fuels and by CCS implementation of CO_2 generated.	Cost reduction of hydrogen production, efficiency improvement, infrastructure development, etc.
	CO_2 sequestration and usage (CCU)	Produce carbon compounds to be chemical raw materials, etc. using CO_2 as feedstocks by electrochemical method, photochemical method, biochemical method, or thermochemical method. CO_2 can be removed from the atmosphere.	Dramatic improvement in quantity and efficiency, etc.
	Bio-energy with carbon capture and storage (BECCS)	Absorption of carbon from the atmosphere by photosynthesis with biological process and CCS.	It requires large-scale land and may affect land area available for the production of food, etc.

Although research is underway around the world, there is insufficient knowledge on how to estimate the damage caused by climate change. IEEJ Outlook 2020 discusses some of the sources of uncertainty (tipping elements), such as “melting of the Greenland ice sheet” beyond a certain point, which can irreversibly shift the Earth from its current equilibrium state to another equilibrium state.

- The melting of the Greenland ice sheet, the melting of the Siberian permafrost, and the changing albedo of the Arctic Ocean do not significantly alter the picture drawn by cost minimisation approaches. However, it is desirable to continue the quantitative assessment of climate change issues based on the latest data at all times, including other tipping elements and other uncertainties.

Those that are most slow in making a promise are the most faithful in the performance of it. (Jean-Jacques Rousseau)

Part Ⅰ

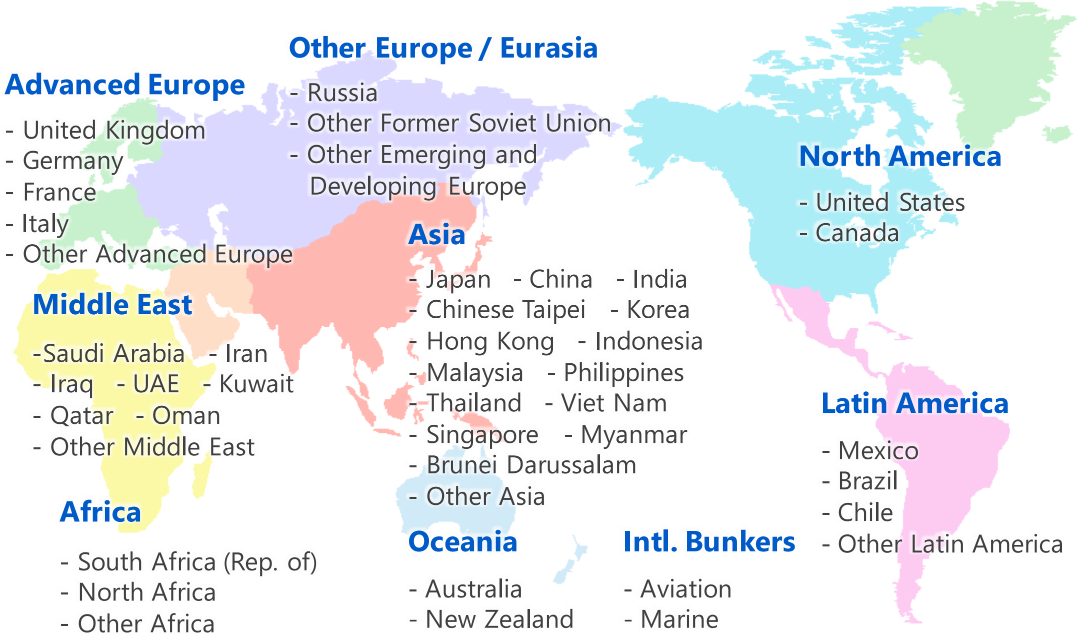
World and Asia energy supply/demand outlook

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 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



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 expected policies 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.

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.

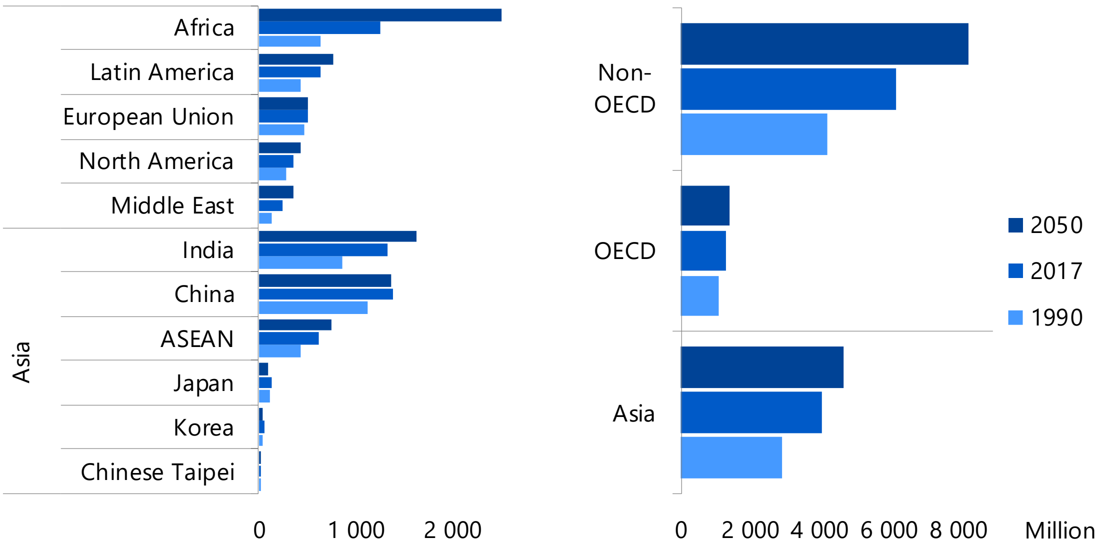
1.2 Major assumptions

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 population and economic growth among these factors are common to the two scenarios.

Population

In assuming population changes, we referred to the United Nations’ “World Population Prospects.” In many OECD countries, 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 therefore increasing the downward pressures on population. The TFR is trending down in non-OECD countries, in line with income growth and women’s increasing social participation. However, non-OECD 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 7.5 billion in 2017 (Figure 1-3).

Figure 1-3 | Population



Among OECD countries, 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. Among Asian countries, Japan's population has been decreasing since 2011 and will in the future post the fastest world's population decline. In 2050, Japan's population will decrease from the current level by some 20% to 105 million. In Korea, population will peak out in the middle of the 2030s.

Non-OECD population will continue increasing substantially, driven by Africa and populous countries. African population will continuously increase at a high annual rate of 2.1% 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. In non-OECD Europe, Russia has been plagued with a population decline since the collapse of the Soviet Union and will see a continued downward trend. East European countries will expand population moderately. In Asia, India will maintain a high population growth rate, with its population surpassing the Chinese population in the first half of the 2020s. By 2050, India will be the world's most populated country 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. As the young Chinese population concentrates in urban regions, the issue of rural population aging will grow more serious. Population in the Association of Southeast Asian Nations (ASEAN) will increase to 760 million in the 2050s, surpassing half the Chinese population size.

Asia will experience a continuous population increase, but its share of global population will fall slowly from 54% in 2017 to 48% in 2050.

Economy

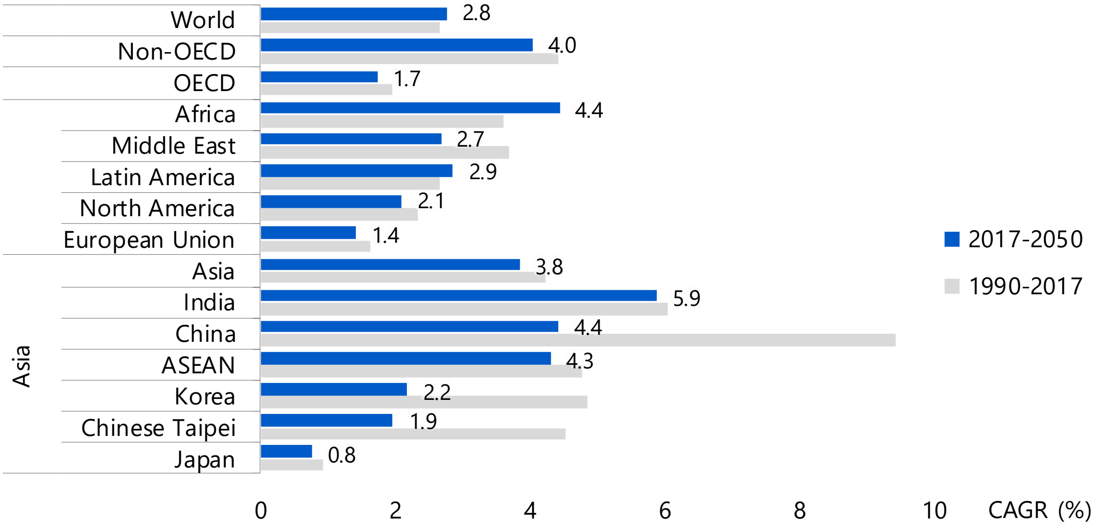
The world economy currently sees patchy growth rates accompanying the escalating U.S.-China disputes, the slowing Chinese economy and the growing geopolitical risks. Although concerns exist about policies of the Trump administration, the United States, the largest economy in the world, is growing remarkably among OECD countries, thanks to employment, income improvements and household tax cuts under a tax reform. The European economy, second to the U.S. economy, is plagued with the United Kingdom's potential exit from the European Union without agreement, while growth continues mainly in Eastern Europe. The Chinese economy, the third largest after the United States and Europe, sees uncertainties ahead of the planned U.S. tariff hikes for $270 billion worth of Chinese goods accounting for a half of Chinese exports to the United States. In response to the risk of a global economic slowdown, oil prices are falling, with the prolonged joint oil production cut exerting downward pressure on resource-rich countries including Russia as well as Middle Eastern and Latin American countries.

Over the medium to long term, many economies are likely to expand through population growth, productivity growth, technological innovation, appropriate fiscal and monetary policies and international collaboration. While Advanced Economies 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. Despite the fact that India is currently plagued with the negative effects of its structural reform and other policies that are slow to penetrate the economy, it will eventually grow at the world's fastest average annual pace of 5.9% over the outlook period, as these policies promote domestic demand expansion and foreign investment over the long term. China's economic slowdown will continue with its annual growth projected to be 4.4%. Africa will also grow at an average annual rate of 4.4%, 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 an abundance of surplus labour and low costs.

In consideration of the above-explained situation combined with the economic outlooks of the International Monetary Fund, the Asian Development Bank and other international organisations, as well as government economic development programs, we assumed the world's annual economic growth rate at 2.8% over the outlook period (Figure 1-4).

Figure 1-4 | Real GDP growth



International energy prices

Oil prices declined rapidly from the second half of 2014 as an economic slowdown in Europe and China was combined with a glut in the international oil market. The glut was caused by an oil production expansion in the United States and a decision against oil production cuts by the Organization of the Petroleum Exporting Countries (OPEC) to ease the supply-demand imbalance. The Brent crude oil futures price sank to $30.80 per barrel in January 2016. Later, oil prices continued to rise on OPEC's agreement of a coordinated oil production cut, despite further U.S. oil production expansion. After the United States withdrew from the Iran nuclear deal, in May 2018, the September 2018 average Brent oil price rose to around $80/bbl. In November 2018, as the United States announced a 180-day waiver from an Iran oil embargo for eight countries, such as Japan and China, and as concerns about a global economic slowdown triggered by the U.S.-China trade disputes further fuelled an oil price downtrend, the Brent oil price fell to close to $50/bbl. In response, OPEC and non-OPEC oil-producing countries at their meeting in December 2018 agreed to cut their production by 1.2 million barrels per day. Oil prices entered an uptrend again in January 2019 as U.S. Federal Reserve Chairman Jerome Powell offered to revise monetary policy in a manner to indicate a delay in interest rate hikes. In April, however, oil prices resumed their downtrend on high-level U.S. crude oil inventories and concerns about the escalation of the U.S.-China trade disputes. Geopolitical risks have grown since Iran's seizure of a British tanker in the Strait of Hormuz in July and attacks on oil facilities in eastern Saudi Arabia in September.

Reference Scenario

In the Reference Scenario, oil demand will keep on increasing in line with firm global economic growth. 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 both plagued with geopolitical risks. At the same time, marginal oil production costs will rise on a shift to small and medium-sized, polar and ultra-deep-sea oil fields where production costs are relatively higher. No tough restrictions on excessive money inflow into the futures market are likely to be introduced, indicating that speculative investment money could push up oil prices. Given these factors, oil prices are expected to fluctuate wildly over the short term and gradually rise over the medium to long term. The real oil price (in 2018 dollars) is assumed to increase to $95/bbl in 2030 and $125/bbl in 2050 (Table 1-1). Under an assumed annual inflation rate of 2%, the nominal price is projected to reach $120/bbl in 2030 and $236/bbl in 2050.

Table 1-1 | International energy prices

Real prices			Reference			Advanced Technologies		
		2018	2030	2040	2050	2030	2040	2050
Oil	$2018/bbl	71	95	115	125	80	80	80
Natural gas								
Japan	$2018/MBtu	10.1	9.5	9.7	9.9	9.3	9.3	9.3
Europe (UK)	$2018/MBtu	8.1	8.1	8.4	9.0	7.7	7.8	7.9
United States	$2018/MBtu	3.1	3.8	4.2	4.9	3.4	3.9	4.0
Steam coal	$2018/t	118	110	120	125	85	85	85

Nominal prices			Reference			Advanced Technologies		
		2018	2030	2040	2050	2030	2040	2050
Oil	$/bbl	71	120	178	236	101	124	151
Natural gas								
Japan	$/MBtu	10.1	12.0	15.0	18.6	11.8	14.4	17.5
Europe (UK)	$/MBtu	8.1	10.3	13.0	17.0	9.8	12.1	14.9
United States	$/MBtu	3.1	4.8	6.5	9.2	4.3	6.0	7.5
Steam coal	$/t	118	140	186	236	108	131	160

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

Natural gas prices will remain low in the United States. In line with development and production cost hikes, however, they will rise from the current record-low levels. Japan’s real natural gas import price is assumed to fall slightly from $10.1 per million British thermal units in 2018 before returning to the current level. Liquefied natural gas 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. Even at present, slack spot LNG prices are expanding their gaps with long-term contract prices for Asia, prompting some LNG buyers to review contract terms and conditions. However, LNG prices in Japan will still be higher than in Western countries due to limitations on cuts in liquefaction and maritime transportation costs.

Reflecting a loose supply-demand balance, coal prices in the past have been considerably low. Despite less resource constraints for coal, however, coal prices will rise over the long term due to growing Asian demand for coal for power generation and a rebound from the earlier low levels. Nevertheless, prices per thermal unit for coal will still be lower than those for oil or natural gas.

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. Coal prices will fall from their current levels as demand for coal for power generation will decrease sharply in Asia.

2. Energy demand

2.1 Primary energy consumption

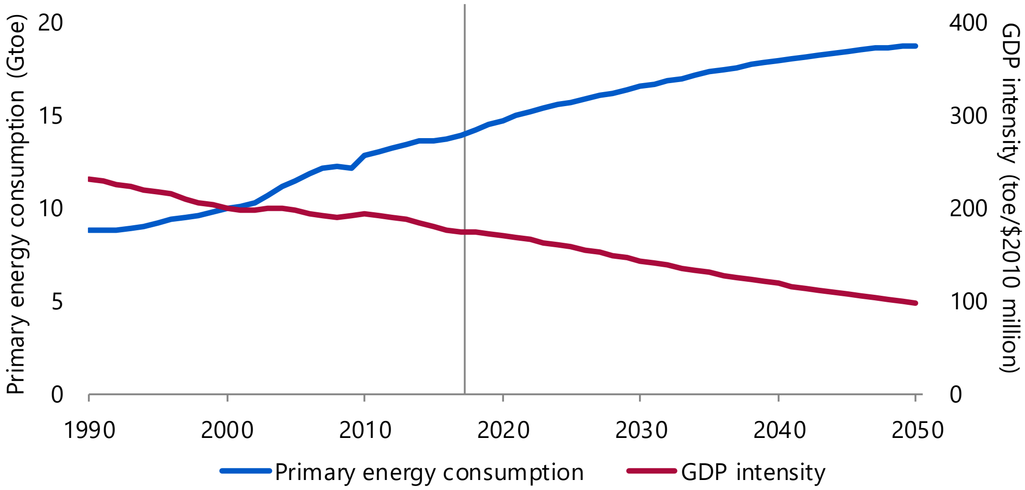
World

Despite robust economic expansion in the mid-2010s, the growth in global primary energy consumption decelerated. The average annual growth rate in energy consumption declined from about 1.4% for the years 2011-2014, to 0.5% for when the direct impact of the global financial crisis began to ease in 2015 and 2016. The energy-GDP elasticity[7], an indicator of energy consumption's relationship with economic growth, decreased substantially from 0.51 to 0.17. In 2017 and in contrast to the previous two years, however, energy consumption grew sharply by 1.9%. Asia accounted for more than 60% of the growth and China captured more than half of the Asian growth. As China completed steel, cement and other production adjustments accompanying its economic deceleration, its energy consumption began to accelerate. According to China's 2018 National Economy and Social Development Statistics Bulletin, its preliminary total energy consumption in 2018 posted an annual increase of 3.3%, slightly faster than the 3.1% reported for the year before.

In addition to China, there are many other regions with high growth potential, including India, ASEAN and Africa. These generally poor regions have yet to enjoy enough energy supply and their energy demand will progressively increase, reflecting economic development and living standard improvements. In the Reference Scenario where current social, economic, policy and technology introduction trends involving energy supply and demand are assumed to continue, global primary energy consumption will increase 1.3-fold from 13 972 million tonnes of oil equivalent (Mtoe) in 2017 to 18 757 Mtoe in 2050 (Figure 2-1). While the annual GDP growth stands at 2.7%, the energy consumption growth will be limited to 0.9% per year, due to energy efficiency improvement (the energy-GDP elasticity is projected at 0.34). Given the energy policies and energy-saving technologies assumed in the Reference Scenario, however, limiting energy consumption while promoting economic growth would be difficult, particularly in the Emerging Market and Developing Economies.

[7] Energy-GDP elasticity = Annual growth rates of primary energy consumption / annual growth rates of real GDP.

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



Asia with its huge population and high growth potential will greatly contribute to the increase in global energy consumption (Figures 2-2 and 2-4). Asia's share of global energy consumption will rise from 41% in 2017 to 46% in 2050. After driving global energy consumption growth so far, however, China's consumption growth will eventually decelerate and peak around 2040, due to its aging and decline in population. In its place, India and ASEAN, expected to experience high economic growth on the strength of relatively younger populations, will expand energy consumption substantially. Their share of global energy consumption will increase from a combined 11% at present to 21% in 2050, surpassing China's share. Following them, the Middle East and North Africa (MENA) which also feature younger populations, will sharply raise their energy consumption. Developed countries, including the United States and the European Union, will keep on reducing consumption during the same period.

Among energy sources, natural gas will feature the largest energy consumption growth, accounting for more than 40% of the growth (Figures 2-3 and 2-4). Natural gas will post a consumption increase of 1.6% per year due mainly to increasing demand in the power generation sector. It will replace coal as the second most consumed energy source after oil in the second half of the 2030s. Oil will log the second largest annual consumption growth at 0.8%, concentrating on the transport sector (including automobiles and international bunkers). Although oil will remain the most consumed energy source, its share of primary energy consumption will be continuously declining. Coal consumption will expand at first to meet a rise in the power generation sector, and will peak around 2040 because of policies aimed at holding down coal consumption to counter air pollution and climate change.

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

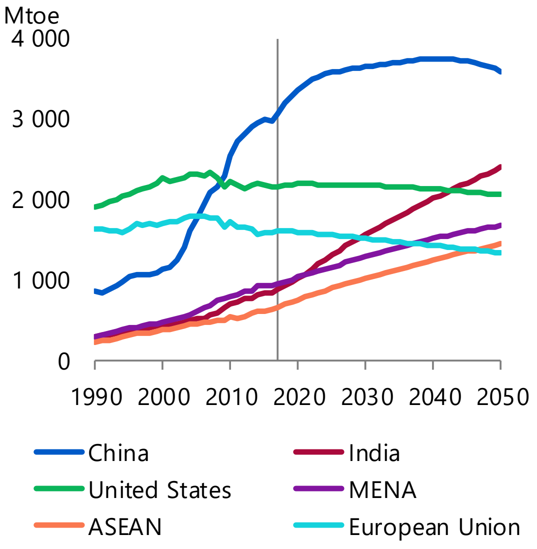


Figure 2-3 | Global primary energy consumption [Reference Scenario]

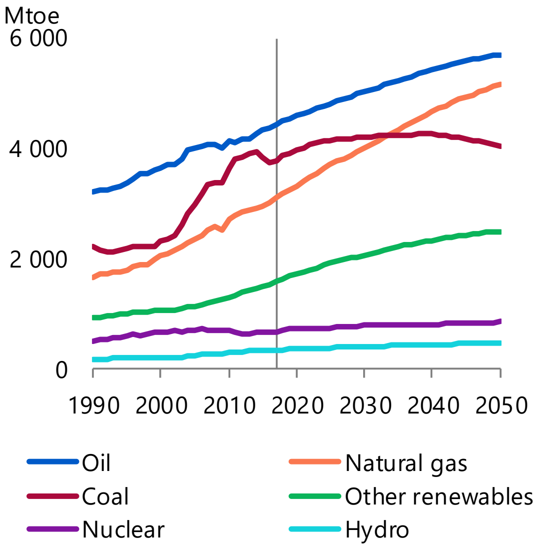
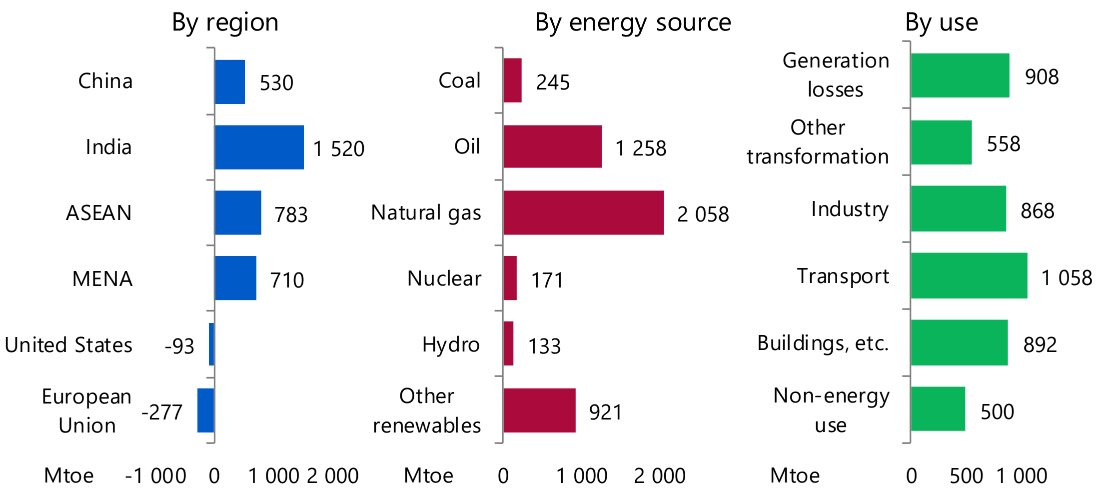


Figure 2-4 | Primary energy consumption growth [Reference Scenario, 2017-2050]



Non-fossil energy sources including nuclear and renewables will register an overall annual consumption increase of 1.2%. Solar energy, wind power, etc.[8] will increase at a high rate of 4.7% per annum, but their share of primary energy consumption will remain limited to only 4% in 2050. Fossil fuels (oil, coal and natural gas) will maintain their high share of primary energy consumption at 79% in 2050, against 81% at present. In recent years, many countries or regions have been seeking to reduce their dependence on fossil fuels to help mitigate climate change. However, even the European Union that has come up with ambitious climate change

[8] Including solar thermal and marine power generation.

countermeasures will still depend on fossil fuels for more than 60% of its primary energy consumption in 2050 (Figure 2-5). Meanwhile, India and ASEAN with their remarkable economic growth will progressively increase their dependence on fossil fuels.

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

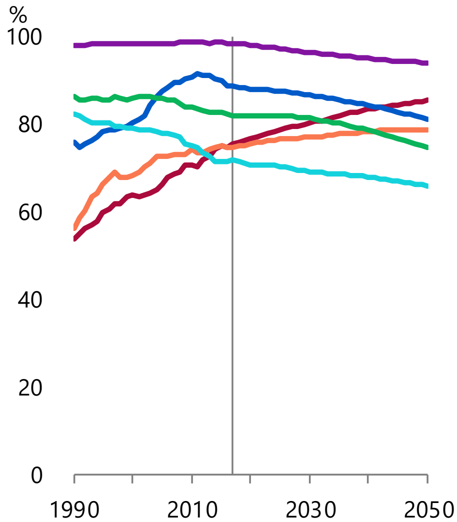
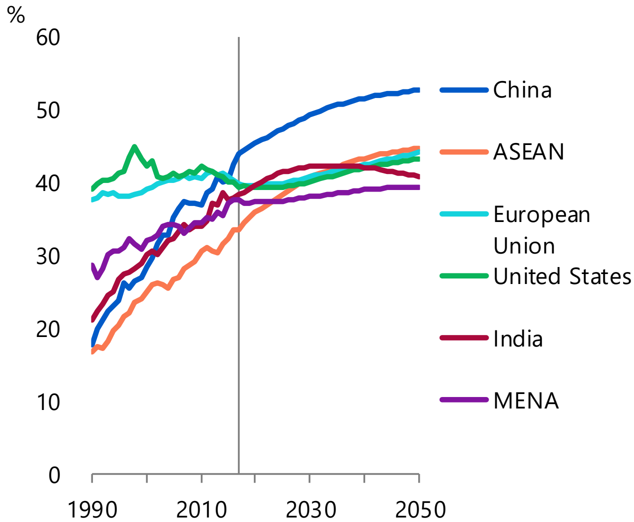


Figure 2-6 | Electrification rates (on the supply side) [Reference Scenario]



Among energy consumption sectors, transport will post the largest consumption growth (Figure 2-4) and automobiles, supported by income growth, will account for most of the energy consumption in the sector. Backed by increasing international travels and trade, international bunkers (aircraft and ships) will also boost energy consumption sharply at an annual rate of 1.8%, to account for 20% of the transport sector's consumption in 2050. The power generation sector will post the second largest growth in energy consumption. Energy consumption for power generation will increase reflecting higher demand for convenient electricity, the result of infrastructure developments in unelectrified regions and because of income hikes. The electrification rate on the supply side[9] will post rapid growth particularly in Asia (Figure 2-6). Improvements in power generation efficiency and reductions in power transmission and distribution losses will be required to limit the rise in the electrification rate on the supply side.

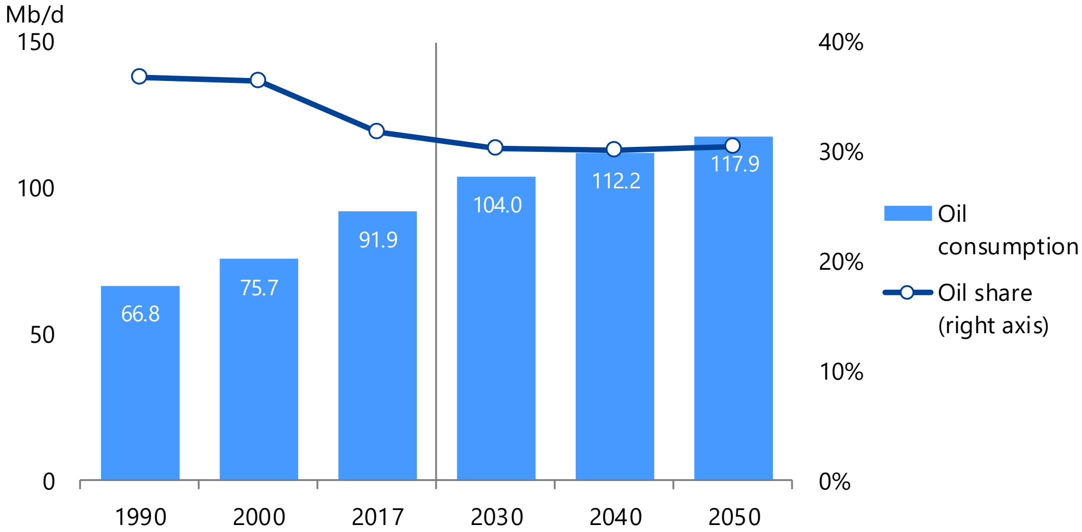
Oil

Oil consumption for transportation and petrochemical production will strongly increase through 2050. From 91.9 million barrels per day (Mb/d) in 2017, oil consumption will expand at an annual rate of about 0.8% to more than 100 Mb/d in the middle of the 2020s and to 117.9 Mb/d in 2050 (Figure 2-7). The consumption increase of 26.0 Mb/d will surpass the combined oil production (of about 25.0 Mb/d) of the United States and Saudi Arabia, the current world's first and second largest oil producers. Oil will remain the most consumed

[9] The percentage share of energy consumption for power generation in total primary energy consumption

energy source, though its share of primary energy consumption will fall from 32% in 2017 to 30% in 2050.

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



Oil consumption in the Advanced Economies peaked and started a downward trend in the mid-2000s. Consumption will continue to decrease at an annual rate of 0.8% (Figure 2-8) for the next 30 years. About 80% of the decline of 9.4 Mb/d from the present level to 2050 is attributable to a decline in automobile fuel consumption, indicating the great contribution of fuel efficiency improvements, including electrification. Meanwhile, oil consumption in the Emerging Market and Developing Economies will increase at a firm rate of 1.6% per year. Of the increase of 30.3 Mb/d through 2050, automobiles will account for 50%, non-energy use such as petrochemical feedstocks for 16% and the buildings sector and others[10] for 14%. Asia will command more than 40% of that volume. The Emerging Market and Developing Economies' share of global oil consumption will expand from 49% in 2017 to 64% in 2050.

Although China will replace the United States as the world's largest oil consumer around 2030, its oil consumption will peak in the 2040s. The decline will primarily be attributable to improvements in automobile fuel efficiency and a deceleration in the growth of vehicle ownership, due to a lower population. Between 2017 to 2050, oil consumption will rise 3.5-fold in India and 2.1-fold in ASEAN. As such, China, India and ASEAN will expand their oil imports to meet domestic consumption growth. The oil self-sufficiency rate will fall from 34% to 26% in China, from 18% to 3% in India and from 50% to 21% in ASEAN. As Asia includes many resource-poor countries and must heavily depend on oil imports, energy security will become an important challenge for the region.

[10] Residential, commercial, agriculture/forestry/fisheries and other sectors

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

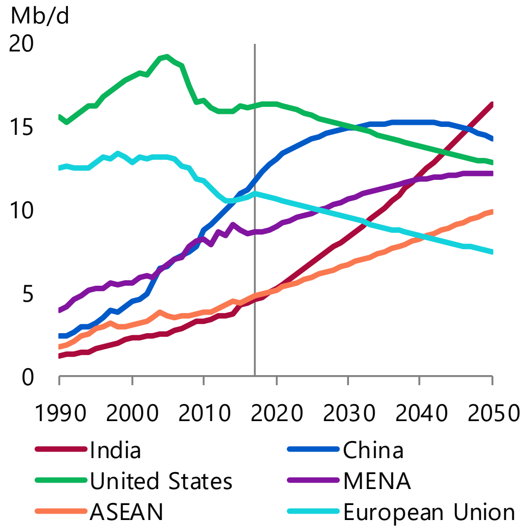
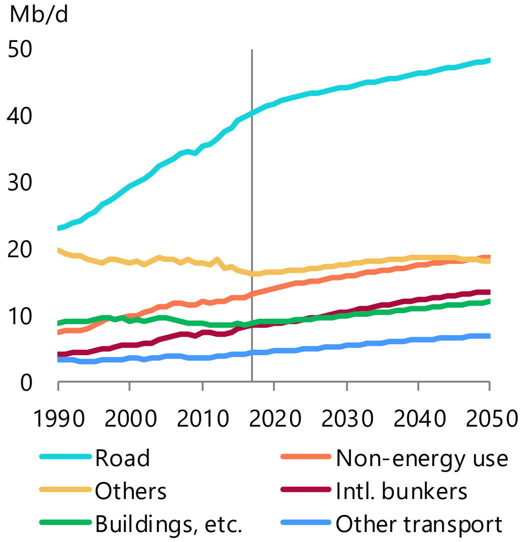


Figure 2-9 | Global oil consumption [Reference Scenario]



The transport sector, including vehicle fuel consumption, will account for nearly 60% of the oil consumption growth through 2050 (Figure 2-9). Global vehicle ownership[11] will double, with growth concentrated in the Emerging Market and Developing Economies. Despite fuel efficiency improvement, vehicle fuel consumption will increase by 7.8 Mb/d. Oil consumption by international bunkers (aviation and shipping) will increase at an annual rate of 1.4% due to the expansion of international travel and trade, capturing 12% of the 26 Mb/d total oil consumption. The non-energy use sector, including the petrochemical industry, will expand consumption by 5.4 Mb/d, commanding the second largest share of the growth. Given high demand for plastics and other petrochemical products, the petrochemical industry is expected to enjoy robust growth. In the buildings sector, oil consumption for water heating and cooking will increase substantially mainly in the Emerging Market and Developing Economies. In line with income improvement, mainly rural areas will switch to oil from coal and solid biomass fuel that are detrimental to health. In 2050, the transport sector will account for 58% of the world oil consumption (41% for automobiles and 12% for international bunkers), the non-energy use sector for 16% and the buildings sector and others for 10%.

Oil is positioned as a strategic good because of its importance. How to secure stable oil supplies at affordable prices is a key energy security challenge, particularly for oil importing countries. Therefore, the rising dependence on oil imports that accompanies vehicle fuel consumption growth is becoming a painstaking problem. Moreover, air pollution has become a serious issue in China, India, Southeast Asia and other regions where the number of automobiles have

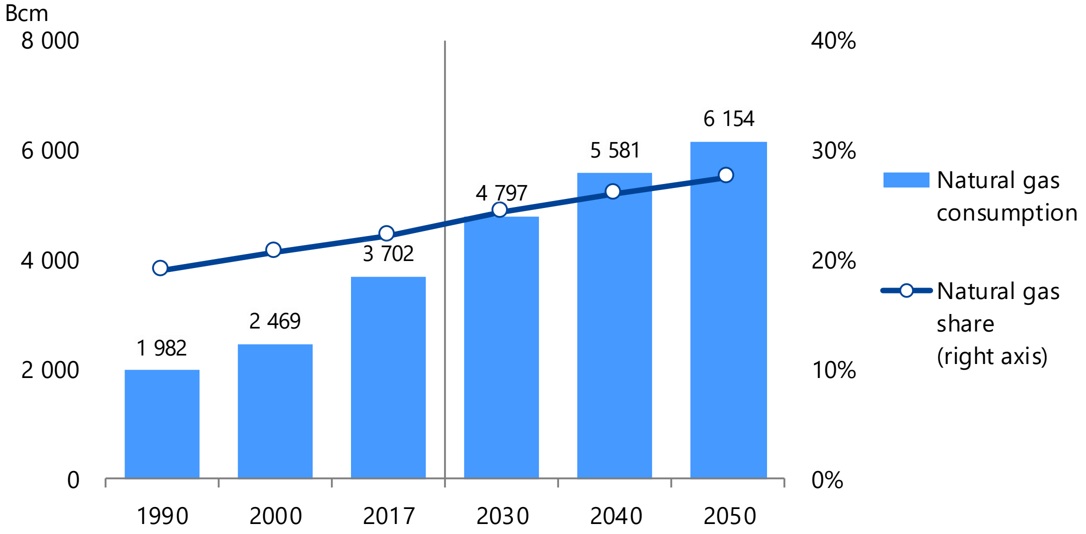
[11] The downward pressure of progress in car sharing services on vehicle ownership growth is not considered here. Unless transport demand changes, the pressure will be neutral to vehicle fuel consumption due to a rise in the operating rate of car sharing services. However, the effect of car sharing on transport demand and the impact of growth in automatic driving are uncertain and should be studied in the future.

increased rapidly. Given the need for climate change countermeasures, the reduction of vehicles' oil consumption is an urgent challenge. One of the key measures to reduce such oil consumption is the diffusion of electric vehicles accompanied by low-carbonisation of the power generation sector. France and the United Kingdom have come up with plans to ban sales of gasoline and diesel vehicles from 2040. Some other countries including China and India are also considering similar regulations. If these policies gain momentum, oil consumption growth may decelerate or become negative (see the IEEJ Outlook 2018 for the impact of such development).

Natural gas

Natural gas will record the largest consumption growth among all energy sources due to the power generation sector's switching from coal to natural gas and an increase in final natural gas consumption. Natural gas consumption will expand 1.7-fold from 3 702 billion cubic metres (Bcm) in 2017 to 6 154 Bcm in 2050 (Figure 2-10). Natural gas will increase its share of primary energy consumption from 22% in 2017 to 28% in 2050, becoming the second largest energy source after oil.

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



The Emerging Market and Developing Economies will account for 88% of the 2 452 Bcm natural gas consumption growth between 2017 and 2050 (Figure 2-11) and their share of global natural gas consumption will expand from 55% to 68%. Among the Emerging Market and Developing Economies, China, India, and MENA will particularly post remarkable growth. Over the next 33 years, natural gas demand will expand by 452 Bcm in China and by 261 Bcm in India. The Middle East, with its limiting domestic oil consumption, is promoting the utilisation of domestic natural gas to earn foreign currencies on oil exports and is encouraging the expansion of petrochemical plants using natural gas to generate jobs. Despite U.S. gas consumption increasing by 150 Bcm by 2040, a noteworthy rise among the Advanced Economies, consumption will peak and turn downward afterwards. In the United States, natural gas will surpass oil consumption, becoming the largest energy source. MENA consumption will match and exceed U.S. consumption in the mid-2030s. While the European Union's consumption will rise and peak in the mid-2030s, Japan's natural gas consumption will decline by 34 Bcm between now and 2050.

Among the different users, natural gas consumption for power generation will increase substantially due to technological progress, economic efficiency and environmental considerations. In other words, natural gas will growingly be used for power generation as oil-fired power generation costs more and coal faces environmental problems. As a result, the power generation sector will account for more than half of the natural gas consumption growth (Figure 2-12) and natural gas will expand its share of global power generation to 30% in 2050, surpassing the share for coal. The industry sector will post the second fastest growth in natural gas consumption, after the power generation sector. In view of convenience and environmental considerations, the sector will growingly switch from oil and coal to natural gas. China will account for more than 80% of natural gas consumption growth in the buildings sector and others as it rapidly switches to city gas from solid fuels such as coal and fuel wood that cause indoor and outdoor air pollution.

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

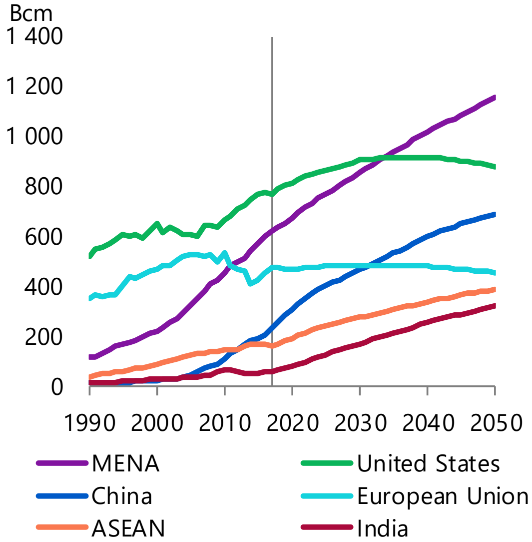
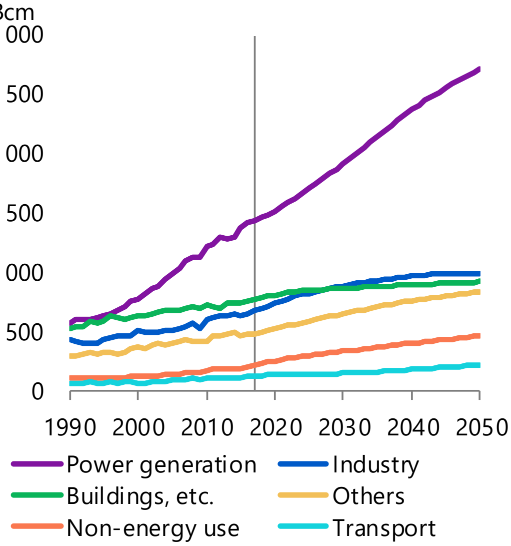


Figure 2-12 | Global natural gas consumption [Reference Scenario]

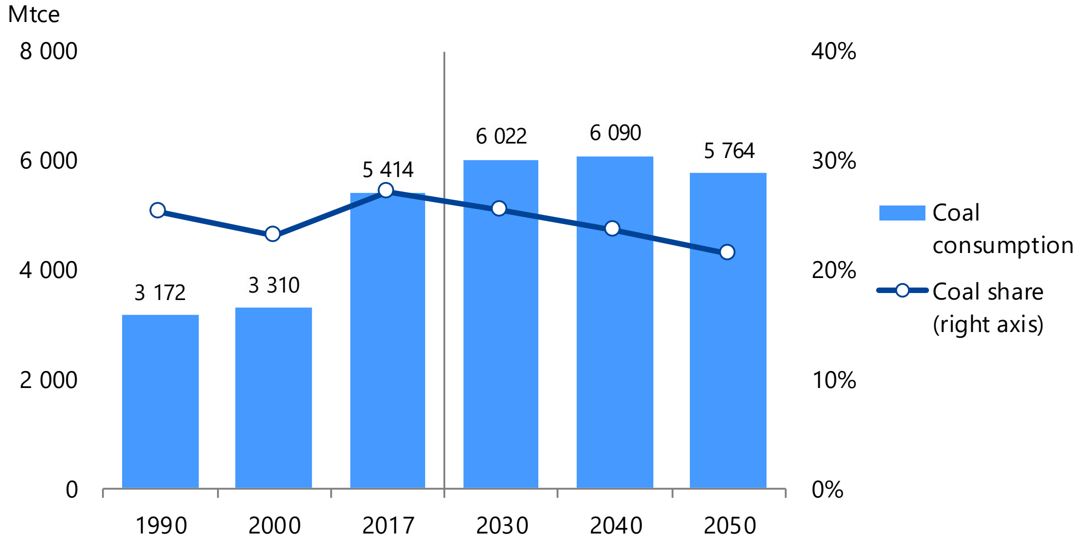


Coal

Coal's consumption trend will differ from those for oil and natural gas. As air pollution, climate change and other coal-related environmental problems encourage the Advanced Economies to switch away from coal to other energy sources, total coal consumption will post a moderate growth relative to oil and natural gas consumption before peaking around 2040 (Figure 2-13). Global coal consumption will increase by 6% from 5 414 million tonnes of coal equivalent

(Mtce[12]) at present to 5 764 Mtce in 2050 and most of the increase will be for power generation. Coal's share of primary energy consumption will shrink from 27% in 2016 to 22% in 2050.

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



As steel and cement production in China is peaking, industrial coal consumption will plunge by about 40% by 2050. Due to increasing consumption for power generation, however, China's coal consumption will moderately increase until the mid-2020s before turning downward later. Chinese coal consumption which currently accounts for 52% of world consumption, will drop to 41% in 2050. In the Advanced Economies including the United States and European Union members, increasing taxes on coal-fired power plants, enhanced regulations on CO_2 and mercury emissions, competition from natural gas and other factors will force coal-fired power generation to decline. While primary coal consumption in the Advanced Economies declines by 491 Mtce or 38% by 2050, consumption in the Emerging Market and Developing Economies will increase by 841 Mtce or 20%. In contrast to China reducing its coal consumption, India and ASEAN will expand theirs and Asia will account for 87% of the consumption growth in the Emerging Market and Developing Economies. India, which overtook the United States in coal consumption in 2015, will post a greater increase than any other country (Figure 2-14).

As coal resources are readily found in many regions of the world, it can be supplied in a far more stable manner than oil or natural gas that are found in a limited range of regions. Mainly due to lower prices, consumption will increase in the power generation sector at an annual rate of 0.3% through 2050, posting a total rise of 1.1-fold from the present level (Figure 2-15). All the increase occurs in the Emerging Market and Developing Economies. In an attempt to address climate change, however, international financial and investment institutions are considering banning loans for coal-fired power generation projects. In the Emerging Market and Developing Economies that have less capacity to raise funds on their own, coal-fired power

[12] 1 tce = 0.7 toe

plant investments assumed in the Reference Scenario could have been overestimated (see the IEEJ Outlook 2019).

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

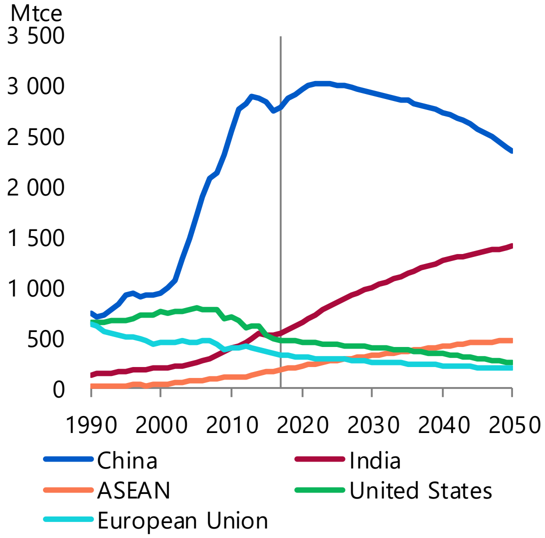
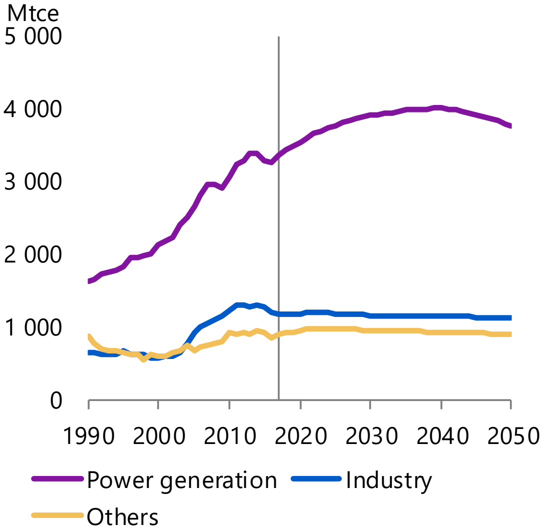


Figure 2-15 | Global coal consumption by sector [Reference Scenario]



Non-fossil energy

Although non-fossil energy consumption will expand 1.5-fold by 2050, its share of primary energy consumption will rise only slightly from 19% in 2017 to 21% in 2050. Power generation accounts for 55% of the non-fossil energy consumption at present, with nuclear and hydro capturing the largest share for power generation (Figure 2-16). Meanwhile, non-fossil energy consumption for heating purposes[13] mostly represents solid biomass including firewood and livestock manure used in rural areas of developing countries (Figure 2-17).

All future non-fossil energy consumption growth will be for power generation. Solar, wind and other non-hydro renewables[14] will post particularly large consumption growth among non-fossil energy sources. Their consumption will increase more than five-fold from 139 Mtoe in 2017 to 728 Mtoe in 2050. However, their share of primary energy consumption will remain very small, standing at 4.2% in 2050. Meanwhile, growth of nuclear and hydro, now dominating the non-fossil energy consumption, will be limited due to nuclear policy modifications and constraints on development sites. Their share of non-fossil energy consumption for power generation will decline from 72% in 2017 to 49% in 2050.

Heat derived from non-fossil energy consumption will grow little before turning downward around 2030. This is because rural areas accounting for most of such non-fossil energy consumption for heating will switch from traditional biomass to electricity and gas, in line with living standard improvement. Heat from solid biomass consumption will lower its share of

[13] Including consumption for chemical production

[14] Solar, wind and other non-hydro renewables cover solar photovoltaics, wind power generation, solar thermal power generation and marine power generation.

direct heat demand in final energy consumption from 12% at present to 8% in 2050. Liquid biomass fuels and biogas consumption mainly for automobiles and buildings will double through 2050. The absolute volume of such consumption, however, will be limited to only 1.7% of direct heat demand.

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

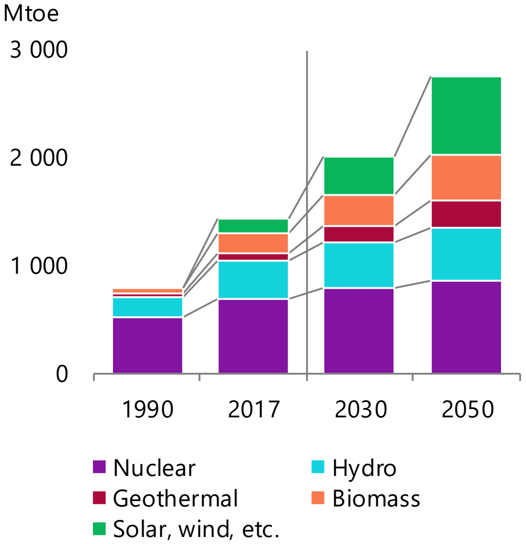
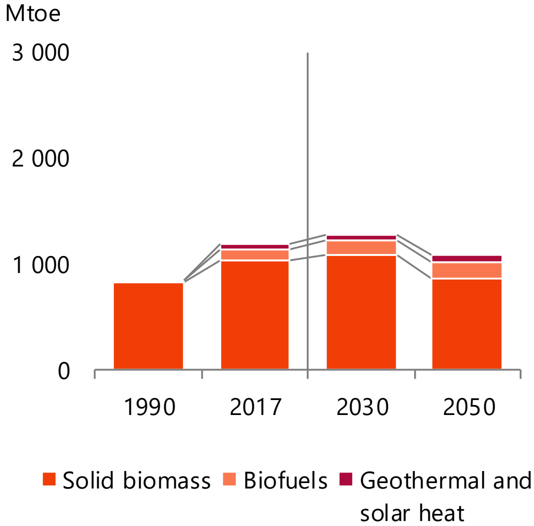


Figure 2-17 | Non-fossil fuel consumption for heat utilisation[15] [Reference Scenario]



Asia

Asian primary energy consumption will grow at an annual rate of 1.3% from 5 669 Mtoe in 2017 to 8 585 Mtoe in 2050 in line with robust economic growth (Figure 2-18). The increase of 2 916 Mtoe will account for more than 60% of global energy consumption growth. Asia's share of global primary energy consumption will increase from 41% in 2017 to 46% in 2050.

China's energy consumption that currently accounts for 54% of Asian consumption will decelerate its growth to peak around 2040, due to its aging and declining population. In its place, India and ASEAN, which are expected to continue robust economic growth on the strength of relatively younger population, will expand energy consumption substantially. India will account for 52% of Asian consumption growth and ASEAN for 27%. Among ASEAN members, Indonesia and Viet Nam will experience rapid growth, accounting for a combined 65% of ASEAN energy consumption growth (Figure 2-19). Meanwhile, energy consumption in mature economies such as Japan, Korea and Chinese Taipei will decrease or turn downward by the mid-2020s at the latest. The gravity centre of the Asian energy market will shift from East Asia to Southeast and South Asia in a clockwise fashion.

[15] Including petrochemical feedstocks

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

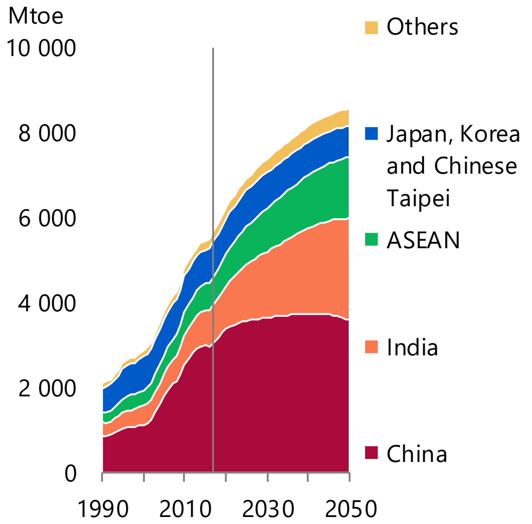


Figure 2-19 | ASEAN primary energy consumption [Reference Scenario]

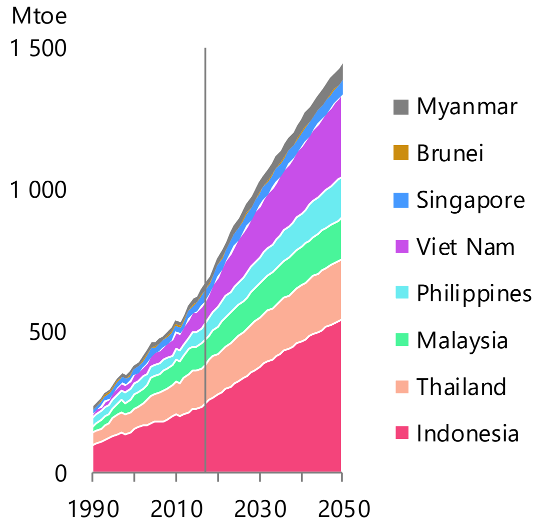
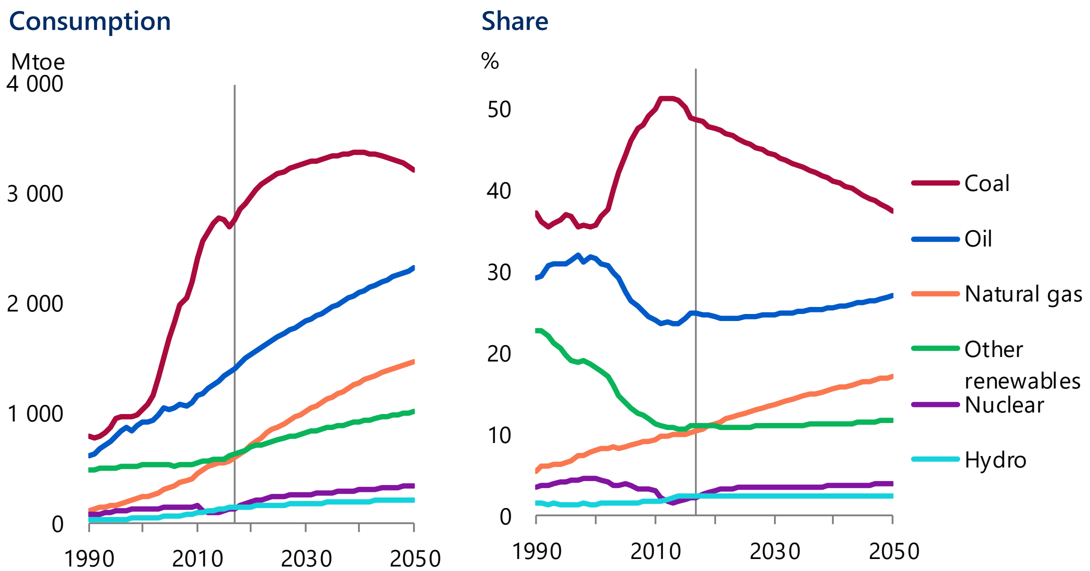


Figure 2-20 | Asian primary energy consumption [Reference Scenario]



Coal currently accounts for 49% of Asian primary energy consumption, followed by 25% for oil and 10% for natural gas. Asia thus depends on fossil fuels for a combined 84% of primary energy consumption and its dependence will only slightly decline to 82% by 2050. Among fossil fuels, coal will reduce its share by 11 percentage points, while natural gas expands his by 7 points, mainly because the power generation sector will favour the more environment friendly natural gas. Of non-fossil fuel consumption, nuclear will increase 2.6-fold from a small level and non-biomass renewables 2.9-fold. On the other hand, traditional biomass consumption including fuel wood and livestock manure will be halved.

Asian oil consumption will expand from 29.1 Mb/d in 2017 to 47.9 Mb/d in 2050 (Figure 2-21). The average annual growth rate will be 1.5%, twice as high as the global growth of 0.8%. Oil consumption will increase in the transport sector (up 11.4 Mb/d), the non-energy use sector (up 3.5 Mb/d) and the buildings sector (up 2.2 Mb/d). The three sectors will account for 90% of total oil consumption growth in Asia. India will capture more than 60%, the largest share of the Asian oil consumption growth, followed by 27% for ASEAN and 14% for China. Oil consumption will decrease in Japan, Korea and Chinese Taipei. Asia will command more than 70% of global oil consumption growth, raising its share of global oil consumption from 32% to 41%. As Asia expands oil imports to meet such consumption growth, its oil self-sufficiency rate will fall from the current 26% to 14% in 2050. Because about 80% of the oil for international transactions is consumed in Asia, Asian countries' presence in the international market will increase further.

Asian natural gas consumption will increase 2.5-fold from 708 Bcm in 2017 to 1 753 Bcm in 2050, with an annual growth averaging 2.8%, much faster than for oil consumption (Figure 2-22). The power generation sector accounts for 43% of natural gas consumption and will capture about half of the future consumption growth. Asia's share of global natural gas consumption will expand from 19% in 2017 to 28% in 2050. China will make great contributions to the Asian natural gas consumption growth, boosting its consumption about three-fold from the present level to 684 Bcm in 2050, accounting for 11% of global consumption. Indian natural gas consumption, though declining since 2011 before turning upward in 2015, will increase mainly for power generation in the future. Japan, currently a major LNG importer, will continue to reduce natural gas consumption from its peak in 2014 due to continuous energy efficiency improvements and the expansion of non-fossil energy consumption.

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

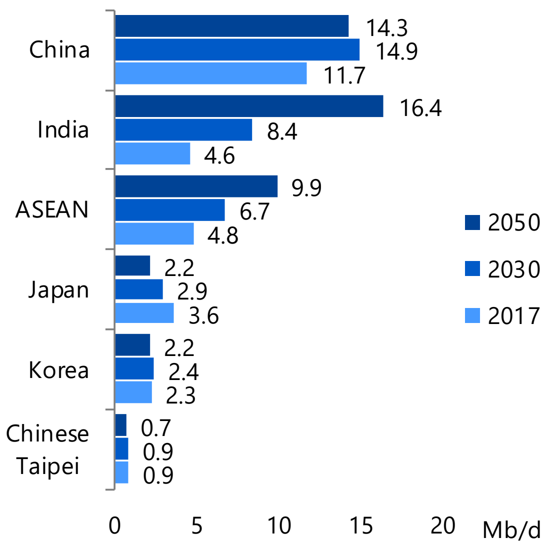
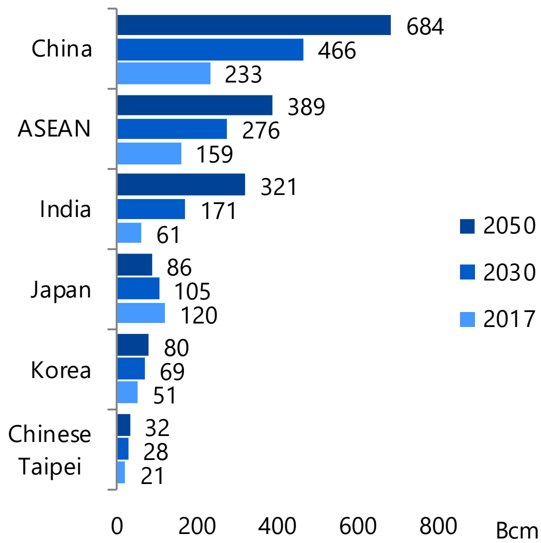


Figure 2-22 | Asian natural gas consumption [Reference Scenario]



In line with the Asian natural gas demand growth, LNG procurement will increase substantially. To achieve stable and low-cost natural gas supply, Asian countries should further negotiate with resource-rich countries and promote market design and other initiatives. They should also develop or enhance measures against supply disruptions, including LNG stockpiling and the installation of pipelines for inter-regional distribution of supply (see Chapter 7 LNG in Asia).

Coal consumption in Asia will rise from 3 944 Mtce in 2017 to 4 602 Mtce in 2050. As the growth rate will be the lowest among energy sources, the coal's share of primary energy consumption will shrink from 49% in 2017 to 38% in 2050. Nevertheless, coal will remain the largest energy source in Asia. While coal consumption will experience robust expansion in India and ASEAN because of their growing economies, consumption in China, currently accounting for 70% of the Asian coal consumption, will peak in the mid-2020s. The industry and buildings sectors will considerably reduce coal consumption, but the power generation sector will by far more than offset the reduction. Although large-scale fossil fuel-fired power generation will be required to meet a robust electricity demand, the construction or expansion of coal-fired power plants often lacking considerations to climate change or air pollution should be avoided. Given that Asia is endowed with rich coal resources, the region will have to sensibly consider the effective use of coal for economic and energy security reasons.

Asian non-fossil energy consumption will rise from 903 Mtoe in 2017 to 1 571 Mtoe in 2050, expanding its share of total primary energy consumption by 2 percentage points to 18%, from the present level. Of the growth, renewables other than biomass will account for 73%, followed by 32% for nuclear. Asia's share of global renewable energy consumption other than biomass will expand from 43% in 2017 to 48% in 2050 and China will command most of the Asian share. Asian nuclear will increase from 130 Mtoe in 2017 to 345 Mtoe in 2050, with the increase concentrated on China and India. Nuclear power generation will decline substantially in the Advanced Economies that now capture 75% of global nuclear consumption, leading Asia's share of global consumption to soar from 19% at present to 40%.

2.2 Final energy consumption

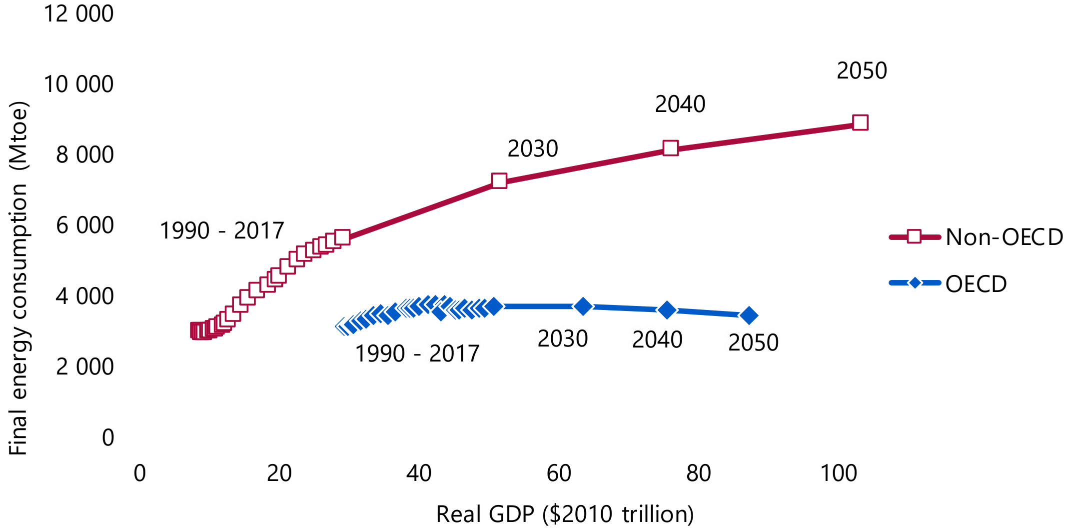
World

Final energy consumption in the world has grown at a slower pace than the world economy. Between 1990 and 2017, the annual rate of growth in final energy consumption came to 1.6% against the annual real GDP growth rate of 2.8%[16]. The trend has grown clearer since 2010, with final energy consumption growing at only 1.4% per year against the average economic growth rate of 2.8%. Of particular interest, OECD final energy consumption peaked in 2007 and started a downtrend due to the services sector's expansion and energy efficiency improvements, implying a so-called decoupling between energy consumption and economic growth. Meanwhile, non-OECD final energy consumption grew at an annual rate of 2.3%, reflecting higher annual economic growth at 4.5%, increase production in energy-intensive industries and growth in population.

[16] Global total final energy consumption covers international bunkers.

As the decoupling makes further progress, OECD final energy consumption will decrease at an annual rate of 0.2% through 2050 to reach 3 441 Mtoe, slightly less than the current level. Despite a fall in non-OECD consumption's elasticity to GDP[17] from 0.53 (between 1990 and 2017) to 0.36 (between 2017 and 2050) due to energy efficiency improvement, final energy consumption will expand 1.6-fold from the present level to 8 840 Mtoe (Figure 2-23). Global final energy consumption will consequently increase at 0.9% per year until 2050, up 1.3-fold from 2017.

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

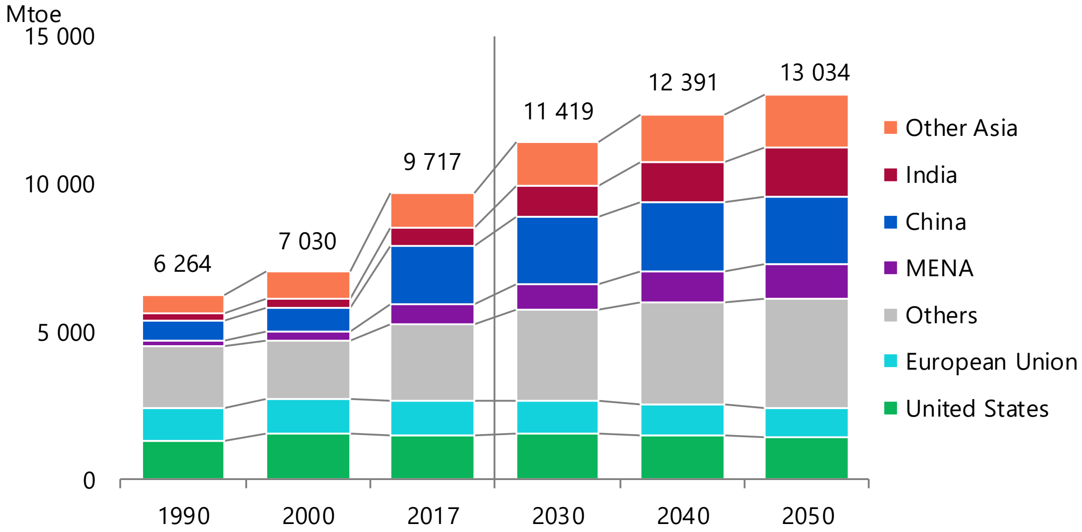


By region

Asia will account for 1 957 Mtoe or nearly 60% of the 3 318 Mtoe in global final energy consumption growth through 2050 (Figure 2-24). In Asia where high economic growth will continue against the backdrop of increasing population, final energy consumption will increase at an annual rate of 1.3% from 3 793 Mtoe in 2017 to 5 750 Mtoe in 2050, due mainly to industrial development, motorisation, urbanisation and improvements in living standards. In India that will replace China as the most populous country in the world, final energy consumption in 2050 will total 1 631 Mtoe, still short of the 2 327 Mtoe for China. However, India will remarkably expand energy consumption, accounting for 53% of the Asian final energy consumption growth, compared with 17% for China. India's per capita consumption in 2050 will be limited to 0.99 toe, still below the Asian average of 1.23 toe (and the 1.70 toe for China), indicating that India may potentially boost further its energy consumption in the future.

[17] Final energy consumption' elasticity to GDP = Annual growth rates of final energy consumption / annual growth rates of real GDP

Figure 2-24 | Final energy consumption by region [Reference Scenario]



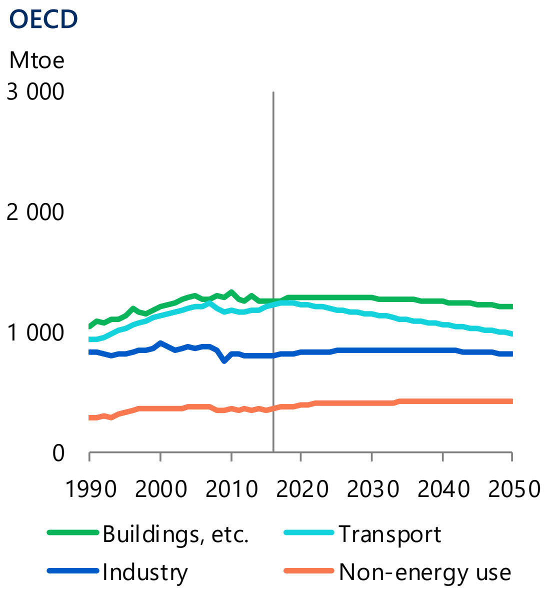
In the Middle East and North Africa (MENA), final energy consumption will grow from 641 Mtoe in 2017 to 1 127 Mtoe in 2050. The MENA growth will top the ASEAN growth, accounting for 15% of global growth. In the United States and European Union where society has matured, final energy consumption will turn downward around 2020, falling by 4% and 16% from the current levels, respectively.

By sector

The transport sector will account for 1 058 Mtoe or one-third of the final energy consumption growth of 3 318 Mtoe, followed by the buildings (residential and commercial) sector with an increase of 892 Mtoe, the industry sector with 868 Mtoe and the non-energy use sector with 500 Mtoe. The annual growth rate will be 1.4% for the non-energy use sector, 1.0% for the transport sector, 0.8% for the industry sector and 0.7% for the buildings sector. OECD final energy consumption will almost level off in the buildings and industry sectors and will decline substantially in the transport sector due to automobile fuel efficiency improvements through the spread of electrified vehicles (Figure 2-25). Non-OECD final energy consumption will increase rapidly in each of the buildings, industry and transport sectors against the backdrop of living standard improvements and economic development.

While the non-OECD buildings sector will post an annual final energy consumption growth rate of 1.2%, reflecting living standard improvements, world final energy consumption will increase by only 0.7% per year, through 2050. In the buildings sector, fuel wood, livestock manure and other traditional biomass for cooking and heating in rural areas account for 23% of final energy consumption (34% in the non-OECD alone). Traditional biomass consumption faces large challenges such as health issues caused by smoke and soot during burning and will be replaced with electricity, gas and other modern energy consumption in line with living standard improvements. In 2050, traditional biomass's share of final energy consumption will decline to 13% (17% in the non-OECD). On the other hand, modern energy consumption will increase at an annual rate of 1.1% (1.9% in the non-OECD).

Figure 2-25 | OECD and non-OECD final energy consumption [Reference Scenario]



In the transport sector, road energy consumption accounts for 75% of final energy consumption, 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[18] will double from 1 410 million vehicles in 2017 to 2 890 million vehicles in 2050, electrically powered automobiles including hybrid and electric vehicles will expand their share of the global vehicle fleet to 47%, leading the transport sector's final energy consumption to be limited to 1.4-fold due to substantial fuel efficiency improvements. The OECD transport sector's energy consumption will decrease at an annual rate of 0.7% due to smaller growth in the vehicle fleet size from the current already high level and substantial fuel efficiency improvements. In the non-OECD transport sector, however, energy consumption will increase at an annual rate of 1.9% as an increase of about three-fold in the vehicle fleet size more than offsets the effect of fuel efficiency improvements. Asia will remarkably develop its motorisation, leading non-OECD Asia to account for about 60% of the global vehicle fleet growth. International bunkers (aviation and marine) will expand energy consumption at an annual rate of 1.8% on growing international travel and trade, raising their share of the transport sector's energy consumption from the current 15% to 20% in 2050.

While global manufacturing GDP will grow at 2.5% per year, driven by non-OECD, the industry sector's energy consumption growth will be limited to 0.8%. The consumption growth will not only reflect progress in technological energy efficiency improvement but also the sector's transition toward higher value-added products and non-energy-intensive production. For example in China, the so-called "world's factory", despite an annual manufacturing GDP growth rate of 3.3%, the industry sector's energy consumption will decrease by 0.1% per year, due to the peaking production in typically energy-intensive steel and cement industries.

[18] The downward pressure of progress in car sharing services on vehicle ownership growth is not considered here.

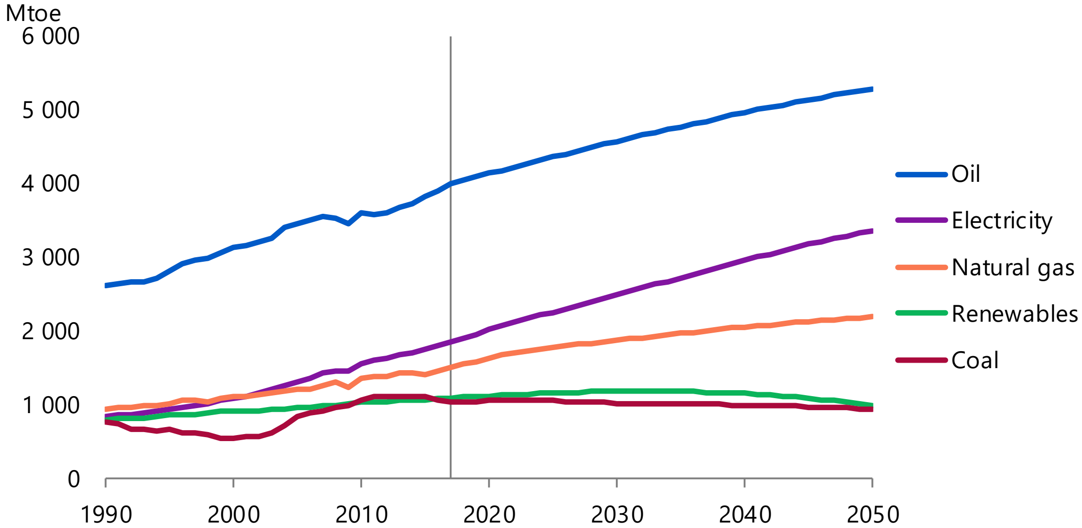
China's share of the global industry sector energy consumption will fall from 36% at present to 23% in 2050. In contrast, the share will expand by 8 percentage points to 15% for India and by 5 points to 10% for ASEAN.

Petrochemical materials account for about 80% of the non-energy use sector's consumption. (The remainder includes lubricant oil). Given high demand for plastics and other petrochemical products, the petrochemical industry will experience robust growth. The non-OECD petrochemical demand and production will grow substantially, capturing more than 90% of global non-energy use growth. As massive plastic waste has been dumped in recent years, it is a concern that plastic waste's flow into the water system as plastic powder would exert serious effects on the marine environment. Therefore, a transition towards biodegradable plastics that can be decomposed by micro-organisms and fermented into water and carbon dioxide is underway. Given that most bioplastics are degradable, biomass will be increasingly used as petrochemical feedstocks.

By energy source

A breakdown of final energy consumption by energy source shows that electricity will score the largest consumption growth among energy sources, accounting for 46% of the total growth. Electricity will post the largest consumption growth among major energy sources in both OECD and non-OECD countries (Figure 2-26). Oil consumption will increase on the account of growth in the non-OECD transport and non-energy use sectors. Natural gas consumption will substantially expand in China's buildings sector and the Middle East's industry sector. Between 2017 and 2050, consumption will increase at an annual rate of 1.8% for electricity, at 1.1% for natural gas and at 0.8% for oil. Meanwhile, coal consumption peaked in 2014 and will almost level off in the future. The share of total energy consumption will rise from 19% to 26% for electricity and from 15% to 17% for natural gas, while remaining unchanged from 41% for oil and falling from 10% to 7% for coal.

Figure 2-26 | Global final energy consumption (by energy source) [Reference Scenario]



Regarding final oil consumption, the transport sector accounts for 65% (including 49% for the road sector and 10% for international bunkers), the non-energy use sector for 16% and the buildings sector for 11%. Among these sectors, the transport sector will post the largest growth, followed by the non-energy use sector. Of interest is the Asian automobile fuel consumption that will lead the oil demand growth, fully offsetting a decline in OECD oil consumption. In Asian Emerging Market and Developing Economies including China, India and ASEAN members, vehicle ownership will increase rapidly on progress in motorisation amid income improvements. In the non-energy use sector, Asia will command nearly 60% of final energy consumption growth and will capture about 70% of global final oil consumption growth through 2050, boosting its share of global oil consumption from 32% in 2017 to 41% in 2050. International bunkers will also sharply expand energy consumption on growing international travel and trade, raising their share of final oil consumption to 12%.

Regarding final natural gas consumption, the buildings sector accounts for 43% (30% for the residential sector and 13% for the commercial sector), the industry sector for 38% 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 will capture 58% of industry sector consumption growth and 45% of non-energy use sector consumption growth, followed by the Middle East commanding 19% of industry sector consumption growth and 18% of non-energy use sector consumption growth. The Middle East is promoting domestic natural gas utilisation to earn foreign currencies with oil exports and expanding petrochemical plants using natural gas to generate jobs. China's residential sector still uses massive coal and biomass fuels such as fuel wood and is rapidly switching to city gas to avoid indoor and outdoor air pollution. China's buildings sector will account for 16% of global final natural gas consumption growth.

Generally, as income grows, people favour highly convenient electricity; this trend will remain unchanged. Electricity will score the highest consumption growth among major energy sources both in the OECD and non-OECD. The global electrification rate (on the consumption side)[19] will rise from 19% in 2017 to 26% in 2050. Driving electricity consumption growth will be Asia, including China, India and ASEAN. China, the largest electricity consumer in the world, will expand electricity consumption by 4 120 TWh exceeding the current consumption of 3 737 TWh in the United States, the second largest electricity consumer in the world. India will increase its electricity consumption by 3 015 TWh, becoming an electricity market rivalling the United States in 2050. Both China and India thus will rapidly boost electricity consumption. Non-OECD electricity consumption will account for 85% of global electricity consumption growth. Particularly, the buildings sector will command 57 percentage points of the share (Figure 2-27) and households will capture more than 54% of the sector's electricity consumption growth. Electricity infrastructure development in unelectrified rural areas and the penetration of convenient electrical home appliances will induce the electricity consumption growth. In the non-OECD countries, the diffusion of electric water heaters, air conditioners, lighting equipment, refrigerators and other electrical home appliances will boost electricity consumption (Figure 2-28). In the OECD where most electrical home appliances have diffused sufficiently, residential electricity consumption will increase little on the

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

improvement of equipment and insulation efficiency, although some oil and gas appliances will be replaced with electrical products.

Figure 2-27 | Final electricity consumption [Reference Scenario]

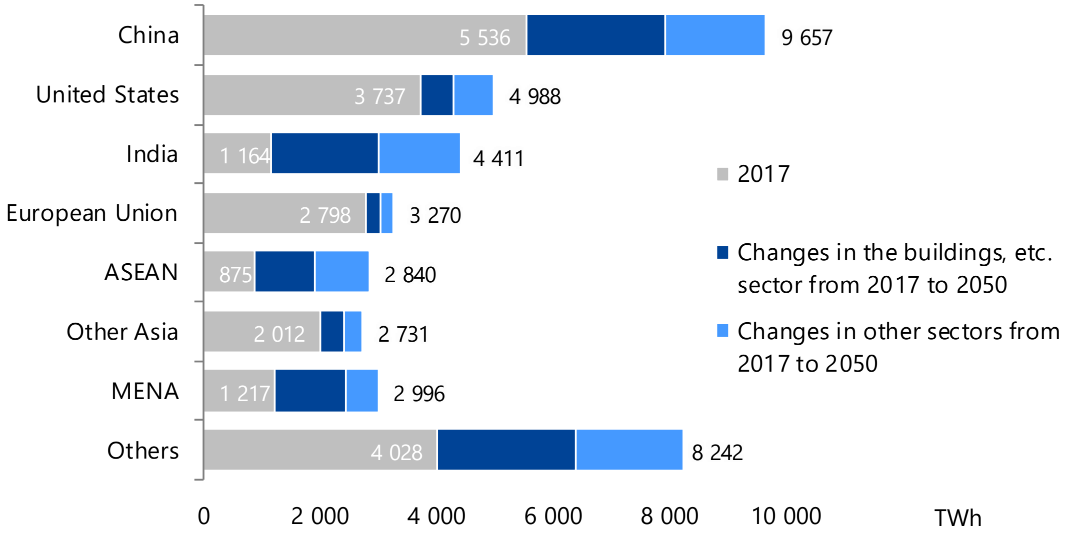
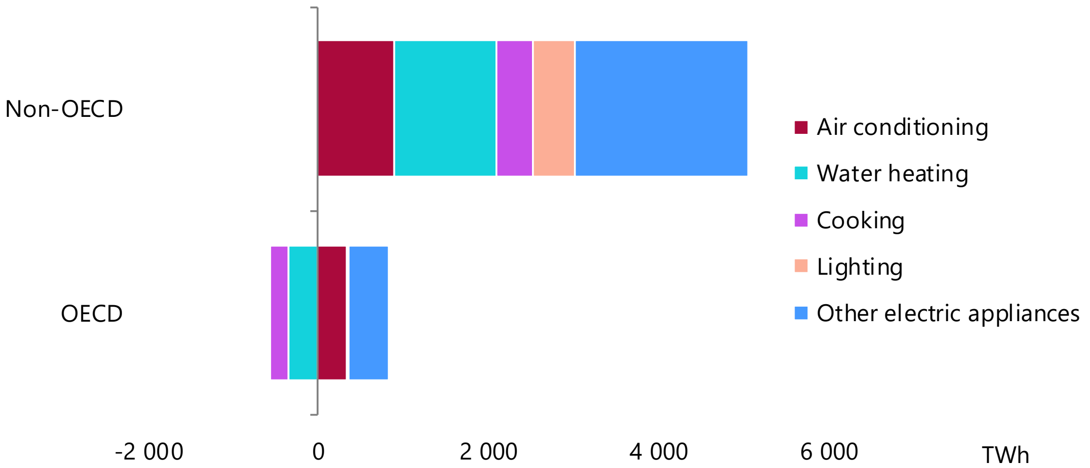


Figure 2-28 | Changes in residential electricity consumption [Reference Scenario, 2017-2050]



With a growing dependence on electricity for economic activities and daily life, the impact of electricity supply disruptions increases. As the risk of electricity supply disruptions rises due to the massive expansion of intermittent electricity sources and potential cyberattacks, technological and institutional preparations for supply disruptions are growing more important.

The industry sector accounts for about 80% of the final coal consumption, and China alone accounts for 65%. While China's industrial coal consumption posts a steep decline of about 50% by 2050 due to peaking steel and cement production, India and ASEAN will expand their coal consumption. Overall, global final coal consumption will decrease at an annual rate of 0.3%. No large growth in coal consumption can be expected, given that many industries are making a transition from coal to electricity or gas because coal, though cheaper, is inferior to other energy sources in terms of environmental friendliness. China with its abundant coal resources, on the other hand, is increasing its coal use as a petrochemical feedstock to restrain oil imports.

Fuel wood, livestock manure and other traditional biomass used in rural areas of developing countries account for about three quarters of final renewable energy consumption. Fuel wood used mainly in fireplaces in Western countries account for a little more than 10%, biofuels for vehicles for a little less than 10%, and solar and geothermal energy for the remainder. Traditional biomass consumption will continue increasing due to rural population growth before peaking around 2030 on the improved access to modern energy.

3. Energy supply

3.1 Crude Oil

Production

In the Reference Scenario, both OPEC and non-OPEC crude oil production (including natural gas liquid) will increase in line with the robust oil consumption growth (Table 3-1). While European, Eurasian and Asian countries among non-OPEC oil producers reduce production, U.S. shale oil (light tight oil) production will strongly increase on firm investments in oil exploration and development, reflecting moderate oil price hikes combined with production cost cuts through digital technologies. Through 2030, particularly, U.S. oil production will expand remarkably, leading North America to account for 54% of global crude oil supply growth. Similarly, Latin America will greatly contribute to non-OPEC oil production growth. Major Latin American players in the production expansion will include Brazil that has stepped up pre-salt oil development by inducing foreign investment through institutional reform, as well as Guyana that has attracted international oil companies with the discovery of large oil fields and plans to launch production under its first large-scale offshore oil development project in 2020. As a result, non-OPEC oil producers' share of global oil supply will slightly increase from 59% in 2017 to 60% in 2030.

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

(Mb/d)

	2017	2030	2040	2050	2017-2050	
					Changes	CAGR
Crude oil production	92.5	104.1	112.2	117.9	25.4	0.7%
OPEC	37.8	41.5	47.7	52.4	14.6	1.0%
Middle East	28.4	31.5	35.7	38.6	10.3	0.9%
Others	9.4	9.9	11.9	13.8	4.3	1.1%
Non-OPEC	54.7	62.6	64.6	65.5	10.8	0.5%
North America	17.9	24.2	24.1	22.8	4.9	0.7%
Latin America	6.8	8.7	10.8	12.7	5.9	1.9%
Europe and Eurasia	17.8	17.4	17.0	16.9	-0.9	-0.2%
Middle East	3.1	3.5	3.9	4.3	1.1	0.9%
Africa	1.3	1.5	1.7	1.8	0.5	1.0%
Asia and Oceania	7.8	7.3	7.1	7.0	-0.7	-0.3%
Processing gains	2.3	2.8	3.2	3.5	1.2	1.3%
Oil supply	94.8	106.9	115.4	121.4	26.6	0.8%

Note: Crude oil includes natural gas liquid.

As shale oil production declines later, non-OPEC oil production growth will decelerate and its share of global oil production will gradually fall, standing at 56% in 2050. OPEC will capture about 75% of global oil production growth between 2030 and 2050, driven by Saudi Arabia with spare production capacity and Iran and Iraq with production expansion potential.

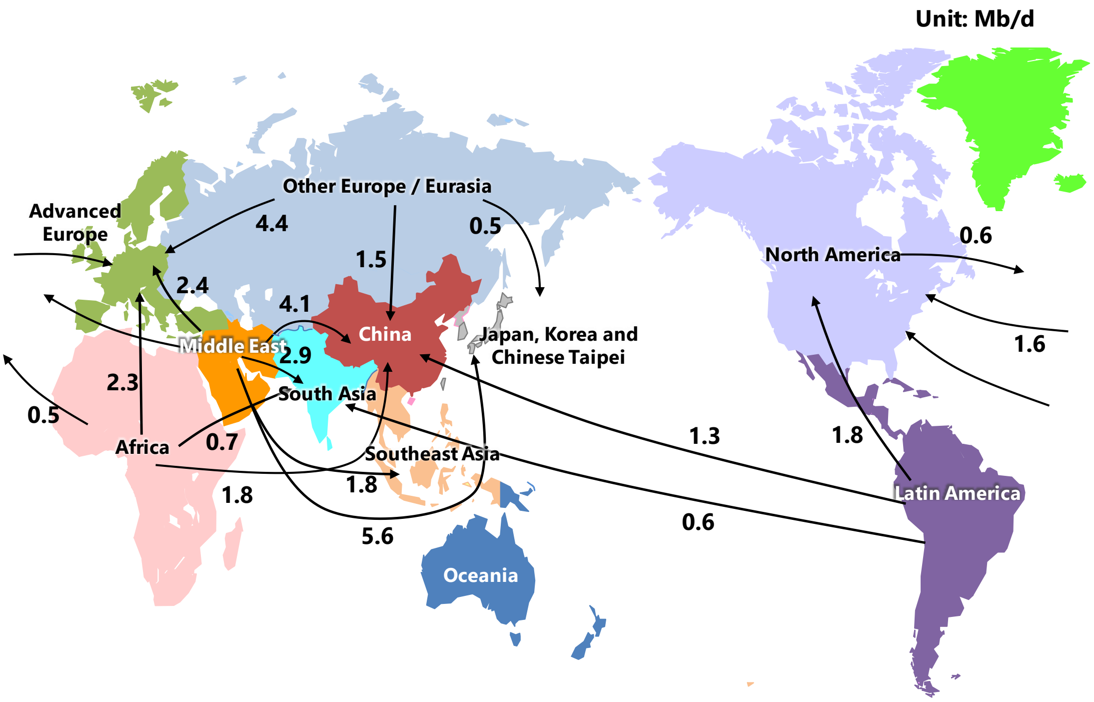
Trade

Crude oil trade between major regions in the world totalled 43 Mb/d in 2018 (Figure 3-1). The largest export source was the Middle East with 44% of total trade between major regions. Asian imports captured a large portion of total trade as nearly 80% of the oil exports from the Middle East were destined for Asia. Other major importers were OECD Europe and North America. OECD Europe imported oil mainly from non-OECD Europe, Central Asia and Africa, while North America bought oil from Latin America and the Middle East. However, North America's crude oil imports have decreased in recent years against the backdrop of remarkable growth in U.S. production.

Crude oil trade will increase slightly to 44 Mb/d in 2030. While OECD countries reduce imports due to a demand decline and a production increase in North America, imports to meet growing demand in Asian emerging countries will drive the growth in global trade (Figure 3-2).

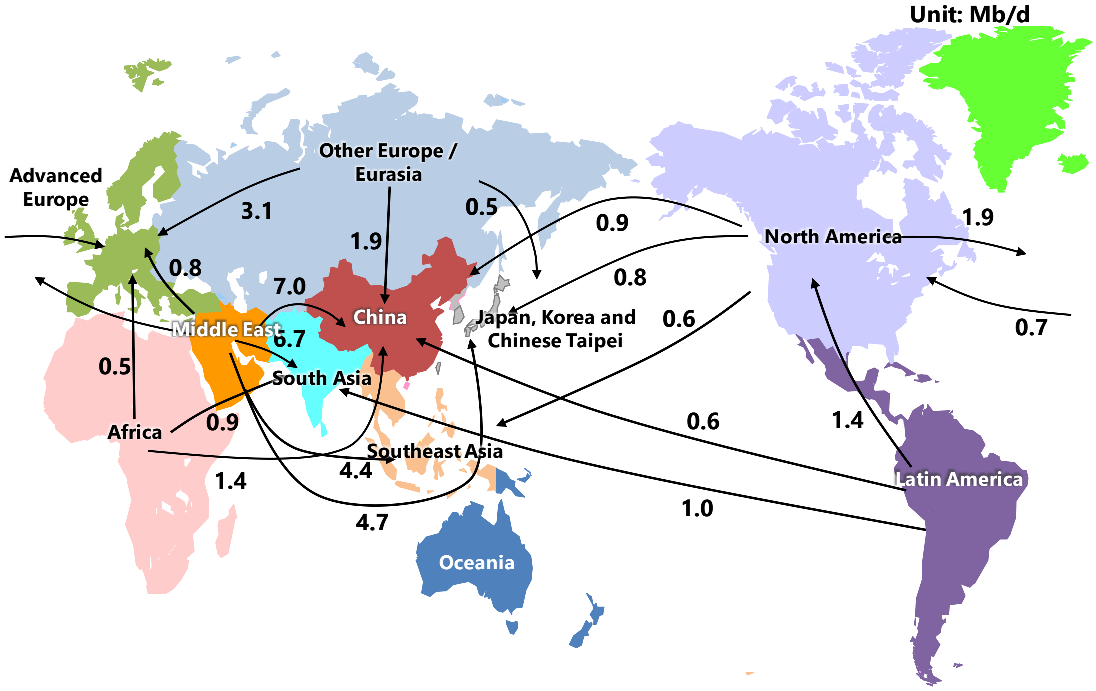
While Asia diversifies its crude oil supply sources by expanding to North America, non-OECD Europe and Central Asia, the Middle East will still account for as much as 70% of Asian crude oil supply in 2030. Although North America will continue to import crude oil from Latin America and the Middle East, it will substantially reduce imports from 2018 to 2030 due to significant domestic production growth. On the other hand, North America will expand exports including destinations in OECD Europe that are geographically proximate. Non-OECD Europe, Central Asia and the Middle East, which have traditionally supplied oil to OECD Europe, will reduce exports to this market and expand exports to meet Asia growing demand.

Figure 3-1 | Major crude oil trade flows [2018]



Note: Flows of 0.5 Mb/d or more are covered.
Sources: "BP Statistical Review of World Energy 2019," national trade statistics

Figure 3-2 | Major crude oil trade flows [Reference Scenario, 2030]



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

3.2 Natural gas

Production

Global natural gas production will grow about 1.6-fold from 2017 to 2050 (Table 3-2). Global upstream investment that had plummeted due to weak oil and natural gas prices from 2014 to 2016 have now turned upward, in line with the price recovery. Natural gas production will thus continue to increase in the future.

Among major regions, North America will post the greatest natural gas production growth at more than 500 billion cubic metres (Bcm) from 2017 to 2050. The United States will account for nearly 80% of the entire growth. As gas development *knowhow* is accumulating and LNG exports from the Gulf of Mexico coast expanding, U.S. production will substantially increase. Canada endowed with rich shale gas resources will also expand production from 2030.

The Middle East will log the second greatest natural gas production growth. Featuring the world's largest proven natural gas reserves, Iran will eventually retain its position as the largest gas producer in the Middle East from 2030 by realising pipeline gas exports to neighbouring countries and LNG projects. (Iran's natural gas development are currently stalled temporarily due to economic sanctions.) Qatar will expand its large-scale LNG export projects and Saudi Arabia will increase natural gas production by promoting resources development. Among the former Soviet republics, Russia is currently developing natural gas resources in the Yamal

Peninsula and the Arctic and will increase natural gas production in Eastern Siberia and Sakhalin.

Table 3-2 | Natural gas production [Reference Scenario]

(Bcm)

	2017	2030	2040	2050	2017-2050	
					Changes	CAGR
World	3 768	4 779	5 559	6 129	2 360	1.5%
North America	945	1 308	1 389	1 415	470	1.2%
Latin America	215	295	403	479	264	2.5%
OECD Europe	248	204	182	144	-104	-1.6%
Non-OECD Europe / Central Asia	920	1 004	1 137	1 273	353	1.0%
Russia	694	739	828	917	223	0.8%
Middle East	629	813	957	1 132	502	1.8%
Africa	215	346	498	536	320	2.8%
Asia	486	624	761	893	407	1.9%
China	142	246	356	429	287	3.4%
India	31	60	86	109	78	3.8%
ASEAN	222	226	237	273	51	0.6%
Oceania	110	185	232	257	146	2.6%

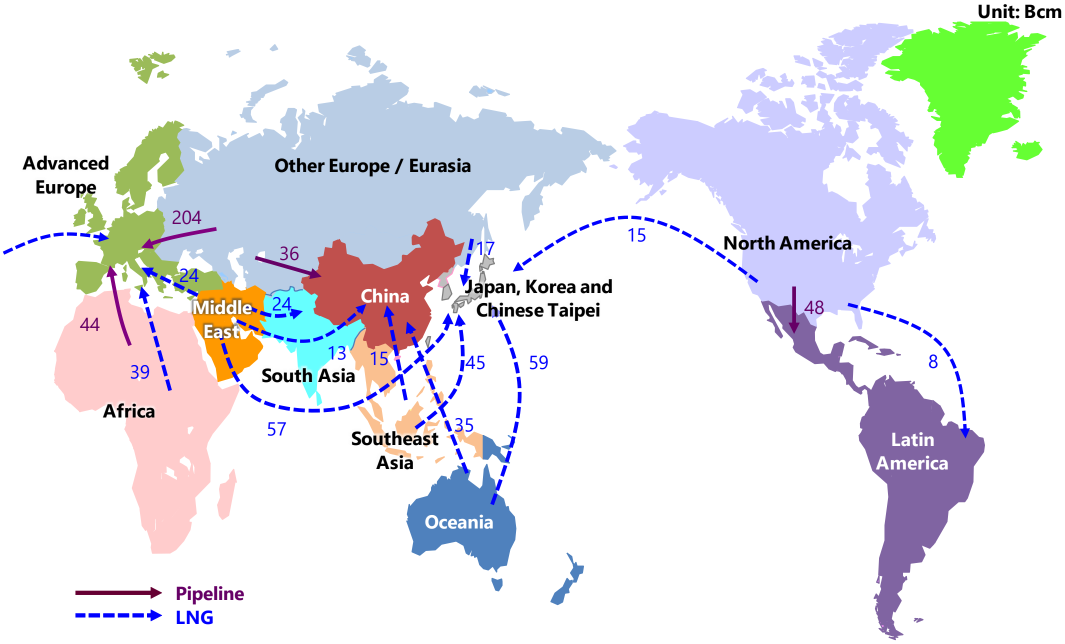
In Asia, China and India will promote domestic gas developments to meet growing demand. China will boost investments in the more difficult development of shale gas resources. In Africa, Mozambique, Tanzania and Senegal have discovered gas fields one after another and will begin to substantially increase production in or after 2030. In contrast, OECD Europe will gradually reduce gas production under geological constraints.

Trade

Natural gas trade between major regions in the world totalled 760 Bcm in 2018 (Figure 3-3). Pipeline gas trade accounted for about 44% of the total, including Russia that captured most of the pipeline trade with exports to Europe. LNG trade has been almost limited to exports from Southeast Asia to Northeast Asia including Japan and Korea. Recently, however, global LNG trade flows have been diversified as production under new LNG projects has started in Australia, Russia and other countries. On the supply side, LNG exports from the U.S. mainland started in 2016, leading to rapid production expansion. In 2018, Cameroon launched LNG exports. On the demand side, Bangladesh and Panama started LNG imports. The LNG trade pattern will continue to be diversified.

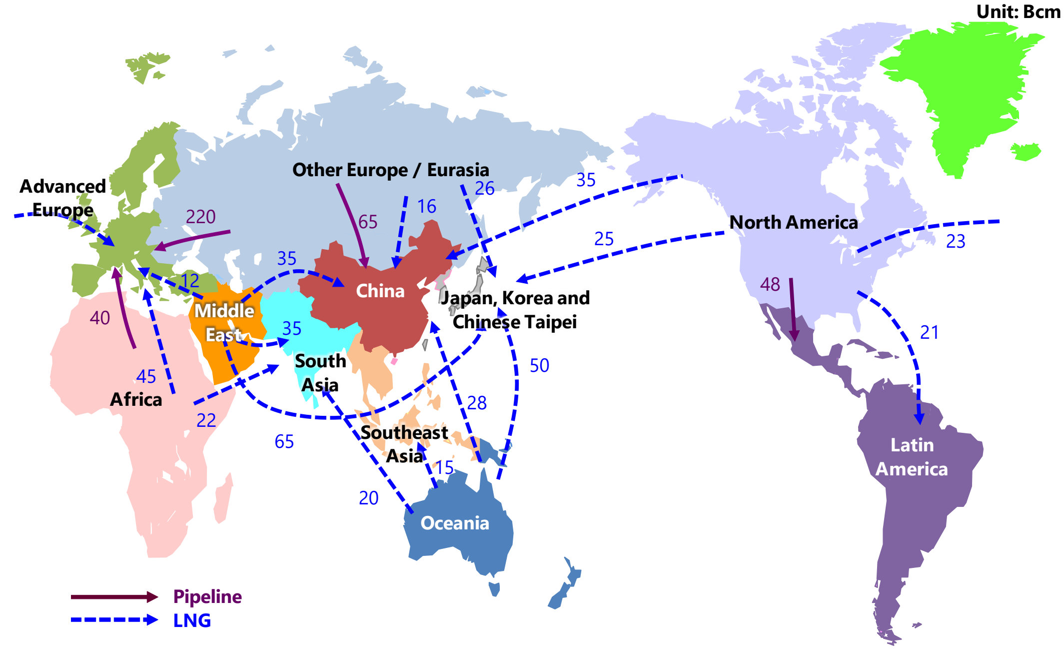
Natural gas trade between major regions will increase due mainly to growth in Asian imports and North American exports, reaching about 1 000 Bcm in 2030. Oceania and North America will post the largest export growth as many LNG projects are planned to enter the production phase from 2020 and 2025, respectively. China will become the largest natural gas importer, purchasing more than 200 Bcm including pipeline gas mainly from Russia and Central Asia and LNG.

Figure 3-3 | Major natural gas trade flows [2018]



Sources: "Cedigaz Revised Estimates 2019," "GIIGNL Annual Report 2019"

Figure 3-4 | Major natural gas trade flows [Reference Scenario, 2030]

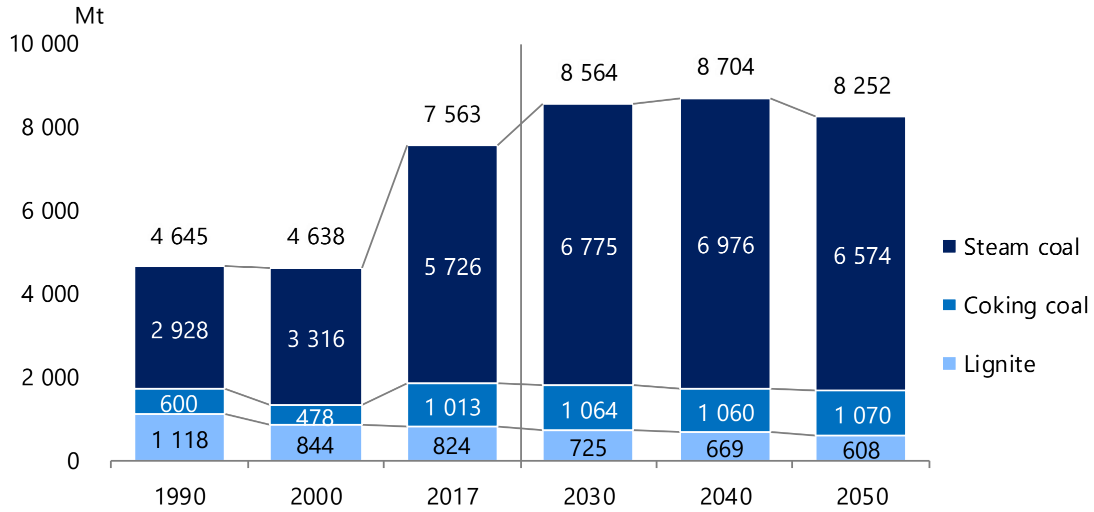


3.3 Coal

Production

Global coal production will increase from 7 563 Mt in 2017 to 8 564 Mt in 2030 as coal consumption expands in Asian, Latin American, African and other non-OECD countries. However, production growth will gradually moderate before turning negative around 2040 (Figure 3-5). Steam coal production will rise 1.22-fold from 5 726 Mt in 2017 to 6 976 Mt in 2040 due to growing demand for power generation before peaking around 2040. Coking coal production mainly for steel production will decrease slightly from 1 033 Mt in 2017 to 1 064 Mt in 2030 before levelling off. Lignite production will gradually decline from 824 Mt in 2017 to 608 Mt in 2050.

Figure 3-5 | Global coal production by type [Reference Scenario]



By region, steam coal production will increase in Asia to meet its growing coal demand and increase in Oceania, Africa and Latin America where major coal exporting countries are present (Table 3-3). However, production will decrease in North America and OECD Europe where coal demand will substantially decline.

Table 3-3 | Coal production [Reference Scenario]

Steam coal production (Mt)

	2017	2030	2040	2050	2017-2050	
					Changes	CAGR
World	5 726	6 775	6 976	6 574	848	0.4%
North America	597	533	452	346	-251	-1.6%
United States	574	519	447	343	-231	-1.6%
Latin America	100	144	170	177	78	1.8%
Colombia	86	129	152	158	72	1.9%
OECD Europe	66	54	47	40	-26	-1.5%
Non-OECD Europe / Central Asia	339	368	429	445	106	0.8%
Russia	227	266	312	326	99	1.1%
Middle East	0	0	0	0	0	-1.0%
Africa	264	314	338	350	86	0.9%
South Africa	253	295	310	313	60	0.6%
Asia	4 107	5 046	5 170	4 845	738	0.5%
China	2 882	3 161	3 017	2 594	-288	-0.3%
India	643	1 168	1 431	1 525	882	2.7%
Indonesia	490	600	600	600	110	0.6%
Oceania	254	318	370	370	116	1.1%
Australia	253	316	369	369	116	1.2%

Coking coal production (Mt)

	2017	2030	2040	2050	2017-2050	
					Changes	CAGR
World	1 013	1 064	1 060	1 070	57	0.2%
North America	94	88	88	86	-7	-0.2%
United States	65	60	59	57	-9	-0.4%
Latin America	9	11	12	13	4	1.0%
Colombia	4	5	6	6	1	0.9%
OECD Europe	18	17	17	18	0	-0.1%
Non-OECD Europe / Central Asia	107	113	116	118	10	0.3%
Russia	86	89	91	90	4	0.1%
Middle East	1	2	2	2	0	0.8%
Africa	11	28	34	41	30	4.1%
Mozambique	7	23	29	35	28	5.0%
Asia	581	596	550	516	-65	-0.4%
China	515	495	418	350	-166	-1.2%
India	36	70	101	137	101	4.1%
Mongolia	26	24	23	22	-4	-0.5%
Oceania	191	209	240	276	85	1.1%
Australia	190	208	239	275	85	1.1%

In Asia, Indian steam coal production will rise from 643 Mt to 1 525 Mt in 2050 in line with local demand growth. China's steam coal production will moderately increase due to growth in demand for power generation but decline in line with a demand downturn in the mid-2020s. Indonesia will expand production on growth in domestic and export demand before holding down production for the protection and sustainable utilisation of domestic coal resources.

Among major coal exporters, Australia, Colombia, Russia and South Africa will substantially increase steam coal production to meet markets' expansion. Australia's steam coal production will rise by 116 Mt from 253 Mt in 2017 to 369 Mt in 2050 to meet growth in exports to the Asian market. Russian production will increase from 227 Mt in 2017 to 326 Mt in 2050 due to additional exports to the Asian market, despite a decline in those to the European market. Colombia will raise production from 86 Mt in 2017 to 158 Mt in 2050 on growth in African and Latin American imports and will also export to the Asian market, while its major export destination, the European market, is shrinking. South Africa will boost production from 253 Mt in 2017 to 313 Mt in 2050 to meet rising domestic demand and growing exports to the Asian market including India.

Meanwhile, steam coal production in North America will plunge from 597 Mt in 2017 to 346 Mt in 2050 due mainly to a U.S. consumption decline. In OECD Europe, steam coal production will fall from 66 Mt in 2017 to 40 Mt in 2050 also in line with a domestic consumption decrease.

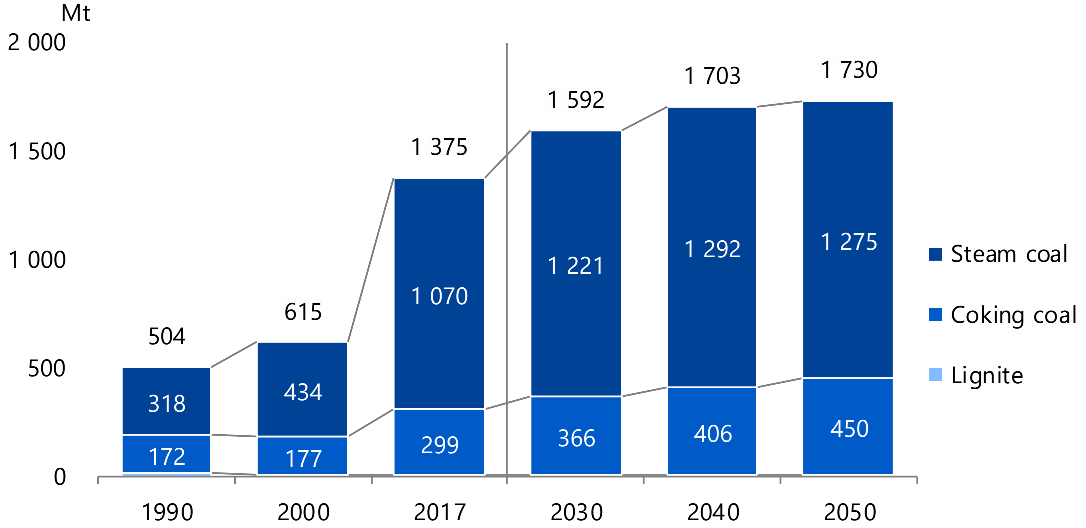
Coking coal production will rise in India featuring sharp domestic consumption growth and in Oceania and Africa that have major exporters. While increasing production to meet its domestic demand rise, India will depend primarily on imports for covering much of its demand growth due to its limited high-quality coking coal reserves. China will reduce coking coal production as its demand peaks around 2020.

Meanwhile, major coking coal exporters such as Australia and Mozambique will promote coking coal mine development in response to growth in exports, mainly to India. Coking coal production will increase from 190 Mt in 2017 to 275 Mt in 2050 in Australia and from 7 Mt to 35 Mt in Mozambique.

Trade

Coal trade (import volume) will expand from 1 375 Mt in 2017 to 1 730 Mt in 2050 in line with consumption growth (Figure 3-6). Steam coal trade will increase from 1 070 Mt in 2017 to 1 275 Mt in 2050 in response to consumption growth mainly in India and Southeast Asia. Coking coal trade will grow from 299 Mt in 2017 to 450 Mt in 2050 due mainly to increasing Indian consumption.

Figure 3-6 | Global coal trade (Import volume) [Reference Scenario]

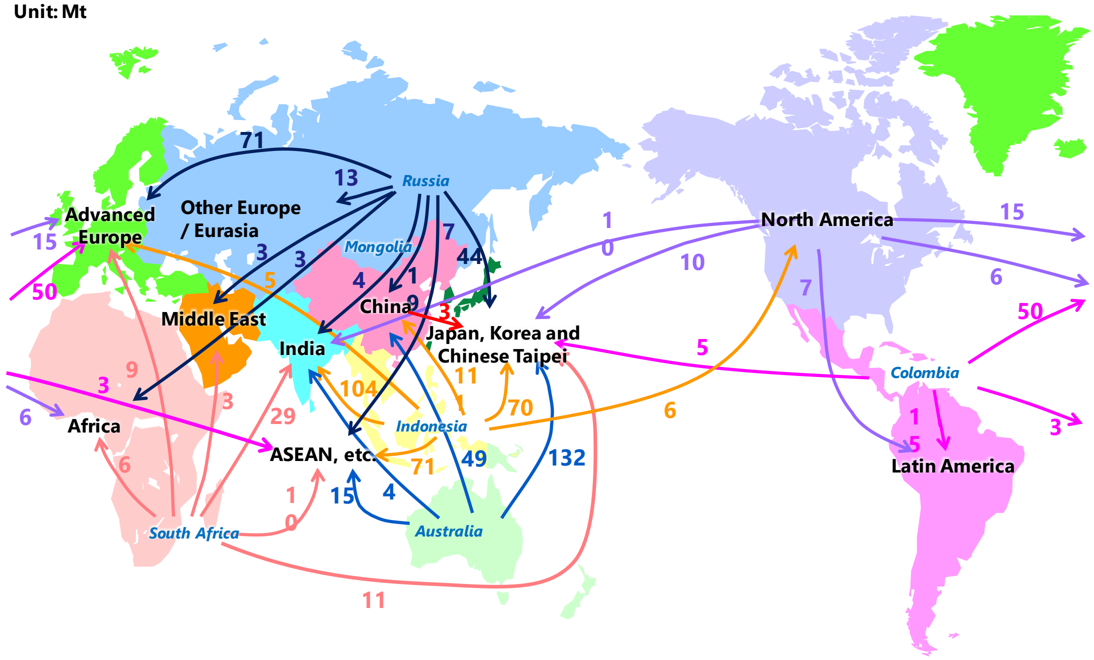


In steam coal trade, imports in Asia will increase by 260 Mt from 802 Mt in 2017 to 1 062 Mt in 2050, while imports in other regions will expand by 20 Mt in Africa and by 9 Mt in Latin America. Among Asian countries, India and four major ASEAN members (Malaysia, Thailand, the Philippines and Viet Nam) will substantially expand imports. Japan, Korea and Chinese Taipei will gradually cut imports in line with their demand decline and China's steam coal imports will peak around 2025. OECD Europe will reduce imports sharply from 160 Mt in 2017 to 81 Mt in 2050 due to a consumption drop. On the supply side, exports will increase from Australia, South Africa, Russia and Colombia. Indonesia will reduce exports over a medium to long term due to production adjustments and domestic consumption growth.

In coking coal trade, India will increase imports sharply from 52 Mt in 2017 to 221 Mt in 2050, while, China will reduce its imports by 22 Mt due to a consumption drop. Japan, Korea and Chinese Taipei will also cut imports by a combined 17 Mt. On the supply side, Australia, Mozambique and Russia will expand exports.

Figure 3-7 | Major steam coal trade flows [2018]

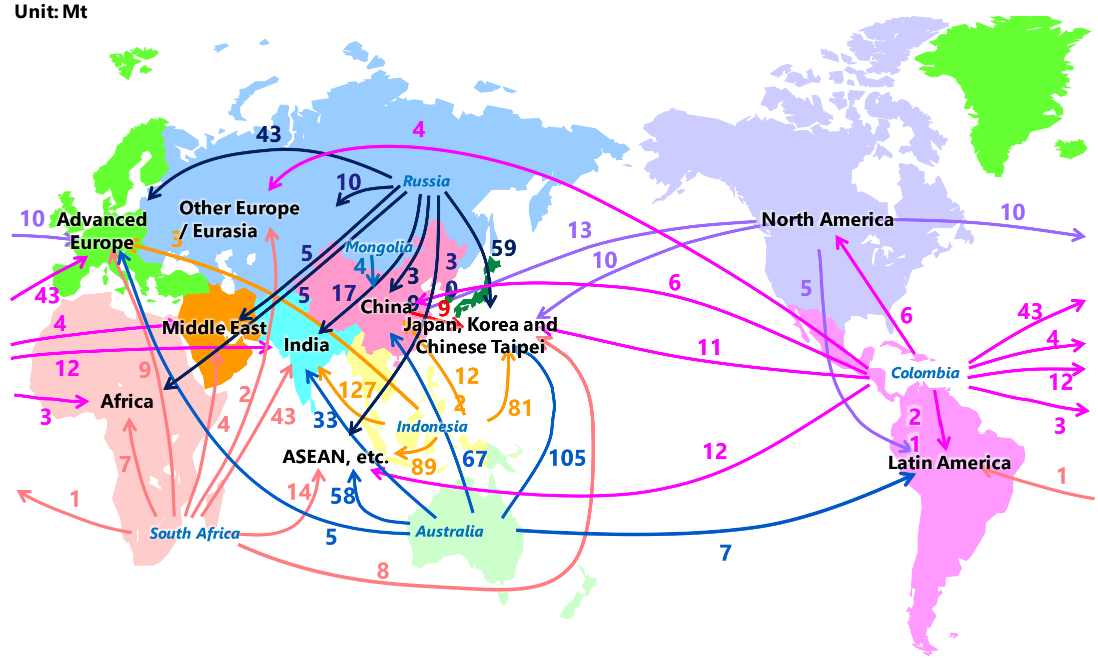
Unit: Mt



Note: Estimated imports totalling 2 Mt or more are specified.
Source: IEA "Coal Information 2019"

Figure 3-8 | Major steam coal trade flows [Reference Scenario, 2030]

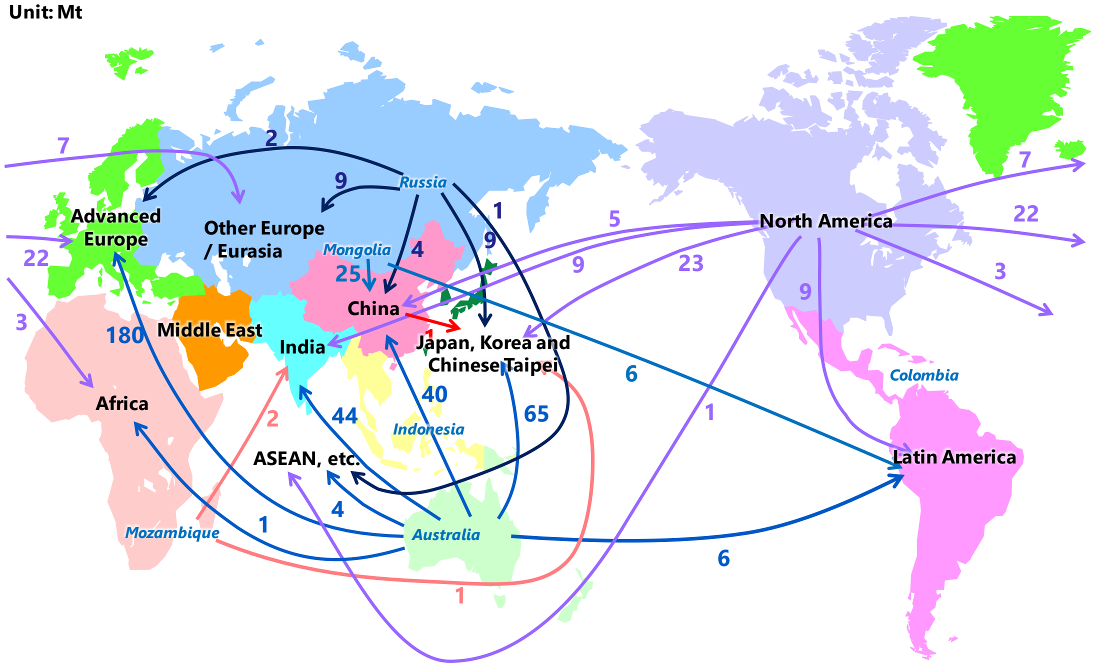
Unit: Mt



Note: Estimated imports totalling 2 Mt or more are specified.

Figure 3-9 | Major coking coal trade flows [2018]

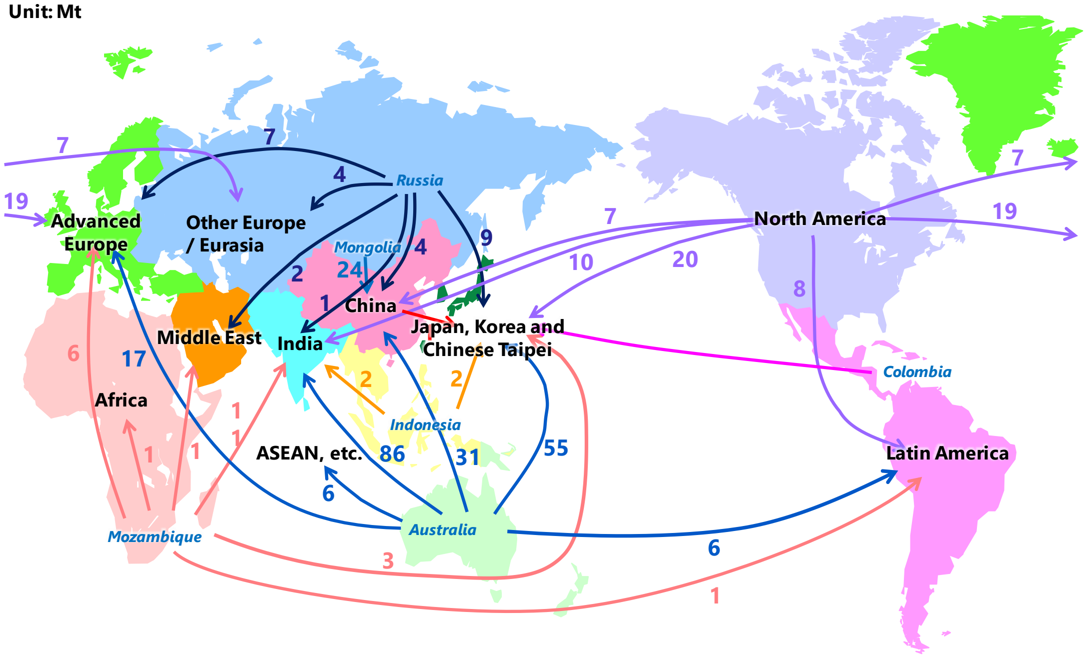
Unit: Mt



Note: Estimated imports totalling 1 Mt or more are specified.
Source: IEA "Coal Information 2019"

Figure 3-10 | Major coking coal trade flows [Reference Scenario, 2030]

Unit: Mt



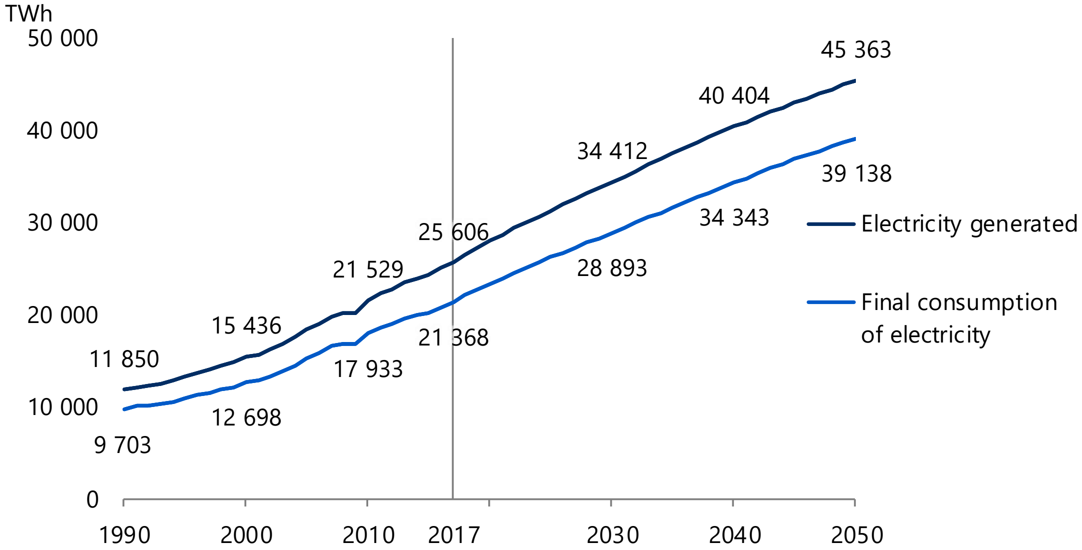
Note: Estimated imports totalling 1 Mt or more are specified.

3.4 Power generation

Power generation and its mix

In line with electricity consumption growth, global power generation will increase at an annual rate of 1.7% to 45 361 terawatt-hours (TWh) in 2050, up 1.8-fold from the current level (Figure 3-11). The increase of 19 754 TWh is three times as large as the current power generation in China known as the world's largest electricity generator. Of the increase, the non-OECD will account for about 90%. In Asia keeping on rapid economic growth, power generation will rise at an annual rate of 2.1% from 11 340 TWh in 2017 to 22 576 TWh in 2050 (Figure 3-12).

Figure 3-11 | Global power generation and final consumption [Reference Scenario]



Coal accounted for the largest share of global power generation in 2017, followed by natural gas, hydro and nuclear (Figure 3-13). In 2050, natural gas will capture the largest share, followed by coal, hydro, solar photovoltaics, wind and nuclear, in that order. Natural gas will expand its share from 23% in 2017 to 30% in 2050, becoming the largest electricity source. The expansion will come as the diffusion of combined cycle gas turbines (CCGTs) through technological development is coupled with natural gas's growing role in adjusting for intermittent renewable energy 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, nuclear power generation growth will fail to exceed electricity demand growth through 2050, consequently, the nuclear share of power generation will thus fall to 7% in 2050. Wind, solar PV and other renewable energy generation, excluding hydropower generation, will expand at a rapid annual rate of 5.5% on the strength of policy support and cost reduction, boosting its electricity mix share to about 20% in 2050. Driven by robust investment, natural gas-fired power plants will account for the largest share of global installed power generation capacity as well as power generation.

Figure 3-12 | Power generation in selected countries/regions [Reference Scenario]

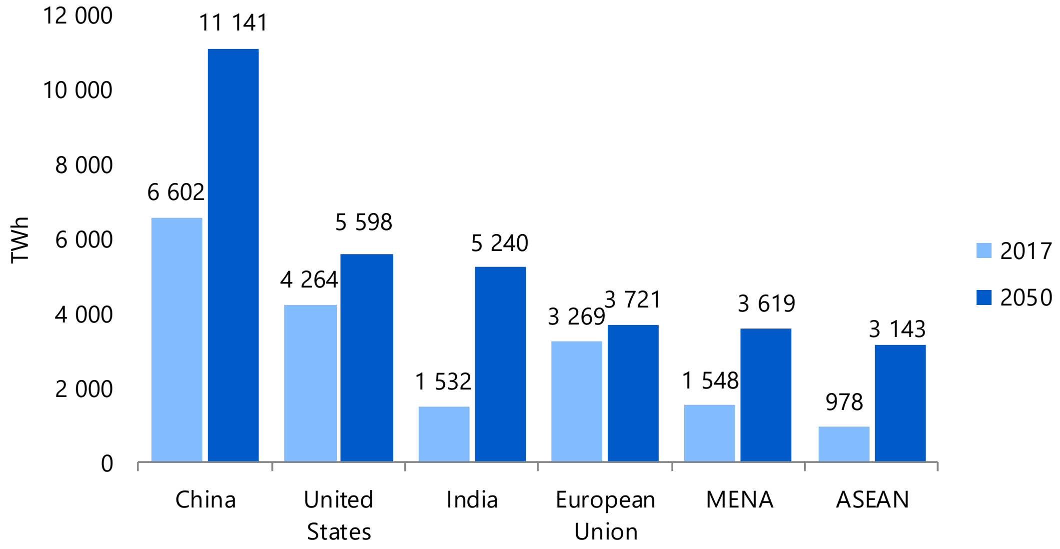
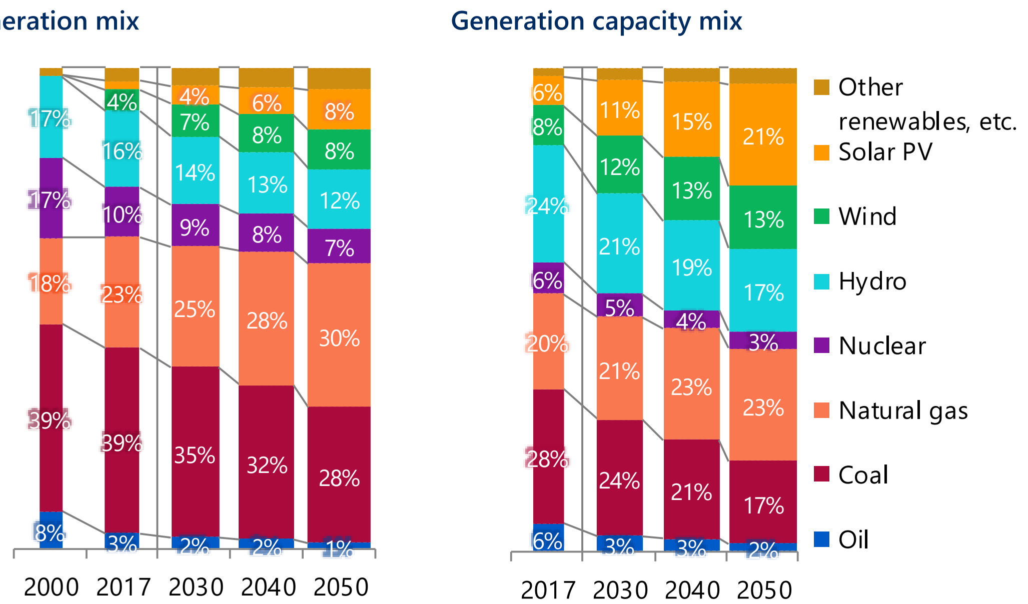


Figure 3-13 | Global power generation mix [Reference Scenario]

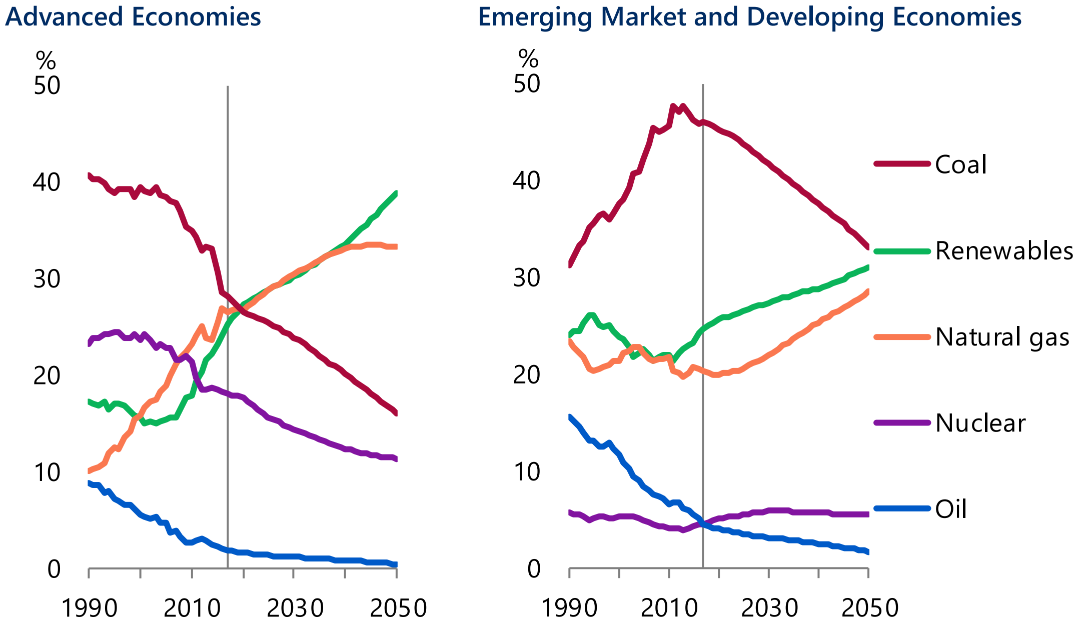


Note: Bar widths are proportionate to total power generation.

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

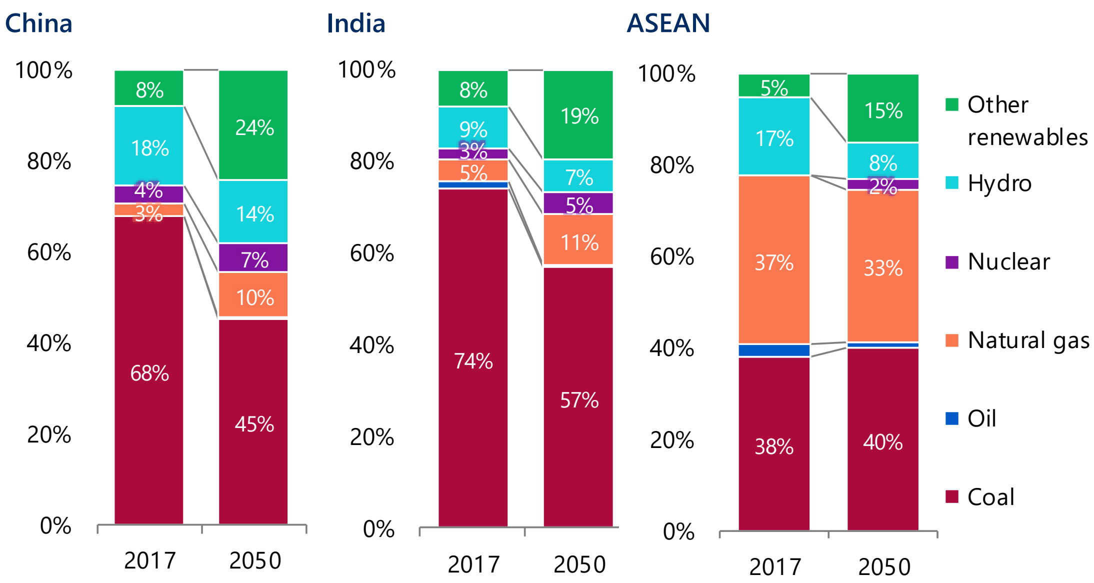
In the Advanced Economies, renewable energy's share of total power generation will reach 30% in 2030 and 40% in 2050, replacing natural gas as the largest share (Figure 3-14). Solar PV and wind among renewables will account for 23% of total power generation, requiring each region to promote adjustments for output fluctuations. Coal's share, now the largest, will substantially decline to 16% in 2050 under a policy of shifting away from coal-fired power generation in such countries as Canada and Italy and financial institutions' policy of keeping from investment 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, despite falling from the current level. The development of a highly predictable investment environment and of solutions to air pollution and other environmental problems will be urgently required for coal-fired power generation to meet their robust electricity demand. Natural gas and renewable energy will expand their respective shares to nearly 30% in 2050, becoming major electricity sources.

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



In China and India, coal will remain a mainstay electricity source in response to the rapid electricity demand growth. However, its high share of the power generation mix will fall gradually, while renewable energy and natural gas expand theirs (Figure 3-15). In ASEAN, meanwhile, natural gas's share of the power generation mix will decline on domestic natural gas production's failure to catch up with electricity demand growth, allowing coal's share to continue rising.

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



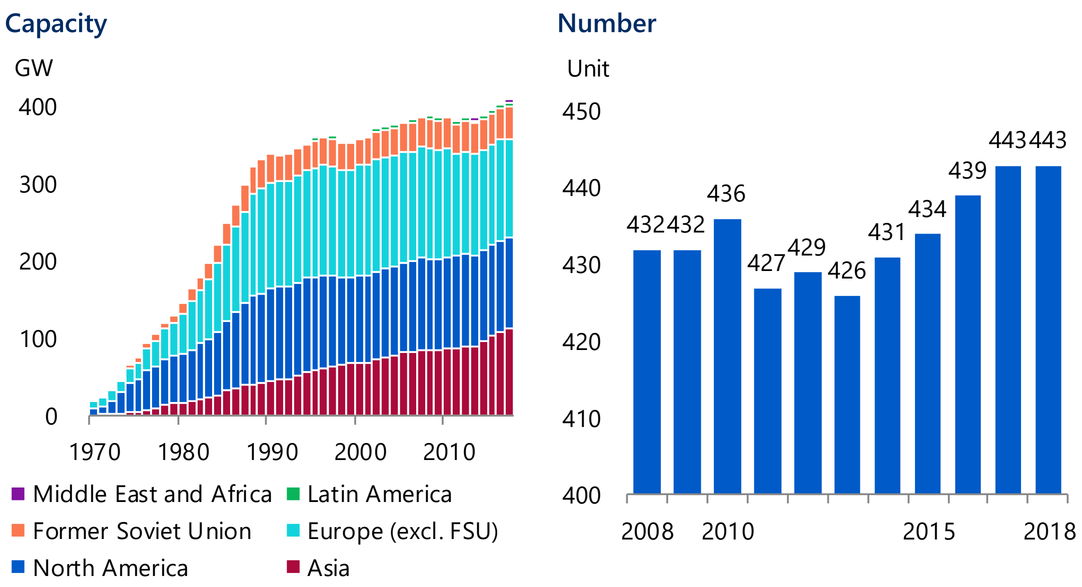
Nuclear

Global installed nuclear power generation capacity rapidly expanded mainly in Europe and the United States in the 1970s and 1980s before slowing down and levelling off in the 1990s. In the second half of the 1990s, the capacity decreased as poorly performing reactors were decommissioned in Europe and the United States. Since the 2000s, however, the capacity has been steadily expanding mainly in Asia, though more slowly than in the 1970s. (Figure 3-16 left side).

After the March 2011 Fukushima Daiichi Nuclear Power Station accident, the number of nuclear reactors in operation in the world declined temporarily due to the shutdown of reactors for the implementation of safety measures under new regulatory standards in Japan and the decommissioning of reactors based on a nuclear policy change in Germany and on economic reasons in the United States. Thanks to new nuclear reactor construction mainly in Asia, however, the present number of operating nuclear reactors exceeds the level before the Fukushima accident (Figure 3-16 right side).

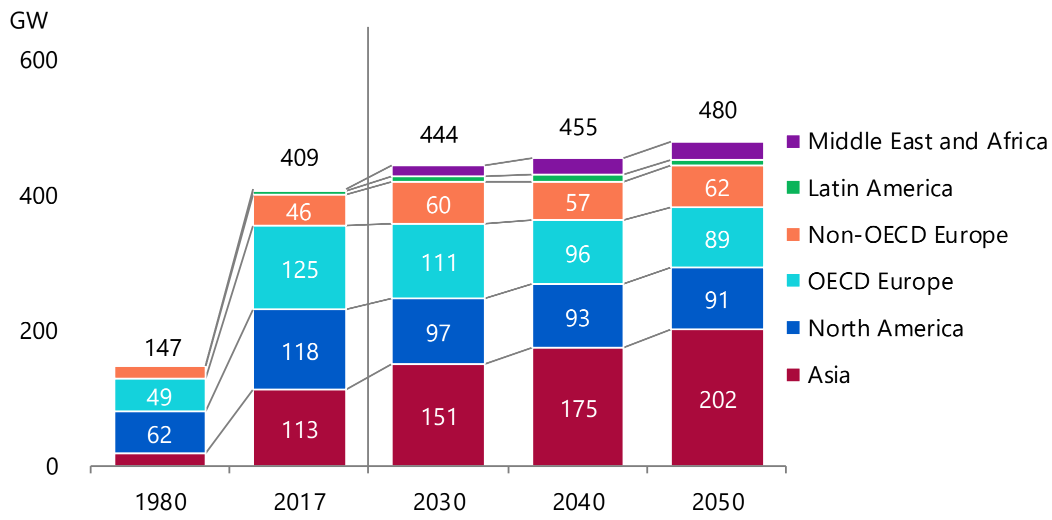
Because of changes in public opinion triggered by the Fukushima accident, growth in construction cost and other factors, it is now difficult to build new nuclear plants as planned earlier in Japan, Korea, the United States and some European countries. Compounding the issue, the reactors constructed in the 1970s and 1980s are being decommissioned. In the future, therefore, not a small number of countries will reduce nuclear power generation. These countries, however, will retain some nuclear power generation capacity to secure stable energy supply, address climate change, and maintain and enhance international competitiveness through their respective nuclear industry promotion. On the other hand, China and some other countries will further promote nuclear power generation. Therefore, global nuclear power generation capacity will increase gradually through 2050 (Figure 3-17).

Figure 3-16 | Capacity and number of nuclear reactors



In the United States, the world's largest nuclear generating country with 98 reactors, new nuclear plant construction has slowed down as the economic advantages of natural gas-fired power generation increased thanks to shale gas developments and because of the expansion of low-cost renewable energy power generation. The country is even shutting down some existing reactors for economic reasons. Efforts are being pursued to build new reactors and extend the lifespan of existing reactors to 60-80 years and some states are promoting measures to avoid the early decommissioning of existing reactors. However, U.S. installed capacity for nuclear power generation will decrease gradually through 2050 (Figure 3-17).

Figure 3-17 | Nuclear power generation capacity by region [Reference Scenario]



In France, known as the largest nuclear energy promoter in Europe, the Energy Transition Law was enacted in 2015 to limit installed nuclear power generation capacity to the present 66 GW (63.2 GW in net power output) and reduce the nuclear share of power generation to 50% by 2025 (from 75% in 2016). 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 current nuclear power generation capacity for the immediate future and reduce the capacity over a longer term. Germany, Switzerland and Belgium have made clear their nuclear phase-out plans in response to the Fukushima accident and will eliminate nuclear power generation between 2025 and 2035 under government plans. Other European OECD countries will reduce their capacity through 2050, despite some moves to construct new capacity, as outdated reactors are decommissioned. 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 33 GW in 2030 before leveling off later.

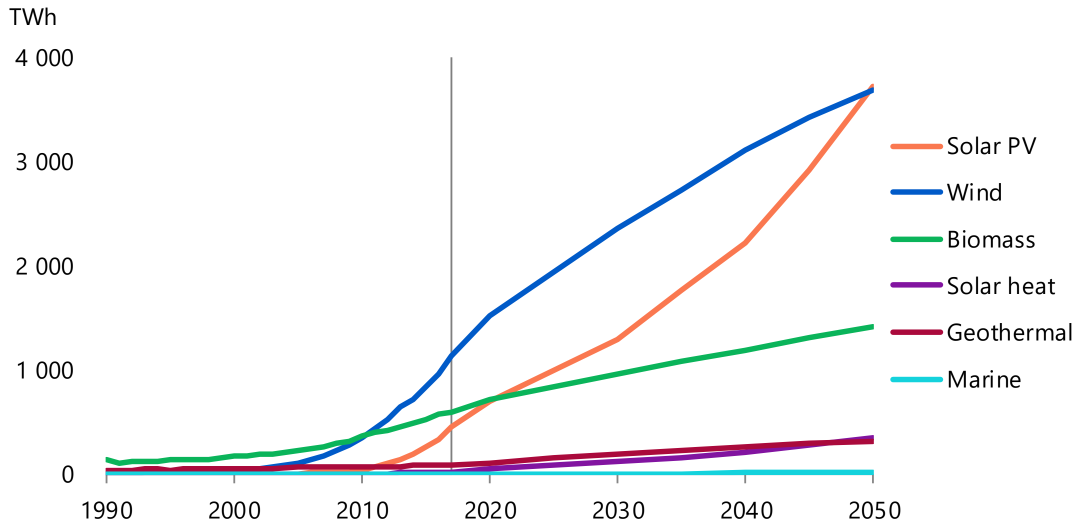
From 2030, Middle Eastern, African, Latin American and other countries, which have so far developed little nuclear power generation, will rise as nuclear power generators. The United Arab Emirates, Saudi Arabia and Iran will lead the Middle East to raise the region's installed nuclear power generation 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 plants.

The presence of Asia, including China and India, in nuclear power generation will increase more and more. China will boost its installed nuclear power generation capacity from 36 GW in 2017 to 93 GW in 2040, replacing the United States as the largest nuclear power generator in the world. Asian installed nuclear power generation capacity will reach 187 GW in 2045, surpassing the combined OECD Europe and North American capacity of 185 GW.

Renewables

Great expectations are globally placed on renewable energy. Since the mid-2000s, variable renewable energies such as solar PV and wind have remarkably expanded due to cost drops as well as incentive policies mainly in European developed countries, Japan, the United States and China. As the economic efficiency of renewable energy power generation has improved, governments have accelerated moves to modify or scale down incentive policies for wind and solar PV power generation in recent years. The United States is planning to phase out or terminate relevant investment and production tax credits. China publicly invited bids for unsubsidised wind and solar PV power generation projects in 2019, with more than 20 GW projects for construction. Japan is considering building new institutions to encourage independent wind and solar PV power generation when the Feed-in Tariff Scheme will be fundamentally modified in FY2020. In this way, renewable energy power generation capacity will continue expanding, centering on wind and solar PV power plants backed by substantial cost reductions (Figure 3-18). Generation from variable renewables will increase from 1 722 TWh in 2017 to 5 101 TWh in 2050. Variable renewables will boost their share of global power generation from only 6% in 2017 to 16% in 2050, increasing their presence in the electricity system.

Figure 3-18 | Global renewable power generation except hydro [Reference Scenario]



Europe, China and North America are major wind power generation markets at present and will continue to drive the global wind power generation expansion (Figure 3-19). While growth for onshore wind power generation capacity is decelerating due to transmission line constraints and a decline in suitable onshore locations for wind power development, offshore wind power generation will take advantage of its increasing economic efficiency to expand the overall wind power generation in these regions. In other regions, emerging market economies such as India, Brazil and Mexico will raise their onshore wind power generation capacity. Installed wind power generation capacity in the world will nearly quadruple from 515 GW in 2017 to 1 810 GW in 2050.

The global solar PV market will continue expanding as China, India, the United States and Japan replace Europe as the market leader (Figure 3-20) despite the fact that on a global basis, solar PV power generation still costs more than traditional power generation technologies. In solar PV auctions in Chile, Mexico, the United Arab Emirates, the United States and other countries rich with solar radiation, however, bid prices as low as less than $35/MWh have been recorded, indicating that solar PV generation will grow more competitive. In the Reference Scenario, installed solar PV generation capacity in the world will expand more than seven-fold from 386 GW in 2017 to 2 954 GW in 2050. As costs fall continuously over the long term, the net capacity growth will accelerate in the second half of the outlook period, reaching 1 157 GW between 2040 and 2050.

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

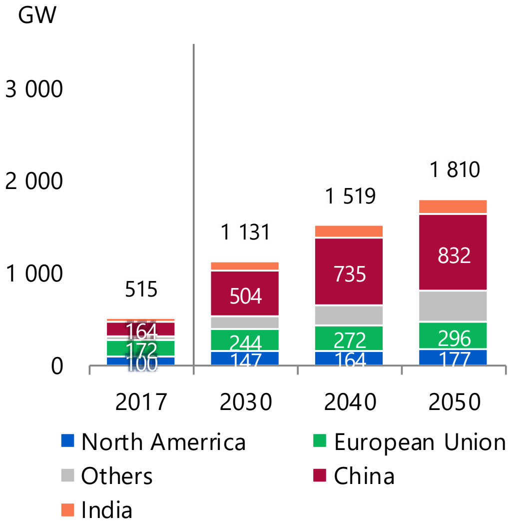
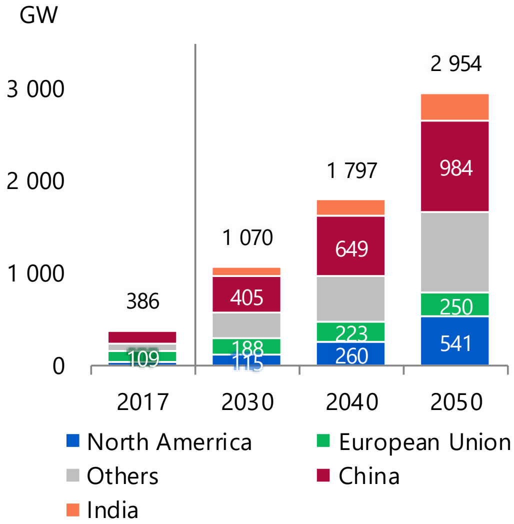


Figure 3-20 | Global solar PV power generation capacity [Reference Scenario]



For the IEEJ Outlook 2020, we have developed detailed power mix models for China, India, Japan, the United States, ASEAN and the European Union to track costs for variable renewables. Considering the uneven distribution of wind and solar PV resources, hourly fluctuations, constraints and costs regarding storage, transmission and output restrictions, we have found 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 cuts and more abundant suitable sites for such power generation.

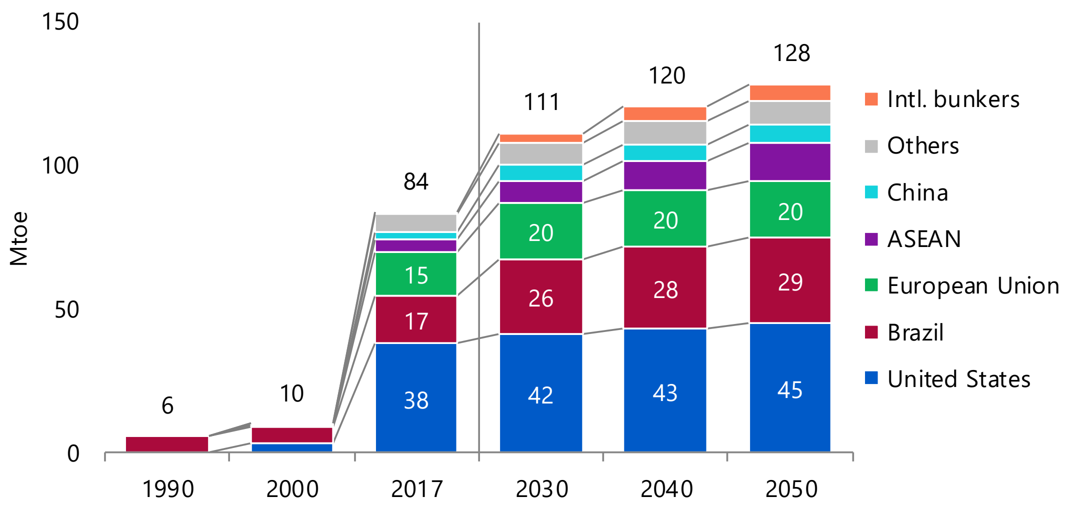
Renewable energy will potentially contribute to holding down fossil fuel price hikes as well as reducing carbon emissions from power supply and dependence on foreign energy sources. Even in the Reference Scenario, renewable energy power generation capacity will increase robustly. To expand renewable energy more than in the Reference Scenario, however, research and development efforts to further cut costs and increase efficiency will be required along with innovative incentive policies for power sources that tend to be plagued with slow diffusion and renewables' harmony with energy and social systems. For such harmony, variable renewables will have to be coupled with technologies and institutions for integrating them into the electricity system. Also, for such harmony, biomass power generation must be supported by a sustainable biomass supply chain giving considerations to land utilisation, and geothermal power generation with environmental protection and understanding by existing uses of geothermal resources.

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 more than 80% of biofuel consumption in 2017.

Global biofuel consumption will increase from 84 Mtoe in 2017 to 128 Mtoe in 2050 (Figure 3-21). In the future, biofuel consumption will remain concentrated in the same regions. In the United States, biofuel consumption will slightly increase on the penetration of vehicles that can run on fuels with high bioethanol contents. In Brazil, biofuel consumption will expand thanks to the spread of flexible fuel vehicles that can use both ethanol and gasoline. In the European Union, biofuel consumption growth will decelerate 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 countries will sharply boost biofuel consumption, Asian biofuel consumption will fall short of rivalling European, U.S. or Brazilian levels. Bio jet fuel, which is used little at present, will begin to be used for international aviation in 2020 or later.

Figure 3-21 | Liquid biofuel consumption [Reference Scenario]



4. Advanced Technologies Scenario

4.1 Major measures

In the Advanced Technologies Scenario, measures that 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 further enhancing climate change measures. As such, the policies will accelerate the development and introduction of innovative technologies globally. Against the backdrop of introducing environmental regulations and national targets, of enhancing technological development and of promoting international technological cooperation, the demand side will strongly adopt energy efficient equipment and the supply side will further promote renewable and nuclear energy (Table 4-1).

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

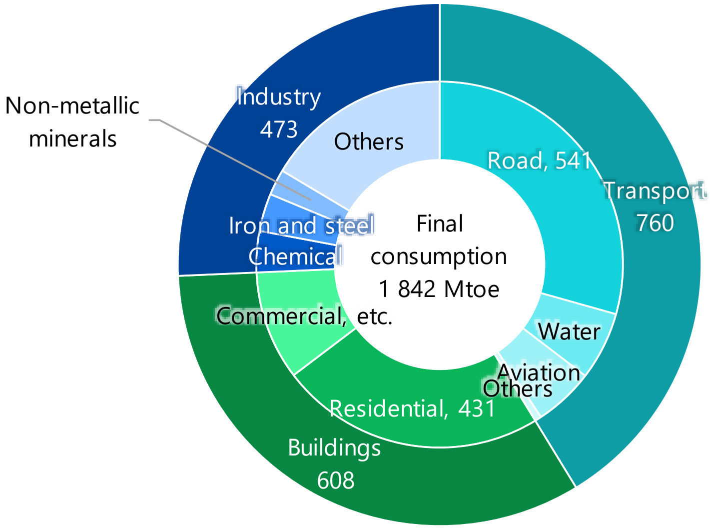
2017 → 2050 (Reference Scenario, 2050)

	Advanced Economies	Emerging Market and Developing Economies
Fossil fuel-fired power generation	Developing an initial investment finance scheme. Share of IGCC in newly installed plats: 0% → 60% (20%) Installing CCS from 2030 (Countries with carbon storage potential excluding aquifers)	
[Thermal efficiency (stock basis)]	Natural gas: 48.8% → 62.2% (59.8%) Coal: 37.3% → 44.2% (44.6%)	Natural gas: 37.1% → 55.9% (47.5%) Coal: 35.6% → 43.0% (41.3%)
Nuclear power generation	Maintaining appropriate wholesale power prices	Developing an initial investment finance framework
[Capacity]	2017: 308 GW → 290 (215)	2017: 101 GW → 426 (265)
Renewables [Capacity]	System cost reduction Power system stabilisation technology cost reduction Efficient power system operation Wind: 260 GW → 1 315 (886) Solar PV: 186 GW → 1 050 (751)	System cost reduction Low-cost finance Advancing power systems Wind: 205 GW → 2 036 (1 368) Solar PV: 104 GW → 1 943 (1 359)
Biofuels	Developing next-generation biofuels Diffusing FFVs further	Biofuel cost reduction Agricultural policy position
[Consumption]	57 Mtoe → 108 (69)	27 Mtoe → 84 (54)
Industry	Full diffusion of best available technologies in 2050	
Transportation	Reducing fuel-efficient vehicle costs. Doubling ZEV travel distances.	
[New car fuel efficiency]	15.0 km/L → 40.9 (29.3)	13.3 km/L → 31.6 (22.3)
[ZEV' share of new vehicle sales]	1.2% → 68% (43%)	1.2% → 50% (26%)
Buildings	Doubling the pace of improving new electrical appliance efficiency 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 1 842 Mtoe less than in the Reference Scenario. The energy savings amount to 19% of global final energy consumption in 2017. Of the energy savings, the transport sector will account for 760 Mtoe, the buildings sector for 608 Mtoe and the industry sector for 473 Mtoe (Figure 4-1). The road sector will be responsible for 541 Mtoe in the transport sector and the residential sector for 431 Mtoe in the buildings sector. This is because vehicles and home appliances offer huge potential to improve energy efficiency. The Non-OECD will capture more than 50% of the energy savings in all final energy consumption sectors, including the industry sector where the non-OECD will account for 80% of energy savings. Whether or not the non-OECD would realise potential energy savings mainly in the industry sector is key to global energy savings progress.

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



By introducing already available high-efficiency technologies to energy-intensive industries such as steel, chemical, pulp and paper, and others, these industries could improve their energy intensity in 2050 by some 12% from the Reference Scenario (Table 4-2). Through energy intensity improvements, the non-OECD industry sector would reduce energy consumption by 379 Mtoe from the Reference Scenario. Asia, where basic materials industries account for a large share of production, will command 57% of the global energy savings. OECD countries are expected to implement energy conservation technology research programs and positive cooperation with developing countries. OECD countries' transfer of highly efficient technologies to non-OECD countries will make great contributions to improving energy efficiency.

In the transport sector, fuel efficiency and vehicle fleet mix improvements will make further progress. Hybrid vehicles and ZEVs, including electric, plug-in hybrid and fuel cell vehicles, will expand their share of vehicle sales in 2050 by 21 percentage points from the Reference Scenario. As a result of fuel efficiency and vehicle fleet mix improvements, the global average new vehicle fuel efficiency in 2050 will improve by 9.9 km/L from the Reference Scenario to 33.8 km/L (3.0 L/100 km). As ZEVs' share of the vehicle fleet mix in developed countries increases faster, the transport sector will post the largest energy savings among sectors in the OECD. 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.

Table 4-2 | Energy indicators

		2017	2050 Reference	2050 Advanced Technologies
Industry	Intensities (2017 = 100)			
	Iron and steel	100	74.7	65.4
	Non-metallic minerals	100	73.7	64.7
	Chemical	100	79.3	70.0
	Paper and pulp	100	85.3	75.4
	Other industries	100	67.9	59.0
Transport	New passenger vehicle fuel efficiency (km/L)	14.1	23.9	33.8
	ZEVs' share of vehicle sales	0.9%	27%	48%
	Natural gas's share in intl. marine bunkers	0.0%	21%	41%
	Biofuel's share of intl. aviation bunkers	0.0%	1.6%	19%
Buildings	Overall energy efficiency (2017 = 100)	100	65.1	53.3
	Residential	100	35.8	30.1
	Commercial	100	35.8	30.1
	Electrification rate			
	Residential	24%	38%	41%
	Commercial	52%	65%	65%

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

It is more difficult for energy conservation incentives to work in the buildings sector than in the industry sector that is highly conscious of energy conservation for economic reasons. Therefore, both the OECD and non-OECD have great potential to reduce energy consumption in the buildings sector. The overall global residential and commercial energy efficiency will improve by about 15%. Energy efficiency improvements for space and water heating systems in cold regions and insulation improvements in the non-OECD will make great contributions towards 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 mainly through the expansion of electrification and the diffusion of modern cooking equipment in such areas. Electricity consumption will decline substantially as energy conservation in fields such as cooling, powering and lighting more than offsets 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 2017 to 24% in 2050, 8 percentage points higher than in the Reference Scenario. Particularly, wind and solar PV power generation will boost their combined share from 1.0% in 2017 to 7.3% in 2050.

As decarbonisation initiatives are enhanced, the spread of wind power generation will accelerate in all regions thanks to the development of electricity transmission infrastructure, the lower cost of energy storage technologies and the subsequent promotion of wind power generation. Onshore wind power generation will remarkably expand in China, India and other regions. Offshore wind power generation will spread due to technological development and cost cuts in China in addition to Europe that has so far led the expansion of such form of power generation (Figure 4-2). Installed capacity for onshore and offshore wind power generation in the world in 2050 in the Advanced Technologies Scenario will reach 3 065 GW, 1.7 times as much as in the Reference Scenario.

Solar PV power generation will also accelerate its expansion globally. Its spread will be remarkable in regions other than the current major solar PV power generation markets (Figure 4-3). More specifically, solar PV power generation will significantly grow in the Sun Belt rich with sunlight resources, including the Middle East, North Africa and Latin America. Global installed solar PV power generation capacity in 2050 will be 4 434 GW, 1.5 times as large as in the Reference Scenario.

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

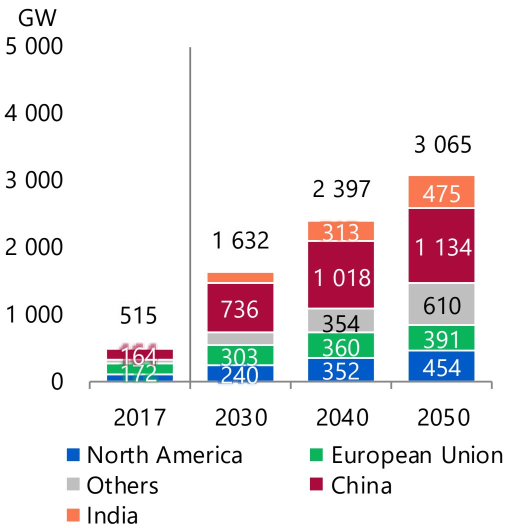
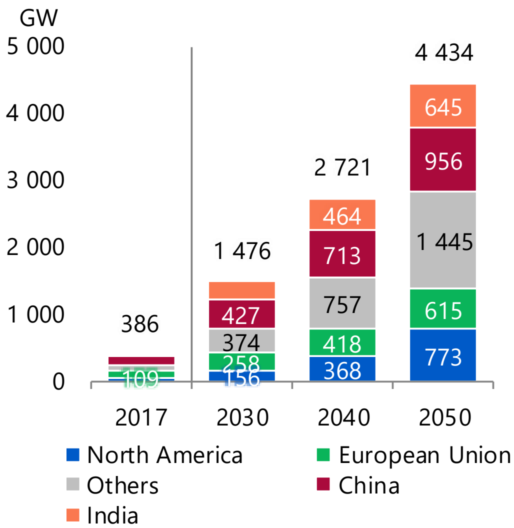


Figure 4-3 | Global installed solar PV power generation capacity [Advanced Technologies Scenario]



Factors for accelerating the spread of variable renewables include not only the reduction of costs for renewable energy power generation and energy storage technologies but also the mitigation of environmental load and the improvement of investors' and consumers' environmental consciousness. Also playing major roles in spreading these intermittent electricity sources will be power generation prediction technologies, output control, energy storage technologies, transmission and distribution network expansion and the enhancement of grid stabilisation through smart grid systems and information technologies.

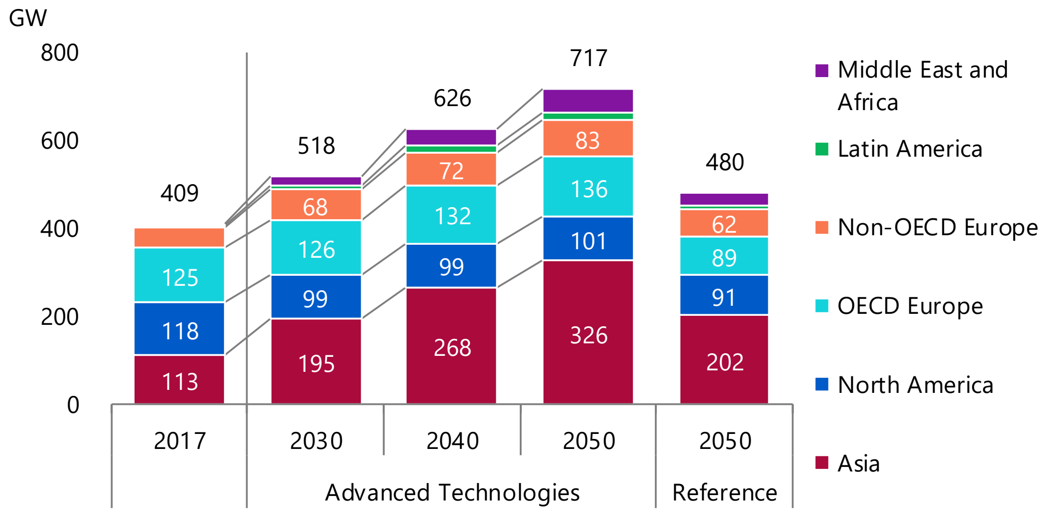
In addition to short-term energy storage technologies such as batteries, long-term energy storage technologies to adjust for seasonal output fluctuations could be required to realise the massive expansion of renewable energy power sources. Such technologies include hydrogen technologies. Europe and other regions have recently conducted conceptual design studies and demonstration tests for power-to-gas systems to use renewable energy electricity for producing hydrogen. Hydrogen can be used as fuel for power generation, transportation and heat supply in industrial and buildings sectors and as feedstocks for industrial processes. As such, great hopes are placed on hydrogen from the viewpoint of system integration to utilise renewable energy electricity in a cross-sectoral manner. If these technologies spread over the long term, renewable energy power sources may be promoted further.

Nuclear

Great expectations are placed on the introduction of nuclear power generation as a decarbonisation measure. Emerging Market and Developing Economies are considering introducing nuclear power generation to meet the rapid growth in their electricity demand and promote decarbonisation. Among countries that have traditionally and proactively promoted nuclear power generation, the United States and France will reduce their nuclear power generation capacity from 2017. On the other hand, the United Kingdom and Russia will build new nuclear power plants to increase their capacity. Countries such as Belgium clarified their nuclear phase-out policy in response to the Fukushima accident but could change that nuclear power plants phase-out policy and replace decommissioned capacity to promote decarbonisation and maintain their industrial competitiveness.

In the Advanced Technologies Scenario, installed nuclear power generation capacity will increase from 409 GW in 2017 to 717 GW in 2050 (Figure 4-4), some 1.5 times as much as 480 GW 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 101 GW in 2050 due primarily to a decrease in the United States. Factors behind the U.S. capacity decrease include shutdowns due to with deteriorated efficiency, a recent slowdown in electricity demand, and cheap natural gas and renewable energy prices. The U.S. federal government and some state governments are reassessing nuclear energy’s low-carbon value and the reliability of nuclear energy supply. As such they are considering incentives for nuclear research and development and nuclear power generation could play a slightly greater role than in the Reference Scenario. North American installed nuclear power generation capacity in the Advanced Technologies Scenario will be 90 GW (against 87 GW in the Reference Scenario) in 2050.

OECD Europe will decommission outdated reactors and construct replacements, eventually increasing installed nuclear power generation capacity in 2050 to 136 GW from 125 GW in 2017. In the United Kingdom, for example, installed capacity will increase to 16 GW in 2050 as new plants are built, while some outdated reactors are being decommissioned.

Russia will accelerate the construction of new nuclear power plants, sharply expanding installed nuclear power generation capacity from 28 GW in 2017 to 34 GW in 2040. While Russian capacity levels off later, East European countries will steadily implement their nuclear power plant construction.

In Asia, China and India will lead new nuclear power plant construction and Southeast Asian countries will make some progress. Asia's installed nuclear power generation capacity will surpass the combined capacity of OECD Europe and North America (at 225 GW) in 2035 and reach 326 GW in 2050. China will boost its capacity beyond the U.S. level of 88 GW and replace the United States as the world's largest nuclear power generator in 2035. It will expand its capacity further to 143 GW in 2050. India, though with installed nuclear power generation capacity limited to 7 GW in 2017, has put forward a proactive nuclear capacity expansion target and will boost its capacity to 29 GW in 2030 and to 71 GW in 2050.

The Middle East, Africa and Latin America, known as emerging nuclear energy markets, will launch the operation of new reactors around 2025 and steadily expand installed nuclear capacity thereafter. In the Middle East where mainly the United Arab Emirates and Saudi Arabia are planning to build nuclear power plants, installed nuclear power generation capacity will reach 15 GW in 2030 and 30 GW in 2050.

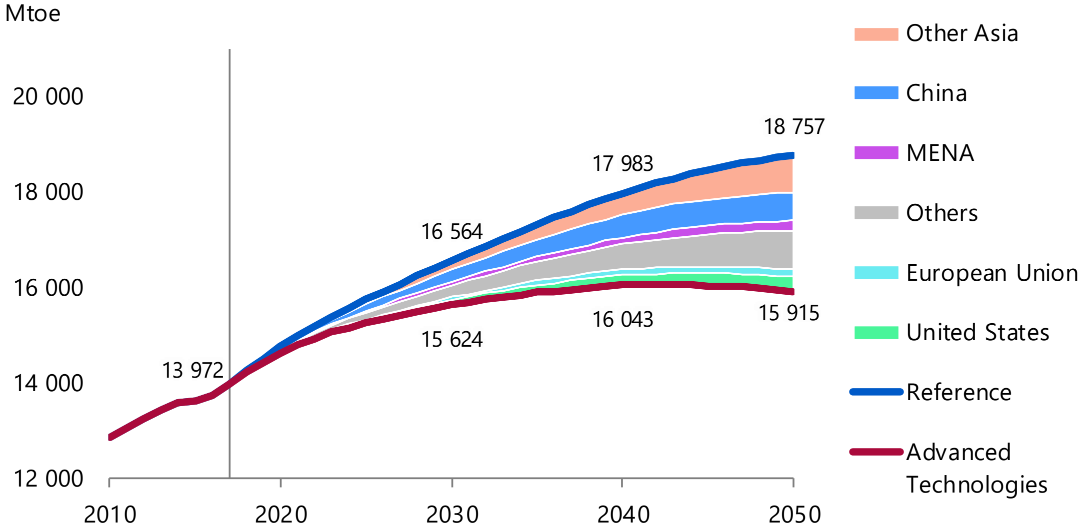
4.2 Energy supply and demand

Primary energy consumption

The strong implementation of the abovementioned energy conservation and climate change measures will substantially reduce primary energy consumption (Figure 4-5). Primary energy consumption in 2050 in the Advanced Technologies Scenario will total 15 915 Mtoe, down 2 841 Mtoe from the Reference Scenario. The gap corresponds to some 20% of global primary energy consumption in 2017. Accumulated energy savings through 2050 will total about 45 Gtoe, 3.2 times as much as the current annual global primary energy consumption.

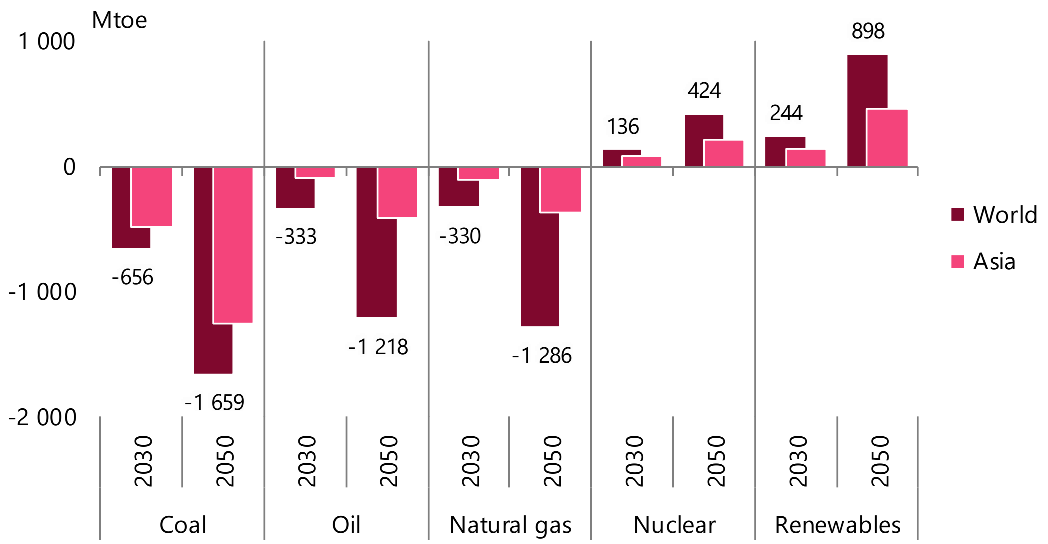
The Emerging Market and Developing Economies and Asia, projected to expand energy demand while offering great energy conservation potential, will play a great role in the transition towards the Advanced Technologies Scenario. The Emerging Market and Developing Economies will account for 73% of global energy savings in 2050 and Asia for 48%. Energy consumption in the Emerging Market and Developing Economies and Asia holds the key to reforming the broadly defined global energy system, including consumption and production patterns for energy sources required by the world and energy consumption's influence on the global environment.

Figure 4-5 | Global primary energy consumption and savings by region



Among energy sources, fossil fuels will post great primary energy consumption savings (Figure 4-6). Of the 2 841 Mtoe decline in primary energy consumption from the Reference Scenario in 2050, coal will account for 1 659 Mtoe, oil for 1 218 Mtoe and natural gas for 1 286 Mtoe. Meanwhile, nuclear and renewable energy will accelerate their penetration. Nuclear consumption in the Advanced Technologies Scenario will be 424 Mtoe (222 Mtoe in Asia) more than in the Reference Scenario. Renewable energy consumption excluding hydro will be 898 Mtoe (465 Mtoe in Asia) more. As a result, fossil fuels' share of primary energy consumption in the Advanced Technologies Scenario will fall from 81% in 2017 to 68% in 2050.

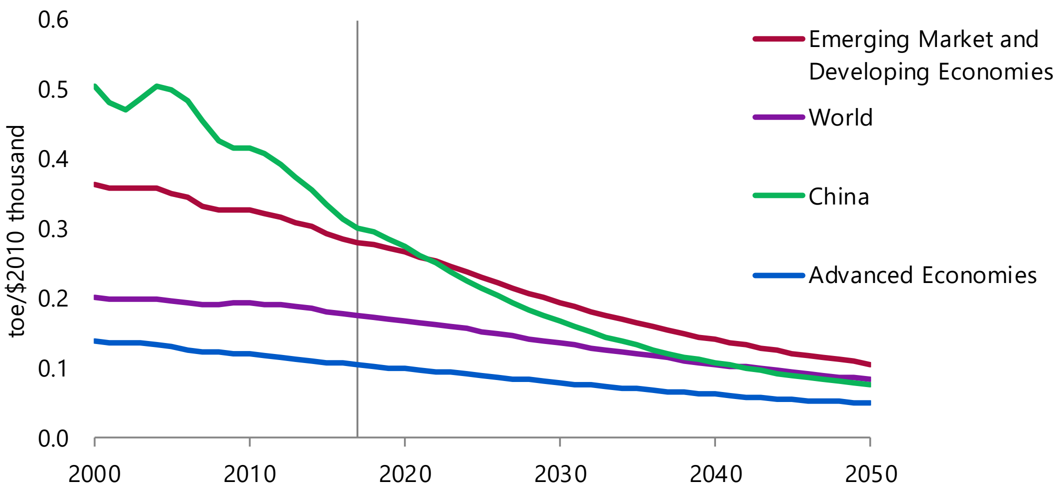
Figure 4-6 | Final energy consumption changes from Reference Scenario [Advanced Technologies Scenario]



Asia, including China and India, will account for 49% of the fossil fuel consumption savings. Particularly, Asia will capture as much as 78% of the coal consumption savings while accounting for 52% of the growth in nuclear and renewable energy consumption.

The world's GDP energy intensity, or primary energy consumption per unit of GDP, an indicator of macro energy efficiency, will plunge by 52% from 2017 to 2050 (Figure 4-7). The Advanced Economies will post a moderate decline of 53% against 62% for the Emerging Market and Developing Economies, which have greater potential to improve energy efficiency. The gap is narrowing between the two groups. China's GDP energy intensity, which has already been rapidly declining due to industrial structure changes, will continue declining to soon slipping below the average for the Emerging Market and Developing Economies; it will catch up with the global average by around 2040. Asia's GDP energy intensity will drop by 61% by 2050.

Figure 4-7 | GDP energy intensity [Advanced Technologies Scenario]

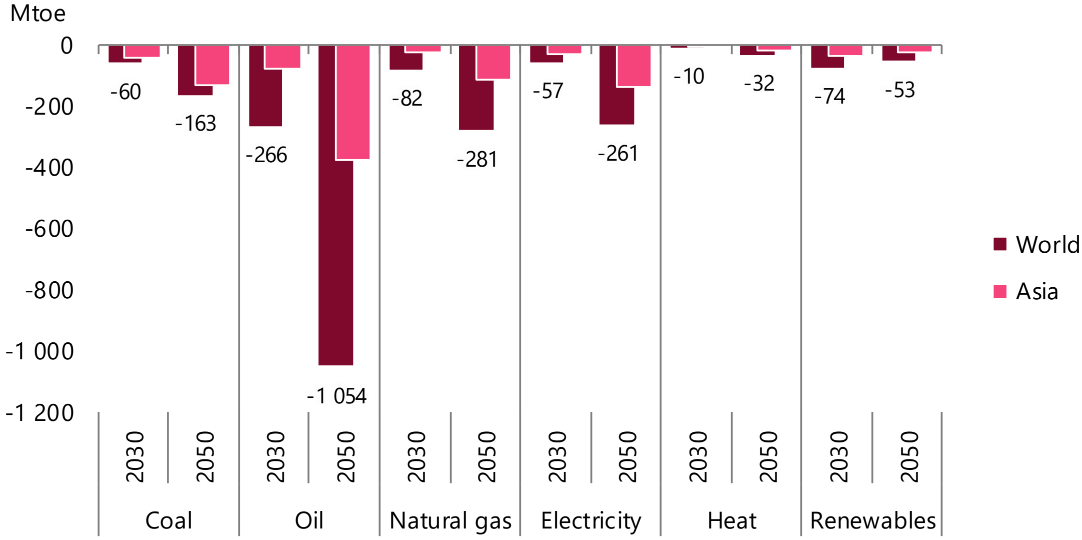


Asia will play a very important role in realising the global energy system depicted in the Advanced Technologies Scenario. Asia must eliminate energy conservation barriers including the lack of fundraising capacity and consciousness that blocks the penetration of technologies. The region must spread energy-saving equipment by offering reasonable prices to low-income people and provide energy-saving technologies that take into consideration differences between urban and suburban lifestyles. Each country must implement education programs to enhance energy conservation consciousness on a nationwide basis. Bilateral cooperation schemes, as well as multilateral frameworks such as the ASEAN+3 and Asia Pacific Economic Cooperation forums, will help promote such education.

Final Energy Consumption

Final energy consumption in 2050 in the Advanced Technologies Scenario will be 1 842 Mtoe less than in the Reference Scenario. Of the energy savings, oil will account for 1 054 Mtoe or 57% (Figure 4-8).

Figure 4-8 | Final energy consumption changes from Reference Scenario [Advanced Technologies Scenario]



Advanced Economies should cooperate with Emerging Market and Developing Economies in improving power generation efficiency globally. Emerging Market and Developing Economies frequently fail to include environmental considerations, giving top priority to high economic growth. For example, they hesitate to address air pollution from fossil fuel-fired power generation as efforts to solve air pollution problems are likely to reduce economic efficiency. Therefore, it will become more important that Advanced Economies take advantage of their overcoming of past environmental problems to cooperate with Emerging Market and Developing Economies.

In addition to technologies for improving power generation efficiency, those for limiting electricity consumption itself are important. A particularly key challenge in Advanced Economies as well as others is how to de-couple increases in electricity consumption in the buildings sector from improvements in living standards. Home energy management systems (HEMS) including smart meters, building energy management systems (BEMS) and other technologies to control energy consumption are expected to spread in Advanced Economies and be transferred to Emerging Market and Developing Economies.

Energy conservation progress in the transport sector will make great contributions to oil consumption savings. In the Advanced Technologies Scenario, oil's share of energy consumption in the road sector will decline from 94% in 2017 to 77% in 2050 as ZEVs spread (Figure 4-9). From the Reference Scenario, electricity will post the largest increase in the sector's energy consumption (Figure 4-10).

Figure 4-9 | Global road sector energy consumption mix

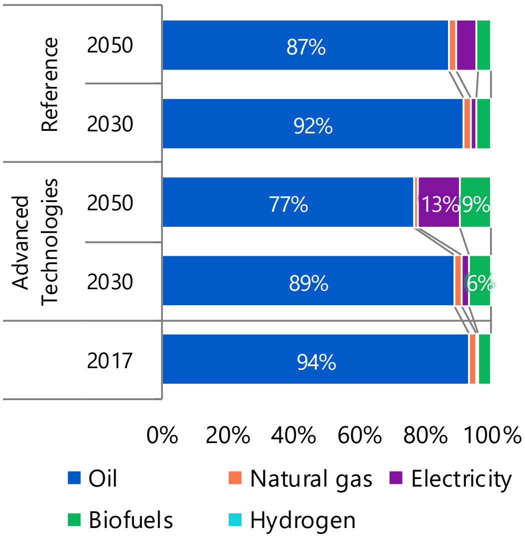
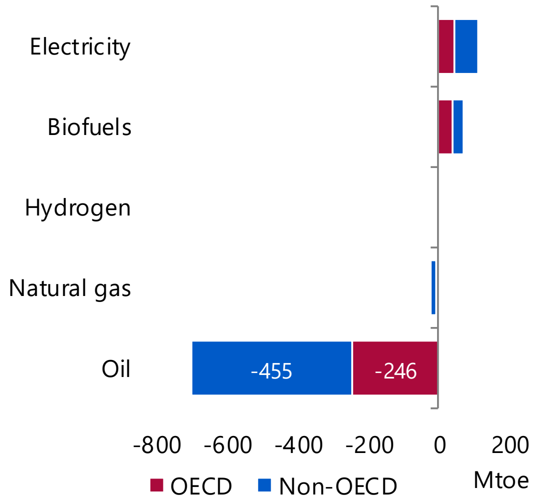


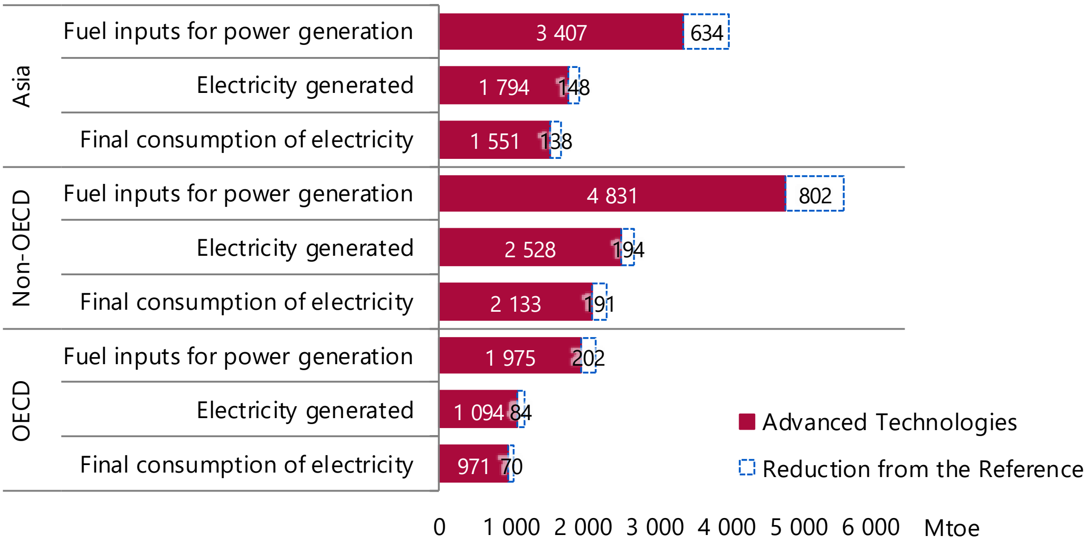
Figure 4-10 | Global road sector energy consumption changes from Reference Scenario [Advanced Technologies Scenario, 2050]



Final electricity consumption in 2050 in the Advanced Technologies Scenario will be reduced by 261 Mtoe from the Reference Scenario, lowering the required power generation by 280 Mtoe and primary energy consumption by 1 010 Mtoe (Figure 4-11). The consumption savings are equivalent to 36% of total primary energy consumption savings. Making great contributions to the savings will be Asia. Through the introduction of new power generation equipment and the replacement of outdated equipment accompanying electricity demand growth, Asian Emerging Market and Developing Economies' power generation efficiency will improve substantially to almost the same levels as in Advanced Economies by 2050.

Asia will account for 79% of the global final coal consumption reduction totaling 163 Mtoe in 2050. In this respect, steelmakers' energy conservation will be important in India and other countries where crude steel production will expand rapidly. Japan's energy consumption per unit of steel production is one of the lowest levels in the world, standing at about one-third of India's. If highly efficient technologies are transferred to Asian Emerging Market and Developing Economies, including India, relevant sectors' energy consumption savings will become more feasible. Advanced Economies will contribute to energy savings not only in energy-saving equipment and other hardware but also in software including equipment operations.

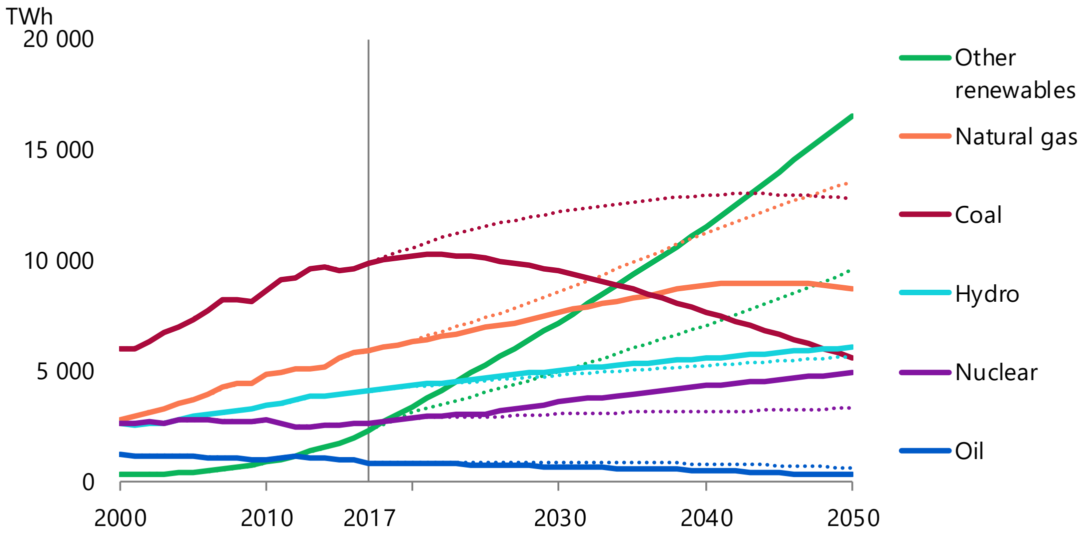
Figure 4-11 | Primary energy consumption reduction through final electricity consumption savings [Advanced Technologies Scenario, 2050]



Power generation mix

In the Advanced Technologies Scenario, final electricity consumption savings will work to cut power generation by about 3 236 TWh, equivalent to power generation in OECD Europe in 2017. The integrated gasification combined cycle (IGCC) for coal-fired power generation and the development of technology for mixing coal with biomass will contribute to cutting coal consumption for power generation substantially. In contrast to coal, non-hydro renewables including solar PV, wind and biomass will become the largest power source and nuclear power generation will gradually increase (Figure 4-12).

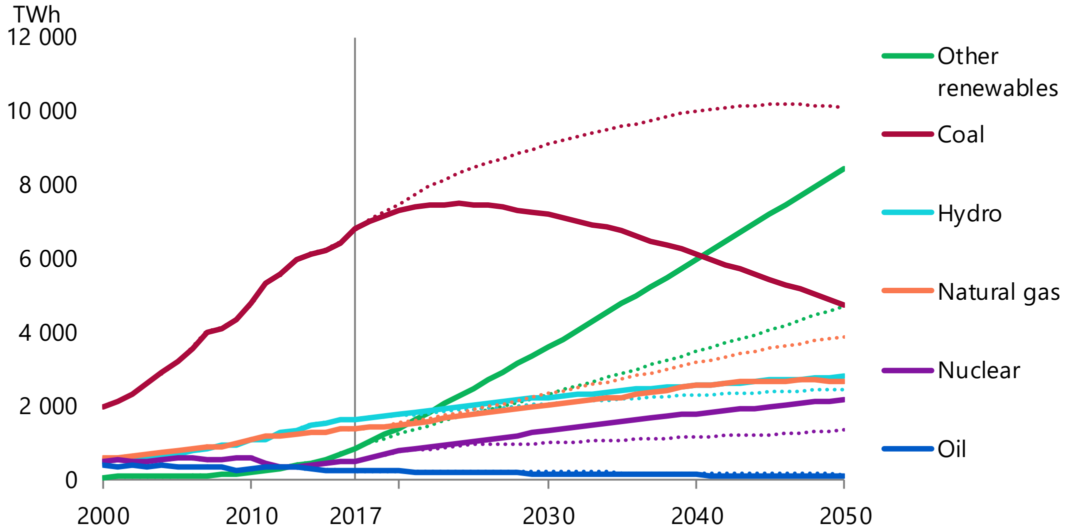
Figure 4-12 | Global power generation mix [Advanced Technologies Scenario]



Note: Dashed lines represent the Reference Scenario.

Although coal-fired power generation will also be reduced substantially in Asia, coal will still account for a major share of power generation in 2050 (Figure 4-13). Particularly, China and India should continue to expand renewable energy to reduce CO_2 emissions.

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



Note: Dashed lines represent the Reference Scenario.

Crude oil production

In the Advanced Technologies Scenario, progress in energy conservation and fuel switching will hold down oil consumption growth and lead oil consumption to peak around 2030 before declining thereafter. As a result, crude oil production in all regions will decrease generally from the Reference Scenario (Table 4-3).

As oil producing countries intensify competition with each other, OPEC's share of global crude oil production will be slightly higher than in the Reference Scenario thanks to an increase in production by the relatively cost competitive Middle Eastern OPEC members. Oil production will be much lower than in the Reference Scenario in Latin America, North America and Africa which are less cost competitive and, as Europe will reduce its oil consumption, production will drop in Europe and Eurasia including Russia. Meanwhile, Asian and other net oil importing countries will try to limit any decline in production from the viewpoint of supply security, even with relatively higher production costs. Their oil self-sufficiency rates will be higher than in the Reference Scenario.

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

(Mb/d)

	2017	2030	2040	2050	2017-2050	
					Changes	CAGR
Crude oil production	92.5	97.2	96.6	92.7	0.2	0.0%
OPEC	37.8	39.1	41.4	41.6	3.8	0.3%
Middle East	28.4	29.7	31.1	31.1	2.7	0.3%
Others	9.4	9.4	10.3	10.5	1.1	0.3%
Non-OPEC	54.7	58.0	55.2	51.1	-3.6	-0.2%
North America	17.9	22.2	20.4	17.5	-0.4	-0.1%
Latin America	6.8	7.9	8.8	9.3	2.5	1.0%
Europe and Eurasia	17.8	16.2	14.7	13.4	-4.4	-0.8%
Middle East	3.1	3.3	3.4	3.4	0.3	0.3%
Africa	1.3	1.4	1.4	1.4	0.1	0.2%
Asia and Oceania	7.8	7.0	6.5	6.1	-1.7	-0.8%
Processing gains	2.3	2.6	2.7	2.8	0.5	0.6%
Oil supply	94.8	99.8	99.3	95.5	0.7	0.0%

Note: Crude oil includes NGL.

Natural gas supply

In the Advanced Technologies Scenario, natural gas production will be 16% less than in the Reference Scenario in 2040 and 25% less in 2050. The drop in natural gas consumption reflects progress in energy utilisation technologies, including energy conservation technologies. The gaps for natural gas against the Reference Scenario are smaller than for oil or coal.

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

(Bcm)

	2017	2030	2040	2050	2017-2050	
					Changes	CAGR
World	3 755	4 390	4 685	4 606	851	0.6%
North America	945	1 212	1 239	1 138	193	0.6%
Latin America	215	249	303	308	93	1.1%
OECD Europe	248	136	85	50	-198	-4.8%
Non-OECD Europe / Central Asia	906	935	937	941	35	0.1%
Russia	694	693	722	734	40	0.2%
Middle East	629	766	820	878	249	1.0%
Africa	215	333	441	410	194	2.0%
Asia	486	585	672	688	202	1.1%
China	142	237	330	352	210	2.8%
India	31	57	72	72	41	2.6%
ASEAN	211	196	185	183	-28	-0.4%
Oceania	110	175	187	193	83	1.7%

The drop in production between the Reference and Advanced Technologies Scenarios is quite large in OECD Europe where natural gas development costs are relatively higher. The region's natural gas production in 2050 in the Advanced Technologies Scenario will be less than 40% of the anticipated level in the Reference Scenario. North American production will peak around 2040. The Middle East and non-OECD Europe including Russia will expand natural gas production steadily, though more slowly than in the Reference Scenario.

Coal supply

In the Advanced Technologies Scenario, coal consumption will decline due to improvement in coal utilisation efficiency and a fall in coal's share of the power generation mix. Consequently, coal production will decrease from 7 563 Mt in 2017 to 4 672 Mt in 2050 (Figure 4-14). Steam coal production will decline from 5 726 Mt in 2017 to 3 536 Mt in 2050, coking coal production from 1 013 Mt to 921 Mt and lignite production from 824 Mt to 215 Mt. From the Reference Scenario, coal production in 2050 will decrease by 3 580 Mt including 3 038 Mt for steam coal, 149 Mt for coking coal and 393 Mt for lignite.

Coal production will decline along with demand in all regions (Table 4-5). Particularly, steam coal production in North America, OECD Europe and China will plunge due to falling domestic demand.

Figure 4-14 | Coal production [Advanced Technologies Scenario]

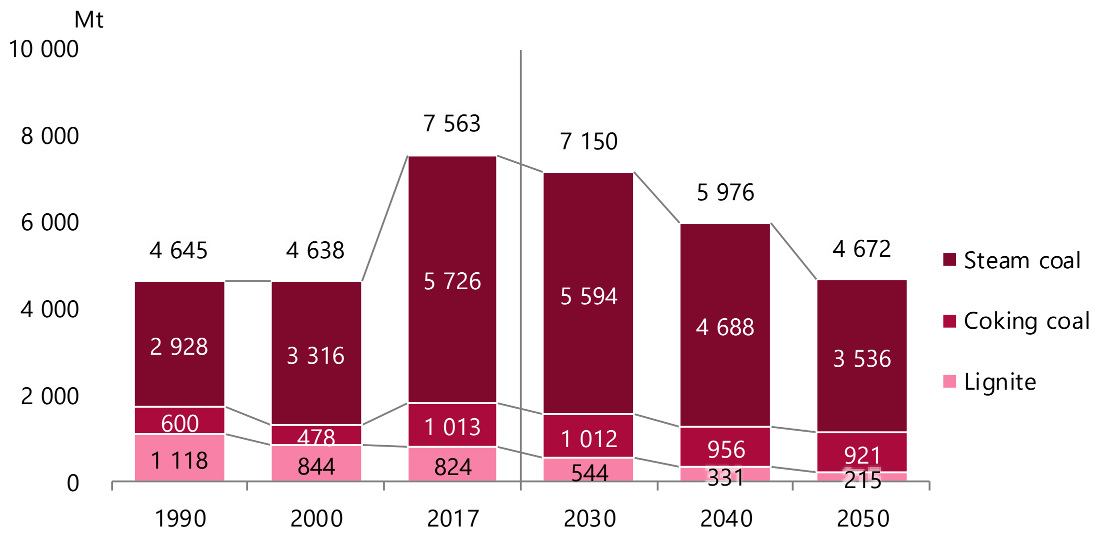


Table 4-5 | Coal production [Advanced Technologies Scenario]

Steam coal production (Mt)

	2017	2030	2040	2050	2017-2050 Changes	2017-2050 CAGR
World	5 726	5 594	4 688	3 536	-2 190	-1.4%
North America	597	407	246	94	-503	-5.5%
United States	574	403	245	93	-481	-5.4%
Latin America	100	96	74	56	-44	-1.8%
Colombia	86	86	66	50	-36	-1.6%
OECD Europe	66	42	26	11	-55	-5.3%
Non-OECD Europe / Central Asia	339	284	254	211	-128	-1.4%
Russia	227	204	176	143	-84	-1.4%
Middle East	0	0	0	0	0	-1.0%
Africa	264	274	240	185	-79	-1.1%
South Africa	253	260	225	172	-81	-1.2%
Asia	4 107	4 234	3 633	2 835	-1 271	-1.1%
China	2 882	2 673	2 144	1 531	-1 351	-1.9%
India	643	916	861	765	122	0.5%
Indonesia	490	533	515	429	-62	-0.4%
Oceania	254	256	215	144	-110	-1.7%
Australia	253	255	214	143	-109	-1.7%

Coking coal production (Mt)

	2017	2030	2040	2050	2017-2050 Changes	2017-2050 CAGR
World	1 013	1 012	956	921	-92	-0.3%
North America	94	86	82	78	-16	-0.5%
United States	65	58	55	51	-14	-0.8%
Latin America	9	11	11	11	2	0.7%
Colombia	4	5	5	6	1	0.7%
OECD Europe	18	16	15	14	-4	-0.8%
Non-OECD Europe / Central Asia	107	108	106	102	-5	-0.1%
Russia	86	86	82	77	-9	-0.3%
Middle East	1	2	2	2	0	0.7%
Africa	11	16	19	23	11	2.2%
Mozambique	7	12	15	19	12	3.0%
Asia	581	576	512	462	-119	-0.7%
China	515	482	402	330	-185	-1.3%
India	36	63	83	108	72	3.4%
Mongolia	26	25	21	18	-8	-1.2%
Oceania	191	198	209	229	37	0.5%
Australia	190	196	207	227	37	0.5%

4.3 CO_2/GHG emissions

In the Advanced Technologies Scenario in which energy conservation and low-carbon technologies will be further advanced, global energy-related CO_2 emissions will peak around 2025 and slowly decline (Figure 4-15) before standing at 25.3 Gt in 2050, down 22.7% from 2017. A CO_2 emission decline of 15.6 Gt or 38% from the Reference Scenario will surpass present OECD emissions at 9.3 Gt. The cumulative decline of 239 Gt through 2050 will be equivalent to 7.3 years' worth of present global annual emissions.

The non-OECD will account for about three quarters of the emission decline from the Reference Scenario in 2050, indicating developing countries' great potential to reduce emissions. A decline in China, the largest CO_2 emitter in the world, will come to 3.8 Gt, almost equivalent to the present emission level of 3.2 Gt for the European Union (Figure 4-16). A little more than 50% of the Chinese emissions decline in 2050 will be attributable to a coal consumption cut in the power generation sector. Power demand reduction, power generation efficiency improvement and switching to non-fossil fuel-fired power sources will become great factors to reduce CO_2 emissions in that sector (Coal-fired power generation accounts for 70% of current total Chinese power generation and will account to nearly 50% in 2050 in the Reference Scenario). India, which will replace the United States as the second largest CO_2 emitter in the world by 2035, will reduce emissions by 2.1 Gt, almost equivalent to its present emissions. As in China, the reduction in coal consumption in India, also heavily dependent on coal-fired power generation, will represent nearly 60% of the emission reduction. The reduction of CO_2 emissions in Asian and other developing countries will be indispensable to counter climate change. In this sense and in addition to developing countries' emission reduction efforts, developed countries' relevant technology transfers and institution-building support to spread low-carbon technologies will be very significant.

Figure 4-15 | Global energy-related CO_2 emissions

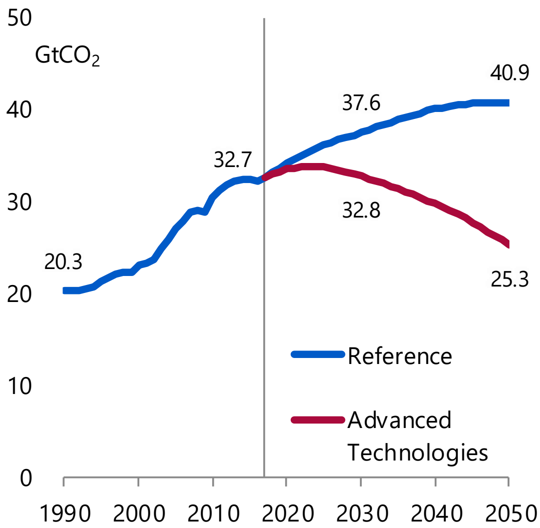
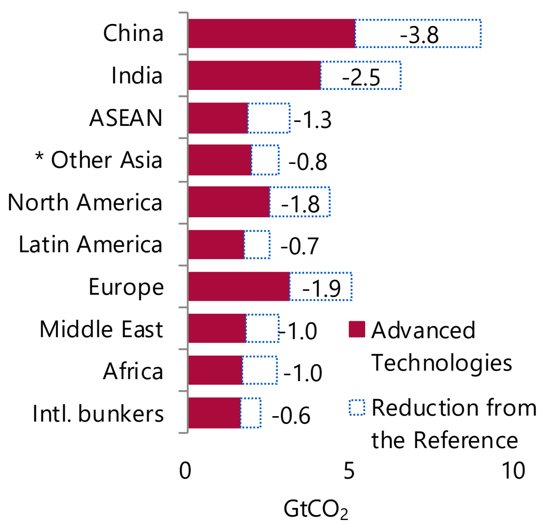


Figure 4-16 | CO_2 emissions [Advanced Technologies Scenario, 2050]



Note: Other Asia includes Oceania.

Of the emission decline from the Reference Scenario in 2050, energy efficiency improvement will account for the largest share at 6.6 Gt, followed by 4.8 Gt for renewable energy expansion, 2.1 Gt for Carbon capture and storage (CCS) and 1.1 Gt for nuclear expansion (Table 4-6). About 40% of the emission decline will arise from the expansion of non-fossil fuel-fired power generation including solar PV, wind and other renewable energy power generation, as well as nuclear power generation. CCS technologies are assumed to be introduced for all new fossil fuel-fired power plants to be built from 2030 in regions with potential for storing CO_2.

Table 4-6 | CO_2 emissions reduction from Reference Scenario [Advanced Technologies Scenario]

($GtCO_2$)

	2050		2018-2050 cumulative reduction	
	Reduction	Share	Reduction	Share
Energy efficiency improvement	6.6	42%	98.8	42%
Biofuels	0.4	3%	5.8	2%
Solar PV, wind, etc.	4.8	31%	81.4	34%
Nuclear	1.1	7%	18.0	8%
Fuel switching	0.6	4%	8.6	4%
CCS	2.1	13%	25.2	11%
Total	15.5	100%	206.3	100%

Each technology is imperfect, having both advantages and disadvantages. These technologies are easy or difficult to introduce, depending on local conditions. It is important to appropriately use various options without depending heavily on certain technologies or measures.

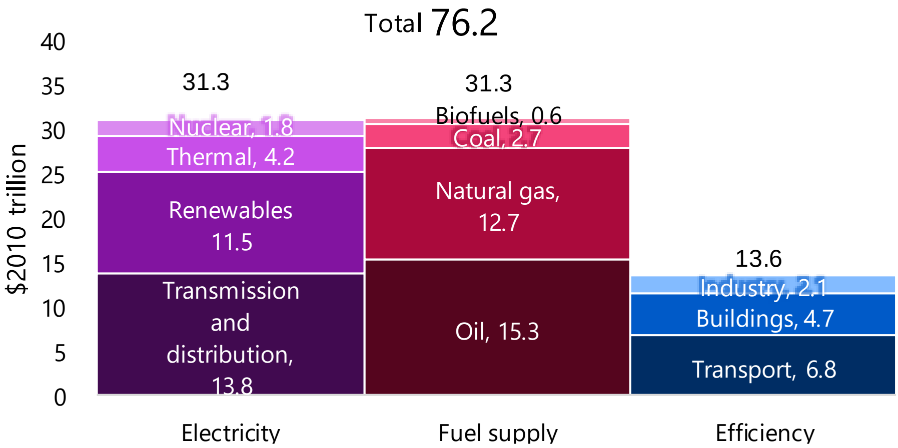
5. Energy-related Investment

5.1 Reference Scenario

Global primary energy consumption will increase from 14.0 Gtoe in 2017 to 18.7 Gtoe in 2050 in the Reference Scenario. As energy consumption growth is remarkable in Emerging Market and Developing Economies, they will have to massively invest in resources development, fuel transportation, power generation, and power transmission and distribution capacity. Regions with sufficient capacity will have to replace existing capacity and invest in energy efficiency improvement.

In the Reference Scenario, $76.2 trillion (in 2010 dollars, the same hereinafter) in energy-related investment[20] will be required over 33 years from 2018 to 2050 (Figure 5-1). The sum will be equivalent to some 2% of the global GDP over the period.

Figure 5-1 | Global energy-related Investment [Reference Scenario, 2018-2050]



Investment in the electricity sector will account for $31.3 trillion or about 40% of the total. As final electricity consumption in 2050 totals 40 477 TWh, up 1.9-fold from 2017, intensive capital investment will be required mainly in Emerging Market and Developing Economies where electricity demand will increase rapidly. Investment will total $11.5 trillion in renewable energy power generation and $4.2 trillion in fossil fuel-fired power generation. Investment in coal-fired power generation will decrease each 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 18% of the total energy-related investment.

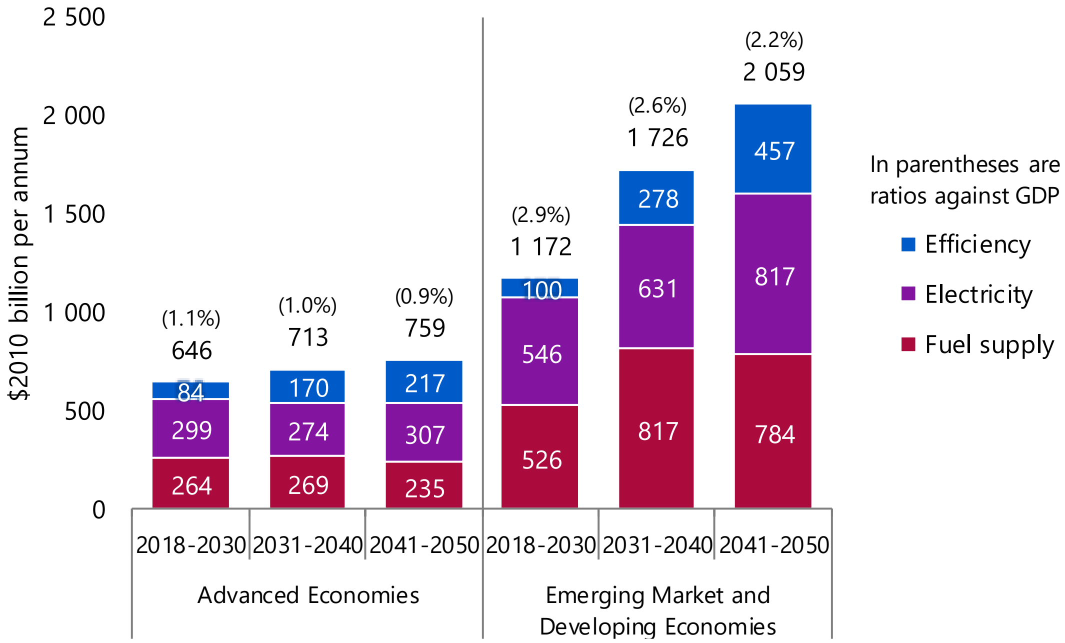
[20] Energy-related investment in this chapter covers resource (oil, natural gas and coal) development, oil refining, fuel transport (oil, natural gas and coal), natural gas liquefaction, biofuels, fossil fuel-fired power generation (coal, natural gas and oil), nuclear power generation, renewables (solar photovoltaics, wind, hydro, geothermal heat, 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).

Investment in fuel supply (oil, natural gas, coal and biofuels) will be as much as the investment in the electricity sector at $31.3 trillion, accounting for about 40% of the total energy-related investment. Most of the fuel supply investment will be supporting 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 the stability of energy supplies. An environment for providing enough funds for the necessary resource development should be recognised and maintained.

On the demand side, $13.6 trillion will be invested in energy efficiency improvement by 2050, accounting for 17% of the total energy-related investment. The sum includes $6.8 trillion (9% of the total energy-related investment) for the transport sector, $4.7 trillion (6%) for the buildings sector and $1.7 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 both groups will increase investment, the Emerging Market and Developing Economies will post a much faster growth (Figure 5-2). Energy-related investment's ratio of GDP will be limited to around 1% in the Advanced Economies against around 2.5% in the Emerging Market and Developing Economies. Particularly, the Emerging Market and Developing Economies' ratio will be large between 2018 and 2030.

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



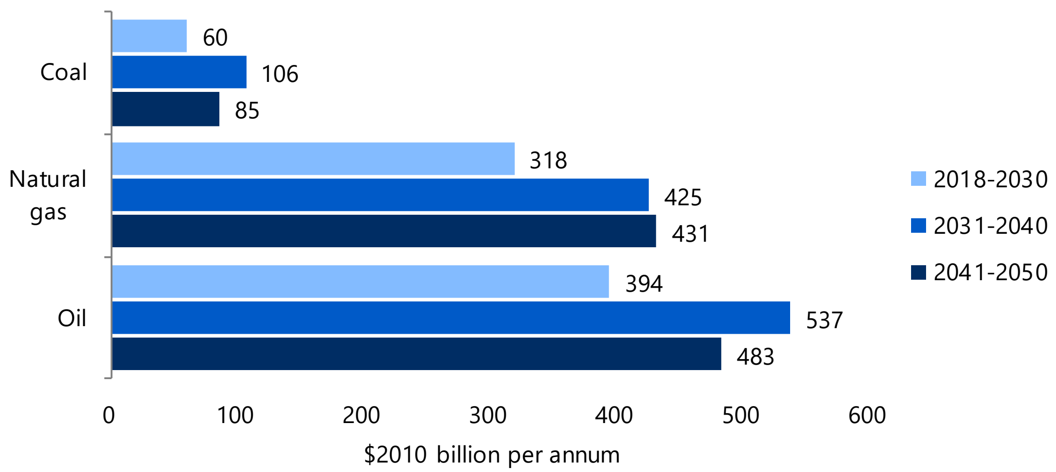
In the Advanced Economies that will implement ambitious climate change countermeasures, zero-emission power sources, such as nuclear and renewables, and the demand side's energy efficiency improvement will account for most of the energy-related investment. In the Emerging Market and Developing Economies,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

Although investment in fossil fuel supply facilities and in electricity generation and transmission equipment will eventually peak in the Advanced Economies, it will continuously expand in the Emerging Market and Developing Economies. Overall investment will triple from the current levels in the 2040s. Investment in fuel supply will gradually decline in the Advanced Economies because the already installed capacity is sufficient to meet the expected slower energy demand growth. In the Emerging Market and Development Economies where energy demand will rapidly expand, however, such investment will increase every year. In the Advanced Economies, the demand side's investment in energy efficiency improvement will be the only energy-related investment category to continue increasing, accounting for about 30% of their total energy-related investment in the 2040s.

5.2 Fossil fuel investment

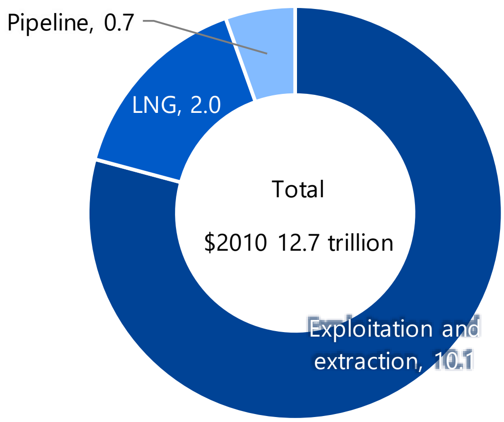
Fossil fuel investment will rapidly expand until the 2030s before decreasing moderately later. Even in the 2040s, however, investment as high as $1 trillion per year will be required to meet demand, accounting for the mainstream of total energy-related investment. As primary coal consumption turns downward 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 construction. Oil investment will turn downward in the 2040s. On the other hand, investment to support a rapidly expanding natural gas production will continue to increase until 2050.

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



As natural gas consumption expands, production, transport and liquefaction capacity will also need to be expanded. Through 2050, resource development will account for $10.1 trillion (or 80%) of the total natural gas investment of $12.7 trillion, (Figure 5-4). As liquified natural gas (LNG) trade expands, about $2.7 trillion will be invested in LNG-related equipment including production facilities and tankers.

Figure 5-4 | Global natural gas investment [Reference Scenario, 2018-2050]



5.3 Electricity investment

Power generation equipment

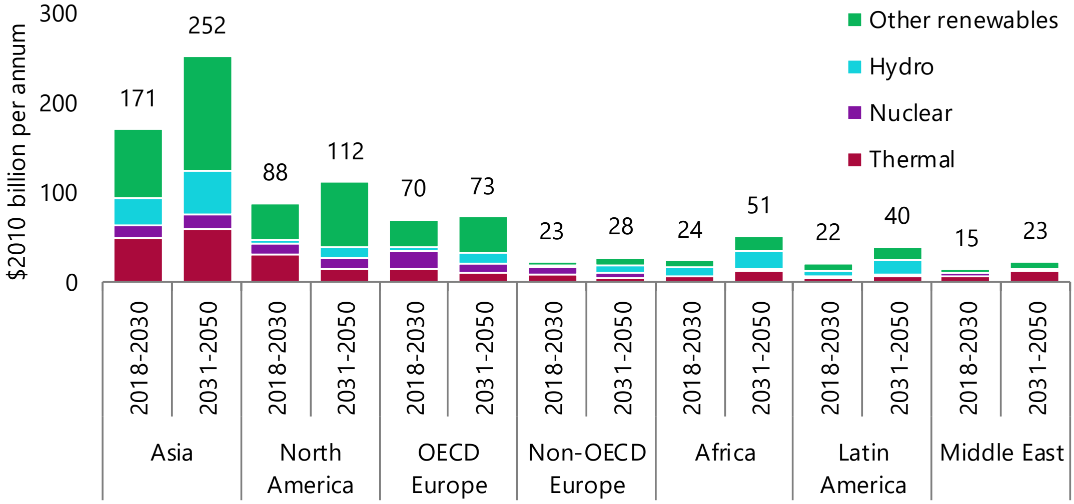
Investment in power generation equipment will continue expanding, totalling $18 trillion through 2050. In both the Advanced Economies and the Emerging Market and Developing Economies, investment in natural gas-fired power generation will expand at a faster pace than at present and become the largest electricity source by 2050. In contrast, coal-fired power generation investment will turn downward in the 2020s and fall to some 50% of the current 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 the United Kingdom and Canada. While nuclear power generation capacity expands every year, investment in nuclear power generation will only increase in Asia; it will level off or decrease in other regions due to cost cuts through technological advancement that followed the intensification of new nuclear power plant construction in the 2020s.

Investment in renewable energy power generation will substantially expand through 2050. Annual investment required in the 2040s will reach $120 billion for hydro, $90 billion for solar photovoltaics (PVs) and $160 billion for wind. Overall investment in renewable energy power generation in the decade will increase 2.5-fold from the 2018-2020 level.

Power generation equipment investment strongly reflects regional differences (Figure 5-5). In Europe and North America, such investment will follow a downtrend. Investment in fossil fuel-fired power generation will post a remarkable decline while, in contrast, renewable energy power generation investment will continue to increase through 2050. Despite a moderate power demand growth, these regions will become a key market for renewable energy power generation equipment.

In Asia, Africa and the Middle East including Emerging Market and Developing Economies, rapid growth in investment in power generation equipment will be required to meet the rapid expansion in power demand. Through 2050, these regions will continuously expand their annual power investment in fossil fuel-fired power generation facilities as well as 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]

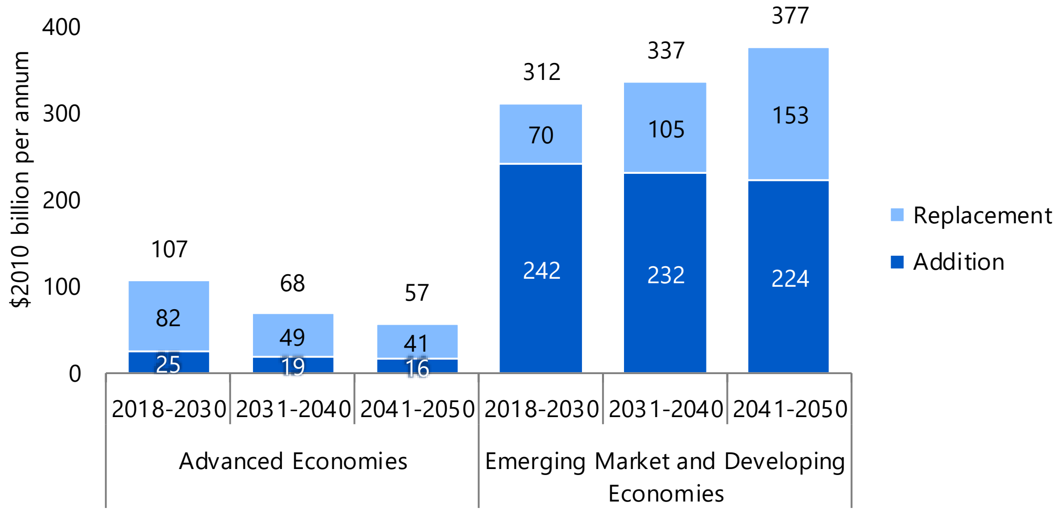


Power transmission/distribution equipment

Investment required in power transmission and distribution equipment through 2050 will total $13.8 trillion, equivalent to three quarters of the power generation equipment investment. Not only power generation equipment development but also power transmission and distribution equipment development should be given priority in response to rapid power demand growth.

The trend in power transmission and distribution equipment investment in Advanced Economies will contrast with that in the Emerging Market and Developing Economies (Figure 5-6). In Advanced Economies where power transmission and distribution networks have already been sufficiently developed to meet power demand, such investment will decrease year after year, mainly to cover the cost of replacing outdated equipment. In Emerging Market and Developing Economies where final electricity consumption will grow at the remarkable annual rate of 2.3%, power transmission and distribution equipment investment will continuously expand, focusing on additional equipment to meet demand. Power transmission and distribution equipment investment will account for only 11% of total energy-related investment in the Advanced Economies, against 21% in the Emerging Market and Developing Economies. The prompt development of power transmission and distribution networks is a key challenge for emerging economies for the next several decades. They will be required to smoothly raise funds, secure lands and create legal systems to realise the development.

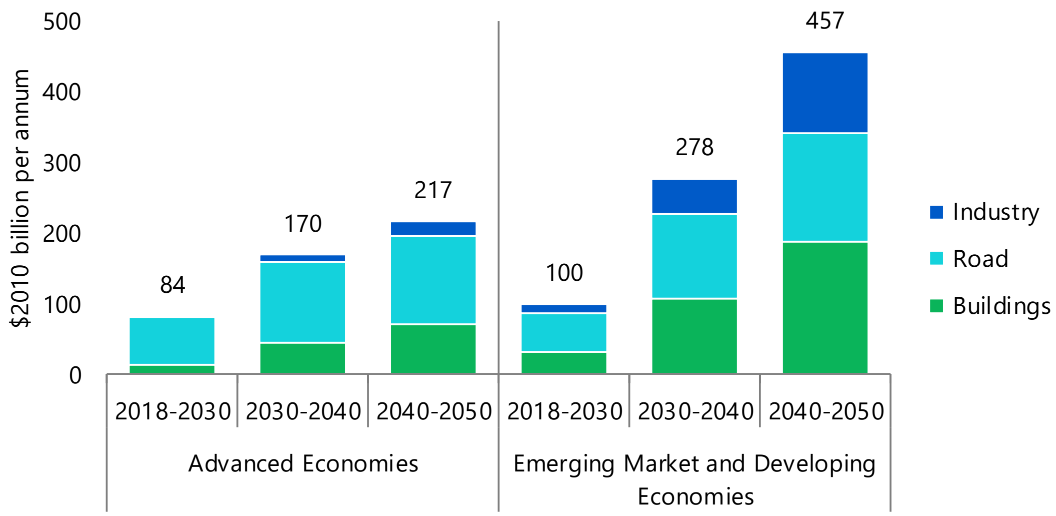
Figure 5-6 | Investment in power transmission and distribution equipment [Reference Scenario]



5.4 Demand-side investment in energy efficiency improvement

Demand-side investment in energy efficiency improvement[21] will increase year by year, totalling $13.6 trillion through 2050 (Figure 5-7).

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



[21] Investment in energy efficiency improvement is defined as a gap between prices paid for a traditional product and a more efficient one. The investment defined in this way fails to explicitly include technological development investment costs but prices for more efficient products can be interpreted as covering such costs.

The buildings sector will have to invest $4.7 trillion in energy efficiency improvement in the next 33 years. The sum includes $3 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. 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 $6.8 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) 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.

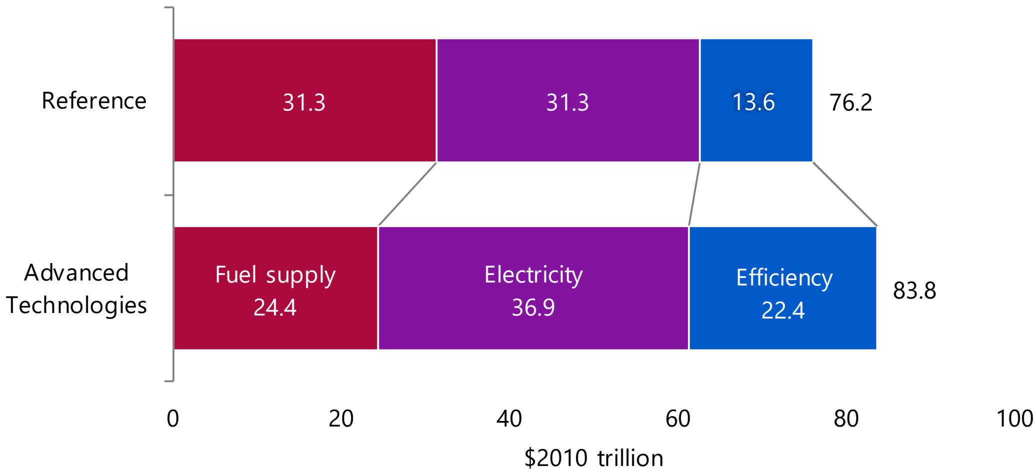
Investment in energy efficiency improvement will be given priority mainly in Advanced Economies, continuing an uptrend through 2050. Particularly, OECD Europe that has set ambitious targets for electric vehicle diffusion and fuel efficiency improvement will be required to intensify investment in energy efficiency improvement over the next several decades.

5.5 Climate change countermeasures – investment and its effects

Cumulative energy-related investment in the Advanced Technologies Scenario will total $85 trillion, $7.6 trillion more than in the Reference Scenario (Figure 5-8). In contrast, cumulative CO_2 emissions in the Advanced Technologies Scenario will be 238 Gt less than in the Reference Scenario. By dividing the additional investment in the Advanced Technologies Scenario by the CO_2 emission reduction, we can estimate an average investment value for cutting emissions. To realise the Advanced Technologies Scenario, an average investment of about $32 per tonne of reduced CO_2 emission will be required.

Fossil fuel investment in the Advanced Technologies Scenario will be equivalent to some 80% of the Reference Scenario level. Particularly, coal investment will decrease by 40% from the Reference Scenario to $1.6 trillion and overall fossil fuel investment in the 2040s will remain at present levels. If fossil fuel development investment declines for environmental conservation and other reasons, energy supply stability may be affected. Financial institutions and other investors and policymakers will be required to make wise decisions for the so-called 3Es + S (energy security, environmental conservation and economic efficiency plus safety).

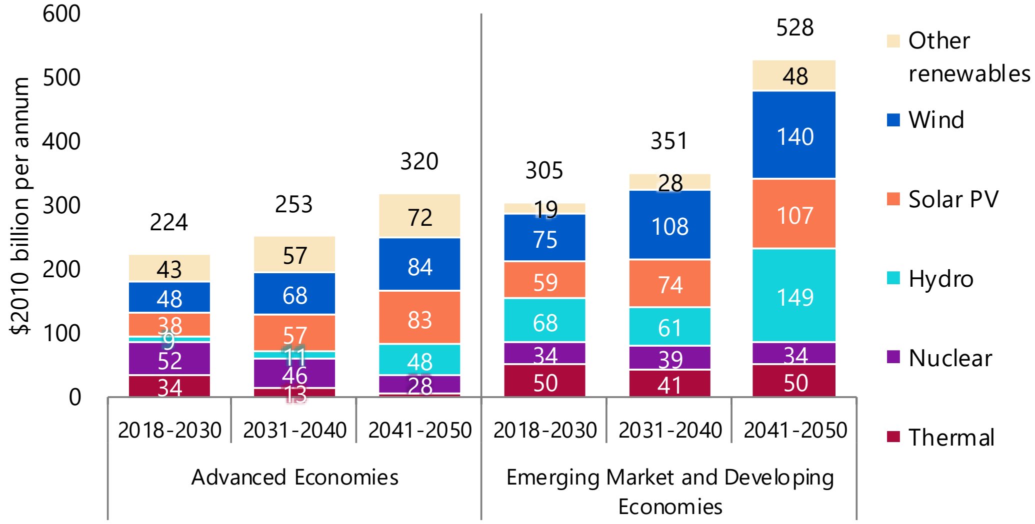
Figure 5-8 | Global energy-related Investment [2018-2050]



Power generation in 2050 in the Advanced Technologies Scenario will be 3 300 TWh less than in the Reference Scenario. However, investment in power generation, transmission and distribution facilities through 2050 will increase by $5.6 trillion from the Reference Scenario to $36.9 trillion. This is because renewable energy and nuclear power generation with higher initial investment costs than for other power sources will replace fossil fuel-fired power generation (including coal-fired generation) with lower costs. Such power source transition, though indispensable for climate change countermeasures, will be accompanied by greater initial investment costs (and far less fuel costs), longer investment recovery periods and changes in the pricing mechanism for the electricity market. Relevant institutions should be designed to secure enough and more predictable earnings for power generation operators.

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). Particularly, investment in wind and solar PV power generation will expand yearly. Investment in fossil fuel-fired power generation will remain almost unchanged from the present level in the Emerging Market and Developing Economies while shrinking year after year in the Advanced Economies. Although the expansion of low-carbon power sources will be significant, more efficient and lower-load technologies for fossil fuel-fired power generation should be selected for their steady investment.

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



As far as some constraints exist on the expansion of renewable energy and nuclear power generation, even in the Advanced Technologies Scenario, the need for fossil fuel-fired power generation will still be high, making carbon capture and storage (CCS) technologies an effective option for reducing CO_2 emissions in the power generation sector. CCS investment will total $200 billion between 2018 and 2050. Investment will be required not only for CO_2 separation and capture equipment at power plants but also in additional power generation equipment for covering a fall (of about 8 percentage points) in power generation efficiency and in equipment for transporting and injecting collected CO_2. 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).

Demand-side investment in energy efficiency improvement through 2050 will total $22 trillion, up $8.8 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 28 000 Mtoe from the Reference Scenario. Investment per toe in additional energy savings will differ from sector to sector, standing at about $400/toe in the buildings sector, at about $500/toe in the transport sector and at $200/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 5-10 | Global fossil fuel-fired power generation and emission intensity [Advanced Technologies Scenario]

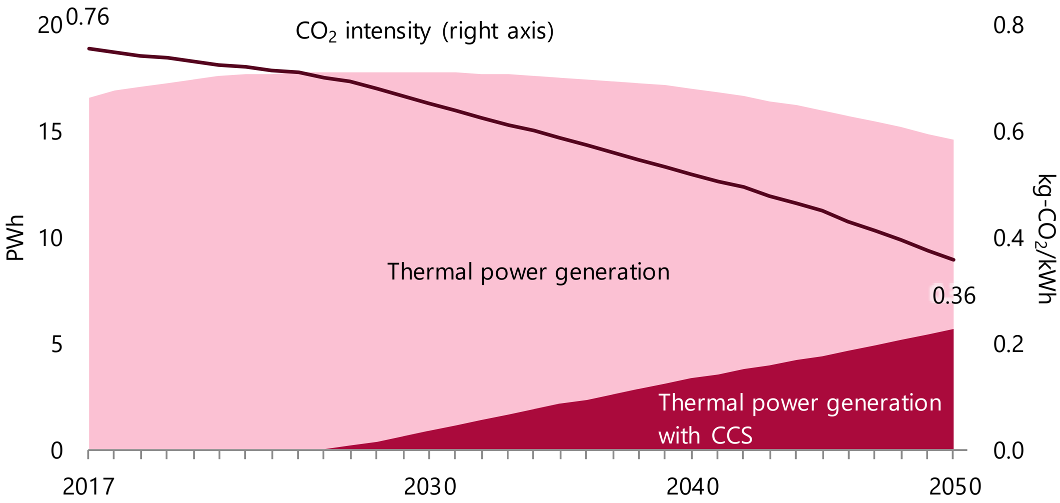
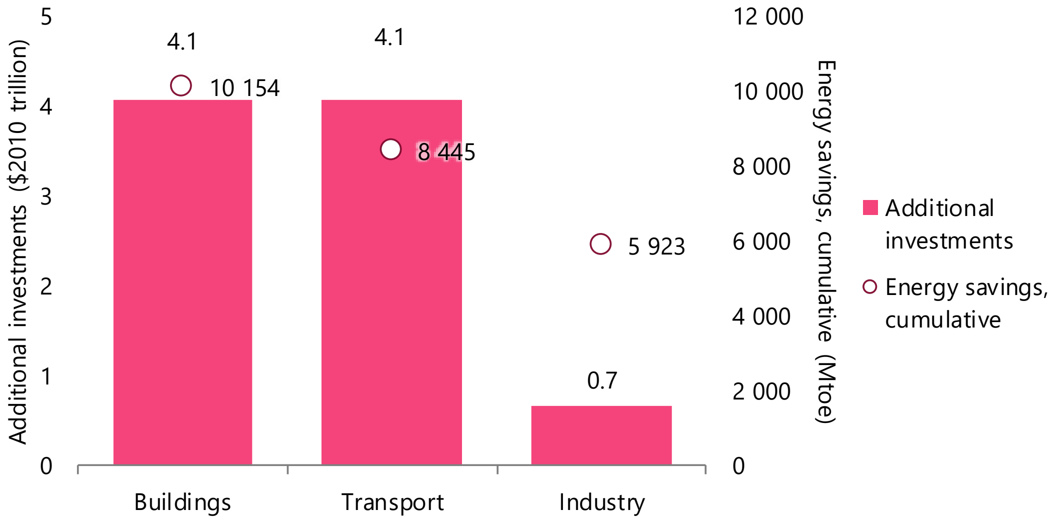


Figure 5-11 | Additional investment in energy efficiency improvement and cumulative energy savings [from Reference Scenario, 2018-2050]



Part II

Challenges for energy transition

6. Possibilities and challenges of mass introduction of renewable energy

6.1 Possibilities of mass introduction of renewable energy and integration costs

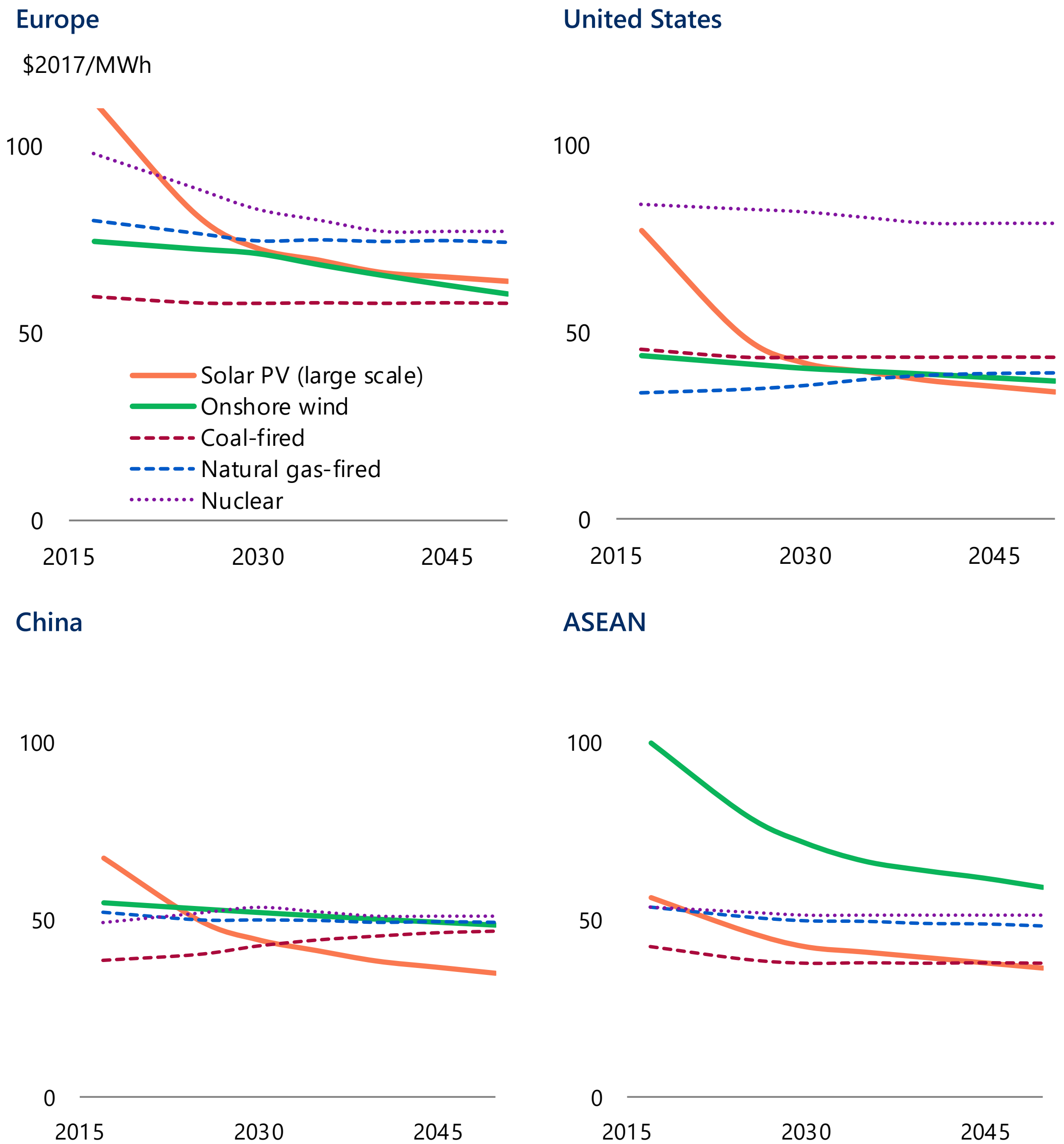
Fall in VRE costs and introduction of ambitious targets

Costs of renewable energy, particularly Variable renewable energies (VREs), such as solar photovoltaic (PV) and wind, have been rapidly falling. Figure 6-1 shows projected power generation costs by source in selected regions in the world.

As indicated in the figure, onshore wind power generation costs have traditionally been low in Europe and North America and will be slipping below fossil fuel-fired power generation costs in some regions. Meanwhile, solar PV power generation costs have remarkably declined in recent years, sliding below fossil fuel-fired power generation costs in the most favourable regions for solar PV. By 2050 at the latest, such a drop in prices will be true in many regions.

Reflecting such situation, VRE has rapidly expanded in many countries and some countries have set ambitious renewable energy expansion targets for the future. In Germany, wind and solar PV raised their share of total power generation from 5% in 2005 to 23% in 2017. In OECD Europe, the share reached 14%. The European Union has proposed a scenario for boosting the renewables' share of total power generation to 97% by 2050. Some countries including Spain have set official targets of covering all power generation with renewables. Such trend is not limited to Europe. For example, the China National Renewable Energy Center presented a scenario for increasing renewables' share of total power generation to 85% by 2050. Japan also has set a target of cutting greenhouse gas emissions by 80% by 2050 and gave a plan to make renewables a major electricity source, although without any specific target share.

Figure 6-1 | Power generation costs by source (LCOE with a real discount rate of 7%)



VRE resource potential

It is important to first understand that VRE and other renewable energy resources, as well as any other energy resources, are not evenly distributed in the world. Figure 6-2 shows the distribution of wind energy resources in Europe and for the Association of Southeast Asian Nations (ASEAN). While Europe is generally rich with wind energy resources, wind conditions are generally unfavourable in the ASEAN region. Except for Viet Nam and the Philippines, ASEAN countries are devoid of wind energy resources.

Figure 6-2 | Regional distribution of wind energy resources

Europe

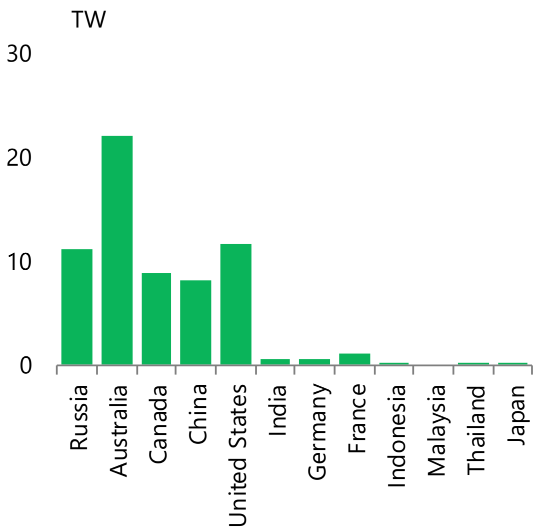
ASEAN

Source: Global Wind Atlas[22]

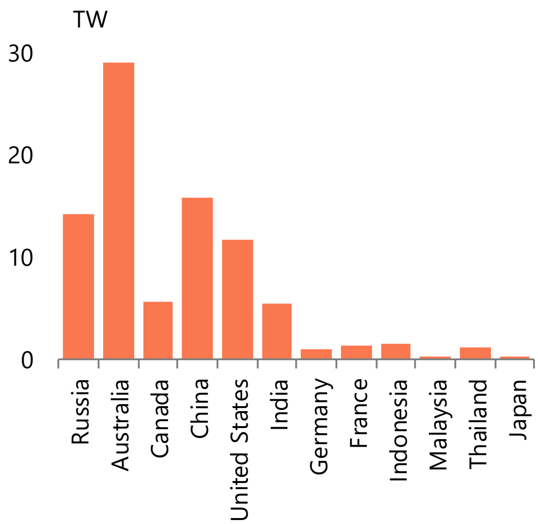
As shown in Figure 6-3, VRE resources are abundant in the larger countries of the world. Russia, Australia and other vast countries are generally rich with VRE resources.

Figure 6-3 | Solar PV and wind power generation resources

Onshore wind power generation



Solar PV power generation



[22] Global Wind Atlas 2.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU) in partnership with the World Bank Group, utilising data provided by Vortex, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

VRE expansion and integration costs

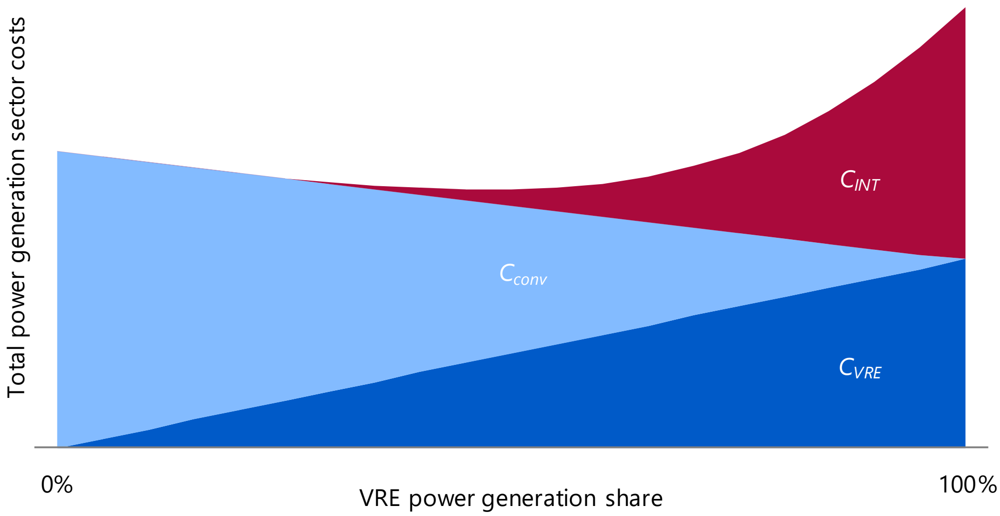
The second important component to be understood when considering the possibilities of expanding the shares of VRE is the costs required for the expansion. As VRE output is intermittent and cannot be artificially controlled, the costs of any VRE capacity expansion must be augmented by its related "integration costs" for either the curtailment of output amid excess supply, for ensuring flexibility or for the installation of storage batteries, etc.

The integration costs are defined as the total electricity system costs minus the costs proportional to the levelised costs of electricity (LCOEs) as shown in Figure 6-4. Given a combination of conventional and VRE power sources, the C_{conv} value is determined by multiplying electricity generated from the conventional source by its LCOE (L_{conv}), and the C_{VRE} value is determined by multiplying electricity generated from the VRE source by its LCOE (L_{VRE}). The integration cost (C_{INT}) is defined as the difference between the sum of C_{conv} and C_{VRE} and the total cost C. The VRE capacity (x) to minimise C is determined as the point meeting the following equation:

$$L_{\boldsymbol{conv}} = L_{VRE} + \frac{dC_{INT}}{dx} \equiv L_{VRE} + L_{INT}$$

The value on the righthand side is called the (marginal) system LCOE. In this way, the combination of the conventional LCOE and the marginal integration cost (L_{INT}) is used for determining the economics of the power generation sector.

Figure 6-4 | Conceptual diagram of integration costs



Integration costs (C_{INT}) are usually classified as follows[23, 24]:

[23] Hirth L., Ueckerdt F. and Edenhofer O. (2015). Integration costs revisited – an economic framework for wind and solar variability, *Renew. Energy*, 74, 925-939.

[24] Organisation for Economic Co-operation and Development (OECD)/Nuclear Energy Agency (NEA) (2019). *The costs of decarbonisation: System costs with high shares of nuclear and renewables*. OECD publications, Paris.

1/ Balancing cost

The balancing cost covers for imbalances accompanying short-term prediction errors. Conceptually, it is supposed to rise along with increasing share of VRE, but in reality, it can decline as system operation improves[25].

2/ Grid cost

The grid cost is a cost for enhancing or expanding the power grid. More generally, it is defined as a cost originating from a "spatial" deviation between VRE power generation and demand.

3/ Profile cost

The profile cost is an additional cost originating from a "temporal" deviation between VRE power generation and demand. It is also called "utilisation cost." The cost covers the curtailment of VRE output, the introduction of storage batteries, a decline in the utilisation factor for conventional power sources, the partial load operation of thermal power plants, increased ramping and cycling, etc. Unlike the balancing cost, the profile cost would not decline but remain required even if VRE power generation and demand fluctuations are completely predictable.

In the initial stage of VRE expansion, the balancing cost's rise is identified as a big challenge. If the VRE share rises beyond a certain level, however, the profile cost's impact is supposed to increase.

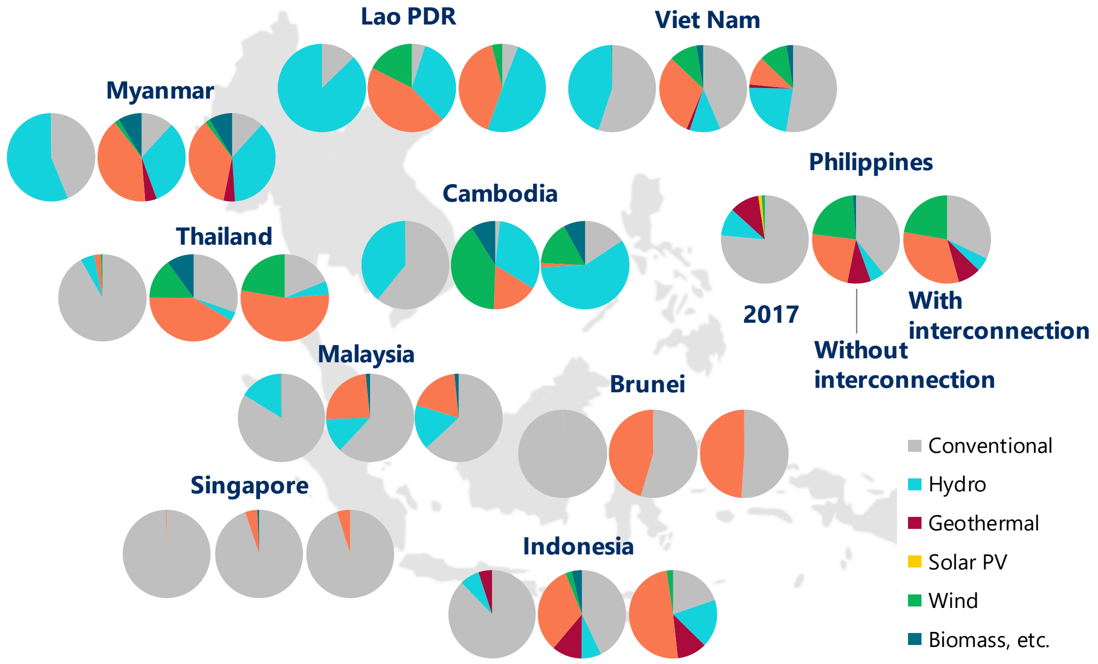
6.2 Integration cost assessment cases: Europe and ASEAN

As the availability of VRE, hydro, geothermal and other renewable energy resources differs widely by country, the power mix for decarbonisation will sharply vary on a country basis.

As shown in Figure 6-5 for the ASEAN countries, two cases using data for 2017 are presented. The first one assumes that international power transmission lines failed to be sufficiently developed (and electricity must be domestically supplied in each country or region). The second case assumes that enough international transmission lines will be developed. In brief, the difference between the two cases depends on whether hydro resources can be utilised efficiently. For example, if international power transmission lines are available, electricity may be supplied from Lao PDR, Myanmar, Cambodia and Viet Nam to Thailand and from Malaysia to Brunei.

[25] Joos M. and Staffell I. (2018). Short-term integration costs of variable renewable energy: Wind curtailment and balancing in Britain and Germany, *Renew. Sustain. Energy Rev.*, 86, 45-65.

Figure 6-5 | Power mix by country for a VRE 40% case (ASEAN)



European power mixes for 2017 and a VRE 40% case (60% for renewable energy and 86% for low-carbon power sources including nuclear) are shown below. While the United Kingdom and Spain will develop massive wind power generation capacity and export electricity, Italy will proactively expand its solar PV capacity due to good sunshine conditions.

Figure 6-6 | Power mix by region for a VRE 40% case (Europe)

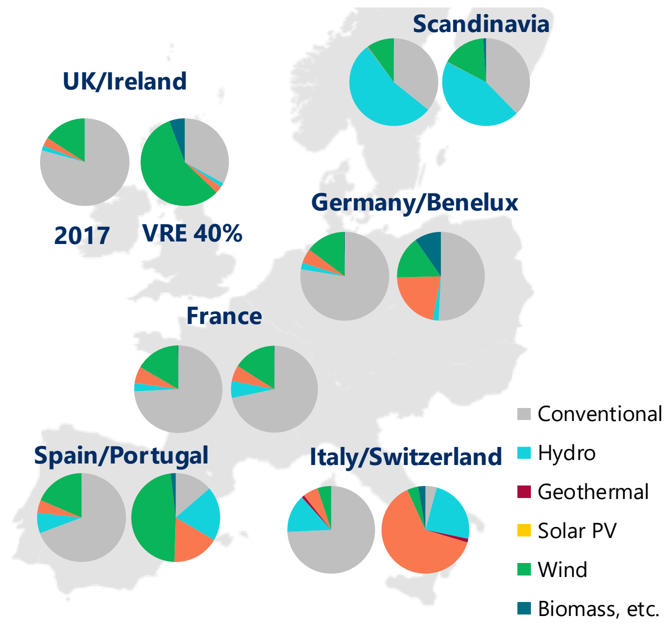
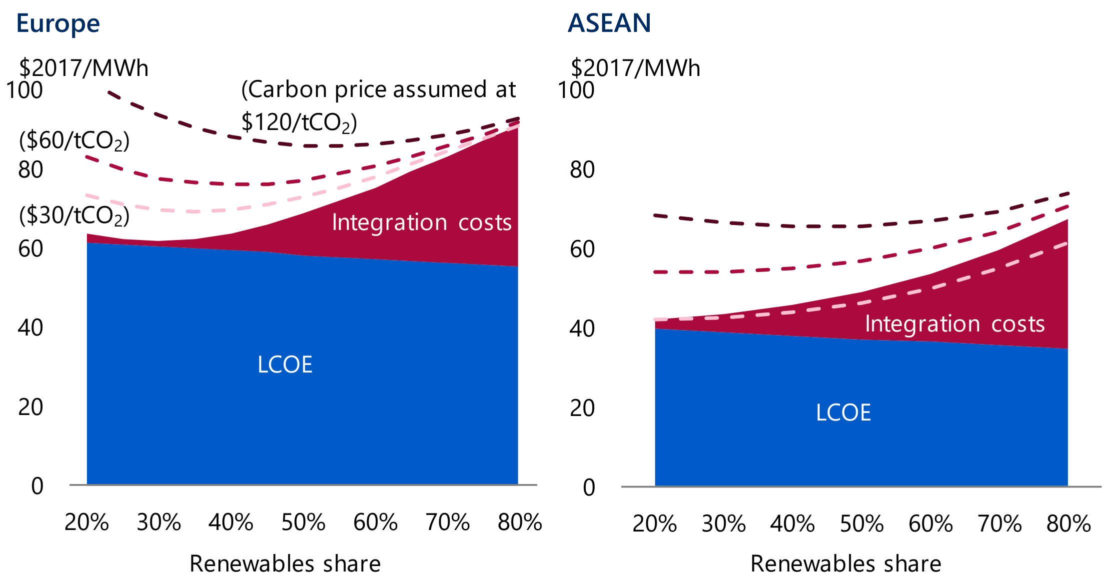


Figure 6-7 shows the relationship between renewables' share of the power mix on the horizontal scale and the unit power generation costs (combining the LCOE and average integration costs) on the vertical scale. When the LCOE for VRE is lower than for conventional power sources, the average LCOE falls in response to a rise in the renewables share. As integration costs increase along with the renewables share, however, the total costs generally stand at the minimum level within a lower range for the VRE share and increase along with the VRE share. If thermal power generation costs reflect a carbon price, total costs would rise within a lower range for the VRE share, with the minimum cost point shifting rightward.

Figure 6-7 | Integration costs assessment



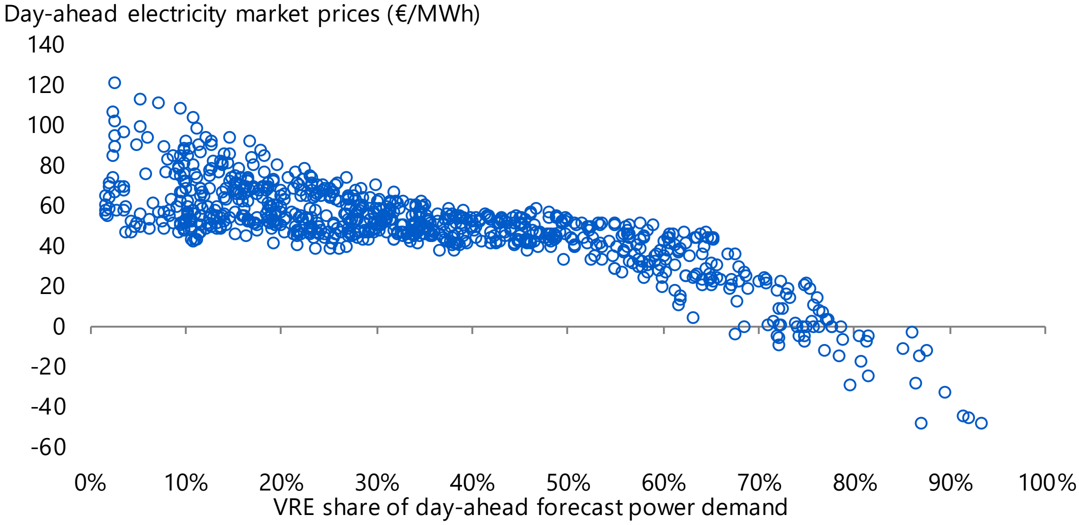
6.3 Challenges for renewable energy expansion

Market values and cannibalisation effect

The above assessment indicated the economics of the power sector under high VRE penetration from the cost perspective. Meanwhile, they can also be seen from the "market value" perspective, producing a different picture.

Here, special attention must be paid to the fact that as VRE power generation requires no fuels and is operated and maintained at relatively low cost, marginal costs are very low. Once VRE capacity expands, therefore, wholesale electricity market prices decline significantly during the daytime on sunny days or when the wind is blowing. Figure 6-8 shows the relationship between day-ahead forecast VRE generation and day-ahead electricity market prices (between 1 January and 31 July 2019) in Germany and adjacent areas. As the VRE share of total power demand expands, electricity market prices decline remarkably.

Figure 6-8 | Market price fall as the VRE share of power demand increases (Germany and adjacent areas)



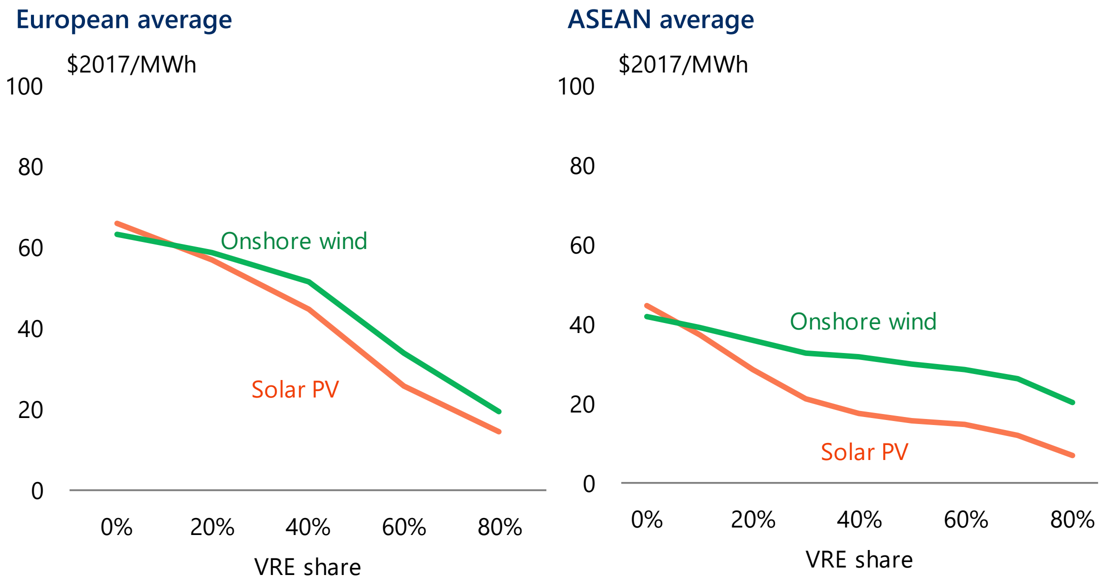
Source: Entso-E Transparency Platform

Figure 6-8 implies that this phenomenon may come if the VRE expansions are huge. If solar PV capacity is massively expanded, wholesale electricity market prices will remarkably decline, stand at zero or even become negative during the daytime on sunny days. While conventional power sources get some profit by operating during evening and night-time periods, exempt from market price falls, solar PV facilities that operate only during the daytime on sunny days despite very low electricity market prices may earn much less than other power generation facilities. This means that the value of solar PV declines as capacity expands. To a lesser extent, a similar phenomenon may emerge for wind power generation. The phenomenon in which an increase in VRE facilities hurts their market value is called the "cannibalisation effect."

Mathematically, VRE capacity's costs should be equivalent to its value when the capacity is at the optimal point. If the capacity is less than that, its value is greater than its costs. If the capacity exceeds the point, however, its value is smaller than its costs and the cannibalisation effect will emerge.

Figure 6-9 shows the estimated cannibalisation effect in Europe and ASEAN. As indicated by the figure, the value of solar PV and wind facilities slips below $50/MWh if the VRE share rises beyond 40-50%. In ASEAN, solar PV facilities' value falls below $20/MWh if the VRE share rises above 30-40%. Wind power generation facilities' value falls more moderately not only because wind energy resources in ASEAN are widely dispersed, but also because of the small installed capacity due to the limited wind resources.

Figure 6-9 | Estimated cannibalisation effect

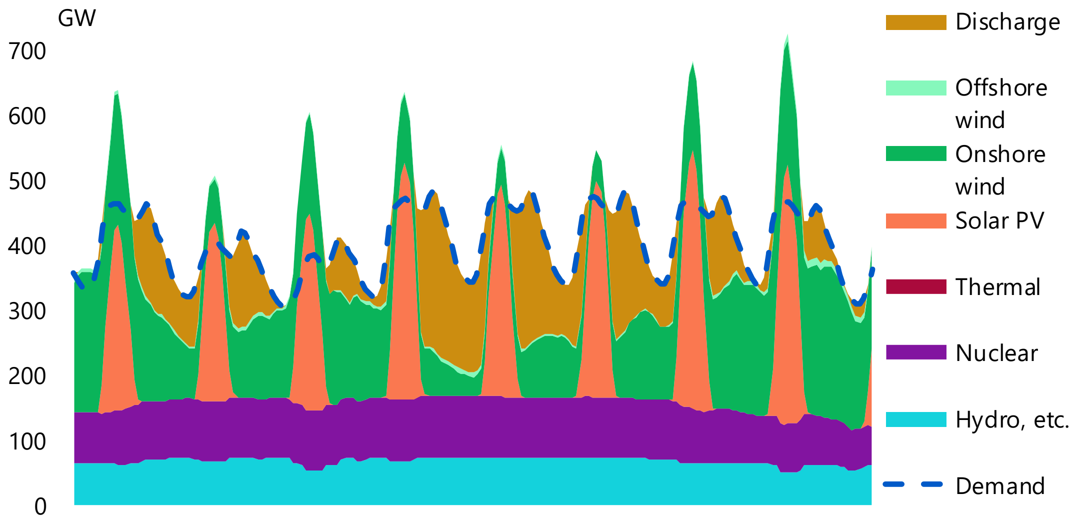


Weather conditions and power supply disruption risks

As VRE expands, consideration must be given particularly to power supply disruption risks accompanying VRE's natural variability. "Dark doldrums," or "windless and sunless" periods, in which wind and solar PV power generation declines to extremely low levels, may come once or twice a year. Figure 6-10 shows power supply and demand in Europe based on data around 15 April 2014, for an extreme case in which fossil fuel-fired power generation is absent. As indicated here, wind and solar PV power generation are limited to a small level over several days, requiring power storage systems to discharge power to meet demand. Storage battery capacity would be required to cover electricity demand during the dark doldrums.

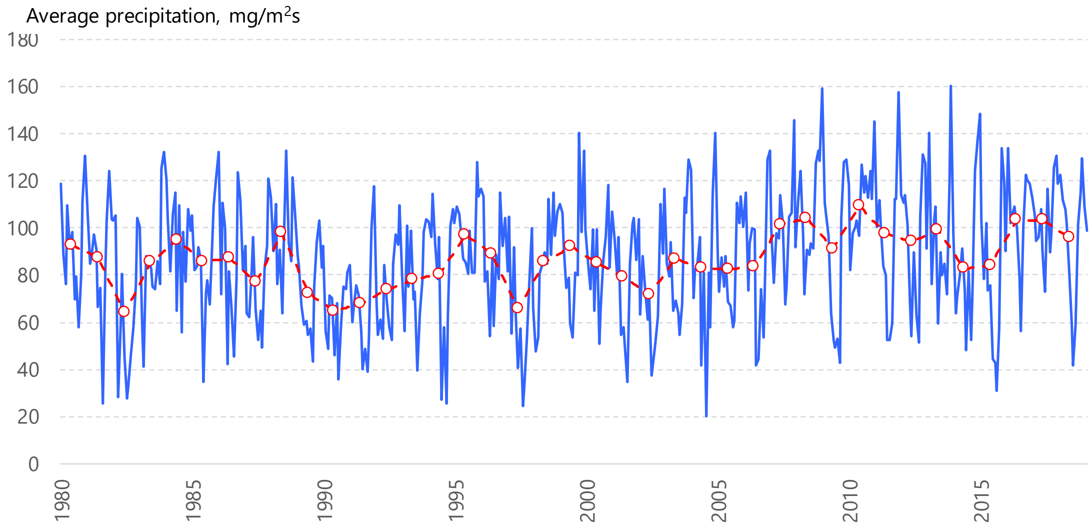
In order to achieve extremely high VRE shares, an appropriate assessment of the risks of dark doldrums and related required electricity storage systems will need to be performed, based on multi-year data analyses.

Figure 6-10 | Power supply and demand during dark doldrums (Europe)



It should be mentioned that the risks of power supply disruptions are not limited to VRE but they could accompany hydropower as well. Figure 6-11 shows the average precipitation trends from 1980 for the Borneo Island (data estimated through a reanalysis). As shown in this figure, the average precipitation changes drastically by season and by year. If hydro power generation capacity is massively expanded in ASEAN, measures will need to be taken to fully cover drought risks.

Figure 6-11 | Average precipitation trend for Borneo Island



Source: NASA "MERRA-2"

Toward sustainable renewable energy expansion

The LCOEs of VRE have rapidly declined in recent years, indicating rapid VRE capacity expansion in the future. Even if they become remarkably lower than the LCOEs of conventional power sources, however, VRE expansion will face a big challenge due to their variability/intermittency, implying that policy support for VRE will need to be maintained over a long term for the sustainable decarbonisation of the power generation sector. It is important to remember that a massive expansion in VRE and hydro power generation will be subject to power supply disruption risks due to their natural variability. Therefore, batteries, pumped hydro power, and other energy storage systems like hydrogen storage will be required. For the further decarbonisation of the sector, zero-emission thermal power, as well as nuclear power, could be useful as stable power sources.

An important point for future policy planning is that the traditional metric of LCOE alone cannot assess the economics of the power sector amid decarbonisation. While many studies on integration costs for massive VRE expansion have been published in recent years, their results are still uncertain, with their conclusions varying. Appropriate assessment methods must be established, with consideration being continued for more accurate assessment.

7. LNG in Asia

7.1 Asian natural gas supply and demand

Natural gas, which features the lowest environmental footprint among fossil fuels, is expected to play a major role in Asia set to drive the global energy demand growth. In the Reference Scenario, natural gas demand in Asia will increase at an annual rate of 2.8% to 1 467 Mtoe (1 748 Bcm) (Figure 7-1). Within Asia, China and India will expand their natural gas demand the most while the growth in the Association of Southeast Asian Nations (ASEAN) will also be remarkable. Among demand sectors, the power generation sector will post the largest demand growth (Figure 7-2). In China, India and ASEAN that heavily depend on coal-fired power generation, natural gas will inevitably face competition from inexpensive coal in the power generation sector.

Figure 7-1 | Asian natural gas demand by region [Reference Scenario]

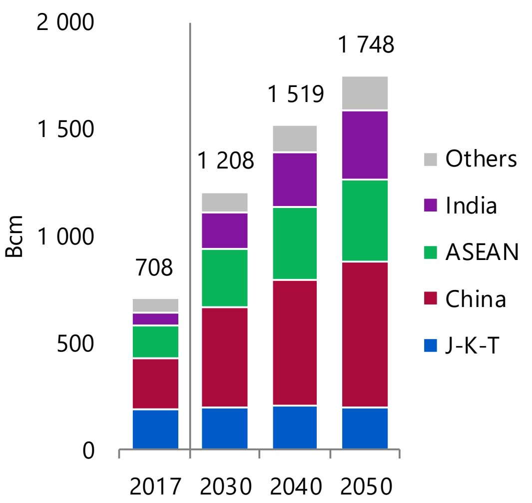
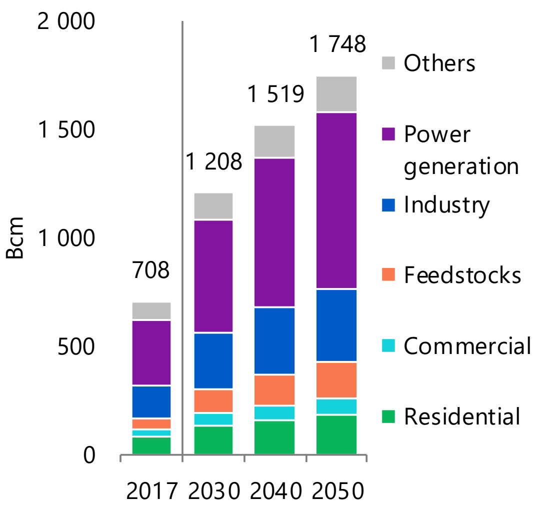


Figure 7-2 | Asian natural gas demand by sector [Reference Scenario]

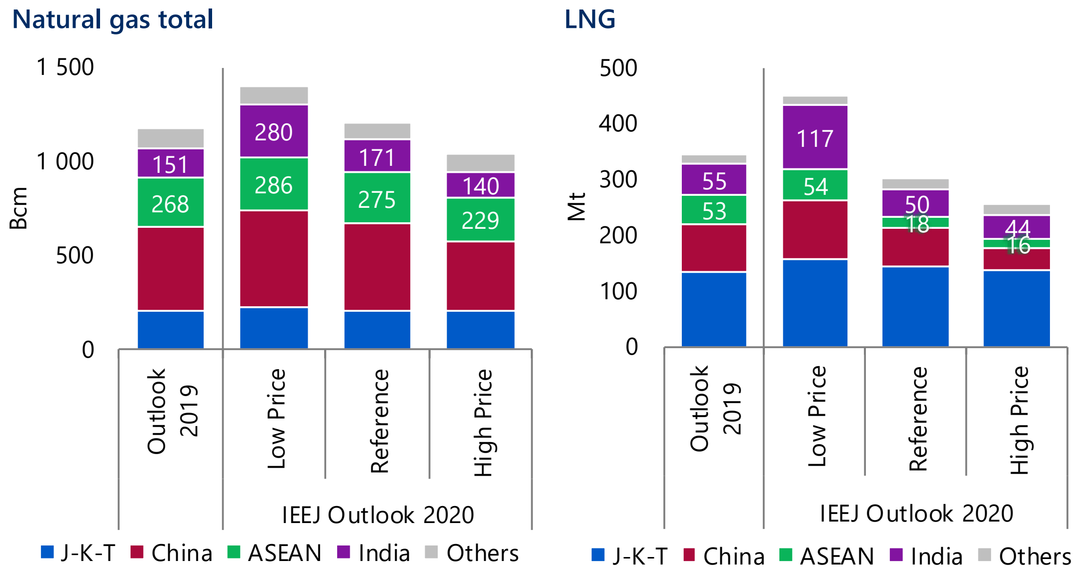


Note: J-K-T stands for Japan, Korea and Chinese Taipei.

Given assumptions of further progress in energy efficiency improvements and an acceleration of renewable energy expansion, any fossil energy demand outlook would inevitably include uncertainties. Natural gas and coal used in large quantities in the power generation sector cannot be exempt from the influence of such developments. If the competitiveness of natural gas and liquified natural gas (LNG) is enhanced, however, the influence may be mitigated.

As noted later, this chapter considers LNG demand in a High and a Low-Price Cases, in addition to the Reference Scenario. The following shows Asian LNG demand outlooks for these cases in 2030 in comparison with those in last year's IEEJ Outlook 2019. As energy supply must be affordable for low-income countries, high LNG prices will have remarkable impacts in India and ASEAN. Therefore, LNG demand projections are revised downward from the IEEJ Outlook 2019, while the total natural gas demand estimate is left unchanged.

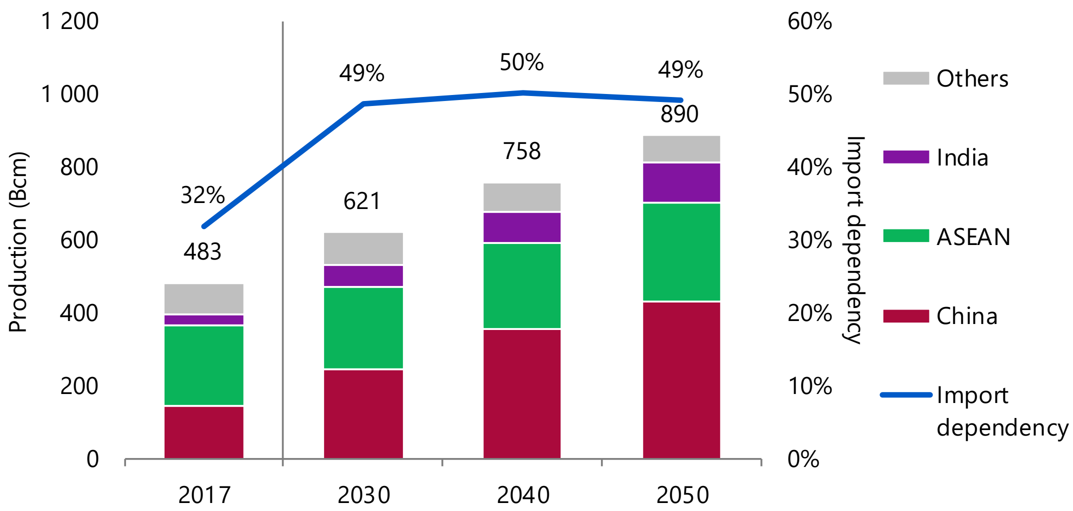
Figure 7-3 | Comparison of Asian natural gas and LNG demand [2030]



Note: J-K-T stands for Japan, Korea and Chinese Taipei.

Natural gas production in Asia alone will most probably fail to meet domestic demand and demand growth will be met mainly by imports, boosting Asia's natural gas import dependency from 32% in 2017 to 49% in 2050 (Figure 7-4). Even after considering the potential of pipeline gas imports from the former Soviet Union and the Middle East, the need for LNG imports will grow faster. Therefore, the competitivity of LNG will become even more significant in Asia.

Figure 7-4 | Natural gas production and import dependency in Asia [Reference Scenario]



In consideration of the abovementioned point, this Chapter's Section 7.2 analyses how demand would change in response to changes in LNG prices and how price changes would influence the supply side. Given the high possibility of Asia accounting for most of the LNG demand growth, Section 7.3 considers what initiatives would be required to enhance LNG supply security in Asia.

7.2 LNG demand

Real LNG prices

Table 7-1 shows assumed LNG prices in Asia. In the Reference Scenario, the real LNG import price (in 2018 prices) for Japan will almost level off from $10.1/MBtu in 2018 to $10.4/MBtu in 2050. Although LNG prices in Asia are still indexed mainly to oil prices, pricing formulas have been diversifying, with some LNG prices indexed to Henry Hub, spot LNG or even coal prices. The Reference Scenario assumes a decline in the number of LNG import contracts indexed to oil prices or with a weaker indexation to oil prices.

How the assumed price would be competitive in emerging LNG-importing countries[26] would differ widely on a sector-by-sector basis and would depend on demand, prices of competing fuels, electricity prices, infrastructure development and incentives for fuels in those countries. Generally, however, the competitiveness of imported LNG at current price levels, in emerging or planned LNG importing countries in Asia, is considered as weak.

In many Asian emerging LNG importing countries where natural gas is in competition with coal, particularly, LNG consumption in the Reference Scenario may slip far below potential demand.

Table 7-1 | Assumed real LNG prices in Asia

($2018/MBtu)

	2018	2030	2040	2050
Reference Scenario	10.1	10.0	10.2	10.4
Ref.) Crude oil prices ($2018/bbl)	*71.31*	*95*	*115*	*125*
High Price Case	10.1	13.3	16.1	17.5
Low Price Case	10.1	5.4	5.4	5.4

In the High Price Case, the degree of the average Japanese LNG import price's indexation to crude oil prices in 2018 is assumed to remain unchanged until 2050. As the real crude oil price is assumed to rise from $71/bbl in 2018 to $125/bbl in 2050, the real LNG price in 2050 works out to be $17.5/MBtu, with the oil price indexation degree of 83% applied to the oil price in 2050[27]. In this case, LNG will fail to be competitive as a power generation fuel in emerging LNG importers in South Asia and Southeast Asia, resulting in slower growth in LNG demand in

[26] In the Asian LNG market, Japan, Korea and Chinese Taipei are generally classified as traditional LNG importers and others as emerging LNG importers.

[27] In the indexation of LNG prices to oil prices under long-term contracts, crude oil price changes are reflected in LNG prices after a certain time lag. In this section, however, such time lag is not considered.

these countries. As Asian LNG consumption remains concentrated in Northeast Asia, Asian and global LNG demand growth will be far slower than assumed at present.

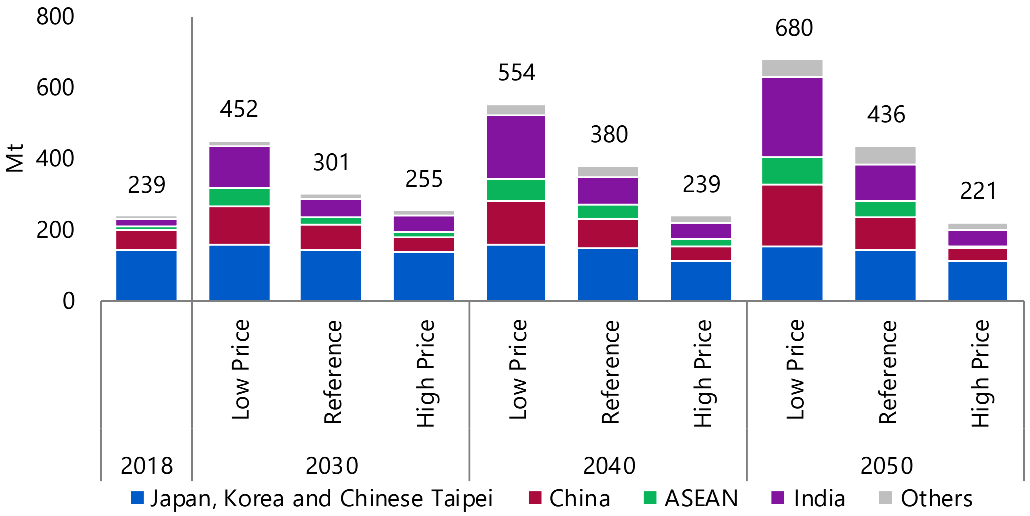
In the Low Price Case, the real average spot LNG price between January and August 2019 is assumed to remain unchanged until 2050[28]. At this price level, LNG may become competitive as a power generation fuel in emerging LNG importers in South Asia and Southeast Asia[29]. To satisfy LNG demand in this case, however, liquefaction and transportation costs will need to be substantially reduced, with appropriate investment implemented to meet expanding demand.

LNG demand in Asia

The abovementioned price changes, whether they are feasible or not, will undoubtedly bring about a major change in Asian LNG demand. This section reviews the Asian LNG demand for each case. In the High Price Case, no new natural gas-fired power plants will be installed in Asia. In the Low Price Case, half the growth in coal-fired power generation capacity will be replaced by natural gas-fired capacity.

In the Reference Scenario, Asian LNG demand will increase at an annual rate of 1.9% from 239 Mt in 2018 to 436 Mt in 2050. India will feature the largest demand at 105 Mt, followed by 93 Mt for China. LNG demand will post no growth in the traditional LNG importers Japan, Korea and Chinese Taipei, while increasing at a very high annual rate of 4.4-6.2% in Southeast Asia, India and other South Asian countries (Figure 7-5).

Figure 7-5 | LNG demand in Asia



[28] Here, a simple average of Platts JKM front-month futures prices reported between January and August 2019 is adopted.

[29] In India that depends on coal-fired power generation more heavily than China and is expected to substantially increase natural gas demand, LNG is estimated to become more competitive than coal at prices below $5/MBtu (Platts LNG Daily, 25 March 2019). Given transportation costs, the LNG price for India may be $0.1/MBtu lower than the JKM price.

In the High Price Case, LNG demand growth will almost level off through 2050, when demand will total 221 Mt, approximately 200 Mt or 49% less than in the Reference Scenario. Demand will decrease slightly in Japan, Korea and Chinese Taipei, with demand growth decelerating considerably in other Asian economies. In the Low Price Case, LNG demand will rise at an annual rate of 3.3% to 680 Mt in 2050. In this case, demand will increase slightly from the Reference Scenario in Japan, Korea and Chinese Taipei, while growing at a very high annual rate of 6.1-7.5% in Southeast Asia, India and other South Asian countries.

As oil prices have recovered, investment in LNG projects has picked up since 2018. Natural gas liquefaction capacity that had made final investment decisions by the first half of 2019 reached 54 Mt. By the end of 2020, additional capacity totalling 120 Mt are still in a pipeline of making final investment decisions. If 80% of the production from new LNG projects is destined for the Asian market, additional supply capacity for Asia alone may total about 140 Mt by the middle of the 2020s, paving the way for the High Price Case demand through 2050. New LNG project investment from the 2020s will slow down, leading to a greater dependency on coal-fired power generation and an increase in the environmental footprint for Asia. In the Low Price Case, Asia will benefit from the environmental merits of natural gas more easily but to secure investment in new LNG projects, however, liquefaction plant and transportation costs will need to decline substantially.

Regardless of the case, as noted above, LNG demand growth will shift from Japan, Korea and Chinese Taipei to emerging LNG importers. As explained earlier, these emerging LNG importers mostly depend on coal-fired power generation as a major power source, meaning that LNG demand expansion in these countries would remain limited unless LNG is competitive in the power generation sector which can greatly boost LNG demand. Therefore, as explained above, LNG prices will need to remain low to allow these countries to benefit from the environmental merits of LNG and the LNG suppliers will be required to cut liquefaction and transportation costs. Furthermore, appropriate investment will be required to enable supply to satisfy an expanding demand. It will be important to sustainably and soundly expand the LNG market from the viewpoints of both the supply and demand sides. LNG importers for their part will need to promote infrastructure development, fuel switching to natural gas, the reduction of subsidies for retail gas and electricity prices, and incentives for natural gas-fired power generation, including long-term electricity sales contracts.

7.3 Enhancing LNG supply security

The previous section indicated that while LNG demand continues an uptrend over a long term, its pace of expansion will differ depending on future LNG prices. As LNG's position in energy use expands in the future, interests are expected to increase in LNG supply security. This section considers a recipe for enhancing LNG supply security.

Concept of LNG supply security

Three measures have been considered to ensure LNG supply security. The first is the diversification of import source countries and routes. If there are multiple LNG import source countries, imports from one country subjected to supply disruptions may be substituted by those from another country. Diversification is the most basic security measure. *The more import source countries are diversified, the more security is ensured*. Meanwhile, an LNG importer would have to secure a substantial demand size (or a substantial company size) to have multiple LNG import contracts. Theoretically, LNG supply security risks are higher for small countries or business operators that cannot sufficiently diversify their LNG import sources.

The second measure is the efficient use of natural gas. Higher energy efficiency allows LNG imports to be reduced, resulting in less supply security risks.

Lastly, stable relations with suppliers, based on long-term contracts as featured by traditional LNG trade, have also been viewed as contributing to stable supply.

Thanks to these measures, Asia's LNG supply security has fortunately been kept from failing. For as long as Asia will depend on LNG imports, however, supply risks requiring continuous security measures will always exist. Conceivable measures to further enhance Asia's LNG supply security include "the utilisation of a highly liquid Asian LNG market" and "cooperation with other natural gas markets" (Table 7-2). The two measures are discussed below.

Table 7-2 | LNG supply security measures

Existing measures	**Diversifying import source countries and routes** Substitute imports from a country subject to supply disruption with those from others.
	Reducing demand through efficient use Improve efficiency to reduce imports to cut the impact of and measures against supply disruptions.
	Building stable relations with sellers through long-term contracts Secure supply by building stable relations with sellers through binding long-term contracts. This measure is effective particularly when demand is growing.
New measures	**Creating and utilising a highly liquid Asian LNG market** Import LNG as needed from highly liquid international markets.
	Cooperating with other natural gas markets Take advantage of the characteristics of other natural gas markets such as Europe and China and cooperate with them to build a system to adjust the LNG supply-demand balance.

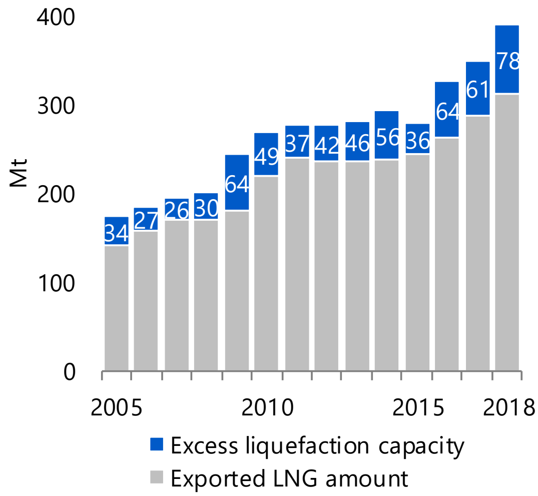
Utilising highly liquid international markets

In recent years, international LNG markets have produced favourable changes for Asian LNG supply security

First, LNG export projects have gradually increased, leading to the steady accumulation of new supply capacity (Figure 7-6). Furthermore, supply capacity growth has been faster than demand expansion. Although equipment failures and civil wars could be combined to reduce available gas liquefaction capacity over a short term, excess liquefaction capacity has generally been increasing. This is because liquefaction capacity growth in the United States, Australia and Russia has exceeded even a remarkable increase in China's LNG imports in recent years. This means that security concerns have decreased, thanks to a supply capacity growth.

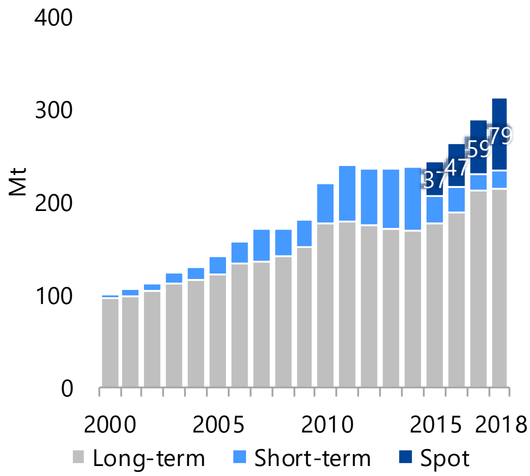
Second, flexible LNG supply and trade have increased. Spot LNG transactions (defined as those for delivery within 90 days) have expanded year after year, accounting for 78.7 Mt or 25% of the total LNG transactions in 2018 estimated at 310 Mt (Figure 7-7). Behind the growth in spot transactions, is a growing demand for more flexible LNG supply while U.S. LNG exports, featuring less restrictions on buyers, have also been expanding. As a rising number of players are having full command of multiple liquefaction portfolios, the security for LNG importers has been improved, thanks to a growing potential for them to procure LNG as needed, in a timely manner.

Figure 7-6 | Global LNG exports and excess liquefaction capacity



Note: Excess liquefaction capacity = Total liquefaction capacity – LNG exports
Source: Annual GIIGNL

Figure 7-7 | LNG exports by contract period



Note: Short-term (four-year or shorter) contracts between 2000 and 2014 include spot deals.
Source: Annual GIIGNL

To maintain a favourable environment, initiatives are required to promote timely investments in the upstream sector (for natural gas development, production and liquefaction) and avoid excessive growth in natural gas demand. Efforts must also be made to eliminate destination restrictions and other practices that hurt the flexibility of LNG transactions.

Cooperating with other natural gas markets

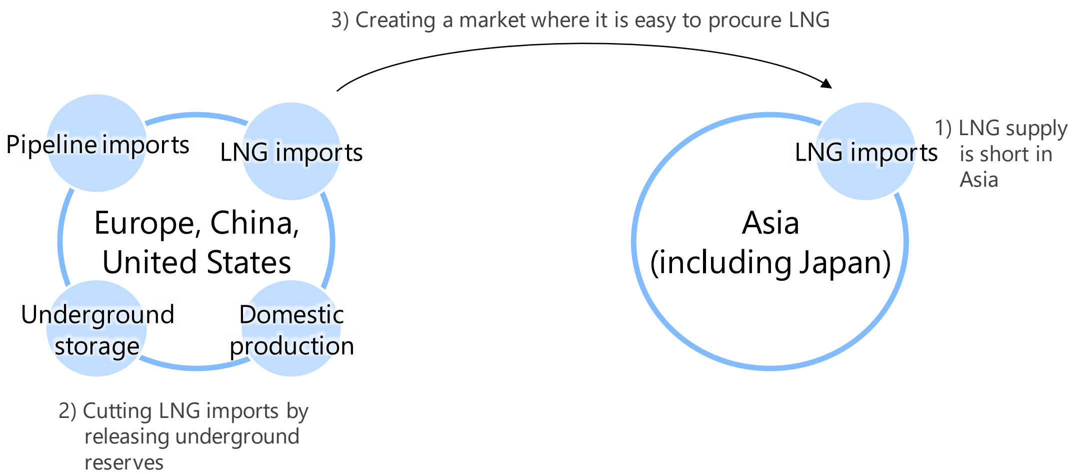
While Japan almost fully depends on LNG imports for its natural gas supply, some other countries or regions do not. For example, the European Union, China and the United States feature multiple natural gas supply means other than LNG. The European Union covers 26% of its natural gas demand with local production (in 2017, IEA 2019), imports natural gas via pipelines from nearby countries such as Russia, Norway and Algeria and uses depleted gas wells and rock salt domes as underground natural gas storage facilities (with working gas capacity equivalent to 24% of demand in 2017). If LNG imports decline, the European Union could take advantage of diverse means such as expanding its domestic production or gas imports via pipelines or releasing gas from its underground storage facilities to maintain stable natural gas supply.

China features a similar situation. While its coastal area facing the East China Sea imports LNG, China can domestically produce natural gas to cover 63% of its demand (in 2017, IEA 2019) and import gas via pipelines from Central Asian countries like Turkmenistan as well as Myanmar. As of 2017, China had underground gas storage facilities with capacity equivalent to 6% of natural gas consumption or about 20 days' consumption (JOGMEC 2019). The United States also has a similar situation.

The ability to adjust capacity in the European Union, China or the United States can be utilised for enhancing the Asian LNG supply security. If LNG imports fall short of satisfying demand in Asia, for example, the European Union or China may provide LNG covering the shortfall while expanding their pipeline gas imports to maintain an appropriate overall supply-demand balance. In this way, any country may build more flexible and resilient gas security arrangements by cooperating with other countries or regions with diverse gas supply options and infrastructure, instead of trying to adjust the supply-demand balance on its own. It may be economically unrealistic for Asian countries to possess massive natural gas/LNG reserves, but by cooperating with the European Union and China, however, other Asian countries may use EU and Chinese underground natural gas storage capacity effectively as if they were their own.

Typically, any excess LNG in the Atlantic market is resold to the Asian market which is usually in a tighter supply-demand balance. It may, therefore, be economically efficient and desirable for business-purpose transactions to contribute to enhancing security of supply. If security measures are expected to work in emergency situations, however, such business-purpose transactions characteristically differ from them. The scope that can be expected from business-purpose deals should be of enhancing security while government interventions should respond to more serious crises. When the LNG supply-demand balance tightens, for example, the European Union and China may release underground gas reserves temporarily to ease their natural gas supply-demand balance and bring about excess supply on a global basis, allowing Asia to procure LNG more easily (Figure 7-8).

Figure 7-8 | Image for utilising supply-demand adjustment capacity of other regions/countries



On the other hand, it may be argued that gas security arrangements that depend on other countries or regions would be unstable. In the oil market, however, a framework for the members of the International Energy Agency to cooperate with each other under the IEA has worked over a long term. This is based on a recognition that any oil importing country may not be free from the influence of the international oil market or cannot take sufficient measures on its own in response to more serious crises. Given that LNG consumption increases with LNG's importance growing more and more, it may be reasonable for LNG importing countries to cooperate in responding to crises. Given that the European Union has aimed at putting strategic goods (coal and steel) under joint management to avoid war, natural gas/LNG security cooperation between countries or regions could become the base for enhancing their relations. Asia's cooperation with other countries or regions to enhance its LNG security would be worthy of consideration, although discussions on the matter may have to be deepened further.

Conclusion

Asian LNG security has so far been mainly dependent on the diversification of import source countries and routes, the highly efficient use of natural gas and the building of stable relations with sellers through long-term contracts. While interests are expected to grow in LNG supply security, favourable LNG market changes for stabilising the LNG supply in Asia are seen, including the expansion of supply capacity and an increase in quantitatively flexible LNG transactions. Given the United States, the European Union and China that have diverse gas supply options other than LNG, Asia could cooperate with them to enhance its LNG supply security.

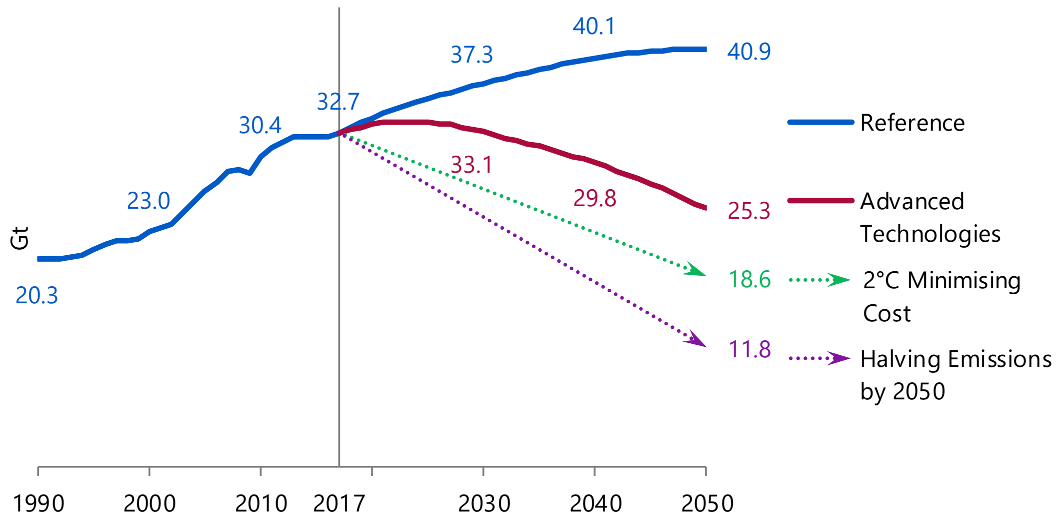
In Asia, majority of natural gas imports are LNG and therefore, LNG supply security is undoubtedly important for the region. While trying to diversify import source countries and routes, Asian importers should pursue LNG security enhancement initiatives to cover all possible options such as the creation of favourable international markets for LNG supply security in Asia, and the development of a crisis response mechanism uniting Asia and other natural gas markets.

8. Pragmatic approach to the climate change issue

8.1 Cutting CO_2 emissions further

Energy-related CO_2 emissions in 2050 in the Advanced Technologies Scenario will fall by 17% from 2010, deviating far from the 11.8 Gt target of halving emissions in 2050. If the temperature increases from the second half of the 19th century is to be limited to 2°C in 2150 (see the "2°C Minimising Cost Path" in the IEEJ Outlook 2018), the CO_2 emissions would need to be further reduced by 7 Gt from the Advanced Technologies Scenario in 2050.

Figure 8-1 | Global energy-related CO_2 emissions (comparison with ultra-long-term analysis)



Note: The ultra-long-term analysis represents results gained with an integrated assessment model (see the IEEJ Outlook 2018).

A massive introduction of innovative technologies would be required to reduce CO_2 emissions by an additional 7 Gt in 2050. Technologies for limiting the temperature rise include not only energy efficiency improvements, renewable energy and nuclear technologies, but also next-generation nuclear power plants, space solar photovoltaics, nuclear fusion, hydrogen utilisation, carbon capture and utilisation (CCU) and bioenergy with CCS (BECCS).

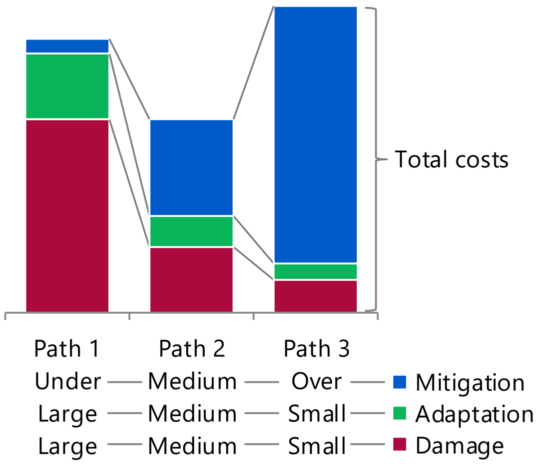
8.2 Long-term GHG emissions path and cost-benefit analysis

Climate change accompanying greenhouse gas (GHG) emissions takes centuries to materialise. This point must be fully understood and considered in the assessment of adequate policy options. Such review has traditionally incorporated long-term cost-benefit analyses.

Figure 8-2 presents a conceptual approach for such cost-benefit analysis. If *damages to* human beings are the only matter of concern regarding global climate (when temperatures increase), the assessment of what and how much *damage*s must be done as accurately as possible. Damages may be lessened by *adaptation* measures such as, the construction of seawalls to counter sea level rises, the improvement of farm breeds to counter changes in harvest, and the introduction of medical and sanitation measures or lifestyle changes to counter health issues. Conceptually, therefore, the cost for such adaptation measures should also be assessed. If reducing emissions could hold down temperature rises, or "mitigate" the impact of climate change, the abovementioned damage and adaptation costs would be reduced accordingly. Consequently, the additional cost of cutting GHG emissions also need to be considered. Therefore, an attempt to assess the optimum balance of "*mitigation*," "*adaptation*" and "*damage*" costs is the long-term cost-benefit analysis regarding climate change. The mathematical model for the analysis is called an integrated assessment model (IAM).

Figure 8-2 | Conceptual diagram of cost-benefit analysis

Mitigation	Representative among mitigation measures is GHG emission reduction, including CCS to prevent GHG from being released into the atmosphere. Mitigation measures are designed to mitigate climate change.
Adaptation	An increase in temperature could cause a sea level rise, droughts, new disease epidemics, etc. Seawalls and reservoir construction, agricultural research, and disease prevention and treatment to respond to these problems are adaptation measures.
Damage	When mitigation and adaptation fail to sufficiently reduce the effects of climate change, damages from sea level rise, droughts or new disease epidemics may emerge



Cost-benefit analyses related to climate change have a long history. In 1992, William Nordhaus published the Dynamic Integrated Climate-Economy (DICE) model as a representative IAM (decades before winning the Nobel Prize in Economic Sciences in 2018). While the DICE model has continuously been improved, many other integrated assessment models have been developed and modified, including the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model by Richard Tol et al., and the Policy Analysis of the Greenhouse Effect (PAGE) model by Chris Hope et al.

While such assessments have been conducted globally, there have been deep-rooted criticisms of cost-benefit analysis approaches. The major criticisms follow[30]:

(1) Uncertainty accompanying damage estimates

Great uncertainty accompanies climate change damage estimates and could make IAMs' assessments vulnerable and most models do not necessarily cover all categories of damage.

[30] D. Diaz and F. Moore (2017). Quantifying the economic risks of climate change, *Nature Climate Change*, 7, 774-782.

Some models, even though covering most of the damage categories, fail to consider the interactions between damage categories. While assessments for Europe and North America, at relatively lower temperature increases (1-3°C), are extrapolated to other regions with higher temperature increases, the legitimacy of the extrapolation is seen as questionable. In recent years, many studies have been published on how temperature increases affect climate change and their damage. The establishment of damage functions (relationships between temperature increases and damages) has remained a key challenge for such studies.

(2) Effects of "tipping elements"

The earth's climate has been in a kind of "equilibrium state." Disturbances below a certain level, such as an increase in the atmospheric concentration of CO_2, are often offset by negative feedback, such as an increase in CO_2 absorptions into the surface of the earth or sea water, preventing the earth from deviating too far from the equilibrium state. If disturbances exceed a certain level, however, the earth system could go in the direction of accelerating the disturbances in a positive feedback loop, instead of restricting them, shifting the earth to a different equilibrium state (e.g., a state with higher temperatures)[31]. Here, a saddle point or a tipping point is assumed between the two different equilibrium states. If some disturbance surpasses the point, the earth is assumed to acceleratingly shift to a different equilibrium state. Large-scale components of the Earth system that may pass a tipping point are usually referred to as tipping elements.

Examples of tipping elements include the melting of the Greenland ice sheet. The 1 600 metres thick ice sheet that covers Greenland has begun to melt at an unprecedentedly high rate as of 2019 and if the ice sheet were to melt completely, the sea level in the world is estimated to rise by 7 m. It is a serious concern that such event would inflict significant impacts on human life. Here, it is important that a kind of hysteresis phenomenon would arise in the absence of any unique relationship between the temperature increase and the ice melting level. Even if temperatures fall back after the melting of the Greenland ice sheet, the ice sheet would not be restored at least immediately. Such (almost) irreversible phenomenon may create a new equilibrium state.

Cited as another tipping element is the melting of the Siberian permafrost. If the permafrost containing massive carbon melts, methane and CO_2 would be released into the atmosphere. Even if only a small portion of the estimated at 1.7 trillion tonnes of carbon contained in the permafrost is released, it may cause a greenhouse effect pushing temperatures up remarkably. Unlike the abovementioned ice sheet melting, the carbon release from the permafrost would be essentially irreversible.

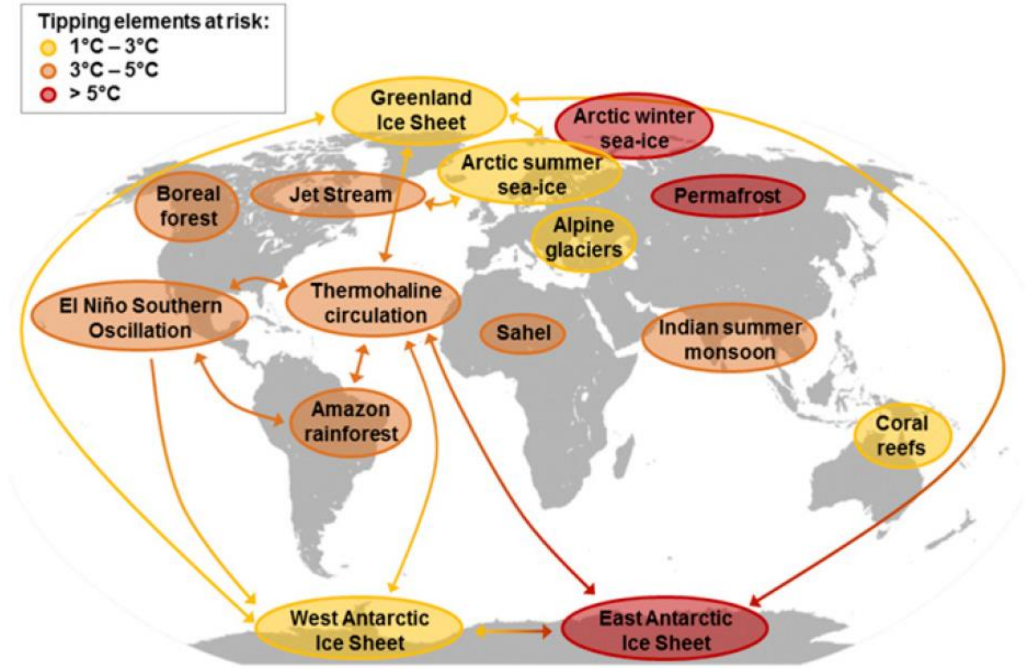
In addition, various other tipping elements are presented (Figure 8-3)[32]. These events accompanying temperature increases are more or less irreversible and likely to exert great

[31] It must be noted that the "different equilibrium state" would not necessarily be any unprecedented one in the history of the earth. Around the Palaeocene-Eocene period some 55 million years ago, for example, temperatures were 5-8°C higher than at present, indicating an equilibrium state that is different from the present one.

[32] W. Steffen et al. (2018). Trajectories of the earth system in the Anthropocene, *PNAS*, 115 (33), 8252-8259.

influence on human beings. The world that would reach a different equilibrium state through these events is called "hothouse earth," seen as one of the major future crises for human beings.

Figure 8-3 | Tipping elements



Source: Steffen et al. (2018)

(3) Other issues

Cost-benefit analyses related to climate change are known for numerous academic arguments. Probably the most famous argument deals with the long-term discount rate. A discount rate is used to convert future monetary values into present values. For example, if a real interest rate of 3% can be expected for sure, $1 000 at present would be equal to $1 305 a decade later. This means that $1 305 a decade later would be discounted to $1 000 in present value. In this case, 3% is equal to the real discount rate. If damage that may arise in the far future due to long-term climate change is discounted at a certain rate into present value, it may fall towards zero in an exponential manner. The result may lead to an argument that costs for the present generation should be reduced even at the risk of increasing costs for future generations. Such argument is doubtful from the viewpoint of intergenerational equity. In fact, it is recommended that a falling discount rate be used instead of any constant discount rate in consideration of economic issues over the ultra-long term[33, 34]. However, no consensus exists on how the discount rate should be assumed to fall. Historically, Stern[35] and some others have assumed a very low

[33] M.L. Weitzman (1998). Why the far-distant future should be discounted at its lowest possible rate, *Journal of Environmental Economics and Management*, 36, 201-208.
[34] C. Gollier (2012). Pricing the Planet's Future: The Economics of Discounting in an Uncertain World, Princeton University Press, Princeton.
[35] N. Stern (2007). *The Economics of Climate Change: The Stern Review*, Cambridge University Press, Cambridge.

discount rate from the viewpoint of intergenerational equity, while Nordhaus and some others have criticised such low discount rate as unreasonable from the viewpoint of economics. The argument has not yet been settled but continues.

Another famous argument is a *fat tail distribution* as pointed out by Weitzman[36] and some others. For example, the equilibrium climate sensitivity (ECS), a key indicator for forecasting future temperature rises, is seen as very uncertain and could be very high. The fourth assessment report by the Intergovernmental Panel on Climate Change gave 3.0°C as the best ECS estimate, a probable ECS range of 2.0-4.5°C and provided comments that the ECS could exceed 4.5°C. Weitzman claimed that as we don't know with accuracy the ECS, we should conceive the ECS as some subjective probability distribution range and that it is at least mathematically proven that unless the probability of extreme events converges quickly to zero at the upper end of the distribution, a cost-benefit analysis based on a probability theory would have to consider the ECS (or equivalently, damage from climate change) to be infinite. Weitzman called this "a dismal theorem." In this case, an argument that greenhouse gas emissions should be reduced at any cost would be established, at least theoretically. Although a similar mathematical argument can be used to assess the costs required to reduce global GHG emission to zero on a net basis within the 21st century, an argument says that the probability distribution would not be fat-tailed in this case because the upper limit of costs for GHG emission reduction measures is defined by a so-called backstop price, i.e. the cost of the technologies such as the direct air capture of carbon. However, whether such backstop price exists could be arguable. This topic is still subject to considerable ongoing debate: If one person views the cost for emitting 1 tonne of carbon at present as infinite, it may be meaningful to question why such person does not immediately stop consuming electricity, gas or gasoline. A study has proposed that a cost-benefit analysis would still be effective because a fat-tailed probability distribution of the equilibrium climate sensitivity means a fat-tailed probability distribution of temperature rises but not necessarily a fat-tailed probability distribution of damage[37].

8.3 Refining cost-benefit analyses

As shown above, there are numerous arguments about the long-term climate change issue. As climate change cost-benefit analyses are directly linked to current climate change policies, however, we should consider what should be done now to refine the analyses even in the face of numerous arguments. Regarding the refinement of the damage functions described in (1), particularly, many researchers mainly in the United States have continued specific efforts. Figure 8-4 shows an attempt to assess damages in the United States with the latest knowledge reflected[38]. Damages from a temperature rise of 4°C from pre-industrial levels are here estimated at 2-3% of GDP, indicating no major essential difference from traditional DICE

[36] M.L. Weitzman (2009). On modelling and interpreting the economics of catastrophic climate change, *Review of Economics and Statistics*, 91 (1), 1-19.

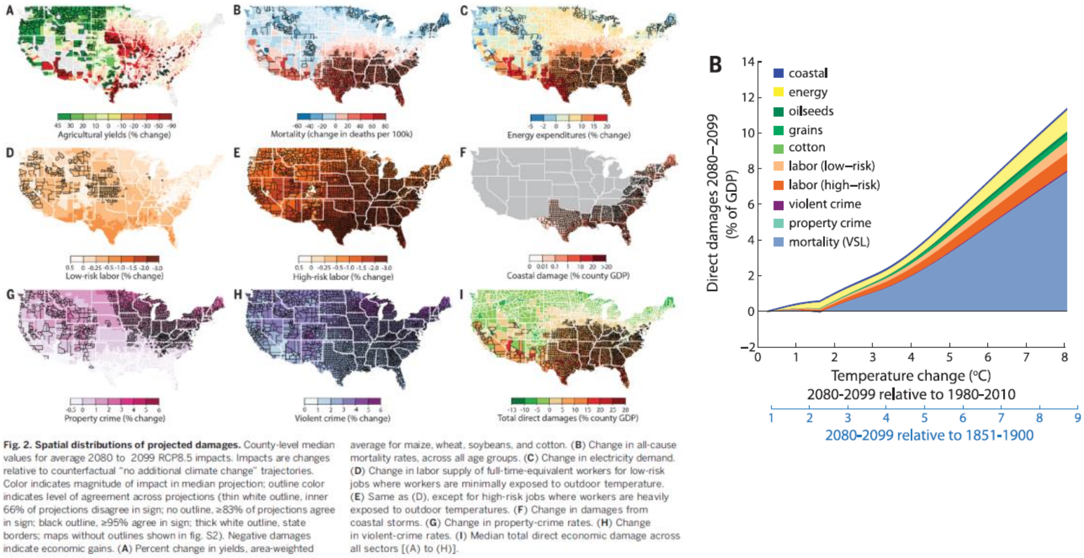
[37] I.C. Hwang et al. (2016). Fat-tailed risk about climate change and climate policy, *Energy Policy*, 89, 25-35.

[38] S. Hsiang et al. (2017). Estimating economic damage from climate change in the United States, *Science*, 356, 1362-1369.

model assumptions. However, the absence of any major difference is a key finding. This kind of assessment efforts should be continued.

Figure 8-4 | Damage function assessment for the United States

Spatial distribution of projected damages by category **Total damages (% of GDP)**



Source: Hsiang et al. (2017)

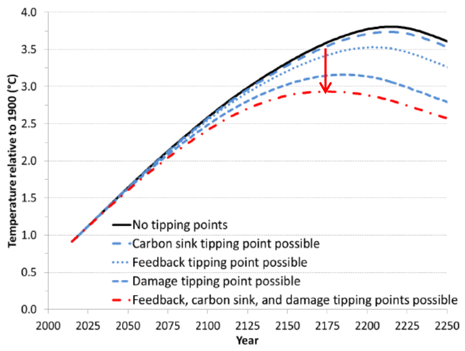
Efforts have also been made to conduct cost-benefit analyses that would include the tipping elements, not explicitly considered in traditional IAMs. Specific results of such cost-benefit analysis assessments are shown in Figure 8-5[39, 40]. The left figure indicates that a dynamic programming assessment considering carbon sink, climate feedback and damage tipping points could lower the maximum temperature rise for an optimum emission path from nearly 4°C to nearly 3°C. The right figure shows that if consideration is given to tipping elements such as Atlantic current changes, the melting of the Greenland and West Antarctic ice sheets, the depletion of the Amazon rainforest and a transition to frequent El Nino phenomena, the temperature rise for an optimum path would be lowered from 2.8°C in 2100 to less than 1.5°C. It must be noted that such analyses are behind the 1.5°C goal that has attracted much attention since the Paris Agreement.

[39] D. Lemoine and C.P. Traeger (2016). Economics of tipping the climate dominoes, *Nature Climate Change*, 6, 514-520.

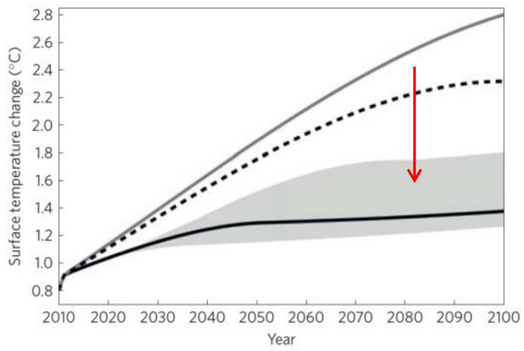
[40] Y. Cai et al. (2016). Risk of multiple interacting tipping points should encourage rapid CO_2 emission reduction, *Nature Climate Change*, 6, 520-527.

Figure 8-5 | Changes in optimum path temperature rises considering cost-benefit analysis assessments of tipping elements

Lemoine and Traeger (2016)



Cai et al. (2016)



However, the two analyses in Figure 8-5 might have assessed the effects of tipping elements too simply. For example, Lemoine and Traeger (2016) for the left figure assumes that if the carbon sink tipping point is passed, the global carbon absorption rate would plunge by 50% and never restore its original level. Cai et al (2016) assumes that once changes in the Atlantic current occur, 15% of global GDP would be lost and never be restored. Tipping elements, though considered (almost) irreversible processes caused by temperature rises, may progress very slowly over an ultra-long term on a human time scale. Such processes may not necessarily be completed. Even if the Greenland ice sheet begins to melt, for example, the termination of temperature increases may prevent the ice sheet from melting completely.

It has growingly been recognised that the reflection of tipping elements in models should not be as simple as in the past but cover the dynamism of their changes accurately. Assessments based on the recognition are attempted as of 2019. For example, Nordhaus (2019) has assumed a hysteresis response to the melting of the Greenland ice sheet based on earlier studies and incorporated the response into the DICE model, indicating that the effect of the melting would be relatively minor[41]. Under this kind of formulation, the minor effect results from the very slow process of the ice sheet melting. Yumashev et al. (2019) has explicitly incorporated the melting of the Siberian permafrost and a change in the Arctic albedo[42] into the PAGE model and indicated that a minor but significant effect would be exerted on a cost-benefit analysis[43, 44]. Assessments that explicitly reflect the dynamism of tipping elements could indicate a risk that would differ far from the traditionally conceived risk of a different equilibrium state.

[41] W. Nordhaus (2019). Economics of the disintegration of the Greenland ice sheet, *PNAS*, 116 (25), 12261-12269.

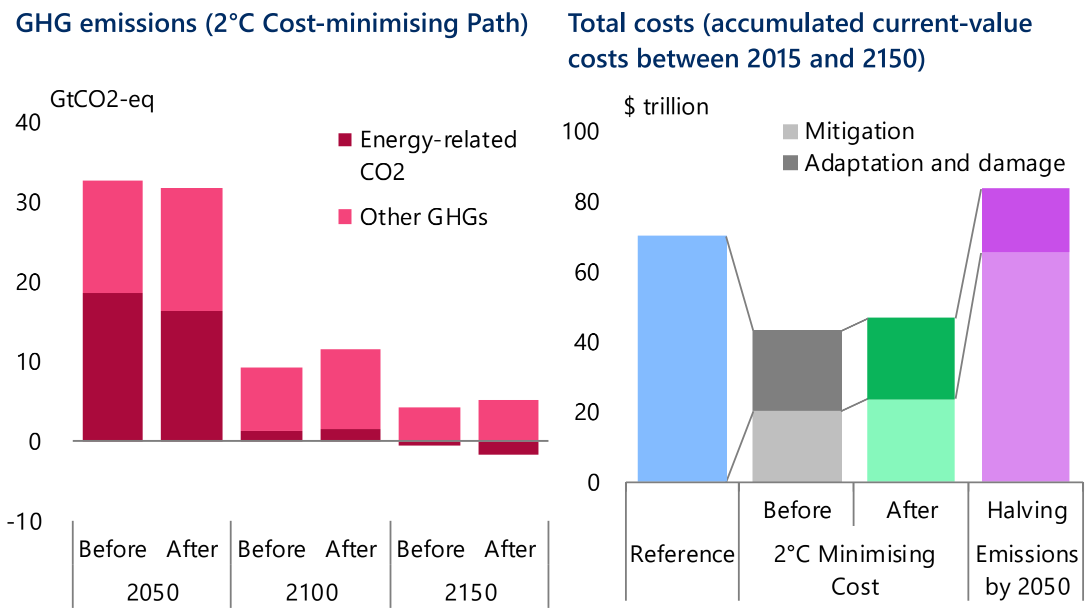
[42] The albedo is the ratio of solar energy directed upward from a surface over energy incident upon the surface.

[43] D. Yumashev et al. (2019). Climate Policy implications of nonlinear decline of Arctic land permafrost and other cryosphere elements, *Nature Communications*, 10, 1900.

[44] However, it must be noted that the PAGE model used by Yumashev et al. assumes the mitigation cost at a relatively low level, allowing the 2°C or 1.5°C goal to be close to the optimum path even before tipping elements are considered.

Figure 8-6 is a cost-benefit analysis that explicitly incorporated the melting of the Green Island ice sheet and the Siberian permafrost and the Arctic albedo change as mentioned above into the 2°C Cost-minimising Path (a path in which total costs would be minimised with a temperature increase in 2150 limited to 2°C) given in the IEEJ Outlook 2018. If these tipping elements are considered, GHG emission cuts would have to be accelerated somewhat to attain the 2°C goal. Energy-related CO_2 emissions would have to be reduced further to offset methane and other GHGs released through the melting of the permafrost, increasing the total costs accordingly. However, the overall picture of the path would not change much.

Figure 8-6 | Cost-benefit analysis reflecting three tipping elements



Note: The three tipping elements are the melting of the Greenland ice sheet, the Siberian permafrost and the Arctic albedo change.

Important here is whether a similar finding could be made for any tipping elements. We should not forget that the cost-benefit analysis approach itself is plagued with great uncertainties as noted above. Quantitative assessments regarding climate change directly exert great influence on current energy and environment policies. Therefore, we should consider the uncertainties, continuously update the assessments with the latest data and sustain efforts to reduce the uncertainties by as much as possible.

Annex

Table A1 | Regional groupings

Asia	People's Republic of China	
	Hong Kong	
	India	
	Japan	
	Korea	
	Chinese Taipei	
	ASEAN	Brunei Darussalam
		Indonesia
		Malaysia
		Myanmar
		Philippines
		Singapore
		Thailand
		Viet Nam
	Others	Bangladesh, D. P. R. Korea, 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, 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, Lithuania, 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, Sweden, and the United Kingdom
Advanced Economies	Hong Kong, Japan, Korea, North America, Oceania, Advanced Europe, 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, Ecuador, 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 A2 | Major energy and economic indicators

				Reference		Advanced Technologies		CAGR (%)		
								1990/	2017/2050	
		1990	2017	2030	2050	2030	2050	2017	Reference	Adv. Tech.
Total primary energy	**World**	**8 766**	**13 972**	**16 564**	**18 757**	**15 624**	**15 915**	**1.7**	**0.9**	**0.4**
consumption	AEs*1	4 468	5 228	5 181	4 767	4 959	4 131	0.6	-0.3	-0.7
(Mtoe)	EMDEs*2	4 096	8 331	10 854	13 236	10 180	11 168	2.7	1.4	0.9
	Asia	2 110	5 669	7 386	8 585	6 937	7 223	3.7	1.3	0.7
	Non-Asia	6 453	7 890	8 650	9 418	8 201	8 076	0.7	0.5	0.1
Oil consumption	**World**	**3 233**	**4 449**	**5 035**	**5 707**	**4 702**	**4 489**	**1.2**	**0.8**	**0.0**
(Mtoe)	AEs	1 826	1 874	1 711	1 421	1 594	1 110	0.1	-0.8	-1.6
	EMDEs	1 205	2 163	2 813	3 628	2 650	2 961	2.2	1.6	1.0
	Asia	618	1 410	1 836	2 321	1 741	1 905	3.1	1.5	0.9
	Non-Asia	2 413	2 627	2 688	2 728	2 503	2 167	0.3	0.1	-0.6
Natural gas	**World**	**1 664**	**3 107**	**4 026**	**5 165**	**3 696**	**3 879**	**2.3**	**1.6**	**0.7**
consumption	AEs	827	1 389	1 551	1 538	1 409	1 011	1.9	0.3	-1.0
(Mtoe)	EMDEs	837	1 718	2 462	3 537	2 266	2 730	2.7	2.2	1.4
	Asia	116	595	1 016	1 471	917	1 097	6.2	2.8	1.9
	Non-Asia	1 548	2 512	2 997	3 604	2 758	2 644	1.8	1.1	0.2
Coal consumption	**World**	**2 220**	**3 790**	**4 215**	**4 035**	**3 559**	**2 375**	**2.0**	**0.2**	**-1.4**
(Mtoe)	AEs	1 088	904	782	560	625	254	-0.7	-1.4	-3.8
	EMDEs	1 133	2 886	3 433	3 474	2 934	2 121	3.5	0.6	-0.9
	Asia	788	2 761	3 279	3 222	2 799	1 963	4.8	0.5	-1.0
	Non-Asia	1 432	1 029	936	813	760	412	-1.2	-0.7	-2.7
Power generation	**World**	**11 850**	**25 606**	**34 412**	**45 363**	**33 552**	**42 127**	**2.9**	**1.7**	**1.5**
(TWh)	AEs	7 668	10 868	12 177	13 258	11 899	12 292	1.3	0.6	0.4
	EMDEs	4 182	14 738	22 235	32 105	21 653	29 835	4.8	2.4	2.2
	Asia	2 241	11 340	16 958	22 578	16 482	20 859	6.2	2.1	1.9
	Non-Asia	9 608	14 266	17 455	22 785	17 070	21 268	1.5	1.4	1.2
Energy-related	**World**	**20 302**	**32 711**	**37 571**	**40 858**	**32 793**	**25 288**	**1.8**	**0.7**	**-0.8**
carbon dioxide	AEs	10 801	11 347	10 660	8 879	9 282	5 411	0.2	-0.7	-2.2
emissions	EMDEs	8 873	20 081	25 293	29 744	22 043	18 290	3.1	1.2	-0.3
(Mt)	Asia	4 631	15 157	19 038	20 987	16 511	12 709	4.5	1.0	-0.5
	Non-Asia	15 043	16 271	16 916	17 636	14 814	10 993	0.3	0.2	-1.2
GDP	**World**	**38 050**	**79 936**	**115 397**	**190 750**	**115 397**	**190 750**	**2.8**	**2.7**	**2.7**
($2010 billion)	AEs	28 914	50 277	62 850	85 161	62 850	85 161	2.1	1.6	1.6
	EMDEs	9 137	29 659	52 547	105 589	52 547	105 589	4.5	3.9	3.9
	Asia	7 628	24 564	42 742	81 204	42 742	81 204	4.4	3.7	3.7
	Non-Asia	30 422	55 373	72 655	109 546	72 655	109 546	2.2	2.1	2.1
Population	**World**	**5 281**	**7 519**	**8 522**	**9 716**	**8 522**	**9 716**	**1.3**	**0.8**	**0.8**
(Million)	AEs	999	1 181	1 222	1 238	1 222	1 238	0.6	0.1	0.1
	EMDEs	4 282	6 338	7 300	8 478	7 300	8 478	1.5	0.9	0.9
	Asia	2 933	4 072	4 449	4 681	4 449	4 681	1.2	0.4	0.4
	Non-Asia	2 348	3 447	4 073	5 035	4 073	5 035	1.4	1.2	1.2

*1 Advanced Economies *2 Emerging Market and Developing Economies

Table A3 | Population

(Million)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/2017	2017/2030	2030/2040	2040/2050	2017/2050
World	5 281 (100)	6 112 (100)	7 519 (100)	8 522 (100)	9 176 (100)	9 716 (100)	1.3	1.0	0.7	0.6	0.8
Asia	2 933 (55.5)	3 410 (55.8)	4 072 (54.2)	4 449 (52.2)	4 617 (50.3)	4 681 (48.2)	1.2	0.7	0.4	0.1	0.4
China	1 135 (21.5)	1 263 (20.7)	1 386 (18.4)	1 429 (16.8)	1 414 (15.4)	1 368 (14.1)	0.7	0.2	-0.1	-0.3	0.0
India	870 (16.5)	1 053 (17.2)	1 339 (17.8)	1 504 (17.7)	1 593 (17.4)	1 640 (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)	51 (0.7)	52 (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	430 (8.1)	506 (8.3)	625 (8.3)	699 (8.2)	739 (8.0)	761 (7.8)	1.4	0.9	0.5	0.3	0.6
Indonesia	181 (3.4)	212 (3.5)	264 (3.5)	299 (3.5)	318 (3.5)	331 (3.4)	1.4	1.0	0.6	0.4	0.7
Malaysia	18 (0.3)	23 (0.4)	32 (0.4)	37 (0.4)	39 (0.4)	41 (0.4)	2.1	1.2	0.7	0.5	0.8
Myanmar	41 (0.8)	46 (0.8)	53 (0.7)	58 (0.7)	61 (0.7)	62 (0.6)	1.0	0.7	0.5	0.2	0.5
Philippines	62 (1.2)	78 (1.3)	105 (1.4)	123 (1.4)	135 (1.5)	144 (1.5)	2.0	1.3	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)	2.3	0.7	0.3	-0.1	0.4
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	-0.1
Viet Nam	68 (1.3)	80 (1.3)	96 (1.3)	105 (1.2)	109 (1.2)	111 (1.1)	1.3	0.7	0.3	0.2	0.4
North America	277 (5.3)	313 (5.1)	362 (4.8)	391 (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)	325 (4.3)	350 (4.1)	367 (4.0)	379 (3.9)	1.0	0.6	0.5	0.3	0.5
Latin America	441 (8.4)	521 (8.5)	640 (8.5)	712 (8.4)	748 (8.2)	769 (7.9)	1.4	0.8	0.5	0.3	0.6
Advanced Europe	505 (9.6)	527 (8.6)	575 (7.6)	588 (6.9)	590 (6.4)	585 (6.0)	0.5	0.2	0.0	-0.1	0.1
European Union	478 (9.1)	488 (8.0)	512 (6.8)	518 (6.1)	518 (5.6)	511 (5.3)	0.3	0.1	0.0	-0.1	0.0
Other Europe / Eurasia	337 (6.4)	335 (5.5)	341 (4.5)	345 (4.0)	343 (3.7)	341 (3.5)	0.0	0.1	-0.1	-0.1	0.0
Africa	634 (12.0)	816 (13.4)	1 255 (16.7)	1 703 (20.0)	2 095 (22.8)	2 511 (25.8)	2.6	2.4	2.1	1.8	2.1
Middle East	132 (2.5)	168 (2.8)	246 (3.3)	302 (3.5)	335 (3.7)	365 (3.8)	2.3	1.6	1.1	0.8	1.2
Oceania	20 (0.4)	23 (0.4)	29 (0.4)	33 (0.4)	36 (0.4)	39 (0.4)	1.4	1.0	0.8	0.7	0.8
Advanced Economies	999 (18.9)	1 070 (17.5)	1 181 (15.7)	1 222 (14.3)	1 237 (13.5)	1 238 (12.7)	0.6	0.3	0.1	0.0	0.1
Emerging Market and Developing Economies	4 282 (81.1)	5 043 (82.5)	6 338 (84.3)	7 300 (85.7)	7 938 (86.5)	8 478 (87.3)	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 A4 | GDP

($2010 billion)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	38 050 (100)	50 096 (100)	79 936 (100)	115 397 (100)	151 856 (100)	190 750 (100)	2.8	2.9	2.8	2.3	2.7
Asia	7 628 (20.0)	11 102 (22.2)	24 564 (30.7)	42 742 (37.0)	61 349 (40.4)	81 204 (42.6)	4.4	4.4	3.7	2.8	3.7
China	830 (2.2)	2 237 (4.5)	10 161 (12.7)	20 439 (17.7)	30 536 (20.1)	39 687 (20.8)	9.7	5.5	4.1	2.7	4.2
India	506 (1.3)	870 (1.7)	2 651 (3.3)	6 273 (5.4)	10 518 (6.9)	16 320 (8.6)	6.3	6.9	5.3	4.5	5.7
Japan	4 704 (12.4)	5 349 (10.7)	6 158 (7.7)	6 762 (5.9)	7 291 (4.8)	7 787 (4.1)	1.0	0.7	0.8	0.7	0.7
Korea	363 (1.0)	710 (1.4)	1 346 (1.7)	1 886 (1.6)	2 308 (1.5)	2 664 (1.4)	5.0	2.6	2.0	1.4	2.1
Chinese Taipei	155 (0.4)	297 (0.6)	529 (0.7)	707 (0.6)	847 (0.6)	971 (0.5)	4.6	2.3	1.8	1.4	1.9
ASEAN	741 (1.9)	1 180 (2.4)	2 747 (3.4)	5 008 (4.3)	7 463 (4.9)	10 499 (5.5)	5.0	4.7	4.1	3.5	4.1
Indonesia	310 (0.8)	453 (0.9)	1 090 (1.4)	2 100 (1.8)	3 296 (2.2)	4 779 (2.5)	4.8	5.2	4.6	3.8	4.6
Malaysia	82 (0.2)	163 (0.3)	365 (0.5)	645 (0.6)	919 (0.6)	1 238 (0.6)	5.7	4.5	3.6	3.0	3.8
Myanmar	7 (0.0)	13 (0.0)	67 (0.1)	142 (0.1)	237 (0.2)	366 (0.2)	8.9	6.0	5.3	4.5	5.3
Philippines	95 (0.2)	125 (0.3)	303 (0.4)	623 (0.5)	922 (0.6)	1 311 (0.7)	4.4	5.7	4.0	3.6	4.5
Singapore	68 (0.2)	134 (0.3)	310 (0.4)	421 (0.4)	496 (0.3)	549 (0.3)	5.8	2.4	1.6	1.0	1.7
Thailand	142 (0.4)	218 (0.4)	423 (0.5)	672 (0.6)	929 (0.6)	1 221 (0.6)	4.1	3.6	3.3	2.8	3.3
Viet Nam	29 (0.1)	61 (0.1)	175 (0.2)	383 (0.3)	637 (0.4)	1 005 (0.5)	6.8	6.2	5.2	4.7	5.4
North America	10 078 (26.5)	14 056 (28.1)	19 232 (24.1)	25 073 (21.7)	31 059 (20.5)	37 311 (19.6)	2.4	2.1	2.2	1.9	2.0
United States	9 064 (23.8)	12 713 (25.4)	17 349 (21.7)	22 684 (19.7)	28 174 (18.6)	33 922 (17.8)	2.4	2.1	2.2	1.9	2.1
Latin America	2 835 (7.4)	3 819 (7.6)	5 798 (7.3)	8 300 (7.2)	11 426 (7.5)	14 589 (7.6)	2.7	2.8	3.2	2.5	2.8
Advanced Europe	12 721 (33.4)	15 953 (31.8)	20 808 (26.0)	25 402 (22.0)	28 941 (19.1)	32 256 (16.9)	1.8	1.5	1.3	1.1	1.3
European Union	11 891 (31.3)	14 783 (29.5)	18 824 (23.5)	22 909 (19.9)	26 160 (17.2)	29 207 (15.3)	1.7	1.5	1.3	1.1	1.3
Other Europe / Eurasia	2 145 (5.6)	1 472 (2.9)	2 759 (3.5)	3 792 (3.3)	4 804 (3.2)	6 014 (3.2)	0.9	2.5	2.4	2.3	2.4
Africa	893 (2.3)	1 166 (2.3)	2 391 (3.0)	4 084 (3.5)	6 571 (4.3)	9 731 (5.1)	3.7	4.2	4.9	4.0	4.3
Middle East	1 029 (2.7)	1 532 (3.1)	2 770 (3.5)	3 805 (3.3)	5 059 (3.3)	6 552 (3.4)	3.7	2.5	2.9	2.6	2.6
Oceania	721 (1.9)	996 (2.0)	1 614 (2.0)	2 199 (1.9)	2 647 (1.7)	3 092 (1.6)	3.0	2.4	1.9	1.6	2.0
Advanced Economies	28 914 (76.0)	37 649 (75.2)	50 277 (62.9)	62 850 (54.5)	74 064 (48.8)	85 161 (44.6)	2.1	1.7	1.7	1.4	1.6
Emerging Market and Developing Economies	9 137 (24.0)	12 448 (24.8)	29 659 (37.1)	52 547 (45.5)	77 792 (51.2)	105 589 (55.4)	4.5	4.5	4.0	3.1	3.9

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

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

Table A5 | GDP per capita

($2010 thousand/person)

							CAGR (%)				
	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	7.2	8.2	10.6	13.5	16.6	19.6	1.5	1.9	2.0	1.7	1.9
Asia	2.6	3.3	6.0	9.6	13.3	17.3	3.2	3.6	3.3	2.7	3.3
China	0.7	1.8	7.3	14.3	21.6	29.0	8.9	5.3	4.2	3.0	4.3
India	0.6	0.8	2.0	4.2	6.6	10.0	4.6	5.9	4.7	4.2	5.0
Japan	38.1	42.2	48.6	56.3	64.7	74.0	0.9	1.1	1.4	1.4	1.3
Korea	8.5	15.1	26.2	36.6	46.0	56.5	4.3	2.6	2.3	2.1	2.4
Chinese Taipei	7.6	13.3	22.4	29.6	36.1	43.5	4.1	2.1	2.0	1.9	2.0
ASEAN	1.7	2.3	4.4	7.2	10.1	13.8	3.5	3.8	3.5	3.2	3.5
Indonesia	1.7	2.1	4.1	7.0	10.4	14.5	3.3	4.2	3.9	3.4	3.9
Malaysia	4.5	7.0	11.5	17.6	23.3	30.0	3.5	3.3	2.9	2.6	2.9
Myanmar	0.2	0.3	1.2	2.4	3.9	5.9	7.8	5.2	4.8	4.3	4.8
Philippines	1.5	1.6	2.9	5.1	6.8	9.1	2.4	4.4	3.0	2.9	3.5
Singapore	22.2	33.4	55.2	68.4	78.3	87.2	3.4	1.7	1.4	1.1	1.4
Thailand	2.5	3.5	6.1	9.6	13.5	18.6	3.4	3.5	3.5	3.2	3.4
Viet Nam	0.4	0.8	1.8	3.6	5.9	9.1	5.5	5.4	4.9	4.5	5.0
North America	36.3	44.9	53.1	64.2	75.7	87.8	1.4	1.5	1.7	1.5	1.5
United States	36.3	45.1	53.4	64.9	76.8	89.4	1.4	1.5	1.7	1.5	1.6
Latin America	6.4	7.3	9.1	11.7	15.3	19.0	1.3	2.0	2.7	2.2	2.3
Advanced Europe	25.2	30.3	36.2	43.2	49.0	55.1	1.4	1.4	1.3	1.2	1.3
European Union	24.9	30.3	36.7	44.2	50.5	57.1	1.5	1.4	1.3	1.2	1.3
Other Europe / Eurasia	6.4	4.4	8.1	11.0	14.0	17.6	0.9	2.4	2.4	2.3	2.4
Africa	1.4	1.4	1.9	2.4	3.1	3.9	1.1	1.8	2.7	2.1	2.2
Middle East	7.8	9.1	11.3	12.6	15.1	18.0	1.4	0.9	1.8	1.8	1.4
Oceania	35.3	43.3	54.9	65.7	73.2	80.2	1.6	1.4	1.1	0.9	1.2
Advanced Economies	29.0	35.2	42.6	51.4	59.9	68.8	1.4	1.5	1.5	1.4	1.5
Emerging Market and Developing Economies	2.1	2.5	4.7	7.2	9.8	12.5	3.0	3.4	3.1	2.4	3.0

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

Table A6 | International energy prices

Real prices			Reference			Advanced Technologies		
		2018	2030	2040	2050	2030	2040	2050
Oil	$2018/bbl	71	95	115	125	80	80	80
Natural gas								
Japan	$2018/MBtu	10.1	9.5	9.7	9.9	9.3	9.3	9.3
Europe (UK)	$2018/MBtu	8.1	8.1	8.4	9.0	7.7	7.8	7.9
United States	$2018/MBtu	3.1	3.8	4.2	4.9	3.4	3.9	4.0
Steam coal	$2018/t	118	110	120	125	85	85	85

Nominal prices			Reference			Advanced Technologies		
		2018	2030	2040	2050	2030	2040	2050
Oil	$/bbl	71	120	178	236	101	124	151
Natural gas								
Japan	$/MBtu	10.1	12.0	15.0	18.6	11.8	14.4	17.5
Europe (UK)	$/MBtu	8.1	10.3	13.0	17.0	9.8	12.1	14.9
United States	$/MBtu	3.1	4.8	6.5	9.2	4.3	6.0	7.5
Steam coal	$/t	118	140	186	236	108	131	160

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

Table A7 | Primary energy consumption [Reference Scenario]

(Mtoe)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	8 766 (100)	10 025 (100)	13 972 (100)	16 564 (100)	17 983 (100)	18 757 (100)	1.7	1.3	0.8	0.4	0.9
Asia	2 110 (24.1)	2 887 (28.8)	5 669 (40.6)	7 386 (44.6)	8 171 (45.4)	8 585 (45.8)	3.7	2.1	1.0	0.5	1.3
China	874 (10.0)	1 130 (11.3)	3 063 (21.9)	3 654 (22.1)	3 752 (20.9)	3 594 (19.2)	4.8	1.4	0.3	-0.4	0.5
India	306 (3.5)	441 (4.4)	882 (6.3)	1 566 (9.5)	2 016 (11.2)	2 402 (12.8)	4.0	4.5	2.6	1.8	3.1
Japan	439 (5.0)	518 (5.2)	432 (3.1)	408 (2.5)	378 (2.1)	347 (1.8)	-0.1	-0.4	-0.8	-0.9	-0.7
Korea	93 (1.1)	188 (1.9)	282 (2.0)	306 (1.8)	297 (1.7)	274 (1.5)	4.2	0.6	-0.3	-0.8	-0.1
Chinese Taipei	48 (0.5)	85 (0.8)	110 (0.8)	113 (0.7)	109 (0.6)	102 (0.5)	3.1	0.2	-0.3	-0.7	-0.2
ASEAN	232 (2.7)	379 (3.8)	666 (4.8)	1 026 (6.2)	1 249 (6.9)	1 449 (7.7)	4.0	3.4	2.0	1.5	2.4
Indonesia	99 (1.1)	156 (1.6)	244 (1.7)	374 (2.3)	464 (2.6)	539 (2.9)	3.4	3.3	2.2	1.5	2.4
Malaysia	21 (0.2)	48 (0.5)	85 (0.6)	120 (0.7)	136 (0.8)	144 (0.8)	5.3	2.7	1.2	0.6	1.6
Myanmar	11 (0.1)	13 (0.1)	23 (0.2)	37 (0.2)	48 (0.3)	58 (0.3)	2.9	3.8	2.6	2.0	2.9
Philippines	29 (0.3)	40 (0.4)	58 (0.4)	95 (0.6)	119 (0.7)	146 (0.8)	2.6	3.8	2.3	2.0	2.8
Singapore	12 (0.1)	19 (0.2)	37 (0.3)	42 (0.3)	45 (0.3)	47 (0.2)	4.4	1.1	0.7	0.3	0.7
Thailand	42 (0.5)	72 (0.7)	138 (1.0)	173 (1.0)	197 (1.1)	218 (1.2)	4.5	1.7	1.3	1.0	1.4
Viet Nam	18 (0.2)	29 (0.3)	78 (0.6)	181 (1.1)	237 (1.3)	294 (1.6)	5.6	6.7	2.7	2.2	4.1
North America	2 126 (24.3)	2 527 (25.2)	2 444 (17.5)	2 473 (14.9)	2 430 (13.5)	2 347 (12.5)	0.5	0.1	-0.2	-0.3	-0.1
United States	1 915 (21.8)	2 274 (22.7)	2 155 (15.4)	2 178 (13.1)	2 136 (11.9)	2 062 (11.0)	0.4	0.1	-0.2	-0.4	-0.1
Latin America	464 (5.3)	600 (6.0)	830 (5.9)	1 043 (6.3)	1 214 (6.7)	1 311 (7.0)	2.2	1.8	1.5	0.8	1.4
Advanced Europe	1 643 (18.7)	1 759 (17.5)	1 761 (12.6)	1 669 (10.1)	1 578 (8.8)	1 487 (7.9)	0.3	-0.4	-0.6	-0.6	-0.5
European Union	1 645 (18.8)	1 695 (16.9)	1 619 (11.6)	1 519 (9.2)	1 431 (8.0)	1 342 (7.2)	-0.1	-0.5	-0.6	-0.6	-0.6
Other Europe / Eurasia	1 513 (17.3)	993 (9.9)	1 122 (8.0)	1 178 (7.1)	1 227 (6.8)	1 268 (6.8)	-1.1	0.4	0.4	0.3	0.4
Africa	385 (4.4)	490 (4.9)	812 (5.8)	1 101 (6.6)	1 363 (7.6)	1 537 (8.2)	2.8	2.4	2.2	1.2	2.0
Middle East	223 (2.5)	372 (3.7)	773 (5.5)	1 031 (6.2)	1 199 (6.7)	1 316 (7.0)	4.7	2.2	1.5	0.9	1.6
Oceania	99 (1.1)	125 (1.2)	148 (1.1)	156 (0.9)	155 (0.9)	150 (0.8)	1.5	0.4	0.0	-0.3	0.0
Advanced Economies	4 468 (51.0)	5 235 (52.2)	5 228 (37.4)	5 181 (31.3)	5 008 (27.8)	4 767 (25.4)	0.6	-0.1	-0.3	-0.5	-0.3
Emerging Market and Developing Economies	4 096 (46.7)	4 517 (45.1)	8 331 (59.6)	10 854 (65.5)	12 329 (68.6)	13 236 (70.6)	2.7	2.1	1.3	0.7	1.4

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

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

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

(Mtoe)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	2 220 (100)	2 317 (100)	3 790 (100)	4 215 (100)	4 263 (100)	4 035 (100)	2.0	0.8	0.1	-0.5	0.2
Asia	788 (35.5)	1 037 (44.7)	2 761 (72.8)	3 279 (77.8)	3 376 (79.2)	3 222 (79.9)	4.8	1.3	0.3	-0.5	0.5
China	531 (23.9)	665 (28.7)	1 953 (51.5)	2 060 (48.9)	1 923 (45.1)	1 646 (40.8)	4.9	0.4	-0.7	-1.5	-0.5
India	93 (4.2)	146 (6.3)	391 (10.3)	706 (16.8)	886 (20.8)	990 (24.5)	5.5	4.7	2.3	1.1	2.9
Japan	77 (3.5)	97 (4.2)	116 (3.1)	99 (2.3)	91 (2.1)	79 (1.9)	1.6	-1.3	-0.8	-1.5	-1.2
Korea	25 (1.1)	42 (1.8)	83 (2.2)	87 (2.1)	82 (1.9)	71 (1.8)	4.5	0.4	-0.6	-1.4	-0.5
Chinese Taipei	11 (0.5)	30 (1.3)	41 (1.1)	42 (1.0)	37 (0.9)	32 (0.8)	4.9	0.1	-1.2	-1.6	-0.8
ASEAN	13 (0.6)	32 (1.4)	132 (3.5)	233 (5.5)	295 (6.9)	334 (8.3)	9.1	4.5	2.4	1.3	2.9
Indonesia	4 (0.2)	12 (0.5)	48 (1.3)	85 (2.0)	116 (2.7)	135 (3.4)	10.2	4.4	3.2	1.5	3.2
Malaysia	1 (0.1)	2 (0.1)	21 (0.5)	28 (0.7)	31 (0.7)	31 (0.8)	10.6	2.3	1.0	0.1	1.2
Myanmar	0 (0.0)	0 (0.0)	1 (0.0)	3 (0.1)	5 (0.1)	7 (0.2)	8.7	11.2	6.0	4.6	7.6
Philippines	2 (0.1)	5 (0.2)	17 (0.4)	24 (0.6)	29 (0.7)	33 (0.8)	9.3	2.8	1.8	1.3	2.0
Singapore	0 (0.0)	- (-)	1 (0.0)	1 (0.0)	1 (0.0)	1 (0.0)	14.8	0.2	-0.2	-0.7	-0.2
Thailand	4 (0.2)	8 (0.3)	16 (0.4)	21 (0.5)	22 (0.5)	22 (0.5)	5.5	1.8	0.8	-0.1	0.9
Viet Nam	2 (0.1)	4 (0.2)	28 (0.7)	72 (1.7)	91 (2.1)	105 (2.6)	9.9	7.5	2.4	1.5	4.1
North America	484 (21.8)	566 (24.4)	348 (9.2)	297 (7.0)	245 (5.7)	183 (4.5)	-1.2	-1.2	-1.9	-2.9	-1.9
United States	460 (20.7)	534 (23.0)	331 (8.7)	287 (6.8)	242 (5.7)	180 (4.5)	-1.2	-1.1	-1.7	-2.9	-1.8
Latin America	21 (1.0)	27 (1.2)	45 (1.2)	51 (1.2)	60 (1.4)	63 (1.6)	2.8	0.9	1.6	0.6	1.0
Advanced Europe	448 (20.2)	331 (14.3)	263 (7.0)	212 (5.0)	184 (4.3)	160 (4.0)	-2.0	-1.7	-1.4	-1.4	-1.5
European Union	454 (20.4)	321 (13.9)	234 (6.2)	187 (4.4)	161 (3.8)	140 (3.5)	-2.4	-1.7	-1.4	-1.4	-1.5
Other Europe / Eurasia	365 (16.4)	209 (9.0)	209 (5.5)	199 (4.7)	209 (4.9)	211 (5.2)	-2.0	-0.4	0.5	0.1	0.0
Africa	74 (3.3)	90 (3.9)	110 (2.9)	128 (3.0)	145 (3.4)	156 (3.9)	1.5	1.2	1.2	0.8	1.1
Middle East	3 (0.1)	8 (0.3)	9 (0.2)	12 (0.3)	12 (0.3)	11 (0.3)	4.1	2.6	-0.3	-1.0	0.6
Oceania	36 (1.6)	49 (2.1)	45 (1.2)	38 (0.9)	33 (0.8)	29 (0.7)	0.8	-1.4	-1.2	-1.5	-1.4
Advanced Economies	1 088 (49.0)	1 118 (48.3)	904 (23.9)	782 (18.6)	680 (16.0)	560 (13.9)	-0.7	-1.1	-1.4	-1.9	-1.4
Emerging Market and Developing Economies	1 133 (51.0)	1 198 (51.7)	2 886 (76.1)	3 433 (81.4)	3 583 (84.0)	3 474 (86.1)	3.5	1.3	0.4	-0.3	0.6

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

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

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

(Mtoe)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	3 233 (100)	3 663 (100)	4 449 (100)	5 035 (100)	5 429 (100)	5 707 (100)	1.2	1.0	0.8	0.5	0.8
Asia	618 (19.1)	916 (25.0)	1 410 (31.7)	1 836 (36.5)	2 098 (38.6)	2 321 (40.7)	3.1	2.1	1.3	1.0	1.5
China	119 (3.7)	221 (6.0)	568 (12.8)	722 (14.3)	742 (13.7)	693 (12.1)	6.0	1.9	0.3	-0.7	0.6
India	61 (1.9)	112 (3.1)	223 (5.0)	408 (8.1)	586 (10.8)	792 (13.9)	4.9	4.7	3.7	3.1	3.9
Japan	250 (7.7)	255 (7.0)	176 (4.0)	142 (2.8)	122 (2.2)	105 (1.8)	-1.3	-1.6	-1.5	-1.5	-1.6
Korea	50 (1.5)	99 (2.7)	109 (2.5)	117 (2.3)	113 (2.1)	104 (1.8)	3.0	0.5	-0.4	-0.8	-0.1
Chinese Taipei	26 (0.8)	38 (1.0)	42 (1.0)	42 (0.8)	39 (0.7)	36 (0.6)	1.9	-0.2	-0.5	-0.9	-0.5
ASEAN	89 (2.7)	153 (4.2)	234 (5.3)	326 (6.5)	402 (7.4)	479 (8.4)	3.7	2.6	2.1	1.8	2.2
Indonesia	33 (1.0)	58 (1.6)	76 (1.7)	105 (2.1)	128 (2.4)	147 (2.6)	3.1	2.6	2.0	1.4	2.0
Malaysia	11 (0.4)	19 (0.5)	29 (0.7)	37 (0.7)	40 (0.7)	43 (0.7)	3.5	1.8	0.9	0.7	1.2
Myanmar	1 (0.0)	2 (0.1)	7 (0.1)	13 (0.3)	19 (0.4)	25 (0.4)	8.5	5.5	3.8	2.6	4.1
Philippines	11 (0.3)	16 (0.4)	20 (0.4)	36 (0.7)	50 (0.9)	67 (1.2)	2.2	4.7	3.4	3.0	3.8
Singapore	11 (0.4)	17 (0.5)	26 (0.6)	29 (0.6)	32 (0.6)	34 (0.6)	3.1	0.9	0.9	0.6	0.8
Thailand	18 (0.6)	32 (0.9)	56 (1.3)	63 (1.3)	72 (1.3)	80 (1.4)	4.3	0.9	1.3	1.0	1.1
Viet Nam	3 (0.1)	8 (0.2)	20 (0.4)	42 (0.8)	60 (1.1)	84 (1.5)	7.6	6.0	3.6	3.4	4.5
North America	833 (25.8)	958 (26.2)	890 (20.0)	824 (16.4)	757 (13.9)	697 (12.2)	0.2	-0.6	-0.8	-0.8	-0.7
United States	757 (23.4)	871 (23.8)	790 (17.8)	729 (14.5)	672 (12.4)	621 (10.9)	0.2	-0.6	-0.8	-0.8	-0.7
Latin America	238 (7.4)	303 (8.3)	350 (7.9)	412 (8.2)	445 (8.2)	447 (7.8)	1.4	1.3	0.8	0.1	0.7
Advanced Europe	617 (19.1)	655 (17.9)	577 (13.0)	504 (10.0)	449 (8.3)	401 (7.0)	-0.3	-1.0	-1.1	-1.1	-1.1
European Union	607 (18.8)	624 (17.0)	531 (11.9)	461 (9.2)	409 (7.5)	364 (6.4)	-0.5	-1.1	-1.2	-1.2	-1.1
Other Europe / Eurasia	458 (14.2)	199 (5.4)	237 (5.3)	230 (4.6)	228 (4.2)	228 (4.0)	-2.4	-0.2	-0.1	0.0	-0.1
Africa	85 (2.6)	101 (2.8)	191 (4.3)	265 (5.3)	365 (6.7)	463 (8.1)	3.0	2.5	3.3	2.4	2.7
Middle East	146 (4.5)	217 (5.9)	332 (7.5)	404 (8.0)	445 (8.2)	451 (7.9)	3.1	1.5	1.0	0.1	0.9
Oceania	35 (1.1)	40 (1.1)	50 (1.1)	48 (1.0)	45 (0.8)	41 (0.7)	1.3	-0.2	-0.7	-1.0	-0.6
Advanced Economies	1 826 (56.5)	2 069 (56.5)	1 874 (42.1)	1 711 (34.0)	1 561 (28.7)	1 421 (24.9)	0.1	-0.7	-0.9	-0.9	-0.8
Emerging Market and Developing Economies	1 205 (37.3)	1 320 (36.0)	2 163 (48.6)	2 813 (55.9)	3 272 (60.3)	3 628 (63.6)	2.2	2.0	1.5	1.0	1.6

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

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

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

(Mtoe)

							CAGR (%)				
	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	1 664 (100)	2 072 (100)	3 107 (100)	4 026 (100)	4 685 (100)	5 165 (100)	2.3	2.0	1.5	1.0	1.6
Asia	116 (7.0)	233 (11.2)	595 (19.1)	1 016 (25.2)	1 278 (27.3)	1 471 (28.5)	6.2	4.2	2.3	1.4	2.8
China	13 (0.8)	21 (1.0)	195 (6.3)	391 (9.7)	501 (10.7)	574 (11.1)	10.6	5.5	2.5	1.4	3.3
India	11 (0.6)	23 (1.1)	51 (1.6)	144 (3.6)	213 (4.5)	270 (5.2)	6.0	8.3	4.0	2.4	5.2
Japan	44 (2.7)	66 (3.2)	101 (3.2)	88 (2.2)	82 (1.8)	72 (1.4)	3.1	-1.1	-0.7	-1.2	-1.0
Korea	3 (0.2)	17 (0.8)	43 (1.4)	58 (1.4)	64 (1.4)	67 (1.3)	10.8	2.3	1.0	0.4	1.3
Chinese Taipei	1 (0.1)	6 (0.3)	18 (0.6)	24 (0.6)	26 (0.5)	27 (0.5)	9.9	2.2	0.8	0.3	1.2
ASEAN	30 (1.8)	74 (3.6)	134 (4.3)	231 (5.7)	283 (6.0)	326 (6.3)	5.7	4.3	2.0	1.4	2.7
Indonesia	16 (1.0)	27 (1.3)	39 (1.3)	67 (1.7)	89 (1.9)	109 (2.1)	3.4	4.3	2.9	2.0	3.2
Malaysia	7 (0.4)	25 (1.2)	32 (1.0)	51 (1.3)	56 (1.2)	58 (1.1)	5.9	3.6	0.9	0.5	1.8
Myanmar	1 (0.0)	1 (0.1)	4 (0.1)	10 (0.3)	15 (0.3)	20 (0.4)	6.0	8.3	3.8	2.8	5.2
Philippines	- (-)	0 (0.0)	3 (0.1)	6 (0.2)	9 (0.2)	11 (0.2)	-	5.0	3.5	2.7	3.9
Singapore	- (-)	1 (0.1)	9 (0.3)	10 (0.3)	10 (0.2)	10 (0.2)	-	1.2	0.0	-0.6	0.3
Thailand	5 (0.3)	17 (0.8)	36 (1.2)	43 (1.1)	47 (1.0)	47 (0.9)	7.6	1.5	0.8	0.0	0.8
Viet Nam	0 (0.0)	1 (0.1)	8 (0.3)	40 (1.0)	54 (1.2)	69 (1.3)	34.3	13.4	3.0	2.4	6.8
North America	493 (29.6)	622 (30.0)	745 (24.0)	879 (21.8)	910 (19.4)	887 (17.2)	1.5	1.3	0.3	-0.3	0.5
United States	438 (26.3)	548 (26.4)	644 (20.7)	758 (18.8)	769 (16.4)	740 (14.3)	1.4	1.3	0.1	-0.4	0.4
Latin America	72 (4.3)	119 (5.7)	205 (6.6)	278 (6.9)	375 (8.0)	451 (8.7)	3.9	2.4	3.1	1.9	2.4
Advanced Europe	267 (16.1)	396 (19.1)	435 (14.0)	444 (11.0)	446 (9.5)	424 (8.2)	1.8	0.2	0.0	-0.5	-0.1
European Union	297 (17.9)	396 (19.1)	398 (12.8)	402 (10.0)	403 (8.6)	382 (7.4)	1.1	0.1	0.0	-0.5	-0.1
Other Europe / Eurasia	596 (35.8)	486 (23.4)	542 (17.5)	571 (14.2)	603 (12.9)	618 (12.0)	-0.3	0.4	0.6	0.2	0.4
Africa	30 (1.8)	47 (2.3)	123 (3.9)	198 (4.9)	287 (6.1)	387 (7.5)	5.4	3.8	3.8	3.0	3.5
Middle East	72 (4.3)	145 (7.0)	427 (13.7)	583 (14.5)	693 (14.8)	790 (15.3)	6.8	2.4	1.7	1.3	1.9
Oceania	19 (1.1)	24 (1.2)	36 (1.1)	44 (1.1)	48 (1.0)	48 (0.9)	2.4	1.7	0.8	0.0	0.9
Advanced Economies	827 (49.7)	1 134 (54.7)	1 389 (44.7)	1 551 (38.5)	1 590 (33.9)	1 538 (29.8)	1.9	0.8	0.3	-0.3	0.3
Emerging Market and Developing Economies	837 (50.3)	938 (45.3)	1 718 (55.3)	2 462 (61.2)	3 050 (65.1)	3 537 (68.5)	2.7	2.8	2.2	1.5	2.2

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

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

Table A11 | Final energy consumption [Reference Scenario]

(Mtoe)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/2017	2017/2030	2030/2040	2040/2050	2017/2050
World	6 264 (100)	7 030 (100)	9 717 (100)	11 420 (100)	12 392 (100)	13 035 (100)	1.6	1.2	0.8	0.5	0.9
Asia	1 554 (24.8)	1 992 (28.3)	3 793 (39.0)	4 828 (42.3)	5 369 (43.3)	5 751 (44.1)	3.4	1.9	1.1	0.7	1.3
China	658 (10.5)	781 (11.1)	1 995 (20.5)	2 304 (20.2)	2 375 (19.2)	2 328 (17.9)	4.2	1.1	0.3	-0.2	0.5
India	243 (3.9)	314 (4.5)	591 (6.1)	1 035 (9.1)	1 343 (10.8)	1 631 (12.5)	3.3	4.4	2.6	2.0	3.1
Japan	287 (4.6)	332 (4.7)	293 (3.0)	266 (2.3)	245 (2.0)	224 (1.7)	0.1	-0.7	-0.8	-0.9	-0.8
Korea	65 (1.0)	127 (1.8)	183 (1.9)	203 (1.8)	201 (1.6)	191 (1.5)	3.9	0.8	-0.1	-0.5	0.1
Chinese Taipei	29 (0.5)	49 (0.7)	70 (0.7)	74 (0.6)	73 (0.6)	70 (0.5)	3.3	0.4	-0.1	-0.4	0.0
ASEAN	173 (2.8)	269 (3.8)	477 (4.9)	703 (6.2)	850 (6.9)	990 (7.6)	3.8	3.0	1.9	1.5	2.2
Indonesia	80 (1.3)	120 (1.7)	174 (1.8)	238 (2.1)	284 (2.3)	324 (2.5)	2.9	2.5	1.8	1.3	1.9
Malaysia	13 (0.2)	29 (0.4)	61 (0.6)	88 (0.8)	99 (0.8)	108 (0.8)	5.7	2.9	1.2	0.9	1.8
Myanmar	9 (0.2)	11 (0.2)	20 (0.2)	29 (0.3)	36 (0.3)	43 (0.3)	2.8	3.0	2.3	1.7	2.4
Philippines	20 (0.3)	24 (0.3)	33 (0.3)	57 (0.5)	76 (0.6)	98 (0.7)	2.0	4.1	2.9	2.6	3.3
Singapore	5 (0.1)	8 (0.1)	25 (0.3)	28 (0.2)	30 (0.2)	31 (0.2)	6.1	1.1	0.6	0.3	0.7
Thailand	29 (0.5)	51 (0.7)	99 (1.0)	121 (1.1)	140 (1.1)	156 (1.2)	4.7	1.6	1.4	1.1	1.4
Viet Nam	16 (0.3)	25 (0.4)	64 (0.7)	140 (1.2)	182 (1.5)	227 (1.7)	5.3	6.2	2.7	2.2	3.9
North America	1 455 (23.2)	1 738 (24.7)	1 716 (17.7)	1 739 (15.2)	1 699 (13.7)	1 646 (12.6)	0.6	0.1	-0.2	-0.3	-0.1
United States	1 294 (20.7)	1 546 (22.0)	1 520 (15.6)	1 540 (13.5)	1 506 (12.2)	1 462 (11.2)	0.6	0.1	-0.2	-0.3	-0.1
Latin America	343 (5.5)	446 (6.3)	612 (6.3)	761 (6.7)	869 (7.0)	936 (7.2)	2.2	1.7	1.3	0.7	1.3
Advanced Europe	1 142 (18.2)	1 235 (17.6)	1 258 (12.9)	1 208 (10.6)	1 140 (9.2)	1 071 (8.2)	0.4	-0.3	-0.6	-0.6	-0.5
European Union	1 133 (18.1)	1 178 (16.8)	1 154 (11.9)	1 104 (9.7)	1 039 (8.4)	973 (7.5)	0.1	-0.3	-0.6	-0.7	-0.5
Other Europe / Eurasia	1 056 (16.9)	646 (9.2)	726 (7.5)	757 (6.6)	774 (6.2)	787 (6.0)	-1.4	0.3	0.2	0.2	0.2
Africa	287 (4.6)	364 (5.2)	594 (6.1)	815 (7.1)	1 001 (8.1)	1 112 (8.5)	2.7	2.5	2.1	1.1	1.9
Middle East	157 (2.5)	253 (3.6)	509 (5.2)	680 (6.0)	790 (6.4)	876 (6.7)	4.4	2.3	1.5	1.0	1.7
Oceania	66 (1.1)	83 (1.2)	96 (1.0)	103 (0.9)	104 (0.8)	102 (0.8)	1.4	0.5	0.1	-0.2	0.2
Advanced Economies	3 056 (48.8)	3 581 (50.9)	3 651 (37.6)	3 632 (31.8)	3 502 (28.3)	3 345 (25.7)	0.7	0.0	-0.4	-0.5	-0.3
Emerging Market and Developing Economies	3 006 (48.0)	3 175 (45.2)	5 654 (58.2)	7 260 (63.6)	8 244 (66.5)	8 937 (68.6)	2.4	1.9	1.3	0.8	1.4

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

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

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

(Mtoe)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	1 804 (100)	1 873 (100)	2 821 (100)	3 356 (100)	3 607 (100)	3 689 (100)	1.7	1.3	0.7	0.2	0.8
Asia	516 (28.6)	653 (34.9)	1 544 (54.7)	1 885 (56.2)	2 005 (55.6)	2 026 (54.9)	4.1	1.5	0.6	0.1	0.8
China	234 (13.0)	302 (16.1)	986 (35.0)	987 (29.4)	934 (25.9)	855 (23.2)	5.5	0.0	-0.5	-0.9	-0.4
India	67 (3.7)	83 (4.5)	205 (7.3)	416 (12.4)	519 (14.4)	565 (15.3)	4.2	5.6	2.2	0.9	3.1
Japan	108 (6.0)	104 (5.5)	86 (3.1)	80 (2.4)	73 (2.0)	65 (1.7)	-0.8	-0.6	-0.9	-1.2	-0.9
Korea	19 (1.1)	38 (2.1)	48 (1.7)	54 (1.6)	54 (1.5)	50 (1.3)	3.5	0.9	-0.1	-0.8	0.1
Chinese Taipei	12 (0.7)	19 (1.0)	24 (0.8)	25 (0.7)	24 (0.7)	23 (0.6)	2.5	0.3	-0.1	-0.6	-0.1
ASEAN	43 (2.4)	75 (4.0)	148 (5.2)	255 (7.6)	316 (8.8)	368 (10.0)	4.7	4.3	2.2	1.5	2.8
Indonesia	18 (1.0)	30 (1.6)	45 (1.6)	70 (2.1)	88 (2.4)	103 (2.8)	3.4	3.5	2.3	1.6	2.6
Malaysia	6 (0.3)	12 (0.6)	18 (0.6)	24 (0.7)	28 (0.8)	31 (0.8)	4.4	2.5	1.3	0.9	1.7
Myanmar	0 (0.0)	1 (0.1)	3 (0.1)	7 (0.2)	10 (0.3)	13 (0.4)	8.4	5.3	4.3	2.7	4.2
Philippines	5 (0.3)	5 (0.3)	8 (0.3)	12 (0.4)	14 (0.4)	17 (0.5)	2.0	3.2	1.8	1.6	2.3
Singapore	1 (0.0)	2 (0.1)	7 (0.2)	8 (0.2)	8 (0.2)	8 (0.2)	9.4	1.4	0.3	-0.4	0.5
Thailand	9 (0.5)	17 (0.9)	31 (1.1)	42 (1.3)	49 (1.4)	54 (1.5)	4.9	2.4	1.5	0.8	1.7
Viet Nam	5 (0.3)	8 (0.4)	35 (1.3)	91 (2.7)	117 (3.3)	141 (3.8)	7.9	7.6	2.6	1.9	4.3
North America	331 (18.4)	388 (20.7)	307 (10.9)	327 (9.7)	327 (9.1)	319 (8.6)	-0.3	0.5	0.0	-0.2	0.1
United States	284 (15.7)	332 (17.7)	261 (9.3)	281 (8.4)	281 (7.8)	274 (7.4)	-0.3	0.6	0.0	-0.2	0.1
Latin America	114 (6.3)	148 (7.9)	190 (6.7)	242 (7.2)	288 (8.0)	311 (8.4)	1.9	1.9	1.7	0.8	1.5
Advanced Europe	330 (18.3)	325 (17.4)	297 (10.5)	295 (8.8)	286 (7.9)	271 (7.3)	-0.4	0.0	-0.3	-0.6	-0.3
European Union	345 (19.1)	308 (16.4)	263 (9.3)	261 (7.8)	253 (7.0)	239 (6.5)	-1.0	-0.1	-0.3	-0.6	-0.3
Other Europe / Eurasia	390 (21.6)	204 (10.9)	215 (7.6)	236 (7.0)	251 (7.0)	258 (7.0)	-2.2	0.7	0.6	0.3	0.5
Africa	53 (2.9)	57 (3.0)	88 (3.1)	134 (4.0)	183 (5.1)	227 (6.2)	1.9	3.3	3.2	2.2	2.9
Middle East	47 (2.6)	71 (3.8)	153 (5.4)	207 (6.2)	236 (6.5)	248 (6.7)	4.5	2.3	1.3	0.5	1.5
Oceania	23 (1.3)	28 (1.5)	27 (1.0)	31 (0.9)	32 (0.9)	31 (0.8)	0.6	1.1	0.2	-0.3	0.4
Advanced Economies	826 (45.8)	906 (48.4)	798 (28.3)	822 (24.5)	806 (22.3)	767 (20.8)	-0.1	0.2	-0.2	-0.5	-0.1
Emerging Market and Developing Economies	978 (54.2)	967 (51.6)	2 023 (71.7)	2 534 (75.5)	2 801 (77.7)	2 921 (79.2)	2.7	1.7	1.0	0.4	1.1

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

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

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

(Mtoe)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	1 571 (100)	1 958 (100)	2 808 (100)	3 228 (100)	3 553 (100)	3 866 (100)	2.2	1.1	1.0	0.8	1.0
Asia	183 (11.7)	318 (16.2)	692 (24.6)	965 (29.9)	1 160 (32.6)	1 351 (34.9)	5.0	2.6	1.9	1.5	2.0
China	30 (1.9)	84 (4.3)	310 (11.0)	438 (13.6)	463 (13.0)	432 (11.2)	9.0	2.7	0.5	-0.7	1.0
India	21 (1.3)	32 (1.6)	98 (3.5)	192 (6.0)	317 (8.9)	486 (12.6)	5.9	5.3	5.1	4.4	5.0
Japan	68 (4.4)	86 (4.4)	71 (2.5)	58 (1.8)	51 (1.4)	44 (1.1)	0.1	-1.5	-1.4	-1.3	-1.4
Korea	15 (0.9)	26 (1.3)	36 (1.3)	37 (1.1)	35 (1.0)	30 (0.8)	3.4	0.3	-0.7	-1.2	-0.5
Chinese Taipei	7 (0.4)	12 (0.6)	13 (0.5)	12 (0.4)	10 (0.3)	9 (0.2)	2.5	-0.4	-1.4	-2.0	-1.2
ASEAN	32 (2.1)	61 (3.1)	127 (4.5)	174 (5.4)	216 (6.1)	264 (6.8)	5.2	2.5	2.2	2.0	2.2
Indonesia	11 (0.7)	21 (1.1)	49 (1.8)	68 (2.1)	85 (2.4)	103 (2.7)	5.8	2.5	2.3	1.9	2.2
Malaysia	5 (0.3)	11 (0.6)	21 (0.7)	23 (0.7)	23 (0.6)	22 (0.6)	5.5	0.6	-0.1	-0.4	0.1
Myanmar	0 (0.0)	1 (0.1)	2 (0.1)	4 (0.1)	7 (0.2)	10 (0.3)	5.8	6.2	4.7	3.6	5.0
Philippines	5 (0.3)	8 (0.4)	12 (0.4)	25 (0.8)	36 (1.0)	50 (1.3)	3.6	5.8	3.9	3.4	4.5
Singapore	1 (0.1)	2 (0.1)	3 (0.1)	2 (0.1)	2 (0.1)	2 (0.1)	2.3	-0.2	-0.7	-1.2	-0.7
Thailand	9 (0.6)	15 (0.7)	27 (1.0)	31 (0.9)	33 (0.9)	36 (0.9)	4.2	0.9	0.9	0.7	0.8
Viet Nam	1 (0.1)	3 (0.2)	13 (0.5)	21 (0.7)	30 (0.8)	42 (1.1)	8.6	4.1	3.4	3.4	3.7
North America	531 (33.8)	640 (32.7)	687 (24.5)	638 (19.8)	595 (16.8)	561 (14.5)	1.0	-0.6	-0.7	-0.6	-0.6
United States	488 (31.0)	588 (30.0)	625 (22.3)	578 (17.9)	541 (15.2)	511 (13.2)	0.9	-0.6	-0.7	-0.6	-0.6
Latin America	103 (6.6)	141 (7.2)	223 (7.9)	281 (8.7)	308 (8.7)	321 (8.3)	2.9	1.8	0.9	0.4	1.1
Advanced Europe	269 (17.1)	318 (16.2)	353 (12.6)	311 (9.6)	278 (7.8)	251 (6.5)	1.0	-1.0	-1.1	-1.0	-1.0
European Union	259 (16.5)	303 (15.5)	327 (11.6)	287 (8.9)	255 (7.2)	229 (5.9)	0.9	-1.0	-1.2	-1.0	-1.1
Other Europe / Eurasia	170 (10.8)	109 (5.6)	146 (5.2)	140 (4.3)	135 (3.8)	131 (3.4)	-0.6	-0.3	-0.4	-0.3	-0.3
Africa	38 (2.4)	55 (2.8)	117 (4.2)	159 (4.9)	211 (5.9)	267 (6.9)	4.2	2.4	2.9	2.4	2.5
Middle East	51 (3.2)	75 (3.8)	140 (5.0)	168 (5.2)	184 (5.2)	194 (5.0)	3.8	1.4	0.9	0.5	1.0
Oceania	24 (1.5)	30 (1.5)	39 (1.4)	38 (1.2)	37 (1.0)	36 (0.9)	1.8	-0.1	-0.3	-0.4	-0.2
Advanced Economies	916 (58.3)	1 117 (57.0)	1 202 (42.8)	1 100 (34.1)	1 010 (28.4)	935 (24.2)	1.0	-0.7	-0.8	-0.8	-0.8
Emerging Market and Developing Economies	453 (28.8)	568 (29.0)	1 193 (42.5)	1 601 (49.6)	1 897 (53.4)	2 177 (56.3)	3.7	2.3	1.7	1.4	1.8

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

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

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

(Mtoe)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/2017	2017/2030	2030/2040	2040/2050	2017/2050
World	2 414 (100)	2 592 (100)	3 209 (100)	3 713 (100)	3 969 (100)	4 101 (100)	1.1	1.1	0.7	0.3	0.7
Asia	740 (30.7)	843 (32.5)	1 178 (36.7)	1 453 (39.1)	1 600 (40.3)	1 709 (41.7)	1.7	1.6	1.0	0.7	1.1
China	351 (14.5)	338 (13.1)	537 (16.7)	653 (17.6)	726 (18.3)	780 (19.0)	1.6	1.5	1.1	0.7	1.1
India	142 (5.9)	172 (6.6)	242 (7.5)	341 (9.2)	392 (9.9)	434 (10.6)	2.0	2.7	1.4	1.0	1.8
Japan	78 (3.2)	107 (4.1)	101 (3.1)	95 (2.6)	90 (2.3)	85 (2.1)	1.0	-0.4	-0.6	-0.6	-0.5
Korea	24 (1.0)	37 (1.4)	47 (1.5)	50 (1.3)	49 (1.2)	46 (1.1)	2.4	0.5	-0.3	-0.5	0.0
Chinese Taipei	7 (0.3)	10 (0.4)	12 (0.4)	14 (0.4)	14 (0.4)	15 (0.4)	2.3	1.0	0.5	0.1	0.6
ASEAN	87 (3.6)	112 (4.3)	144 (4.5)	186 (5.0)	209 (5.3)	228 (5.6)	1.9	2.0	1.2	0.8	1.4
Indonesia	44 (1.8)	59 (2.3)	73 (2.3)	88 (2.4)	95 (2.4)	98 (2.4)	1.9	1.4	0.8	0.3	0.9
Malaysia	2 (0.1)	4 (0.2)	9 (0.3)	12 (0.3)	14 (0.4)	16 (0.4)	5.6	2.1	1.5	1.1	1.6
Myanmar	8 (0.4)	9 (0.4)	14 (0.4)	17 (0.5)	18 (0.5)	19 (0.5)	1.8	1.7	0.6	0.3	0.9
Philippines	10 (0.4)	10 (0.4)	12 (0.4)	18 (0.5)	21 (0.5)	24 (0.6)	0.7	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	1.0	0.1	-0.2	0.4
Thailand	11 (0.4)	14 (0.5)	18 (0.5)	22 (0.6)	24 (0.6)	25 (0.6)	1.8	1.7	0.7	0.7	1.1
Viet Nam	10 (0.4)	14 (0.5)	15 (0.5)	26 (0.7)	34 (0.8)	42 (1.0)	1.6	4.2	2.5	2.3	3.1
North America	460 (19.0)	537 (20.7)	556 (17.3)	579 (15.6)	575 (14.5)	561 (13.7)	0.7	0.3	-0.1	-0.3	0.0
United States	403 (16.7)	473 (18.2)	488 (15.2)	508 (13.7)	507 (12.8)	495 (12.1)	0.7	0.3	0.0	-0.2	0.0
Latin America	100 (4.2)	119 (4.6)	162 (5.0)	194 (5.2)	221 (5.6)	245 (6.0)	1.8	1.4	1.3	1.0	1.3
Advanced Europe	442 (18.3)	477 (18.4)	501 (15.6)	491 (13.2)	466 (11.8)	441 (10.8)	0.5	-0.1	-0.5	-0.6	-0.4
European Union	430 (17.8)	454 (17.5)	461 (14.4)	452 (12.2)	428 (10.8)	403 (9.8)	0.3	-0.1	-0.5	-0.6	-0.4
Other Europe / Eurasia	431 (17.9)	285 (11.0)	284 (8.9)	292 (7.9)	289 (7.3)	290 (7.1)	-1.5	0.2	-0.1	0.0	0.1
Africa	185 (7.7)	238 (9.2)	368 (11.5)	491 (13.2)	565 (14.2)	566 (13.8)	2.6	2.2	1.4	0.0	1.3
Middle East	40 (1.7)	75 (2.9)	137 (4.3)	187 (5.0)	223 (5.6)	259 (6.3)	4.7	2.4	1.8	1.5	2.0
Oceania	15 (0.6)	19 (0.7)	25 (0.8)	27 (0.7)	29 (0.7)	29 (0.7)	1.9	0.8	0.5	0.3	0.5
Advanced Economies	1 028 (42.6)	1 193 (46.0)	1 248 (38.9)	1 264 (34.0)	1 230 (31.0)	1 184 (28.9)	0.7	0.1	-0.3	-0.4	-0.2
Emerging Market and Developing Economies	1 385 (57.4)	1 399 (54.0)	1 961 (61.1)	2 449 (66.0)	2 739 (69.0)	2 918 (71.1)	1.3	1.7	1.1	0.6	1.2

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

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

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

(TWh)

							CAGR (%)				
	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	9 703 (100)	12 698 (100)	21 368 (100)	28 893 (100)	34 343 (100)	39 138 (100)	3.0	2.3	1.7	1.3	1.9
Asia	1 826 (18.8)	3 257 (25.6)	9 588 (44.9)	14 364 (49.7)	17 325 (50.4)	19 640 (50.2)	6.3	3.2	1.9	1.3	2.2
China	454 (4.7)	1 036 (8.2)	5 536 (25.9)	7 880 (27.3)	9 049 (26.3)	9 658 (24.7)	9.7	2.8	1.4	0.7	1.7
India	215 (2.2)	376 (3.0)	1 164 (5.4)	2 518 (8.7)	3 497 (10.2)	4 411 (11.3)	6.5	6.1	3.3	2.3	4.1
Japan	765 (7.9)	973 (7.7)	964 (4.5)	975 (3.4)	981 (2.9)	976 (2.5)	0.9	0.1	0.1	-0.1	0.0
Korea	94 (1.0)	263 (2.1)	523 (2.4)	625 (2.2)	661 (1.9)	663 (1.7)	6.5	1.4	0.6	0.0	0.7
Chinese Taipei	77 (0.8)	160 (1.3)	241 (1.1)	283 (1.0)	303 (0.9)	312 (0.8)	4.3	1.2	0.7	0.3	0.8
ASEAN	130 (1.3)	320 (2.5)	875 (4.1)	1 643 (5.7)	2 233 (6.5)	2 840 (7.3)	7.3	5.0	3.1	2.4	3.6
Indonesia	28 (0.3)	79 (0.6)	223 (1.0)	435 (1.5)	654 (1.9)	873 (2.2)	8.0	5.3	4.2	2.9	4.2
Malaysia	20 (0.2)	61 (0.5)	147 (0.7)	213 (0.7)	263 (0.8)	311 (0.8)	7.7	2.9	2.1	1.7	2.3
Myanmar	2 (0.0)	3 (0.0)	17 (0.1)	43 (0.2)	72 (0.2)	108 (0.3)	8.8	7.4	5.2	4.2	5.8
Philippines	21 (0.2)	37 (0.3)	78 (0.4)	137 (0.5)	190 (0.6)	246 (0.6)	4.9	4.5	3.3	2.6	3.5
Singapore	13 (0.1)	27 (0.2)	50 (0.2)	62 (0.2)	66 (0.2)	65 (0.2)	5.1	1.7	0.5	0.0	0.8
Thailand	38 (0.4)	88 (0.7)	185 (0.9)	286 (1.0)	357 (1.0)	421 (1.1)	6.0	3.4	2.2	1.7	2.5
Viet Nam	6 (0.1)	22 (0.2)	173 (0.8)	463 (1.6)	628 (1.8)	810 (2.1)	13.1	7.9	3.1	2.6	4.8
North America	3 051 (31.4)	3 980 (31.3)	4 246 (19.9)	4 896 (16.9)	5 339 (15.5)	5 663 (14.5)	1.2	1.1	0.9	0.6	0.9
United States	2 633 (27.1)	3 499 (27.6)	3 737 (17.5)	4 315 (14.9)	4 707 (13.7)	4 988 (12.7)	1.3	1.1	0.9	0.6	0.9
Latin America	517 (5.3)	798 (6.3)	1 311 (6.1)	1 849 (6.4)	2 403 (7.0)	2 897 (7.4)	3.5	2.7	2.7	1.9	2.4
Advanced Europe	2 247 (23.2)	2 716 (21.4)	3 136 (14.7)	3 444 (11.9)	3 592 (10.5)	3 667 (9.4)	1.2	0.7	0.4	0.2	0.5
European Union	2 160 (22.3)	2 526 (19.9)	2 798 (13.1)	3 067 (10.6)	3 200 (9.3)	3 270 (8.4)	1.0	0.7	0.4	0.2	0.5
Other Europe / Eurasia	1 449 (14.9)	1 001 (7.9)	1 247 (5.8)	1 502 (5.2)	1 751 (5.1)	1 980 (5.1)	-0.6	1.4	1.5	1.2	1.4
Africa	256 (2.6)	361 (2.8)	652 (3.1)	1 118 (3.9)	1 778 (5.2)	2 686 (6.9)	3.5	4.2	4.7	4.2	4.4
Middle East	199 (2.0)	379 (3.0)	939 (4.4)	1 415 (4.9)	1 820 (5.3)	2 246 (5.7)	5.9	3.2	2.5	2.1	2.7
Oceania	158 (1.6)	207 (1.6)	250 (1.2)	305 (1.1)	335 (1.0)	358 (0.9)	1.7	1.6	1.0	0.6	1.1
Advanced Economies	6 428 (66.3)	8 362 (65.9)	9 453 (44.2)	10 638 (36.8)	11 327 (33.0)	11 753 (30.0)	1.4	0.9	0.6	0.4	0.7
Emerging Market and Developing Economies	3 274 (33.7)	4 336 (34.1)	11 915 (55.8)	18 255 (63.2)	23 016 (67.0)	27 385 (70.0)	4.9	3.3	2.3	1.8	2.6

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

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

Table A16 | Electricity generated [Reference Scenario]

(TWh)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/2017	2017/2030	2030/2040	2040/2050	2017/2050
World	11 850 (100)	15 436 (100)	25 606 (100)	34 412 (100)	40 404 (100)	45 363 (100)	2.9	2.3	1.6	1.2	1.7
Asia	2 241 (18.9)	3 980 (25.8)	11 340 (44.3)	16 958 (49.3)	20 212 (50.0)	22 578 (49.8)	6.2	3.1	1.8	1.1	2.1
China	621 (5.2)	1 356 (8.8)	6 602 (25.8)	9 315 (27.1)	10 574 (26.2)	11 141 (24.6)	9.1	2.7	1.3	0.5	1.6
India	293 (2.5)	570 (3.7)	1 532 (6.0)	3 223 (9.4)	4 313 (10.7)	5 240 (11.6)	6.3	5.9	3.0	2.0	3.8
Japan	862 (7.3)	1 055 (6.8)	1 061 (4.1)	1 072 (3.1)	1 077 (2.7)	1 069 (2.4)	0.8	0.1	0.0	-0.1	0.0
Korea	105 (0.9)	289 (1.9)	563 (2.2)	675 (2.0)	713 (1.8)	713 (1.6)	6.4	1.4	0.6	0.0	0.7
Chinese Taipei	88 (0.7)	181 (1.2)	265 (1.0)	310 (0.9)	332 (0.8)	341 (0.8)	4.2	1.2	0.7	0.3	0.8
ASEAN	154 (1.3)	370 (2.4)	978 (3.8)	1 826 (5.3)	2 478 (6.1)	3 143 (6.9)	7.1	4.9	3.1	2.4	3.6
Indonesia	33 (0.3)	93 (0.6)	255 (1.0)	495 (1.4)	740 (1.8)	984 (2.2)	7.9	5.2	4.1	2.9	4.2
Malaysia	23 (0.2)	69 (0.4)	165 (0.6)	239 (0.7)	294 (0.7)	348 (0.8)	7.6	2.9	2.1	1.7	2.3
Myanmar	2 (0.0)	5 (0.0)	22 (0.1)	73 (0.2)	115 (0.3)	165 (0.4)	8.5	9.5	4.7	3.7	6.2
Philippines	26 (0.2)	45 (0.3)	94 (0.4)	165 (0.5)	224 (0.6)	286 (0.6)	4.8	4.4	3.1	2.4	3.4
Singapore	16 (0.1)	32 (0.2)	52 (0.2)	65 (0.2)	69 (0.2)	69 (0.2)	4.6	1.7	0.5	0.0	0.8
Thailand	44 (0.4)	96 (0.6)	187 (0.7)	271 (0.8)	335 (0.8)	392 (0.9)	5.5	2.9	2.2	1.6	2.3
Viet Nam	9 (0.1)	27 (0.2)	199 (0.8)	514 (1.5)	695 (1.7)	894 (2.0)	12.3	7.6	3.1	2.6	4.7
North America	3 685 (31.1)	4 631 (30.0)	4 922 (19.2)	5 645 (16.4)	6 107 (15.1)	6 418 (14.1)	1.1	1.1	0.8	0.5	0.8
United States	3 203 (27.0)	4 026 (26.1)	4 264 (16.7)	4 907 (14.3)	5 321 (13.2)	5 598 (12.3)	1.1	1.1	0.8	0.5	0.8
Latin America	623 (5.3)	1 009 (6.5)	1 615 (6.3)	2 249 (6.5)	2 872 (7.1)	3 392 (7.5)	3.6	2.6	2.5	1.7	2.3
Advanced Europe	2 697 (22.8)	3 238 (21.0)	3 666 (14.3)	4 001 (11.6)	4 140 (10.2)	4 189 (9.2)	1.1	0.7	0.3	0.1	0.4
European Union	2 577 (21.7)	3 006 (19.5)	3 269 (12.8)	3 563 (10.4)	3 683 (9.1)	3 721 (8.2)	0.9	0.7	0.3	0.1	0.4
Other Europe / Eurasia	1 857 (15.7)	1 415 (9.2)	1 750 (6.8)	2 038 (5.9)	2 280 (5.6)	2 470 (5.4)	-0.2	1.2	1.1	0.8	1.0
Africa	315 (2.7)	441 (2.9)	817 (3.2)	1 376 (4.0)	2 145 (5.3)	3 170 (7.0)	3.6	4.1	4.5	4.0	4.2
Middle East	244 (2.1)	472 (3.1)	1 194 (4.7)	1 778 (5.2)	2 252 (5.6)	2 731 (6.0)	6.0	3.1	2.4	1.9	2.5
Oceania	187 (1.6)	249 (1.6)	302 (1.2)	366 (1.1)	396 (1.0)	416 (0.9)	1.8	1.5	0.8	0.5	1.0
Advanced Economies	7 668 (64.7)	9 706 (62.9)	10 868 (42.4)	12 177 (35.4)	12 878 (31.9)	13 258 (29.2)	1.3	0.9	0.6	0.3	0.6
Emerging Market and Developing Economies	4 182 (35.3)	5 730 (37.1)	14 738 (57.6)	22 235 (64.6)	27 526 (68.1)	32 105 (70.8)	4.8	3.2	2.2	1.6	2.4

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

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

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

(toe/person)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	1.66	1.64	1.86	1.94	1.96	1.93	0.4	0.3	0.1	-0.2	0.1
Asia	0.72	0.85	1.39	1.66	1.77	1.83	2.5	1.4	0.6	0.4	0.8
China	0.77	0.89	2.21	2.56	2.65	2.63	4.0	1.1	0.4	-0.1	0.5
India	0.35	0.42	0.66	1.04	1.27	1.46	2.4	3.6	2.0	1.5	2.5
Japan	3.55	4.09	3.41	3.40	3.36	3.29	-0.2	0.0	-0.1	-0.2	-0.1
Korea	2.17	4.00	5.48	5.94	5.92	5.81	3.5	0.6	0.0	-0.2	0.2
Chinese Taipei	2.34	3.81	4.67	4.72	4.65	4.57	2.6	0.1	-0.2	-0.2	-0.1
ASEAN	0.54	0.75	1.07	1.47	1.69	1.90	2.6	2.5	1.4	1.2	1.8
Indonesia	0.54	0.74	0.92	1.25	1.46	1.63	2.0	2.4	1.5	1.1	1.7
Malaysia	1.18	2.08	2.68	3.27	3.44	3.49	3.1	1.5	0.5	0.1	0.8
Myanmar	0.26	0.28	0.43	0.63	0.78	0.94	1.8	3.0	2.2	1.8	2.4
Philippines	0.46	0.51	0.55	0.77	0.88	1.01	0.7	2.5	1.4	1.4	1.8
Singapore	3.78	4.63	6.53	6.86	7.14	7.38	2.0	0.4	0.4	0.3	0.4
Thailand	0.74	1.15	2.00	2.47	2.87	3.32	3.7	1.6	1.5	1.5	1.5
Viet Nam	0.26	0.36	0.82	1.72	2.17	2.65	4.3	5.9	2.4	2.0	3.6
North America	7.66	8.08	6.75	6.33	5.93	5.52	-0.5	-0.5	-0.7	-0.7	-0.6
United States	7.67	8.06	6.63	6.23	5.83	5.43	-0.5	-0.5	-0.7	-0.7	-0.6
Latin America	1.05	1.15	1.30	1.47	1.62	1.71	0.8	1.0	1.0	0.5	0.8
Advanced Europe	3.25	3.34	3.06	2.84	2.67	2.54	-0.2	-0.6	-0.6	-0.5	-0.6
European Union	3.44	3.47	3.16	2.93	2.76	2.62	-0.3	-0.6	-0.6	-0.5	-0.6
Other Europe / Eurasia	4.48	2.96	3.29	3.41	3.57	3.72	-1.1	0.3	0.5	0.4	0.4
Africa	0.61	0.60	0.65	0.65	0.65	0.61	0.2	0.0	0.1	-0.6	-0.2
Middle East	1.68	2.21	3.15	3.42	3.57	3.61	2.3	0.6	0.4	0.1	0.4
Oceania	4.85	5.44	5.03	4.65	4.30	3.89	0.1	-0.6	-0.8	-1.0	-0.8
Advanced Economies	4.47	4.89	4.43	4.24	4.05	3.85	0.0	-0.3	-0.5	-0.5	-0.4
Emerging Market and Developing Economies	0.96	0.90	1.31	1.49	1.55	1.56	1.2	1.0	0.4	0.1	0.5

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

Note: World includes international bunkers.

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

(toe/$2010 million)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/ 2017	2017/ 2030	2030/ 2040	2040/ 2050	2017/ 2050
World	230	200	175	144	118	98	-1.0	-1.5	-1.9	-1.8	-1.7
Asia	277	260	231	173	133	106	-0.7	-2.2	-2.6	-2.3	-2.3
China	1 053	505	301	179	123	91	-4.5	-3.9	-3.7	-3.0	-3.6
India	605	507	333	250	192	147	-2.2	-2.2	-2.6	-2.6	-2.4
Japan	93	97	70	60	52	45	-1.0	-1.1	-1.5	-1.5	-1.4
Korea	256	265	210	162	129	103	-0.7	-2.0	-2.3	-2.2	-2.1
Chinese Taipei	308	286	208	160	129	105	-1.4	-2.0	-2.1	-2.0	-2.1
ASEAN	314	321	243	205	167	138	-0.9	-1.3	-2.0	-1.9	-1.7
Indonesia	318	343	224	178	141	113	-1.3	-1.7	-2.3	-2.2	-2.1
Malaysia	259	297	233	186	148	116	-0.4	-1.7	-2.3	-2.4	-2.1
Myanmar	1 594	960	343	260	202	159	-5.5	-2.1	-2.5	-2.3	-2.3
Philippines	304	319	192	152	129	111	-1.7	-1.8	-1.6	-1.5	-1.6
Singapore	171	139	118	100	91	85	-1.3	-1.3	-0.9	-0.7	-1.0
Thailand	296	332	327	258	212	179	0.4	-1.8	-1.9	-1.7	-1.8
Viet Nam	607	470	446	472	371	292	-1.1	0.4	-2.4	-2.4	-1.3
North America	211	180	127	99	78	63	-1.9	-1.9	-2.3	-2.2	-2.1
United States	211	179	124	96	76	61	-1.9	-2.0	-2.3	-2.2	-2.1
Latin America	164	157	143	126	106	90	-0.5	-1.0	-1.7	-1.7	-1.4
Advanced Europe	129	110	85	66	55	46	-1.6	-1.9	-1.8	-1.7	-1.8
European Union	138	115	86	66	55	46	-1.7	-2.0	-1.9	-1.7	-1.9
Other Europe / Eurasia	705	674	407	311	255	211	-2.0	-2.1	-1.9	-1.9	-2.0
Africa	432	420	340	269	207	158	-0.9	-1.8	-2.6	-2.7	-2.3
Middle East	216	243	279	271	237	201	0.9	-0.2	-1.3	-1.6	-1.0
Oceania	137	126	92	71	59	49	-1.5	-2.0	-1.9	-1.9	-1.9
Advanced Economies	155	139	104	82	68	56	-1.5	-1.8	-2.0	-1.9	-1.9
Emerging Market and Developing Economies	448	363	281	207	158	125	-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 A19 | Energy-related carbon dioxide emissions [Reference Scenario]

(Mt)

	1990	2000	2017	2030	2040	2050	CAGR (%) 1990/2017	2017/2030	2030/2040	2040/2050	2017/2050
World	20 302 (100)	23 029 (100)	32 711 (100)	37 571 (100)	40 095 (100)	40 858 (100)	1.8	1.1	0.7	0.2	0.7
Asia	4 631 (22.8)	6 714 (29.2)	15 157 (46.3)	19 038 (50.7)	20 612 (51.4)	20 987 (51.4)	4.5	1.8	0.8	0.2	1.0
China	2 146 (10.6)	3 140 (13.6)	9 230 (28.2)	10 323 (27.5)	10 021 (25.0)	8 942 (21.9)	5.6	0.9	-0.3	-1.1	-0.1
India	529 (2.6)	885 (3.8)	2 163 (6.6)	4 077 (10.9)	5 411 (13.5)	6 504 (15.9)	5.4	5.0	2.9	1.9	3.4
Japan	1 046 (5.2)	1 145 (5.0)	1 122 (3.4)	953 (2.5)	861 (2.1)	742 (1.8)	0.3	-1.3	-1.0	-1.5	-1.2
Korea	208 (1.0)	402 (1.7)	594 (1.8)	640 (1.7)	618 (1.5)	561 (1.4)	4.0	0.6	-0.4	-1.0	-0.2
Chinese Taipei	109 (0.5)	212 (0.9)	265 (0.8)	275 (0.7)	254 (0.6)	224 (0.5)	3.4	0.3	-0.8	-1.2	-0.5
ASEAN	344 (1.7)	669 (2.9)	1 344 (4.1)	2 171 (5.8)	2 704 (6.7)	3 129 (7.7)	5.2	3.8	2.2	1.5	2.6
Indonesia	133 (0.7)	255 (1.1)	496 (1.5)	779 (2.1)	1 013 (2.5)	1 179 (2.9)	5.0	3.5	2.7	1.5	2.7
Malaysia	51 (0.3)	111 (0.5)	203 (0.6)	254 (0.7)	271 (0.7)	271 (0.7)	5.2	1.8	0.6	0.0	0.9
Myanmar	4 (0.0)	10 (0.0)	30 (0.1)	73 (0.2)	109 (0.3)	147 (0.4)	7.8	7.0	4.1	3.0	4.9
Philippines	36 (0.2)	67 (0.3)	126 (0.4)	206 (0.5)	269 (0.7)	334 (0.8)	4.7	3.8	2.7	2.2	3.0
Singapore	21 (0.1)	33 (0.1)	48 (0.1)	54 (0.1)	56 (0.1)	55 (0.1)	3.1	0.9	0.4	-0.1	0.4
Thailand	77 (0.4)	147 (0.6)	244 (0.7)	291 (0.8)	311 (0.8)	309 (0.8)	4.4	1.3	0.7	-0.1	0.7
Viet Nam	17 (0.1)	43 (0.2)	189 (0.6)	508 (1.4)	668 (1.7)	828 (2.0)	9.4	7.9	2.8	2.2	4.6
North America	5 174 (25.5)	6 161 (26.8)	5 328 (16.3)	5 163 (13.7)	4 815 (12.0)	4 325 (10.6)	0.1	-0.2	-0.7	-1.1	-0.6
United States	4 763 (23.5)	5 656 (24.6)	4 781 (14.6)	4 622 (12.3)	4 283 (10.7)	3 813 (9.3)	0.0	-0.3	-0.8	-1.2	-0.7
Latin America	873 (4.3)	1 194 (5.2)	1 596 (4.9)	1 952 (5.2)	2 290 (5.7)	2 473 (6.1)	2.3	1.6	1.6	0.8	1.3
Advanced Europe	3 929 (19.4)	3 911 (17.0)	3 523 (10.8)	3 120 (8.3)	2 853 (7.1)	2 573 (6.3)	-0.4	-0.9	-0.9	-1.0	-0.9
European Union	3 980 (19.6)	3 783 (16.4)	3 201 (9.8)	2 761 (7.3)	2 511 (6.3)	2 248 (5.5)	-0.8	-1.1	-0.9	-1.1	-1.1
Other Europe / Eurasia	3 678 (18.1)	2 225 (9.7)	2 349 (7.2)	2 318 (6.2)	2 396 (6.0)	2 408 (5.9)	-1.6	-0.1	0.3	0.0	0.1
Africa	541 (2.7)	667 (2.9)	1 196 (3.7)	1 623 (4.3)	2 169 (5.4)	2 716 (6.6)	3.0	2.4	2.9	2.3	2.5
Middle East	568 (2.8)	942 (4.1)	1 858 (5.7)	2 329 (6.2)	2 622 (6.5)	2 785 (6.8)	4.5	1.8	1.2	0.6	1.2
Oceania	282 (1.4)	363 (1.6)	422 (1.3)	409 (1.1)	389 (1.0)	357 (0.9)	1.5	-0.3	-0.5	-0.9	-0.5
Advanced Economies	10 801 (53.2)	12 266 (53.3)	11 347 (34.7)	10 660 (28.4)	9 890 (24.7)	8 879 (21.7)	0.2	-0.5	-0.7	-1.1	-0.7
Emerging Market and Developing Economies	8 873 (43.7)	9 912 (43.0)	20 081 (61.4)	25 293 (67.3)	28 256 (70.5)	29 744 (72.8)	3.1	1.8	1.1	0.5	1.2

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

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

Table A20 | World [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	7 203	8 766	10 025	13 972	16 564	17 983	18 757	100	100	100	1.7	1.3	0.6	0.9
Coal	1 783	2 220	2 317	3 790	4 215	4 263	4 035	25	27	22	2.0	0.8	-0.2	0.2
Oil	3 105	3 233	3 663	4 449	5 035	5 429	5 707	37	32	30	1.2	1.0	0.6	0.8
Natural gas	1 232	1 664	2 072	3 107	4 026	4 685	5 165	19	22	28	2.3	2.0	1.3	1.6
Nuclear	186	526	675	687	794	817	858	6.0	4.9	4.6	1.0	1.1	0.4	0.7
Hydro	148	184	225	351	413	449	484	2.1	2.5	2.6	2.4	1.3	0.8	1.0
Geothermal	12	34	52	86	182	240	289	0.4	0.6	1.5	3.5	6.0	2.3	3.7
Solar, wind, etc.	0.1	2.5	7.9	171	386	562	782	0.0	1.2	4.2	17.0	6.5	3.6	4.7
Biomass and waste	737	902	1 012	1 329	1 510	1 536	1 435	10	9.5	7.7	1.4	1.0	-0.3	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	5 369	6 264	7 030	9 717	11 420	12 392	13 035	100	100	100	1.6	1.2	0.7	0.9
Industry	1 766	1 804	1 873	2 821	3 356	3 607	3 689	29	29	28	1.7	1.3	0.5	0.8
Transport	1 246	1 571	1 958	2 808	3 228	3 553	3 866	25	29	30	2.2	1.1	0.9	1.0
Buildings, etc.	2 000	2 414	2 592	3 209	3 713	3 969	4 101	39	33	31	1.1	1.1	0.5	0.7
Non-energy use	358	476	607	879	1 122	1 264	1 379	7.6	9.0	11	2.3	1.9	1.0	1.4
Coal	703	753	542	1 020	1 017	990	931	12	10	7.1	1.1	0.0	-0.4	-0.3
Oil	2 449	2 604	3 122	3 985	4 573	4 961	5 279	42	41	41	1.6	1.1	0.7	0.9
Natural gas	815	944	1 116	1 502	1 871	2 051	2 183	15	15	17	1.7	1.7	0.8	1.1
Electricity	586	834	1 092	1 838	2 485	2 954	3 366	13	19	26	3.0	2.3	1.5	1.9
Heat	121	336	248	289	299	294	284	5.4	3.0	2.2	-0.6	0.2	-0.2	-0.1
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-7.0	n.a.
Renewables	696	794	910	1 083	1 176	1 143	992	13	11	7.6	1.2	0.6	-0.8	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	8 283	11 850	15 436	25 606	34 412	40 404	45 363	100	100	100	2.9	2.3	1.4	1.7
Coal	3 137	4 430	5 994	9 863	12 190	12 954	12 762	37	39	28	3.0	1.6	0.2	0.8
Oil	1 659	1 325	1 207	842	833	787	593	11	3.3	1.3	-1.7	-0.1	-1.7	-1.1
Natural gas	999	1 750	2 760	5 883	8 585	11 250	13 553	15	23	30	4.6	3.0	2.3	2.6
Nuclear	713	2 013	2 591	2 636	3 049	3 136	3 295	17	10	7.3	1.0	1.1	0.4	0.7
Hydro	1 717	2 141	2 613	4 082	4 806	5 225	5 624	18	16	12	2.4	1.3	0.8	1.0
Geothermal	14	36	52	85	191	263	319	0.3	0.3	0.7	3.2	6.4	2.6	4.1
Solar PV	-	0.1	1.0	444	1 290	2 228	3 731	0.0	1.7	8.2	37.0	8.6	5.5	6.7
Wind	0.0	3.9	31	1 127	2 358	3 114	3 688	0.0	4.4	8.1	23.4	5.8	2.3	3.7
CSP and marine	0.5	1.2	1.1	12	119	214	351	0.0	0.0	0.8	8.9	19.4	5.6	10.8
Biomass and waste	44	130	164	596	955	1 196	1 413	1.1	2.3	3.1	5.8	3.7	2.0	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	36	36	36	36	0.2	0.1	0.1	2.2	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	28 173	38 050	50 096	79 936	115 397	151 856	190 750	2.8	2.9	2.5	2.7
Population (million)	4 437	5 281	6 112	7 519	8 522	9 176	9 716	1.3	1.0	0.7	0.8
CO_2 emissions (Mt)	17 777	20 302	23 029	32 711	37 571	40 095	40 858	1.8	1.1	0.4	0.7
GDP per capita ($2010 thousand)	6.4	7.2	8.2	11	14	17	20	1.5	1.9	1.9	1.9
Primary energy consump. per capita (toe)	1.6	1.7	1.6	1.9	1.9	2.0	1.9	0.4	0.3	0.0	0.1
Primary energy consumption per GDP[*2]	256	230	200	175	144	118	98	-1.0	-1.5	-1.9	-1.7
CO_2 emissions per GDP[*3]	631	534	460	409	326	264	214	-1.0	-1.7	-2.1	-1.9
CO_2 per primary energy consumption[*4]	2.5	2.3	2.3	2.3	2.3	2.2	2.2	0.0	-0.2	-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 A21 | Asia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	1 439	2 110	2 887	5 669	7 386	8 171	8 585	100	100	100	3.7	2.1	0.8	1.3
Coal	466	788	1 037	2 761	3 279	3 376	3 222	37	49	38	4.8	1.3	-0.1	0.5
Oil	477	618	916	1 410	1 836	2 098	2 321	29	25	27	3.1	2.1	1.2	1.5
Natural gas	51	116	233	595	1 016	1 278	1 471	5.5	10	17	6.2	4.2	1.9	2.8
Nuclear	25	77	132	130	256	299	345	3.6	2.3	4.0	2.0	5.3	1.5	3.0
Hydro	20	32	41	141	176	196	211	1.5	2.5	2.5	5.7	1.7	0.9	1.2
Geothermal	2.6	8.2	23	44	94	120	145	0.4	0.8	1.7	6.4	6.1	2.2	3.7
Solar, wind, etc.	-	1.2	2.1	75	193	287	390	0.1	1.3	4.5	16.4	7.5	3.6	5.1
Biomass and waste	397	471	503	513	533	516	479	22	9.0	5.6	0.3	0.3	-0.5	-0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	1 133	1 554	1 992	3 793	4 828	5 369	5 751	100	100	100	3.4	1.9	0.9	1.3
Industry	383	516	653	1 544	1 885	2 005	2 026	33	41	35	4.1	1.5	0.4	0.8
Transport	124	183	318	692	965	1 160	1 351	12	18	23	5.0	2.6	1.7	2.0
Buildings, etc.	568	740	843	1 178	1 453	1 600	1 709	48	31	30	1.7	1.6	0.8	1.1
Non-energy use	58	115	179	380	524	604	665	7.4	10	12	4.5	2.5	1.2	1.7
Coal	301	424	373	859	859	836	785	27	23	14	2.7	0.0	-0.4	-0.3
Oil	330	458	734	1 261	1 672	1 928	2 152	29	33	37	3.8	2.2	1.3	1.6
Natural gas	21	46	87	295	514	610	679	2.9	7.8	12	7.2	4.4	1.4	2.6
Electricity	88	157	280	825	1 235	1 490	1 689	10	22	29	6.3	3.2	1.6	2.2
Heat	7.5	14	30	102	117	121	121	0.9	2.7	2.1	7.6	1.0	0.2	0.5
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-11.3	n.a.
Renewables	385	455	488	452	431	384	325	29	12	5.7	0.0	-0.4	-1.4	-1.0

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	1 196	2 241	3 980	11 340	16 958	20 212	22 578	100	100	100	6.2	3.1	1.4	2.1
Coal	298	868	1 983	6 788	9 109	9 995	10 096	39	60	45	7.9	2.3	0.5	1.2
Oil	476	436	385	213	197	171	132	19	1.9	0.6	-2.6	-0.6	-2.0	-1.4
Natural gas	90	237	570	1 352	2 314	3 156	3 871	11	12	17	6.7	4.2	2.6	3.2
Nuclear	97	294	505	500	983	1 148	1 323	13	4.4	5.9	2.0	5.3	1.5	3.0
Hydro	232	368	478	1 638	2 051	2 282	2 455	16	14	11	5.7	1.7	0.9	1.2
Geothermal	3.0	8.4	20	26	61	78	95	0.4	0.2	0.4	4.2	6.9	2.2	4.0
Solar PV	-	0.1	0.6	228	745	1 258	2 059	0.0	2.0	9.1	34.9	9.5	5.2	6.9
Wind	-	0.0	2.4	362	1 113	1 619	1 926	0.0	3.2	8.5	41.0	9.0	2.8	5.2
CSP and marine	-	0.0	0.0	0.5	7.5	14	26	0.0	0.0	0.1	17.4	22.6	6.4	12.5
Biomass and waste	0.0	9.4	16	210	355	469	573	0.4	1.9	2.5	12.2	4.1	2.4	3.1
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	22	22	22	22	0.9	0.2	0.1	0.4	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	4 510	7 628	11 102	24 564	42 742	61 349	81 204	4.4	4.4	3.3	3.7
Population (million)	2 440	2 933	3 410	4 072	4 449	4 617	4 681	1.2	0.7	0.3	0.4
CO_2 emissions (Mt)	3 103	4 631	6 714	15 157	19 038	20 612	20 987	4.5	1.8	0.5	1.0
GDP per capita ($2010 thousand)	1.8	2.6	3.3	6.0	9.6	13	17	3.2	3.6	3.0	3.3
Primary energy consump. per capita (toe)	0.6	0.7	0.8	1.4	1.7	1.8	1.8	2.5	1.4	0.5	0.8
Primary energy consumption per GDP[*2]	319	277	260	231	173	133	106	-0.7	-2.2	-2.4	-2.3
CO_2 emissions per GDP[*3]	688	607	605	617	445	336	258	0.1	-2.5	-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 A22 | China [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	598	874	1 130	3 063	3 654	3 752	3 594	100	100	100	4.8	1.4	-0.1	0.5
Coal	313	531	665	1 953	2 060	1 923	1 646	61	64	46	4.9	0.4	-1.1	-0.5
Oil	89	119	221	568	722	742	693	14	19	19	6.0	1.9	-0.2	0.6
Natural gas	12	13	21	195	391	501	574	1.5	6.4	16	10.6	5.5	1.9	3.3
Nuclear	-	-	4.4	65	129	159	189	-	2.1	5.3	n.a.	5.4	1.9	3.3
Hydro	5.0	11	19	99	120	128	131	1.2	3.2	3.7	8.5	1.4	0.5	0.8
Geothermal	-	-	1.7	10	13	15	16	-	0.3	0.4	n.a.	1.9	0.9	1.3
Solar, wind, etc.	-	0.0	1.0	60	141	202	251	0.0	1.9	7.0	32.0	6.9	2.9	4.4
Biomass and waste	180	200	198	114	79	84	95	23	3.7	2.6	-2.1	-2.8	0.9	-0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	487	658	781	1 995	2 304	2 375	2 328	100	100	100	4.2	1.1	0.1	0.5
Industry	181	234	302	986	987	934	855	36	49	37	5.5	0.0	-0.7	-0.4
Transport	22	30	84	310	438	463	432	4.6	16	19	9.0	2.7	-0.1	1.0
Buildings, etc.	274	351	338	537	653	726	780	53	27	33	1.6	1.5	0.9	1.1
Non-energy use	10	43	57	162	226	252	261	6.5	8.1	11	5.1	2.6	0.7	1.5
Coal	214	311	274	663	560	483	403	47	33	17	2.8	-1.3	-1.6	-1.5
Oil	59	85	180	514	664	683	639	13	26	27	6.9	2.0	-0.2	0.7
Natural gas	6.4	8.9	12	132	220	249	268	1.3	6.6	12	10.5	4.0	1.0	2.2
Electricity	21	39	89	476	678	778	831	5.9	24	36	9.7	2.8	1.0	1.7
Heat	7.4	13	26	96	109	114	113	2.0	4.8	4.9	7.6	1.0	0.2	0.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	180	200	199	114	74	67	74	30	5.7	3.2	-2.1	-3.3	0.0	-1.3

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	301	621	1 356	6 602	9 315	10 574	11 141	100	100	100	9.1	2.7	0.9	1.6
Coal	159	441	1 060	4 485	5 414	5 447	5 063	71	68	45	9.0	1.5	-0.3	0.4
Oil	82	50	47	9.9	9.6	7.6	5.0	8.1	0.1	0.0	-5.9	-0.3	-3.2	-2.1
Natural gas	0.7	2.8	5.8	183	569	873	1 119	0.4	2.8	10	16.8	9.1	3.4	5.6
Nuclear	-	-	17	248	493	611	725	-	3.8	6.5	n.a.	5.4	1.9	3.3
Hydro	58	127	222	1 157	1 390	1 487	1 528	20	18	14	8.5	1.4	0.5	0.8
Geothermal	-	0.1	0.1	0.1	0.3	0.4	0.5	0.0	0.0	0.0	3.0	7.8	2.2	4.3
Solar PV	-	0.0	0.0	131	392	628	952	0.0	2.0	8.5	50.8	8.8	4.5	6.2
Wind	-	0.0	0.6	295	907	1 321	1 497	0.0	4.5	13	55.4	9.0	2.5	5.0
CSP and marine	-	0.0	0.0	0.0	1.0	3.7	8.0	0.0	0.0	0.1	6.6	28.7	10.7	17.5
Biomass and waste	-	-	2.4	93	139	195	244	-	1.4	2.2	n.a.	3.2	2.8	3.0
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	341	830	2 237	10 161	20 439	30 536	39 687	9.7	5.5	3.4	4.2
Population (million)	981	1 135	1 263	1 386	1 429	1 414	1 368	0.7	0.2	-0.2	0.0
CO_2 emissions (Mt)	1 399	2 146	3 140	9 230	10 323	10 021	8 942	5.6	0.9	-0.7	-0.1
GDP per capita ($2010 thousand)	0.3	0.7	1.8	7.3	14	22	29	8.9	5.3	3.6	4.3
Primary energy consump. per capita (toe)	0.6	0.8	0.9	2.2	2.6	2.7	2.6	4.0	1.1	0.1	0.5
Primary energy consumption per GDP[*2]	1 752	1 053	505	301	179	123	91	-4.5	-3.9	-3.3	-3.6
CO_2 emissions per GDP[*3]	4 097	2 587	1 404	908	505	328	225	-3.8	-4.4	-4.0	-4.1
CO_2 per primary energy consumption[*4]	2.3	2.5	2.8	3.0	2.8	2.7	2.5	0.8	-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 A23 | India [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	200	306	441	882	1 566	2 016	2 402	100	100	100	4.0	4.5	2.2	3.1
Coal	44	93	146	391	706	886	990	30	44	41	5.5	4.7	1.7	2.9
Oil	33	61	112	223	408	586	792	20	25	33	4.9	4.7	3.4	3.9
Natural gas	1.3	11	23	51	144	213	270	3.5	5.8	11	6.0	8.3	3.2	5.2
Nuclear	0.8	1.6	4.4	10.0	43	54	68	0.5	1.1	2.8	7.0	11.9	2.3	6.0
Hydro	4.0	6.2	6.4	12	21	27	33	2.0	1.4	1.4	2.6	4.3	2.2	3.0
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	0.0	0.2	7.5	33	53	81	0.0	0.8	3.4	27.6	12.1	4.5	7.5
Biomass and waste	116	133	149	187	212	197	168	44	21	7.0	1.3	1.0	-1.1	-0.3

Final energy consumption

	Mtoe							Shares (%)						
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total	174	243	314	591	1 035	1 343	1 631	100	100	100	3.3	4.4	2.3	3.1
Industry	41	67	83	205	416	519	565	27	35	35	4.2	5.6	1.5	3.1
Transport	17	21	32	98	192	317	486	8.5	17	30	5.9	5.3	4.7	5.0
Buildings, etc.	110	142	172	242	341	392	434	59	41	27	2.0	2.7	1.2	1.8
Non-energy use	5.7	13	27	46	86	116	146	5.5	7.8	9.0	4.7	5.0	2.7	3.6
Coal	25	38	33	101	184	225	248	16	17	15	3.7	4.7	1.5	2.8
Oil	27	50	94	196	372	543	742	21	33	45	5.2	5.1	3.5	4.1
Natural gas	0.7	5.6	9.7	36	97	135	163	2.3	6.1	10	7.1	7.9	2.6	4.7
Electricity	7.8	18	32	100	217	301	379	7.6	17	23	6.5	6.1	2.8	4.1
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	114	130	144	158	166	139	99	54	27	6.1	0.7	0.4	-2.6	-1.4

Electricity generation

	(TWh)							Shares (%)						
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total	120	293	570	1 532	3 223	4 313	5 240	100	100	100	6.3	5.9	2.5	3.8
Coal	61	192	390	1 134	2 116	2 684	2 991	65	74	57	6.8	4.9	1.7	3.0
Oil	8.8	13	29	25	23	20	12	4.5	1.6	0.2	2.4	-0.6	-3.4	-2.3
Natural gas	0.6	10.0	56	71	234	404	578	3.4	4.6	11	7.5	9.6	4.6	6.6
Nuclear	3.0	6.1	17	38	165	206	262	2.1	2.5	5.0	7.0	11.9	2.3	6.0
Hydro	47	72	74	142	244	313	381	24	9.3	7.3	2.6	4.3	2.2	3.0
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	0.0	26	200	359	591	-	1.7	11	n.a.	17.0	5.6	9.9
Wind	-	0.0	1.7	51	150	206	270	0.0	3.3	5.2	31.4	8.7	3.0	5.2
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	-	3.0	2.8	n.a.	5.1	2.6	3.6
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	295	506	870	2 651	6 273	10 518	16 320	6.3	6.9	4.9	5.7
Population (million)	697	870	1 053	1 339	1 504	1 593	1 640	1.6	0.9	0.4	0.6
CO_2 emissions (Mt)	258	529	885	2 163	4 077	5 411	6 504	5.4	5.0	2.4	3.4
GDP per capita ($2010 thousand)	0.4	0.6	0.8	2.0	4.2	6.6	10.0	4.6	5.9	4.4	5.0
Primary energy consump. per capita (toe)	0.3	0.4	0.4	0.7	1.0	1.3	1.5	2.4	3.6	1.7	2.5
Primary energy consumption per GDP[*2]	679	605	507	333	250	192	147	-2.2	-2.2	-2.6	-2.4
CO_2 emissions per GDP[*3]	876	1 046	1 017	816	650	514	399	-0.9	-1.7	-2.4	-2.1
CO_2 per primary energy consumption[*4]	1.3	1.7	2.0	2.5	2.6	2.7	2.7	1.3	0.5	0.2	0.3

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

Table A24 | Japan [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	345	439	518	432	408	378	347	100	100	100	-0.1	-0.4	-0.8	-0.7
Coal	60	77	97	116	99	91	79	17	27	23	1.6	-1.3	-1.1	-1.2
Oil	234	250	255	176	142	122	105	57	41	30	-1.3	-1.6	-1.5	-1.6
Natural gas	21	44	66	101	88	82	72	10	23	21	3.1	-1.1	-1.0	-1.0
Nuclear	22	53	84	8.6	40	37	37	12	2.0	11	-6.5	12.5	-0.4	4.5
Hydro	7.6	7.6	7.2	7.1	7.3	7.4	7.4	1.7	1.6	2.1	-0.2	0.2	0.1	0.1
Geothermal	0.8	1.6	3.1	2.2	5.3	8.4	11	0.4	0.5	3.1	1.3	6.8	3.7	4.9
Solar, wind, etc.	-	1.2	0.8	5.5	8.8	11	16	0.3	1.3	4.7	5.9	3.6	3.1	3.3
Biomass and waste	-	4.6	5.4	15	19	19	20	1.0	3.5	5.7	4.6	1.6	0.3	0.8

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	236	287	332	293	266	245	224	100	100	100	0.1	-0.7	-0.9	-0.8
Industry	91	108	104	86	80	73	65	38	30	29	-0.8	-0.6	-1.0	-0.9
Transport	54	68	86	71	58	51	44	24	24	20	0.1	-1.5	-1.4	-1.4
Buildings, etc.	58	78	107	101	95	90	85	27	35	38	1.0	-0.4	-0.6	-0.5
Non-energy use	32	33	36	35	33	32	31	11	12	14	0.2	-0.4	-0.4	-0.4
Coal	25	27	21	22	19	16	14	9.5	7.4	6.0	-0.8	-1.1	-1.6	-1.4
Oil	160	177	202	151	125	109	95	61	52	42	-0.6	-1.4	-1.4	-1.4
Natural gas	5.8	14	21	30	31	29	26	4.7	10	12	3.0	0.3	-0.9	-0.4
Electricity	44	66	84	83	84	84	84	23	28	37	0.9	0.1	0.0	0.0
Heat	0.1	0.2	0.5	0.5	0.4	0.4	0.3	0.1	0.2	0.1	3.7	-1.5	-1.8	-1.6
Hydrogen	-	-	-	-	0.0	0.0	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	-	3.9	4.3	6.6	6.3	5.8	5.2	1.4	2.2	2.3	2.0	-0.3	-0.9	-0.7

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	573	862	1 055	1 061	1 072	1 077	1 069	100	100	100	0.8	0.1	0.0	0.0
Coal	55	123	223	352	290	284	256	14	33	24	4.0	-1.5	-0.6	-1.0
Oil	265	250	134	70	34	17	1.7	29	6.6	0.2	-4.6	-5.3	-13.9	-10.6
Natural gas	81	168	258	398	325	317	285	20	38	27	3.2	-1.5	-0.7	-1.0
Nuclear	83	202	322	33	152	141	141	23	3.1	13	-6.5	12.5	-0.4	4.5
Hydro	88	88	84	83	85	86	87	10	7.8	8.1	-0.2	0.2	0.1	0.1
Geothermal	0.9	1.7	3.3	2.5	6.0	9.7	13	0.2	0.2	1.2	1.3	7.1	3.7	5.1
Solar PV	-	0.1	0.4	55	84	103	123	0.0	5.2	11	28.2	3.3	1.9	2.5
Wind	-	-	0.1	6.5	16	28	64	-	0.6	6.0	n.a.	7.1	7.2	7.2
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	8.7	9.9	41	60	70	78	1.0	3.9	7.3	5.9	3.0	1.3	2.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	20	20	20	20	2.3	1.9	1.9	0.2	0.0	0.0	0.0

Energy and economic indicators

								1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	2017	2030	2050	2050
GDP ($2010 billion)	3 019	4 704	5 349	6 158	6 762	7 291	7 787	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	1 046	1 145	1 122	953	861	742	0.3	-1.3	-1.2	-1.2
GDP per capita ($2010 thousand)	26	38	42	49	56	65	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	3.4	3.3	-0.2	0.0	-0.2	-0.1
Primary energy consumption per GDP*2	114	93	97	70	60	52	45	-1.0	-1.1	-1.5	-1.4
CO_2 emissions per GDP*3	299	222	214	182	141	118	95	-0.7	-2.0	-1.9	-1.9
CO_2 per primary energy consumption*4	2.6	2.4	2.2	2.6	2.3	2.3	2.1	0.3	-0.8	-0.4	-0.6

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

Table A25 | Korea [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	41	93	188	282	306	297	274	100	100	100	4.2	0.6	-0.5	-0.1
Coal	14	25	42	83	87	82	71	27	29	26	4.5	0.4	-1.0	-0.5
Oil	27	50	99	109	117	113	104	54	39	38	3.0	0.5	-0.6	-0.1
Natural gas	-	2.7	17	43	58	64	67	2.9	15	24	10.8	2.3	0.7	1.3
Nuclear	0.9	14	28	39	32	25	17	15	14	6.3	3.9	-1.5	-3.0	-2.4
Hydro	0.2	0.5	0.3	0.2	0.3	0.3	0.3	0.6	0.1	0.1	-3.0	1.7	0.0	0.6
Geothermal	-	-	-	0.2	0.2	0.2	0.2	-	0.1	0.1	n.a.	1.4	-0.2	0.4
Solar, wind, etc.	-	0.0	0.0	1.0	2.7	4.1	6.0	0.0	0.4	2.2	18.6	8.0	4.1	5.6
Biomass and waste	-	0.7	1.4	7.2	9.0	9.0	8.3	0.8	2.5	3.0	8.8	1.7	-0.4	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	31	65	127	183	203	201	191	100	100	100	3.9	0.8	-0.3	0.1
Industry	10	19	38	48	54	54	50	30	26	26	3.5	0.9	-0.4	0.1
Transport	4.8	15	26	36	37	35	30	22	19	16	3.4	0.3	-0.9	-0.5
Buildings, etc.	13	24	37	47	50	49	46	38	25	24	2.4	0.5	-0.4	0.0
Non-energy use	3.1	6.7	25	53	62	64	64	10	29	34	7.9	1.3	0.1	0.6
Coal	9.7	12	9.1	8.6	7.4	6.2	4.9	18	4.7	2.6	-1.1	-1.2	-2.0	-1.7
Oil	19	44	80	97	105	101	94	67	53	49	3.0	0.6	-0.6	-0.1
Natural gas	-	0.7	11	22	27	27	25	1.0	12	13	13.8	1.4	-0.2	0.4
Electricity	2.8	8.1	23	45	54	57	57	13	25	30	6.5	1.4	0.3	0.7
Heat	-	-	3.3	5.1	5.3	5.1	4.7	-	2.8	2.5	n.a.	0.3	-0.6	-0.2
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	-	0.7	1.3	5.0	5.6	5.4	4.8	1.1	2.7	2.5	7.3	0.9	-0.8	-0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	37	105	289	563	675	713	713	100	100	100	6.4	1.4	0.3	0.7
Coal	2.5	18	111	256	298	302	279	17	45	39	10.4	1.2	-0.3	0.3
Oil	29	19	35	12	9.2	5.1	0.1	18	2.1	0.0	-1.7	-1.9	-19.7	-13.1
Natural gas	-	9.6	29	126	197	246	278	9.1	22	39	10.0	3.5	1.7	2.4
Nuclear	3.5	53	109	148	122	94	66	50	26	9.3	3.9	-1.5	-3.0	-2.4
Hydro	2.0	6.4	4.0	2.8	3.5	3.5	3.5	6.0	0.5	0.5	-3.0	1.7	0.0	0.6
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	0.0	0.0	7.1	22	33	46	0.0	1.3	6.5	38.8	9.2	3.7	5.9
Wind	-	-	0.0	2.2	5.7	9.6	16	-	0.4	2.2	n.a.	7.7	5.2	6.2
CSP and marine	-	-	-	0.5	3.2	4.7	8.0	-	0.1	1.1	n.a.	15.5	4.7	8.8
Biomass and waste	-	-	0.1	6.9	12	13	14	-	1.2	2.0	n.a.	4.2	0.9	2.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	1.6	1.6	1.6	1.6	-	0.3	0.2	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	141	363	710	1 346	1 886	2 308	2 664	5.0	2.6	1.7	2.1
Population (million)	38	43	47	51	52	50	47	0.7	0.0	-0.4	-0.3
CO_2 emissions (Mt)	109	208	402	594	640	618	561	4.0	0.6	-0.7	-0.2
GDP per capita ($2010 thousand)	3.7	8.5	15	26	37	46	56	4.3	2.6	2.2	2.4
Primary energy consump. per capita (toe)	1.1	2.2	4.0	5.5	5.9	5.9	5.8	3.5	0.6	-0.1	0.2
Primary energy consumption per GDP[*2]	292	256	265	210	162	129	103	-0.7	-2.0	-2.2	-2.1
CO_2 emissions per GDP[*3]	772	573	566	442	339	268	211	-1.0	-2.0	-2.4	-2.2
CO_2 per primary energy consumption[*4]	2.6	2.2	2.1	2.1	2.1	2.1	2.0	-0.2	0.0	-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 A26 | Chinese Taipei [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	28	48	85	110	113	109	102	100	100	100	3.1	0.2	-0.5	-0.2
Coal	3.9	11	30	41	42	37	32	24	38	31	4.9	0.1	-1.4	-0.8
Oil	20	26	38	42	42	39	36	54	39	35	1.9	-0.2	-0.7	-0.5
Natural gas	1.6	1.4	5.6	18	24	26	27	2.9	16	26	9.9	2.2	0.6	1.2
Nuclear	2.1	8.6	10	5.8	0.0	0.0	0.0	18	5.3	0.0	-1.4	-35.0	0.0	-15.6
Hydro	0.3	0.5	0.4	0.5	0.4	0.4	0.4	1.1	0.4	0.4	-0.6	-1.0	0.1	-0.3
Geothermal	-	0.0	-	-	-	-	-	0.0	-	-	-100	n.a.	n.a.	n.a.
Solar, wind, etc.	-	0.0	0.1	0.4	1.5	2.4	3.3	0.0	0.4	3.3	12.1	10.6	4.1	6.7
Biomass and waste	-	-	0.6	1.5	3.6	3.7	3.6	-	1.4	3.5	n.a.	6.8	0.0	2.7

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	19	29	49	70	74	73	70	100	100	100	3.3	0.4	-0.3	0.0
Industry	10	12	19	24	25	24	23	42	34	33	2.5	0.3	-0.3	-0.1
Transport	2.9	6.6	12	13	12	10	8.5	22	18	12	2.5	-0.4	-1.7	-1.2
Buildings, etc.	3.6	6.5	10	12	14	14	15	22	17	21	2.3	1.0	0.3	0.6
Non-energy use	2.0	4.0	7.8	22	23	24	24	14	31	34	6.4	0.5	0.1	0.3
Coal	2.2	3.6	5.0	7.8	7.6	7.1	6.5	12	11	9.2	2.9	-0.2	-0.8	-0.6
Oil	12	18	28	38	37	35	32	62	54	46	2.7	-0.1	-0.7	-0.5
Natural gas	1.4	0.9	1.6	3.2	3.9	3.9	3.6	3.0	4.6	5.2	4.9	1.5	-0.4	0.4
Electricity	3.2	6.6	14	21	24	26	27	22	30	38	4.3	1.2	0.5	0.8
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
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	0.8	0.8	13.4	0.6	-0.3	0.0

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	43	88	181	265	310	332	341	100	100	100	4.2	1.2	0.5	0.8
Coal	6.0	24	89	126	137	128	113	28	48	33	6.3	0.6	-1.0	-0.3
Oil	26	23	30	13	13	11	8.5	26	4.9	2.5	-2.1	-0.1	-2.1	-1.3
Natural gas	-	1.2	17	91	132	153	168	1.4	34	49	17.2	2.9	1.2	1.9
Nuclear	8.2	33	39	22	0.1	0.1	0.1	37	8.5	0.0	-1.4	-35.0	0.0	-15.6
Hydro	2.9	6.4	4.6	5.4	4.8	4.8	4.9	7.2	2.1	1.4	-0.6	-1.0	0.1	-0.3
Geothermal	-	0.0	-	-	-	-	-	0.0	-	-	-100	n.a.	n.a.	n.a.
Solar PV	-	-	-	1.7	6.5	10	14	-	0.6	4.2	n.a.	10.9	4.1	6.7
Wind	-	-	0.0	1.7	9.6	16	23	-	0.7	6.8	n.a.	14.1	4.5	8.2
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	1.7	3.5	7.3	8.3	8.8	-	1.3	2.6	n.a.	5.9	0.9	2.9
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	70	155	297	529	707	847	971	4.6	2.3	1.6	1.9
Population (million)	18	20	22	24	24	23	22	0.5	0.1	-0.3	-0.2
CO_2 emissions (Mt)	71	109	212	265	275	254	224	3.4	0.3	-1.0	-0.5
GDP per capita ($2010 thousand)	3.9	7.6	13	22	30	36	44	4.1	2.1	2.0	2.0
Primary energy consump. per capita (toe)	1.6	2.3	3.8	4.7	4.7	4.6	4.6	2.6	0.1	-0.2	-0.1
Primary energy consumption per GDP[*2]	396	308	286	208	160	129	105	-1.4	-2.0	-2.1	-2.1
CO_2 emissions per GDP[*3]	1 004	701	713	501	389	300	231	-1.2	-1.9	-2.6	-2.3
CO_2 per primary energy consumption[*4]	2.5	2.3	2.5	2.4	2.4	2.3	2.2	0.2	0.1	-0.5	-0.3

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

Table A27 | ASEAN [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	142	232	379	666	1 026	1 249	1 449	100	100	100	4.0	3.4	1.7	2.4
Coal	3.6	13	32	132	233	295	334	5.4	20	23	9.1	4.5	1.8	2.9
Oil	58	89	153	234	326	402	479	38	35	33	3.7	2.6	1.9	2.2
Natural gas	8.6	30	74	134	231	283	326	13	20	23	5.7	4.3	1.7	2.7
Nuclear	-	-	-	-	-	9.7	18	-	-	1.3	n.a.	n.a.	n.a.	n.a.
Hydro	0.8	2.3	4.1	14	17	20	21	1.0	2.1	1.5	6.9	1.5	1.0	1.2
Geothermal	1.8	6.6	18	31	75	96	117	2.9	4.6	8.1	5.8	7.1	2.3	4.1
Solar, wind, etc.	-	-	-	0.8	4.2	11	28	-	0.1	1.9	n.a.	14.0	9.8	11.5
Biomass and waste	69	92	98	119	136	131	121	40	18	8.3	1.0	1.0	-0.6	0.0

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	112	173	269	477	703	850	990	100	100	100	3.8	3.0	1.7	2.2
Industry	22	43	75	148	255	316	368	25	31	37	4.7	4.3	1.8	2.8
Transport	17	32	61	127	174	216	264	19	27	27	5.2	2.5	2.1	2.2
Buildings, etc.	70	87	112	144	186	209	228	50	30	23	1.9	2.0	1.0	1.4
Non-energy use	2.4	11	21	57	87	108	131	6.3	12	13	6.3	3.3	2.0	2.5
Coal	2.1	6.1	13	39	60	73	81	3.5	8.1	8.1	7.1	3.4	1.5	2.2
Oil	41	67	123	219	306	377	453	39	46	46	4.5	2.6	2.0	2.2
Natural gas	2.5	7.5	17	42	90	112	130	4.4	8.8	13	6.6	6.0	1.9	3.5
Electricity	4.7	11	28	75	141	192	244	6.5	16	25	7.3	5.0	2.8	3.6
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-7.9	n.a.
Renewables	61	81	89	102	106	96	81	47	21	8.2	0.8	0.4	-1.3	-0.7

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	62	154	370	978	1 826	2 478	3 143	100	100	100	7.1	4.9	2.8	3.6
Coal	3.0	28	79	372	769	1 040	1 256	18	38	40	10.1	5.8	2.5	3.8
Oil	47	66	72	26	40	46	42	43	2.7	1.3	-3.4	3.2	0.3	1.5
Natural gas	0.7	26	154	362	667	872	1 051	17	37	33	10.2	4.8	2.3	3.3
Nuclear	-	-	-	-	-	37	71	-	-	2.3	n.a.	n.a.	n.a.	n.a.
Hydro	9.8	27	47	166	200	227	245	18	17	7.8	6.9	1.5	1.0	1.2
Geothermal	2.1	6.6	16	23	54	67	81	4.3	2.4	2.6	4.7	6.7	2.1	3.9
Solar PV	-	-	-	6.3	32	99	278	-	0.6	8.9	n.a.	13.4	11.4	12.2
Wind	-	-	-	2.5	17	27	40	-	0.3	1.3	n.a.	15.5	4.6	8.8
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	20	47	63	78	0.4	2.0	2.5	13.8	7.0	2.5	4.3
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	440	741	1 180	2 747	5 008	7 463	10 499	5.0	4.7	3.8	4.1
Population (million)	346	430	506	625	699	739	761	1.4	0.9	0.4	0.6
CO_2 emissions (Mt)	185	344	669	1 344	2 171	2 704	3 129	5.2	3.8	1.8	2.6
GDP per capita ($2010 thousand)	1.3	1.7	2.3	4.4	7.2	10	14	3.5	3.8	3.3	3.5
Primary energy consump. per capita (toe)	0.4	0.5	0.7	1.1	1.5	1.7	1.9	2.6	2.5	1.3	1.8
Primary energy consumption per GDP[*2]	322	314	321	243	205	167	138	-0.9	-1.3	-2.0	-1.7
CO_2 emissions per GDP[*3]	421	464	567	489	434	362	298	0.2	-0.9	-1.9	-1.5
CO_2 per primary energy consumption[*4]	1.3	1.5	1.8	2.0	2.1	2.2	2.2	1.2	0.4	0.1	0.2

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

Table A28 | Indonesia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/2017	2017/2030	2030/2050	2017/2050
Total*1	56	99	156	244	374	464	539	100	100	100	3.4	3.3	1.8	2.4
Coal	0.2	3.5	12	48	85	116	135	3.6	20	25	10.2	4.4	2.4	3.2
Oil	20	33	58	76	105	128	147	34	31	27	3.1	2.6	1.7	2.0
Natural gas	5.0	16	27	39	67	89	109	16	16	20	3.4	4.3	2.5	3.2
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.5	0.9	1.6	2.0	2.5	3.0	0.5	0.7	0.6	4.5	1.9	2.0	1.9
Geothermal	-	1.9	8.4	22	58	76	96	2.0	9.0	18	9.4	7.8	2.6	4.6
Solar, wind, etc.	-	-	-	0.0	0.3	2.6	11	-	0.0	2.0	n.a.	42.4	19.6	28.1
Biomass and waste	30	44	50	58	57	49	39	44	24	7.1	1.0	-0.1	-1.9	-1.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	50	80	120	174	238	284	324	100	100	100	2.9	2.5	1.6	1.9
Industry	6.7	18	30	45	70	88	103	23	26	32	3.4	3.5	2.0	2.6
Transport	6.0	11	21	49	68	85	103	13	28	32	5.8	2.5	2.1	2.2
Buildings, etc.	36	44	59	73	88	95	98	55	42	30	1.9	1.4	0.5	0.9
Non-energy use	1.2	7.4	9.8	6.4	13	17	21	9.2	3.7	6.4	-0.5	5.3	2.5	3.6
Coal	0.1	2.3	4.7	11	17	21	25	2.8	6.4	7.9	6.1	3.2	2.1	2.5
Oil	17	27	48	72	98	118	136	34	42	42	3.7	2.3	1.7	1.9
Natural gas	2.4	6.0	12	15	32	43	52	7.5	8.5	16	3.4	6.0	2.5	3.9
Electricity	0.6	2.4	6.8	19	37	56	75	3.0	11	23	8.0	5.3	3.5	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	56	55	47	36	53	32	11	1.1	-0.2	-2.1	-1.3

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	7.5	33	93	255	495	740	984	100	100	100	7.9	5.2	3.5	4.2
Coal	-	9.8	34	148	286	420	507	30	58	52	10.6	5.2	2.9	3.8
Oil	6.2	15	18	19	31	39	38	47	7.6	3.8	0.9	3.7	1.0	2.0
Natural gas	-	0.7	26	55	113	173	218	2.2	22	22	17.4	5.7	3.3	4.2
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	1.3	5.7	10	19	24	29	35	17	7.3	3.5	4.5	1.9	2.0	1.9
Geothermal	-	1.1	4.9	13	34	44	56	3.4	5.0	5.7	9.4	7.8	2.6	4.6
Solar PV	-	-	-	0.0	2.1	27	119	-	0.0	12	n.a.	39.2	22.2	28.7
Wind	-	-	-	0.0	1.3	2.7	5.6	-	0.0	0.6	n.a.	51.5	7.4	23.0
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	0.0	0.8	3.4	4.6	5.8	-	0.3	0.6	n.a.	11.6	2.6	6.1
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	2017	2030	2040	2050	1990/2017	2017/2030	2030/2050	2017/2050
GDP ($2010 billion)	182	310	453	1 090	2 100	3 296	4 779	4.8	5.2	4.2	4.6
Population (million)	147	181	212	264	299	318	331	1.4	1.0	0.5	0.7
CO_2 emissions (Mt)	64	133	255	496	779	1 013	1 179	5.0	3.5	2.1	2.7
GDP per capita ($2010 thousand)	1.2	1.7	2.1	4.1	7.0	10	14	3.3	4.2	3.7	3.9
Primary energy consump. per capita (toe)	0.4	0.5	0.7	0.9	1.3	1.5	1.6	2.0	2.4	1.3	1.7
Primary energy consumption per GDP*2	307	318	343	224	178	141	113	-1.3	-1.7	-2.3	-2.1
CO_2 emissions per GDP*3	351	430	562	455	371	307	247	0.2	-1.6	-2.0	-1.8
CO_2 per primary energy consumption*4	1.1	1.3	1.6	2.0	2.1	2.2	2.2	1.5	0.2	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 A29 | Malaysia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	11	21	48	85	120	136	144	100	100	100	5.3	2.7	0.9	1.6
Coal	0.1	1.4	2.3	21	28	31	31	6.4	24	22	10.6	2.3	0.5	1.2
Oil	7.9	11	19	29	37	40	43	54	34	30	3.5	1.8	0.8	1.2
Natural gas	2.2	6.8	25	32	51	56	58	32	38	41	5.9	3.6	0.7	1.8
Nuclear	-	-	-	-	-	3.7	3.7	-	-	2.5	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.3	0.6	2.3	2.9	3.2	3.3	1.6	2.7	2.3	7.3	1.8	0.7	1.1
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	0.0	0.2	0.4	2.8	-	0.0	2.0	n.a.	15.5	14.6	15.0
Biomass and waste	1.2	1.2	1.3	0.6	1.6	2.0	2.3	5.9	0.7	1.6	-2.7	8.0	1.6	4.1

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	6.9	13	29	61	88	99	108	100	100	100	5.7	2.9	1.0	1.8
Industry	3.1	5.6	12	18	24	28	31	42	29	28	4.4	2.5	1.1	1.7
Transport	2.1	4.9	11	21	23	23	22	36	35	20	5.5	0.6	-0.2	0.1
Buildings, etc.	1.4	2.1	4.3	9.3	12	14	16	16	15	15	5.6	2.1	1.3	1.6
Non-energy use	0.3	0.8	2.2	13	29	35	40	6.3	21	37	10.5	6.6	1.7	3.6
Coal	0.1	0.5	1.0	1.8	2.0	2.1	2.1	3.8	3.0	2.0	4.8	0.8	0.3	0.5
Oil	5.3	9.3	18	29	37	40	43	70	48	40	4.3	1.8	0.8	1.2
Natural gas	0.0	1.1	3.9	17	31	34	36	8.2	28	33	10.7	4.7	0.8	2.3
Electricity	0.7	1.7	5.3	13	18	23	27	13	21	25	7.7	2.9	1.9	2.3
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	0.6	0.6	-2.6	3.0	1.1	1.8

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	10	23	69	165	239	294	348	100	100	100	7.6	2.9	1.9	2.3
Coal	-	2.9	7.7	72	106	126	139	13	44	40	12.6	3.0	1.3	2.0
Oil	8.5	11	3.6	1.5	1.6	1.3	0.8	46	0.9	0.2	-6.9	0.4	-3.2	-1.8
Natural gas	0.1	5.5	51	63	92	108	117	24	38	34	9.4	2.9	1.2	1.9
Nuclear	-	-	-	-	-	14	14	-	-	4.0	n.a.	n.a.	n.a.	n.a.
Hydro	1.4	4.0	7.0	27	33	37	38	17	16	11	7.3	1.8	0.7	1.1
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	0.3	2.2	4.3	33	-	0.2	9.5	n.a.	15.5	14.6	15.0
Wind	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	-	0.8	3.4	4.5	5.7	-	0.5	1.6	n.a.	11.3	2.6	6.0
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	46	82	163	365	645	919	1 238	5.7	4.5	3.3	3.8
Population (million)	14	18	23	32	37	39	41	2.1	1.2	0.6	0.8
CO_2 emissions (Mt)	26	51	111	203	254	271	271	5.2	1.8	0.3	0.9
GDP per capita ($2010 thousand)	3.3	4.5	7.0	12	18	23	30	3.5	3.3	2.7	2.9
Primary energy consump. per capita (toe)	0.8	1.2	2.1	2.7	3.3	3.4	3.5	3.1	1.5	0.3	0.8
Primary energy consumption per GDP*2	251	259	297	233	186	148	116	-0.4	-1.7	-2.3	-2.1
CO_2 emissions per GDP*3	568	625	680	556	395	295	219	-0.4	-2.6	-2.9	-2.8
CO_2 per primary energy consumption*4	2.3	2.4	2.3	2.4	2.1	2.0	1.9	0.0	-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 A30 | Myanmar [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	9.4	11	13	23	37	48	58	100	100	100	2.9	3.8	2.3	2.9
Coal	0.2	0.1	0.3	0.6	2.5	4.5	7.1	0.6	2.8	12	8.7	11.2	5.3	7.6
Oil	1.3	0.7	2.0	6.7	13	19	25	6.8	29	43	8.5	5.5	3.2	4.1
Natural gas	0.3	0.8	1.2	3.6	10	15	20	7.1	16	34	6.0	8.3	3.3	5.2
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.1	0.2	1.1	1.4	1.7	1.9	1.0	4.7	3.3	9.1	1.8	1.7	1.7
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	0.0	0.1	0.2	0.5	-	0.0	0.8	n.a.	41.2	9.7	21.2
Biomass and waste	7.6	9.0	9.2	11	11	9.6	7.4	84	48	13	0.7	0.1	-2.0	-1.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	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	3.4	6.7	10	13	4.2	17	31	8.4	5.3	3.5	4.2
Transport	0.6	0.4	1.2	2.0	4.5	7.0	10	4.7	10	23	5.8	6.2	4.1	5.0
Buildings, etc.	7.0	8.5	9.1	14	17	18	19	90	70	43	1.8	1.7	0.4	0.9
Non-energy use	0.1	0.1	0.1	0.5	0.7	0.9	1.1	1.0	2.3	2.6	6.0	3.2	2.4	2.7
Coal	0.1	0.1	0.3	0.2	0.3	0.4	0.4	0.5	1.1	0.9	5.6	2.5	1.3	1.8
Oil	1.2	0.6	1.5	6.7	13	19	25	6.2	34	58	9.4	5.4	3.2	4.1
Natural gas	0.1	0.2	0.3	0.5	0.8	1.0	1.2	2.4	2.7	2.8	3.3	2.6	2.4	2.5
Electricity	0.1	0.1	0.3	1.5	3.7	6.2	9.3	1.6	7.4	22	8.8	7.4	4.7	5.8
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-2.0	n.a.
Renewables	6.9	8.4	9.0	11	11	9.6	7.3	89	55	17	1.0	0.1	-2.0	-1.2

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	1.5	2.5	5.1	22	73	115	165	100	100	100	8.5	9.5	4.2	6.2
Coal	0.0	0.0	-	1.4	11	21	35	1.6	6.3	21	14.1	16.7	6.2	10.2
Oil	0.5	0.3	0.7	0.1	0.3	0.3	0.2	11	0.3	0.1	-4.9	11.3	-0.7	3.8
Natural gas	0.2	1.0	2.5	8.3	45	72	102	39	37	62	8.3	13.9	4.2	7.9
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.8	1.2	1.9	13	16	19	22	48	56	13	9.1	1.8	1.7	1.7
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	0.0	0.6	1.8	4.7	-	0.0	2.8	n.a.	36.8	11.3	20.7
Wind	-	-	-	0.0	0.3	0.4	0.7	-	0.0	0.4	n.a.	108	4.4	37.0
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	5.9	6.7	13	67	142	237	366	8.9	6.0	4.9	5.3
Population (million)	33	41	46	53	58	61	62	1.0	0.7	0.3	0.5
CO_2 emissions (Mt)	5.2	4.0	9.5	30	73	109	147	7.8	7.0	3.6	4.9
GDP per capita ($2010 thousand)	0.2	0.2	0.3	1.2	2.4	3.9	5.9	7.8	5.2	4.5	4.8
Primary energy consump. per capita (toe)	0.3	0.3	0.3	0.4	0.6	0.8	0.9	1.8	3.0	2.0	2.4
Primary energy consumption per GDP[*2]	1 597	1 594	960	343	260	202	159	-5.5	-2.1	-2.4	-2.3
CO_2 emissions per GDP[*3]	879	602	711	455	514	461	402	-1.0	0.9	-1.2	-0.4
CO_2 per primary energy consumption[*4]	0.6	0.4	0.7	1.3	2.0	2.3	2.5	4.8	3.1	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 A31 | Philippines [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	22	29	40	58	95	119	146	100	100	100	2.6	3.8	2.2	2.8
Coal	0.5	1.5	5.2	17	24	29	33	5.3	29	23	9.3	2.8	1.6	2.0
Oil	10	11	16	20	36	50	67	38	34	46	2.2	4.7	3.2	3.8
Natural gas	-	-	0.0	3.2	6.1	8.7	11	-	5.6	7.8	n.a.	5.0	3.1	3.9
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.3	0.5	0.7	0.8	1.0	1.2	1.3	1.8	1.4	0.9	1.7	1.8	1.0	1.3
Geothermal	1.8	4.7	10	8.8	17	19	21	16	15	15	2.4	5.2	1.1	2.7
Solar, wind, etc.	-	-	-	0.2	0.8	1.6	2.7	-	0.3	1.9	n.a.	11.1	6.5	8.3
Biomass and waste	9.4	11	8.1	8.5	9.7	9.5	9.1	39	15	6.3	-1.0	0.9	-0.3	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	16	20	24	33	57	76	98	100	100	100	2.0	4.1	2.8	3.3
Industry	3.4	4.7	5.3	8.0	12	14	17	24	24	17	2.0	3.2	1.7	2.3
Transport	3.3	4.5	8.1	12	25	36	50	23	35	51	3.6	5.8	3.6	4.5
Buildings, etc.	9.4	10	10	12	18	21	24	52	37	25	0.7	2.8	1.7	2.1
Non-energy use	0.3	0.2	0.3	1.3	2.5	3.9	6.3	1.2	4.0	6.4	6.7	4.9	4.8	4.8
Coal	0.2	0.6	0.8	3.1	4.3	4.8	5.3	3.1	9.3	5.5	6.2	2.5	1.1	1.7
Oil	6.8	8.1	13	18	33	48	65	41	53	66	2.9	5.0	3.4	4.0
Natural gas	-	-	-	0.1	0.1	0.2	0.2	-	0.2	0.2	n.a.	6.0	2.7	4.0
Electricity	1.5	1.8	3.1	6.7	12	16	21	9.3	20	22	4.9	4.5	2.9	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	6.9	6.7	6.2	46	18	6.4	-1.6	1.3	-0.5	0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	18	26	45	94	165	224	286	100	100	100	4.8	4.4	2.8	3.4
Coal	0.2	1.9	17	47	79	106	131	7.3	50	46	12.5	4.1	2.6	3.2
Oil	12	12	9.2	3.8	4.4	3.7	1.8	47	4.0	0.6	-4.3	1.1	-4.4	-2.3
Natural gas	-	-	0.0	21	40	59	80	-	22	28	n.a.	5.2	3.6	4.2
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	3.5	6.1	7.8	9.6	12	13	15	23	10	5.2	1.7	1.8	1.0	1.3
Geothermal	2.1	5.5	12	10	20	23	25	21	11	8.7	2.4	5.3	1.1	2.7
Solar PV	-	-	-	1.2	4.9	12	20	-	1.3	7.1	n.a.	11.4	7.4	9.0
Wind	-	-	-	1.1	4.2	6.8	12	-	1.2	4.0	n.a.	10.9	5.2	7.4
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	0.4	-	1.0	1.3	1.8	2.2	1.6	1.1	0.8	3.2	2.1	2.6	2.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

								1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	2017	2030	2050	2050
GDP ($2010 billion)	80	95	125	303	623	922	1 311	4.4	5.7	3.8	4.5
Population (million)	47	62	78	105	123	135	144	2.0	1.3	0.8	1.0
CO_2 emissions (Mt)	31	36	67	126	206	269	334	4.7	3.8	2.5	3.0
GDP per capita ($2010 thousand)	1.7	1.5	1.6	2.9	5.1	6.8	9.1	2.4	4.4	3.0	3.5
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	192	152	129	111	-1.7	-1.8	-1.5	-1.6
CO_2 emissions per GDP*3	392	382	532	417	330	291	255	0.3	-1.8	-1.3	-1.5
CO_2 per primary energy consumption*4	1.4	1.3	1.7	2.2	2.2	2.3	2.3	2.0	0.0	0.3	0.2

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

Table A32 | Thailand [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	22	42	72	138	173	197	218	100	100	100	4.5	1.7	1.2	1.4
Coal	0.5	3.8	7.7	16	21	22	22	9.1	12	10	5.5	1.8	0.3	0.9
Oil	11	18	32	56	63	72	80	43	41	36	4.3	0.9	1.1	1.1
Natural gas	-	5.0	17	36	43	47	47	12	26	21	7.6	1.5	0.4	0.8
Nuclear	-	-	-	-	-	1.8	6.2	-	-	2.8	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.4	0.5	0.8	0.7	0.8	0.8	1.0	0.6	0.4	2.4	-0.7	0.5	0.0
Geothermal	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	1.1	5.3
Solar, wind, etc.	-	-	-	0.5	2.0	3.7	6.5	-	0.4	3.0	n.a.	11.2	6.2	8.1
Biomass and waste	11	15	15	26	39	45	50	35	19	23	2.2	3.0	1.3	2.0

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	15	29	51	99	121	140	156	100	100	100	4.7	1.6	1.3	1.4
Industry	4.0	8.7	17	31	42	49	54	30	32	34	4.9	2.4	1.2	1.7
Transport	3.2	9.0	15	27	31	33	36	31	28	23	4.2	0.9	0.8	0.8
Buildings, etc.	7.8	11	14	18	22	24	25	37	18	16	1.8	1.7	0.7	1.1
Non-energy use	0.2	0.4	5.6	23	26	34	42	1.5	23	27	15.9	1.1	2.3	1.8
Coal	0.1	1.3	3.5	7.5	8.3	8.1	7.4	4.5	7.6	4.8	6.7	0.8	-0.5	0.0
Oil	7.3	15	29	54	61	69	76	52	54	49	4.9	1.0	1.1	1.1
Natural gas	-	0.1	1.1	7.0	9.5	13	16	0.5	7.1	10	15.7	2.3	2.7	2.5
Electricity	1.1	3.3	7.6	16	25	31	36	11	16	23	6.0	3.4	2.0	2.5
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	6.7	9.2	9.4	15	18	19	20	32	15	13	1.7	1.6	0.6	1.0

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	14	44	96	187	271	335	392	100	100	100	5.5	2.9	1.9	2.3
Coal	1.4	11	18	36	54	66	71	25	19	18	4.4	3.2	1.4	2.1
Oil	12	10	10	0.3	-	-	-	23	0.2	-	-12.2	-100	n.a.	-100
Natural gas	-	18	62	120	150	162	153	40	64	39	7.3	1.7	0.1	0.7
Nuclear	-	-	-	-	-	7.0	24	-	-	6.1	n.a.	n.a.	n.a.	n.a.
Hydro	1.3	5.0	6.0	9.5	8.6	9.3	9.5	11	5.1	2.4	2.4	-0.7	0.5	0.0
Geothermal	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	1.1	5.3
Solar PV	-	-	-	4.5	18	35	66	-	2.4	17	n.a.	11.0	6.8	8.4
Wind	-	-	-	1.1	4.9	7.4	8.8	-	0.6	2.2	n.a.	12.1	3.0	6.5
CSP and marine	-	-	-	-	0.1	0.2	0.3	-	-	0.1	n.a.	n.a.	8.3	n.a.
Biomass and waste	-	-	0.5	15	36	48	60	-	8.3	15	n.a.	6.7	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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	67	142	218	423	672	929	1 221	4.1	3.6	3.0	3.3
Population (million)	47	57	63	69	70	69	66	0.7	0.1	-0.3	-0.1
CO_2 emissions (Mt)	31	77	147	244	291	311	309	4.4	1.3	0.3	0.7
GDP per capita ($2010 thousand)	1.4	2.5	3.5	6.1	9.6	13	19	3.4	3.5	3.4	3.4
Primary energy consump. per capita (toe)	0.5	0.7	1.1	2.0	2.5	2.9	3.3	3.7	1.6	1.5	1.5
Primary energy consumption per GDP[*2]	331	296	332	327	258	212	179	0.4	-1.8	-1.8	-1.8
CO_2 emissions per GDP[*3]	466	546	674	577	433	335	253	0.2	-2.2	-2.7	-2.5
CO_2 per primary energy consumption[*4]	1.4	1.8	2.0	1.8	1.7	1.6	1.4	-0.2	-0.4	-0.9	-0.7

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

Table A33 | Viet Nam [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	14	18	29	78	181	237	294	100	100	100	5.6	6.7	2.5	4.1
Coal	2.3	2.2	4.4	28	72	91	105	12	36	36	9.9	7.5	1.9	4.1
Oil	1.8	2.7	7.8	20	42	60	84	15	25	28	7.6	6.0	3.5	4.5
Natural gas	-	0.0	1.1	7.8	40	54	69	0.0	10.0	23	34.3	13.4	2.7	6.8
Nuclear	-	-	-	-	-	4.2	8.6	-	-	2.9	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.5	1.3	7.7	9.2	10	11	2.6	9.8	3.7	11.0	1.4	0.8	1.0
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	0.0	0.8	2.2	4.0	-	0.0	1.4	n.a.	29.4	8.4	16.2
Biomass and waste	10	12	14	15	16	14	12	70	19	4.1	0.6	0.8	-1.5	-0.6

Final energy consumption

	Mtoe							Shares (%)			1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050				
Total	13	16	25	64	140	182	227	100	100	100	5.3	6.2	2.5	3.9
Industry	3.8	4.5	7.9	35	91	117	141	28	55	62	7.9	7.6	2.2	4.3
Transport	0.6	1.4	3.5	13	21	30	42	8.6	20	18	8.6	4.1	3.4	3.7
Buildings, etc.	8.6	10	14	15	26	34	42	63	24	19	1.6	4.2	2.4	3.1
Non-energy use	0.0	0.0	0.1	0.6	1.0	1.4	1.8	0.2	1.0	0.8	12.2	4.1	2.8	3.3
Coal	1.5	1.3	3.2	15	28	36	40	8.3	23	17	9.3	5.1	1.7	3.0
Oil	1.7	2.3	6.5	20	42	60	84	15	31	37	8.2	5.9	3.5	4.5
Natural gas	-	-	0.0	1.0	15	19	23	-	1.6	10	n.a.	22.7	2.2	9.8
Electricity	0.2	0.5	1.9	15	40	54	70	3.3	23	31	13.1	7.9	2.8	4.8
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	9.7	12	13	14	15	13	11	74	21	4.8	0.5	0.8	-1.6	-0.7

Electricity generation

	(TWh)							Shares (%)			1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050				
Total	3.6	8.7	27	199	514	695	894	100	100	100	12.3	7.6	2.8	4.7
Coal	1.4	2.0	3.1	68	234	301	372	23	34	42	13.9	10.0	2.4	5.3
Oil	0.7	1.3	4.5	0.7	1.8	1.6	1.0	15	0.4	0.1	-2.3	7.4	-3.0	1.0
Natural gas	-	0.0	4.4	41	162	231	315	0.1	21	35	38.7	11.2	3.4	6.4
Nuclear	-	-	-	-	-	16	33	-	-	3.7	n.a.	n.a.	n.a.	n.a.
Hydro	1.5	5.4	15	89	107	119	125	62	45	14	11.0	1.4	0.8	1.0
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	-	3.4	16	33	-	-	3.7	n.a.	n.a.	11.9	n.a.
Wind	-	-	-	0.3	5.8	9.6	14	-	0.2	1.5	n.a.	24.9	4.4	12.1
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	-	0.1	0.2	0.2	0.3	-	0.0	0.0	n.a.	6.4	2.6	4.1
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	17	29	61	175	383	637	1 005	6.8	6.2	4.9	5.4
Population (million)	54	68	80	96	105	109	111	1.3	0.7	0.3	0.4
CO_2 emissions (Mt)	15	17	43	189	508	668	828	9.4	7.9	2.5	4.6
GDP per capita ($2010 thousand)	0.3	0.4	0.8	1.8	3.6	5.9	9.1	5.5	5.4	4.7	5.0
Primary energy consump. per capita (toe)	0.3	0.3	0.4	0.8	1.7	2.2	2.7	4.3	5.9	2.2	3.6
Primary energy consumption per GDP*2	851	607	470	446	472	371	292	-1.1	0.4	-2.4	-1.3
CO_2 emissions per GDP*3	859	572	699	1 080	1 325	1 049	823	2.4	1.6	-2.4	-0.8
CO_2 per primary energy consumption*4	1.0	0.9	1.5	2.4	2.8	2.8	2.8	3.6	1.1	0.0	0.5

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

Table A34 | North America [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	1 997	2 126	2 527	2 444	2 473	2 430	2 347	100	100	100	0.5	0.1	-0.3	-0.1
Coal	397	484	566	348	297	245	183	23	14	7.8	-1.2	-1.2	-2.4	-1.9
Oil	885	833	958	890	824	757	697	39	36	30	0.2	-0.6	-0.8	-0.7
Natural gas	522	493	622	745	879	910	887	23	30	38	1.5	1.3	0.0	0.5
Nuclear	80	179	227	245	197	190	186	8.4	10	7.9	1.2	-1.7	-0.3	-0.8
Hydro	46	49	53	60	61	62	63	2.3	2.4	2.7	0.7	0.1	0.2	0.2
Geothermal	4.6	14	13	9.2	18	31	37	0.7	0.4	1.6	-1.6	5.1	3.8	4.3
Solar, wind, etc.	-	0.3	2.1	33	65	100	156	0.0	1.4	6.6	18.7	5.3	4.4	4.8
Biomass and waste	62	73	87	115	132	136	139	3.4	4.7	5.9	1.7	1.1	0.3	0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	1 466	1 455	1 738	1 716	1 739	1 699	1 646	100	100	100	0.6	0.1	-0.3	-0.1
Industry	437	331	388	307	327	327	319	23	18	19	-0.3	0.5	-0.1	0.1
Transport	470	531	640	687	638	595	561	36	40	34	1.0	-0.6	-0.6	-0.6
Buildings, etc.	446	460	537	556	579	575	561	32	32	34	0.7	0.3	-0.2	0.0
Non-energy use	114	134	173	166	195	202	206	9.2	9.7	13	0.8	1.2	0.3	0.7
Coal	60	59	36	20	17	15	12	4.0	1.1	0.8	-4.0	-1.1	-1.6	-1.4
Oil	769	752	874	837	781	720	667	52	49	40	0.4	-0.5	-0.8	-0.7
Natural gas	374	346	413	394	419	408	387	24	23	24	0.5	0.5	-0.4	-0.1
Electricity	200	262	342	365	421	459	487	18	21	30	1.2	1.1	0.7	0.9
Heat	1.0	2.8	6.1	6.4	6.0	5.5	4.9	0.2	0.4	0.3	3.1	-0.5	-1.1	-0.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	62	33	66	94	95	92	88	2.3	5.5	5.4	4.0	0.1	-0.4	-0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	2 801	3 685	4 631	4 922	5 645	6 107	6 418	100	100	100	1.1	1.1	0.6	0.8
Coal	1 303	1 782	2 247	1 381	1 329	1 114	830	48	28	13	-0.9	-0.3	-2.3	-1.5
Oil	277	147	133	40	34	25	14	4.0	0.8	0.2	-4.7	-1.1	-4.5	-3.2
Natural gas	380	391	668	1 395	1 986	2 320	2 387	11	28	37	4.8	2.8	0.9	1.6
Nuclear	304	685	871	940	756	729	714	19	19	11	1.2	-1.7	-0.3	-0.8
Hydro	530	570	612	695	708	725	735	15	14	11	0.7	0.1	0.2	0.2
Geothermal	5.4	16	15	19	36	64	77	0.4	0.4	1.2	0.6	5.2	3.8	4.4
Solar PV	-	0.0	0.2	71	160	364	759	0.0	1.4	12	45.2	6.5	8.1	7.4
Wind	-	3.1	5.9	286	416	463	494	0.1	5.8	7.7	18.3	2.9	0.9	1.7
CSP and marine	-	0.7	0.6	3.6	52	100	174	0.0	0.1	2.7	6.3	22.7	6.3	12.5
Biomass and waste	1.8	90	80	86	162	196	228	2.5	1.7	3.6	-0.2	5.0	1.7	3.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	5.7	5.7	5.7	5.7	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	7 310	10 078	14 056	19 232	25 073	31 059	37 311	2.4	2.1	2.0	2.0
Population (million)	252	277	313	362	391	410	425	1.0	0.6	0.4	0.5
CO_2 emissions (Mt)	4 997	5 174	6 161	5 328	5 163	4 815	4 325	0.1	-0.2	-0.9	-0.6
GDP per capita ($2010 thousand)	29	36	45	53	64	76	88	1.4	1.5	1.6	1.5
Primary energy consump. per capita (toe)	7.9	7.7	8.1	6.8	6.3	5.9	5.5	-0.5	-0.5	-0.7	-0.6
Primary energy consumption per GDP[*2]	273	211	180	127	99	78	63	-1.9	-1.9	-2.2	-2.1
CO_2 emissions per GDP[*3]	684	513	438	277	206	155	116	-2.3	-2.3	-2.8	-2.6
CO_2 per primary energy consumption[*4]	2.5	2.4	2.4	2.2	2.1	2.0	1.8	-0.4	-0.3	-0.6	-0.5

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

Table A35 | United States [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	1 805	1 915	2 274	2 155	2 178	2 136	2 062	100	100	100	0.4	0.1	-0.3	-0.1
Coal	376	460	534	331	287	242	180	24	15	8.7	-1.2	-1.1	-2.3	-1.8
Oil	797	757	871	790	729	672	621	40	37	30	0.2	-0.6	-0.8	-0.7
Natural gas	477	438	548	644	758	769	740	23	30	36	1.4	1.3	-0.1	0.4
Nuclear	69	159	208	219	176	176	179	8.3	10	8.7	1.2	-1.6	0.1	-0.6
Hydro	24	23	22	26	26	27	27	1.2	1.2	1.3	0.4	0.0	0.2	0.1
Geothermal	4.6	14	13	9.2	18	31	37	0.7	0.4	1.8	-1.6	5.1	3.8	4.3
Solar, wind, etc.	-	0.3	2.1	30	60	92	146	0.0	1.4	7.1	18.4	5.3	4.6	4.9
Biomass and waste	54	62	73	101	119	123	127	3.3	4.7	6.2	1.8	1.2	0.3	0.7

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	1 311	1 294	1 546	1 520	1 540	1 506	1 462	100	100	100	0.6	0.1	-0.3	-0.1
Industry	387	284	332	261	281	281	274	22	17	19	-0.3	0.6	-0.1	0.1
Transport	425	488	588	625	578	541	511	38	41	35	0.9	-0.6	-0.6	-0.6
Buildings, etc.	397	403	473	488	508	507	495	31	32	34	0.7	0.3	-0.1	0.0
Non-energy use	102	119	153	145	172	178	182	9.2	9.6	12	0.7	1.3	0.3	0.7
Coal	56	56	33	17	15	13	11	4.3	1.1	0.7	-4.3	-1.0	-1.6	-1.4
Oil	689	683	793	748	694	640	594	53	49	41	0.3	-0.6	-0.8	-0.7
Natural gas	338	303	360	346	369	360	342	23	23	23	0.5	0.5	-0.4	0.0
Electricity	174	226	301	321	371	405	429	18	21	29	1.3	1.1	0.7	0.9
Heat	-	2.2	5.3	5.9	5.5	5.0	4.4	0.2	0.4	0.3	3.8	-0.5	-1.1	-0.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Renewables	54	23	54	82	85	83	81	1.8	5.4	5.6	4.8	0.3	-0.3	0.0

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	2 427	3 203	4 026	4 264	4 907	5 321	5 598	100	100	100	1.1	1.1	0.7	0.8
Coal	1 243	1 700	2 129	1 321	1 292	1 110	829	53	31	15	-0.9	-0.2	-2.2	-1.4
Oil	263	131	118	32	27	18	8.5	4.1	0.8	0.2	-5.0	-1.5	-5.6	-4.0
Natural gas	370	382	634	1 338	1 859	2 120	2 158	12	31	39	4.8	2.6	0.7	1.5
Nuclear	266	612	798	839	677	676	685	19	20	12	1.2	-1.6	0.1	-0.6
Hydro	279	273	253	302	302	310	314	8.5	7.1	5.6	0.4	0.0	0.2	0.1
Geothermal	5.4	16	15	19	36	64	77	0.5	0.4	1.4	0.6	5.2	3.8	4.4
Solar PV	-	0.0	0.2	67	153	354	744	0.0	1.6	13	44.9	6.5	8.2	7.6
Wind	-	3.1	5.7	257	360	389	399	0.1	6.0	7.1	17.8	2.6	0.5	1.3
CSP and marine	-	0.7	0.5	3.6	52	100	174	0.0	0.1	3.1	6.5	22.8	6.3	12.5
Biomass and waste	0.5	86	72	79	144	175	203	2.7	1.8	3.6	-0.4	4.8	1.7	2.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	5.4	5.4	5.4	5.4	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	6 529	9 064	12 713	17 349	22 684	28 174	33 922	2.4	2.1	2.0	2.1
Population (million)	227	250	282	325	350	367	379	1.0	0.6	0.4	0.5
CO_2 emissions (Mt)	4 582	4 763	5 656	4 781	4 622	4 283	3 813	0.0	-0.3	-1.0	-0.7
GDP per capita ($2010 thousand)	29	36	45	53	65	77	89	1.4	1.5	1.6	1.6
Primary energy consump. per capita (toe)	7.9	7.7	8.1	6.6	6.2	5.8	5.4	-0.5	-0.5	-0.7	-0.6
Primary energy consumption per GDP*2	276	211	179	124	96	76	61	-1.9	-2.0	-2.3	-2.1
CO_2 emissions per GDP*3	702	525	445	276	204	152	112	-2.4	-2.3	-2.9	-2.7
CO_2 per primary energy consumption*4	2.5	2.5	2.5	2.2	2.1	2.0	1.8	-0.4	-0.3	-0.7	-0.5

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

Table A36 | Latin America [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	382	464	600	830	1 043	1 214	1 311	100	100	100	2.2	1.8	1.2	1.4
Coal	13	21	27	45	51	60	63	4.6	5.4	4.8	2.8	0.9	1.1	1.0
Oil	223	238	303	350	412	445	447	51	42	34	1.4	1.3	0.4	0.7
Natural gas	48	72	119	205	278	375	451	16	25	34	3.9	2.4	2.5	2.4
Nuclear	0.6	3.2	5.3	8.6	18	19	16	0.7	1.0	1.2	3.7	5.9	-0.6	1.9
Hydro	19	33	50	64	73	78	83	7.2	7.7	6.3	2.4	1.1	0.7	0.8
Geothermal	1.2	5.1	6.4	6.4	21	30	37	1.1	0.8	2.8	0.8	9.7	2.7	5.4
Solar, wind, etc.	-	0.0	0.2	7.6	22	31	41	0.0	0.9	3.2	25.2	8.4	3.3	5.3
Biomass and waste	78	92	88	143	169	176	173	20	17	13	1.7	1.3	0.1	0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	288	343	446	612	761	869	936	100	100	100	2.2	1.7	1.0	1.3
Industry	98	114	148	190	242	288	311	33	31	33	1.9	1.9	1.3	1.5
Transport	85	103	141	223	281	308	321	30	36	34	2.9	1.8	0.7	1.1
Buildings, etc.	88	100	119	162	194	221	245	29	26	26	1.8	1.4	1.2	1.3
Non-energy use	16	26	38	38	44	52	58	7.5	6.2	6.2	1.4	1.3	1.4	1.3
Coal	6.1	7.8	11	15	18	20	21	2.3	2.5	2.2	2.5	1.1	0.7	0.9
Oil	159	179	240	303	366	402	418	52	50	45	2.0	1.5	0.7	1.0
Natural gas	27	38	54	74	96	117	131	11	12	14	2.6	2.0	1.5	1.7
Electricity	27	44	69	113	159	207	249	13	18	27	3.5	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	68	74	73	106	122	123	117	22	17	12	1.4	1.0	-0.2	0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	380	623	1 009	1 615	2 249	2 872	3 392	100	100	100	3.6	2.6	2.1	2.3
Coal	7.8	23	43	98	117	157	175	3.8	6.1	5.1	5.5	1.3	2.0	1.8
Oil	111	128	198	146	135	112	43	21	9.0	1.3	0.5	-0.6	-5.5	-3.6
Natural gas	35	60	141	440	704	1 096	1 472	9.6	27	43	7.7	3.7	3.8	3.7
Nuclear	2.3	12	20	33	69	73	61	2.0	2.0	1.8	3.7	5.9	-0.6	1.9
Hydro	218	386	584	740	849	911	967	62	46	28	2.4	1.1	0.7	0.8
Geothermal	1.4	5.9	7.8	9.8	34	48	60	1.0	0.6	1.8	1.9	9.9	2.9	5.6
Solar PV	-	0.0	0.0	8.2	47	81	124	0.0	0.5	3.7	39.6	14.4	5.0	8.6
Wind	-	0.0	0.3	66	182	253	331	0.0	4.1	9.7	50.9	8.1	3.0	5.0
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	3.9	7.6	14	74	113	140	159	1.2	4.6	4.7	8.8	3.3	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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	2 441	2 835	3 819	5 798	8 300	11 426	14 589	2.7	2.8	2.9	2.8
Population (million)	360	441	521	640	712	748	769	1.4	0.8	0.4	0.6
CO_2 emissions (Mt)	765	873	1 194	1 596	1 952	2 290	2 473	2.3	1.6	1.2	1.3
GDP per capita ($2010 thousand)	6.8	6.4	7.3	9.1	12	15	19	1.3	2.0	2.5	2.3
Primary energy consump. per capita (toe)	1.1	1.1	1.2	1.3	1.5	1.6	1.7	0.8	1.0	0.8	0.8
Primary energy consumption per GDP*2	157	164	157	143	126	106	90	-0.5	-1.0	-1.7	-1.4
CO_2 emissions per GDP*3	313	308	313	275	235	200	169	-0.4	-1.2	-1.6	-1.5
CO_2 per primary energy consumption*4	2.0	1.9	2.0	1.9	1.9	1.9	1.9	0.1	-0.2	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 A37 | Advanced Europe [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	1 494	1 643	1 759	1 761	1 669	1 578	1 487	100	100	100	0.3	-0.4	-0.6	-0.5
Coal	464	448	331	263	212	184	160	27	15	11	-2.0	-1.7	-1.4	-1.5
Oil	688	617	655	577	504	449	401	38	33	27	-0.3	-1.0	-1.1	-1.1
Natural gas	206	267	396	435	444	446	424	16	25	29	1.8	0.2	-0.2	-0.1
Nuclear	60	210	247	215	187	162	151	13	12	10	0.1	-1.1	-1.1	-1.1
Hydro	36	39	47	45	50	51	53	2.4	2.6	3.5	0.6	0.8	0.3	0.5
Geothermal	3.0	4.9	7.1	17	27	30	32	0.3	1.0	2.1	4.8	3.5	0.8	1.9
Solar, wind, etc.	0.1	0.4	2.7	48	75	87	98	0.0	2.7	6.6	19.9	3.5	1.4	2.2
Biomass and waste	36	56	72	160	169	168	166	3.4	9.1	11	4.0	0.4	-0.1	0.1

Final energy consumption

	Mtoe 1980	1990	2000	2017	2030	2040	2050	Shares (%) 1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total	1 081	1 142	1 235	1 258	1 208	1 140	1 071	100	100	100	0.4	-0.3	-0.6	-0.5
Industry	356	330	325	297	295	286	271	29	24	25	-0.4	0.0	-0.4	-0.3
Transport	209	269	318	353	311	278	251	24	28	23	1.0	-1.0	-1.1	-1.0
Buildings, etc.	425	442	477	501	491	466	441	39	40	41	0.5	-0.1	-0.5	-0.4
Non-energy use	90	101	115	108	110	110	109	8.9	8.6	10	0.2	0.2	-0.1	0.0
Coal	156	124	62	48	39	33	29	11	3.8	2.7	-3.5	-1.7	-1.4	-1.5
Oil	551	527	573	520	454	400	356	46	41	33	-0.1	-1.0	-1.2	-1.1
Natural gas	161	205	269	274	273	260	243	18	22	23	1.1	0.0	-0.6	-0.4
Electricity	147	193	234	270	296	309	315	17	21	29	1.2	0.7	0.3	0.5
Heat	35	45	42	49	45	40	35	3.9	3.9	3.3	0.3	-0.7	-1.2	-1.0
Hydrogen	-	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	31	48	55	97	102	97	93	4.2	7.7	8.6	2.7	0.3	-0.5	-0.1

Electricity generation

	(TWh) 1980	1990	2000	2017	2030	2040	2050	Shares (%) 1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total	2 049	2 697	3 238	3 666	4 001	4 140	4 189	100	100	100	1.1	0.7	0.2	0.4
Coal	887	1 030	968	768	676	590	499	38	21	12	-1.1	-1.0	-1.5	-1.3
Oil	364	210	180	56	41	39	28	7.8	1.5	0.7	-4.8	-2.3	-1.9	-2.0
Natural gas	138	176	514	760	919	1 078	1 135	6.5	21	27	5.6	1.5	1.1	1.2
Nuclear	230	804	948	823	716	622	580	30	22	14	0.1	-1.1	-1.1	-1.1
Hydro	416	451	549	526	581	597	612	17	14	15	0.6	0.8	0.3	0.5
Geothermal	2.7	3.6	6.2	18	30	34	36	0.1	0.5	0.9	6.1	4.1	0.9	2.2
Solar PV	-	0.0	0.1	114	194	231	259	0.0	3.1	6.2	38.8	4.1	1.5	2.5
Wind	0.0	0.8	22	373	529	588	640	0.0	10	15	25.7	2.7	1.0	1.6
CSP and marine	0.5	0.5	0.5	6.4	34	47	65	0.0	0.2	1.5	9.9	13.6	3.3	7.3
Biomass and waste	11	21	48	215	275	308	329	0.8	5.9	7.8	9.1	1.9	0.9	1.3
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	0.3	1.5	6.0	6.0	6.0	6.0	0.0	0.2	0.1	11.1	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	9 925	12 721	15 953	20 808	25 402	28 941	32 256	1.8	1.5	1.2	1.3
Population (million)	475	505	527	575	588	590	585	0.5	0.2	0.0	0.1
CO_2 emissions (Mt)	4 101	3 929	3 911	3 523	3 120	2 853	2 573	-0.4	-0.9	-1.0	-0.9
GDP per capita ($2010 thousand)	21	25	30	36	43	49	55	1.4	1.4	1.2	1.3
Primary energy consump. per capita (toe)	3.1	3.3	3.3	3.1	2.8	2.7	2.5	-0.2	-0.6	-0.6	-0.6
Primary energy consumption per GDP[*2]	151	129	110	85	66	55	46	-1.6	-1.9	-1.8	-1.8
CO_2 emissions per GDP[*3]	413	309	245	169	123	99	80	-2.2	-2.4	-2.1	-2.3
CO_2 per primary energy consumption[*4]	2.7	2.4	2.2	2.0	1.9	1.8	1.7	-0.7	-0.5	-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 A38 | Other Europe / Eurasia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	1 241	1 513	993	1 122	1 178	1 227	1 268	100	100	100	-1.1	0.4	0.4	0.4
Coal	362	365	209	209	199	209	211	24	19	17	-2.0	-0.4	0.3	0.0
Oil	464	458	199	237	230	228	228	30	21	18	-2.4	-0.2	-0.1	-0.1
Natural gas	355	596	486	542	571	603	618	39	48	49	-0.3	0.4	0.4	0.4
Nuclear	21	55	61	83	109	103	112	3.6	7.4	8.9	1.6	2.1	0.1	0.9
Hydro	20	22	23	26	29	30	31	1.5	2.3	2.4	0.6	0.8	0.4	0.5
Geothermal	-	0.0	0.1	0.2	0.5	0.6	0.6	0.0	0.0	0.0	8.5	7.0	0.7	3.1
Solar, wind, etc.	-	-	0.0	1.6	4.1	6.5	9.5	-	0.1	0.8	n.a.	7.4	4.2	5.5
Biomass and waste	21	17	15	23	37	47	59	1.1	2.1	4.7	1.2	3.7	2.3	2.9

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	869	1 056	646	726	757	774	787	100	100	100	-1.4	0.3	0.2	0.2
Industry	395	390	204	215	236	251	258	37	30	33	-2.2	0.7	0.5	0.5
Transport	107	170	109	146	140	135	131	16	20	17	-0.6	-0.3	-0.3	-0.3
Buildings, etc.	301	431	285	284	292	289	290	41	39	37	-1.5	0.2	0.0	0.1
Non-energy use	67	65	48	81	90	99	108	6.2	11	14	0.8	0.8	1.0	0.9
Coal	152	113	36	50	52	51	49	11	7.0	6.2	-2.9	0.2	-0.3	-0.1
Oil	310	274	143	190	192	191	190	26	26	24	-1.3	0.1	0.0	0.0
Natural gas	215	258	199	229	235	238	240	24	32	30	-0.4	0.2	0.1	0.1
Electricity	95	125	86	107	129	151	170	12	15	22	-0.6	1.4	1.4	1.4
Heat	78	274	170	132	131	128	123	26	18	16	-2.7	0.0	-0.3	-0.2
Hydrogen	-	-	-	-	0.0	0.0	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	21	13	11	16	18	16	14	1.2	2.2	1.8	0.9	0.6	-1.1	-0.4

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	1 461	1 857	1 415	1 750	2 038	2 280	2 470	100	100	100	-0.2	1.2	1.0	1.0
Coal	471	429	338	388	436	513	546	23	22	22	-0.4	0.9	1.1	1.0
Oil	357	252	69	17	14	13	9.8	14	1.0	0.4	-9.4	-1.4	-1.9	-1.7
Natural gas	295	707	504	702	754	872	918	38	40	37	0.0	0.6	1.0	0.8
Nuclear	79	209	234	318	419	397	431	11	18	17	1.6	2.1	0.1	0.9
Hydro	232	260	267	301	334	350	360	14	17	15	0.6	0.8	0.4	0.5
Geothermal	-	0.0	0.1	0.4	1.7	2.0	2.2	0.0	0.0	0.1	10.7	11.2	1.1	5.0
Solar PV	-	-	-	5.2	16	27	41	-	0.3	1.7	n.a.	8.7	5.0	6.4
Wind	-	-	0.0	12	31	47	67	-	0.7	2.7	n.a.	7.4	4.0	5.3
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	4.9	33	59	93	0.0	0.3	3.8	18.7	15.7	5.4	9.3
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	1 765	2 145	1 472	2 759	3 792	4 804	6 014	0.9	2.5	2.3	2.4
Population (million)	321	337	335	341	345	343	341	0.0	0.1	-0.1	0.0
CO_2 emissions (Mt)	3 319	3 678	2 225	2 349	2 318	2 396	2 408	-1.6	-0.1	0.2	0.1
GDP per capita ($2010 thousand)	5.5	6.4	4.4	8.1	11	14	18	0.9	2.4	2.4	2.4
Primary energy consump. per capita (toe)	3.9	4.5	3.0	3.3	3.4	3.6	3.7	-1.1	0.3	0.4	0.4
Primary energy consumption per GDP*2	703	705	674	407	311	255	211	-2.0	-2.1	-1.9	-2.0
CO_2 emissions per GDP*3	1 881	1 714	1 512	851	611	499	400	-2.6	-2.5	-2.1	-2.3
CO_2 per primary energy consumption*4	2.7	2.4	2.2	2.1	2.0	2.0	1.9	-0.6	-0.5	-0.2	-0.3

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

Table A39 | European Union [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	n.a.	1 645	1 695	1 619	1 519	1 431	1 342	100	100	100	-0.1	-0.5	-0.6	-0.6
Coal	n.a.	454	321	234	187	161	140	28	14	10	-2.4	-1.7	-1.4	-1.5
Oil	n.a.	607	624	531	461	409	364	37	33	27	-0.5	-1.1	-1.2	-1.1
Natural gas	n.a.	297	396	398	402	403	382	18	25	28	1.1	0.1	-0.3	-0.1
Nuclear	n.a.	207	246	216	188	164	154	13	13	11	0.2	-1.1	-1.0	-1.0
Hydro	n.a.	25	31	26	29	30	31	1.5	1.6	2.3	0.1	1.0	0.2	0.5
Geothermal	n.a.	3.2	4.6	6.8	8.8	9.6	10	0.2	0.4	0.8	2.9	2.0	0.8	1.3
Solar, wind, etc.	n.a.	0.3	2.4	46	72	84	95	0.0	2.8	7.1	20.1	3.6	1.4	2.3
Biomass and waste	n.a.	48	67	159	168	167	164	2.9	9.8	12	4.6	0.4	-0.1	0.1

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	n.a.	1 133	1 178	1 154	1 104	1 039	973	100	100	100	0.1	-0.3	-0.6	-0.5
Industry	n.a.	345	308	263	261	253	239	30	23	25	-1.0	-0.1	-0.4	-0.3
Transport	n.a.	259	303	327	287	255	229	23	28	24	0.9	-1.0	-1.1	-1.1
Buildings, etc.	n.a.	430	454	461	452	428	403	38	40	41	0.3	-0.1	-0.6	-0.4
Non-energy use	n.a.	99	112	102	103	103	101	8.7	8.9	10	0.1	0.1	-0.1	0.0
Coal	n.a.	120	51	35	29	25	22	11	3.1	2.3	-4.4	-1.6	-1.3	-1.4
Oil	n.a.	506	542	479	417	366	324	45	42	33	-0.2	-1.1	-1.3	-1.2
Natural gas	n.a.	227	272	254	252	240	224	20	22	23	0.4	-0.1	-0.6	-0.4
Electricity	n.a.	186	217	241	264	275	281	16	21	29	1.0	0.7	0.3	0.5
Heat	n.a.	55	45	49	44	39	35	4.9	4.2	3.6	-0.5	-0.7	-1.2	-1.0
Hydrogen	n.a.	-	-	-	0.0	-	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	n.a.	40	50	96	99	93	87	3.5	8.3	9.0	3.3	0.3	-0.6	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	n.a.	2 577	3 006	3 269	3 563	3 683	3 721	100	100	100	0.9	0.7	0.2	0.4
Coal	n.a.	1 050	968	710	622	542	459	41	22	12	-1.4	-1.0	-1.5	-1.3
Oil	n.a.	224	181	61	46	42	30	8.7	1.9	0.8	-4.7	-2.2	-2.0	-2.1
Natural gas	n.a.	193	480	663	792	932	973	7.5	20	26	4.7	1.4	1.0	1.2
Nuclear	n.a.	795	945	830	723	630	590	31	25	16	0.2	-1.1	-1.0	-1.0
Hydro	n.a.	290	357	301	342	349	355	11	9.2	9.6	0.1	1.0	0.2	0.5
Geothermal	n.a.	3.2	4.8	6.7	8.9	9.8	11	0.1	0.2	0.3	2.8	2.2	0.9	1.4
Solar PV	n.a.	0.0	0.1	114	192	233	264	0.0	3.5	7.1	39.1	4.1	1.6	2.6
Wind	n.a.	0.8	22	362	527	588	640	0.0	11	17	25.6	2.9	1.0	1.7
CSP and marine	n.a.	0.5	0.5	6.4	34	47	63	0.0	0.2	1.7	9.9	13.7	3.1	7.2
Biomass and waste	n.a.	20	46	211	272	306	330	0.8	6.4	8.9	9.2	2.0	1.0	1.4
Hydrogen	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	n.a.	0.2	1.4	4.9	4.9	4.9	4.9	0.0	0.1	0.1	12.3	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	n.a.	11 891	14 783	18 824	22 909	26 160	29 207	1.7	1.5	1.2	1.3
Population (million)	n.a.	478	488	512	518	518	511	0.3	0.1	-0.1	0.0
CO_2 emissions (Mt)	n.a.	3 980	3 783	3 201	2 761	2 511	2 248	-0.8	-1.1	-1.0	-1.1
GDP per capita ($2010 thousand)	n.a.	25	30	37	44	51	57	1.5	1.4	1.3	1.3
Primary energy consump. per capita (toe)	n.a.	3.4	3.5	3.2	2.9	2.8	2.6	-0.3	-0.6	-0.6	-0.6
Primary energy consumption per GDP*2	n.a.	138	115	86	66	55	46	-1.7	-2.0	-1.8	-1.9
CO_2 emissions per GDP*3	n.a.	335	256	170	121	96	77	-2.5	-2.6	-2.2	-2.4
CO_2 per primary energy consumption*4	n.a.	2.4	2.2	2.0	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 A40 | Africa [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	272	385	490	812	1 101	1 363	1 537	100	100	100	2.8	2.4	1.7	2.0
Coal	52	74	90	110	128	145	156	19	13	10	1.5	1.2	1.0	1.1
Oil	65	85	101	191	265	365	463	22	24	30	3.0	2.5	2.8	2.7
Natural gas	12	30	47	123	198	287	387	7.7	15	25	5.4	3.8	3.4	3.5
Nuclear	-	2.2	3.4	3.7	5.8	10	8.8	0.6	0.5	0.6	1.9	3.5	2.1	2.6
Hydro	4.1	4.8	6.4	11	19	25	37	1.3	1.3	2.4	2.9	4.6	3.4	3.9
Geothermal	-	0.3	0.4	4.1	13	21	29	0.1	0.5	1.9	10.5	9.4	4.0	6.1
Solar, wind, etc.	-	0.0	0.0	2.0	13	29	51	0.0	0.2	3.3	35.8	15.9	7.0	10.4
Biomass and waste	139	189	240	367	458	480	404	49	45	26	2.5	1.7	-0.6	0.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	216	287	364	594	815	1 001	1 112	100	100	100	2.7	2.5	1.6	1.9
Industry	46	53	57	88	134	183	227	18	15	20	1.9	3.3	2.7	2.9
Transport	28	38	55	117	159	211	267	13	20	24	4.2	2.4	2.6	2.5
Buildings, etc.	137	185	238	368	491	565	566	64	62	51	2.6	2.2	0.7	1.3
Non-energy use	5.4	11	15	22	33	42	51	3.8	3.6	4.6	2.5	3.2	2.2	2.6
Coal	21	20	19	21	26	28	29	6.9	3.6	2.6	0.3	1.4	0.5	0.9
Oil	54	70	90	166	233	318	408	25	28	37	3.2	2.6	2.8	2.8
Natural gas	2.8	8.6	14	41	64	84	103	3.0	6.9	9.3	6.0	3.5	2.4	2.8
Electricity	14	22	31	56	96	153	231	7.7	9.4	21	3.5	4.2	4.5	4.4
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	-	-	-	-	n.a.	n.a.	-100	n.a.
Renewables	124	166	210	309	397	418	341	58	52	31	2.3	1.9	-0.8	0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	184	315	441	817	1 376	2 145	3 170	100	100	100	3.6	4.1	4.3	4.2
Coal	100	164	209	254	331	405	461	52	31	15	1.6	2.1	1.7	1.8
Oil	22	41	51	75	103	159	187	13	9.2	5.9	2.3	2.5	3.0	2.8
Natural gas	14	45	92	325	564	963	1 549	14	40	49	7.6	4.3	5.2	4.8
Nuclear	-	8.4	13	14	22	39	34	2.7	1.7	1.1	1.9	3.5	2.1	2.6
Hydro	47	56	75	123	219	295	430	18	15	14	2.9	4.6	3.4	3.9
Geothermal	-	0.3	0.4	4.8	16	24	34	0.1	0.6	1.1	10.5	9.4	4.0	6.1
Solar PV	-	-	0.0	4.7	52	139	284	-	0.6	9.0	n.a.	20.4	8.9	13.3
Wind	-	-	0.2	12	38	63	106	-	1.5	3.4	n.a.	9.1	5.3	6.8
CSP and marine	-	-	-	1.1	20	42	66	-	0.1	2.1	n.a.	25.0	6.2	13.2
Biomass and waste	0.2	0.4	0.9	1.8	9.1	14	17	0.1	0.2	0.5	5.7	13.3	3.2	7.1
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.1	1.6	1.6	1.6	1.6	-	0.2	0.0	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	718	893	1 166	2 391	4 084	6 571	9 731	3.7	4.2	4.4	4.3
Population (million)	479	634	816	1 255	1 703	2 095	2 511	2.6	2.4	2.0	2.1
CO_2 emissions (Mt)	397	541	667	1 196	1 623	2 169	2 716	3.0	2.4	2.6	2.5
GDP per capita ($2010 thousand)	1.5	1.4	1.4	1.9	2.4	3.1	3.9	1.1	1.8	2.4	2.2
Primary energy consump. per capita (toe)	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.2	0.0	-0.3	-0.2
Primary energy consumption per GDP*2	379	432	420	340	269	207	158	-0.9	-1.8	-2.6	-2.3
CO_2 emissions per GDP*3	553	606	572	500	398	330	279	-0.7	-1.8	-1.8	-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	0.6

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

Table A41 | Middle East [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	121	223	372	773	1 031	1 199	1 316	100	100	100	4.7	2.2	1.2	1.6
Coal	1.2	3.0	8.1	8.8	12	12	11	1.3	1.1	0.8	4.1	2.6	-0.7	0.6
Oil	90	146	217	332	404	445	451	66	43	34	3.1	1.5	0.5	0.9
Natural gas	29	72	145	427	583	693	790	32	55	60	6.8	2.4	1.5	1.9
Nuclear	-	-	-	2.0	22	33	39	-	0.3	3.0	n.a.	20.4	3.0	9.5
Hydro	0.8	1.0	0.7	1.5	2.1	2.3	2.4	0.5	0.2	0.2	1.5	2.5	0.8	1.4
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	0.4	0.7	1.1	6.9	12	22	0.2	0.1	1.7	3.6	15.2	5.9	9.5
Biomass and waste	0.3	0.4	0.4	1.0	0.9	0.8	0.8	0.2	0.1	0.1	2.9	-0.7	-0.4	-0.5

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	84	157	253	509	680	790	876	100	100	100	4.4	2.3	1.3	1.7
Industry	30	47	71	153	207	236	248	30	30	28	4.5	2.3	0.9	1.5
Transport	26	51	75	140	168	184	194	32	28	22	3.8	1.4	0.7	1.0
Buildings, etc.	22	40	75	137	187	223	259	25	27	30	4.7	2.4	1.7	2.0
Non-energy use	5.6	20	32	79	118	148	175	12	15	20	5.3	3.2	2.0	2.4
Coal	0.3	0.2	0.5	3.2	3.9	3.8	3.6	0.1	0.6	0.4	11.1	1.4	-0.4	0.3
Oil	67	108	153	245	314	358	385	69	48	44	3.1	1.9	1.0	1.4
Natural gas	9.8	31	65	178	239	271	293	20	35	33	6.7	2.3	1.0	1.5
Electricity	6.5	17	33	81	122	157	193	11	16	22	5.9	3.2	2.3	2.7
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-2.8	n.a.
Renewables	0.2	0.7	1.0	1.4	1.5	1.5	1.7	0.5	0.3	0.2	2.5	0.3	0.7	0.5

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	95	244	472	1 194	1 778	2 252	2 731	100	100	100	6.0	3.1	2.2	2.5
Coal	0.1	11	30	23	35	34	29	4.3	1.9	1.1	2.9	3.3	-0.8	0.8
Oil	47	108	188	290	303	266	177	44	24	6.5	3.7	0.4	-2.6	-1.5
Natural gas	39	114	246	851	1 273	1 688	2 144	47	71	78	7.7	3.1	2.6	2.8
Nuclear	-	-	-	7.5	83	127	151	-	0.6	5.5	n.a.	20.4	3.0	9.5
Hydro	9.7	12	8.0	18	24	26	28	4.9	1.5	1.0	1.5	2.5	0.8	1.4
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	3.9	44	77	136	-	0.3	5.0	n.a.	20.3	5.9	11.4
Wind	-	0.0	0.0	0.9	9.5	22	44	0.0	0.1	1.6	28.8	19.5	7.9	12.4
CSP and marine	-	-	-	0.3	6.0	10	20	-	0.0	0.7	n.a.	27.5	6.2	14.1
Biomass and waste	-	-	-	0.0	0.3	0.4	0.6	-	0.0	0.0	n.a.	20.7	2.9	9.6
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	976	1 029	1 532	2 770	3 805	5 059	6 552	3.7	2.5	2.8	2.6
Population (million)	92	132	168	246	302	335	365	2.3	1.6	1.0	1.2
CO_2 emissions (Mt)	311	568	942	1 858	2 329	2 622	2 785	4.5	1.8	0.9	1.2
GDP per capita ($2010 thousand)	11	7.8	9.1	11	13	15	18	1.4	0.9	1.8	1.4
Primary energy consump. per capita (toe)	1.3	1.7	2.2	3.1	3.4	3.6	3.6	2.3	0.6	0.3	0.4
Primary energy consumption per GDP[*2]	124	216	243	279	271	237	201	0.9	-0.2	-1.5	-1.0
CO_2 emissions per GDP[*3]	318	552	615	671	612	518	425	0.7	-0.7	-1.8	-1.4
CO_2 per primary energy consumption[*4]	2.6	2.6	2.5	2.4	2.3	2.2	2.1	-0.2	-0.5	-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 A42 | Oceania [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	79	99	125	148	156	155	150	100	100	100	1.5	0.4	-0.2	0.0
Coal	28	36	49	45	38	33	29	36	31	19	0.8	-1.4	-1.4	-1.4
Oil	34	35	40	50	48	45	41	35	34	27	1.3	-0.2	-0.9	-0.6
Natural gas	8.3	19	24	36	44	48	48	19	24	32	2.4	1.7	0.4	0.9
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	2.7	3.2	3.5	3.5	3.4	3.3	3.3	3.2	2.4	2.2	0.4	-0.3	-0.2	-0.3
Geothermal	1.0	1.5	2.0	4.9	7.7	8.1	8.4	1.5	3.3	5.6	4.5	3.5	0.5	1.7
Solar, wind, etc.	0.0	0.1	0.1	2.4	6.7	10.0	13	0.1	1.6	8.9	11.9	8.4	3.5	5.4
Biomass and waste	4.1	4.7	6.2	6.6	7.5	8.0	8.2	4.8	4.5	5.5	1.3	0.9	0.5	0.7

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	54	66	83	96	103	104	102	100	100	100	1.4	0.5	0.0	0.2
Industry	20	23	28	27	31	32	31	35	28	30	0.6	1.1	-0.1	0.4
Transport	19	24	30	39	38	37	36	36	40	35	1.8	-0.1	-0.3	-0.2
Buildings, etc.	11	15	19	25	27	29	29	22	26	29	1.9	0.8	0.4	0.5
Non-energy use	3.1	4.6	6.1	6.3	6.6	6.6	6.5	6.9	6.5	6.4	1.2	0.4	0.0	0.1
Coal	5.3	5.2	4.7	3.1	3.2	3.1	2.9	7.9	3.2	2.8	-1.9	0.3	-0.6	-0.2
Oil	31	33	40	50	50	47	44	50	52	43	1.6	-0.1	-0.6	-0.4
Natural gas	5.4	10	14	16	18	18	18	16	16	17	1.5	0.8	0.1	0.4
Electricity	8.5	14	18	21	26	29	31	20	22	30	1.7	1.6	0.8	1.1
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-11.2	n.a.
Renewables	4.0	4.1	5.6	5.9	6.6	6.7	6.6	6.2	6.1	6.4	1.3	0.9	0.0	0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	118	187	249	302	366	396	416	100	100	100	1.8	1.5	0.6	1.0
Coal	70	122	176	163	158	145	125	65	54	30	1.1	-0.3	-1.2	-0.8
Oil	5.2	3.6	1.8	5.3	4.2	3.2	2.0	1.9	1.7	0.5	1.5	-1.7	-3.5	-2.8
Natural gas	8.7	20	26	58	72	77	77	11	19	19	4.0	1.7	0.4	0.9
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	32	37	41	41	39	39	38	20	14	9.1	0.4	-0.3	-0.2	-0.3
Geothermal	1.2	2.1	2.9	7.9	13	13	14	1.1	2.6	3.3	5.0	3.7	0.5	1.7
Solar PV	-	-	0.0	8.1	33	51	67	-	2.7	16	n.a.	11.4	3.6	6.6
Wind	-	-	0.2	15	39	58	80	-	4.9	19	n.a.	7.9	3.6	5.3
CSP and marine	-	-	-	0.0	0.0	0.1	0.2	-	0.0	0.0	n.a.	26.8	6.5	14.1
Biomass and waste	0.7	1.2	1.7	4.1	7.4	10	13	0.7	1.4	3.1	4.5	4.6	2.8	3.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.1	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	528	721	996	1 614	2 199	2 647	3 092	3.0	2.4	1.7	2.0
Population (million)	18	20	23	29	33	36	39	1.4	1.0	0.7	0.8
CO_2 emissions (Mt)	230	282	363	422	409	389	357	1.5	-0.3	-0.7	-0.5
GDP per capita ($2010 thousand)	30	35	43	55	66	73	80	1.6	1.4	1.0	1.2
Primary energy consump. per capita (toe)	4.4	4.9	5.4	5.0	4.6	4.3	3.9	0.1	-0.6	-0.9	-0.8
Primary energy consumption per GDP*2	149	137	126	92	71	59	49	-1.5	-2.0	-1.9	-1.9
CO_2 emissions per GDP*3	435	391	365	262	186	147	115	-1.5	-2.6	-2.4	-2.5
CO_2 per primary energy consumption*4	2.9	2.8	2.9	2.9	2.6	2.5	2.4	0.0	-0.6	-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 A43 | Advanced Economies [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	3 993	4 468	5 235	5 228	5 181	5 008	4 767	100	100	100	0.6	-0.1	-0.4	-0.3
Coal	966	1 088	1 118	904	782	680	560	24	17	12	-0.7	-1.1	-1.7	-1.4
Oil	1 898	1 826	2 069	1 874	1 711	1 561	1 421	41	36	30	0.1	-0.7	-0.9	-0.8
Natural gas	760	827	1 134	1 389	1 551	1 590	1 538	19	27	32	1.9	0.8	0.0	0.3
Nuclear	164	463	596	513	455	413	391	10	9.8	8.2	0.4	-0.9	-0.8	-0.8
Hydro	92	100	111	116	122	125	127	2.2	2.2	2.7	0.6	0.4	0.2	0.3
Geothermal	9.4	22	25	34	58	77	88	0.5	0.6	1.9	1.6	4.2	2.1	2.9
Solar, wind, etc.	0.1	2.0	5.9	90	160	215	293	0.0	1.7	6.1	15.2	4.5	3.1	3.6
Biomass and waste	102	139	173	306	341	345	347	3.1	5.8	7.3	3.0	0.8	0.1	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	2 891	3 056	3 581	3 651	3 632	3 502	3 345	100	100	100	0.7	0.0	-0.4	-0.3
Industry	927	826	906	798	822	806	767	27	22	23	-0.1	0.2	-0.3	-0.1
Transport	761	916	1 117	1 202	1 100	1 010	935	30	33	28	1.0	-0.7	-0.8	-0.8
Buildings, etc.	959	1 028	1 193	1 248	1 264	1 230	1 184	34	34	35	0.7	0.1	-0.3	-0.2
Non-energy use	245	286	366	402	445	456	458	9.3	11	14	1.3	0.8	0.1	0.4
Coal	259	231	138	110	94	82	71	7.6	3.0	2.1	-2.7	-1.2	-1.4	-1.3
Oil	1 545	1 557	1 808	1 716	1 577	1 439	1 315	51	47	39	0.4	-0.6	-0.9	-0.8
Natural gas	547	578	732	741	773	748	705	19	20	21	0.9	0.3	-0.5	-0.2
Electricity	407	553	719	813	915	974	1 011	18	22	30	1.4	0.9	0.5	0.7
Heat	36	48	52	61	57	51	45	1.6	1.7	1.4	0.9	-0.6	-1.1	-0.9
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-11.7	n.a.
Renewables	97	89	133	209	216	207	198	2.9	5.7	5.9	3.2	0.2	-0.4	-0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	5 639	7 668	9 706	10 868	12 177	12 878	13 258	100	100	100	1.3	0.9	0.4	0.6
Coal	2 323	3 127	3 833	3 070	2 912	2 588	2 126	41	28	16	-0.1	-0.4	-1.6	-1.1
Oil	985	669	539	196	137	101	55	8.7	1.8	0.4	-4.4	-2.7	-4.5	-3.8
Natural gas	607	767	1 531	2 891	3 708	4 274	4 412	10	27	33	5.0	1.9	0.9	1.3
Nuclear	629	1 776	2 288	1 967	1 746	1 587	1 501	23	18	11	0.4	-0.9	-0.8	-0.8
Hydro	1 071	1 159	1 294	1 354	1 421	1 455	1 479	15	12	11	0.6	0.4	0.2	0.3
Geothermal	10	23	27	47	85	120	140	0.3	0.4	1.1	2.6	4.7	2.5	3.4
Solar PV	-	0.1	0.7	258	501	794	1 271	0.0	2.4	9.6	34.4	5.2	4.8	5.0
Wind	0.0	3.8	29	684	1 016	1 164	1 317	0.1	6.3	9.9	21.2	3.1	1.3	2.0
CSP and marine	0.5	1.2	1.1	11	88	152	247	0.0	0.1	1.9	8.4	17.8	5.3	10.0
Biomass and waste	13	121	142	358	528	611	675	1.6	3.3	5.1	4.1	3.0	1.2	1.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	34	34	34	34	0.3	0.3	0.3	2.0	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	21 080	28 914	37 649	50 277	62 850	74 064	85 161	2.1	1.7	1.5	1.6
Population (million)	925	999	1 070	1 181	1 222	1 237	1 238	0.6	0.3	0.1	0.1
CO_2 emissions (Mt)	10 435	10 801	12 266	11 347	10 660	9 890	8 879	0.2	-0.5	-0.9	-0.7
GDP per capita ($2010 thousand)	23	29	35	43	51	60	69	1.4	1.5	1.5	1.5
Primary energy consump. per capita (toe)	4.3	4.5	4.9	4.4	4.2	4.0	3.8	0.0	-0.3	-0.5	-0.4
Primary energy consumption per GDP[*2]	189	155	139	104	82	68	56	-1.5	-1.8	-1.9	-1.9
CO_2 emissions per GDP[*3]	495	374	326	226	170	134	104	-1.8	-2.2	-2.4	-2.3
CO_2 per primary energy consumption[*4]	2.6	2.4	2.3	2.2	2.1	2.0	1.9	-0.4	-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 A44 | Emerging Market and Developing Economies [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	3 032	4 096	4 517	8 331	10 854	12 329	13 236	100	100	100	2.7	2.1	1.0	1.4
Coal	817	1 133	1 198	2 886	3 433	3 583	3 474	28	35	26	3.5	1.3	0.1	0.6
Oil	1 029	1 205	1 320	2 163	2 813	3 272	3 628	29	26	27	2.2	2.0	1.3	1.6
Natural gas	472	837	938	1 718	2 462	3 050	3 537	20	21	27	2.7	2.8	1.8	2.2
Nuclear	22	62	79	175	339	404	467	1.5	2.1	3.5	3.9	5.2	1.6	3.0
Hydro	56	84	113	235	291	324	356	2.1	2.8	2.7	3.9	1.7	1.0	1.3
Geothermal	3.0	12	27	52	124	163	201	0.3	0.6	1.5	5.6	6.9	2.4	4.2
Solar, wind, etc.	-	0.5	2.1	80	226	348	489	0.0	1.0	3.7	20.9	8.3	3.9	5.6
Biomass and waste	635	763	839	1 023	1 166	1 186	1 083	19	12	8.2	1.1	1.0	-0.4	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	2 300	3 006	3 175	5 654	7 260	8 244	8 937	100	100	100	2.4	1.9	1.0	1.4
Industry	839	978	967	2 023	2 534	2 801	2 921	33	36	33	2.7	1.7	0.7	1.1
Transport	307	453	568	1 193	1 601	1 897	2 177	15	21	24	3.7	2.3	1.5	1.8
Buildings, etc.	1 041	1 385	1 399	1 961	2 449	2 739	2 918	46	35	33	1.3	1.7	0.9	1.2
Non-energy use	113	190	241	477	676	808	921	6.3	8.4	10	3.5	2.7	1.6	2.0
Coal	444	522	404	910	923	908	860	17	16	9.6	2.1	0.1	-0.4	-0.2
Oil	726	844	1 040	1 856	2 485	2 925	3 306	28	33	37	3.0	2.3	1.4	1.8
Natural gas	267	366	384	761	1 084	1 258	1 388	12	13	16	2.7	2.8	1.2	1.8
Electricity	178	282	373	1 025	1 570	1 979	2 355	9.4	18	26	4.9	3.3	2.0	2.6
Heat	85	288	196	228	242	243	239	9.6	4.0	2.7	-0.9	0.4	-0.1	0.1
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	-4.9	n.a.
Renewables	599	704	777	873	956	931	788	23	15	8.8	0.8	0.7	-1.0	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	2 644	4 182	5 730	14 738	22 235	27 526	32 105	100	100	100	4.8	3.2	1.9	2.4
Coal	813	1 303	2 162	6 794	9 278	10 366	10 635	31	46	33	6.3	2.4	0.7	1.4
Oil	674	655	668	645	696	686	538	16	4.4	1.7	-0.1	0.6	-1.3	-0.6
Natural gas	392	984	1 228	2 992	4 877	6 977	9 140	24	20	28	4.2	3.8	3.2	3.4
Nuclear	85	236	303	669	1 302	1 549	1 793	5.7	4.5	5.6	3.9	5.3	1.6	3.0
Hydro	646	982	1 319	2 729	3 385	3 770	4 145	23	19	13	3.9	1.7	1.0	1.3
Geothermal	3.5	13	25	38	106	143	179	0.3	0.3	0.6	4.1	8.1	2.7	4.8
Solar PV	-	0.0	0.3	186	790	1 435	2 460	0.0	1.3	7.7	50.5	11.8	5.8	8.1
Wind	-	0.0	2.8	443	1 342	1 950	2 371	0.0	3.0	7.4	41.7	8.9	2.9	5.2
CSP and marine	-	0.0	0.0	1.4	30	63	104	0.0	0.0	0.3	21.6	26.7	6.4	14.0
Biomass and waste	31	8.5	22	238	427	585	738	0.2	1.6	2.3	13.1	4.6	2.8	3.5
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	7 093	9 137	12 448	29 659	52 547	77 792	105 589	4.5	4.5	3.6	3.9
Population (million)	3 512	4 282	5 043	6 338	7 300	7 938	8 478	1.5	1.1	0.8	0.9
CO_2 emissions (Mt)	6 787	8 873	9 912	20 081	25 293	28 256	29 744	3.1	1.8	0.8	1.2
GDP per capita ($2010 thousand)	2.0	2.1	2.5	4.7	7.2	9.8	12	3.0	3.4	2.8	3.0
Primary energy consump. per capita (toe)	0.9	1.0	0.9	1.3	1.5	1.6	1.6	1.2	1.0	0.2	0.5
Primary energy consumption per GDP*2	427	448	363	281	207	158	125	-1.7	-2.3	-2.5	-2.4
CO_2 emissions per GDP*3	957	971	796	677	481	363	282	-1.3	-2.6	-2.6	-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 A45 | World [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	7 203	8 766	10 025	13 972	15 624	16 043	15 915	100	100	100	1.7	0.9	0.1	0.4
Coal	1 783	2 220	2 317	3 790	3 559	3 011	2 375	25	27	15	2.0	-0.5	-2.0	-1.4
Oil	3 105	3 233	3 663	4 449	4 702	4 672	4 489	37	32	28	1.2	0.4	-0.2	0.0
Natural gas	1 232	1 664	2 072	3 107	3 696	3 945	3 879	19	22	24	2.3	1.3	0.2	0.7
Nuclear	186	526	675	687	930	1 125	1 282	6.0	4.9	8.1	1.0	2.4	1.6	1.9
Hydro	148	184	225	351	432	479	522	2.1	2.5	3.3	2.4	1.6	1.0	1.2
Geothermal	12	34	52	86	229	339	437	0.4	0.6	2.7	3.5	7.8	3.3	5.1
Solar, wind, etc.	0.1	2.5	7.9	171	561	946	1 410	0.0	1.2	8.9	17.0	9.6	4.7	6.6
Biomass and waste	737	902	1 012	1 329	1 514	1 525	1 519	10	9.5	9.5	1.4	1.0	0.0	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	5 369	6 264	7 030	9 717	10 872	11 176	11 193	100	100	100	1.6	0.9	0.1	0.4
Industry	1 766	1 804	1 873	2 821	3 275	3 344	3 216	29	29	29	1.7	1.2	-0.1	0.4
Transport	1 246	1 571	1 958	2 808	2 990	3 039	3 106	25	29	28	2.2	0.5	0.2	0.3
Buildings, etc.	2 000	2 414	2 592	3 209	3 487	3 532	3 493	39	33	31	1.1	0.6	0.0	0.3
Non-energy use	358	476	607	879	1 121	1 262	1 378	7.6	9.0	12	2.3	1.9	1.0	1.4
Coal	703	753	542	1 020	957	875	768	12	10	6.9	1.1	-0.5	-1.1	-0.9
Oil	2 449	2 604	3 122	3 985	4 306	4 332	4 226	42	41	38	1.6	0.6	-0.1	0.2
Natural gas	815	944	1 116	1 502	1 789	1 861	1 903	15	15	17	1.7	1.4	0.3	0.7
Electricity	586	834	1 092	1 838	2 428	2 807	3 104	13	19	28	3.0	2.2	1.2	1.6
Heat	121	336	248	289	289	273	252	5.4	3.0	2.2	-0.6	0.0	-0.7	-0.4
Hydrogen	-	-	-	-	0.4	1.3	2.8	-	-	0.0	n.a.	n.a.	10.2	n.a.
Renewables	696	794	910	1 083	1 102	1 027	938	13	11	8.4	1.2	0.1	-0.8	-0.4

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	8 283	11 850	15 436	25 606	33 552	38 465	42 127	100	100	100	2.9	2.1	1.1	1.5
Coal	3 137	4 430	5 994	9 863	9 528	7 675	5 610	37	39	13	3.0	-0.3	-2.6	-1.7
Oil	1 659	1 325	1 207	842	656	485	273	11	3.3	0.6	-1.7	-1.9	-4.3	-3.4
Natural gas	999	1 750	2 760	5 883	7 622	8 905	8 730	15	23	21	4.6	2.0	0.7	1.2
Nuclear	713	2 013	2 591	2 636	3 569	4 317	4 920	17	10	12	1.0	2.4	1.6	1.9
Hydro	1 717	2 141	2 613	4 082	5 023	5 567	6 069	18	16	14	2.4	1.6	1.0	1.2
Geothermal	14	36	52	85	247	369	481	0.3	0.3	1.1	3.2	8.5	3.4	5.4
Solar PV	-	0.1	1.0	444	1 904	3 652	6 102	0.0	1.7	14	37.0	11.9	6.0	8.3
Wind	0.0	3.9	31	1 127	3 637	5 567	7 323	0.0	4.4	17	23.4	9.4	3.6	5.8
CSP and marine	0.5	1.2	1.1	12	173	426	809	0.0	0.0	1.9	8.9	22.9	8.0	13.6
Biomass and waste	44	130	164	596	1 157	1 466	1 773	1.1	2.3	4.2	5.8	5.2	2.2	3.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	36	36	36	36	0.2	0.1	0.1	2.2	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	28 173	38 050	50 096	79 936	115 397	151 856	190 750	2.8	2.9	2.5	2.7
Population (million)	4 437	5 281	6 112	7 519	8 522	9 176	9 716	1.3	1.0	0.7	0.8
CO_2 emissions (Mt)	17 777	20 302	23 029	32 711	32 793	29 761	25 288	1.8	0.0	-1.3	-0.8
GDP per capita ($2010 thousand)	6.4	7.2	8.2	11	14	17	20	1.5	1.9	1.9	1.9
Primary energy consump. per capita (toe)	1.6	1.7	1.6	1.9	1.8	1.7	1.6	0.4	-0.1	-0.6	-0.4
Primary energy consumption per GDP*2	256	230	200	175	135	106	83	-1.0	-1.9	-2.4	-2.2
CO_2 emissions per GDP*3	631	534	460	409	284	196	133	-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	-0.8	-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 A46 | Asia [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	1 439	2 110	2 887	5 669	6 937	7 236	7 223	100	100	100	3.7	1.6	0.2	0.7
Coal	466	788	1 037	2 761	2 799	2 435	1 963	37	49	27	4.8	0.1	-1.8	-1.0
Oil	477	618	916	1 410	1 741	1 855	1 905	29	25	26	3.1	1.6	0.5	0.9
Natural gas	51	116	233	595	917	1 064	1 097	5.5	10	15	6.2	3.4	0.9	1.9
Nuclear	25	77	132	130	339	466	566	3.6	2.3	7.8	2.0	7.6	2.6	4.6
Hydro	20	32	41	141	192	220	240	1.5	2.5	3.3	5.7	2.4	1.1	1.6
Geothermal	2.6	8.2	23	44	117	179	232	0.4	0.8	3.2	6.4	7.9	3.5	5.2
Solar, wind, etc.	-	1.2	2.1	75	293	488	693	0.1	1.3	9.6	16.4	11.0	4.4	7.0
Biomass and waste	397	471	503	513	538	528	525	22	9.0	7.3	0.3	0.4	-0.1	0.1

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	1 133	1 554	1 992	3 793	4 619	4 875	4 962	100	100	100	3.4	1.5	0.4	0.8
Industry	383	516	653	1 544	1 838	1 852	1 755	33	41	35	4.1	1.3	-0.2	0.4
Transport	124	183	318	692	891	982	1 068	12	18	22	5.0	2.0	0.9	1.3
Buildings, etc.	568	740	843	1 178	1 367	1 438	1 475	48	31	30	1.7	1.2	0.4	0.7
Non-energy use	58	115	179	380	524	603	664	7.4	10	13	4.5	2.5	1.2	1.7
Coal	301	424	373	859	817	748	655	27	23	13	2.7	-0.4	-1.1	-0.8
Oil	330	458	734	1 261	1 594	1 716	1 779	29	33	36	3.8	1.8	0.6	1.0
Natural gas	21	46	87	295	490	542	566	2.9	7.8	11	7.2	4.0	0.7	2.0
Electricity	88	157	280	825	1 207	1 410	1 551	10	22	31	6.3	3.0	1.3	1.9
Heat	7.5	14	30	102	113	113	107	0.9	2.7	2.2	7.6	0.8	-0.3	0.1
Hydrogen	-	-	-	-	0.2	0.7	1.6	-	-	0.0	n.a.	n.a.	11.6	n.a.
Renewables	385	455	488	452	399	345	302	29	12	6.1	0.0	-1.0	-1.4	-1.2

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	1 196	2 241	3 980	11 340	16 482	19 052	20 859	100	100	100	6.2	2.9	1.2	1.9
Coal	298	868	1 983	6 788	7 213	6 106	4 725	39	60	23	7.9	0.5	-2.1	-1.1
Oil	476	436	385	213	152	111	71	19	1.9	0.3	-2.6	-2.6	-3.8	-3.3
Natural gas	90	237	570	1 352	2 012	2 544	2 665	11	12	13	6.7	3.1	1.4	2.1
Nuclear	97	294	505	500	1 303	1 789	2 173	13	4.4	10	2.0	7.6	2.6	4.6
Hydro	232	368	478	1 638	2 229	2 553	2 796	16	14	13	5.7	2.4	1.1	1.6
Geothermal	3.0	8.4	20	26	76	116	151	0.4	0.2	0.7	4.2	8.7	3.5	5.5
Solar PV	-	0.1	0.6	228	1 112	2 052	3 195	0.0	2.0	15	34.9	13.0	5.4	8.3
Wind	-	0.0	2.4	362	1 908	3 150	4 268	0.0	3.2	20	41.0	13.6	4.1	7.8
CSP and marine	-	0.0	0.0	0.5	12	28	62	0.0	0.0	0.3	17.4	27.5	8.4	15.6
Biomass and waste	0.0	9.4	16	210	443	580	729	0.4	1.9	3.5	12.2	5.9	2.5	3.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	22	22	22	22	0.9	0.2	0.1	0.4	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	4 510	7 628	11 102	24 564	42 742	61 349	81 204	4.4	4.4	3.3	3.7
Population (million)	2 440	2 933	3 410	4 072	4 449	4 617	4 681	1.2	0.7	0.3	0.4
CO_2 emissions (Mt)	3 103	4 631	6 714	15 157	16 511	15 202	12 709	4.5	0.7	-1.3	-0.5
GDP per capita ($2010 thousand)	1.8	2.6	3.3	6.0	9.6	13	17	3.2	3.6	3.0	3.3
Primary energy consump. per capita (toe)	0.6	0.7	0.8	1.4	1.6	1.6	1.5	2.5	0.9	-0.1	0.3
Primary energy consumption per GDP[*2]	319	277	260	231	162	118	89	-0.7	-2.7	-3.0	-2.8
CO_2 emissions per GDP[*3]	688	607	605	617	386	248	157	0.1	-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	-1.5	-1.3

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

Table A47 | China [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	598	874	1 130	3 063	3 401	3 279	2 997	100	100	100	4.8	0.8	-0.6	-0.1
Coal	313	531	665	1 953	1 786	1 439	1 053	61	64	35	4.9	-0.7	-2.6	-1.9
Oil	89	119	221	568	681	641	558	14	19	19	6.0	1.4	-1.0	-0.1
Natural gas	12	13	21	195	350	426	452	1.5	6.4	15	10.6	4.6	1.3	2.6
Nuclear	-	-	4.4	65	147	196	244	-	2.1	8.1	n.a.	6.5	2.6	4.1
Hydro	5.0	11	19	99	128	139	144	1.2	3.2	4.8	8.5	1.9	0.6	1.1
Geothermal	-	-	1.7	10	13	14	15	-	0.3	0.5	n.a.	1.7	0.6	1.0
Solar, wind, etc.	-	0.0	1.0	60	203	314	402	0.0	1.9	13	32.0	9.9	3.5	6.0
Biomass and waste	180	200	198	114	94	111	132	23	3.7	4.4	-2.1	-1.4	1.7	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	487	658	781	1 995	2 222	2 183	2 052	100	100	100	4.2	0.8	-0.4	0.1
Industry	181	234	302	986	971	887	775	36	49	38	5.5	-0.1	-1.1	-0.7
Transport	22	30	84	310	400	380	329	4.6	16	16	9.0	2.0	-1.0	0.2
Buildings, etc.	274	351	338	537	626	666	687	53	27	34	1.6	1.2	0.5	0.8
Non-energy use	10	43	57	162	225	251	260	6.5	8.1	13	5.1	2.6	0.7	1.4
Coal	214	311	274	663	536	439	345	47	33	17	2.8	-1.6	-2.2	-2.0
Oil	59	85	180	514	627	592	518	13	26	25	6.9	1.5	-1.0	0.0
Natural gas	6.4	8.9	12	132	208	219	223	1.3	6.6	11	10.5	3.6	0.3	1.6
Electricity	21	39	89	476	666	747	775	5.9	24	38	9.7	2.6	0.8	1.5
Heat	7.4	13	26	96	106	106	101	2.0	4.8	4.9	7.6	0.8	-0.3	0.1
Hydrogen	-	-	-	-	0.1	0.5	1.1	-	-	0.1	n.a.	n.a.	12.0	n.a.
Renewables	180	200	199	114	77	79	90	30	5.7	4.4	-2.1	-2.9	0.7	-0.7

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	301	621	1 356	6 602	9 117	10 117	10 563	100	100	100	9.1	2.5	0.7	1.4
Coal	159	441	1 060	4 485	4 383	3 514	2 576	71	68	24	9.0	-0.2	-2.6	-1.7
Oil	82	50	47	9.9	7.7	5.0	2.4	8.1	0.1	0.0	-5.9	-1.9	-5.6	-4.1
Natural gas	0.7	2.8	5.8	183	477	733	857	0.4	2.8	8.1	16.8	7.6	3.0	4.8
Nuclear	-	-	17	248	564	753	937	-	3.8	8.9	n.a.	6.5	2.6	4.1
Hydro	58	127	222	1 157	1 486	1 619	1 675	20	18	16	8.5	1.9	0.6	1.1
Geothermal	-	0.1	0.1	0.1	0.4	0.6	0.8	0.0	0.0	0.0	3.0	10.0	2.8	5.6
Solar PV	-	0.0	0.0	131	492	906	1 328	0.0	2.0	13	50.8	10.7	5.1	7.3
Wind	-	0.0	0.6	295	1 536	2 351	2 870	0.0	4.5	27	55.4	13.5	3.2	7.1
CSP and marine	-	0.0	0.0	0.0	3.5	11	29	0.0	0.0	0.3	6.6	41.2	11.2	22.2
Biomass and waste	-	-	2.4	93	168	225	288	-	1.4	2.7	n.a.	4.7	2.7	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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	341	830	2 237	10 161	20 439	30 536	39 687	9.7	5.5	3.4	4.2
Population (million)	981	1 135	1 263	1 386	1 429	1 414	1 368	0.7	0.2	-0.2	0.0
CO_2 emissions (Mt)	1 399	2 146	3 140	9 230	9 019	7 493	5 136	5.6	-0.2	-2.8	-1.8
GDP per capita ($2010 thousand)	0.3	0.7	1.8	7.3	14	22	29	8.9	5.3	3.6	4.3
Primary energy consump. per capita (toe)	0.6	0.8	0.9	2.2	2.4	2.3	2.2	4.0	0.6	-0.4	0.0
Primary energy consumption per GDP*2	1 752	1 053	505	301	166	107	76	-4.5	-4.5	-3.9	-4.1
CO_2 emissions per GDP*3	4 097	2 587	1 404	908	441	245	129	-3.8	-5.4	-5.9	-5.7
CO_2 per primary energy consumption*4	2.3	2.5	2.8	3.0	2.7	2.3	1.7	0.8	-1.0	-2.2	-1.7

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

Table A48 | India [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	200	306	441	882	1 430	1 685	1 879	100	100	100	4.0	3.8	1.4	2.3
Coal	44	93	146	391	569	563	538	30	44	29	5.5	2.9	-0.3	1.0
Oil	33	61	112	223	391	524	644	20	25	34	4.9	4.4	2.5	3.3
Natural gas	1.3	11	23	51	132	171	187	3.5	5.8	9.9	6.0	7.6	1.7	4.0
Nuclear	0.8	1.6	4.4	10.0	50	93	122	0.5	1.1	6.5	7.0	13.2	4.5	7.9
Hydro	4.0	6.2	6.4	12	24	32	40	2.0	1.4	2.1	2.6	5.2	2.7	3.7
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	0.0	0.2	7.5	62	117	176	0.0	0.8	9.4	27.6	17.6	5.4	10.1
Biomass and waste	116	133	149	187	203	186	173	44	21	9.2	1.3	0.6	-0.8	-0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	174	243	314	591	971	1 179	1 338	100	100	100	3.3	3.9	1.6	2.5
Industry	41	67	83	205	394	448	442	27	35	33	4.2	5.2	0.6	2.4
Transport	17	21	32	98	179	273	385	8.5	17	29	5.9	4.7	3.9	4.2
Buildings, etc.	110	142	172	242	312	342	366	59	41	27	2.0	2.0	0.8	1.3
Non-energy use	5.7	13	27	46	86	116	146	5.5	7.8	11	4.7	5.0	2.7	3.6
Coal	25	38	33	101	173	197	200	16	17	15	3.7	4.2	0.7	2.1
Oil	27	50	94	196	358	487	603	21	33	45	5.2	4.8	2.6	3.5
Natural gas	0.7	5.6	9.7	36	92	117	129	2.3	6.1	9.7	7.1	7.5	1.7	3.9
Electricity	7.8	18	32	100	207	273	336	7.6	17	25	6.5	5.7	2.5	3.7
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.1	0.4	-	-	0.0	n.a.	n.a.	16.6	n.a.
Renewables	114	130	144	158	142	106	70	54	27	5.2	0.7	-0.8	-3.5	-2.5

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	120	293	570	1 532	3 017	3 772	4 484	100	100	100	6.3	5.4	2.0	3.3
Coal	61	192	390	1 134	1 530	1 298	1 064	65	74	24	6.8	2.3	-1.8	-0.2
Oil	8.8	13	29	25	17	10	4.4	4.5	1.6	0.1	2.4	-2.9	-6.6	-5.1
Natural gas	0.6	10.0	56	71	207	285	314	3.4	4.6	7.0	7.5	8.6	2.1	4.6
Nuclear	3.0	6.1	17	38	192	357	467	2.1	2.5	10	7.0	13.2	4.5	7.9
Hydro	47	72	74	142	275	370	466	24	9.3	10	2.6	5.2	2.7	3.7
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	0.0	26	392	705	993	-	1.7	22	n.a.	23.2	4.8	11.7
Wind	-	0.0	1.7	51	284	583	949	0.0	3.3	21	31.4	14.1	6.2	9.3
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	-	3.0	4.6	n.a.	7.5	2.9	4.7
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	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	295	506	870	2 651	6 273	10 518	16 320	6.3	6.9	4.9	5.7
Population (million)	697	870	1 053	1 339	1 504	1 593	1 640	1.6	0.9	0.4	0.6
CO_2 emissions (Mt)	258	529	885	2 163	3 433	3 831	4 031	5.4	3.6	0.8	1.9
GDP per capita ($2010 thousand)	0.4	0.6	0.8	2.0	4.2	6.6	10.0	4.6	5.9	4.4	5.0
Primary energy consump. per capita (toe)	0.3	0.4	0.4	0.7	1.0	1.1	1.1	2.4	2.9	0.9	1.7
Primary energy consumption per GDP[*2]	679	605	507	333	228	160	115	-2.2	-2.9	-3.4	-3.2
CO_2 emissions per GDP[*3]	876	1 046	1 017	816	547	364	247	-0.9	-3.0	-3.9	-3.6
CO_2 per primary energy consumption[*4]	1.3	1.7	2.0	2.5	2.4	2.3	2.1	1.3	-0.2	-0.6	-0.4

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

Table A49 | Japan [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	345	439	518	432	398	355	309	100	100	100	-0.1	-0.6	-1.3	-1.0
Coal	60	77	97	116	88	66	39	17	27	13	1.6	-2.1	-3.9	-3.2
Oil	234	250	255	176	134	110	92	57	41	30	-1.3	-2.1	-1.9	-2.0
Natural gas	21	44	66	101	73	59	38	10	23	12	3.1	-2.5	-3.3	-2.9
Nuclear	22	53	84	8.6	56	59	58	12	2.0	19	-6.5	15.6	0.2	6.0
Hydro	7.6	7.6	7.2	7.1	7.8	8.0	8.1	1.7	1.6	2.6	-0.2	0.7	0.2	0.4
Geothermal	0.8	1.6	3.1	2.2	6.5	11	16	0.4	0.5	5.1	1.3	8.6	4.5	6.1
Solar, wind, etc.	-	1.2	0.8	5.5	12	19	33	0.3	1.3	11	5.9	5.9	5.3	5.5
Biomass and waste	-	4.6	5.4	15	21	24	25	1.0	3.5	8.2	4.6	2.6	0.8	1.5

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	236	287	332	293	256	226	200	100	100	100	0.1	-1.0	-1.2	-1.1
Industry	91	108	104	86	78	69	59	38	30	29	-0.8	-0.8	-1.4	-1.2
Transport	54	68	86	71	53	43	36	24	24	18	0.1	-2.2	-1.9	-2.0
Buildings, etc.	58	78	107	101	92	82	74	27	35	37	1.0	-0.8	-1.0	-0.9
Non-energy use	32	33	36	35	33	32	31	11	12	15	0.2	-0.4	-0.4	-0.4
Coal	25	27	21	22	17	14	11	9.5	7.4	5.5	-0.8	-1.7	-2.3	-2.1
Oil	160	177	202	151	120	99	83	61	52	41	-0.6	-1.8	-1.8	-1.8
Natural gas	5.8	14	21	30	30	26	23	4.7	10	11	3.0	0.0	-1.4	-0.9
Electricity	44	66	84	83	82	80	77	23	28	39	0.9	-0.1	-0.3	-0.2
Heat	0.1	0.2	0.5	0.5	0.4	0.4	0.3	0.1	0.2	0.1	3.7	-1.6	-2.1	-1.9
Hydrogen	-	-	-	-	0.0	0.1	0.1	-	-	0.1	n.a.	n.a.	5.1	n.a.
Renewables	-	3.9	4.3	6.6	6.0	5.5	5.7	1.4	2.2	2.9	2.0	-0.7	-0.3	-0.4

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	573	862	1 055	1 061	1 049	1 026	987	100	100	100	0.8	-0.1	-0.3	-0.2
Coal	55	123	223	352	243	163	60	14	33	6.1	4.0	-2.8	-6.7	-5.2
Oil	265	250	134	70	20	8.4	0.5	29	6.6	0.0	-4.6	-9.0	-17.1	-14.0
Natural gas	81	168	258	398	243	191	89	20	38	9.0	3.2	-3.7	-4.9	-4.4
Nuclear	83	202	322	33	217	225	224	23	3.1	23	-6.5	15.6	0.2	6.0
Hydro	88	88	84	83	90	94	94	10	7.8	9.6	-0.2	0.7	0.2	0.4
Geothermal	0.9	1.7	3.3	2.5	7.5	13	18	0.2	0.2	1.8	1.3	8.9	4.5	6.2
Solar PV	-	0.1	0.4	55	109	143	183	0.0	5.2	19	28.2	5.4	2.6	3.7
Wind	-	-	0.1	6.5	24	78	196	-	0.6	20	n.a.	10.5	11.1	10.9
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	8.7	9.9	41	75	91	101	1.0	3.9	10	5.9	4.7	1.5	2.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	20	20	20	20	2.3	1.9	2.1	0.2	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2017	2030	2040	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
GDP ($2010 billion)	3 019	4 704	5 349	6 158	6 762	7 291	7 787	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	1 046	1 145	1 122	851	674	475	0.3	-2.1	-2.9	-2.6
GDP per capita ($2010 thousand)	26	38	42	49	56	65	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	2.9	-0.2	-0.2	-0.6	-0.5
Primary energy consumption per GDP*2	114	93	97	70	59	49	40	-1.0	-1.3	-2.0	-1.7
CO_2 emissions per GDP*3	299	222	214	182	126	92	61	-0.7	-2.8	-3.6	-3.3
CO_2 per primary energy consumption*4	2.6	2.4	2.2	2.6	2.1	1.9	1.5	0.3	-1.5	-1.6	-1.6

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

Table A50 | ASEAN [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	142	232	379	666	999	1 205	1 346	100	100	100	4.0	3.2	1.5	2.2
Coal	3.6	13	32	132	198	221	207	5.4	20	15	9.1	3.2	0.2	1.4
Oil	58	89	153	234	308	357	398	38	35	30	3.7	2.2	1.3	1.6
Natural gas	8.6	30	74	134	214	241	245	13	20	18	5.7	3.7	0.7	1.8
Nuclear	-	-	-	-	12	46	73	-	-	5.5	n.a.	n.a.	9.6	n.a.
Hydro	0.8	2.3	4.1	14	21	26	30	1.0	2.1	2.2	6.9	3.0	1.8	2.3
Geothermal	1.8	6.6	18	31	97	153	200	2.9	4.6	15	5.8	9.2	3.7	5.8
Solar, wind, etc.	-	-	-	0.8	8.9	23	59	-	0.1	4.3	n.a.	20.7	9.9	14.0
Biomass and waste	69	92	98	119	137	133	130	40	18	9.7	1.0	1.1	-0.2	0.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	112	173	269	477	674	778	866	100	100	100	3.8	2.7	1.3	1.8
Industry	22	43	75	148	250	295	324	25	31	37	4.7	4.1	1.3	2.4
Transport	17	32	61	127	162	187	216	19	27	25	5.2	1.9	1.4	1.6
Buildings, etc.	70	87	112	144	174	187	196	50	30	23	1.9	1.5	0.6	0.9
Non-energy use	2.4	11	21	57	87	108	131	6.3	12	15	6.3	3.3	2.0	2.5
Coal	2.1	6.1	13	39	57	64	66	3.5	8.1	7.6	7.1	3.0	0.8	1.6
Oil	41	67	123	219	291	338	381	39	46	44	4.5	2.2	1.4	1.7
Natural gas	2.5	7.5	17	42	87	102	113	4.4	8.8	13	6.6	5.8	1.3	3.0
Electricity	4.7	11	28	75	138	182	223	6.5	16	26	7.3	4.8	2.4	3.3
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.0	0.0	0.0	-	-	0.0	n.a.	n.a.	7.4	n.a.
Renewables	61	81	89	102	101	91	83	47	21	9.6	0.8	0.0	-1.0	-0.6

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	62	154	370	978	1 817	2 458	3 004	100	100	100	7.1	4.9	2.5	3.5
Coal	3.0	28	79	372	639	740	694	18	38	23	10.1	4.2	0.4	1.9
Oil	47	66	72	26	33	34	26	43	2.7	0.9	-3.4	1.9	-1.2	0.0
Natural gas	0.7	26	154	362	626	751	744	17	37	25	10.2	4.3	0.9	2.2
Nuclear	-	-	-	-	45	178	282	-	-	9.4	n.a.	n.a.	9.6	n.a.
Hydro	9.8	27	47	166	245	302	347	18	17	12	6.9	3.0	1.8	2.3
Geothermal	2.1	6.6	16	23	67	102	131	4.3	2.4	4.4	4.7	8.6	3.4	5.4
Solar PV	-	-	-	6.3	68	191	510	-	0.6	17	n.a.	20.1	10.6	14.3
Wind	-	-	-	2.5	34	82	169	-	0.3	5.6	n.a.	22.2	8.3	13.6
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	20	60	79	100	0.4	2.0	3.3	13.8	8.9	2.6	5.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

								1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	2017	2030	2050	2050
GDP ($2010 billion)	440	741	1 180	2 747	5 008	7 463	10 499	5.0	4.7	3.8	4.1
Population (million)	346	430	506	625	699	739	761	1.4	0.9	0.4	0.6
CO_2 emissions (Mt)	185	344	669	1 344	1 851	1 879	1 833	5.2	2.5	0.0	0.9
GDP per capita ($2010 thousand)	1.3	1.7	2.3	4.4	7.2	10	14	3.5	3.8	3.3	3.5
Primary energy consump. per capita (toe)	0.4	0.5	0.7	1.1	1.4	1.6	1.8	2.6	2.3	1.1	1.5
Primary energy consumption per GDP*2	322	314	321	243	199	161	128	-0.9	-1.5	-2.2	-1.9
CO_2 emissions per GDP*3	421	464	567	489	370	252	175	0.2	-2.1	-3.7	-3.1
CO_2 per primary energy consumption*4	1.3	1.5	1.8	2.0	1.9	1.6	1.4	1.2	-0.6	-1.5	-1.2

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

Table A51 | United States [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total[*1]	1 805	1 915	2 274	2 155	2 072	1 924	1 760	100	100	100	0.4	-0.3	-0.8	-0.6
Coal	376	460	534	331	227	139	55	24	15	3.1	-1.2	-2.9	-6.9	-5.3
Oil	797	757	871	790	671	556	462	40	37	26	0.2	-1.3	-1.8	-1.6
Natural gas	477	438	548	644	701	636	496	23	30	28	1.4	0.7	-1.7	-0.8
Nuclear	69	159	208	219	181	182	184	8.3	10	10	1.2	-1.4	0.1	-0.5
Hydro	24	23	22	26	28	30	33	1.2	1.2	1.9	0.4	0.5	0.8	0.7
Geothermal	4.6	14	13	9.2	25	41	57	0.7	0.4	3.2	-1.6	7.9	4.2	5.7
Solar, wind, etc.	-	0.3	2.1	30	97	182	299	0.0	1.4	17	18.4	9.3	5.8	7.2
Biomass and waste	54	62	73	101	139	153	169	3.3	4.7	9.6	1.8	2.5	1.0	1.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	1 311	1 294	1 546	1 520	1 472	1 364	1 262	100	100	100	0.6	-0.2	-0.8	-0.6
Industry	387	284	332	261	275	262	243	22	17	19	-0.3	0.4	-0.6	-0.2
Transport	425	488	588	625	537	463	413	38	41	33	0.9	-1.2	-1.3	-1.3
Buildings, etc.	397	403	473	488	487	461	425	31	32	34	0.7	0.0	-0.7	-0.4
Non-energy use	102	119	153	145	172	178	182	9.2	9.6	14	0.7	1.3	0.3	0.7
Coal	56	56	33	17	12	9.2	6.9	4.3	1.1	0.5	-4.3	-2.7	-2.7	-2.7
Oil	689	683	793	748	641	536	450	53	49	36	0.3	-1.2	-1.8	-1.5
Natural gas	338	303	360	346	349	319	285	23	23	23	0.5	0.1	-1.0	-0.6
Electricity	174	226	301	321	363	387	398	18	21	32	1.3	0.9	0.5	0.7
Heat	-	2.2	5.3	5.9	5.3	4.6	3.8	0.2	0.4	0.3	3.8	-0.8	-1.6	-1.3
Hydrogen	-	-	-	-	0.1	0.3	0.6	-	-	0.0	n.a.	n.a.	10.3	n.a.
Renewables	54	23	54	82	101	108	117	1.8	5.4	9.3	4.8	1.6	0.7	1.1

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	2 427	3 203	4 026	4 264	4 818	5 119	5 204	100	100	100	1.1	0.9	0.4	0.6
Coal	1 243	1 700	2 129	1 321	999	609	220	53	31	4.2	-0.9	-2.1	-7.3	-5.3
Oil	263	131	118	32	22	12	2.9	4.1	0.8	0.1	-5.0	-2.9	-9.7	-7.1
Natural gas	370	382	634	1 338	1 635	1 499	856	12	31	16	4.8	1.6	-3.2	-1.3
Nuclear	266	612	798	839	695	699	708	19	20	14	1.2	-1.4	0.1	-0.5
Hydro	279	273	253	302	323	353	382	8.5	7.1	7.3	0.4	0.5	0.8	0.7
Geothermal	5.4	16	15	19	52	86	119	0.5	0.4	2.3	0.6	8.1	4.2	5.8
Solar PV	-	0.0	0.2	67	237	560	1 166	0.0	1.6	22	44.9	10.2	8.3	9.0
Wind	-	3.1	5.7	257	608	896	1 145	0.1	6.0	22	17.8	6.8	3.2	4.6
CSP and marine	-	0.7	0.5	3.6	84	208	376	0.0	0.1	7.2	6.5	27.5	7.8	15.1
Biomass and waste	0.5	86	72	79	158	192	224	2.7	1.8	4.3	-0.4	5.5	1.8	3.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	5.4	5.4	5.4	5.4	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

								1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	2017	2030	2050	2050
GDP ($2010 billion)	6 529	9 064	12 713	17 349	22 684	28 174	33 922	2.4	2.1	2.0	2.1
Population (million)	227	250	282	325	350	367	379	1.0	0.6	0.4	0.5
CO_2 emissions (Mt)	4 582	4 763	5 656	4 781	4 005	3 088	2 167	0.0	-1.4	-3.0	-2.4
GDP per capita ($2010 thousand)	29	36	45	53	65	77	89	1.4	1.5	1.6	1.6
Primary energy consump. per capita (toe)	7.9	7.7	8.1	6.6	5.9	5.2	4.6	-0.5	-0.9	-1.2	-1.1
Primary energy consumption per GDP[*2]	276	211	179	124	91	68	52	-1.9	-2.3	-2.8	-2.6
CO_2 emissions per GDP[*3]	702	525	445	276	177	110	64	-2.4	-3.4	-5.0	-4.3
CO_2 per primary energy consumption[*4]	2.5	2.5	2.5	2.2	1.9	1.6	1.2	-0.4	-1.1	-2.2	-1.8

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

Table A52 | European Union [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	1990/ 2017	2017/ 2030	2030/ 2050	2017/ 2050
Total*1	n.a.	1 645	1 695	1 619	1 460	1 317	1 194	100	100	100	-0.1	-0.8	-1.0	-0.9
Coal	n.a.	454	321	234	140	81	60	28	14	5.0	-2.4	-3.9	-4.2	-4.1
Oil	n.a.	607	624	531	429	345	278	37	33	23	-0.5	-1.6	-2.1	-1.9
Natural gas	n.a.	297	396	398	358	310	237	18	25	20	1.1	-0.8	-2.1	-1.6
Nuclear	n.a.	207	246	216	215	226	232	13	13	19	0.2	-0.1	0.4	0.2
Hydro	n.a.	25	31	26	29	30	31	1.5	1.6	2.6	0.1	1.0	0.2	0.5
Geothermal	n.a.	3.2	4.6	6.8	10	12	13	0.2	0.4	1.1	2.9	3.1	1.1	1.9
Solar, wind, etc.	n.a.	0.3	2.4	46	90	122	153	0.0	2.8	13	20.1	5.4	2.7	3.7
Biomass and waste	n.a.	48	67	159	186	188	189	2.9	9.8	16	4.6	1.2	0.1	0.5

Final energy consumption

	Mtoe							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	n.a.	1 133	1 178	1 154	1 059	946	844	100	100	100	0.1	-0.7	-1.1	-0.9
Industry	n.a.	345	308	263	256	237	213	30	23	25	-1.0	-0.2	-0.9	-0.6
Transport	n.a.	259	303	327	267	215	181	23	28	21	0.9	-1.6	-1.9	-1.8
Buildings, etc.	n.a.	430	454	461	434	393	355	38	40	42	0.3	-0.5	-1.0	-0.8
Non-energy use	n.a.	99	112	102	103	101	96	8.7	8.9	11	0.1	0.0	-0.3	-0.2
Coal	n.a.	120	51	35	23	18	15	11	3.1	1.8	-4.4	-3.3	-2.1	-2.6
Oil	n.a.	506	542	479	390	313	253	45	42	30	-0.2	-1.6	-2.1	-1.9
Natural gas	n.a.	227	272	254	242	217	193	20	22	23	0.4	-0.4	-1.1	-0.8
Electricity	n.a.	186	217	241	258	265	266	16	21	32	1.0	0.5	0.2	0.3
Heat	n.a.	55	45	49	43	36	30	4.9	4.2	3.6	-0.5	-0.9	-1.8	-1.4
Hydrogen	n.a.	-	-	-	0.0	0.1	0.2	-	-	0.0	n.a.	n.a.	8.7	n.a.
Renewables	n.a.	40	50	96	103	95	87	3.5	8.3	10	3.3	0.6	-0.8	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	1990	2017	2050	2017	2030	2050	2050
Total	n.a.	2 577	3 006	3 269	3 508	3 568	3 580	100	100	100	0.9	0.5	0.1	0.3
Coal	n.a.	1 050	968	710	410	154	67	41	22	1.9	-1.4	-4.1	-8.7	-6.9
Oil	n.a.	224	181	61	31	15	4.9	8.7	1.9	0.1	-4.7	-5.1	-8.8	-7.4
Natural gas	n.a.	193	480	663	612	517	245	7.5	20	6.8	4.7	-0.6	-4.5	-3.0
Nuclear	n.a.	795	945	830	824	868	890	31	25	25	0.2	-0.1	0.4	0.2
Hydro	n.a.	290	357	301	342	349	355	11	9.2	9.9	0.1	1.0	0.2	0.5
Geothermal	n.a.	3.2	4.8	6.7	10	13	13	0.1	0.2	0.4	2.8	3.4	1.2	2.1
Solar PV	n.a.	0.0	0.1	114	267	433	652	0.0	3.5	18	39.1	6.8	4.6	5.4
Wind	n.a.	0.8	22	362	654	777	844	0.0	11	24	25.6	4.6	1.3	2.6
CSP and marine	n.a.	0.5	0.5	6.4	38	72	101	0.0	0.2	2.8	9.9	14.7	5.0	8.7
Biomass and waste	n.a.	20	46	211	316	365	402	0.8	6.4	11	9.2	3.2	1.2	2.0
Hydrogen	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	n.a.	0.2	1.4	4.9	4.9	4.9	4.9	0.0	0.1	0.1	12.3	0.0	0.0	0.0

Energy and economic indicators

								1990/	2017/	2030/	2017/
	1980	1990	2000	2017	2030	2040	2050	2017	2030	2050	2050
GDP ($2010 billion)	n.a.	11 891	14 783	18 824	22 909	26 160	29 207	1.7	1.5	1.2	1.3
Population (million)	n.a.	478	488	512	518	518	511	0.3	0.1	-0.1	0.0
CO_2 emissions (Mt)	n.a.	3 980	3 783	3 201	2 379	1 792	1 348	-0.8	-2.3	-2.8	-2.6
GDP per capita ($2010 thousand)	n.a.	25	30	37	44	51	57	1.5	1.4	1.3	1.3
Primary energy consump. per capita (toe)	n.a.	3.4	3.5	3.2	2.8	2.5	2.3	-0.3	-0.9	-0.9	-0.9
Primary energy consumption per GDP*2	n.a.	138	115	86	64	50	41	-1.7	-2.3	-2.2	-2.2
CO_2 emissions per GDP*3	n.a.	335	256	170	104	69	46	-2.5	-3.7	-4.0	-3.9
CO_2 per primary energy consumption*4	n.a.	2.4	2.2	2.0	1.6	1.4	1.1	-0.7	-1.5	-1.8	-1.7

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

Slides

The 433rd Forum on Research Work

IEEJ Outlook 2020

Coping with the increasingly challenging energy trilemma (3Es)

Energy, Environment and Economy

Tokyo, 15 October 2019

The Institute of Energy Economics, Japan

Energy supply/demand up to 2050

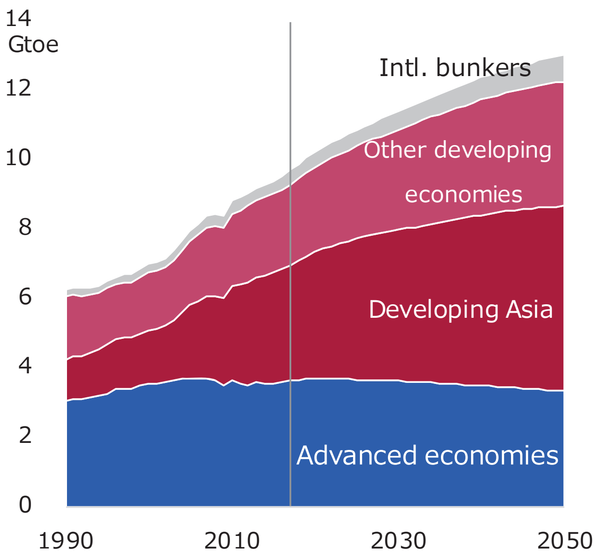
Basic scenarios in IEEJ Outlook

	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.
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.

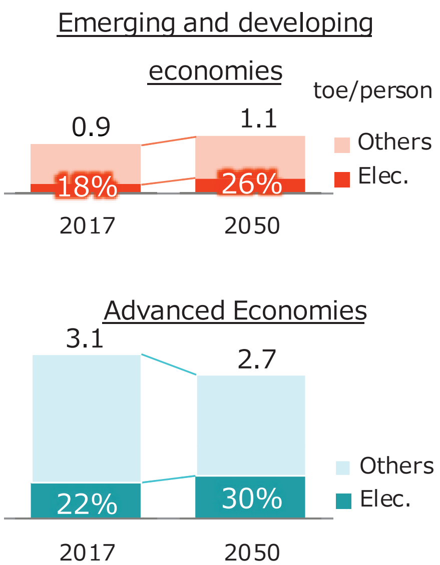
Reference Scenario

Demand level still low in developing economy

Final energy demand



Energy demand per capita



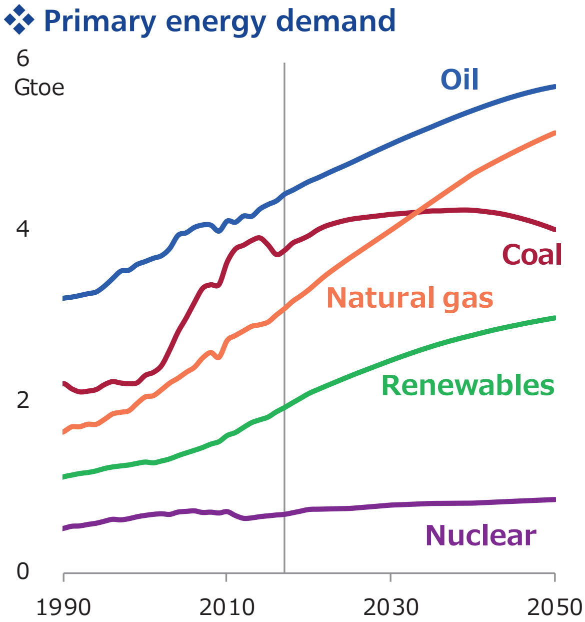
Global final energy demand increases by 30% by 2050 while advanced economies reduce demand.

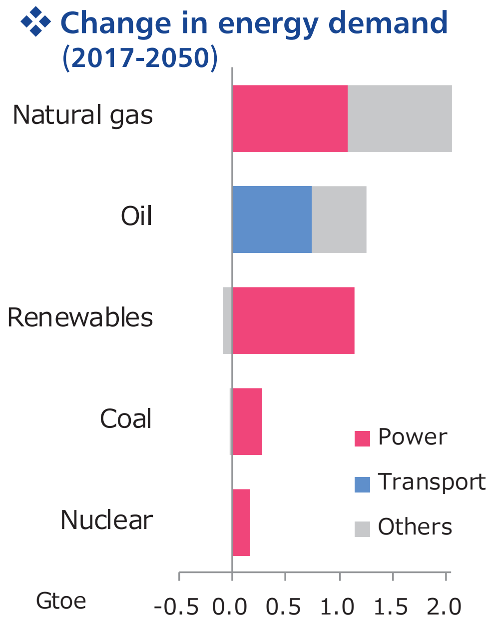
In emerging and developing economies, demand per capita remains under half of advanced economies even in 2050.

Electricity demand continues to increase and electrification rate rises in final energy demand.

Reference Scenario

Dependency to fossil fuels remains unchanged





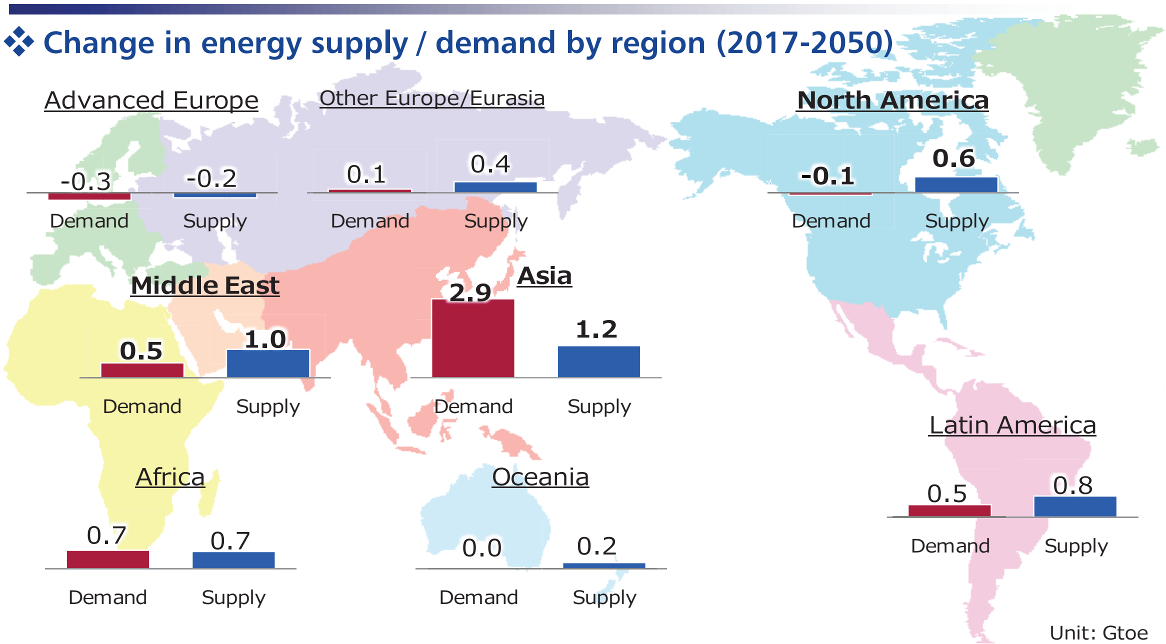
Natural gas increases by 1.7 times especially in the power sector, becoming a second-position energy.

Coal peaks around 2040 and oil remains the most important energy.

Renewables grow rapidly but their share of primary demand mix increase only to 16% from 14%. Lessing dependency on fossil fuels progresses slowly.

Reference Scenario

Growth in demand overwhelms supply in Asia



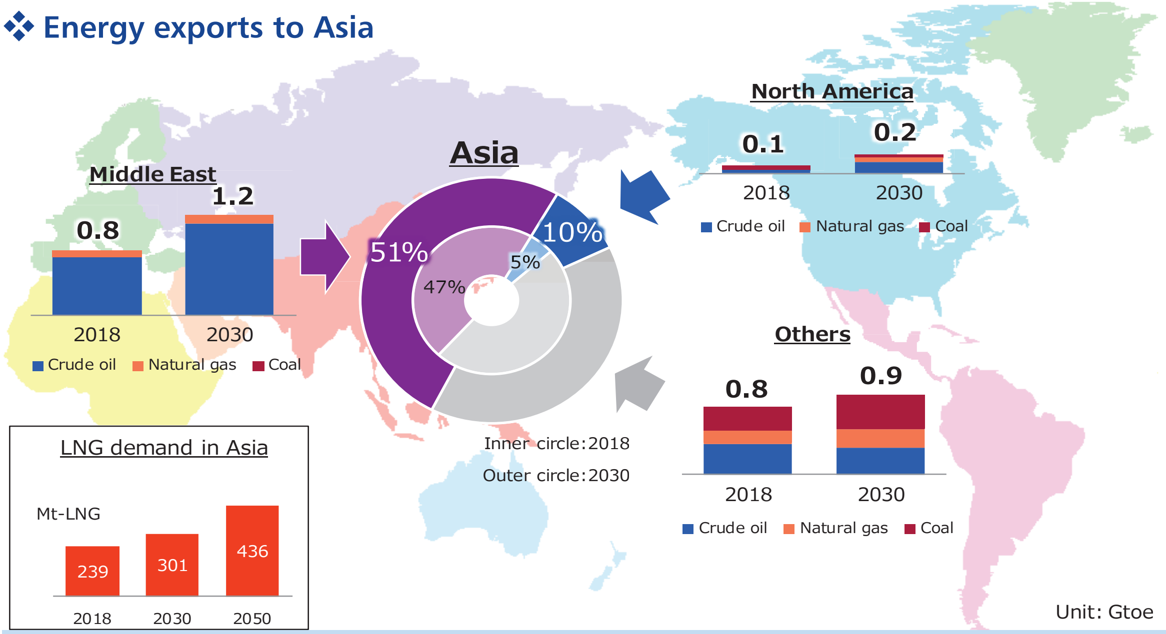
Over 60% of global demand growth comes from Asia. Meanwhile its energy supply cannot catch up, resulting in dropping energy self sufficiency from 72% to 61%.

North America and the Middle East increase surplus export capacity and enlarge their presences as energy suppliers.

Reference Scenario

Global energy goes to Asia

Energy exports to Asia



Destination of 80% of global energy trade will be Asia (67% in 2017).

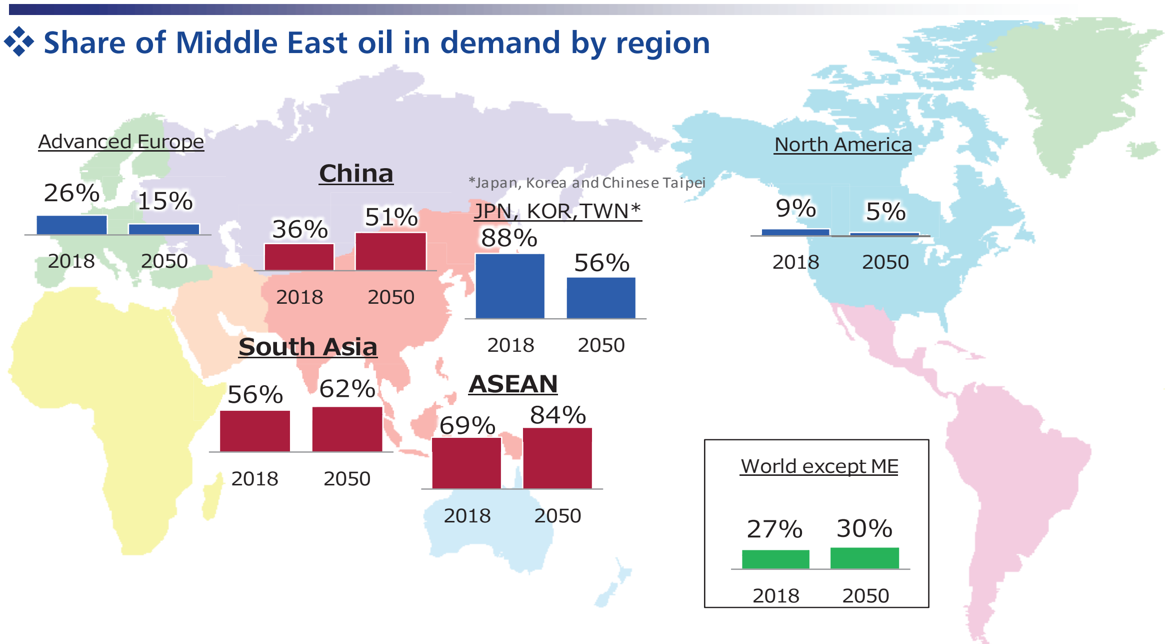
Imports from North America increase by 3 times. Over 50% of energy imports comes from the Middle East and energy relationship between Asia and ME is further strengthened.

LNG demand in Asia also increases rapidly but its import sources diversify.

Reference Scenario

Only Asia pushes up dependence on ME

Share of Middle East oil in demand by region



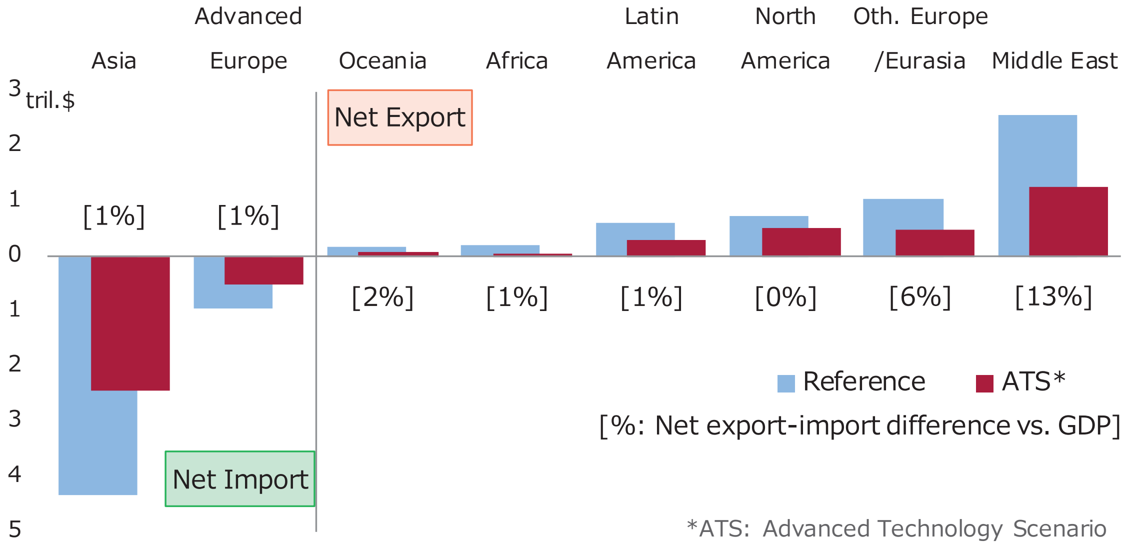
Developing Asia increases dependence on Middle East oil and mitigating risk of supply disruption remains one of the priority issues.

Meanwhile, North America and Advanced Europe reduce the dependence rapidly but would be affected by higher oil price when emergency due to higher dependence at the global level.

Advanced Technologies Scenario

Unclear oil revenue for the Middle East

❖ Net energy exports / imports by region (2050)



In the Advanced Technologies Scenario, demand growth of fossil fuels slows and prices are lower than in the Reference Scenario.

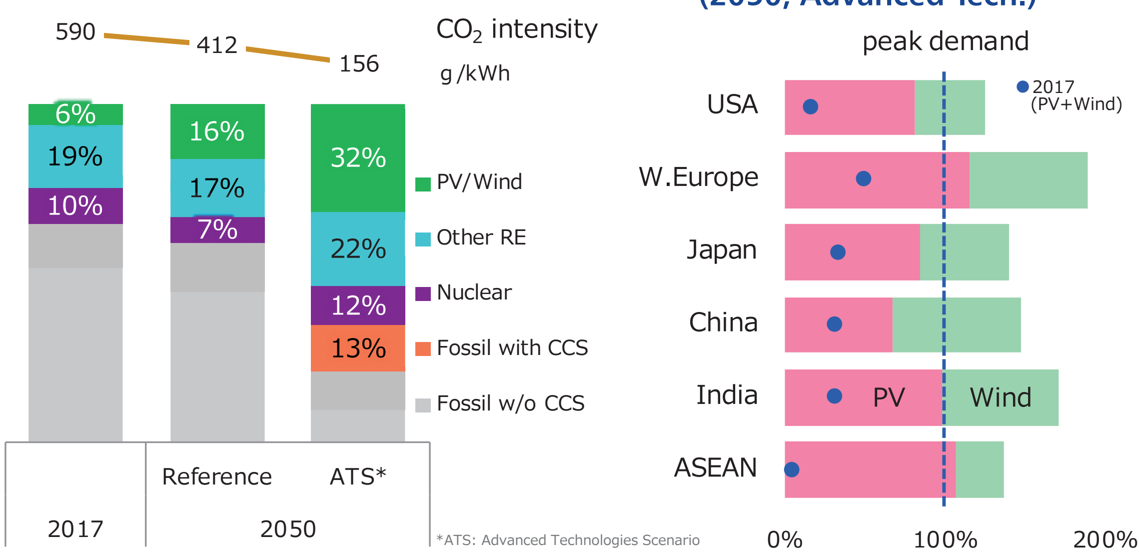
Asia and Advanced Europe can reduce net import bills a lot. Meanwhile, oil and gas export revenues for the Middle East could decrease by the equivalent to 13% of its GDP.

Advanced Technologies Scenario

VRE capacity surpass peak demand

❖ Power mix and CO_2 intensity

❖ Ratio of capacity to peak demand (2050, Advanced Tech.)

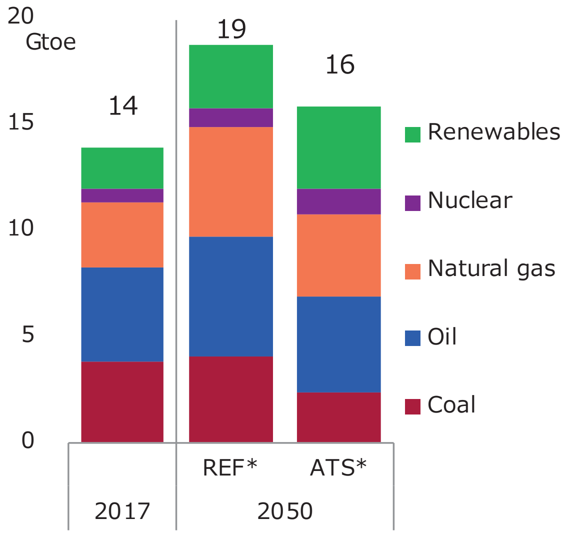


Zero-emission power generation (renewables, nuclear and fossil thermal with CCS) dominates 80% of power generation mix in the Advanced Technologies Scenario.

Generation capacity of variable renewable energy (VRE), such as solar PV and wind, exceeds peak electricity demand. Some regions need system stability measures, such as battery storage.

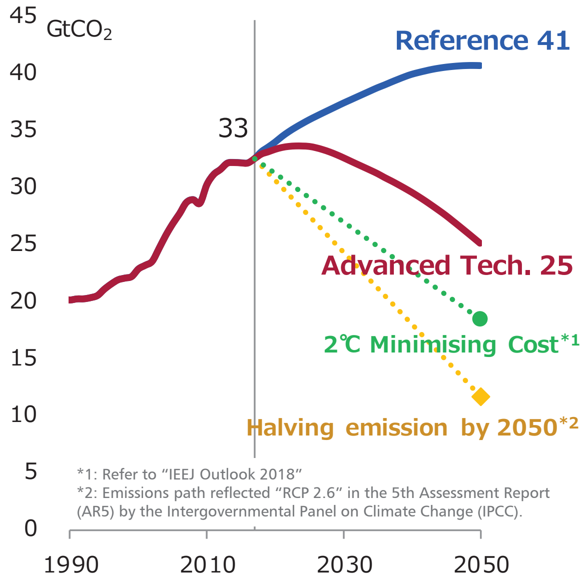
Even after large reduction, 2°C goal still far

Primary energy demand



*REF: Reference Scenario, ATS: Advanced Technologies Scenario

Energy-related CO_2 emissions



*1: Refer to "IEEJ Outlook 2018"
*2: Emissions path reflected "RCP 2.6" in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC).

In the Advanced Technologies Scenario, dependence on fossil fuels drops to 70%, still high level.

Energy-related CO_2 emissions peak at the middle of 2020s and decrease by 23% vs. 2017 in 2050.

To keep temperature rise to below 2 degrees Celsius, additional programs and innovative technologies are required.

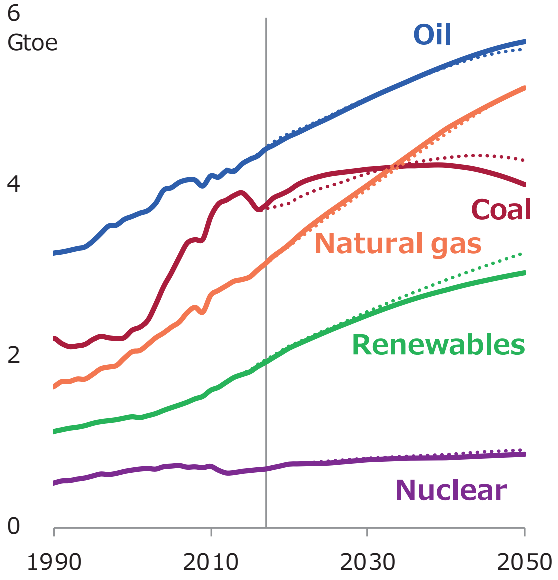
Summary

- ✓ Only emerging and developing economies increase energy demand. They possibly continue to increase after 2050 because their demand per capita is still at lower level.
- ✓ In Asia, demand growth overwhelms supply growth and it increases energy imports from North America and the Middle East. Dependence on ME oil increases and mitigating risk of supply disruption remains one of the priority issues.
- ✓ Results of decarbonizing vary among countries. The Middle East urgently needs of shifting away from an economy that excessively depends on oil export revenues.
- ✓ In the Advanced Technologies Scenario, generation capacity of VRE exceeds peak demand and system stability measures are needed. Meanwhile, dependence on fossil fuels is still high, resulting in falling short of the 2°C goal. R&D for innovative technologies is required.

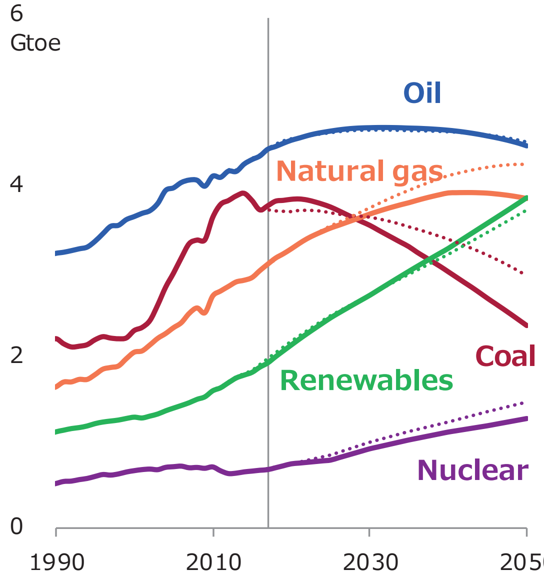
Reference material

Comparison with IEEJ Outlook 2019

❖ Reference Scenario



❖ Advanced Technologies Scenario

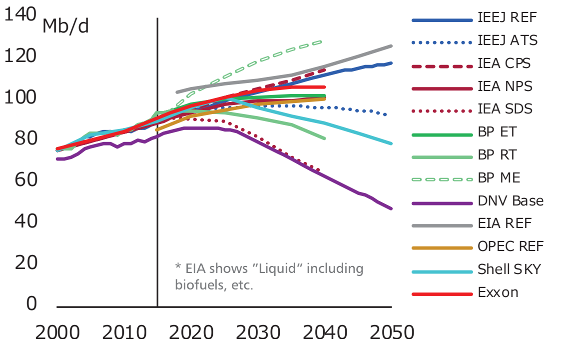


* Primary energy demand
Solid lines: IEEJ Outlook 2020
Dotted lines: IEEJ Outlook 2019

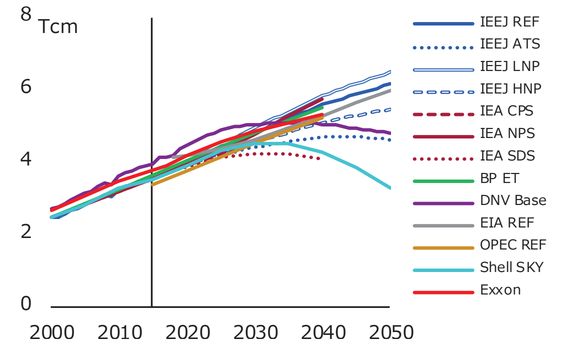
Reference material

Comparison with other institutes (1)

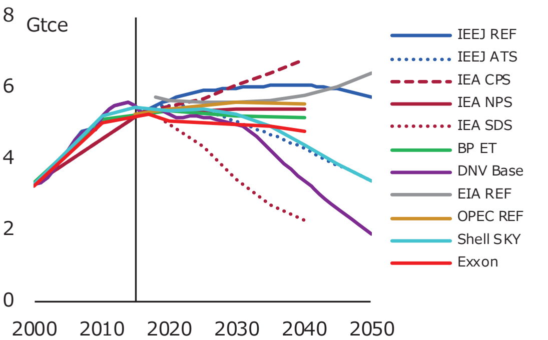
❖ Oil



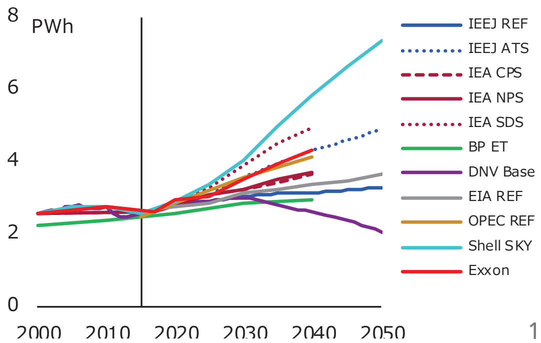
❖ Natural gas



❖ Coal



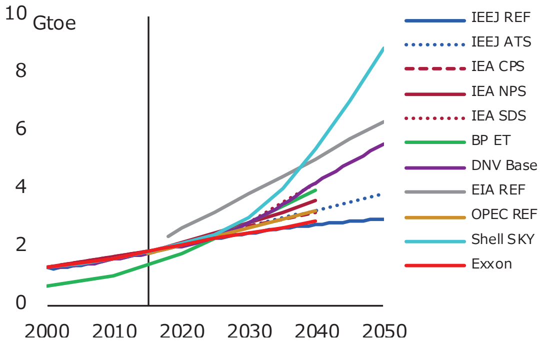
❖ Nuclear



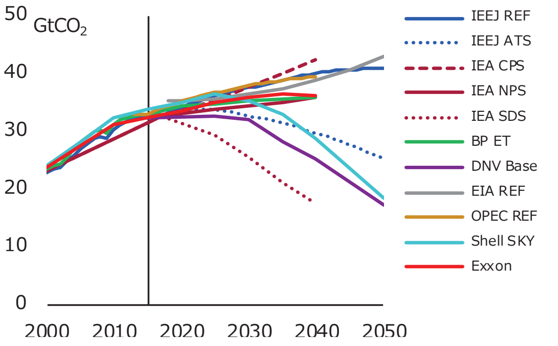
Reference material

Comparison with other institutes (2)

Renewables



Energy-related CO_2



Source

IEEJ "IEEJ Outlook 2020", Oct. 2019
- REF: Reference Scenario
- ATS: Advanced Technologies Scenario
- LNP: Low Price Case
- HNP: High Price Case

IEA "World Energy Outlook 2018", Nov. 2018
- CPS: Current Policies Scenario
- NPS: New Policies Scenario
- SDS: Sustainable Development Scenario

BP "BP Energy Outlook 2019", Feb. 2019
- ET: Evolving transition
- RT: Rapid transition demand
- ME: More energy demand

DNV GL "Energy Transition Outlook 2019", Sep. 2019
- Base: Base Scenario

US EIA "International Energy Outlook 2019", Sep. 2019
- REF: Reference Scenario

OPEC "World Oil Outlook 2040", Oct. 2018
- REF: Reference Scenario

Shell "Shell Scenarios", May 2018
- SKY: Sky Scenario

ExxonMobil "Outlook for Energy", Aug. 2019

Climate change issues

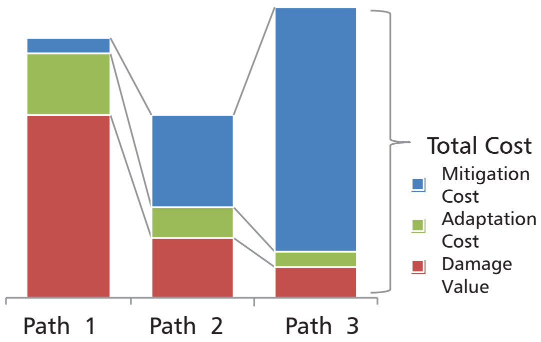
— Challenges for total cost minimization analysis —

Rule for ultra long-term: Minimize the total cost

❖ 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 Total Cost for Each Path



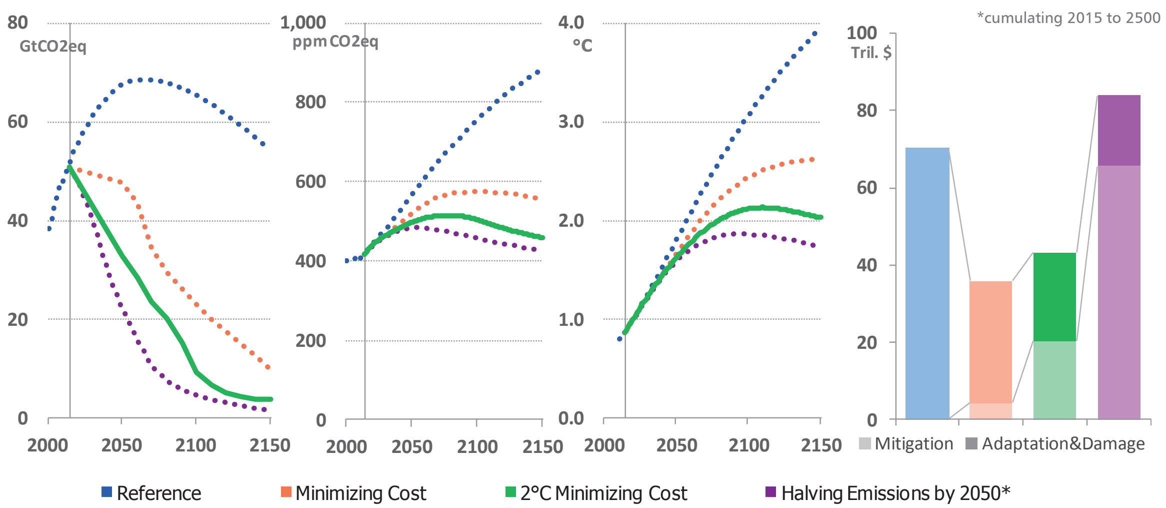
Path 1	Path 2	Path 3	
Too Small	Reasonable	Too Big	Mitigation
Big	Medium	Small	Adaptation
Big	Medium	Small	Damage

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.

Cost-benefit analysis for “2°C target” (IEEJ Outlook 2018)

❖ GHG Emissions ❖ GHG Concentrations (incl. aerosol etc.) ❖ Temperature Rise (vs. 1850-1900) ❖ Total Cost (cumulative present value*)



“2°C Minimizing Cost”, for example, is a path that minimizes total cost under the condition of 2°C temperature rise in 2150. Its total cost is 20% higher than “Minimizing Cost” without the temperature limit, but still 50% lower than “Halving Emissions”. GHG emissions decrease by 30% in 2050 and needs almost zero-emissions after 2100. Temperature rises to slightly above 2°C by 2100 and then declines to 2°C.

*Emissions path reflected “RCP 2.6” in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC).

Technology development for ultra long-term

Technologies		Description	Challenges
Technologies to reduce CO_2 emissions	Next Generation Nuclear Reactors	Fourth-generation nuclear reactors such as ultra-high-temperature gas-cooled reactors (HTGR) and fast reactors, and small- and medium-sized reactors are now being developed internationally.	Expansion of R&D support for next generation reactors
	Nuclear fusion reactor	Technology to extract energy just like the sun by nuclear fusion of small mass number such as hydrogen. Deuterium as fuel exists abundantly and universally. Spent nuclear fuel as high-level radioactive waste is not produced.	Technologies for continuously nuclear fusion and confining them in a certain space, energy balance, cost reduction, financing for large-scale development and establishment of international cooperation system, etc.
	Space Photovoltaic Satellite (SPS)	Technologies for solar PV power generation in space where sunlight rings abundantly above than on the ground and transmitting generated electricity to the earth wirelessly via microwave, etc.	Establishment of wireless energy transfer technology, reduction of cost of carrying construction materials to space, etc.
Technologies to sequestrate CO_2 or to remove CO_2 from the atmosphere	**Hydrogen production and usage**	Production of **carbon-free hydrogen** by steam reforming of fossil fuels and by CCS implementation of CO_2 generated.	Cost reduction of hydrogen production (**fossil and RE basis**), efficiency improvement, infrastructure development (**#1&2 Hydrogen Energy Ministerial Meeting/Tokyo Statement**), etc.
	CO_2 sequestration and usage (**carbon recycling**)	Produce carbon compounds to be chemical raw materials, etc. using CO_2 as feedstocks by electrochemical method, photochemical method, biochemical method, or thermochemical method. **CO_2 can be removed from the atmosphere**.	Dramatic improvement in quantity and efficiency, etc. (**International Conference on Carbon Recycling**).
	Bio-energy with carbon capture and storage (BECCS)	Absorption of carbon from the atmosphere by photosynthesis with biological process and CCS.	It requires large-scale land and may affect land area available for the production of food etc.

Challenges for cost-benefit analysis

1) Is the relationship between temperature rise and damage value accurate?

- Estimation of the damages caused by climate change involves great uncertainties. Although research is progressing around the world, sufficient knowledge has not been accumulated.[*1]。
- It is important to refine the damage function (relationship between temperature rise and damage value) based on the latest scientific knowledge.

*1:Most integrated assessment models do not cover all types of damages, and do not consider the interaction between them. Critics say that in many cases the estimated damages for relatively low temperatures (temperature rise of about 1 to 3 °C) for Europe and the United States are applied to other regions and to higher temperatures, possibly resulting in considerable underestimation.

2) Modeling tipping elements

- If the progress of an event exceeds the critical point, the automatic absorption of GHG by the Earth system will 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.

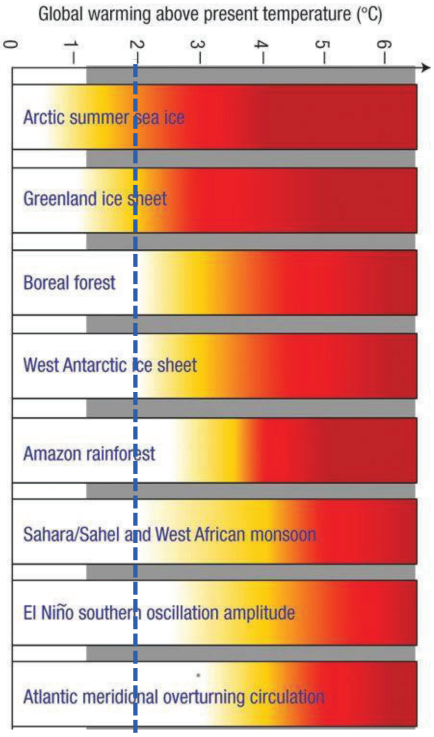
3) Other theoretical issues

- Issues related to long-term discount rates, “fat tails[*2]”, etc.
- Discussions continue, and no consensus has been found among many researchers at present.

*2: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).

Examples of tipping elements

1. Arctic summer sea ice: decrease in areal extent----------
   Decreased albedo, amplified warming
2. Greenland ice sheet: decrease in ice volume-------------
   Decreased albedo, sea level rise
3. Boreal forest: decrease in tree fraction-------------------
   Greenhouse gas emissions, biome switch
4. West Antarctic ice sheet: decrease in ice volume----------
   Decreased albedo, sea level rise
5. Amazon rainforest: decrease in tree fraction--------------
   Greenhouse gas emissions, biodiversity loss
6. Sahara/Sahel and West African monsoon: increased carrying capacity---
   Increase in vegetation fraction
7. El Nino southern oscillation: increase in amplitude--------
   Drought in Southeast Asia and elsewhere
8. Atlantic meridional overturning circulation: decrease in overturning---
   Regional cooling, ITCZ (Intertropical convergence zone) shift



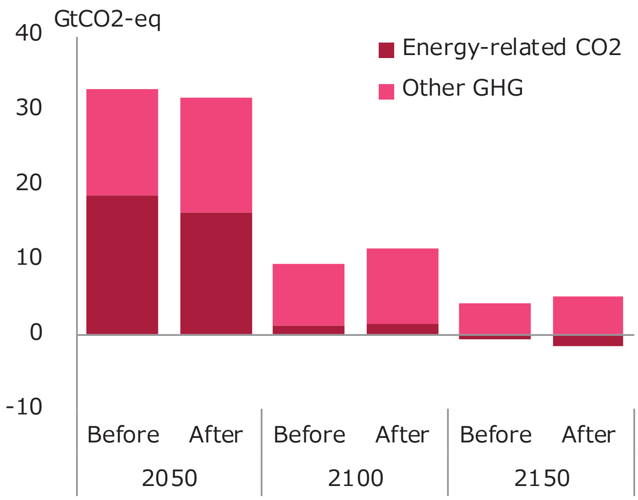
* The deeper red, the more likely to occur.

T. M. Lenton and H. J. Schellnhuber, 2007. Tipping the scales. *Nature Report Climate Change*, 1, 97-98.

Cost-benefit analysis incorporating tipping elements

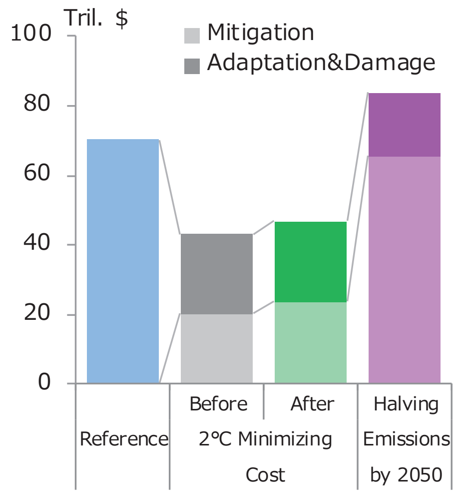
The tipping elements incorporated into the model: (1) Melting of the Greenland ice sheet, (2) CO_2 and CH_4 release due to melting of permafrost, (3) Changes in albedo (sunlight reflection) due to decrease in Arctic sea ice

❖ GHG Emissions (2°C Minimizing Cost)



❖ Total cost (cumulative present value*)

*cumulating 2015 to 2500



Incorporating the three tipping elements will reduce the amount of energy-related CO_2 emissions and increase the total cost. However, since the damage effect occurs over a long period of time, the impact on the results of cost-benefit analysis is not significant.

Summary and way forward

- ✓ Necessary to make efforts to minimize the total cost (total of damage, adaptation cost, and mitigation cost) when considering both economic growth and climate change measures.
- ✓ Must recognize that the cost-benefit analysis approach is still facing many issues.
- ✓ The impact of incorporating three tipping elements in the cost-benefit analysis was not significant because these phenomena take a long time for their full impacts to unfold (for example, the ice sheets melt slowly).
- ✓ Desirable to incorporate the uncertainty of phenomenon occurrence into the analysis and draw a clearer conclusion. In addition, it is necessary to incorporate other tipping elements and confirm whether they produce similar conclusions.
- ✓ Establishing and evaluating damage functions based on the latest scientific knowledge is an important issue for the future. We will continue to further refine the analysis.

Reference material

Example of attempts to refine the damage function

Spatial distribution of projected damages

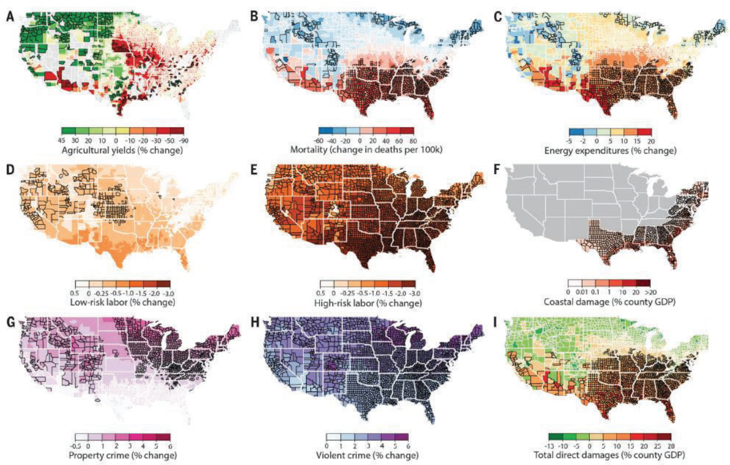
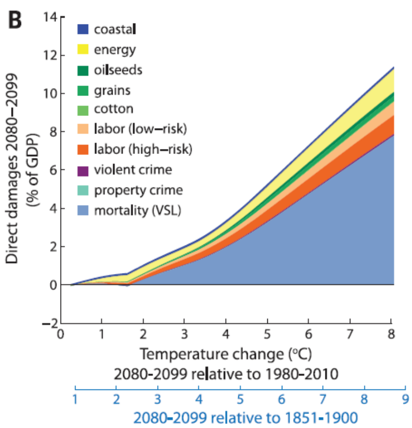


Fig. 2. Spatial distributions of projected damages. County-level median values for average 2080 to 2099 RCP8.5 impacts. Impacts are changes relative to counterfactual "no additional climate change" trajectories. Color indicates magnitude of impact in median projection; outline color indicates level of agreement across projections (thin white outline, inner 66% of projections disagree in sign; no outline, ≥83% of projections agree in sign; black outline, ≥95% agree in sign; thick white outline, state borders; maps without outlines shown in fig. S2). Negative damages indicate economic gains. (**A**) Percent change in yields, area-weighted average for maize, wheat, soybeans, and cotton. (**B**) Change in all-cause mortality rates, across all age groups. (**C**) Change in electricity demand. (**D**) Change in labor supply of full-time-equivalent workers for low-risk jobs where workers are minimally exposed to outdoor temperature. (**E**) Same as (D), except for high-risk jobs where workers are heavily exposed to outdoor temperatures. (**F**) Change in damages from coastal storms. (**G**) Change in property-crime rates. (**H**) Change in violent-crime rates. (**I**) Median total direct economic damage across all sectors [(A) to (H)].

Total damage (as a percentage of GDP)

About 2 to 3% at 4 °C
and about 10 to 11% at 8 °C



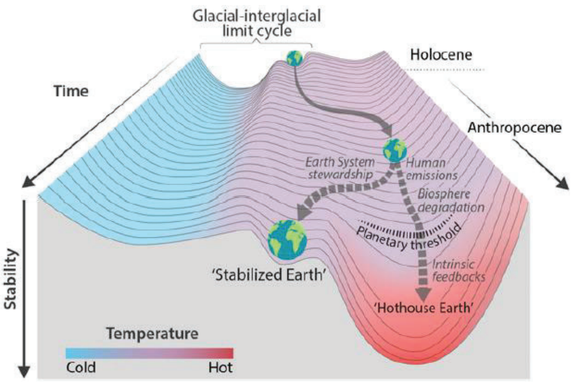
- The efforts to refine the damage function are being promoted in the United States, although the sophisticated results do not always differ significantly from previous estimations.

Hsiang et al., 2017. Estimating economic damage from climate change in the United States. *Science*, 356, 1362-1369.

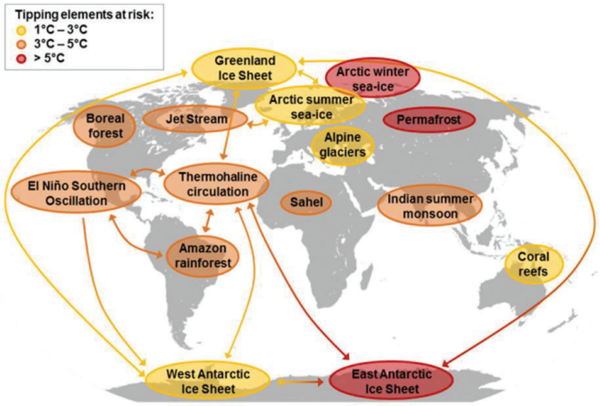
Reference material

Hothouse earth

“Stabilized Earth” & ”Hothouse Earth”



Examples of ”tipping elements”



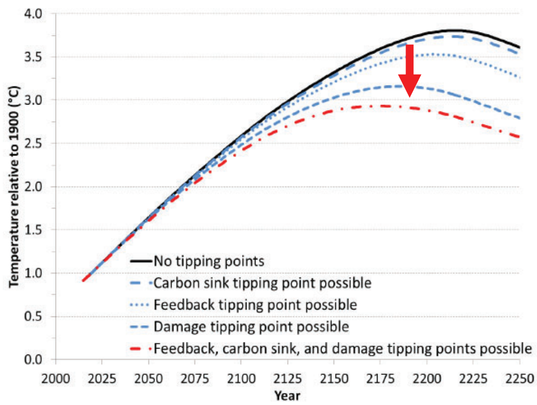
The Earth System is going out of the glacial–interglacial limit cycle. Currently, the Earth System is on a Hothouse Earth pathway driven by human emissions of greenhouse gases and biosphere degradation toward a planetary threshold, beyond which the system follows an essentially irreversible pathway driven by intrinsic biogeophysical feedbacks. The other pathway leads to Stabilized Earth, a pathway of Earth System stewardship.
According to Steffen et al, (2018), when the temperature rises above a certain tipping point, the GHG's automatic absorption function of the Earth system stops functioning. He stated that there is a possibility of going to another equilibrium state (possibly at higher temperatures) than the conventional glacial / interglacial cycle.

W. Steffen et al., 2018. Trajectories of the earth system in the Anthropocene. *PNAS*, 115(33), 8252-8259.

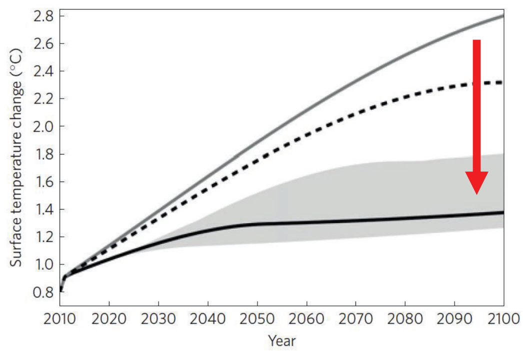
Reference material

Analysis example incorporating Tipping elements

Lemoine and Traeger (2016)



Cai et al. (2016)



According to Lemoine and Traeger (2016), considering three tipping elements related to (1) damage, (2) carbon sink, and (3) temperature feedback, the maximum temperature rise drops from around 4 °C to around 3 °C under the optimization path. Also, according to Cai et al. (2016), taking into account five types of tipping elements, the temperature rise for the optimization path drops from 2.8 °C to less than 1.5 °C in 2100.
Considering tipping elements, the damage with the same mitigation path becomes larger, so the optimum temperature path moves downward. In these calculations, however, the tipping elements are only considered as binary values and does not take into account the dynamism of changes in the earth system.

D. Lemoine and C. P. Traeger, 2016. Economics of tipping the climate dominoes. *Nat. Clim. Change*, 6, 514-519.
Y. Cai, T. M. Lenton and T. S. Lontzek, 2016. Risk of multiple interacting tipping points should encourage rapid CO_2 emission reduction. *Nat. Clim. Change*, 6, 520-525.

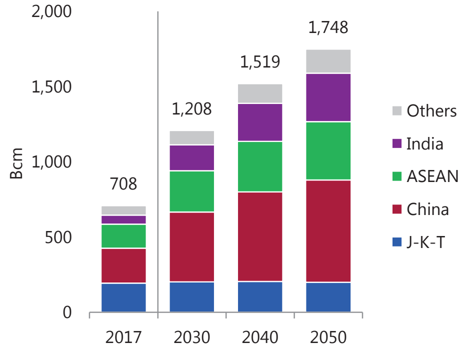
Toward sound development of the Asian LNG market

-Competitiveness and security of supply-

Expanding Asian gas market

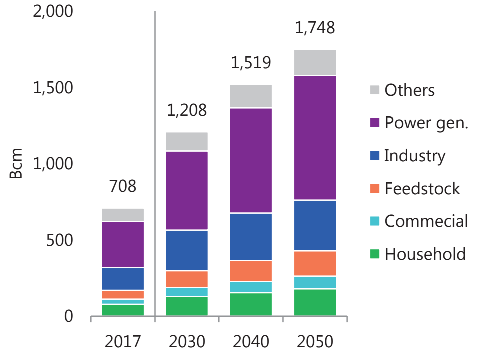
- Natural gas, which has the lowest environmental footprint among fossil fuels, is anticipated to play a bigger role in the future in Asia.
- Though China and India present the largest demand growth, ASEAN is expected to show remarkable growth as well.
- In terms of demand sectors, power generation is the fastest growing. However, LNG cannot avoid competition with coal in the sector.

Natural gas demand outlook in Asia by region



J-K-T = Japan, Korea, and Chinese Taipei
Source: IEEJ

Natural gas demand outlook in Asia by sector



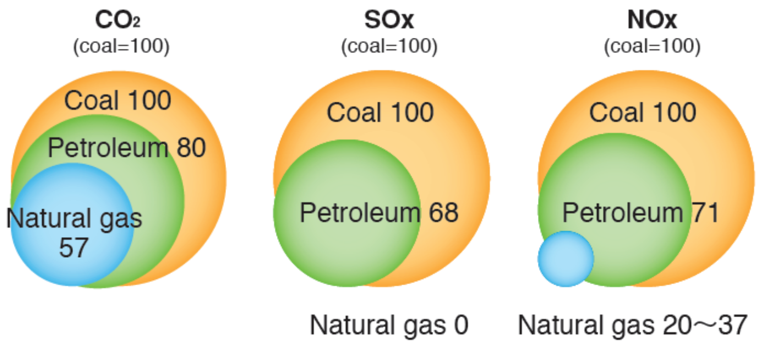
Source: IEEJ

Reference material

Characteristics of fossil fuels

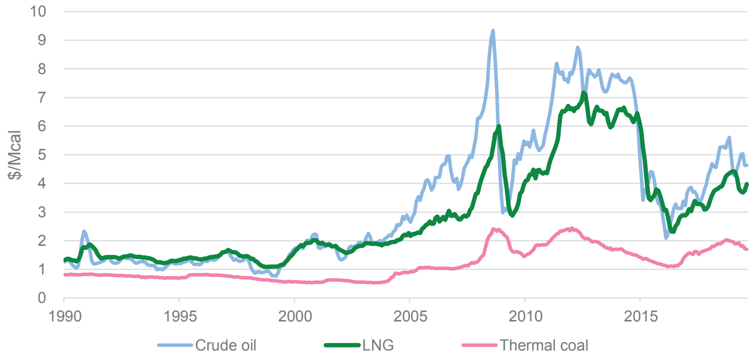
❖ Environmental footprint

Source: Japan Gas Association



❖ Japan's import prices per unit of energy

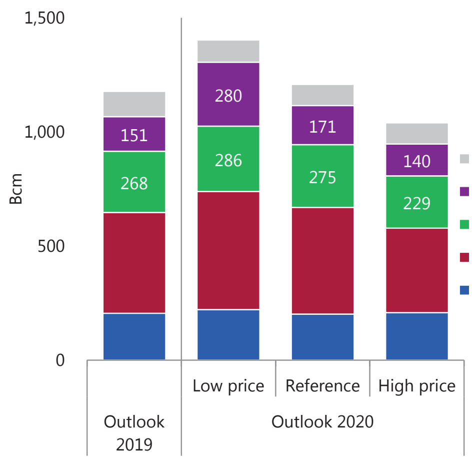
Source: IEEJ

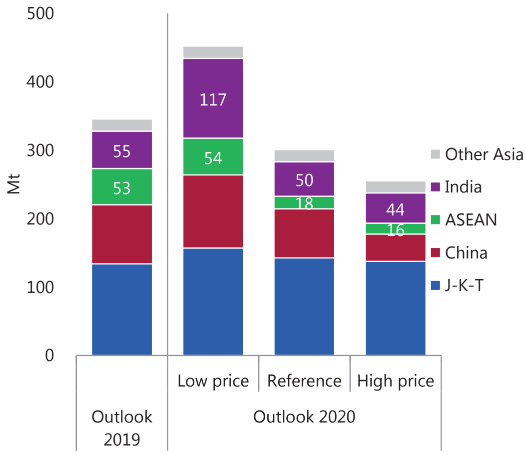


Downward revision of LNG demand

- Current price level (around $10/MBtu) cannot encourage LNG demand in developing Asia where affordability is the primary objective of energy policy.
- Therefore, Asian LNG demand outlook is downgraded, notably in India and ASEAN.

❖ Comparison of demand outlook in 2030 (left: total natural gas, right: LNG)



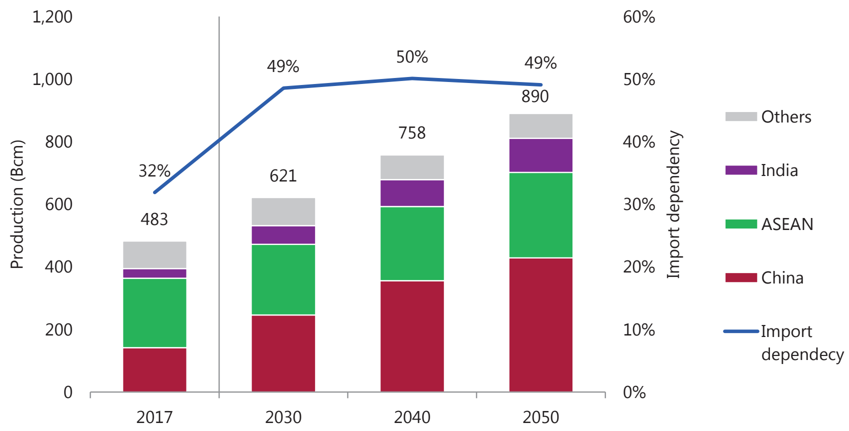


J-K-T = Japan, Korea, and Chinese Taipei
Source: IEEJ

Necessity of competitively priced LNG

- The majority of gas demand growth will be filled by import, which will raise import dependence from 32% in 2017 to 49% in 2050.
- Competitiveness of LNG will become more important than ever in Asia where import requirement grows fast.

❖ Natural gas production and import dependency in Asia



Source: IEEJ

Assumption of LNG price in Asia

- **Reference Scenario**: Real LNG import price in Asia maintains present price range, \$10.1/MBtu in 2018.
  - Assume reduction of amount of oil-linked pricing contract or milder slope of oil linkage.
  - Competitiveness of LNG is low in developing Asia under the current price range.
- **High Price Case**: Oil-linked pricing at an average slope in 2018 in Asia continues until 2050.
  - LNG will lose competitiveness in the power generation sector thus demand will remain low.
- **Low Price Case**: Historically low spot LNG price (average from Jan to Aug 2019) continues until 2050.
  - Requires substantial cost reduction in every aspect of supply chain including liquefaction and shipping.

❖ Assumption of LNG price in Asia (\$2018/MBtu)

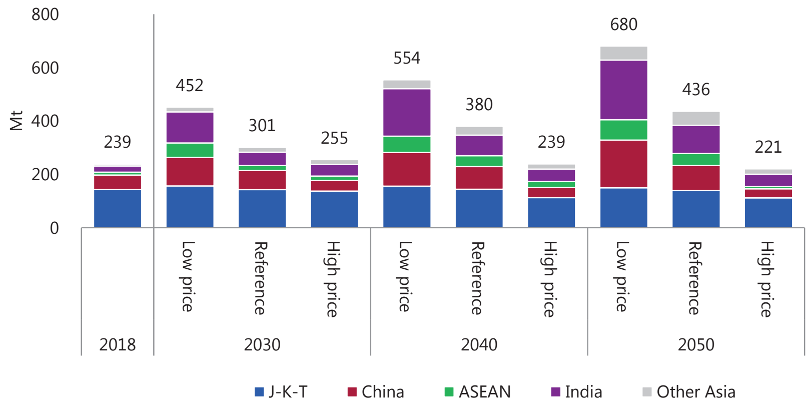
	2018	2030	2040	2050
Reference Scenario	10.1	10.0	10.2	10.4
Ref. Crude oil price	*\$71.31/bbl*	*\$95/bbl*	*\$115/bbl*	*\$125/bbl*
High Price Case	10.1	13.3	16.1	17.5
Low Price Case	10.1	5.4	5.4	5.4

Source: IEEJ

LNG demand outlook in Asia

- **Reference Scenario**: LNG demand in Japan, Korea and Chinese Taipei won't increase.
  Meanwhile, ASEAN and India will see high demand growth (CAGR = 4.4-6.2%).
- **High Price Case**: will see substantial reduction of new development of gas-fired power plants. LNG demand will stagnate (CAGR = -0.1%).
- **Low Price Case**: will see shifting investment from coal-fired to gas-fired power plants resulting in a higher LNG demand increase (CAGR = 3.3%).

❖ LNG demand outlook in Asia



J-K-T = Japan, Korea, and Chinese Taipei Source: IEEJ

Key take away from LNG price cases

- Center of gravity of LNG demand will shift from traditional importers, i.e. Japan, Korea, and Chinese Taipei, to emerging importers.
- Growth of LNG demand would be undermined if LNG fails to become competitive fuel in the power generation sector.
- In relation to the liquefaction capacity;

Remarkable addition of liquefaction capacity can be expected until the end of 2020.

- FIDs were made for 54 million tonnes per year of LNG liquefaction capacity during the first half of 2019.
- Another 120 million tonnes per year of capacity addition is possible.

High Price Case

- Demand in 2050 can be supplied by liquefaction capacity investment in the 2020s.
- Investment for liquefaction capacity would stall after the 2020s.
- Environmental burden would rise due to preference for coal power plant.

Low Price Case

- Substantial increase of supply chain investment will be required.
- Cost reduction of LNG supply chain become inevitable to ensure LNG supply capacity.

Action to enhance LNG security

IEE JAPAN

● LNG supply security would become more important when LNG represents larger part of energy supply.

❖ Actions to enhance LNG supply security

Existing action	**Diversify supply sources and/or routes** Import from other sources when a source is disrupted.
	Curve energy demand by energy efficiency Reduce import requirement and decrease risks.
	Strong tie with suppliers under long-term contracts Establish a strong tie with suppliers to ensure LNG supply.
Possible action	**Create a flexible global LNG market** Import necessary volumes of LNG in time from the flexible global market.
	Cooperation with other gas markets Construct a mechanism to balance LNG supply-demand in cooperation with other markets, e.g. China, EU, US.

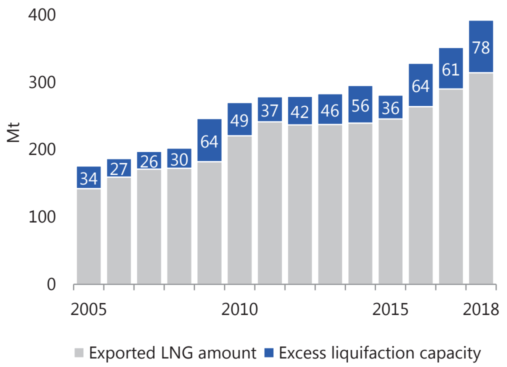
Source: IEEJ

Employ flexibility in global LNG market

IEE JAPAN

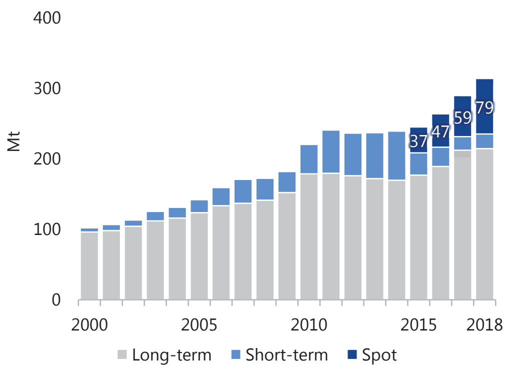
● Favorable changes for LNG supply security are underway in the global market.
- Robust building up of new liquefaction capacity
- Increasing supply and transactions of flexible LNG

❖ Exported LNG volumes and excess liquefaction capacity



Excess liquefaction capacity = total liquefaction capacity – idling liquefaction capacity – exported LNG volumes
Source: based on data from GIIGNL

❖ LNG export by contract period

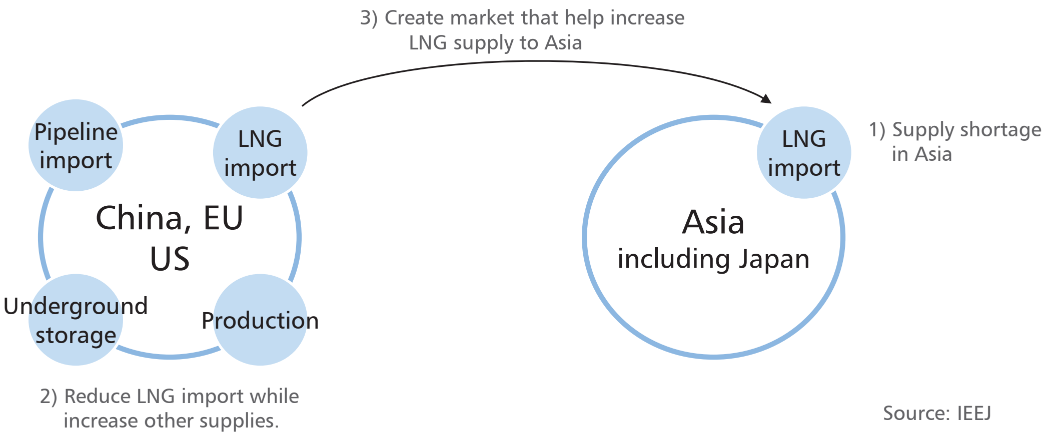


The “short-term (contract period 4 years or less)” from 2000 to 2014 including “spot” transactions.
Source: based on data from GIIGNL

Cooperation with other gas markets

- Some markets, e.g. China, EU, and US, have multiple natural gas supply options. Asia can strengthen LNG supply security by benefiting from flexibility of such markets under their cooperation.
- Is it unstable to depend the supply security on other counties?
  - Oil market has good examples and records.
  - Important to make energy cooperation as a catalyst to strengthen a regional tie.

❖ Concept to employ flexibility in other gas market



Source: IEEJ

Reference material

Underground storage capacity in major countries

	a. Working gas capacity [Bcm]	b. Natural gas demand [Bcm/y]	a. ÷ b.
France	13.6	45.9	30%
Germany	26.7	89.8	30%
Italy	20.0	73.3	27%
United Kingdom	1.7	80.8	2%
EU-28	115.9	474.7	24%
United States	150.9	767.2	20%
China	16.0	235.8	7%
Japan	5.9 (commercial LNG stock)	120.2	5%

* Working gas capacity: A part of stored natural gas is utilized to keep pressure of storage depot thus cannot be utilize as functionable stock. This gas is called as cushion gas. Working gas capacity can be calculated as take cushion gas amount from total storage capacity which indicate actually usable amount of gas stock.
**Amount of commercial LNG stock is not included in countries other than Japan.

Source: Conversion factor = 0.8393 Mtoe/Bcm
Natural gas demand: IEA, Energy Balances 2019, data in 2017
Working gas capacity in Europe: Gas Infrastructure Europe, data as of 1 July 2018
Working gas capacity in US: EIA, Underground Natural Gas Storage Capacity, data in 2017
Working gas capacity in China: JOGMEC, data in 2018
Working gas capacity in Japan: JOGMEC, data in 2017 (average of commercial LNG stock at the end of 12 month)

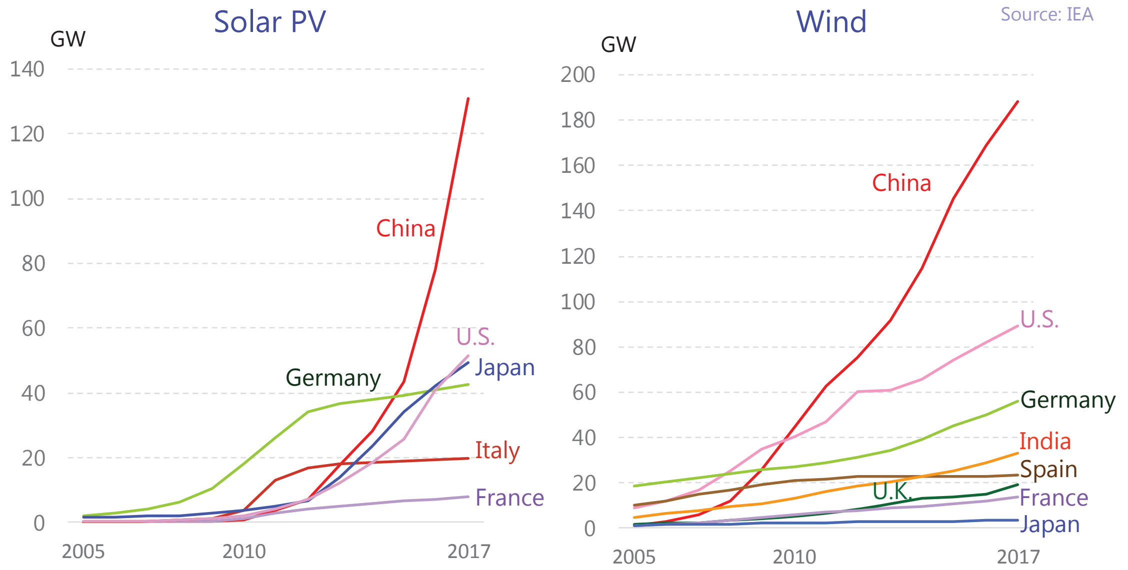
Conclusion

- Under the circumstance that the center of gravity of LNG demand shifting from traditional to emerging importers, if LNG is not a competitive fuel for power generation, LNG demand would stall.
- Prices would dictate demand. Consequently, LNG demand in the High Price Case becomes around 70% smaller than the Low Price Case.
- In the supply side, it is crucial to ensure necessary investment in supply capacity to meet increasing LNG demand. On the other hand in the demand side, promotion of demand as well as development of receiving and distribution infrastructure is required.
- LNG supply security increasingly becomes important as demand soars.
- Favorable changes for Asia's LNG supply security are underway in the global LNG market, thus necessary to promote it further.
- Asia including Japan can strengthen LNG supply security by benefiting from flexibility of other markets like China, EU, and US, under their cooperation. Further investigation of this possibility is suggested.

Economics of the power sector under high penetration of variable renewable energies

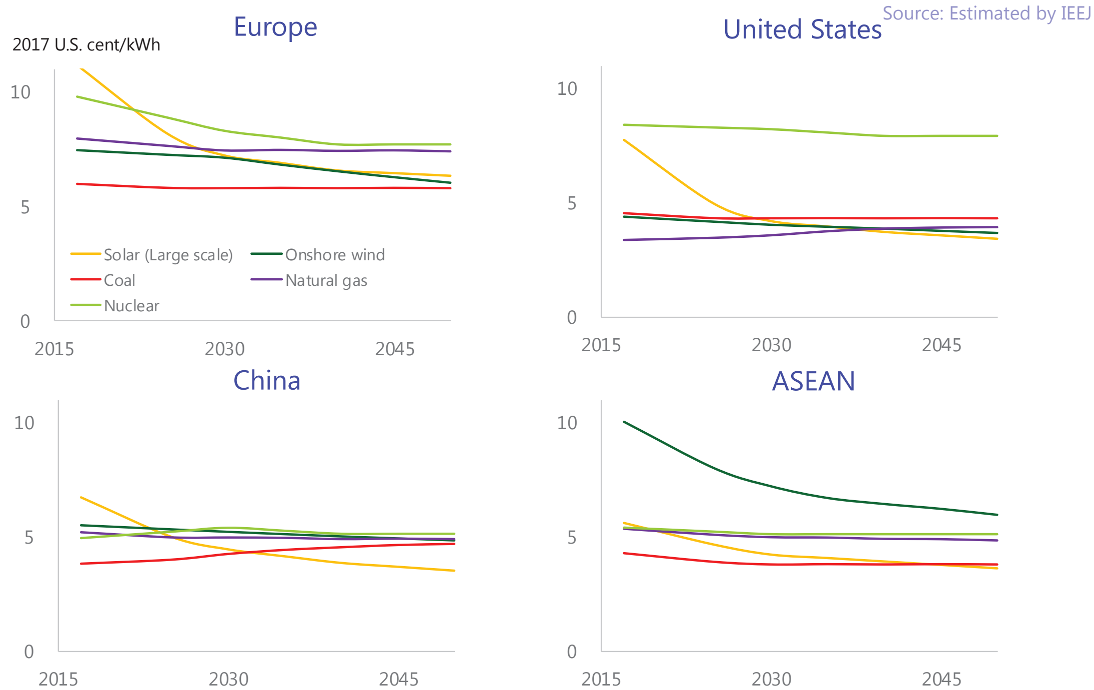
- Evaluation of integration costs and some challenges -

Expanding installed capacity of VREs



- Recent trends exhibit rapid expansion of the power generating capacities of ***Variable Renewable Energies (VREs)***, such as solar and wind, due to continuous cost declines and growing concerns over climate change issues.
- VREs are expected to continue the rapid expansion in the long-term, although we should anticipate several challenges as stated below.

Levelized cost of electricity (LCOE)



- Levelized Cost of Electricity (LCOE) is a metric that has long been used for assessing the specific cost of power generating facilities.
- The LCOE of VREs has been declining rapidly over decades. By 2050, ***the LCOE of solar PV is expected to become lower than that of conventional technologies***, in many region across the world.

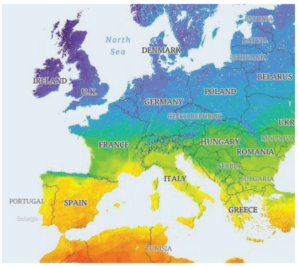
Distributed VRE resources

※1: Obtained from the "Global Solar Atlas 2.0", a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info

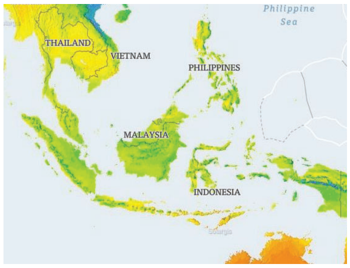
※2: Obtained from the "Global Wind Atlas 2.0", a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU) in partnership with the World Bank Group, utilizing data provided by Vortex, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

Solar

Europe



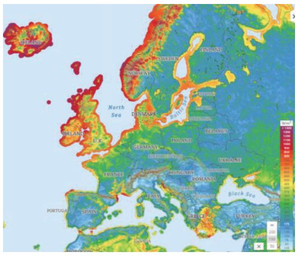
ASEAN



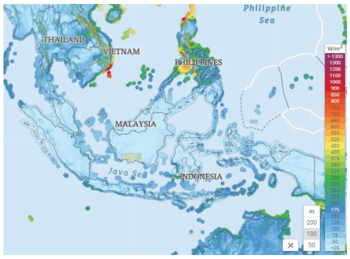
Source:
Global Solar Atlas※1

Wind

Europe



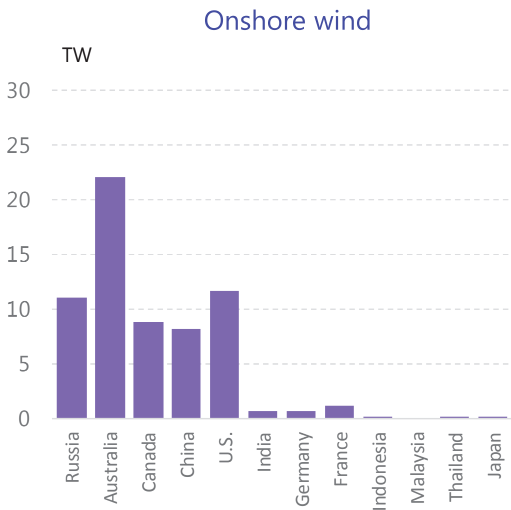
ASEAN

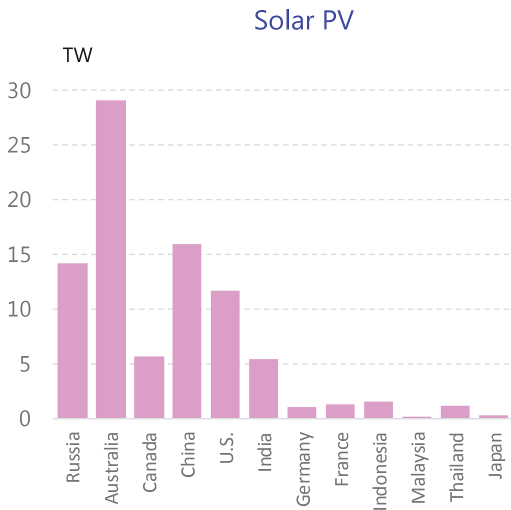


Source:
Global Wind Atlas※2

・***VRE resources differ significantly across regions.*** While wind power resources are abundant in Europe, ASEAN countries see relatively scarce resources except for those in specific areas in Vietnam and the Philippines.

Estimated VRE resources for selected countries



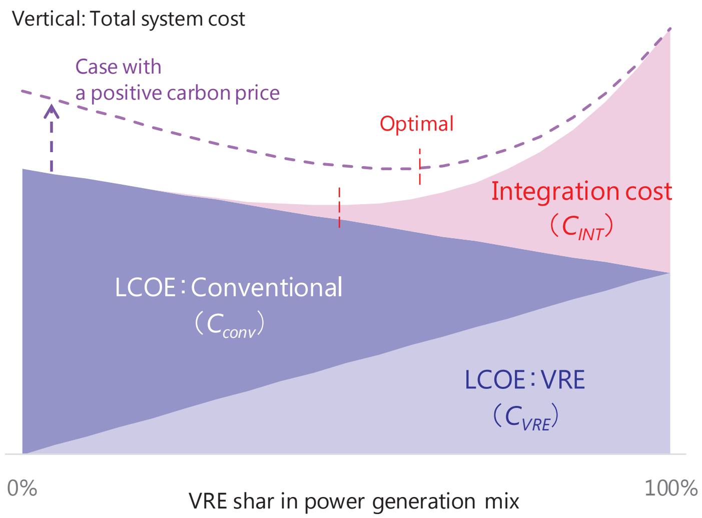


Source: Estimated by IEEJ using GIS data

・Huge VRE resources exist in the countries with large geographic areas, such as Russia, Australia, China, and U.S. Total wind and solar resources can cover all the global energy demand.

・Solar resources are relatively scarce in high-latitude countries, whereas most Asian countries are not endowed with large wind resources.

System integration cost: A conceptual illustration



- If the LCOE of VRE is smaller than that of conventional power sources, the “traditional” power generation cost, which represents the costs proportional to the LCOEs, shown as C_{conv}+C_{VRE} in the above figure, declines with increasing share of VRE.

- However, high penetration of VRE requires additional cost related to the necessity of power storage, VRE output curtailment, and grid extension, etc., known as ***system integration costs***, indicated by C_{INT} as illustrated above.

Breakdown of the integration cost

Sources: Ueckerdt F. et al., 2013. System LCOE: What are the costs of variable renewables?, *Energy*, 63, pp.61-75.
OECD/NEA, 2018. *The full costs of electricity provision*.

1. Balancing cost
   ・Costs related to the uncertainty of power generation due to unforeseen plant outages or forecasting errors.
2. Grid-related cost
   ・Costs related to locational constraints, which can be further divided into two categories: grid reinforcement costs and connection costs.
3. Profile cost
   ・Costs related to the temporal variability of power generation,

   3-1. Adequacy cost / Backup cost

   3-2. Overproducion cost

   3-3. Full-load hour reduction

   3-4. Flexibility effect

Estimation of integrated costs: Cases of Europe and ASEAN

Methodology

・Simulates electricity supply and demand for 2050 with hourly time resolution (24 hours×365 days = 8,760 time slices) based on historical data for 2014.

・Calculates the optimal (=cost minimal) supply-demand balances for the year, also estimating the required investments, using the Linear Programming method.

・Considers the costs of power storage systems, interregional transmission lines, VRE output curtailment, declines in the load factors of conventional power generating facilities, and the load frequency control (LFC) constraints.

・Possibly underestimates the total costs, without some elements being considered explicitly: Increases in the start and stop numbers of thermal facilities, declines in the efficiencies due to partial load operation, and the inertia of the power systems.

・Considers batteries and pumped hydro power generation as electricity storage systems, additionally estimating the use of hydrogen storage.

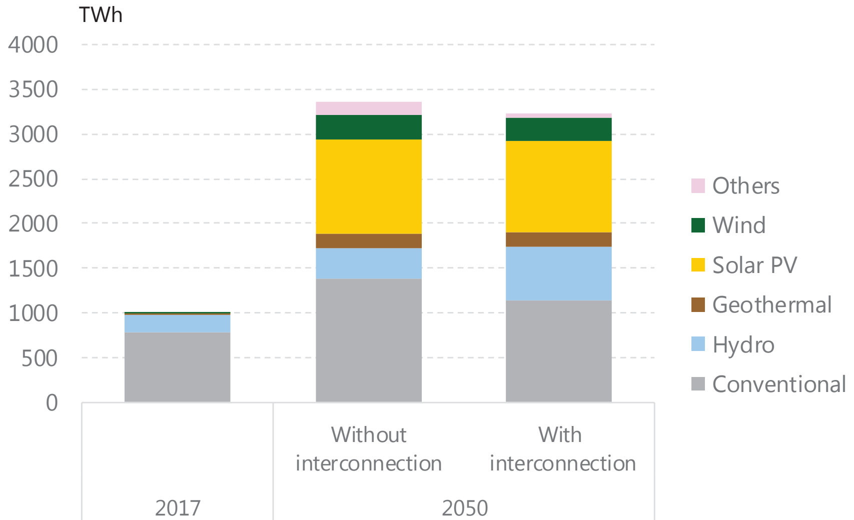
Batteries: Assumes that the average cost declines to USD 80/kWh by 2050.

Hydrogen storage: Although the costs of storage facilities (hydrogen tanks) are much cheaper than batteries at USD 13/kWh, additional expenses are required for electrolysis, etc.

Regional divisions

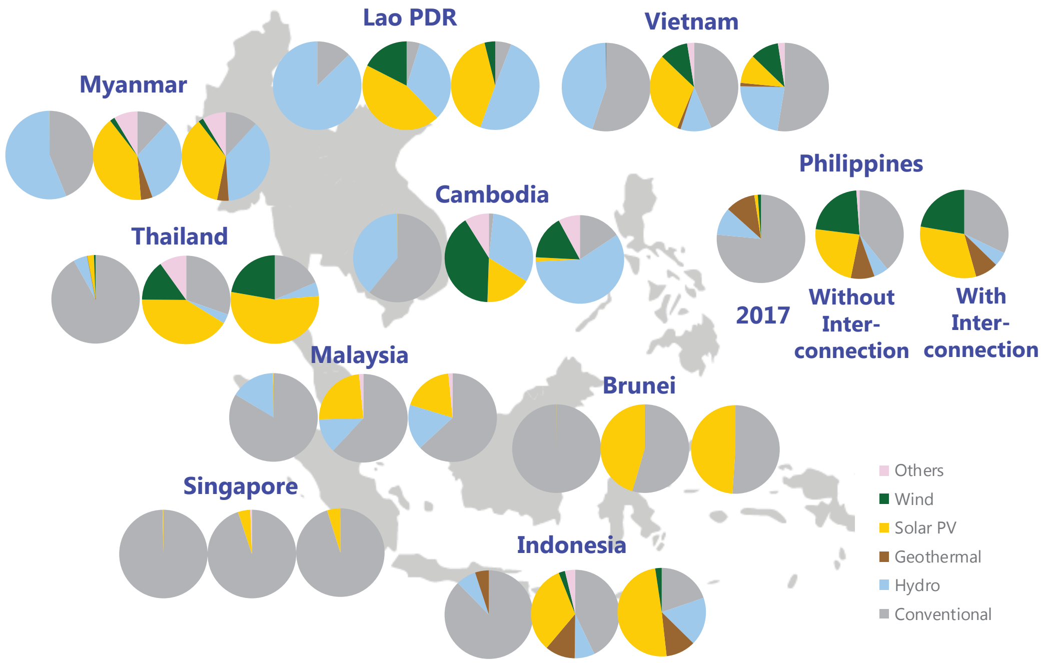
・Europe: 6 subregions, ASEAN: 10 countries

High penetration of renewables in ASEAN: VRE 40%



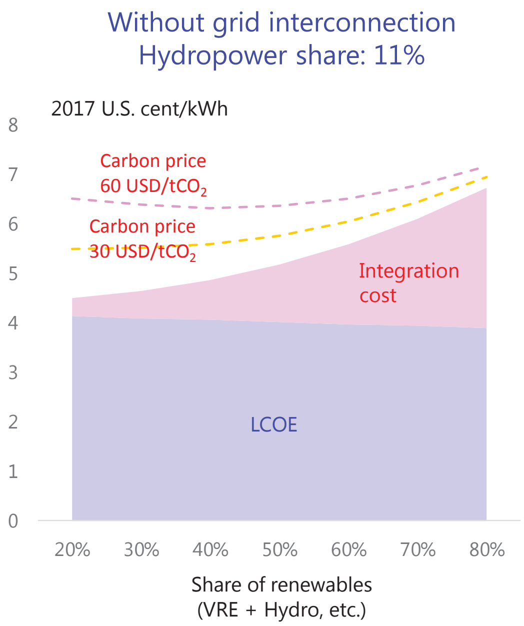
- As wind power resources are relatively scarce in the ASEAN region, solar PV accounts for 32% of power generation mix in a VRE 40% case. Including hydro, geothermal and biomass power, renewable energies account for nearly 60% in total.
- Regional cooperation also plays an important role in ASEAN. If power grid interconnection plans, such as the ASEAN Power Grid (APG), are fully implemented, large hydro resources can be exploited and the renewable share can rise to nearly 70%.

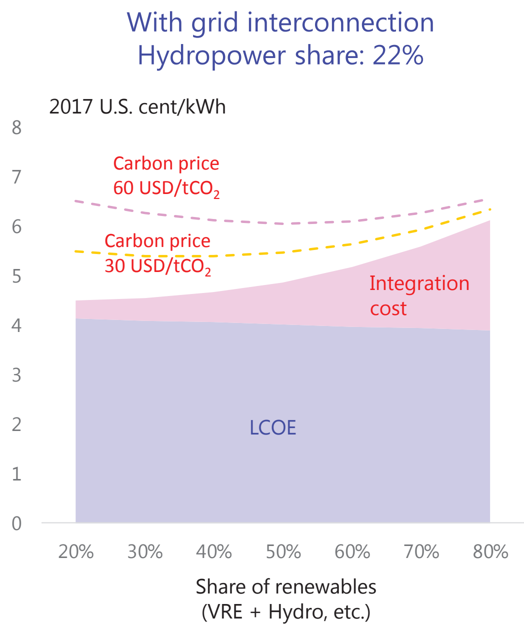
High penetration of renewables in ASEAN: VRE 40%



- Because of different scales of renewable energy resources in different countries, a VRE 40% case would see diverse energy mix across countries.
- If grid interconnection is fully implemented, hydro-powered electricity is exported from Lao PDR, Myanmar, Cambodia, Vietnam to Thailand, as well as from Malaysia to Singapore.

Integration cost with high shares of VRE: ASEAN

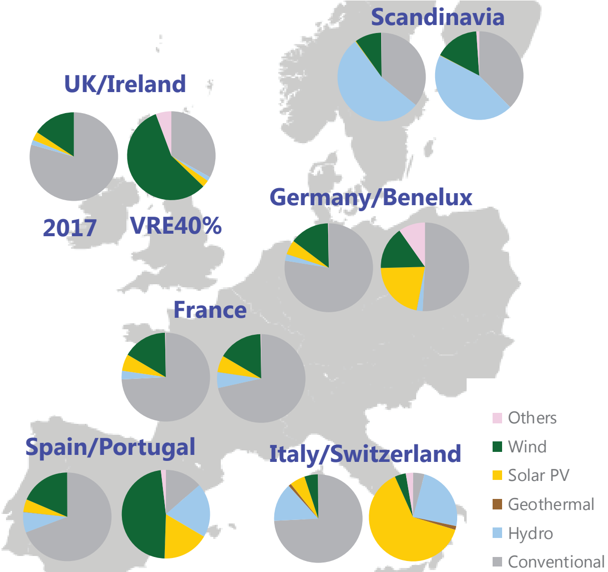




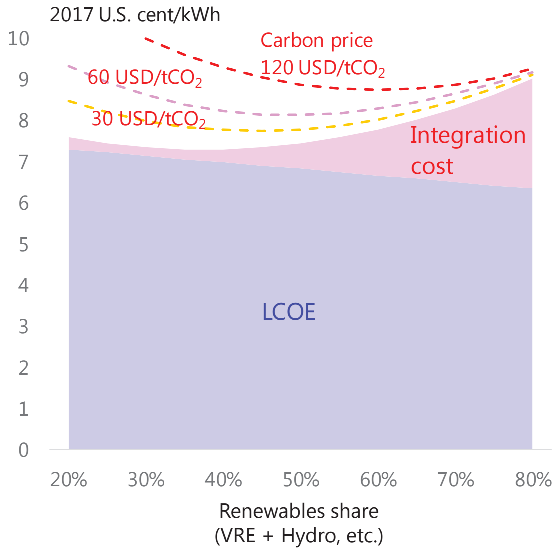
- Integration costs increase along with higher shares of VRE, although the rise can somewhat be mitigated if grid interconnection is implemented, due to efficient use of hydropower potentials that are distributed unevenly across regions.
- ***Strong policy measures need to be implemented*** to cover the cost increases with higher shares of VRE.

High penetration of renewables in Europe: VRE 40%

Regional energy mix
(VRE 40% case)



Integration cost (Europe)



- Renewable energy resources are unevenly distributed in Europe. Hydropower is utilized largely in Scandinavian countries, while wind power is abundant in UK and in Spain. Italy can take advantage of high solar irradiation.
- The total system cost moderately increases as VRE share rises. In comparison with ASEAN, the optimal share of VRE is higher due to higher costs of conventional technologies, while the effects of carbon prices are smaller because of low carbon intensities.

Effect of the use of hydrogen

・Hydrogen is a secondary energy carrier that can be produced from multiple sources. It is expected to play important roles for deep decarbonization of energy systems.

- **From renewable energies**
- **From fossil fuels**
  Produce hydrogen by steam reforming, and store the emitted CO_2 with the CCS technology
- **From nuclear power**

・Under high penetration of VRE, hydrogen is supposed to be produced by excess electricity. It is stored in tanks and used for power generation, when VRE output is small.

Batteries High costs and high efficiencies.
Cycle efficiency※: 80-95%

Hydrogen storage Low storage cost but lower total efficiency and additional costs for electrolysis.
Cycle efficiency: 50-60%

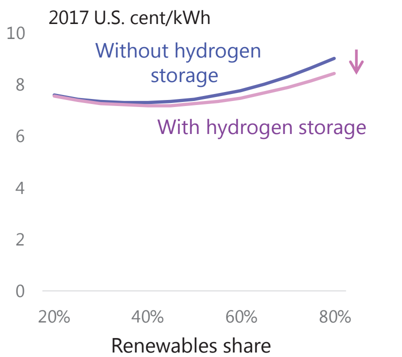
→ Hydrogen is used for long-term (or interseasonal) storage, only in cases with very high penetration of VRE.

・Other options include producing hydrogen in resource-rich countries, storing the emitted CO_2, and transporting the hydrogen to resource-poor countries, where it is used for power generation and/or other purposes.

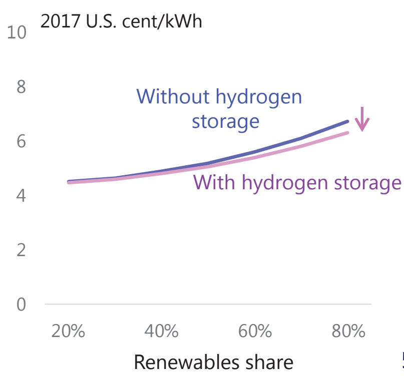
※ The ratio of discharged and charged energy

Integration cost decline with the use of hydrogen storage systems

Europe



ASEAN



Challenges related to high penetration of VRE

1. "Cannibalization" effect: Decline in market values

Once VRE power generating facilities are deployed, they produce electricity with very small marginal costs. This results in very low wholesale electricity prices, which undermines the "values" of the VRE facilities.

2. Supply disruption due to extreme weather conditions

VRE outputs, as well as hydropower outputs, vary significantly depending on meteorological conditions in the short-, mid- and long-term.

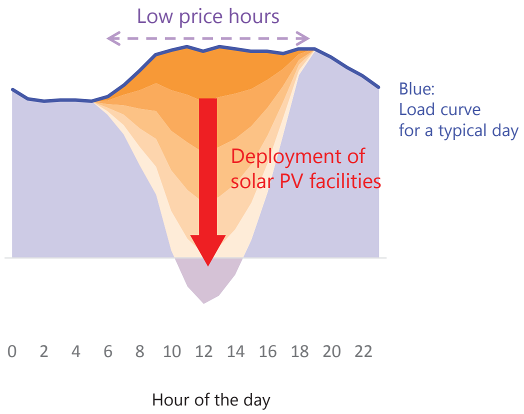
The risk of supply disruption due to long-term fluctuations with extreme weather conditions is one of the major challenges with very high shares of renewable energies.

Challenges for high penetration of VRE (1) Cannibalization effect

◎ With large deployment of solar PV power generating facilities, ...

→ Massive electricity is supplied with very low marginal costs, during the daytime on a sunny day.

→ Wholesale electricity prices take very low values during those hours.



Under such situations, ...

Solar PV power facilities:

- Generate electricity only during low-price hours.
  → ***"Market values" of solar power facilities decline significantly*** in line with solar power deployment.
- If the "value" falls below the LCOE, further deployment of solar PV facilities becomes difficult.

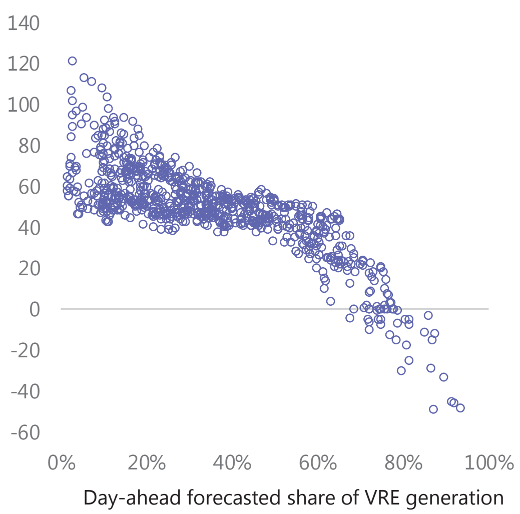
Conventional power facilities:

- Generate electricity during higher price hours as well.
  → Limited declines in market values.
- However, ***recovering the initial costs becomes more difficult*** due to lower wholesale market prices.

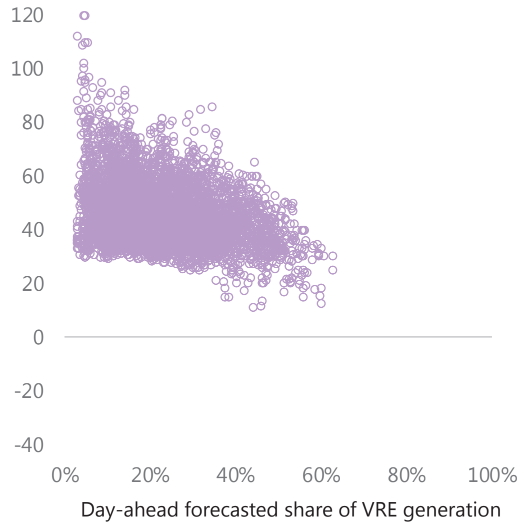
- Similar situations take place, although in a somewhat milder manner, also for large deployment of wind power facilities.

Declines in market values: Actual data for the period from Jan. to Jul. 2019

Germany and adjacent areas



UK and adjacent areas

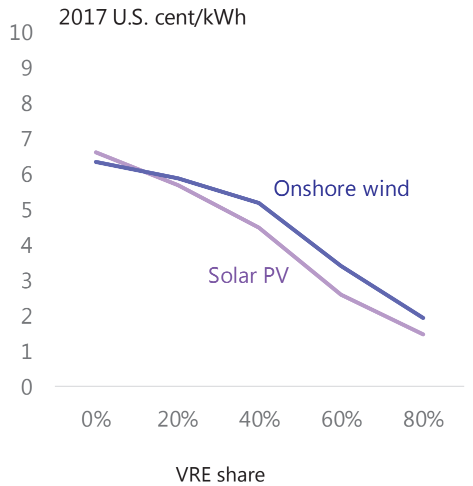


Source: Entso-E Transparency Platform

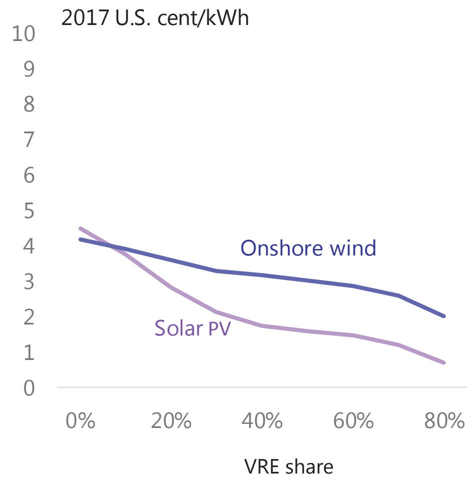
- Historical data exhibit low electricity prices with large VRE outputs.
- The prices can take negative values in Germany, when the VRE share exceeds 80%.

Cannibalization effect: Modeling results for Europe and ASEAN

Europe

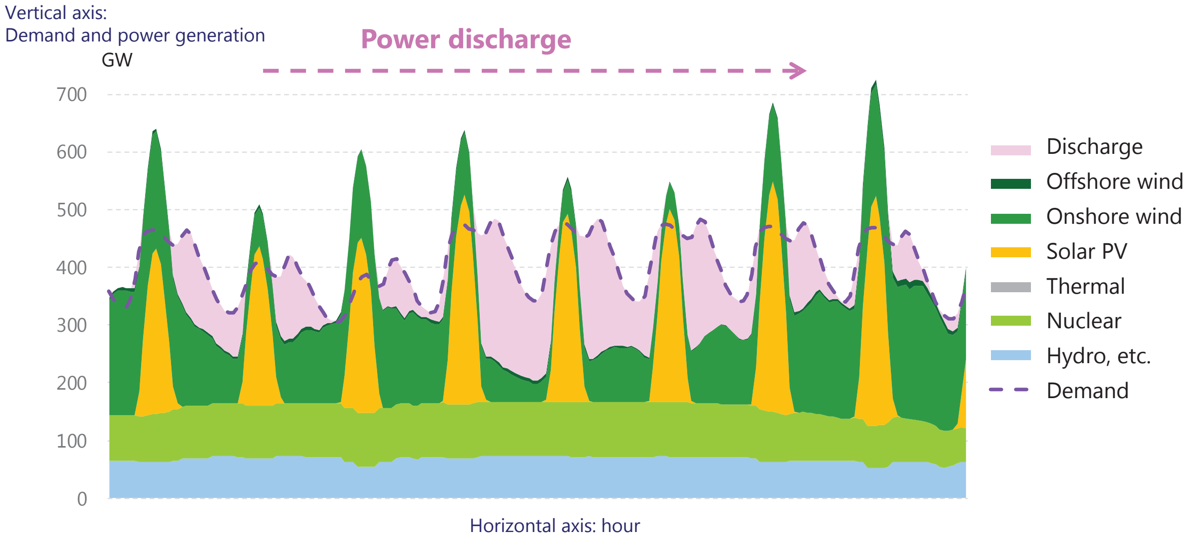


ASEAN



- Due to the cannibalization effects, market values of wind and solar power facilities decline significantly along with higher penetration of VRE. The values of solar power decline more rapidly than wind, because of the strong correlation between power outputs.
- For this reason, ***stable expansion of VRE facilities would require continuous policy supports***, even if the costs of VREs decline significantly in the future.

Challenges for high penetration of VRE (2) "Windless" periods

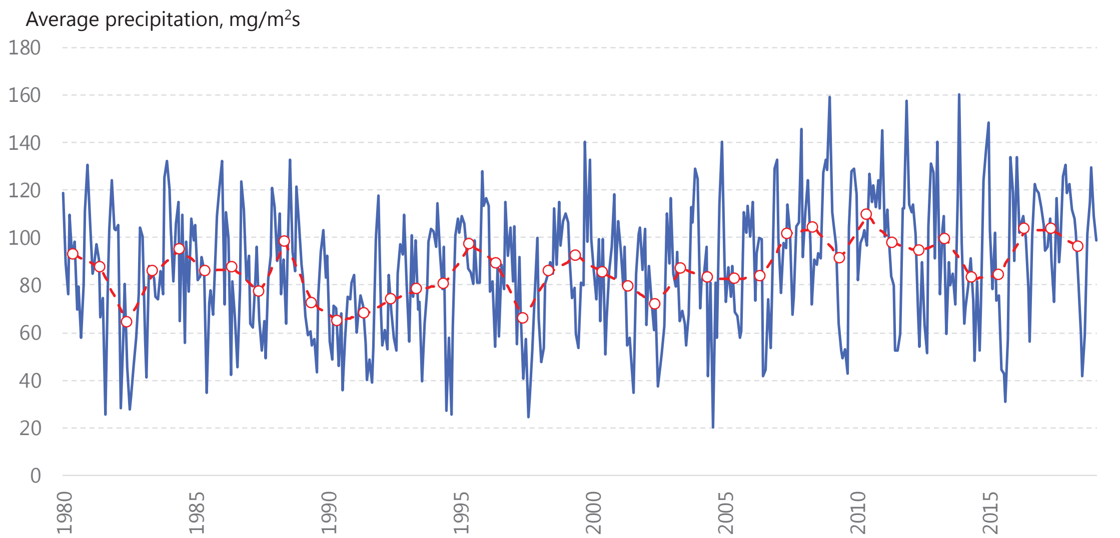


・***Windless (and sunless) periods***, also known as ***dark doldrums***, in which wind and solar power output is exceptionally small, can take place once or twice in a year. The above figure illustrates an extreme case with zero thermal power generation during these periods, in which massive power discharge is required to meet the demand.

・To achieve very high shares of VRE, it would be required to assess the largest risks related to supply disruptions during windless periods, using multiannual meteorological data, and to implement energy storage capacities large enough to meet electricity demands.

Risk of hydropower supply: Long-term trends in precipitation in Borneo Island

Source: NASA MERRA-2



・Another risk of supply disruption is related to fluctuations in weekly, seasonal, and annual average rainfall or precipitation.

・Increasing the share of hydropower in electricity mix, especially by enhancing international grid connections, would highlight the necessity of addressing drought risks under extreme weather conditions.

Summary and conclusion

・Along with rapid cost declines, the share of VRE in power generation mix is expected to rise significantly towards 2050 in many regions of the world, although the shares will be different across countries due to different endowment of energy resources.

・Very high penetration of VRE would require additional integration costs related to the intermittency of power outputs. Although many recent studies have tried to assess these costs, different studies indicate different scales of additional expenses, highlighting the necessity of further efforts to make more precise estimates.

・In the mid-term, decline in the market values of VREs due to cannibalization effects is crucial. In this regard, strong policies promoting renewable energy sources need to be continued even if the costs of VREs decline significantly in the future.

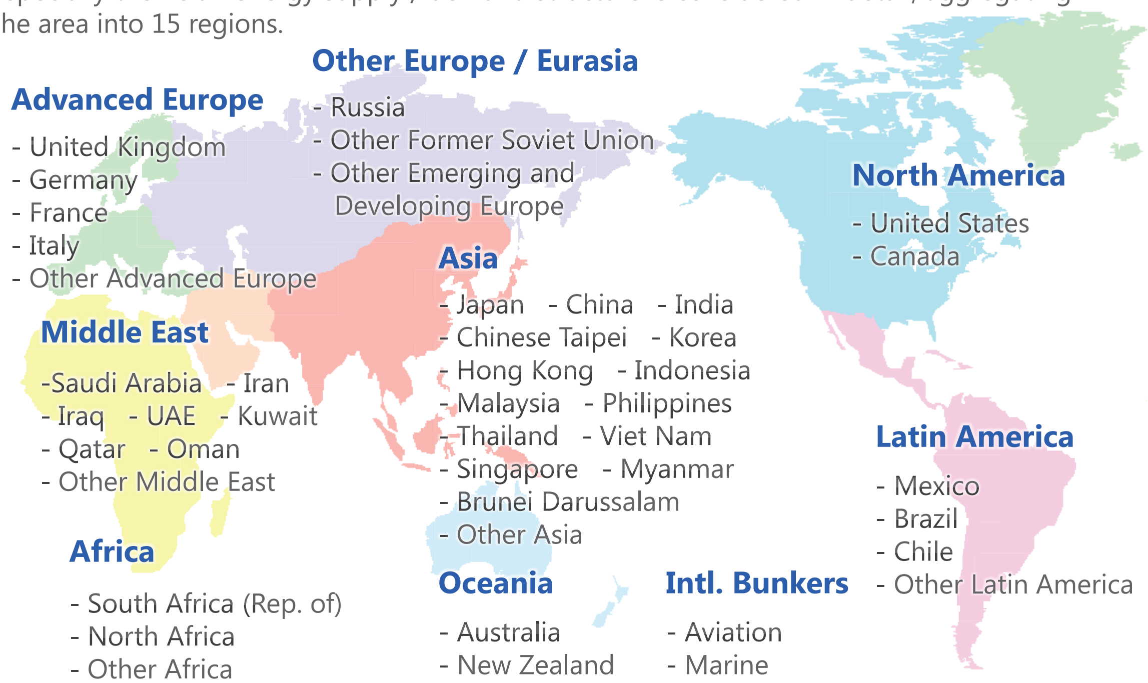
・Under very high penetration of VRE, the risk of supply disruption during “windless” periods, also known as “dark doldrums”, would be one of the most important challenge. Public acceptance for the large-scale land use could also be crucial.

・Relying on one single energy source could enhance the risks of supply disruptions and cost increases significantly. In this regard, a new kind of the “best energy mix” needs to be aimed for, to achieve ambitious decarbonization targets to address climate change issues.

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.



Advanced Europe
- United Kingdom
- Germany
- France
- Italy
- Other Advanced Europe

Other Europe / Eurasia
- Russia
- Other Former Soviet Union
- Other Emerging and Developing Europe

North America
- United States
- Canada

Middle East
- Saudi Arabia - Iran
- Iraq - UAE - Kuwait
- Qatar - Oman
- Other Middle East

Asia
- Japan - China - India
- Chinese Taipei - Korea
- Hong Kong - Indonesia
- Malaysia - Philippines
- Thailand - Viet Nam
- Singapore - Myanmar
- Brunei Darussalam
- Other Asia

Latin America
- Mexico
- Brazil
- Chile
- Other Latin America

Africa
- South Africa (Rep. of)
- North Africa
- Other Africa

Oceania
- Australia
- New Zealand

Intl. Bunkers
- Aviation
- Marine

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.

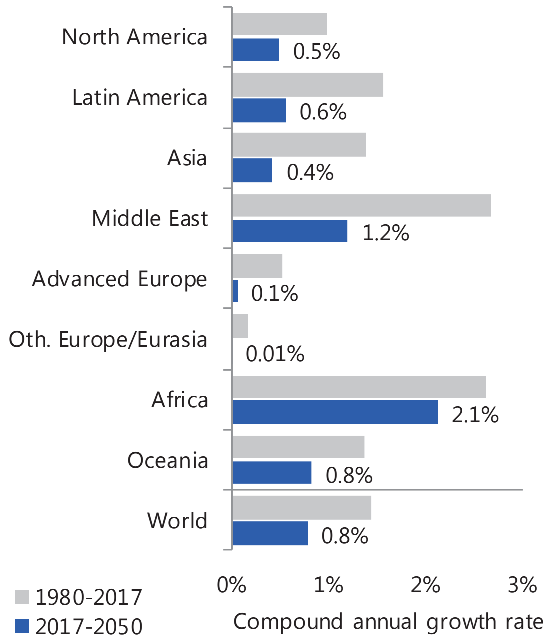
Basic scenarios in IEEJ Outlook

	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

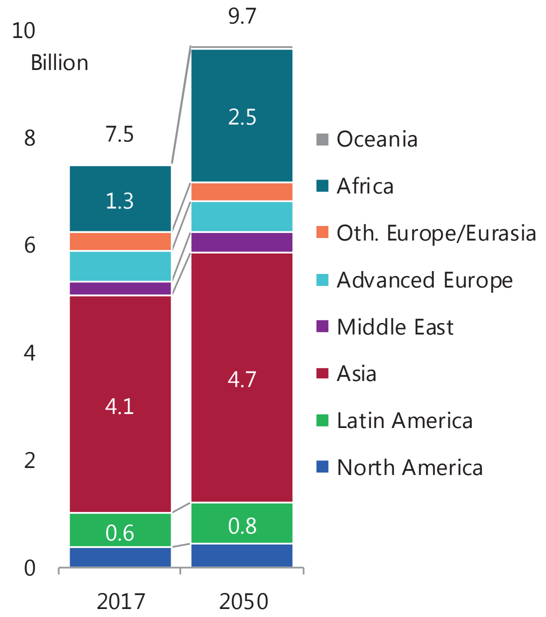
Assumptions

Population

CAGR



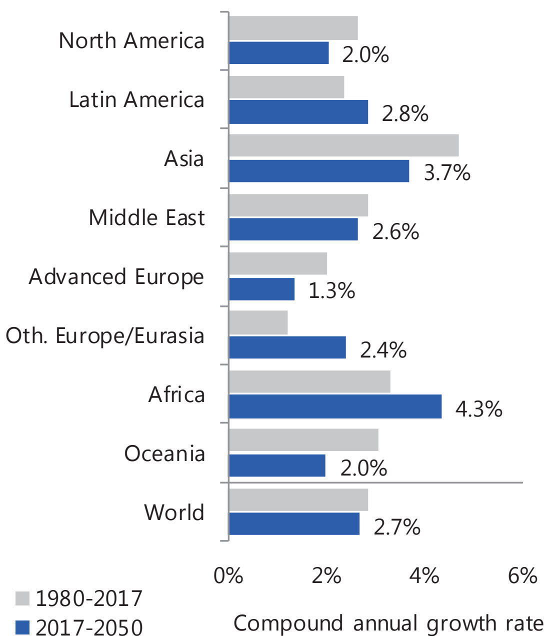
Composition



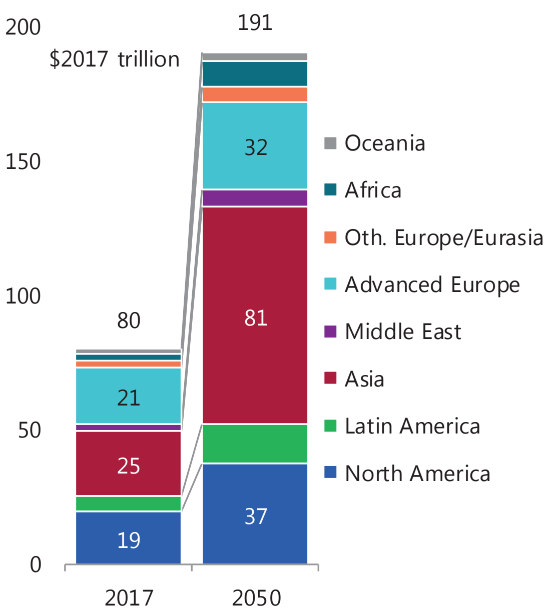
Assumptions

Real GDP

CAGR



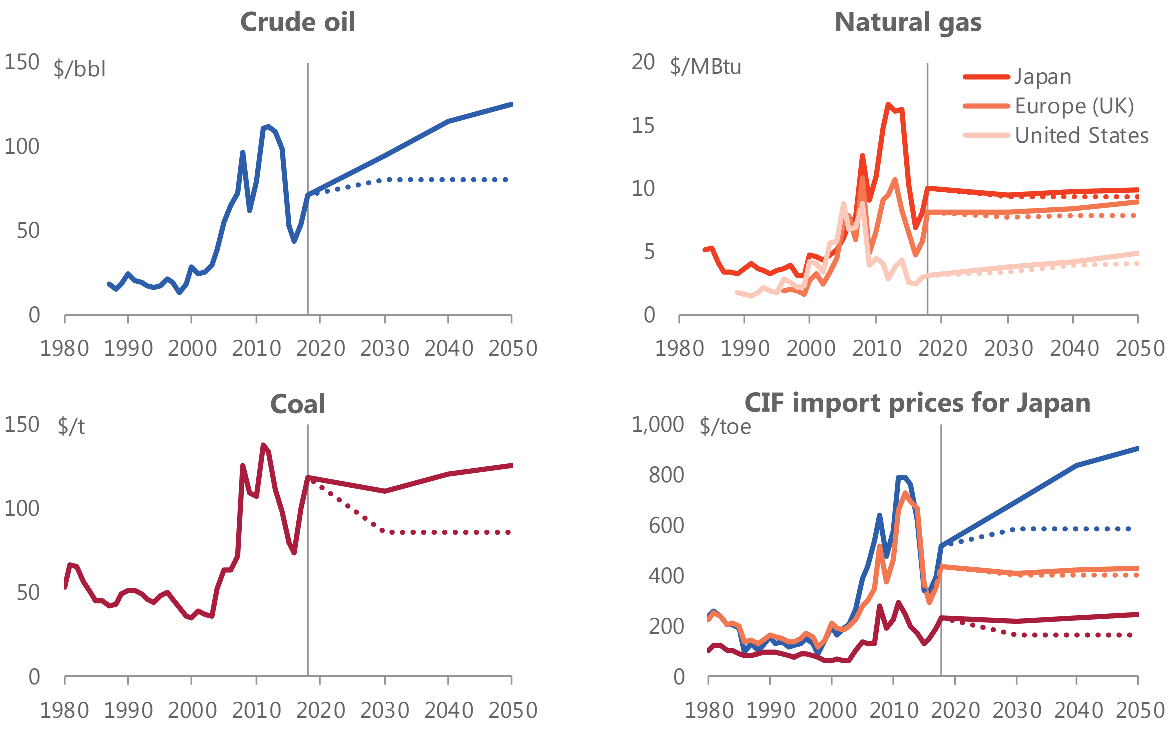
Composition



Assumptions

International energy prices

Reference :
Advanced Technologies :



Note: Historical prices are nominal. Assumed future prices as real in $2018.

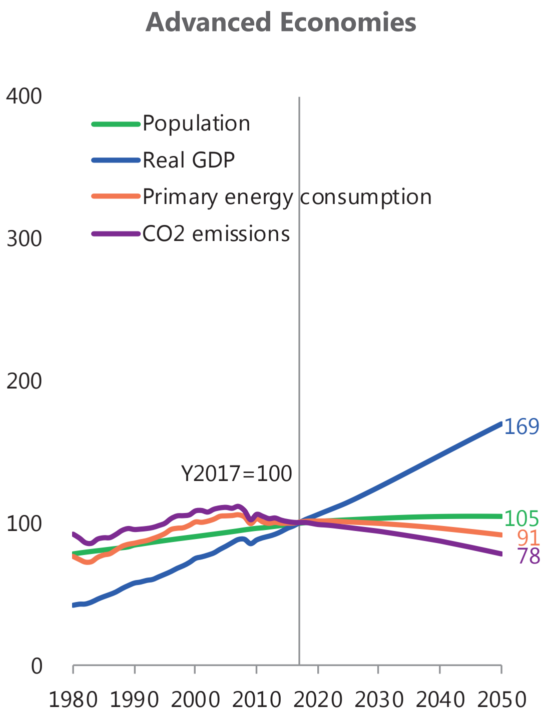
Assumptions

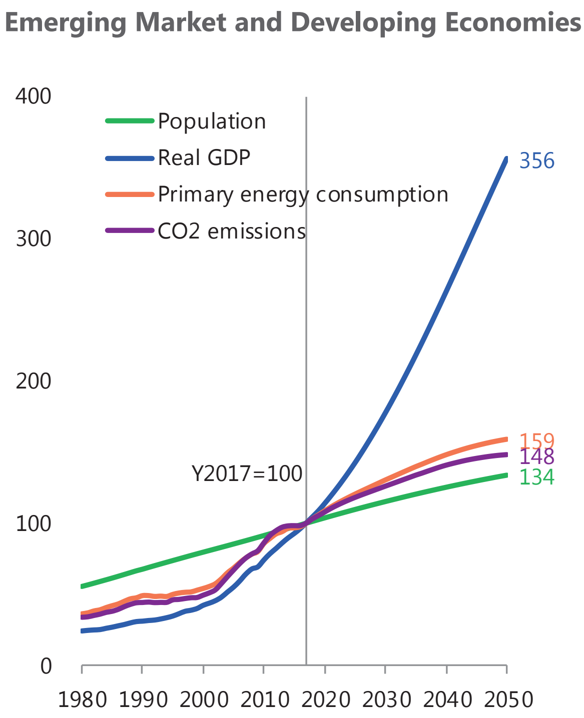
Energy and environmental technology

		2017	2050 Reference	2050 Advanced Technologies	Assumptions for Advanced Technologies Scenario
Improving energy efficiency					
Industry	Intensity in steel industry (ktoe/kt)	0.284	0.250	0.220	100% penetration of Best Available Technology by 2050.
	Intensity in non-metallic minerals industry	0.092	0.066	0.058	
Transport	Electrified vehicle share in passenger car sales	3%	56%	86%	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)	14.1	23.9	33.8	
Buildings	Residential total efficiency (Y2017=100)	100	154	188	Efficiency improvement at twice the speed for newly installed appliance, equipment and insulation. Electrification in space heating, water heater and cooking (clean cooking in developing regions).
	Commercial total efficiency	100	186	220	
Power	Thermal generation efficiency (Power transmission end)	38%	46%	47%	Financial scheme for initial investment in high-efficient thermal power plant.
Penetrating low-carbon technology					
Biofuels for transport (Mtoe)		84	128	253	Development of next generation biofuel with cost reduction. Relating to agricultural policy in developing regions.
Nuclear power generation capacity (GW)		409	480	717	Appropriate price in wholesale electricity market. Framework for financing initial investment in developing regions.
Wind power generation capacity (GW)		515	1,810	3,065	Further reduction of generation cost. Cost reduction of grid stabilization technology. Efficient operation of power system.
Solar PV power generation capacity		386	2,954	4,434	
Thermal power generation capacity with CCS (GW)		0	0	1,270	Installing CCS after 2030 (regions which have storage potential except for aquifer).
Zero-emission generation ratio (incl. CCS)		35%	41%	79%	Efficient operation of power system including international power grid.

Reference Scenario

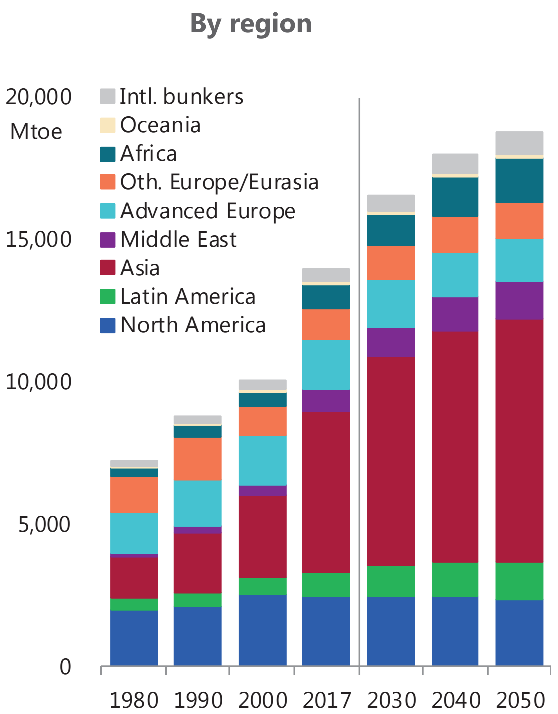
Population, GDP, energy and CO_2

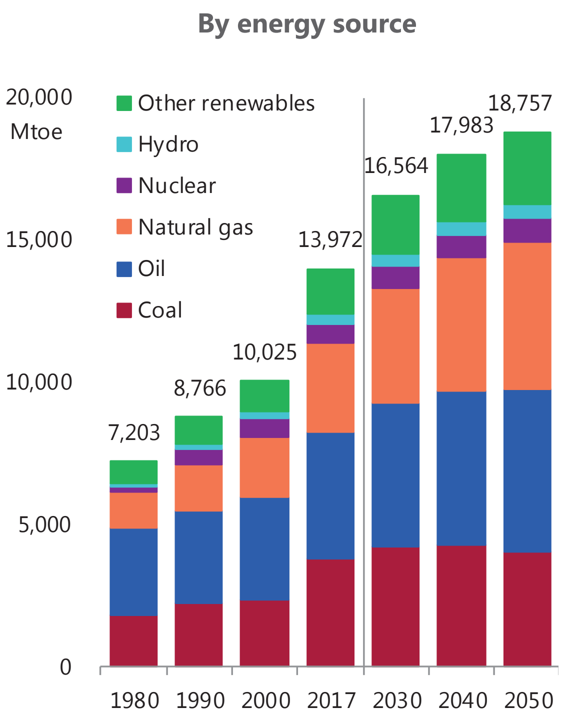




Reference Scenario

Primary energy consumption

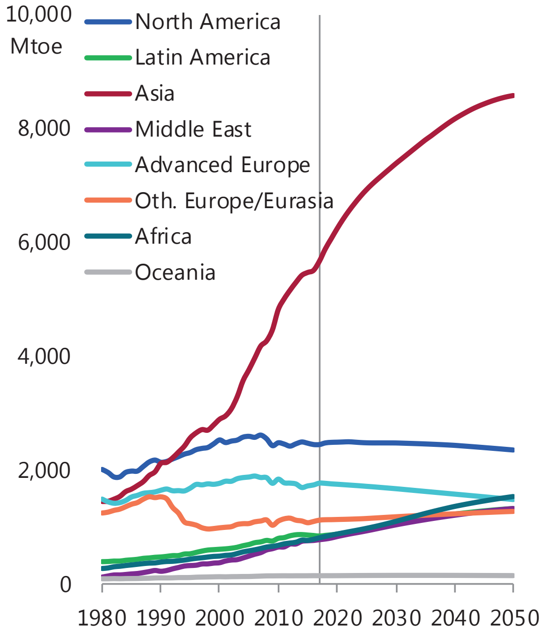




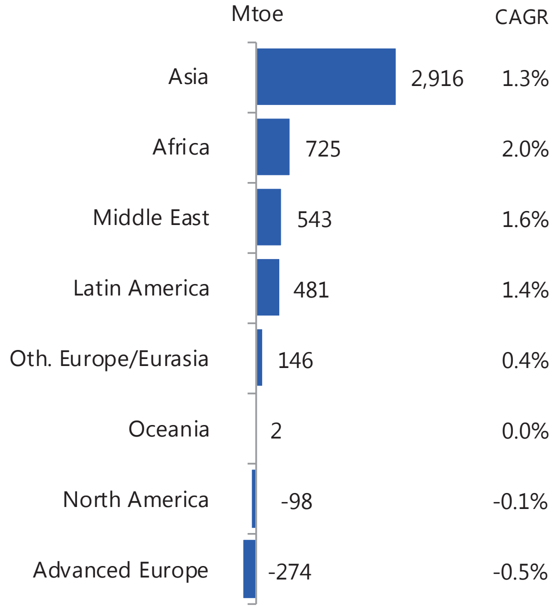
Reference Scenario

Primary energy consumption (by region)

Energy consumption



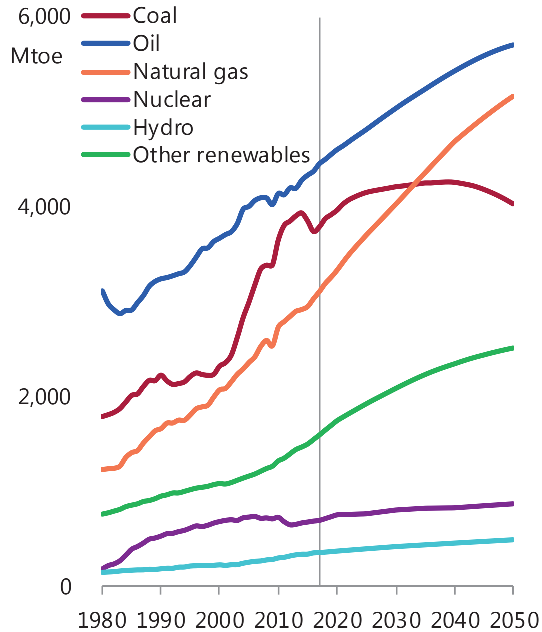
Changes (2017-2050)



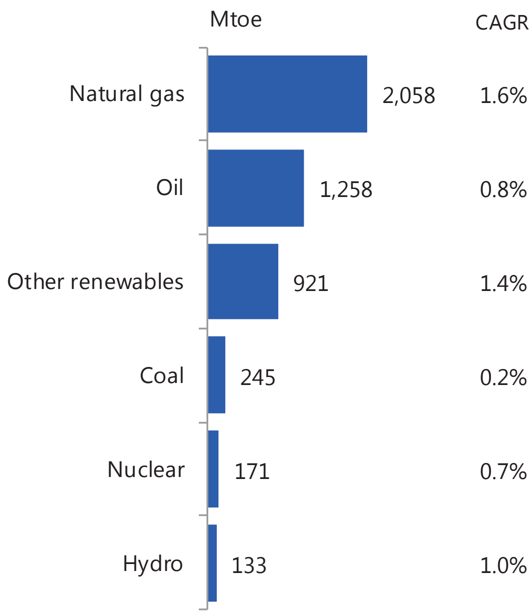
Reference Scenario

Primary energy consumption (by energy source)

Energy consumption



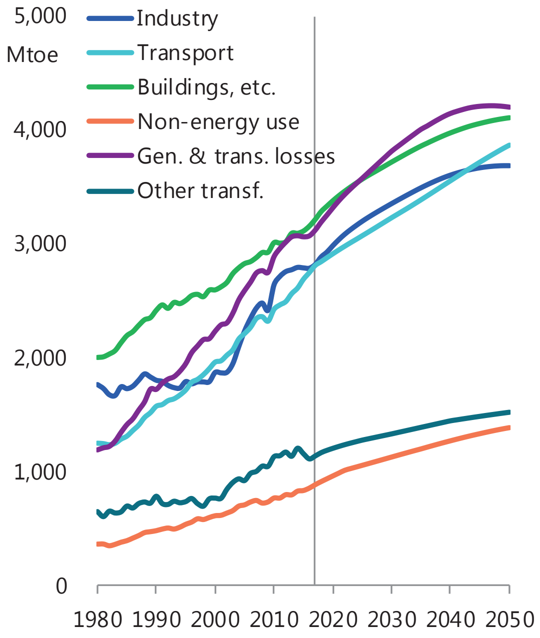
Changes (2017-2050)



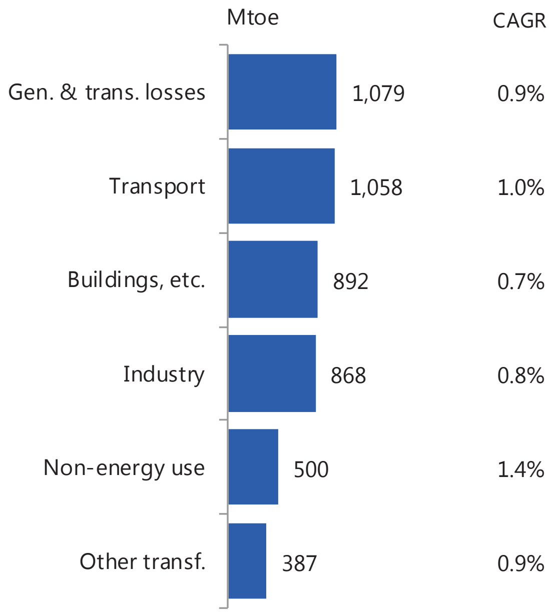
Reference Scenario

Primary energy consumption (by sector)

Energy consumption



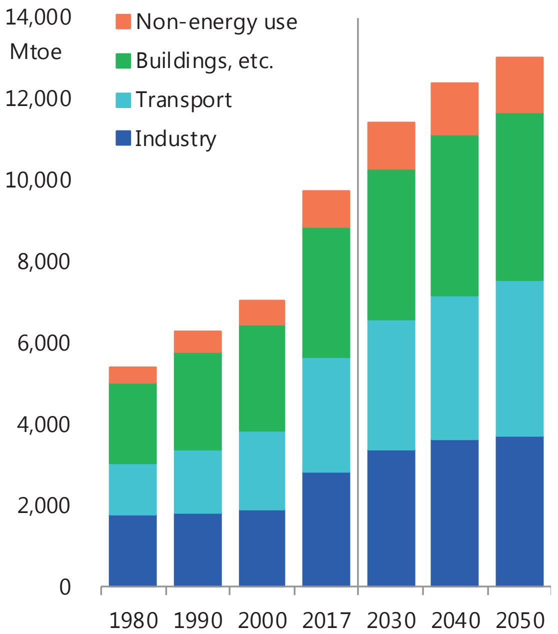
Changes (2017-2050)



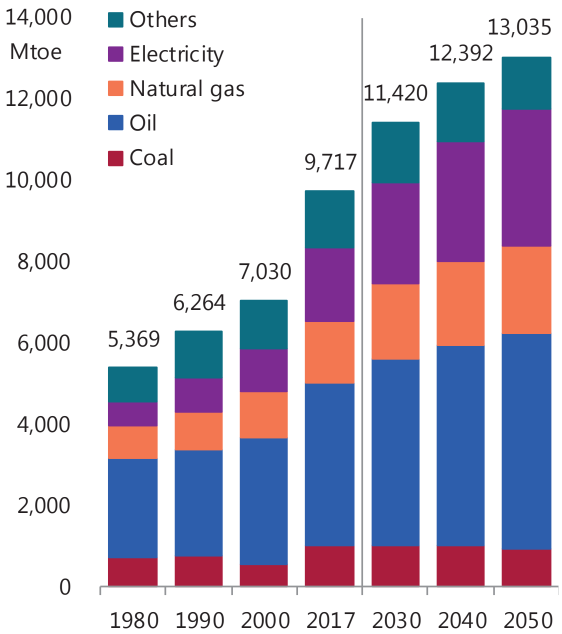
Reference Scenario

Final energy consumption

By sector



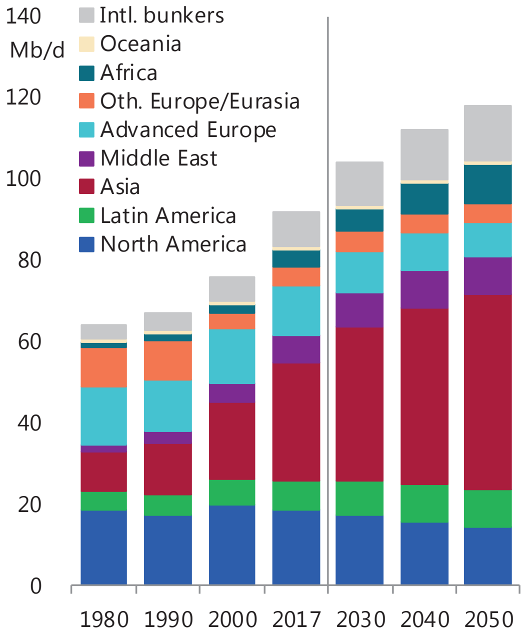
By energy source



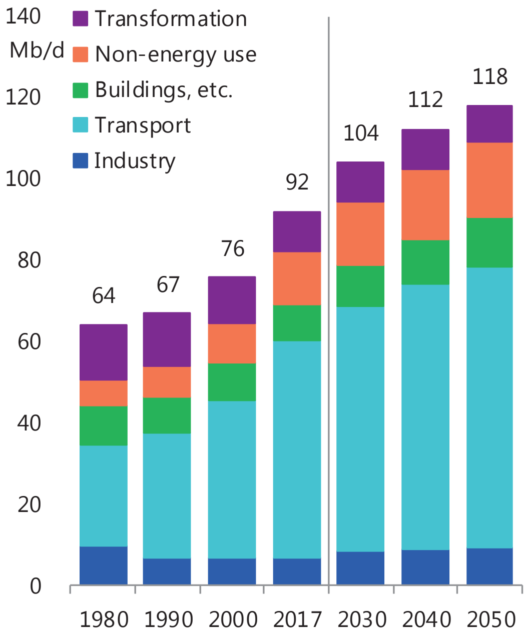
Reference Scenario

Oil consumption

By region



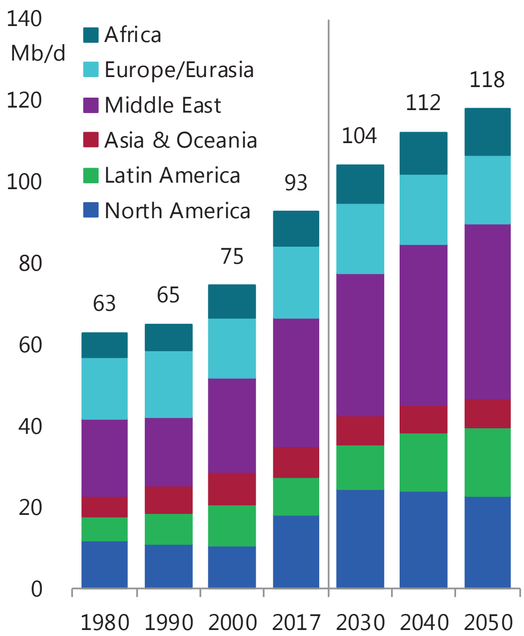
By sector



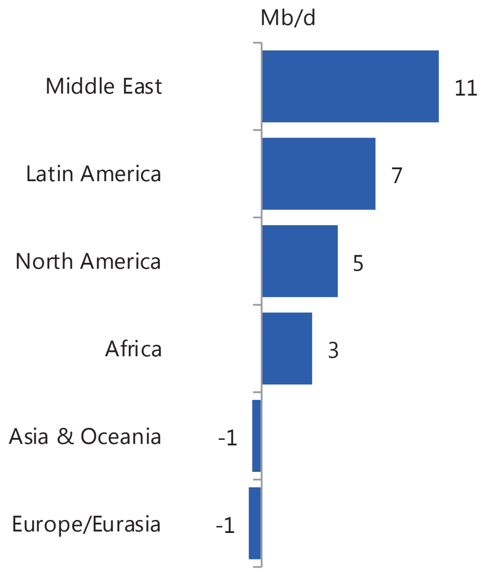
Reference Scenario

Crude oil production

By region

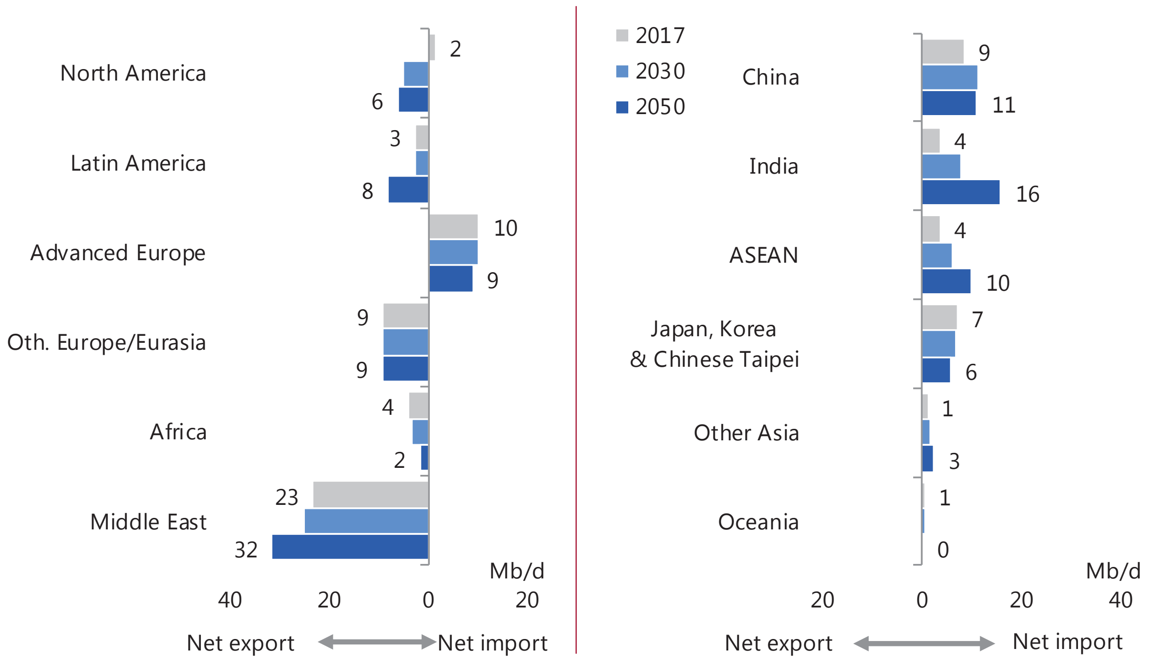


Changes (2017-2050)



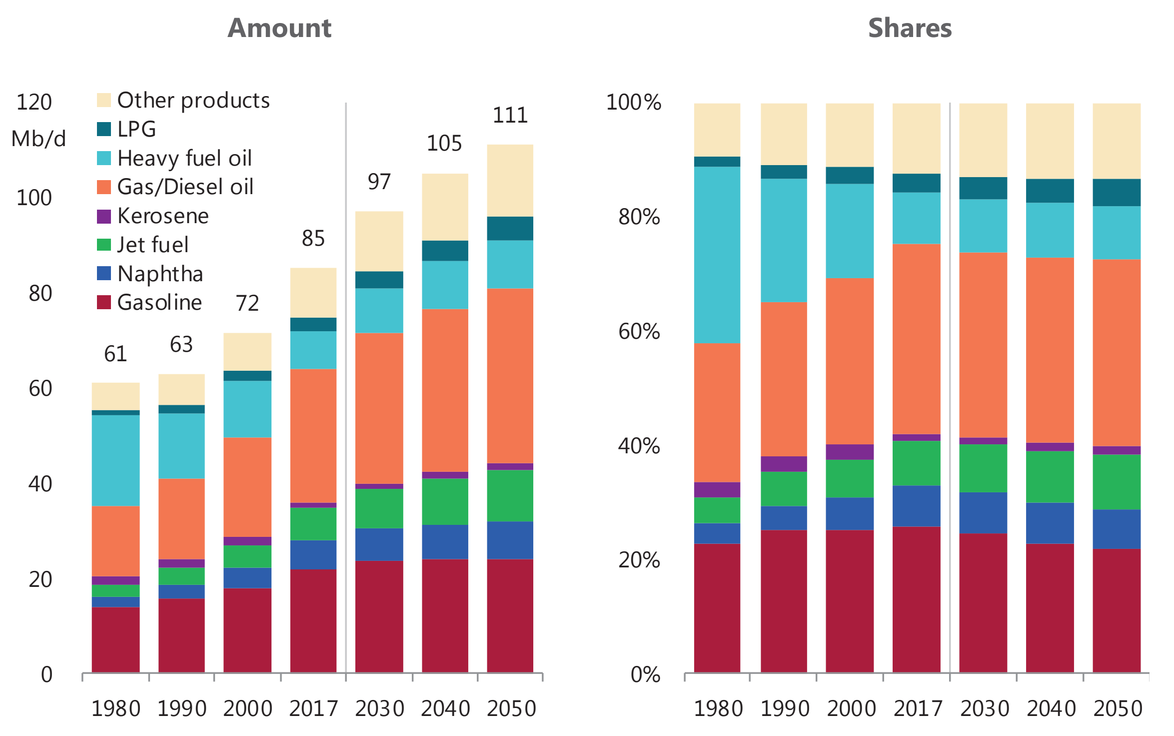
Reference Scenario

Net exports and imports of oil



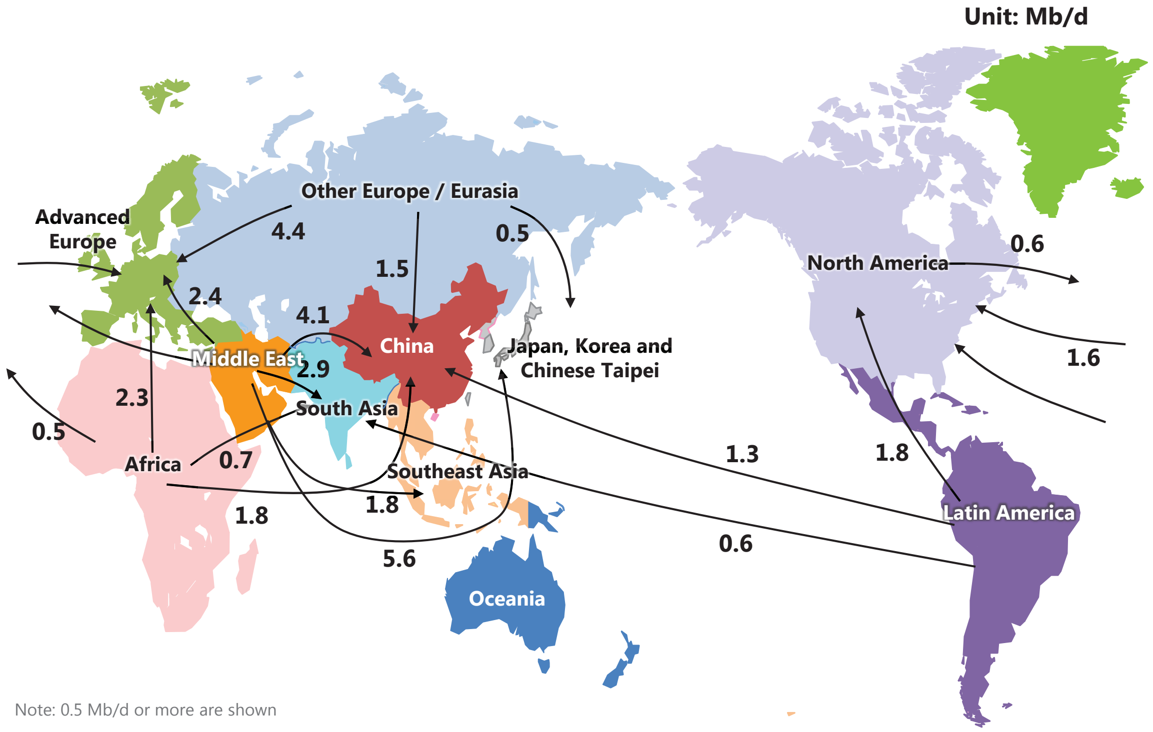
Reference Scenario

Petroleum product consumption



Reference Scenario

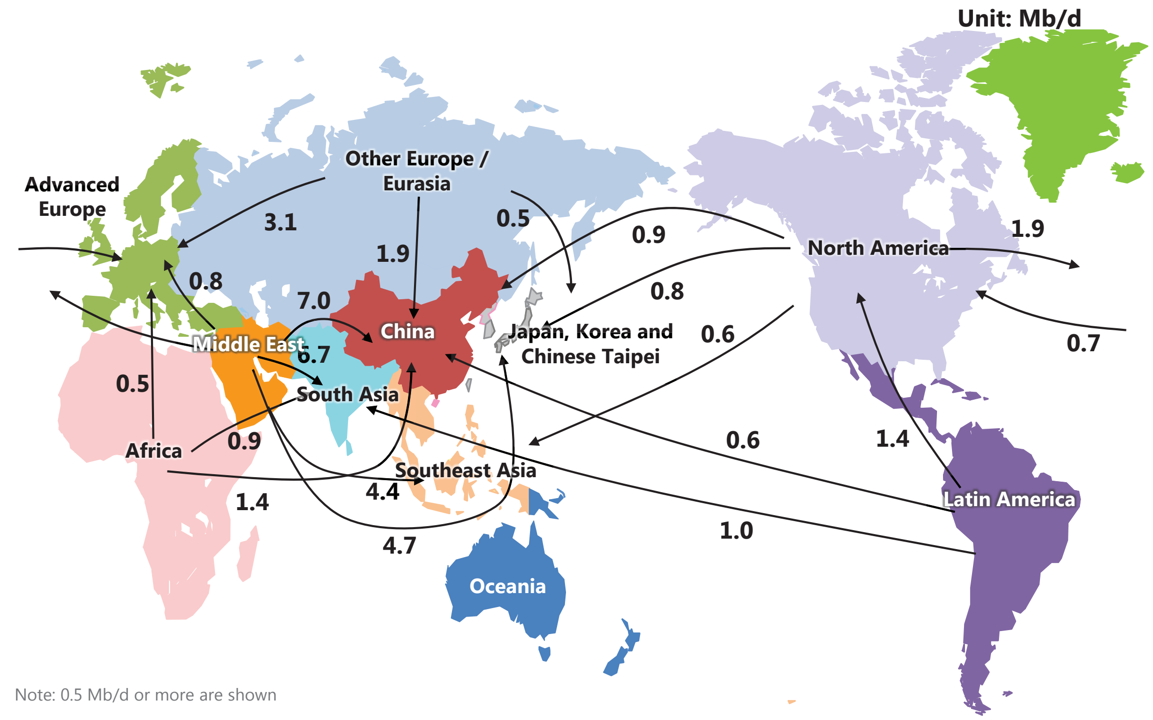
Major trade flows of crude oil (2018)



Note: 0.5 Mb/d or more are shown

Reference Scenario

Major trade flows of crude oil (2030)

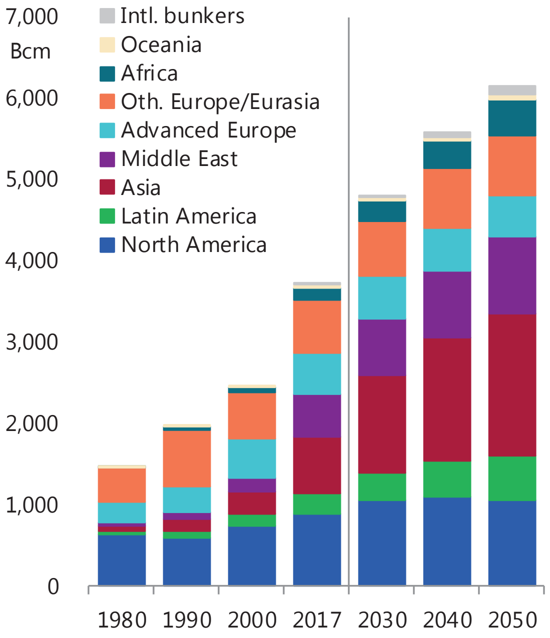


Note: 0.5 Mb/d or more are shown

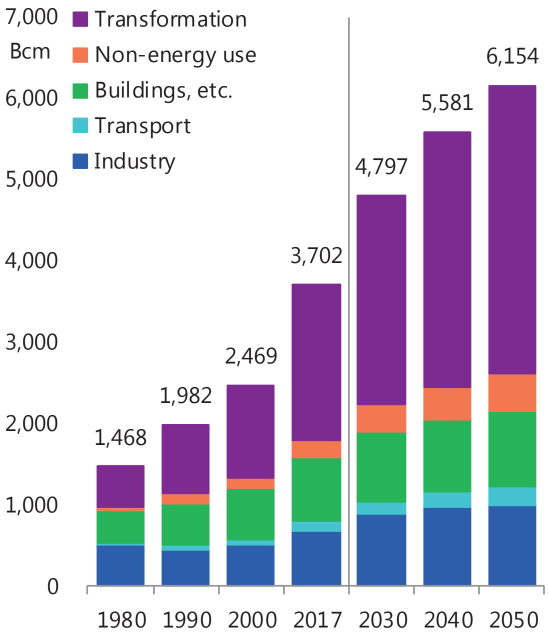
Reference Scenario

Natural gas consumption

By region



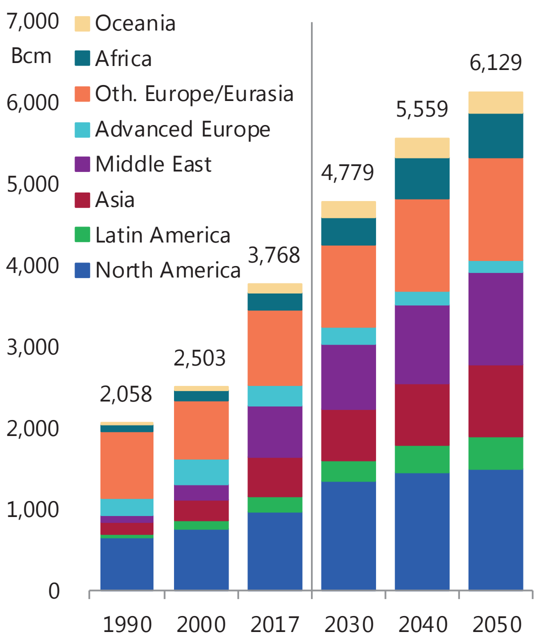
By sector



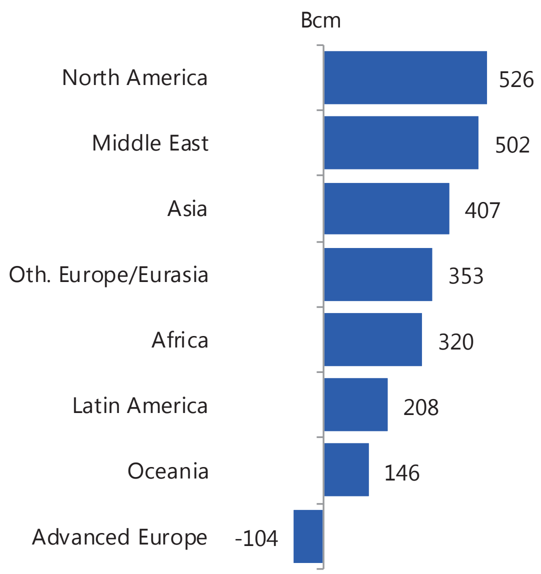
Reference Scenario

Natural gas production

By region

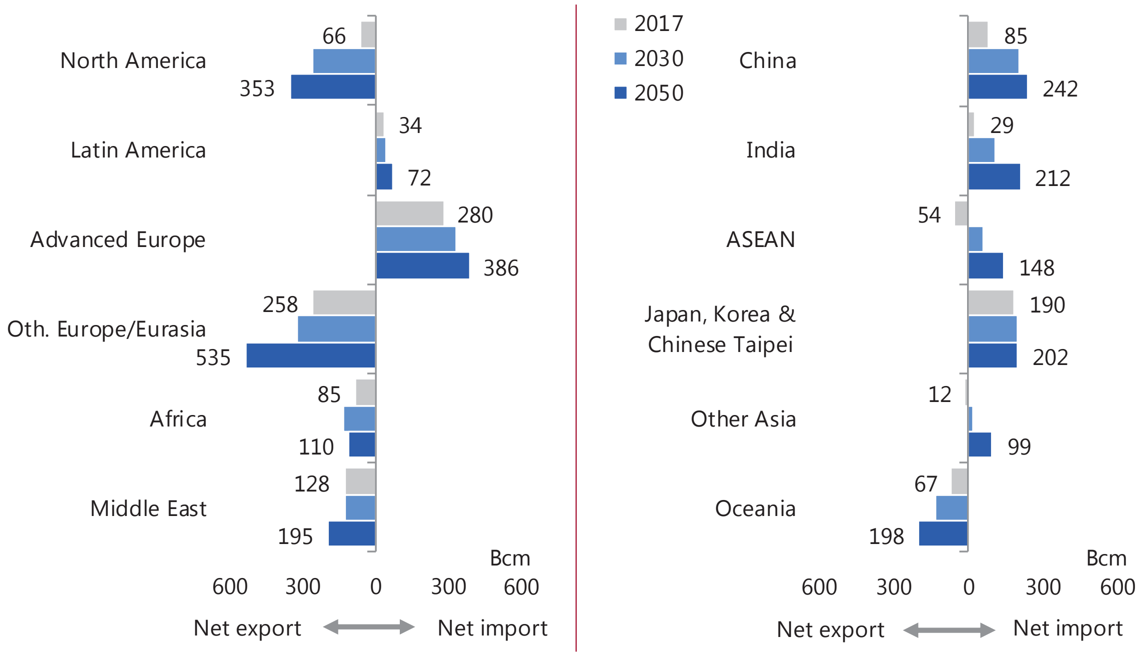


Changes (2017-2050)



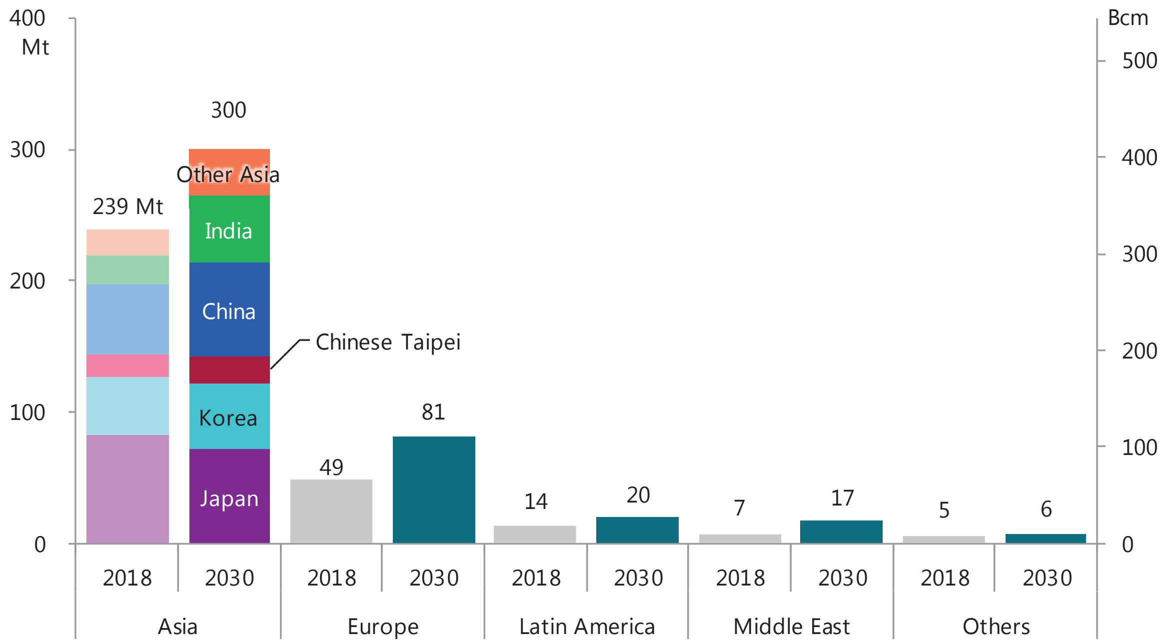
Reference Scenario

Net exports and imports of natural gas



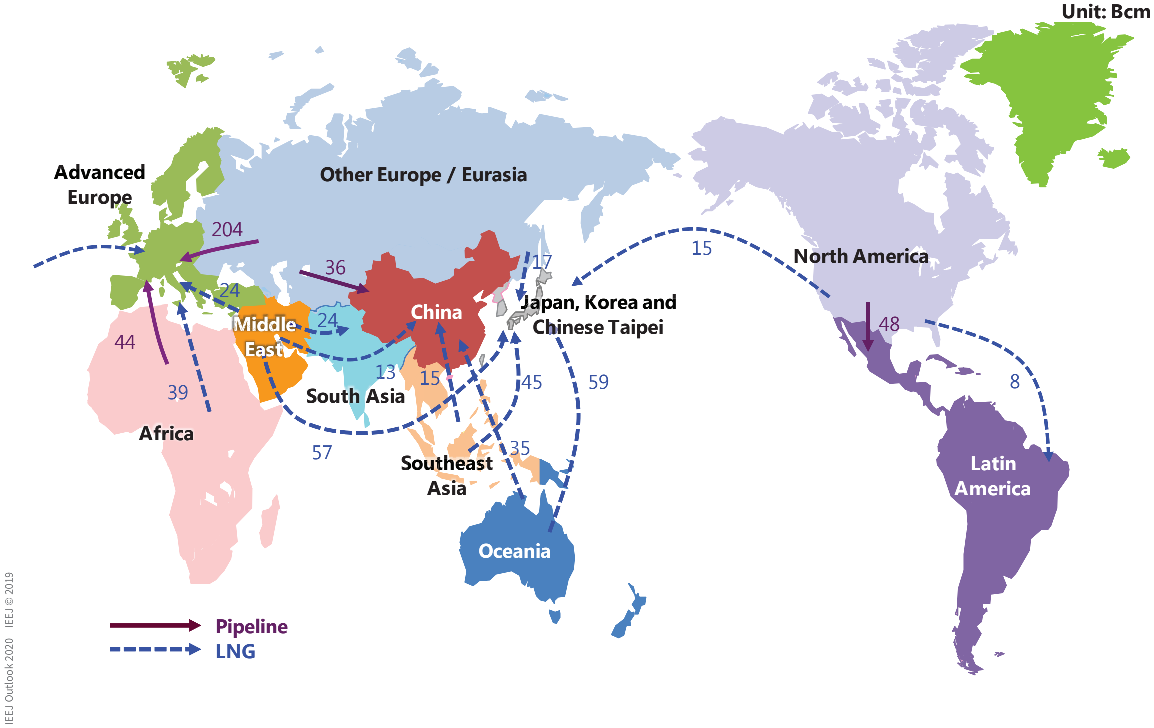
Reference Scenario

LNG imports



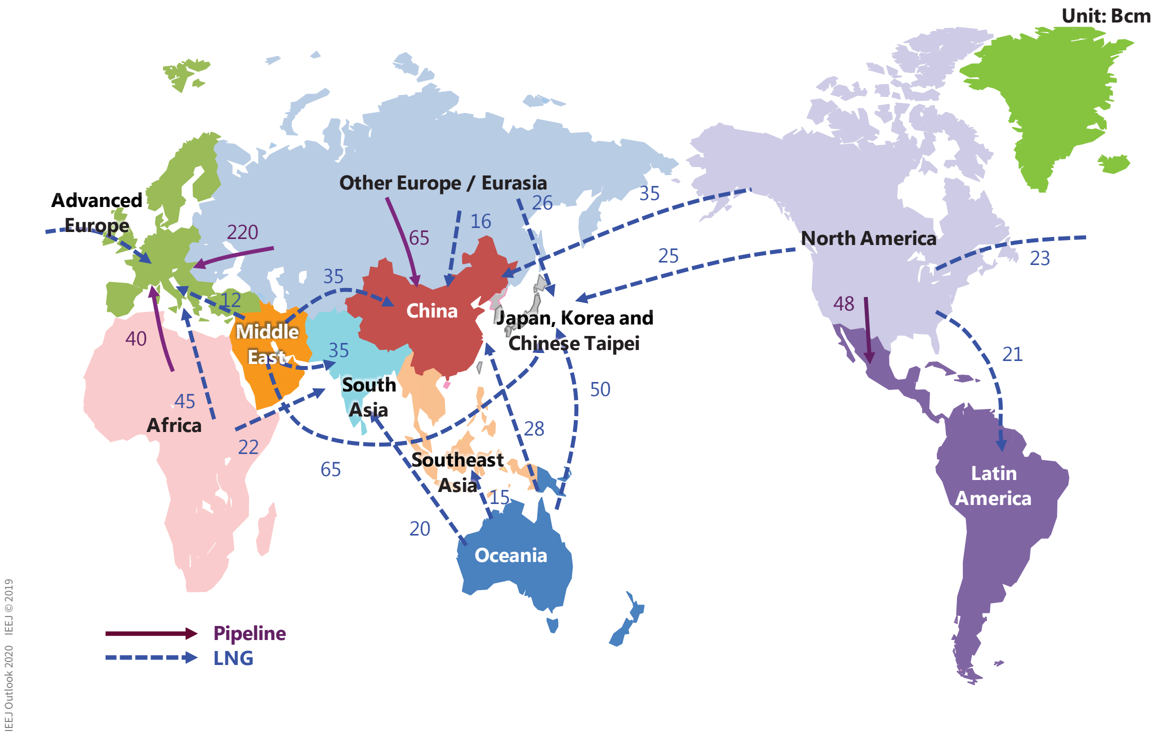
Reference Scenario

Major trade flows of natural gas (2018)



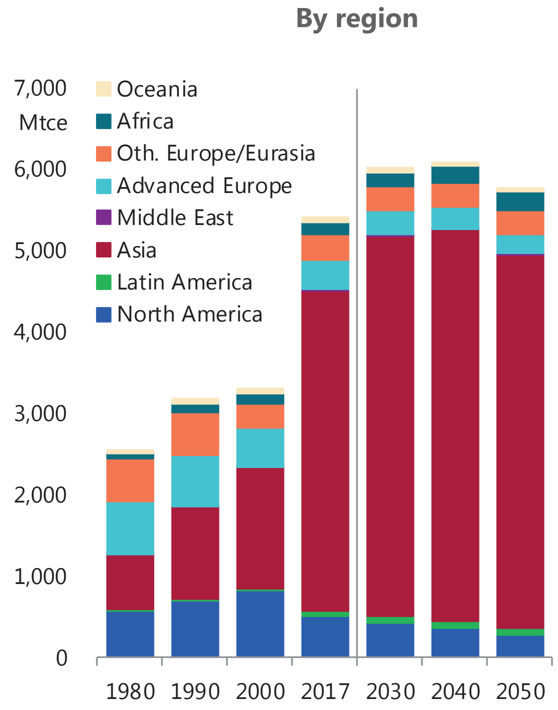
Reference Scenario

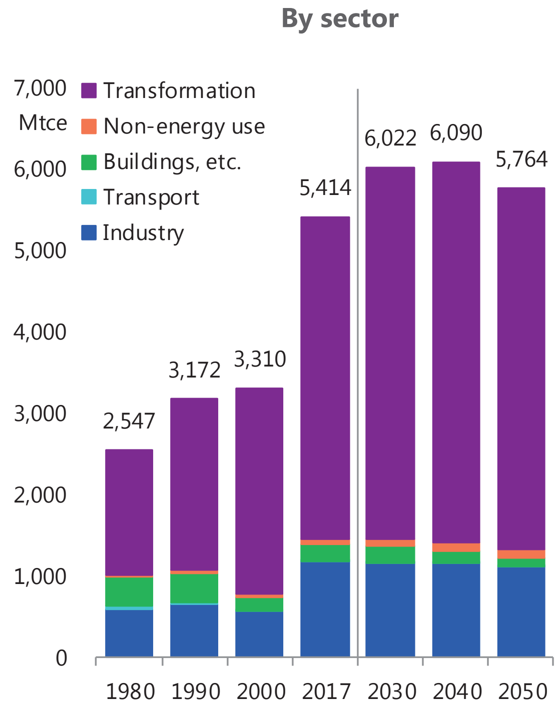
Major trade flows of natural gas (2030)



Reference Scenario

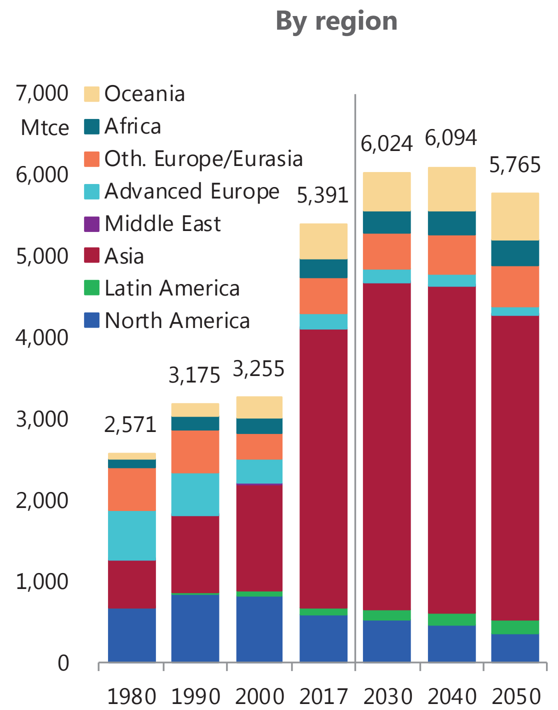
Coal consumption

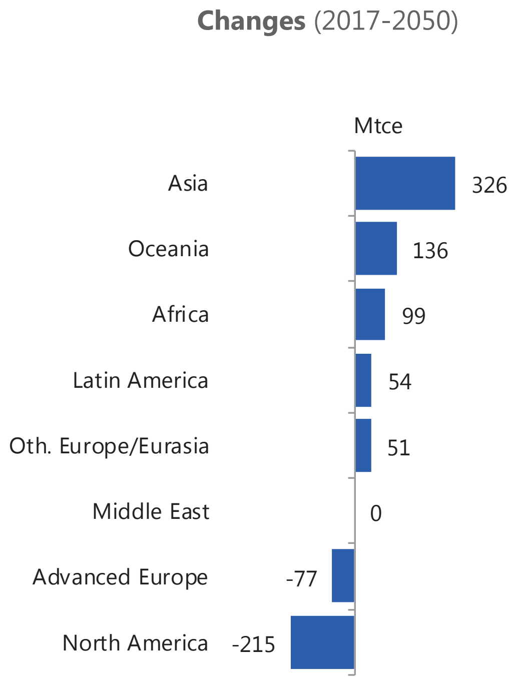




Reference Scenario

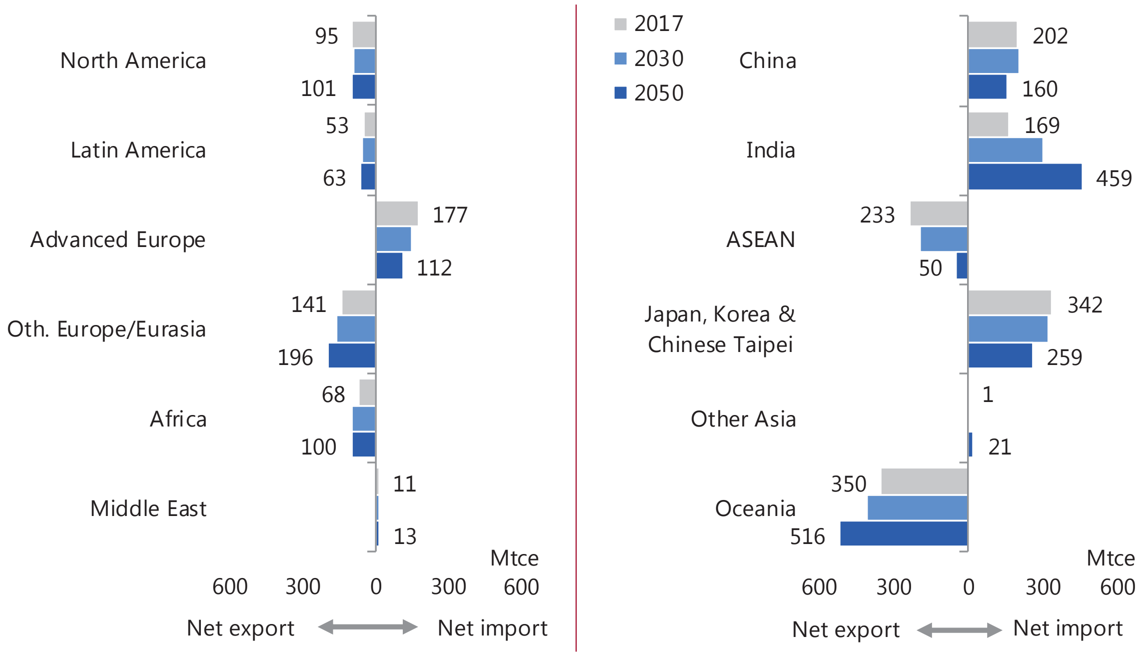
Coal production





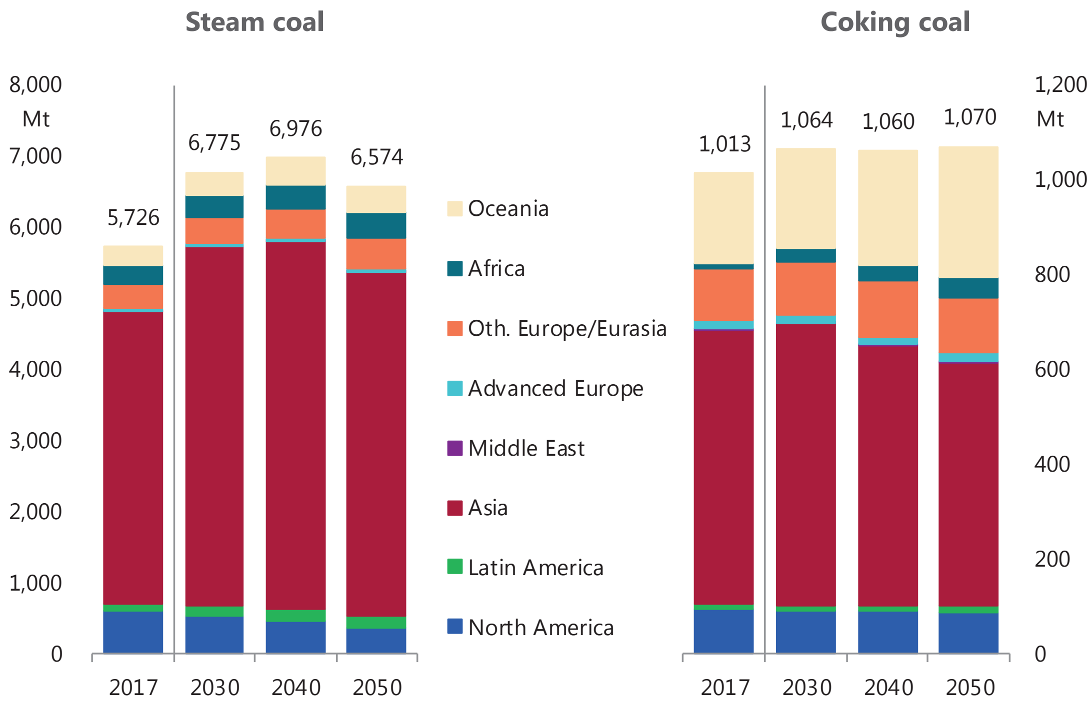
Reference Scenario

Net exports and imports of coal



Reference Scenario

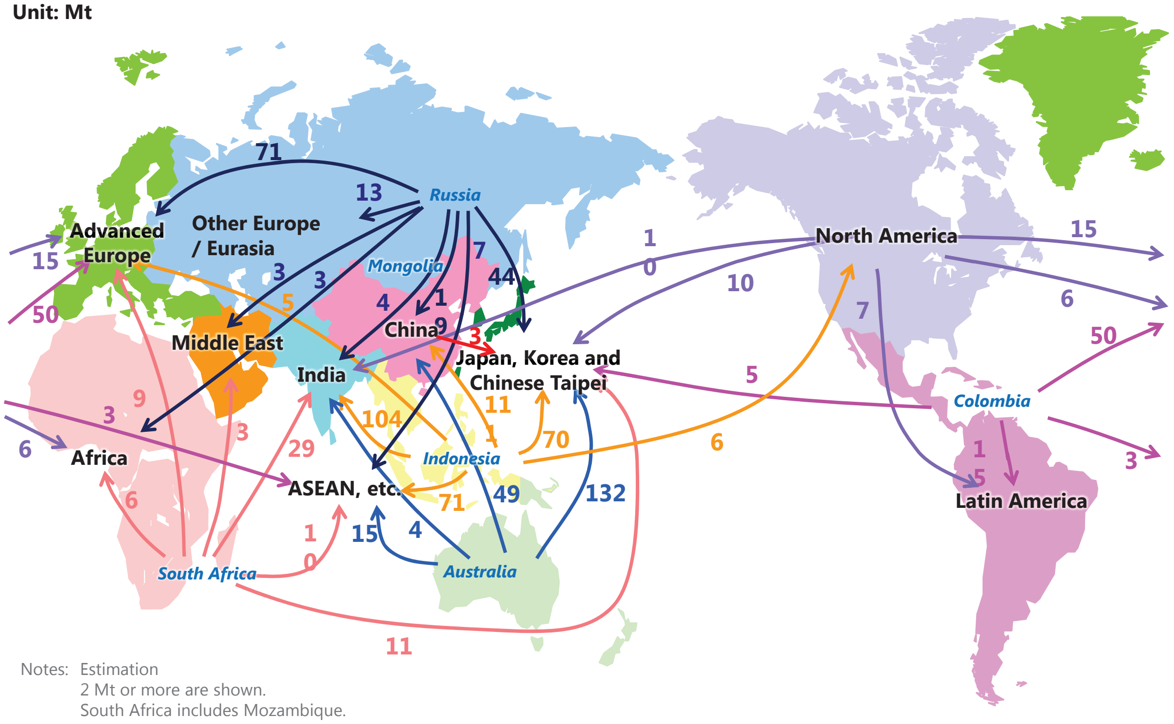
Coal production (steam and coking coal)



Reference Scenario

Major trade flows of steam coal (2018)

Unit: Mt

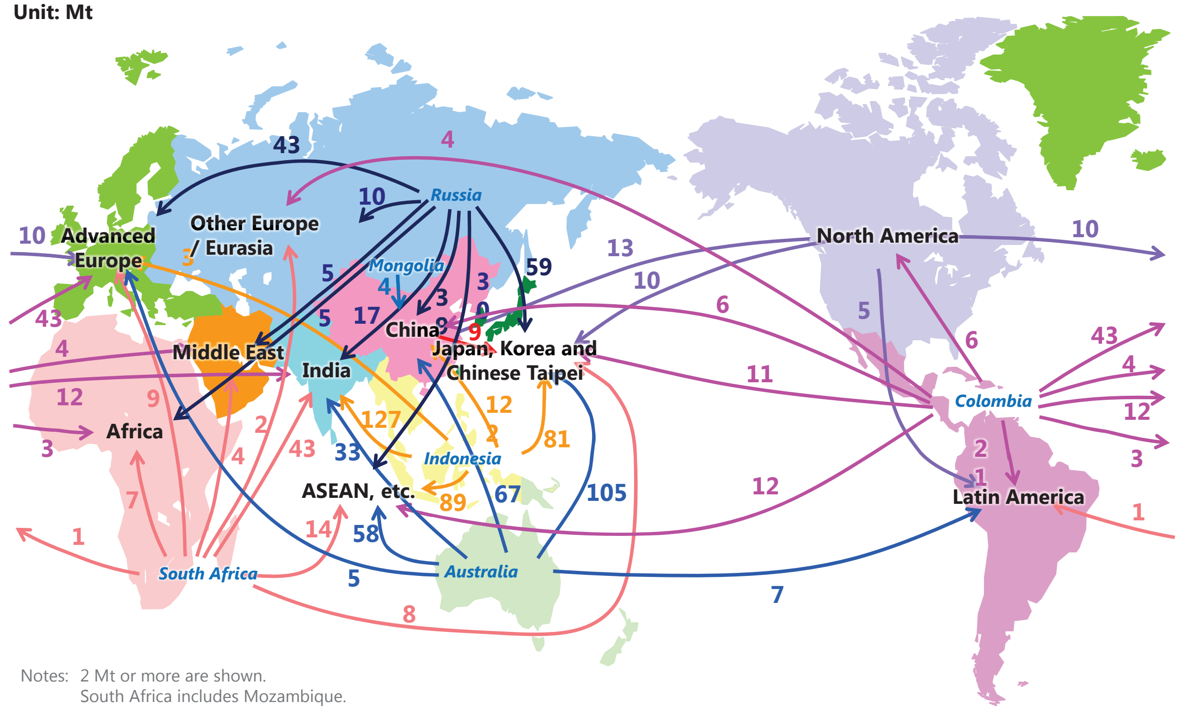


Notes: Estimation
2 Mt or more are shown.
South Africa includes Mozambique.

Reference Scenario

Major trade flows of steam coal (2030)

Unit: Mt

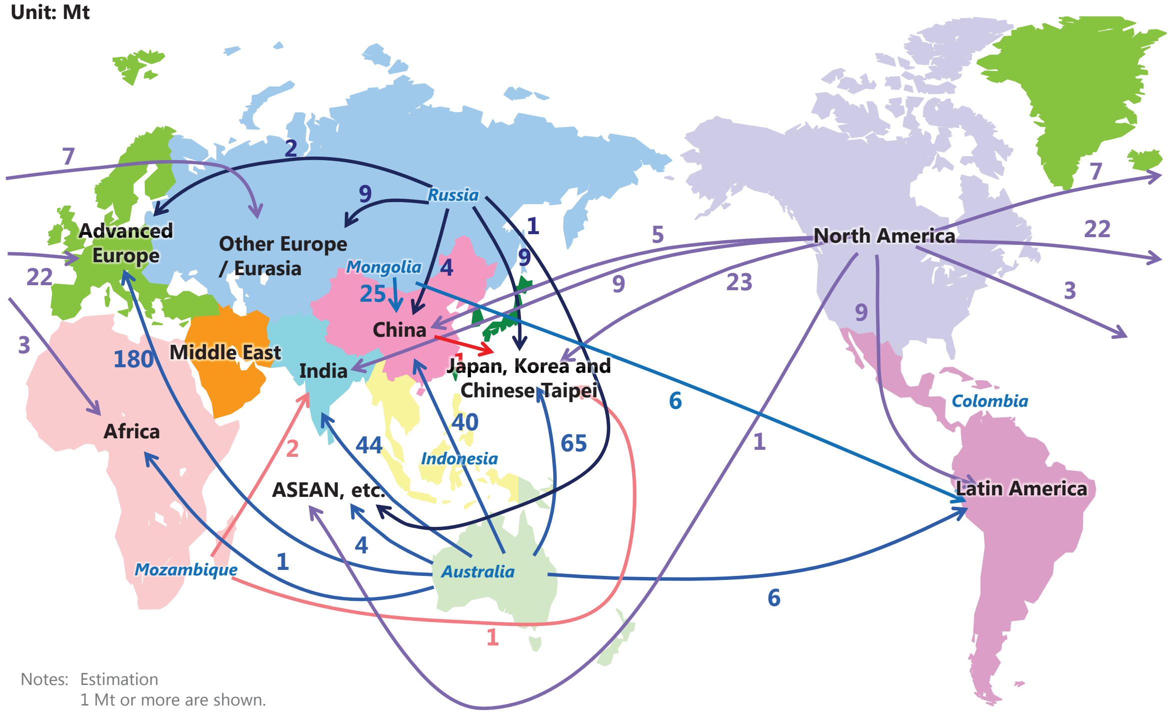


Notes: 2 Mt or more are shown.
South Africa includes Mozambique.

Reference Scenario

Major trade flows of coking coal (2018)

Unit: Mt

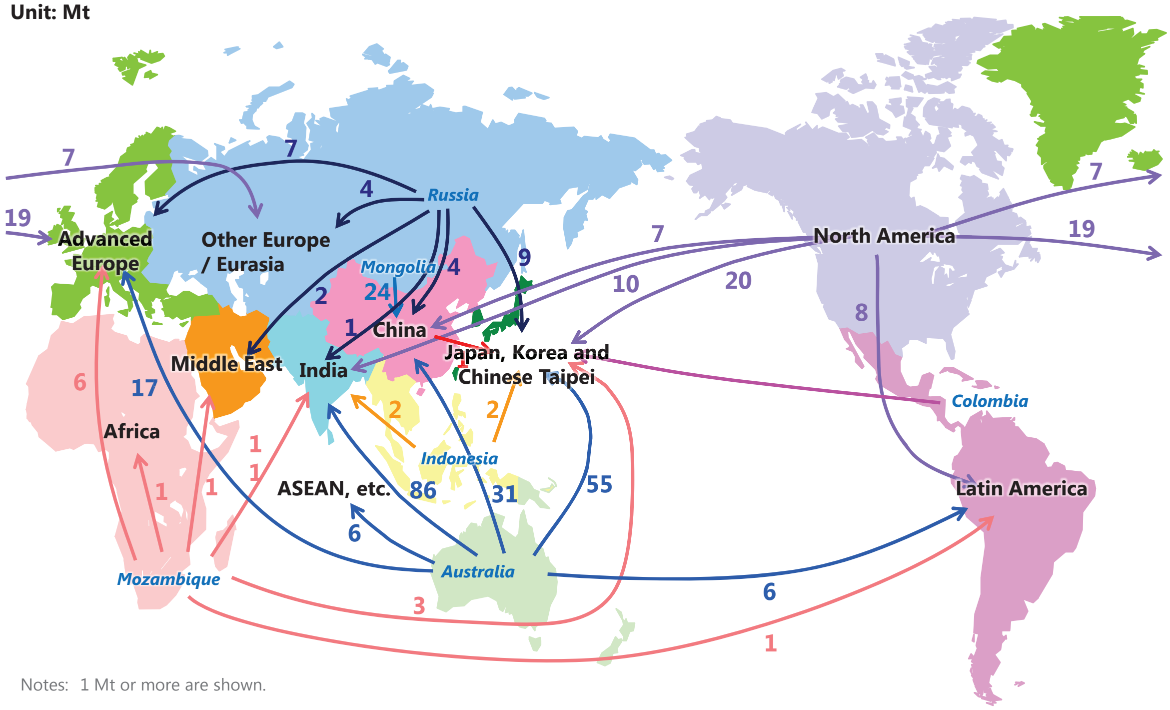


Notes: Estimation
1 Mt or more are shown.

Reference Scenario

Major trade flows of coking coal (2030)

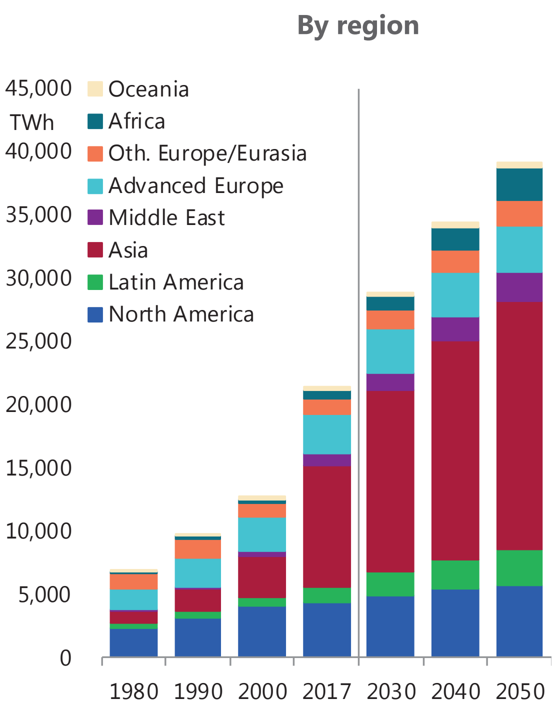
Unit: Mt

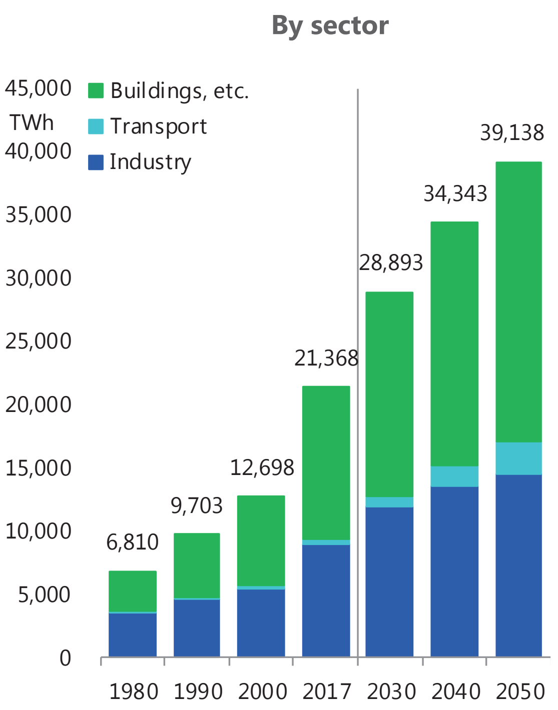


Notes: 1 Mt or more are shown.

Reference Scenario

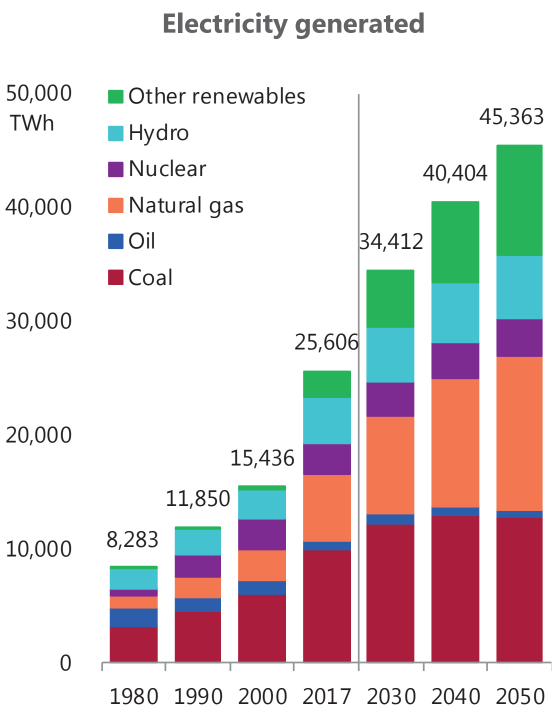
Final consumption of electricity

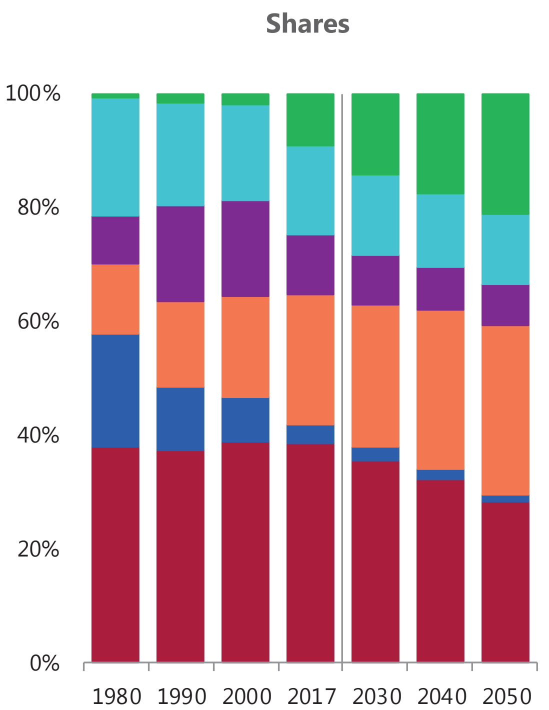




Reference Scenario

Power generation mix

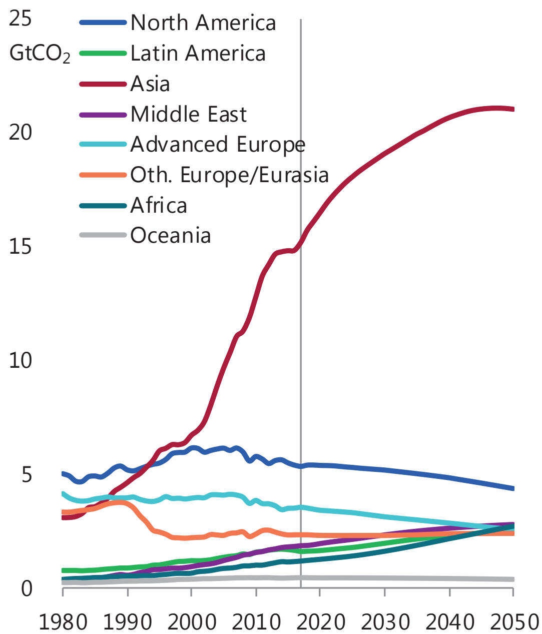




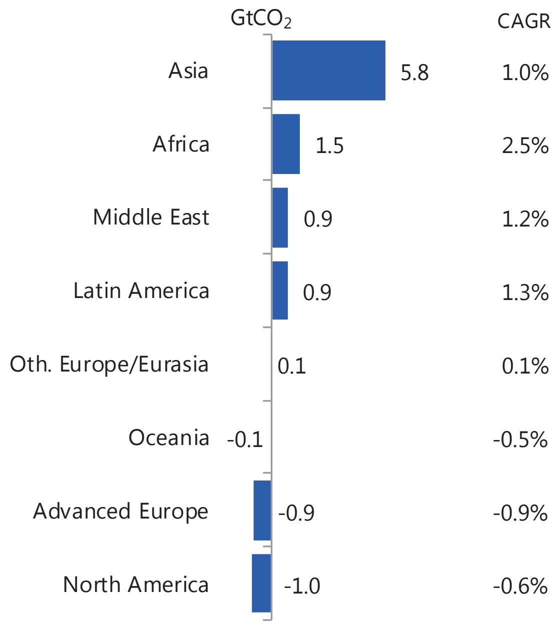
Reference Scenario

Energy-related CO_2 emissions

Emissions



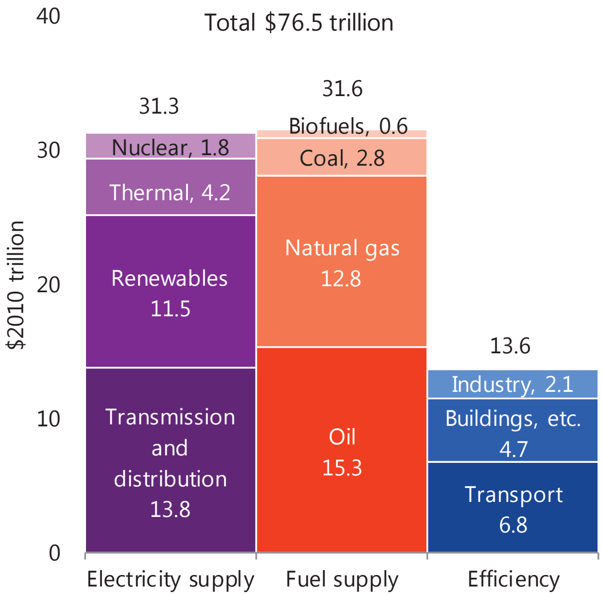
Changes (2017-2050)



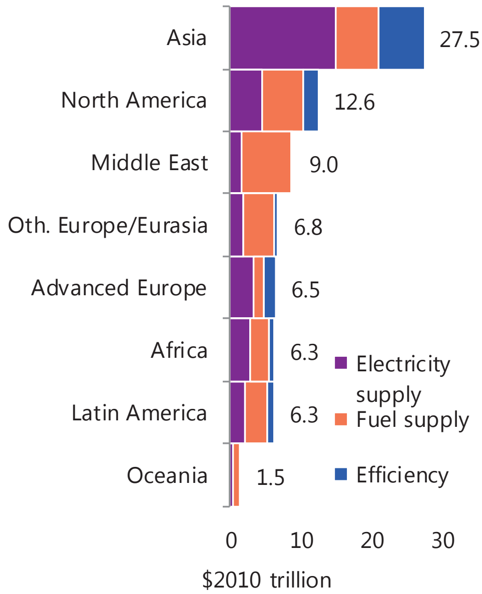
Reference Scenario

Energy-related investments (2018 – 2050)

By sector

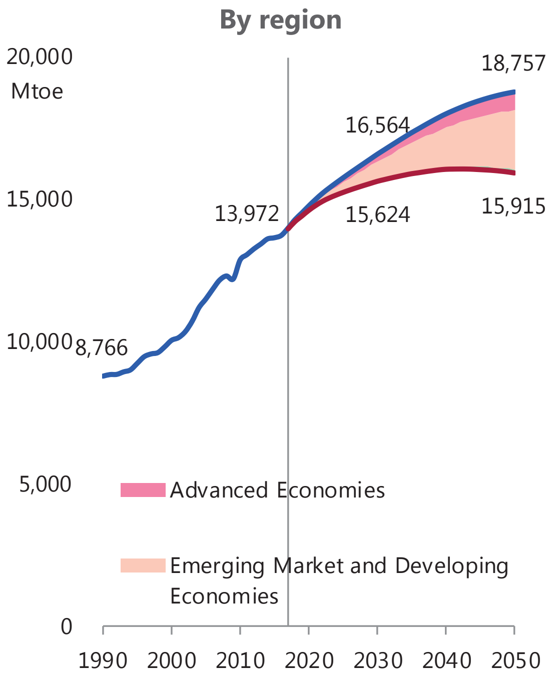


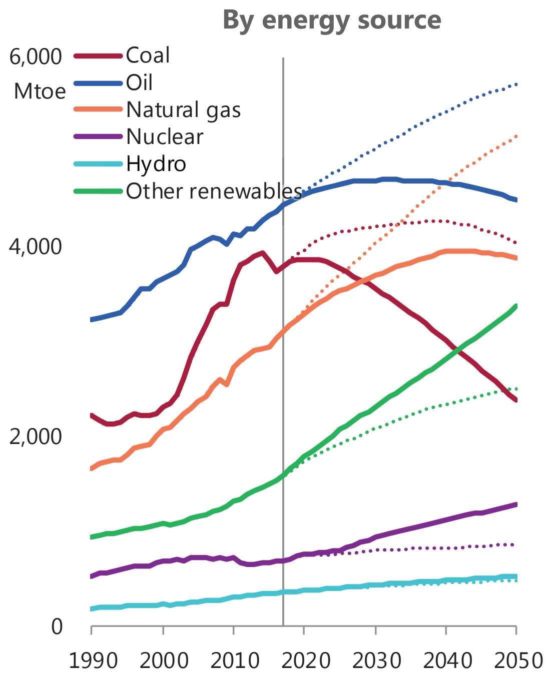
By region



Advanced Technologies Scenario

Primary energy consumption

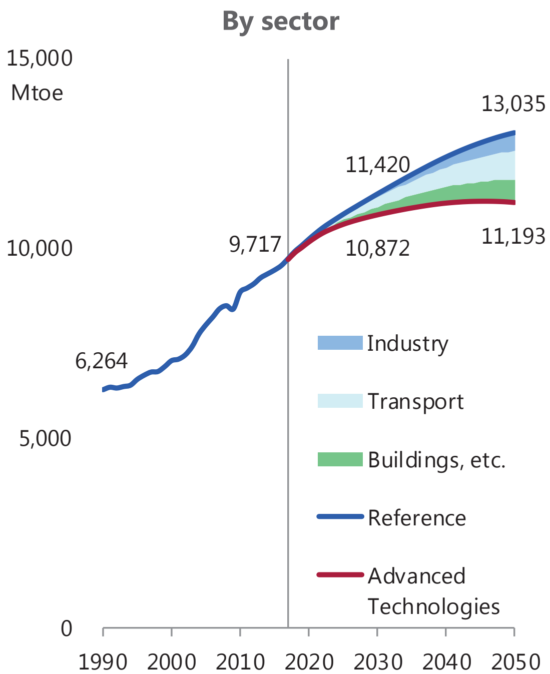


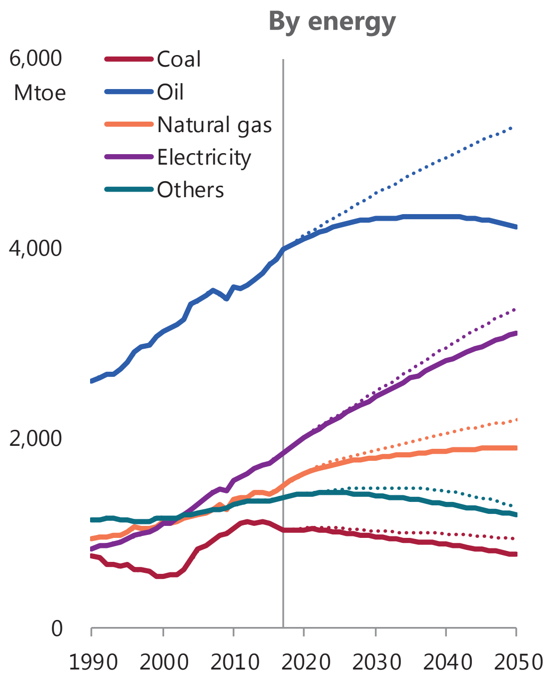


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Advanced Technologies Scenario

Final energy consumption

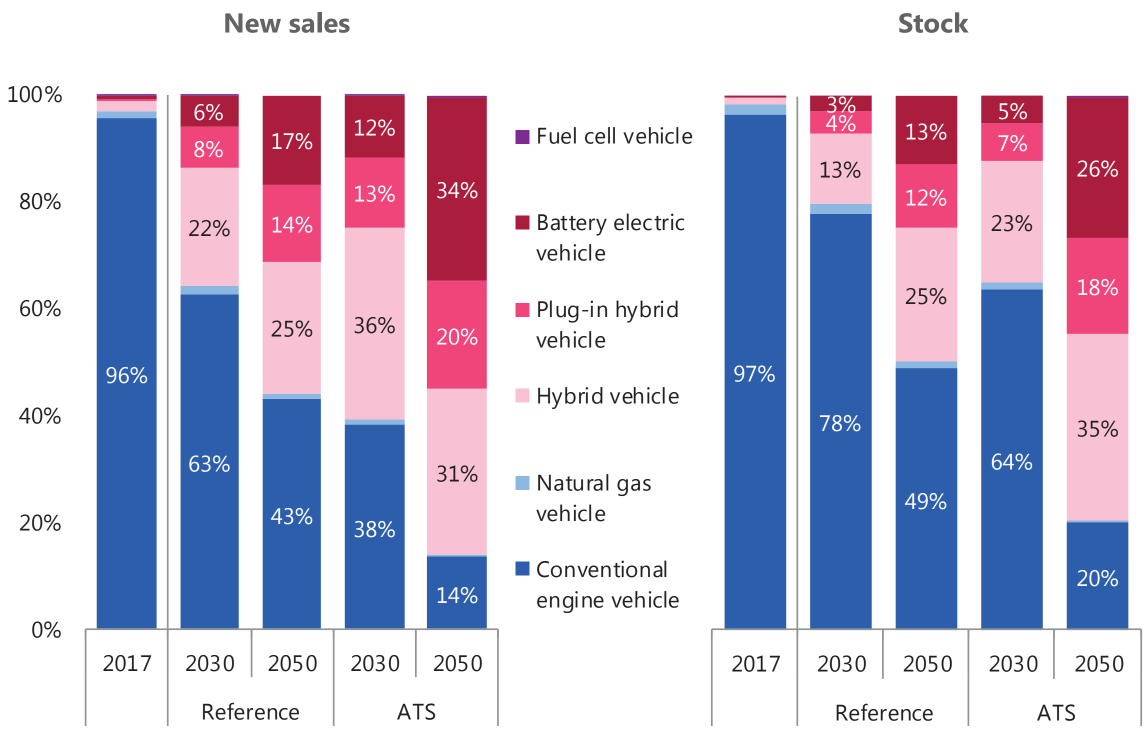




Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

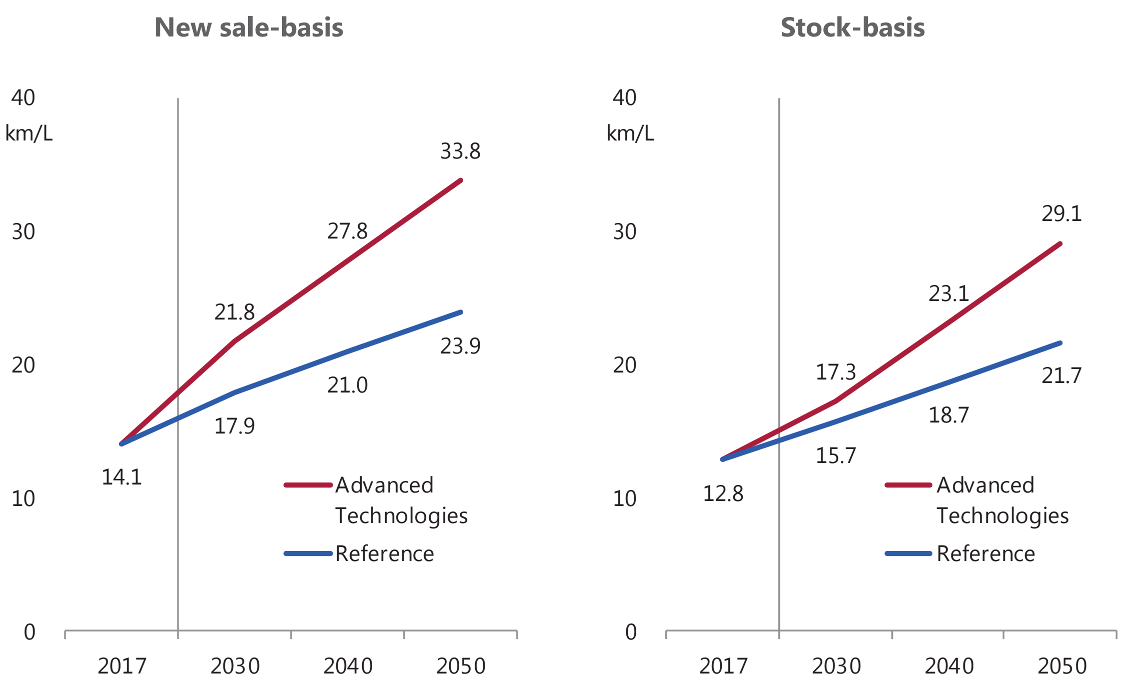
Advanced Technologies Scenario

Share of passenger vehicle



Advanced Technologies Scenario

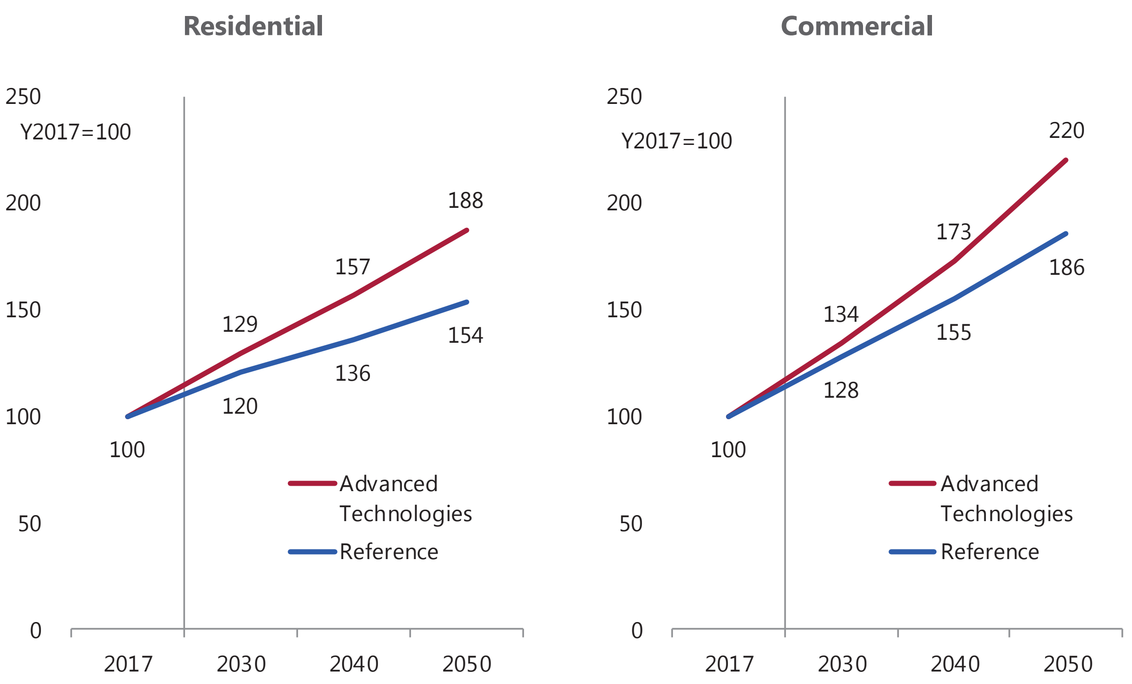
Fuel efficiency of passenger vehicle



Note: Litres of gasoline equivalent

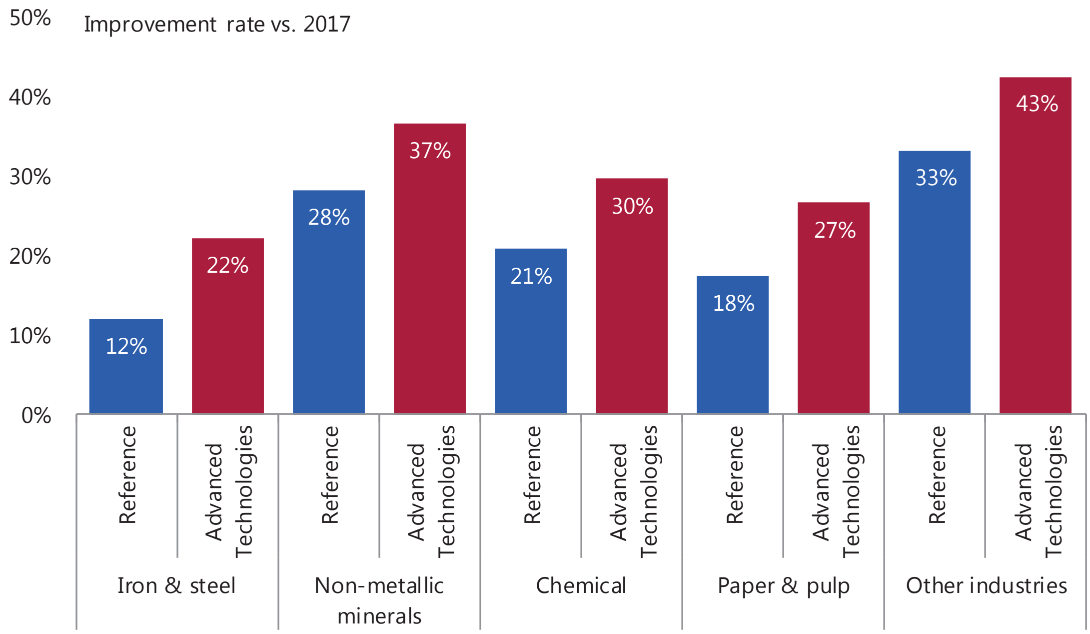
Advanced Technologies Scenario

Energy efficiency in buildings sector



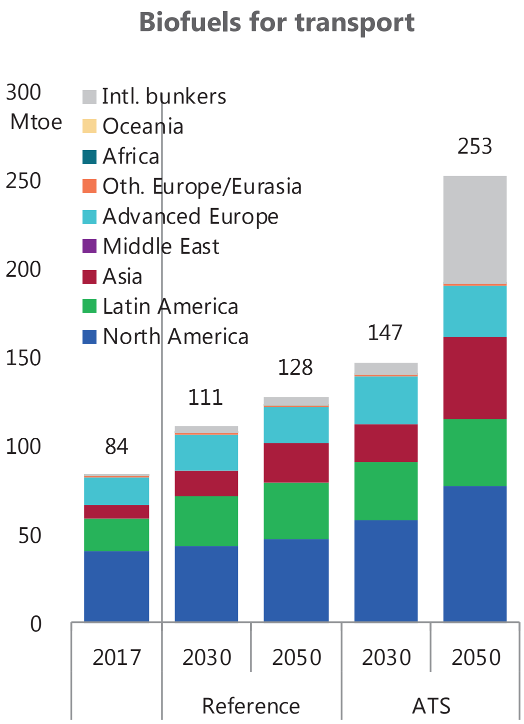
Advanced Technologies Scenario

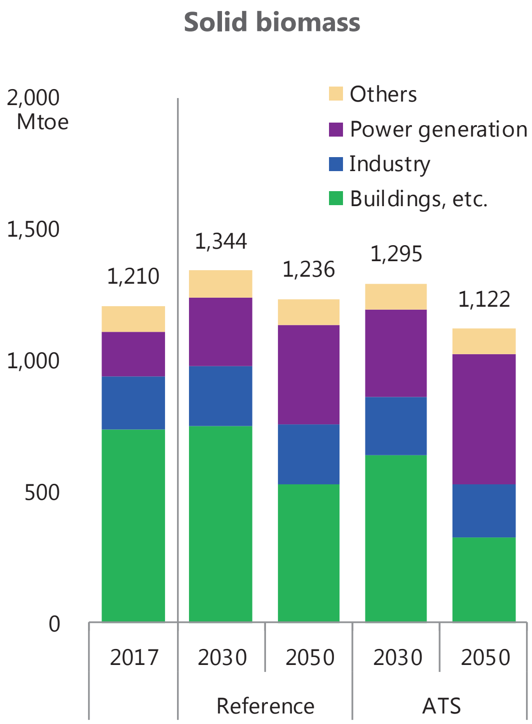
Energy intensity improvement in industry sector



Advanced Technologies Scenario

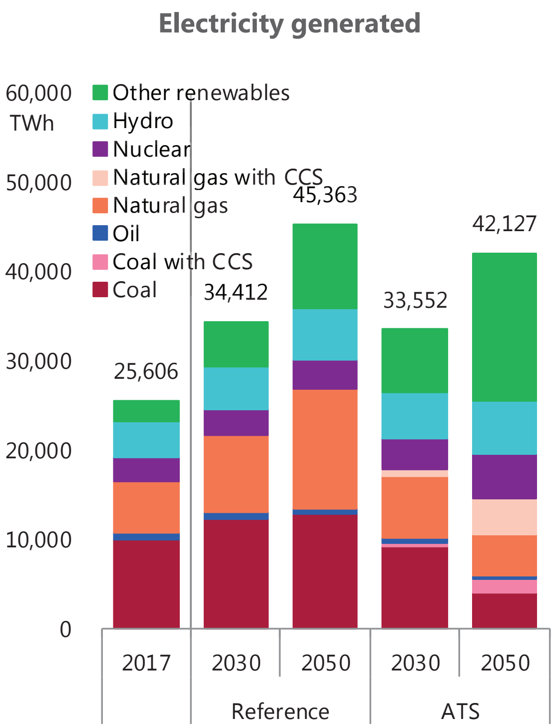
Biomass

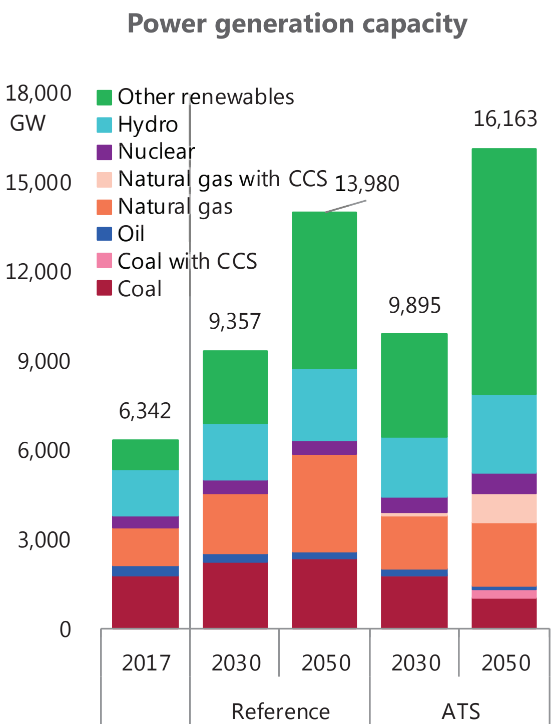




Advanced Technologies Scenario

Power generation mix

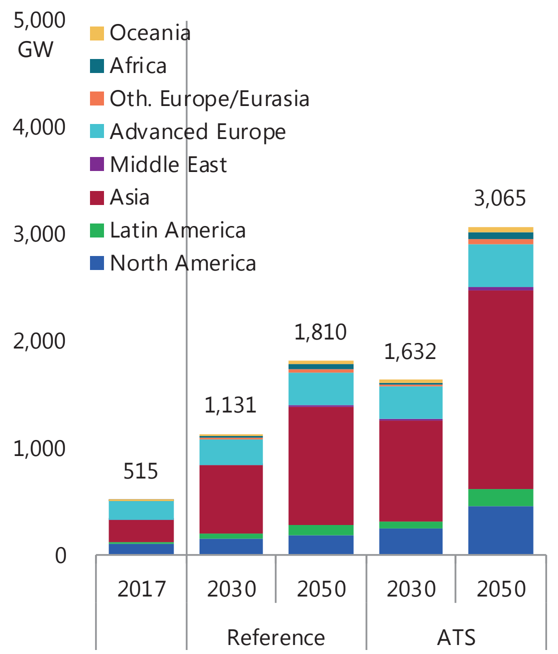




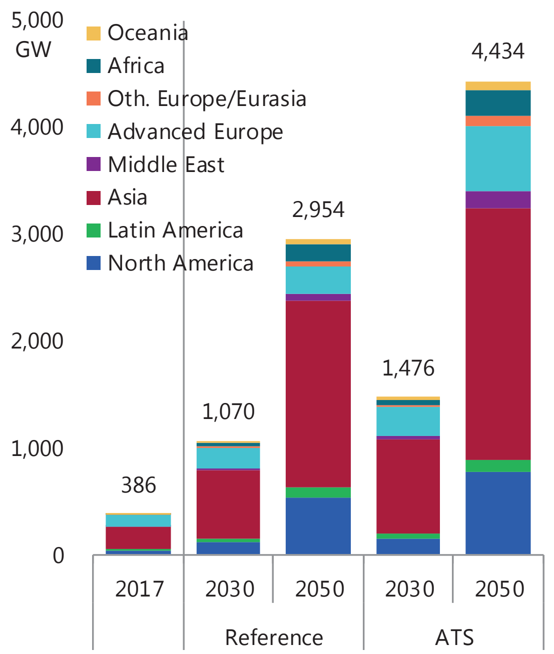
Advanced Technologies Scenario

Wind and solar PV power generation capacity

Wind



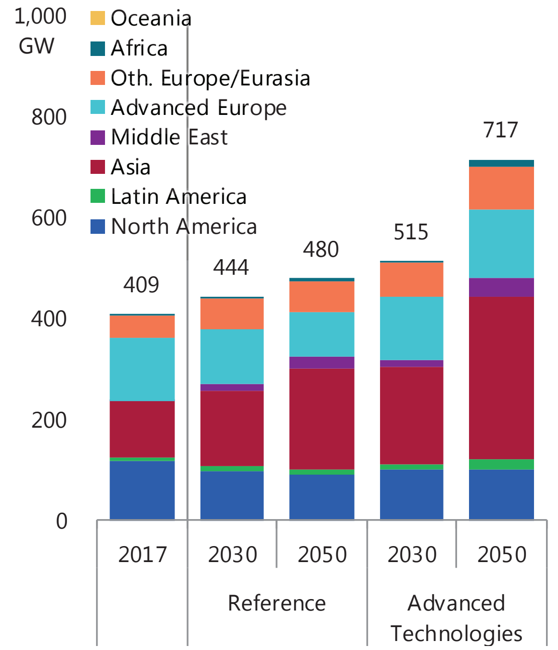
Solar PV



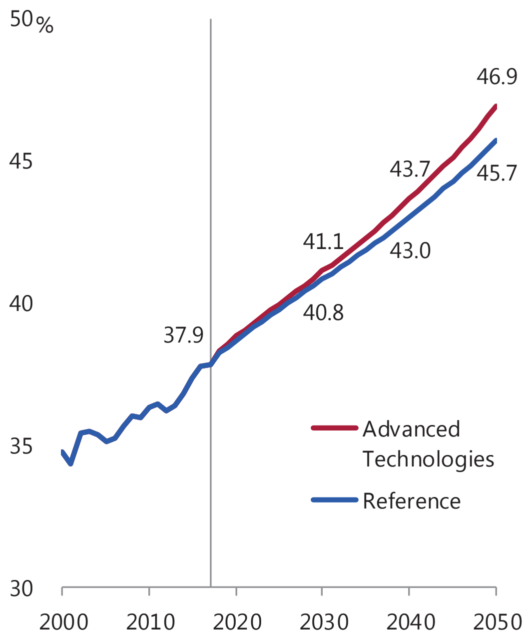
Advanced Technologies Scenario

Nuclear power generation capacity and thermal power generation efficiency

Nuclear



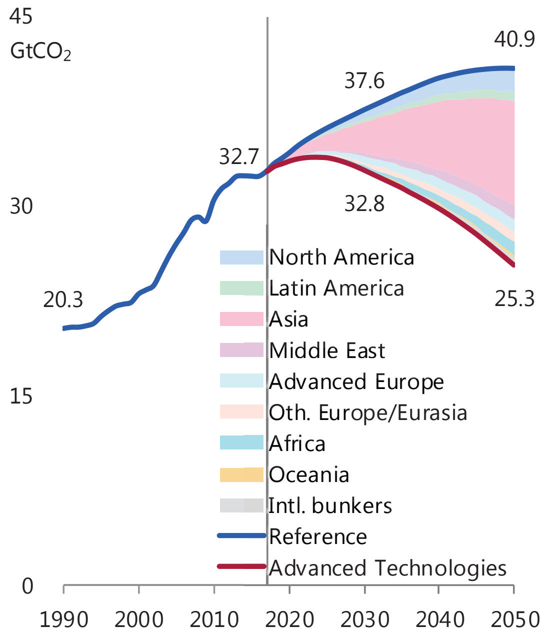
Thermal power generation efficiency
(generation end)



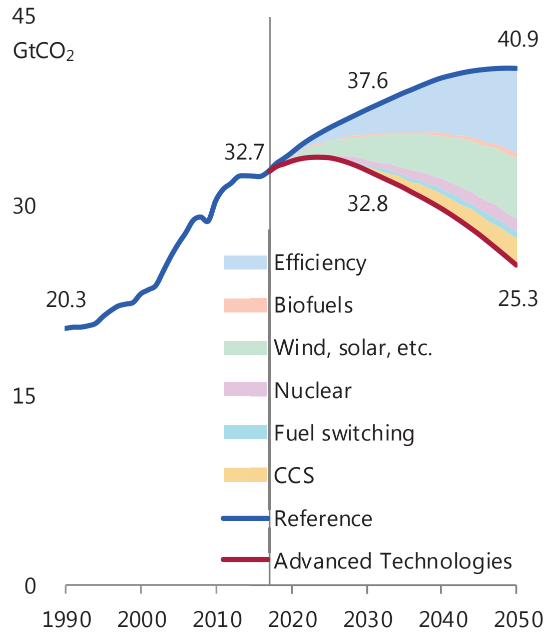
Advanced Technologies Scenario

Energy-related CO_2 emissions

By region



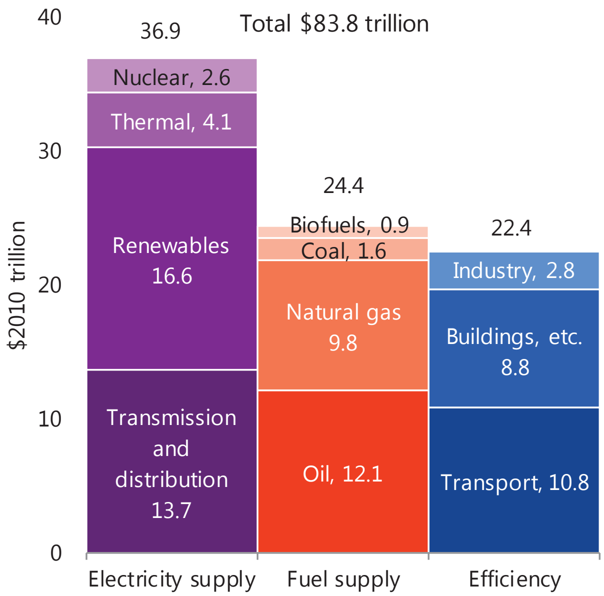
By technology



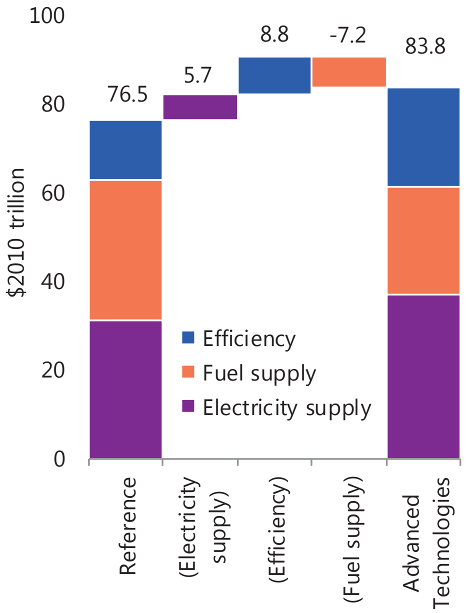
Advanced Technologies Scenario

Energy-related investments (2018 – 2050)

By sector



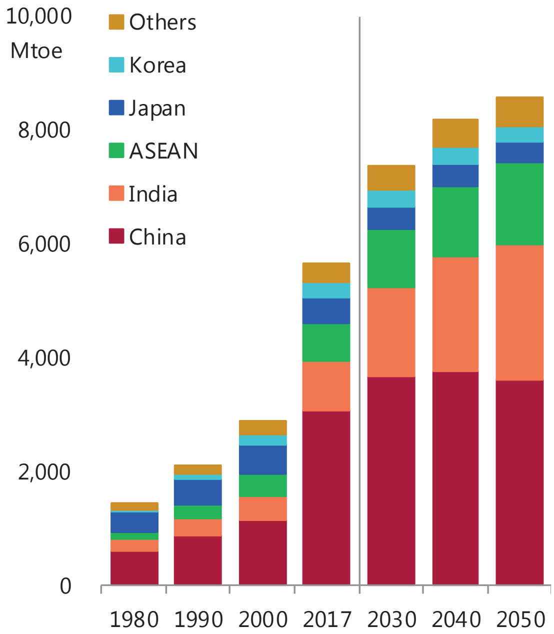
Changes from Reference Scenario



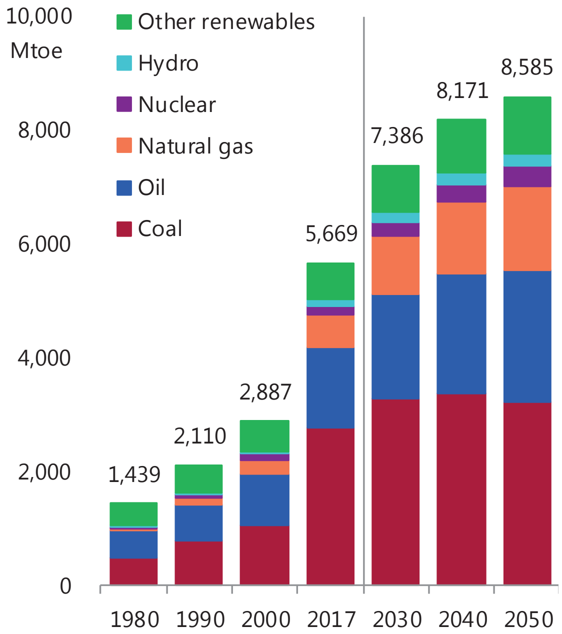
Asia | Reference Scenario

Primary energy consumption

By region



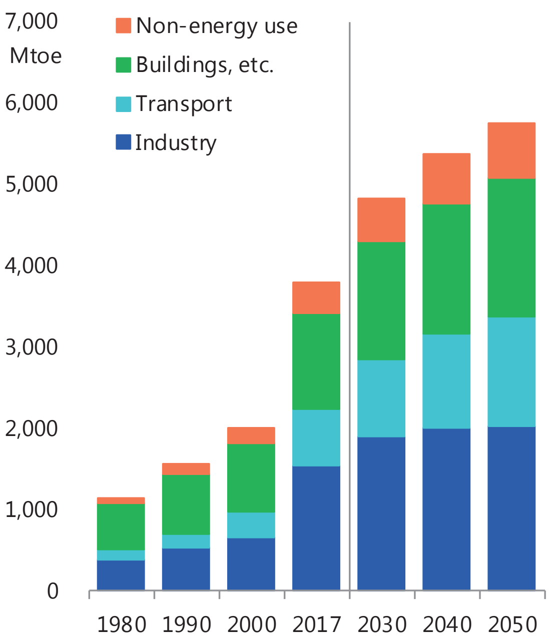
By energy source



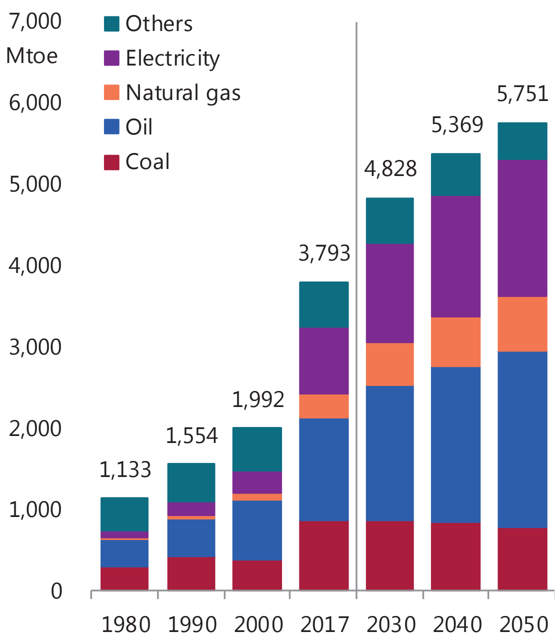
Asia | Reference Scenario

Final energy consumption

By sector

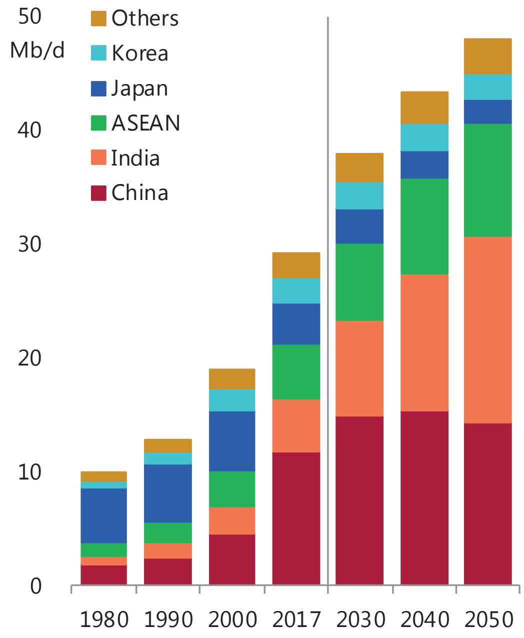


By energy source

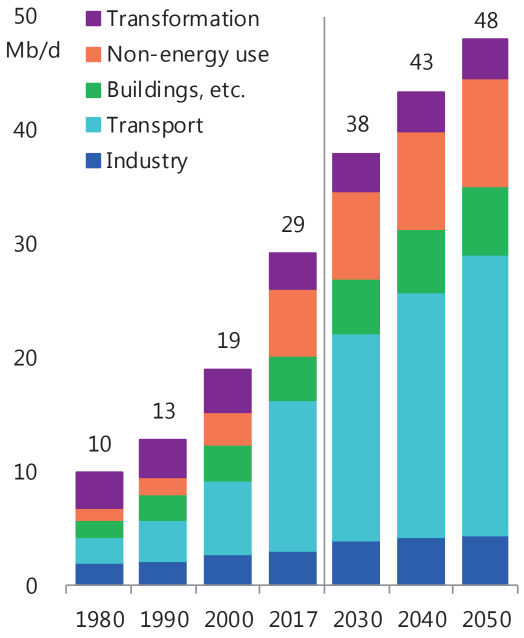


Oil consumption

By region

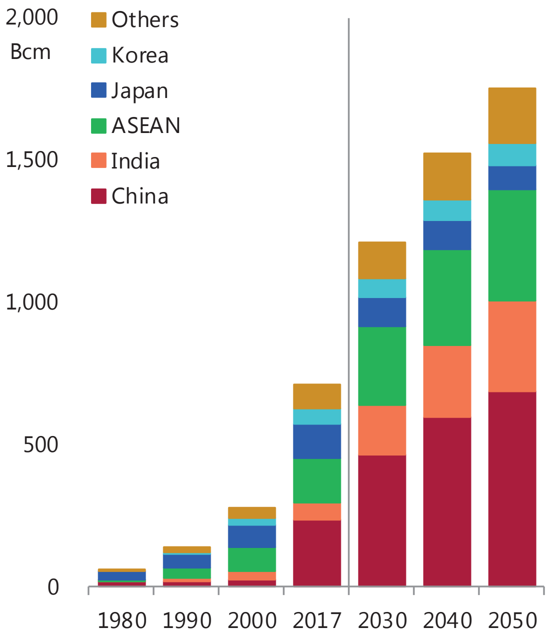


By sector

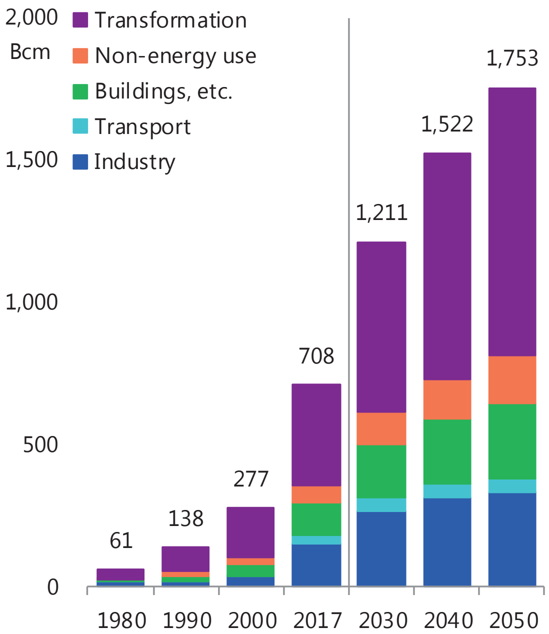


Natural gas consumption

By region

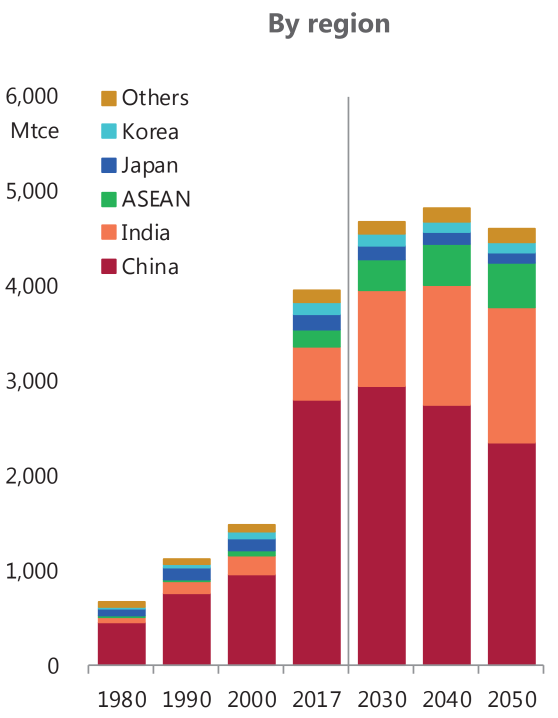


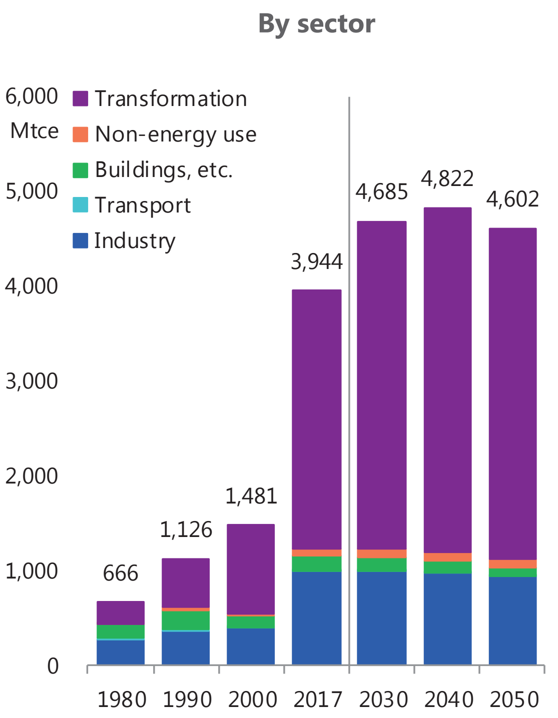
By sector



Asia | Reference Scenario

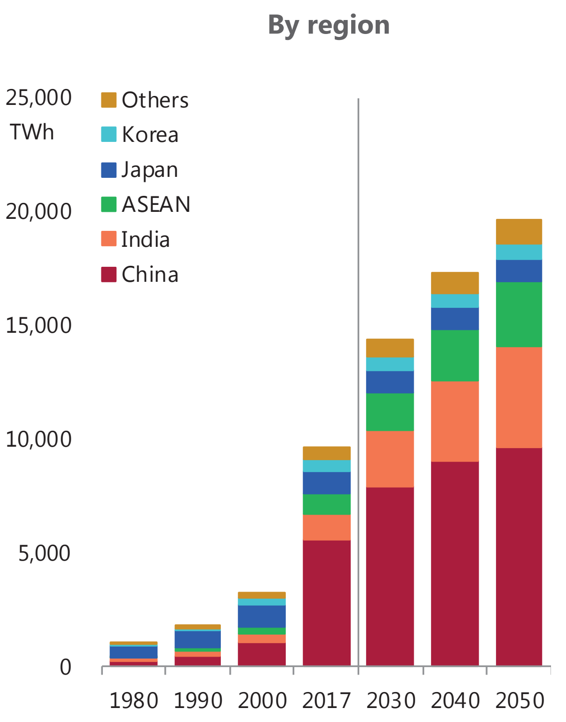
Coal consumption

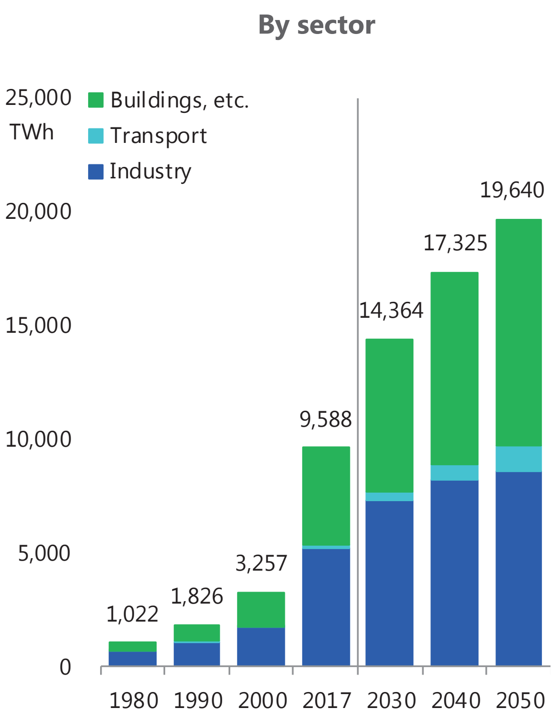




Asia | Reference Scenario

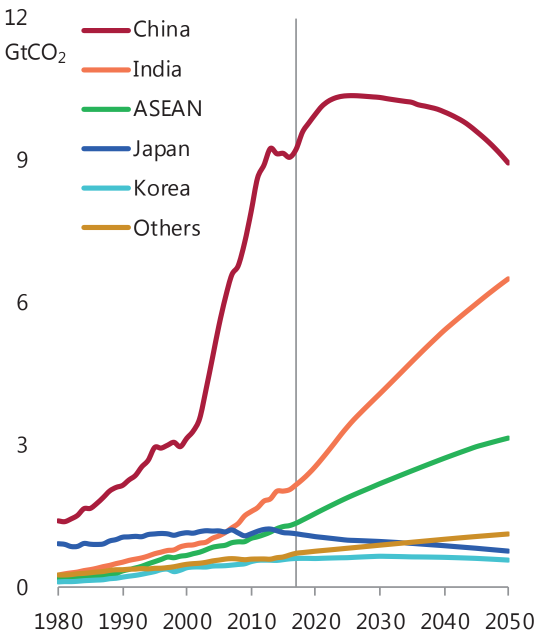
Final consumption of electricity

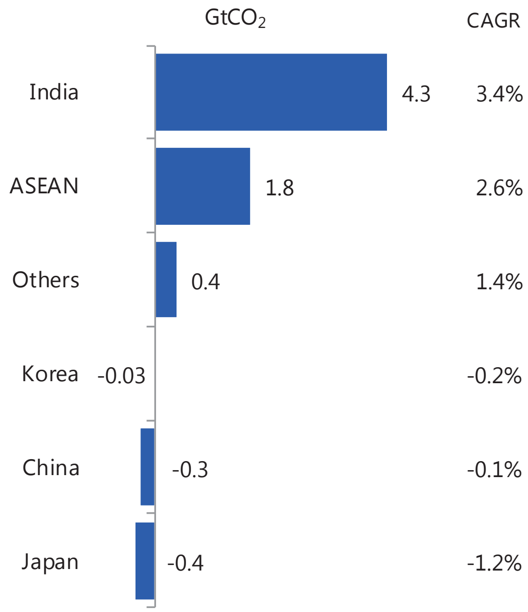




Asia | Reference Scenario

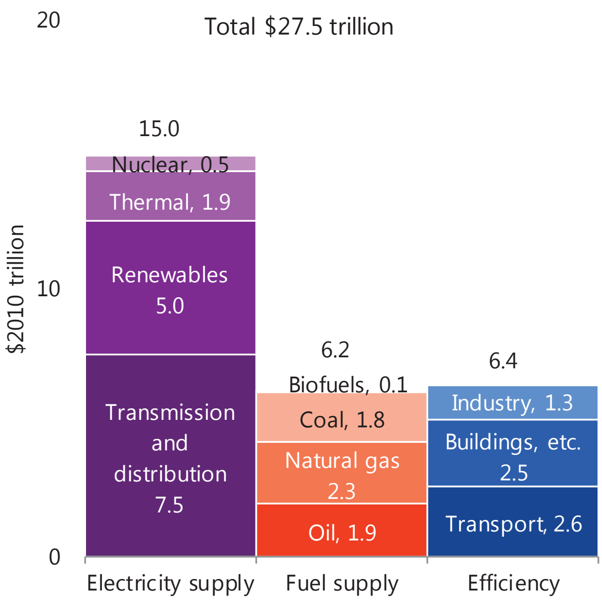
Energy-related CO_2 emissions

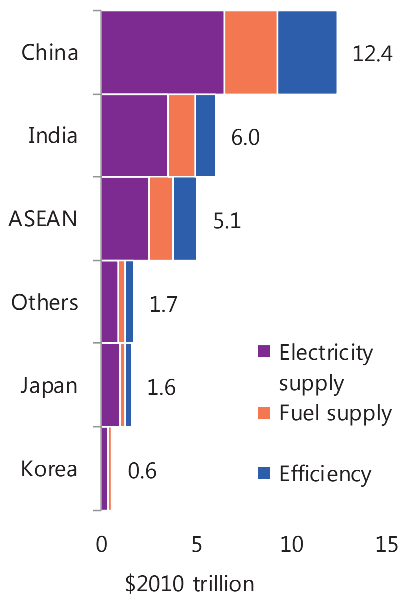




Asia | Reference Scenario

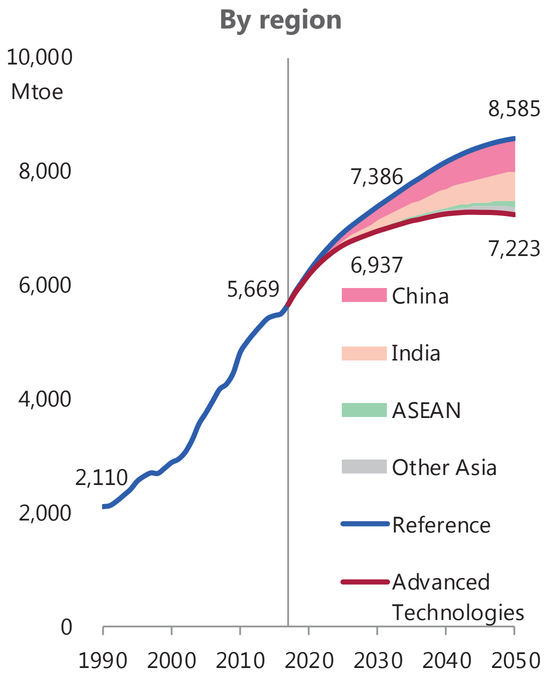
Energy-related investments (2018 – 2050)

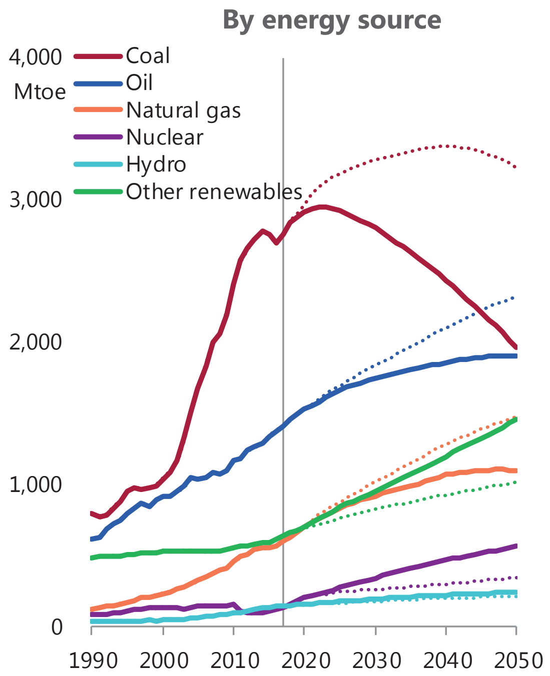




Asia | Advanced Technologies Scenario

Primary energy consumption

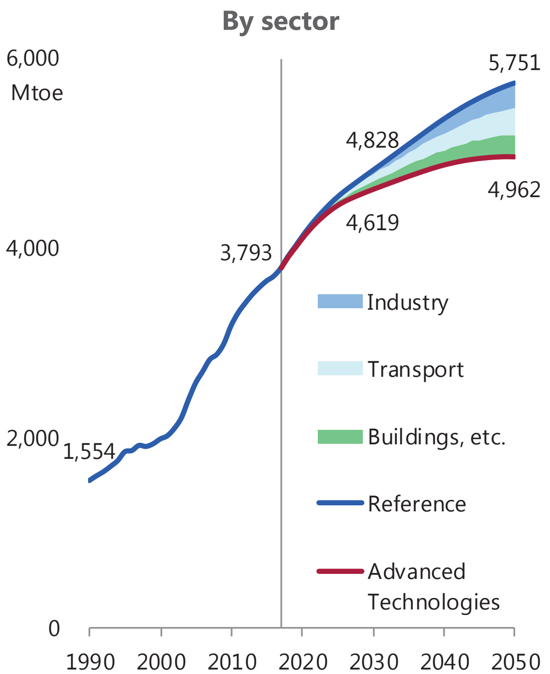


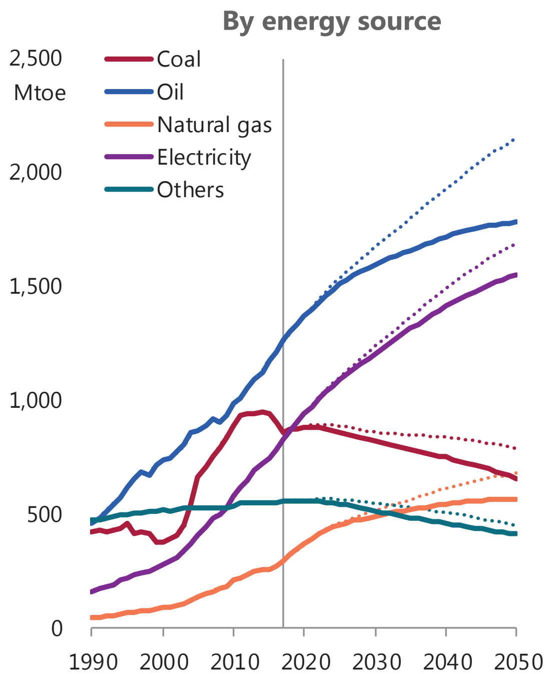


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Asia | Advanced Technologies Scenario

Final energy consumption

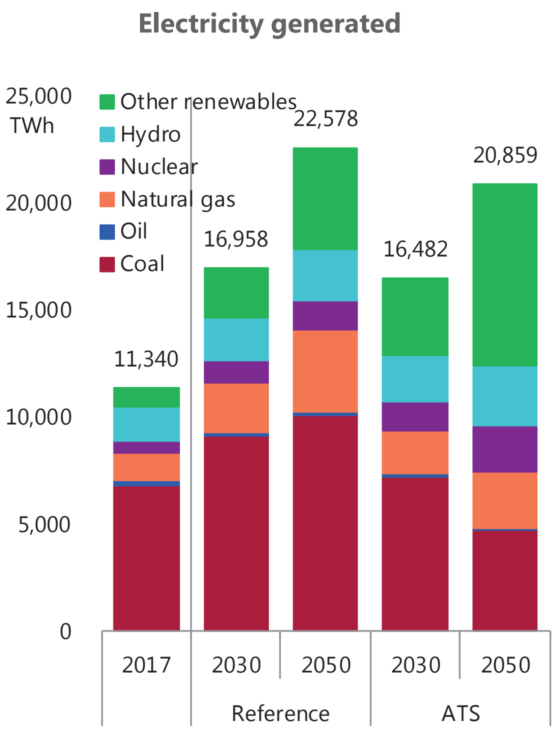


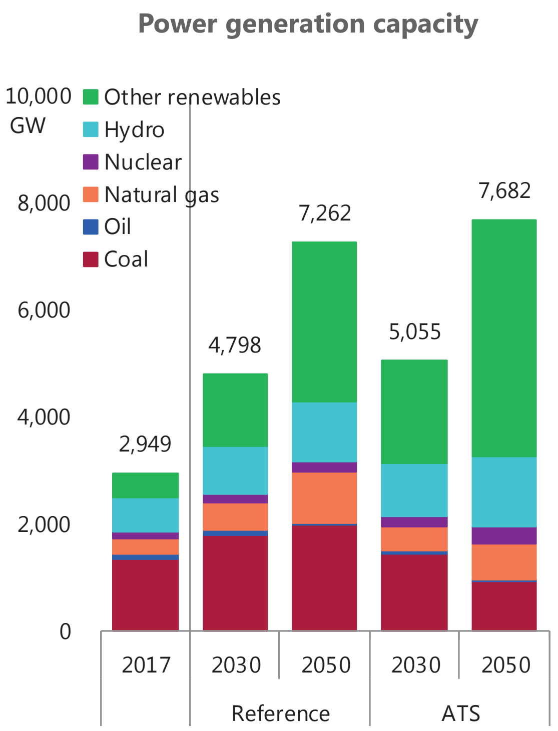


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Asia | Advanced Technologies Scenario

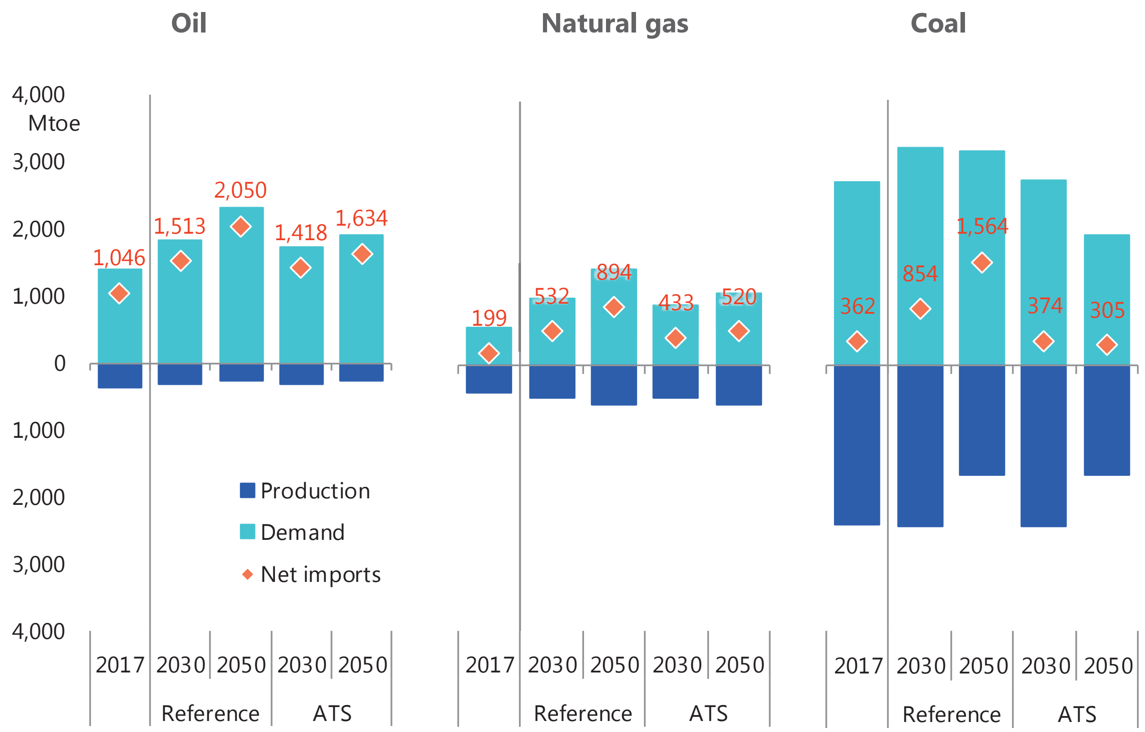
Power generation mix





Asia | Advanced Technologies Scenario

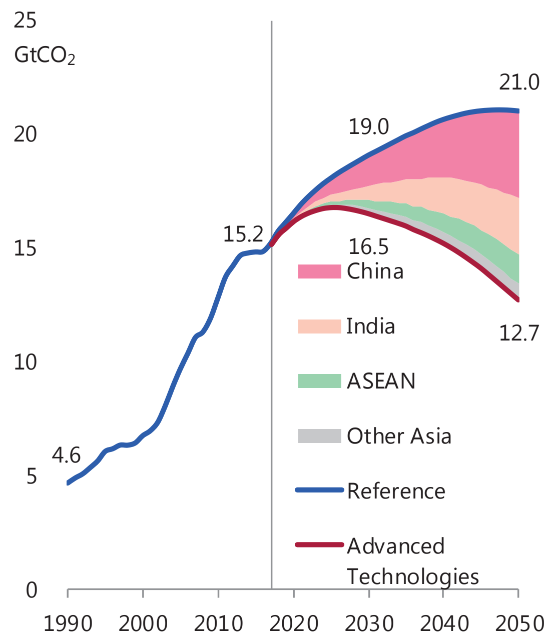
Supply and demand balance of fossil fuels



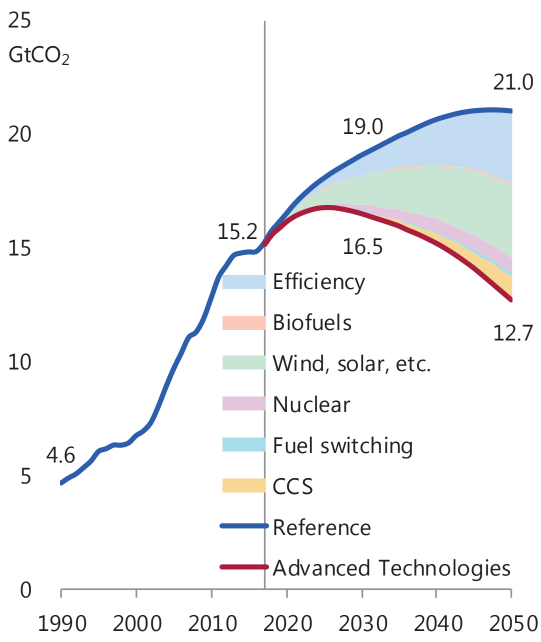
Asia | Advanced Technologies Scenario

Energy-related CO_2 emissions

By region



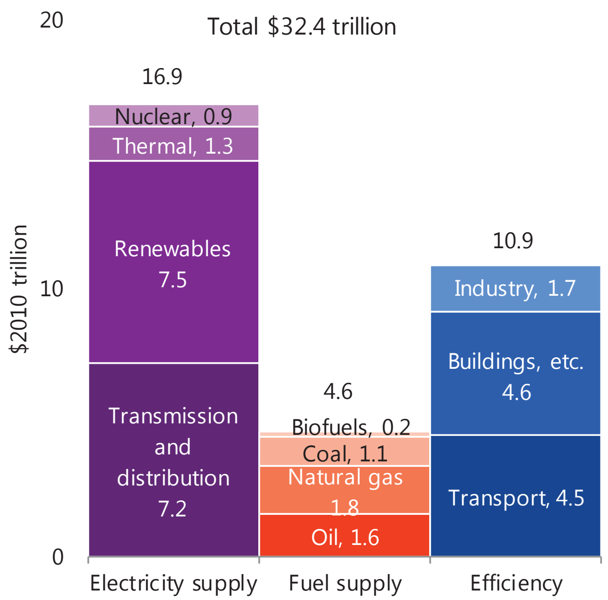
By technology



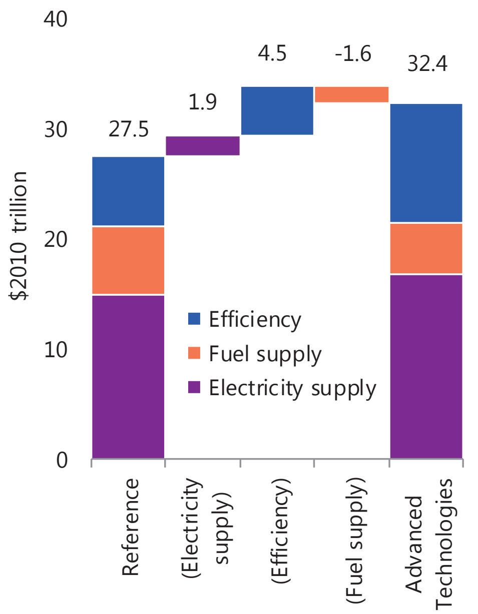
Asia | Advanced Technologies Scenario

Energy-related investments (2018 – 2050)

By sector

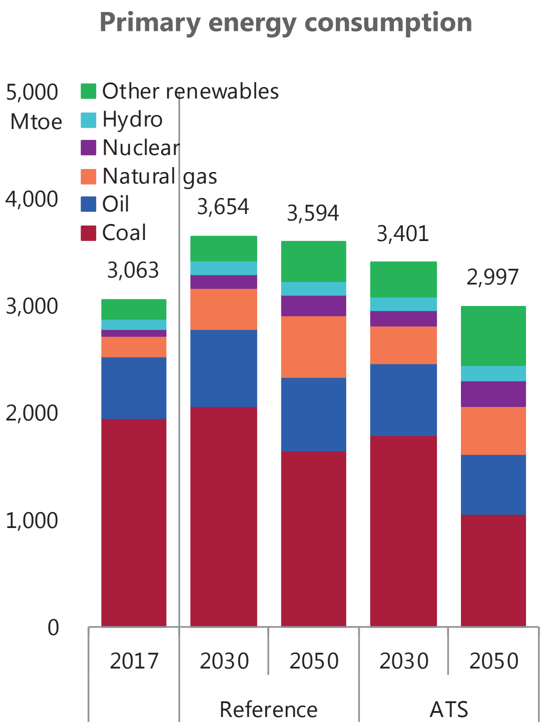


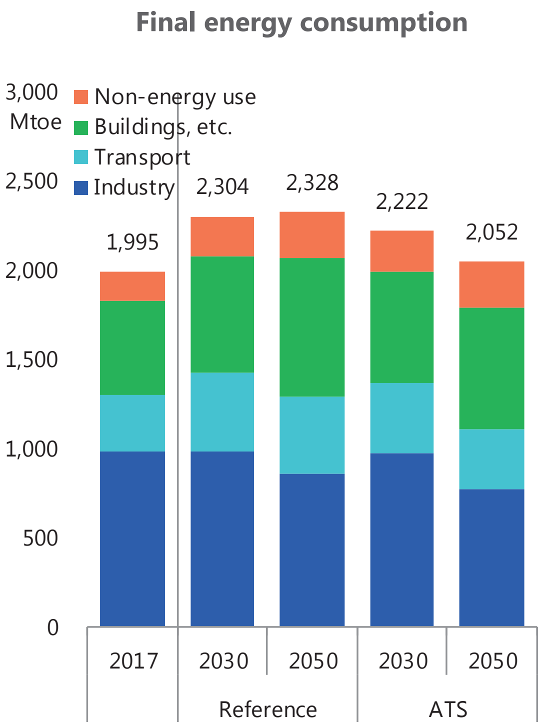
Changes from Reference Scenario



China

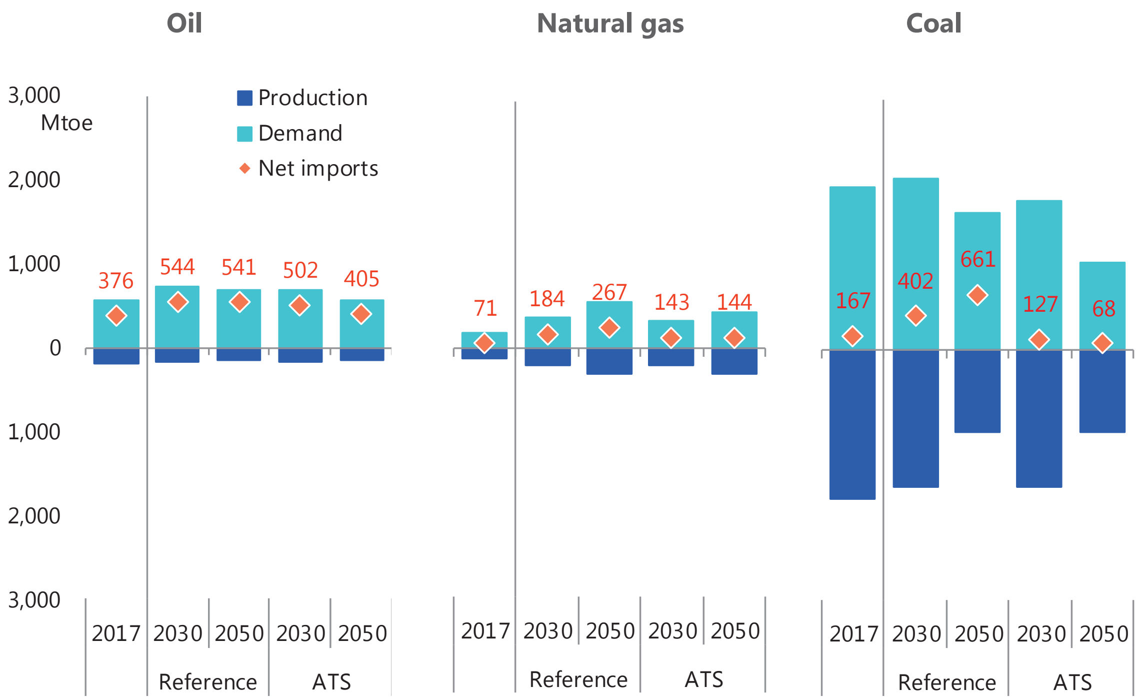
Energy consumption





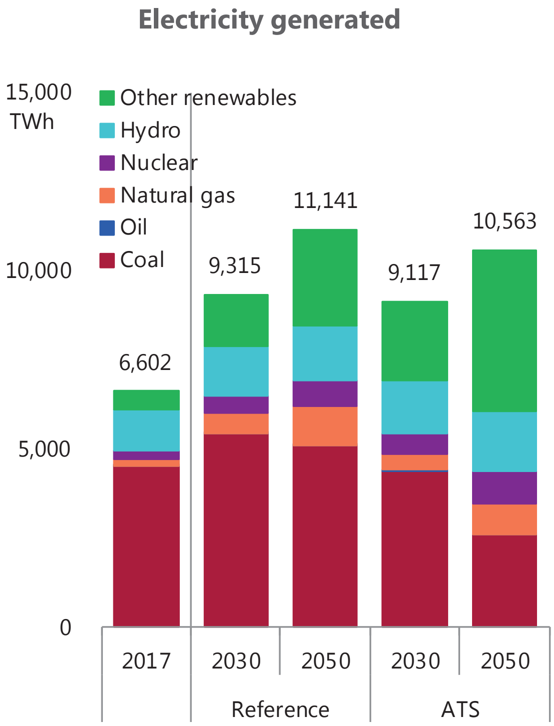
China

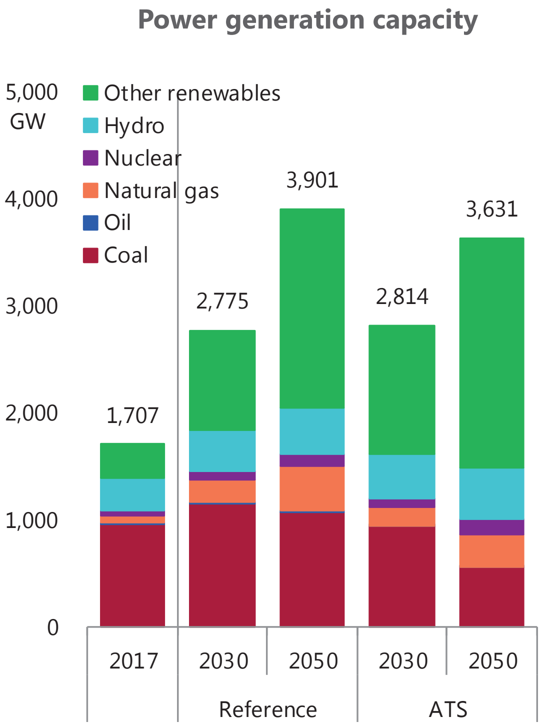
Supply and demand balance of fossil fuels



China

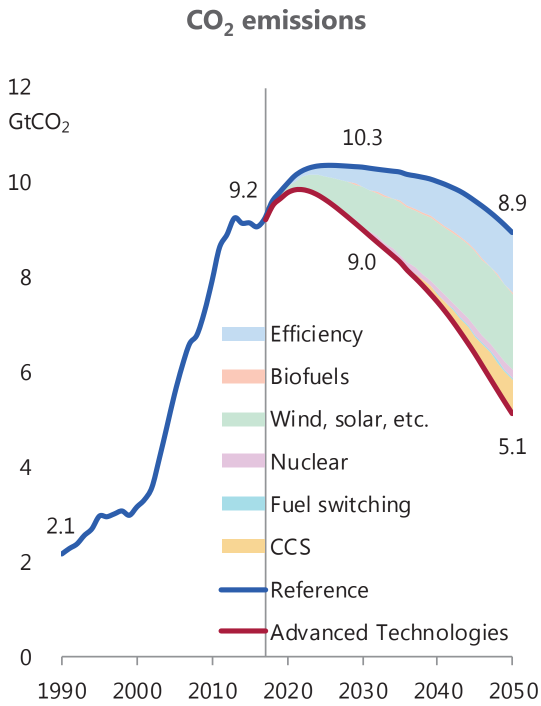
Power generation mix

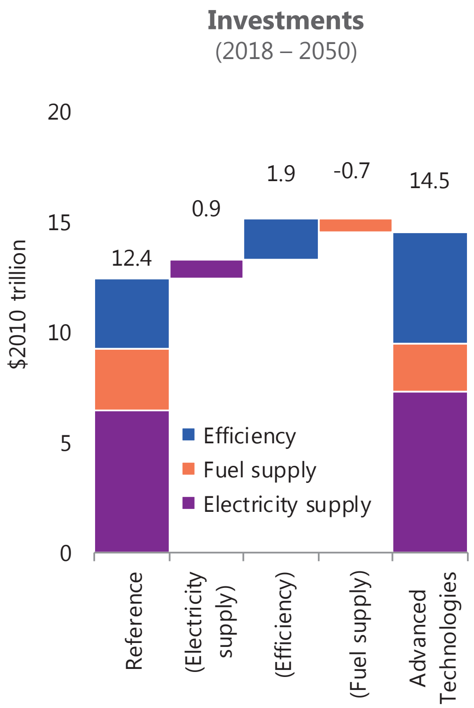




China

Energy-related CO_2 emissions and investments

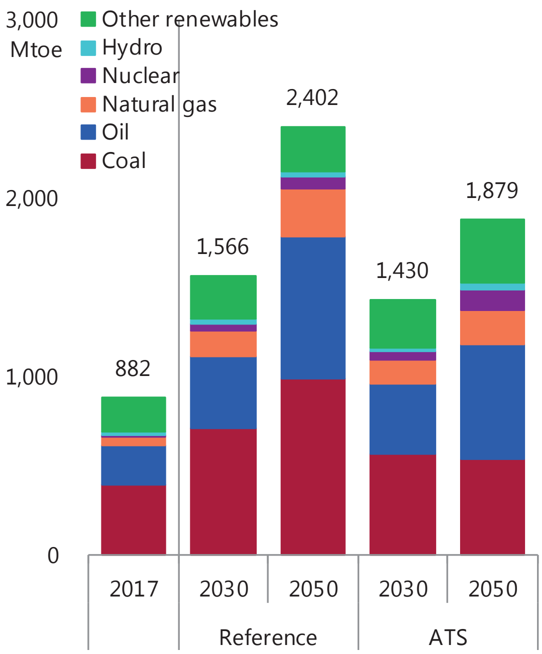




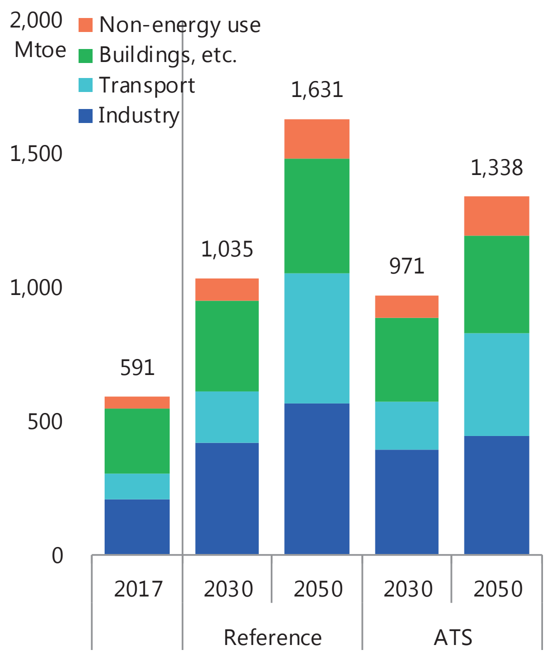
India

Energy consumption

Primary energy consumption

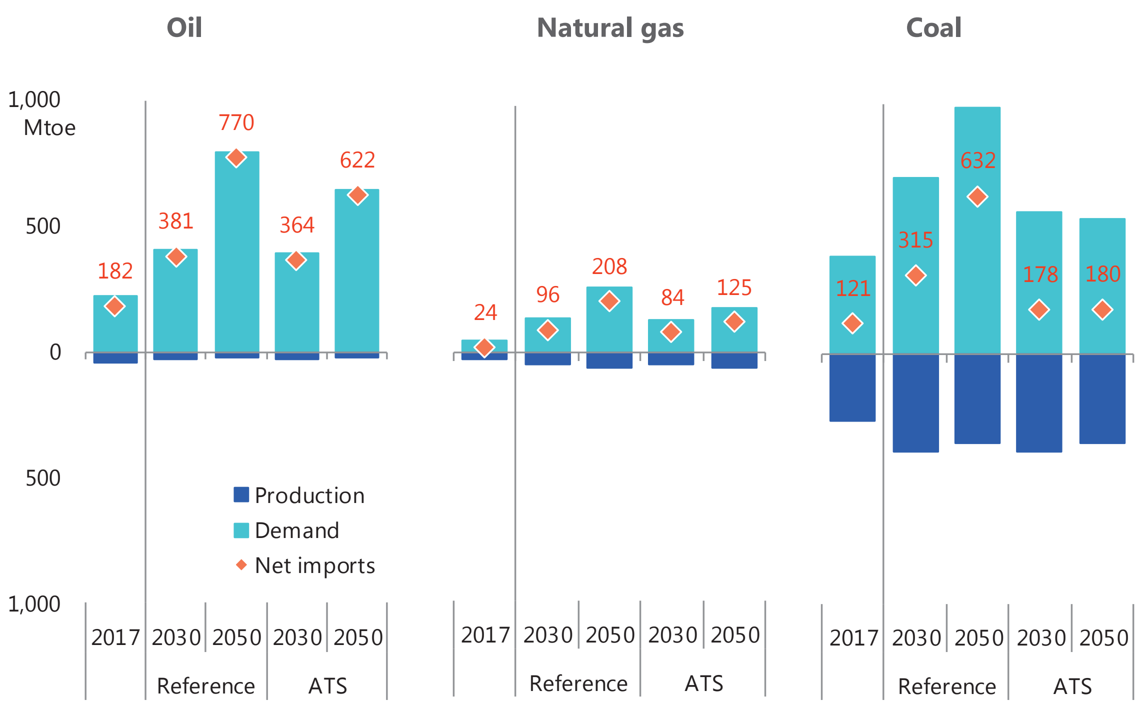


Final energy consumption



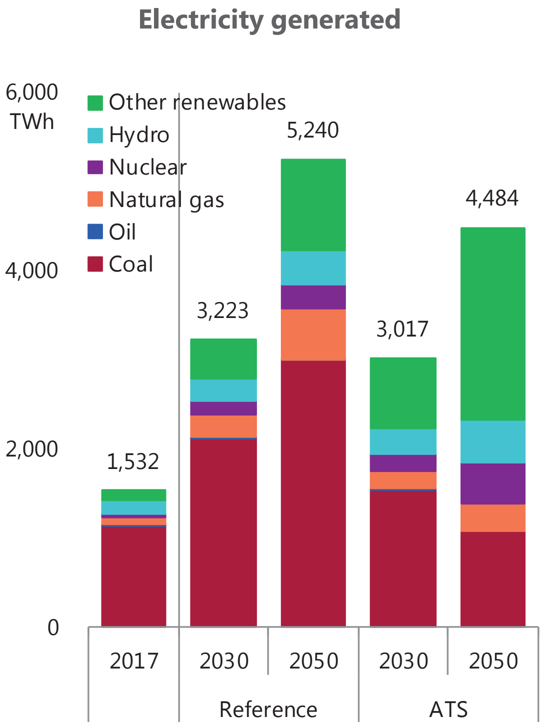
India

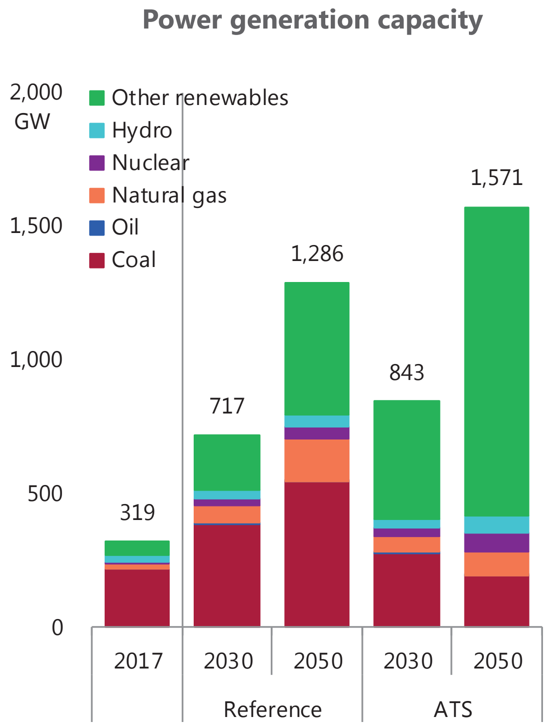
Supply and demand balance of fossil fuels



India

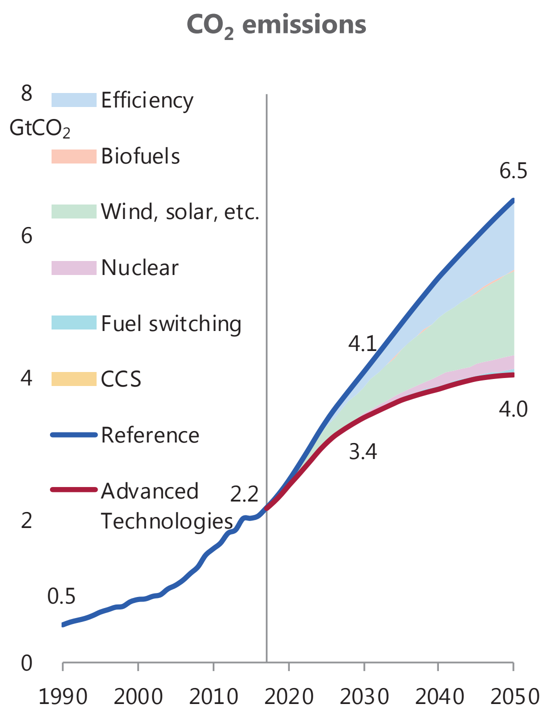
Power generation mix

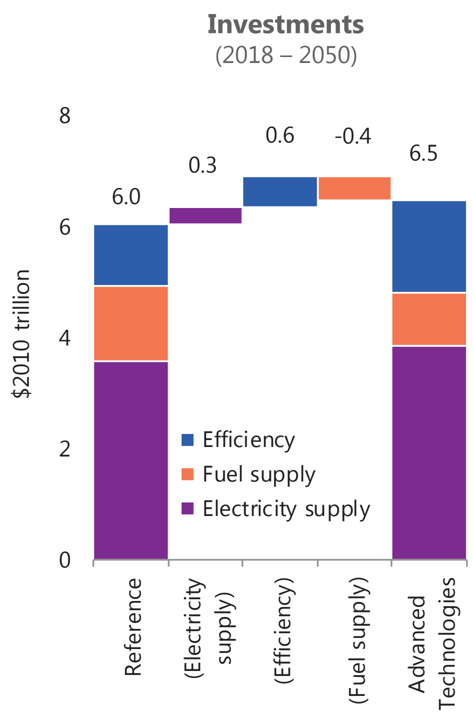




India

Energy-related CO_2 emissions and investments

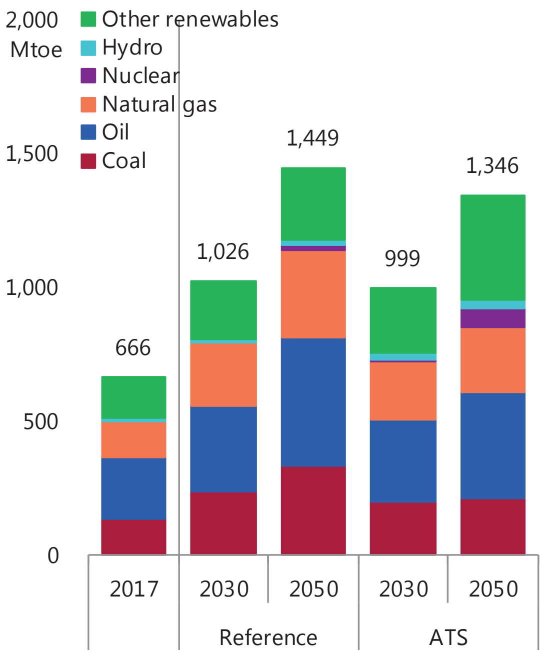




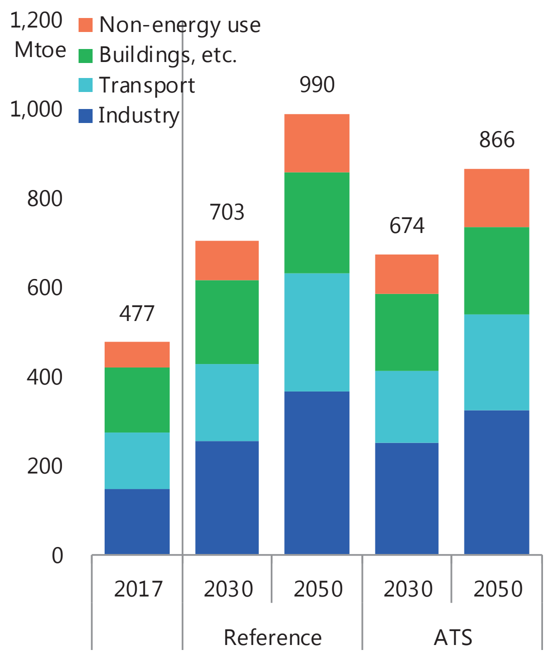
ASEAN

Energy consumption

Primary energy consumption



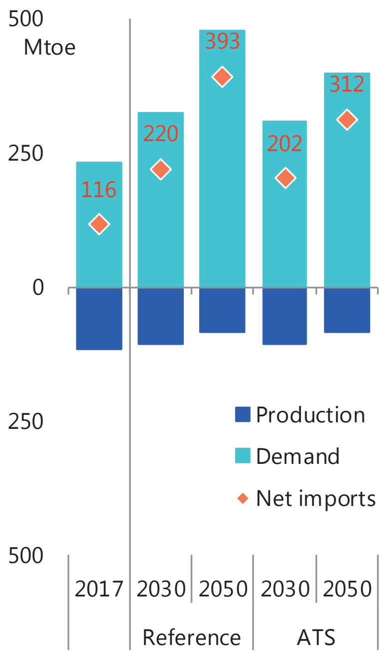
Final energy consumption



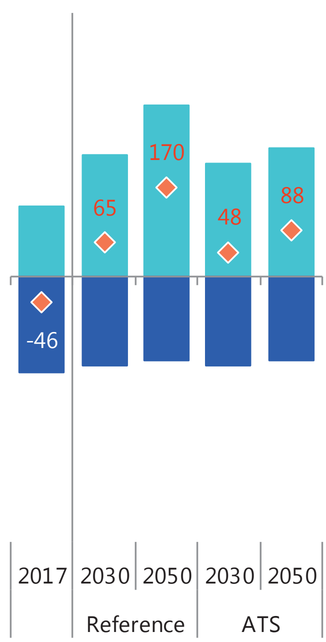
ASEAN

Supply and demand balance of fossil fuels

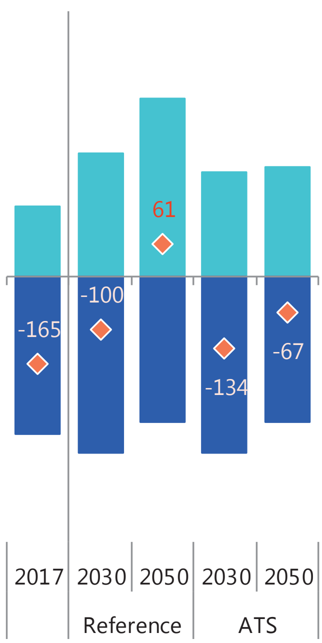
Oil



Natural gas

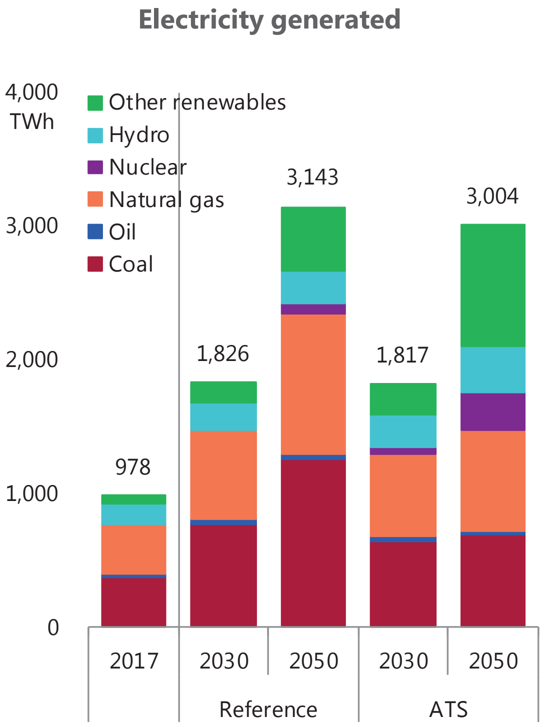


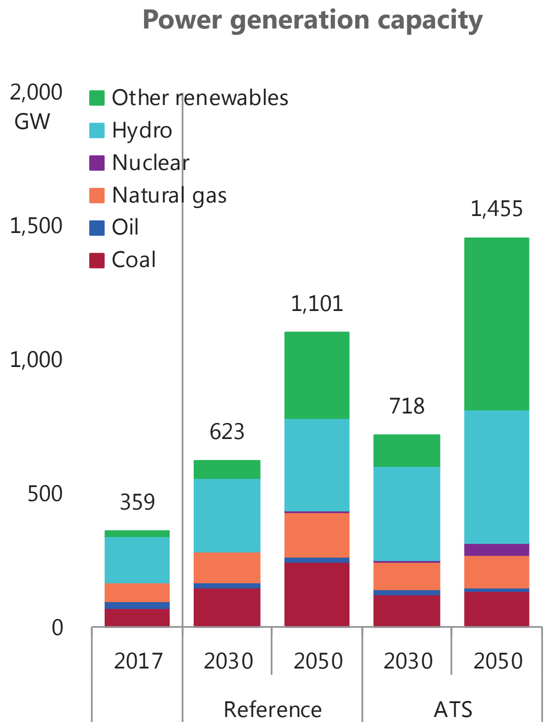
Coal



ASEAN

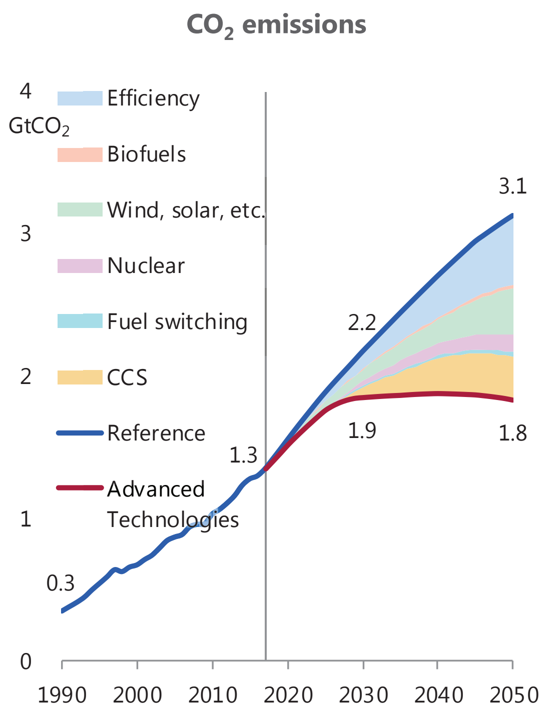
Power generation mix

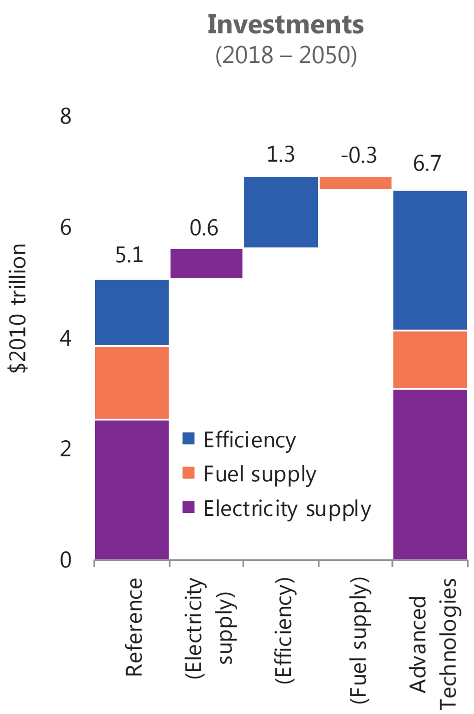




ASEAN

Energy-related CO_2 emissions and investments





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The Institute of Energy Economics, Japan

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