

Executive summary

ASIA / WORLD ENERGY OUTLOOK 2016

**- Consideration of 3E's+S
under new energy circumstances in the world -**

**IEE
JAPAN**

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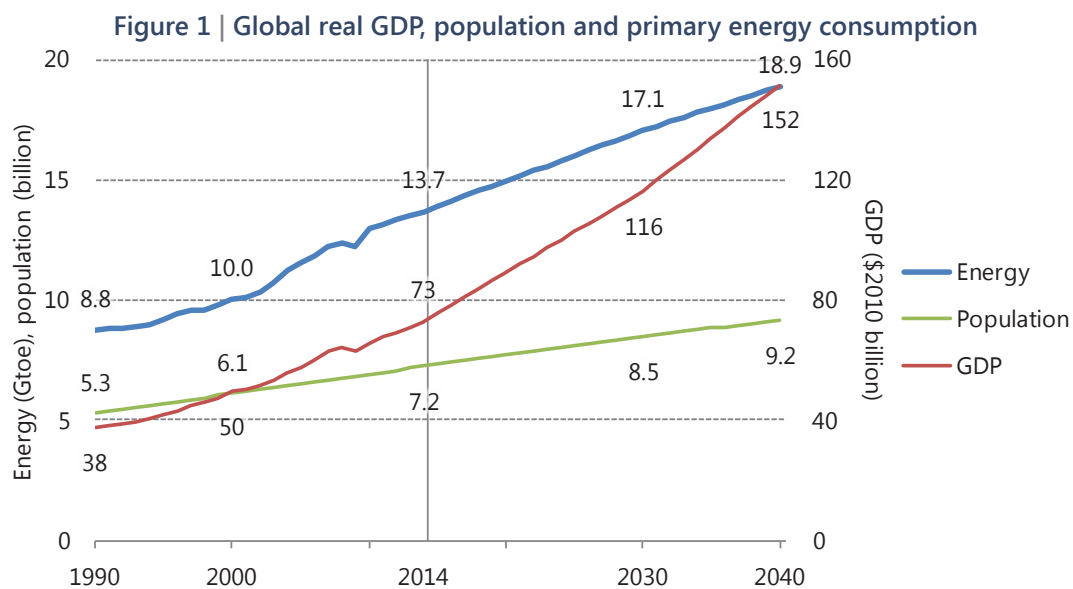
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Executive summary

World energy supply and demand outlook

Demand

Over the next 26 years through 2040, the world's population will increase by 1.9 billion, with the world economy growing 2.1-fold. Energy consumption will expand from 13,699 million tonnes of oil equivalent (Mtoe) to 18,904 Mtoe (in the *Reference Scenario*). Energy consumed for generating \$1,000 in gross domestic product (GDP) will decline by one-third from 2014 to 2040, posting some progress in energy conservation. Nevertheless, the world's energy consumption growth during the period will be 5,205 Mtoe, equivalent to the combined current consumption of the United States and China, the two largest energy consuming countries. In the 50 years from 1990 through 2040, energy consumption will more than double.

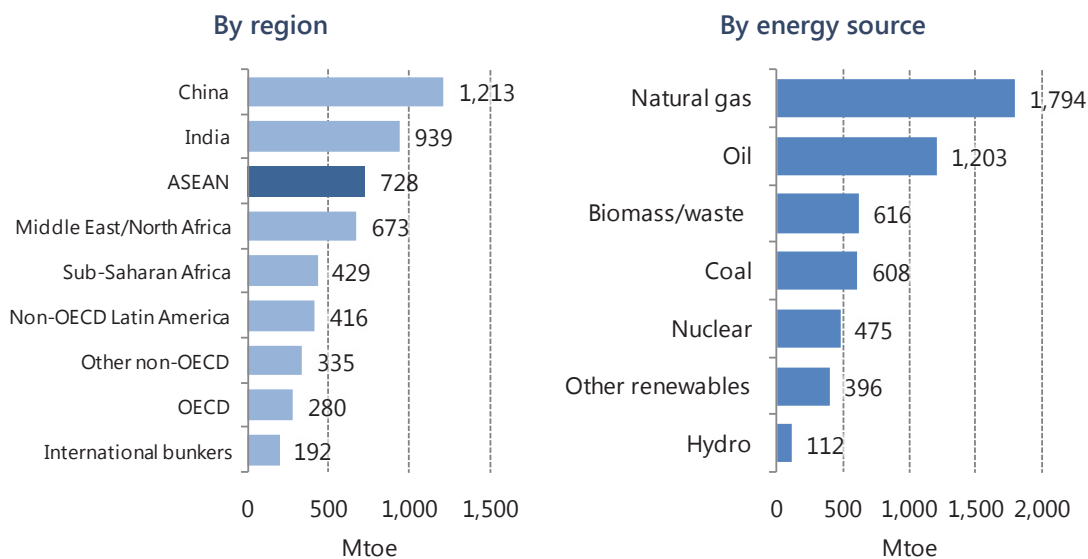


Energy consumption growth will mostly come from countries other than the members of the Organisation for Economic Cooperation and Development (OECD), which will account for only 5% of global growth. Among non-OECD countries, China, India and the members of the Association of Southeast Asian Nations (ASEAN) will post particularly great growth. Their combined energy consumption growth of 2,879 Mtoe would amount to Japan's present energy consumption for six years.

Fossil fuels, especially natural gas and oil, will be the primary energy sources satisfying the massive energy consumption growth. Although great hopes are placed on non-fossil energy, fossil fuel consumption will increase by 2.3 toe as non-fossil energy consumption grows by 1 toe during the outlook period. Fossil fuels, though reducing their present

share of energy consumption from 81%, will still cover 78% of energy consumption in 2040.

Figure 2 | Global primary energy consumption growth [2014-2040]



Although oil consumption growth will slip below natural gas consumption growth, it will still be the largest energy source in 2040. Current oil consumption increased by about 1.5 million barrels per day (Mb/d) from a year earlier, partly due to lower oil prices. Oil consumption will grow steadily in the future, exceeding 100 Mb/d in the middle of the 2020s before reaching 114 Mb/d in 2040. Driving oil consumption growth will be non-OECD countries. China will replace the United States as the world's largest oil consumer in the early 2030s. India will surpass Japan in oil consumption this year and outdo the European Union around the middle of the 2030s, reaching 10 Mb/d in 2040.

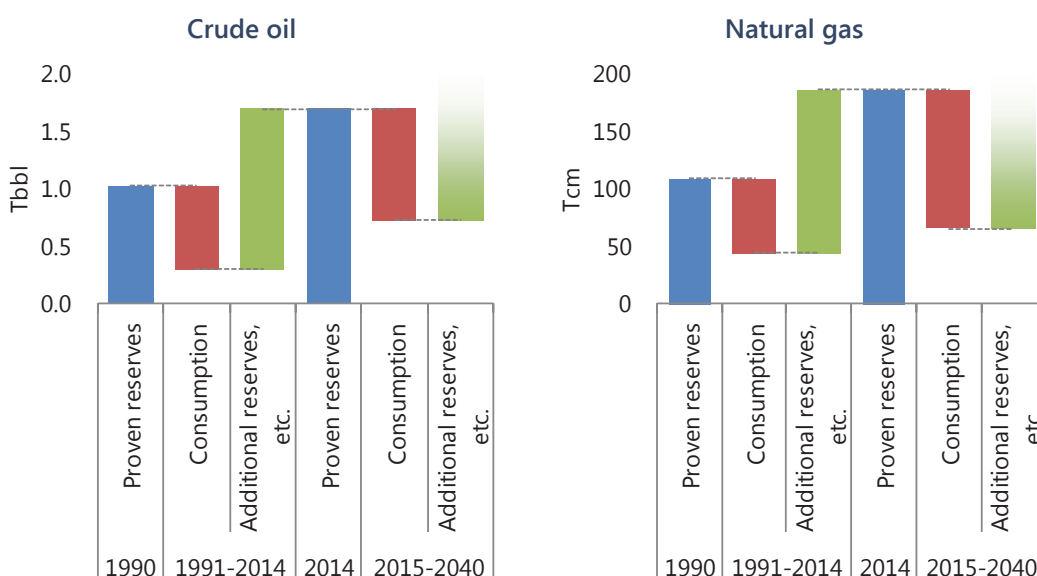
Natural gas will post faster consumption growth than any other energy source. It will be used more widely in the world replacing coal as the second largest energy source by 2040. In the United States, natural gas will replace oil as the largest energy source by 2030 and the same will happen in the European Union in some five years after 2040. Although the United States, Europe and the former Soviet Union currently account for 53% of global natural gas consumption, the others will capture 62% of global consumption in 2040.

Coal consumption grew rapidly in the first decade of this century, covering half of global energy consumption growth. Coal consumption growth is currently decelerating rapidly and this trend will generally continue in the future. However, coal consumption conditions will differ from region to region. While coal consumption will decline in Europe and the United States, it will continue to satisfy more than 50% of the robust energy demand in China and more than 40% of demand in India. ASEAN will grow more dependent on coal, which will account for a quarter of its energy consumption.

Coal will be so indispensable in Asia that cleaner ways to use it will be required to realistically address the climate change issue.

Proven recoverable reserves for oil and natural gas (at present technologies and economic efficiency), as well as abundant coal available for production will be sufficient to cover consumption for the next quarter century (Figure 3). Given growth in reserves through technological development and unproven reserves, the world as a whole is unlikely to experience energy supply constraints attributable to the depletion of resources. A matter of concern is that wild fluctuations of crude oil and natural gas prices over the recent years could impede adequate supply investment.

Figure 3 | Proven reserves and fixed-term consumption



Final electricity consumption will continue growing irrespective of the economic development phases of any country or region (Figure 4). Particularly remarkable growth will be observed in non-OECD countries. Over the next 26 years, China will post the largest final electricity consumption growth, being followed by India, the United States, the European Union and Indonesia, in that order. China will remain the world's largest electricity consumer after becoming so in 2011. India will surpass the European Union and Japan to become the third largest electricity consumer after the United States.

As electricity consumption grows, global electricity supply (generation) will increase rapidly (Figure 5). Although energy consumption for power generation accounted for a little more than one-third of total primary energy consumption in 2000, the share will expand to about 40% in 2040 despite continuous growth in power generation efficiency. Coal consumption for power generation will capture 62% of total coal consumption.

Figure 4 | Final electricity consumption

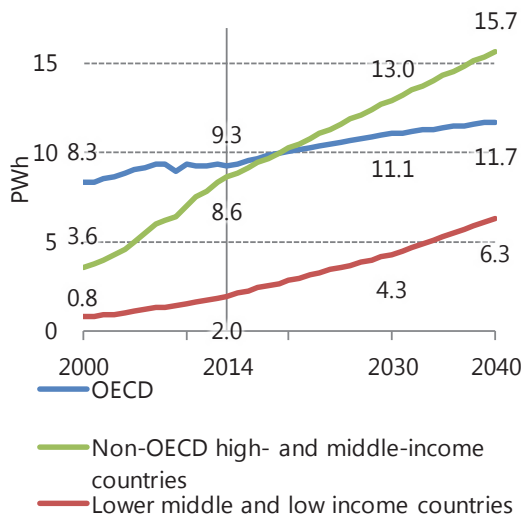
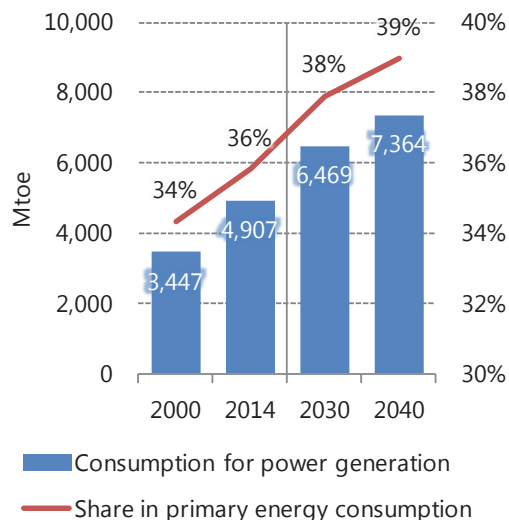


Figure 5 | Global energy consumption for power generation



Note: Lower middle and low income countries here are defined as countries or regions where real GDP per capita is \$4,000 or less.

Supply

The Middle Eastern members of the Organization of the Petroleum Exporting Countries (OPEC) and North America will account for 90% of the global crude oil production growth through 2020 (Figure 6). Driving OPEC production growth will be Saudi Arabia with the largest production capacity, Iran on which Western economic sanctions have been lifted and Iraq that has great potential to expand production. In North America, shale oil productivity has continued to improve and as crude oil prices rise moderately, unconventional oil will drive overall crude oil production growth. Crude oil production will peak out in North America, Europe and Eurasia around 2030, leading non-OPEC oil's share of global oil supply to decrease from 60% in 2014 to 54% in 2040.

Crude oil trade between major regions will increase from 38 Mb/d in 2015 to 48 Mb/d in 2040. While OECD oil imports will decline on a demand fall and a production increase in North America, imports to cover growing demand in China, India, ASEAN and other emerging economies will drive up total crude oil trade. Asia will diversify its oil supply sources to some extent by expanding imports from North America, non-OECD Europe and Central Asia. Still, however, supply from the Middle East and Africa will capture 80% of total oil supply for Asia in 2040 (Figure 7).

Figure 6 | Crude oil production in major regions

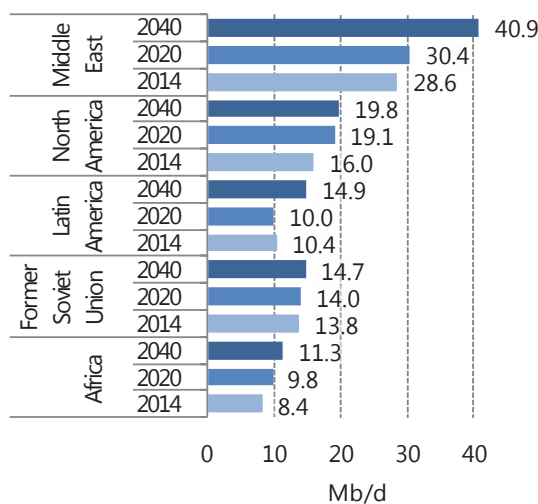
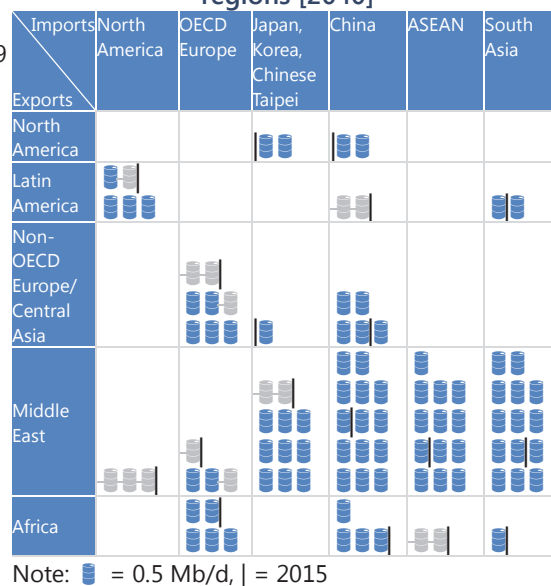


Figure 7 | Crude oil trade between major regions [2040]



Natural gas production will increase by 63% from 2015 to 2040 (Figure 8). Although upstream investment has globally decreased on crude oil price plunges, North American natural gas production will grow steadily due to gas output associated with shale oil production and Russia will develop new gas fields to meet growing exports. In the Middle East, Iran and Saudi Arabia with growing domestic demand will drive the growth in natural gas production. In Asia, China and India will promote gas field development. Particularly, China will further increase natural gas production if shale gas development investment expands from 2025. In Africa, the emergence of new liquefied natural gas (LNG) suppliers such as Mozambique and Tanzania will drive production.

Natural gas trade between major regions will increase from 511 billion cubic metres (Bcm) in 2015 to 887 Bcm in 2040. Trade growth will thus exceed production growth for natural gas, unlike crude oil. Posting the largest growth in natural gas exports through 2030 will be Oceania and North America where many LNG projects are planned to launch production in the first half of the 2020s. After 2030, natural gas trade growth will decelerate slightly because OECD demand growth will slow down while China and Latin America will expand their shale gas production. North America's LNG exports, which started in 2016, will become one of the major suppliers in the world by 2040 (Figure 9). As for trade via pipelines, Russia will remarkably expand natural gas exports to China.

Figure 8 | Natural gas production in major regions

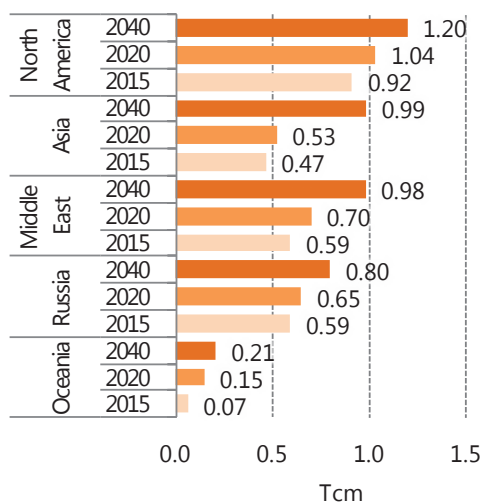
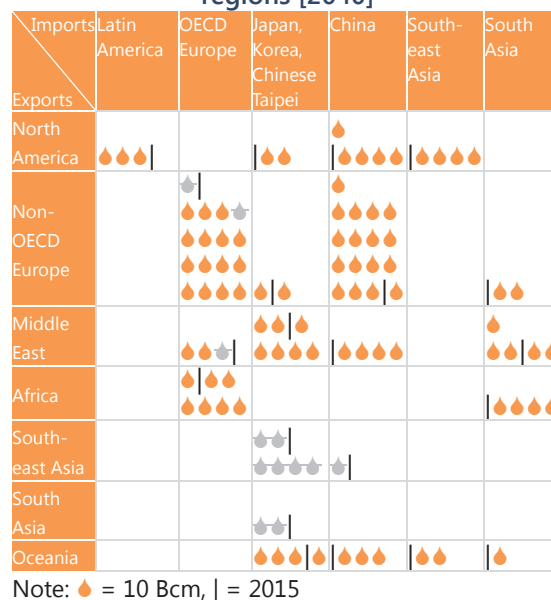


Figure 9 | Natural gas trade between major regions [2040]



Coal production will expand from 7,937 million tonnes (Mt) in 2014 to 9,286 Mt in 2040 as coal demand grows in non-OECD regions including Asia, Latin America, Africa and the Middle East. Steam coal production will increase by 25% from 6,004 Mt in 2014 to 7,522 Mt in 2040 in line with rising demand for steam coal for power generation. Meanwhile, production for coking coal will decrease from 1,116 Mt in 2014 to 988 Mt in 2040 and lignite will decrease from 817 Mt to 776 Mt.

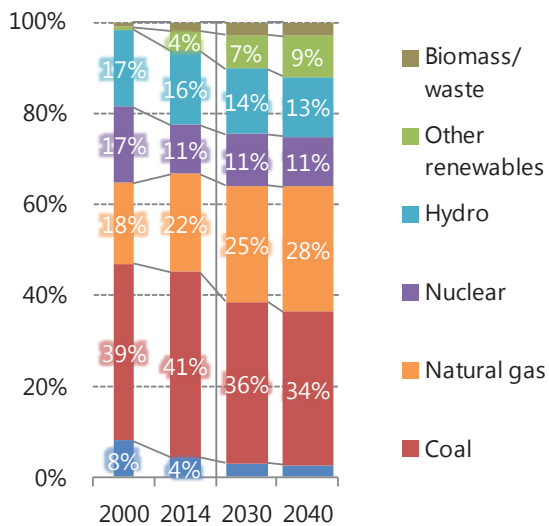
The power generation mix where fossil fuels command the largest share at around two-thirds will be maintained (Figure 10). Although coal will reduce its share of total power generation by 7 percentage points to 34% due to falls in Europe and the United States, it will remain the largest electricity source. Natural gas-fired power generation will increase in all regions other than the United Kingdom and Italy. Among electricity sources, natural gas will score the largest growth, expanding its share of total power generation by 6 points to 28%.

Nuclear power generation will rise from 2,535 terawatt-hours (TWh) in 2014 to 4,357 TWh in 2040, maintaining its share of global power generation in 2040 unchanged from the present level of 11%. Nuclear power generation capacity will decrease in eight countries and regions, including Germany planning to terminate nuclear power generation in the 2020s and Japan cutting capacity by 20 gigawatts (GW) by 2040. Global nuclear power generation capacity will expand from 399 GW in 2015 to 612 GW in 2040 as 14 countries will launch nuclear power generation for the first time, and 18 other countries will increase their capacity.

Among renewable energy sources, hydro will be developed mainly in China, India and Brazil. However, due to a moderate growth in hydro power generation that will fail to increase as fast as total generation, its share of the power generation mix will decrease

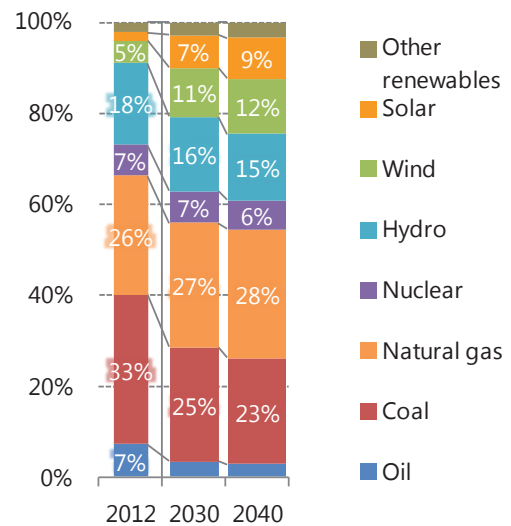
by 3 points. Wind and solar photovoltaics power generation will post a rapid increase of 3.6-fold from 1,005 TWh in 2014 to 3,573 TWh in 2040, accounting for 9% of total power generation. Power generation capacity will expand 3.2-fold from the present level to 1,170 GW for wind and 4.9-fold to 857 GW for solar PV. Wind and solar PV will thus capture 21% of total power generation (Figure 11).

Figure 10 | Global power generation mix



Note: Bar sizes are proportionate to power generation.

Figure 11 | Global power generation capacity mix



Note: Bar sizes are proportionate to power generation capacity.

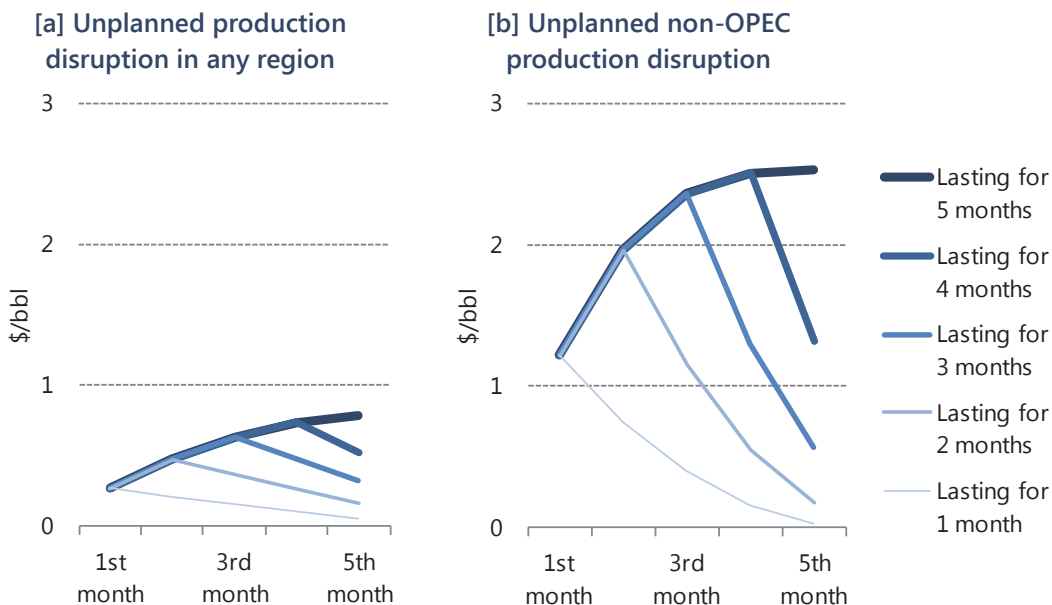
Oil supply disruptions

Fossil fuels including oil and natural gas are key energies supporting the foundation of the modern society, covering more than 80% of the daily human energy demand. Crude oil production disruptions could easily be caused by disasters, accidents, conflicts, terrorist attacks or strikes though no major fossil fuel supply disruptions have occurred in recent years.

A 100 kb/d unplanned oil production disruption can boost the average crude oil prices in a particular month by \$0.3/bbl (Figure 12) and if the disruption continues for five months, the price hike may inflate to \$0.8/bbl. If the disruption is limited to non-OPEC production of which an disruption usually leads to a production cut, the impact on prices may be far greater.

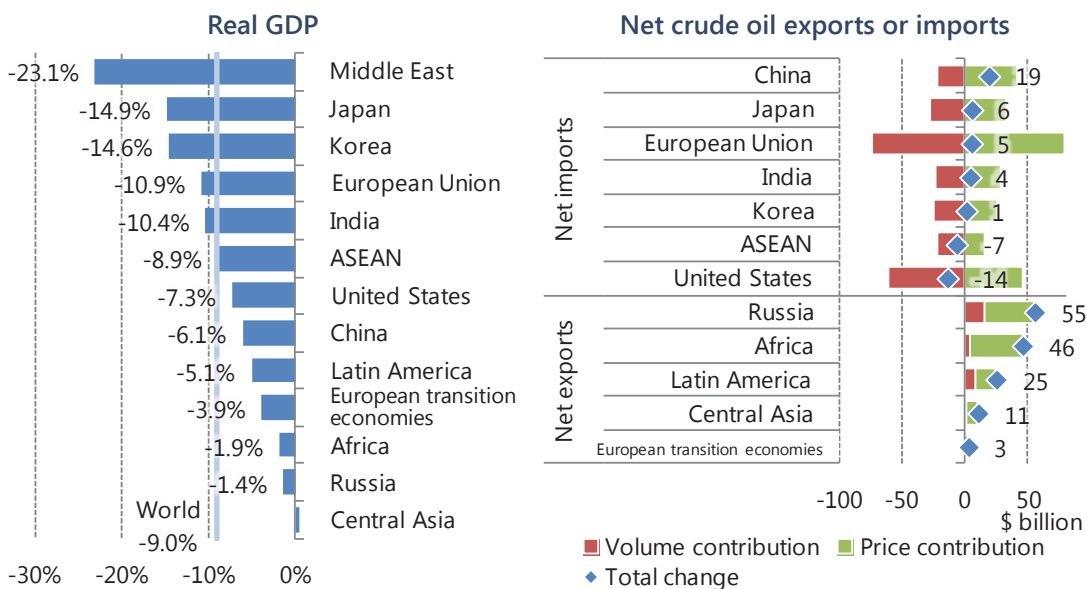
As for price impacts, supply constraints under which energy cannot be procured as required are a major risk factor. If Middle Eastern crude oil production declines unintentionally by as much as 10 Mb/d, with no one making up for the decline, the world economy may contract by 9% (Figure 13).

Figure 12 | Impact of 100 kb/d unplanned crude oil production disruption on oil prices



Note: Average impacts between 2011 and the first half of 2016

Figure 13 | Impact of 10 Mb/d decline in Middle Eastern crude oil production



Note: Net crude oil exports from the Middle East will fall by \$139 billion.

Excluding the Middle East, the source of the supply disruption, East Asia other than China may suffer the largest damage from such disruption. Korea and Chinese Taipei would lose GDP as much as their economic growth for some five years. Japan would lose as much as growth for about 20 years. Even the European Union with less

dependence on Middle Eastern crude oil may suffer an economic contraction of more than 10%. The U.S. economic contraction may be less than the global average and limited to 7% due to growing domestic crude oil production. However, the United States may not be free from any impact of such great oil supply disruption.

The shale revolution is expected by some people to allow the United States to become a swing producer. Analogically, the United States could be expected to cover a supply disruption from the Middle East. Even if the United States expands crude oil production by 3.6 Mb/d, the world economy's contraction may be narrowed only by about 2.5 percentage points. Japanese and European Union contraction may be narrowed only by about 2.0 points, covering one-eighth of the damage for Japan and one-sixth for the European Union.

Energy supply disruptions can bring about great global economic damage that would affect even countries or regions that do not import crude oil or natural gas from countries hit by the disruptions. It may be impossible to completely eliminate risk factors involving energy supply disruptions. Therefore, each country is required to work with the international community to pursue classic, steady efforts to reduce such risks.

ASEAN energy supply/demand outlook

Primary energy consumption

Reflecting strong economic and population growth, ASEAN primary energy consumption will increase at an annual rate of 3.0% from 624 Mtoe in 2014 to 1,352 Mtoe in 2040 (Figure 14). The growth will exceed the combined Japanese and Korean present consumption, accounting for 14% of the global energy demand growth. ASEAN will post the third largest growth after China and India (Figure 2 above).

The ASEAN region, relatively rich with energy resources, is currently a net energy exporter with an energy self-sufficiency rate of 125% (Figure 15). However, as the increase in fossil fuel production will be unable to catch up with the rapid local energy demand growth, the energy self-sufficiency rate will slip below 100% by 2030 and fall to 76% in 2040.

As fossil fuels cover more than 80% of primary energy consumption growth, ASEAN's rate of dependence on fossil fuels will rise from 74% in 2014 to 77% in 2040. Among energy sources, coal will record the largest growth led by power generation demand, accounting for 34% of overall primary energy consumption growth. The growth totalling 356 million tonnes of coal equivalent (Mtce) will capture about 40% of the global coal consumption growth.

Oil consumption in 2040 will expand 1.9-fold from 2014, with automobile fuel accounting for half the growth at 4.1 Mb/d. Liquefied petroleum gas (LPG) in the buildings sector and petrochemical feedstocks will also grow significantly. Although oil's share of ASEAN primary energy consumption will fall from 35% to 31%, oil will remain the most important energy source for the region. As ASEAN oil production decreases, the oil self-sufficiency rate will decrease from 53% to 20%.

Figure 14 | ASEAN primary energy consumption

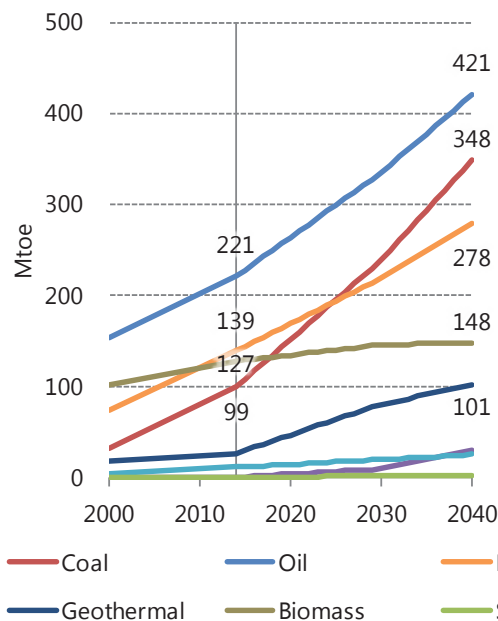
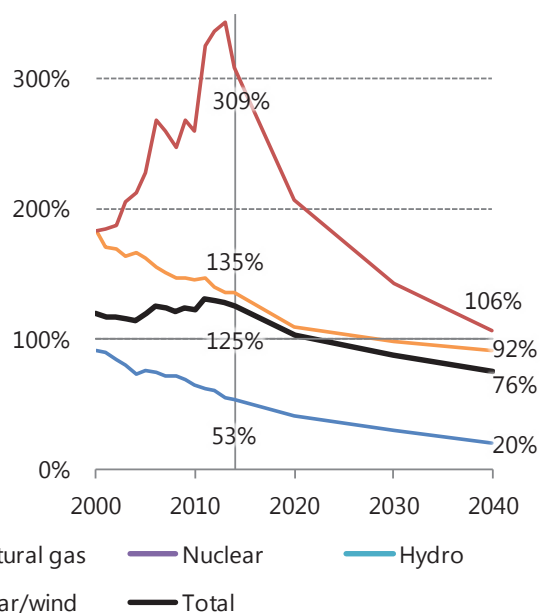


Figure 15 | ASEAN energy self-sufficiency rate



Natural gas consumption will double by 2040. The majority of the natural gas consumption growth of 170 Bcm will be used for power generation, with most of the remainder being for industrial use (including petrochemical feedstocks). Indonesia and Malaysia, which account for most of the ASEAN natural gas consumption growth, are rich with natural gas resources but will experience a decline in their export capacity. ASEAN now exports 60 Bcm on a net basis but will become a net importer by 2030.

No nuclear power plants are in operation in the ASEAN region at the moment. From 2025, however, Thailand, Viet Nam, Indonesia and Malaysia will introduce nuclear power generation capacity totalling 16 GW. However, nuclear will account only for 4% of total power generation and 2% of total primary energy consumption.

ASEAN has great potential to supply renewable energy such as hydro, geothermal and biomass. The Greater Mekong region that spans Cambodia, Thailand, Viet Nam, Laos and Myanmar has a hydro power generation potential at 248 GW, with many hydro development projects being under way. Hydro power generation will expand 2.2-fold by 2040, accounting for about 60% of renewable energy power generation growth in the ASEAN region.

Indonesia and the Philippines have great geothermal potential. The expansion in geothermal power generation will account for about 20% of renewable energy power generation growth. In terms of primary energy consumption, however, geothermal will

increase about five times faster than hydro due to a primary energy conversion efficiency difference¹.

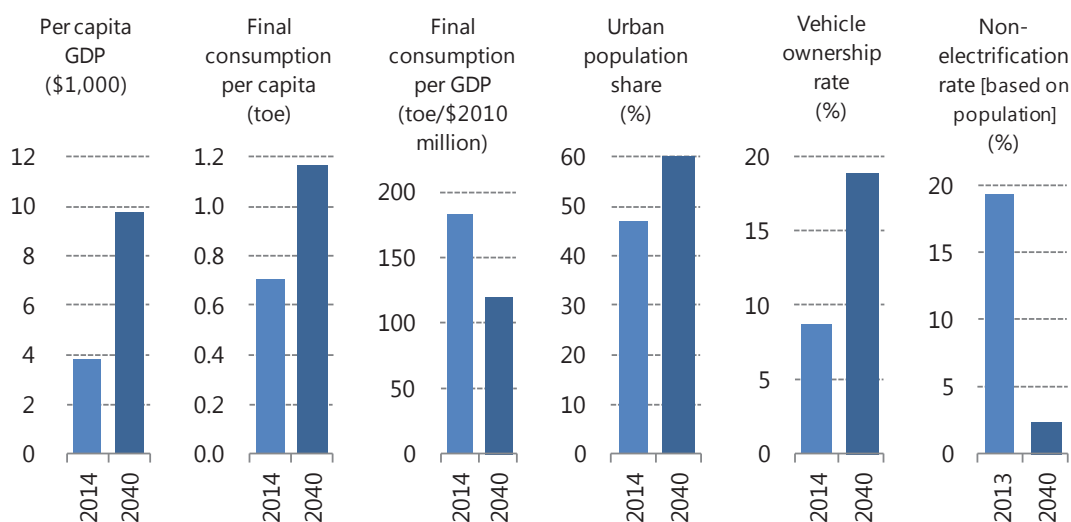
Consumption of traditional biomass fuels such as firewood and livestock manure, among renewables, will decline on progress in urbanisation and living standards. On the other hand, biomass for power generation and liquid biofuels for automobiles will spread. While biomass consumption will increase by 20% by 2040, its share of the energy mix will halve from 20% to 11%.

Although wind and solar PV power generation will record the fastest growth, their share of the ASEAN energy mix in 2040 will still be limited to less than 1%.

Final energy consumption

Final energy consumption will increase at an annual rate of 2.7% from 440 Mtoe in 2014 to 890 Mtoe in 2040 in response to industrialisation, rising living standards and population growth. Final energy consumption per unit of GDP will decline by 35% (Figure 16) due to changes in industrial structure, progress in urbanisation as well as enhancements in energy conservation (including the establishment of energy efficiency standards for automobiles and electrical home appliances and the elimination of fuel subsidies).

Figure 16 | ASEAN economic and energy indicators



The industry sector will expand final energy consumption at an annual rate of 3.5%, faster than any other sector. Foreign companies have rapidly increased direct investment in Malaysia, Thailand, Indonesia, the Philippines and Viet Nam, placing expectations on abundant, cheap labour. As machinery assembly develops greatly, power demand will grow sharply.

¹ The primary energy conversion efficiency is 100% for hydro against 10% for geothermal.

- The transport sector posts the second fastest energy consumption growth at 2.7%/year. The number of vehicles per 1,000 people will increase from 88 in 2014 to 189 in 2040. The regional vehicle fleet will grow 2.7-fold and the road sector's oil demand will rise by 2.0 Mb/d.
- The buildings and agriculture sectors will register a lower annual energy consumption growth rate of 2.2%, as people switch from traditional biomass fuels to LPG cooking stoves with better energy efficiency. In response to urbanisation, to expanding electrified regions and to raising living standards, the annual modern energy (excluding traditional biomass fuels) demand growth rate in those sectors will exceed the growth of the industry and transport sectors at 4.0%
- The non-electrification rate now stands at 19%, with 120 million people failing to receive electricity supply. ASEAN governments have promoted their respective policies to bring electricity in all regions, as early as possible. Such policies will be combined with economic growth to boost electricity demand 3.2-fold to 2,450 TWh by 2040. Energy consumption for power generation will expand 3.1-fold and fossil fuels will cover some two-thirds of the expansion.

ASEAN energy investment and market integration

- Energy investment between 2015 and 2040 will total \$2.3 trillion (Figure 17), amounting to present ASEAN GDP (\$2.4 trillion). Investment each in electricity supply and fuel supply will account for \$1.0 trillion. Of the electricity supply investment, 55% will be for power generation equipment and the remaining 45% for electricity transmission and distribution equipment. Of the fuel supply investment, gas/oil field and other upstream development will capture about 80%. LNG and other fuel transport facility investment will account for a little less than 10% and oil refinery investment for the remainder. Energy conservation investment in the *Reference Scenario* will be limited to \$220 billion.
- As ASEAN as a whole is becoming a net natural gas importer, the legitimacy of pipeline construction within the ASEAN region is losing ground. The only potential pipeline construction project will cover pipelines from the East Natuna gas field to Malaysia and Thailand. If all the production totalling 15 Bcm is provided to Malaysia to replace imported LNG, Malaysia may save \$169 billion in payments for LNG imports from outside the ASEAN region by 2040 (Figure 18).
- Wide-area pipeline development can be expected to help ASEAN diversify energy supply sources for the sake of energy security. Pipelines for international supply will allow ASEAN to mitigate adverse effects of unforeseen LNG supply disruptions and rationalise inventories in peacetime in preparation for supply disruptions. While more than 10 LNG receiving terminals have been or are being constructed in the ASEAN region, their adequate distribution may help ASEAN reduce LNG initial costs.
- Hydro resources are abundant in such ASEAN member countries as Laos and Myanmar. ASEAN is seeking to connect these countries with their neighbours for a more effective use of the resources in meeting electricity demand in the region. On Borneo Island rich with hydro resources, efforts are being made to expand local electric grid lines and achieve interconnection with regions such as the Malay Peninsula and Java Island.

Figure 17 | ASEAN energy investment
[Cumulative investment through 2040]

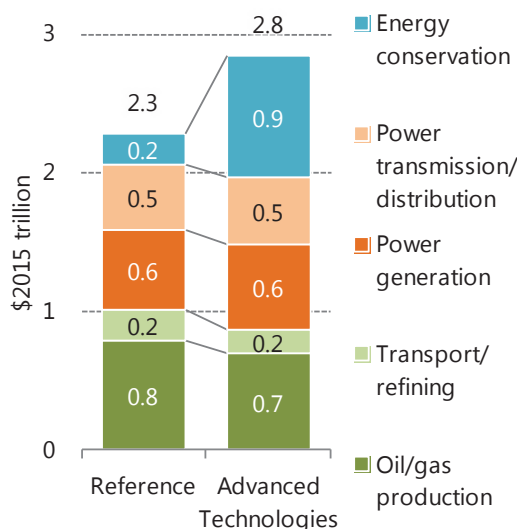
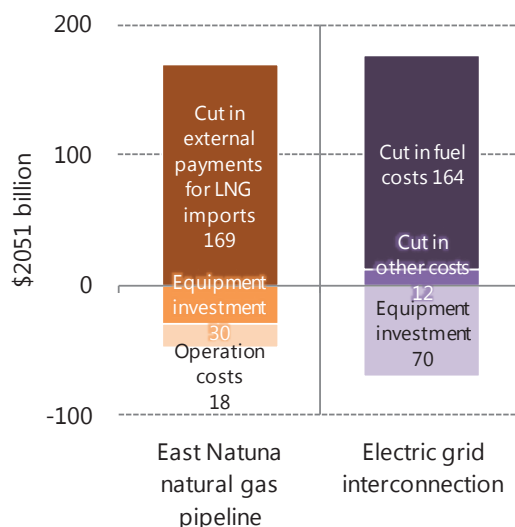


Figure 18 | Effects of ASEAN energy infrastructure development
[Cumulative effects through 2040]



Grid interconnection, though requiring \$70 billion in initial investment in interconnection lines and hydro power generation equipment, will stabilise the grid network, reduce the generation reserve margin and limit power outage durations. The expansion of hydro power generation will allow ASEAN to reduce CO₂ emissions by 78 Mt or 5% and fossil fuel costs by \$164 billion.

Addressing global environmental problems

Paris Agreement

The 21st Conference of Parties to the United Nations Framework Convention on Climate Change (COP21) in December 2015 adopted the Paris Agreement as a new international framework to reduce greenhouse gas emissions from 2020. Global GHG emissions estimated according to intended nationally determined contributions (INDCs) submitted for the agreement total 45.5 GtCO₂, representing an increase from the present level (Figure 19). Although the increase is slower than in the past, the estimated trend deviates far from a target of halving GHG emissions by 2050.

The assessment of major countries' INDCs indicates that developed countries are close to the *Advanced Technologies Scenario* as explained later (Figure 20). China and India are close to the *Reference Scenario*. Indonesia and Brazil are positioned between the *Advanced Technologies Scenario* and the *Reference Scenario*. Each country will have to make the required efforts as much as for achieving the *Advanced Technologies Scenario* and, as such, low carbon technologies will have to further penetrate in developing countries.

Table 1 | Assessment of Paris Agreement

Praiseworthy points

All countries including China, India and other developing countries are required to reduce GHG emissions. More than 180 countries agreed to try to cut GHG emissions.

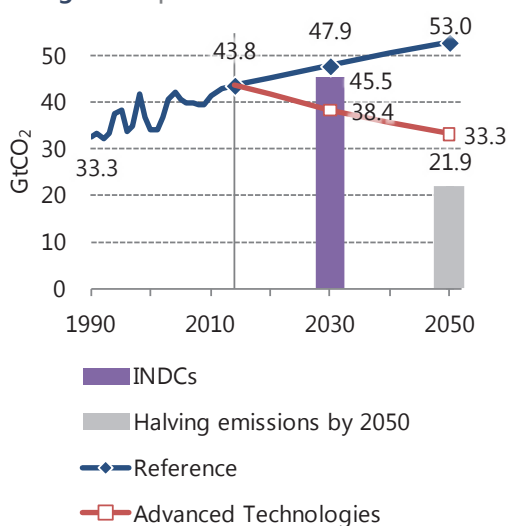
Instead of the top-down approach adopted for the Kyoto Protocol to fix a GHG emission reduction rate before allocating quotas to countries, the Paris Agreement features a bottom-up approach in which countries submit their respective GHG emission reduction targets for accumulation.

Every five years, the total of national targets will be assessed to encourage each country to cut emissions further.

Challenge

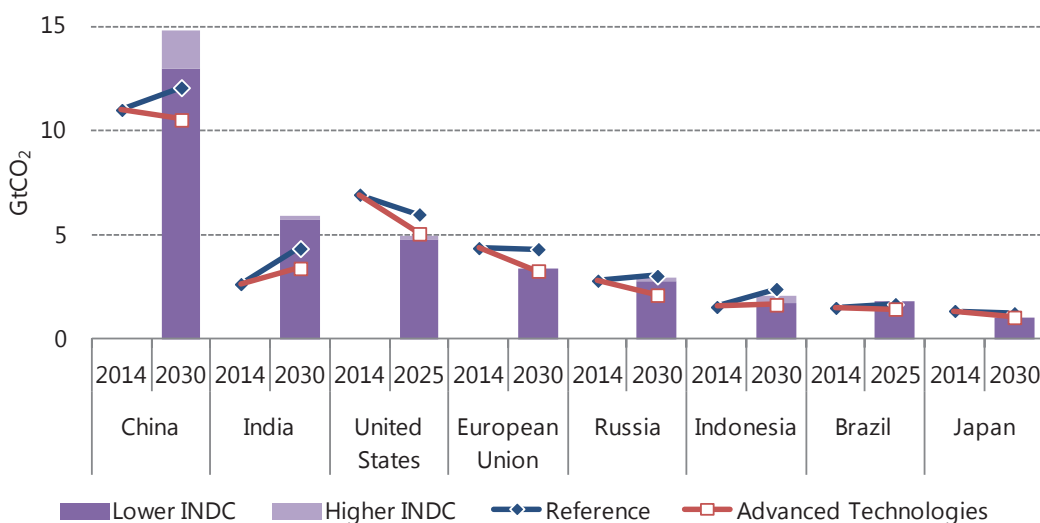
Global GHG emissions will increase from the present level.

Figure 19 | Global GHG emissions



Note: Estimated according to the Group of 20 major countries' INDCs for the Paris Agreement.

Figure 20 | GHG emissions in major countries and European Union



Note: Estimated according to the INDCs for the Paris Agreement

Nevertheless, we should appreciate the Paris Agreement as making its mark as a global step to addressing climate change. It will be important for all countries to realise their agreed targets and reduce GHG emissions further. To this end, technological innovation must be combined with technology transfers and take advantage of market mechanisms such as the bilateral credit system to support global emission reduction efforts.

Advanced Technologies Scenario

The *Advanced Technologies Scenario* assumes maximum CO₂ emission reduction measures based on their application opportunities and acceptability in society. In that *Scenario*, energy consumption in 2040 will be 2,343 Mtoe or 12% less than in the *Reference Scenario*, with the increase from the present level limited to 55% of the growth in the *Reference Scenario*.

Among energy sources, coal will post the largest consumption decline from the *Reference Scenario* as demand for coal for power generation decreases due to less electricity consumption, power generation efficiency improvement and fuel switching to other energy sources. Natural gas will register the second largest consumption fall. (Figure 21). While coal consumption in 2040 will decrease by 17% from the present level, natural gas consumption will continue to increase for the next quarter century even in the *Advanced Technologies Scenario*. Oil consumption in the *Advanced Technologies Scenario* will be 832 Mtoe less than in the *Reference Scenario*, peaking out around 2040. While fossil fuel consumption in the *Advanced Technologies Scenario* will be 3,196 Mtoe less than in the *Reference Scenario*, nuclear consumption will be 433 Mtoe more and renewable energy, including solar and wind energy, 419 Mtoe more. As a result, fossil fuels' share of total energy consumption will fall from 81% in 2014 to 70% in 2040.

Figure 21 | Global primary energy consumption changes

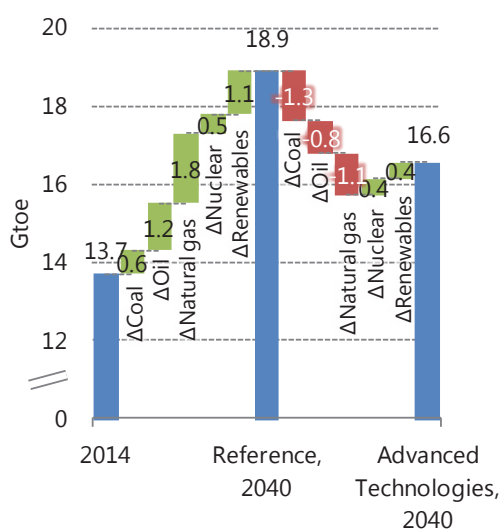
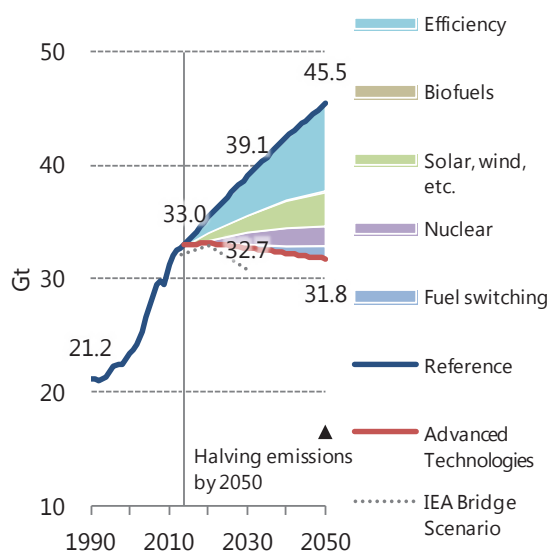


Figure 22 | Global CO₂ emissions and contributions to emission reduction



Although China and India will account for 32% of global primary energy consumption in 2040, their share of an energy consumption decline from the *Reference Scenario* to the *Advanced Technologies Scenario* will amount to 36%, indicating the two giant Asian energy consumers' great role. They will account for as much as 61% of a coal consumption fall and for 38% of nuclear and wind/solar energy consumption growth. The presence or

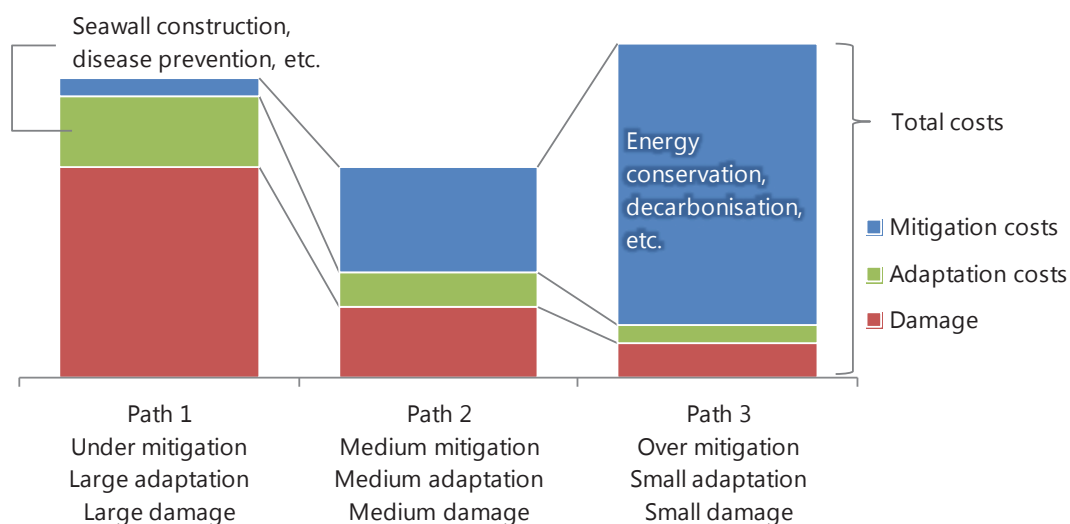
absence of proactive energy conservation and carbon emission reduction in non-OECD and other countries, rich with potential, will determine the future picture of the world.

In the *Advanced Technologies Scenario*, global energy-related CO₂ emissions will peak out around 2020 and slowly decline before reaching 31.8 Gt in 2050, down 1.2 Gt or 3.8% from 2014 (Figure 22). A CO₂ emission decline of 13.7 Gt from the *Reference Scenario* will amount to 42% of present global emissions. A cumulative decline of 259 Gt through 2050 will be equivalent to 7.8 years' worth of present global annual emissions.

Super long-term path for climate change measures

The climate change issue is a long-term challenge that will involve a wide range of areas over numerous generations. When and how specific measures should be taken and what measures should be implemented must be considered carefully. From the viewpoint of sustainability, we analysed a combination of measures to minimise the total costs covering mitigation, adaptation and damage (Figure 23). (An attempt to spend \$1,000 on cutting emissions and building seawalls to prevent \$100 in damage would be very difficult to justify and would risk failure.)

Figure 23 | Image of total mitigation, adaptation and damage costs

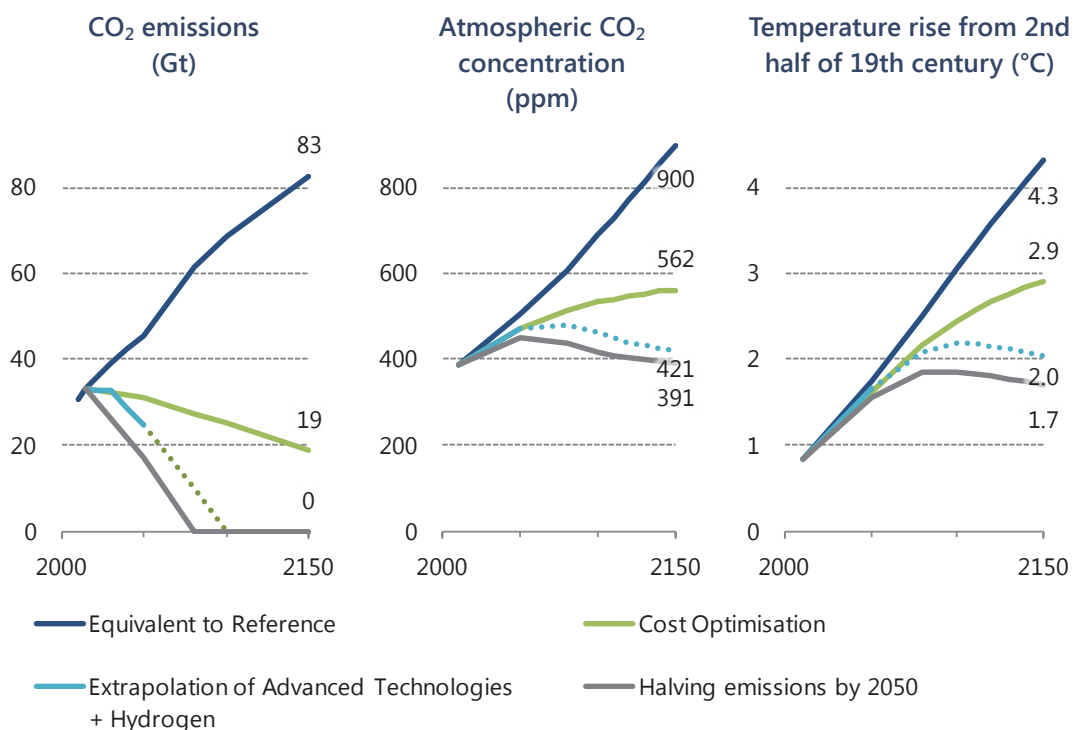


CO₂ emissions under the so-called *Cost Optimisation Path* to minimise total cumulative costs will be reduced substantially from the *Reference Scenario*. However, the emissions in 2050 will not have to be halved from the present level (Figure 24). They will continue falling slowly along the *Cost Optimisation Path* even after 2050 and be halved only after 2150. Under the same *Cost Optimisation Path*, the atmospheric CO₂ concentration will continue to increase slowly, reaching 560 ppm in 2150. The average temperature will also continue to rise slowly, posting an increase of almost 3°C from the second half of the 19th century, as of 2150.

The results, however, will change depending on conditions. If marginal costs for the emission reduction after 2050 are lowered due to rapid technological development, or if

the climate sensitivity² is 2.5°C instead of 3°C, for example, the *Cost Optimisation Path* will differ from what is described above, with the temperature rise limited to a lower level. While humans cannot control the climate sensitivity, mitigation costs can be reduced through low-carbon technology cost cuts and the development of innovative technologies. We are required to cooperate in technological development from the long-term viewpoint while continuing to pursue adequate climate change measures.

Figure 24 | Super long-term path



With more innovative technologies in addition to the carbon free hydrogen (below mentioned) and cost reduction, CO₂ emissions path may become further down to become net zero by 2100. This will reduce the CO₂ concentration down and thus may meet the 2°C target by 2150. Overall total cost will become higher than the optimised total cost of mitigation, damage and adaptation but this result implies that it is possible to return to the 2°C path in the long run.

Hydrogen exploitation scenario

If ambitious global efforts are made to reduce CO₂ emissions over the long term and if some regions such as Japan and China fail to domestically take full advantage of the carbon capture and storage (CCS) technology, power generation using imported hydrogen will play a great role as the fourth zero-emission power source. If coal- and natural gas-fired power plants to be built in regions with limited access to CCS are

² The climate sensitivity represents an average temperature rise (°C) for the case in which the atmospheric GHG concentration in terms of CO₂ is doubled.

replaced with hydrogen-fired power plants after 2030, hydrogen will account for 13% of power generation in 2050. If the supply cost is reduced substantially, fuel cell vehicle (FCV) diffusion would accelerate globally³, with one FCV for every eight passenger cars sold in the world (Figure 25). Global hydrogen consumption will then total 3.2 trillion Nm³, of which 90% will be used by the power generation sector.

Major hydrogen producers and exporters will include the Middle East, North Africa, North America, Australia and Europe mainly Russia. Traditional exporters of oil, natural gas and other energy resources will be key hydrogen suppliers.

Hydrogen lacks expansion because of the high costs for infrastructure development. If no other substitutes are found, however, hydrogen may be adopted as a low-carbon form of energy that is relatively economical. As hydrogen suppliers include North America and Australia as well as the Middle East, the adoption of hydrogen will lead to the diversification of energy supply sources.

Figure 25 | Global power generation mix

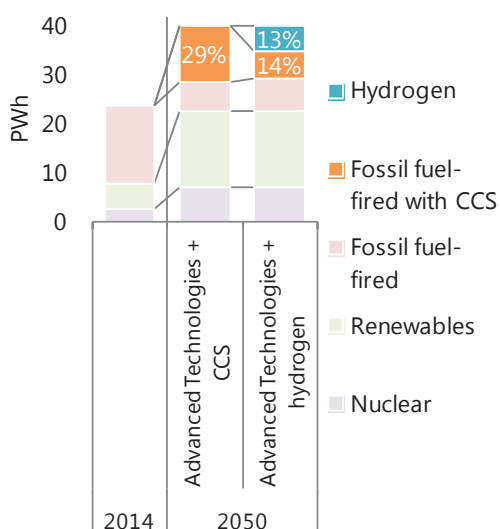
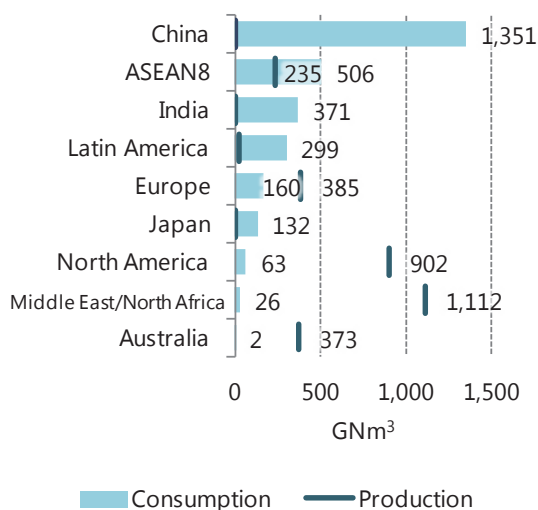


Figure 26 | Hydrogen production and consumption



Importance of nuclear for achieving the 3E's and related challenges

Improvement of safety and independence of regulators

The Fukushima Daiichi Nuclear Power Station accident triggered by the tsunami accompanying the Great East Japan Earthquake was a common cause failure (CCF) in which an external event devastated multiple safety functions. Given that safety measures for power sources, water supply, containment facilities and other equipment

³ "Higher Hydrogen Scenario" in the body of this outlook

and the preparedness against natural disasters such as tsunamis were insufficient, Japan thoroughly revised its regulatory standards. The basic policy for new regulatory standards calls for (1) spreading the idea of defence in depth, (2) enhancing reliability and (3) enhancing protection measures against CCFs caused by natural disasters. Following the development of safety measures based on the basic policy, some nuclear power plants have been recognised as in compliance with the new standards and allowed to restart.

Western industrial countries have been enhancing their safety standards since the 1980s. Rather than being satisfied with compliance with the regulatory standards, their industry introduced voluntary efforts to improve safety beyond the standards. Nuclear business operators acknowledged that there can be no zero risk as indicated by the Three Mile Island accident. Consequently, reasonable voluntary safety improvement efforts were a natural option to realistically and rationally continue business operations. The world can learn much from such process when considering regulations.

Because of their duties, regulators are required to be highly independent from political intentions, economic conditions as well as technical indicators. They must possess high technical capabilities to conduct strict and fair examinations. Recognising that Asian regulatory agencies are less independent than their Western counterparts, Japan and Korea have updated their respective regulatory systems since 2011 to improve the regulators' independence. However, they have a shorter history of enhanced regulations than in Western countries. Regulators' high independence, transparent operations and reliable capabilities are essential conditions for maintaining high safety levels.

High-level radioactive waste produced through nuclear power generation must be appropriately disposed. Geological disposal to bury such waste into deep underground layers and take advantage of the characteristics of rocks to contain the waste has become a common international method. In Japan, total radioactive waste disposal costs are estimated at about JPY2.8 trillion, contributing JPY40/MWh to the nuclear power generation cost. From an economical viewpoint, waste disposal should not be regarded as a huge problem impeding on nuclear power generation.

Nevertheless, a radioactive waste disposal plan is occasionally delayed as the selection of a disposal site fails to make progress due to concern about safety among residents near candidate sites. In Sweden, where a disposal site was selected ahead of any other country in the world, negotiations with residents near the site were repeatedly conducted in accordance with the environmental and nuclear operation laws. Sweden then developed the so-called Oskarshamn Model for conducting negotiations among all stakeholders including local governments, regulators, business operators and environmental groups. Such reciprocal dialogues apparently produced successful results.

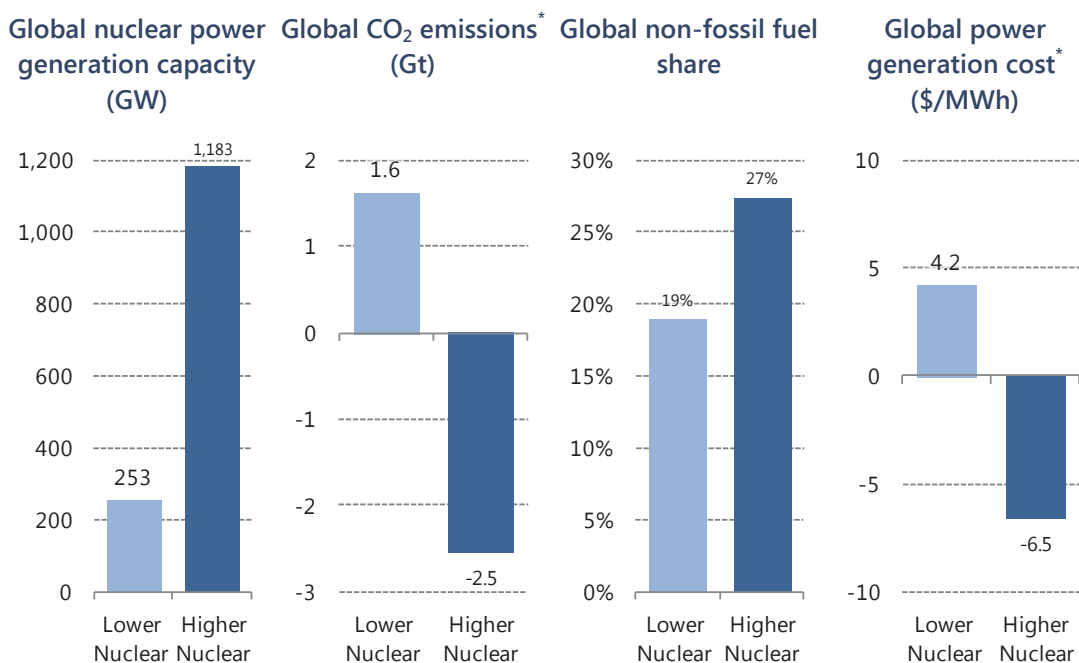
Lower and Higher Nuclear Scenarios

Paying attention to nuclear development drivers in Asia, we have developed and analysed the implications of two scenarios. In the "*Lower Nuclear Scenario*," the negative drivers for nuclear development are stronger than in the *Reference Scenario*. In the

“Higher Nuclear Scenario,” the positive drivers for nuclear development are stronger than in the *Advanced Technologies Scenario*.

In the “Higher Nuclear Scenario,” the nuclear power generation capacity in the world in 2040 will be about 1,200 GW (a three-fold increase from 2014) including 700 GW in Asia (a seven-fold increase) and CO₂ emissions will decline by about 6% in the world and by about 9% in Asia. The Asian energy self-sufficiency rate will be about 74%, almost unchanged from 2014 (Figure 27). The unit power generation cost will be more than \$9/MWh lower than in the *Reference Scenario*. Generally, this scenario will be favourable for all of the so-called 3E’s – energy security, economic growth and environmental protection. A key condition for this scenario will be technology transfer from developed to developing countries. The design of safety regulation systems in emerging countries will be particularly challenging.

Figure 27 | Nuclear Scenarios [2040]



* Compared with the *Reference Scenario*

In the *Lower Nuclear Scenario* in which nuclear power generation capacity in the world in 2040 will be about 250 GW (about 60% of the 2014 level) including 60 GW in Asia (about 60%), CO₂ emissions will increase by about 4% both in the world and Asia. The Asian energy self-sufficiency rate will fall substantially to about 63% and the unit power generation cost will be almost \$4/MWh higher than in the *Reference Scenario*. This scenario will thus have negative effects on all the 3E’s with challenges regarding upholding safety standards and the maintenance of competent human resources in a declining nuclear industry.