Asia-Pacific
Economic Cooperation

APEC Oil and Gas Security Studies

Emerging energy security risks in changing global energy landscape

APEC Energy Working Group

Series 16

September 2019

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Foreword

Historically, oil has always been the primary focus of energy security discussions. However, this has been changing in recent years as awareness of the need to reduce carbon dioxide (CO_2) emissions has led to significant growth in the use of renewable energy. However, increasing the penetration of variable renewables in the power generation sector presents challenges to maintaining grid stability at the same time as it contributes to reducing carbon emissions. This study assesses the traditional and emerging risks in this changing energy landscape and examines the possible measures APEC economies could employ to mitigate these risks.

This is the 16th report released as part of the Oil and Gas Security Studies (OGSS) series, which provides useful information to APEC economies on the latest developments regarding oil and gas security issues. I am hopeful that the research studies under the OGSS will encourage APEC economies to review and further strengthen their policies on oil and gas security.

I would like to express my sincere gratitude to the authors and contributors for their time and effort in undertaking this research study. However, I would like to emphasise that the contents and views in this independent research project only reflect those of the authors and not necessarily of APERC and might change in the future depending on unexpected external events or changes in the oil and gas policy agendas of particular economies.

Kazutomo Irie

Kazutomo IRIE
President
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September 2019

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Executive Summary

Historically, oil has been the primary focus of discussion surrounding energy security. This is because oil plays a key role in meeting energy demand, and because significant oil production occurs in regions with high geopolitical risk. However, the role of oil has been gradually declining in recent years, as the use of electricity and natural gas increases and renewable energy gains more attention as a means of tackling climate change. The energy security framework of the future will therefore have to evolve as the energy supply and demand structure changes, and this report will analyze the key points of such a change.

Traditional Risk

Chapter 1-1

The traditional security risk surrounding oil markets was maintaining stable supply. This is because oil resources are concentrated mainly in the Middle East where geopolitical risks are a long-standing problem. Starting with the Arab–Israeli War in the middle of the 20th century, nationalism over oil resources rose during the 1960s and culminated in the Six-Day War in 1967. In the Yom Kippur War of 1973, Arab oil-producing economies put in place an oil embargo on economies supporting Israel (the so called “oil weapon”). There has been significant unrest in the Middle East ever since then, with the Iranian Revolution, the Iran-Iraq War, the invasion of Kuwait by Iraq, the collapse of the Saddam Hussein regime, and the rise of extremist groups. With the exception of a few self-sufficient economies, most of the APEC region continues to face these security-of-supply risks.

Chapters 1-2, 1-3

Large price fluctuations represent another significant oil security risk. OPEC producers, who suffered from the collapse of crude oil prices that began in the middle of 2014, started to coordinate with non-OPEC members to reduce production in January 2017. The decline in crude oil prices has cast a shadow in the form of declining willingness to invest in upstream development. Many oil demand forecasts expect that future demand will continue to increase moderately. However, the amount of upstream oil investment has not returned to its previous levels after the decline in oil prices, and the IEA and OPEC are sounding the alarm about this situation. With American tight oil being added to the international oil market, attention must be given to how crude oil prices will move in the future.

Chapter 1-4

The majority of global oil trade is conducted by enormous seaborne super-tankers. As such, the oil market is dependent on sea commerce that requires navigating narrow waters and measures to combat piracy. In recent years, the emergence of new oil-exporting economies such as the US has created new trade (sea commerce, pipeline trade) routes. Just like existing measures for trade routes, it is necessary to secure the safety of new routes.

Chapter 1-5

The increasing demand for natural gas creates new security challenges. Traditionally, security of natural gas/LNG supply has been maintained through long-term contracts that bind both exporters and importers. While this approach is still currently effective, it is also a risk in environments where future demand uncertainty is high. This is particularly true of LNG trade in the Asia-Pacific region, where contracts typically extend beyond 10 years and contain rigid terms with destination restrictions that ban resale. This is despite growing demand from buyers for improved liquidity and transparency in transactions. Emerging natural gas importing economies are also introducing floating storage & regasification units (FSRU), but face challenges in loading, distribution and storage, which differ from onshore facilities.

Emerging Risk

Chapter 2-1

Electricity plays an important role in everyday life, industrial activity, economic management, and the stability and security of the state, and that importance is greatly increasing. Across the APEC region, domestically produced renewable energy is growing rapidly in order to reduce CO_2 emissions. However, the expansion of variable electricity generation (such as solar and wind power) is a potential security risk in terms of both electricity supply capacity and its cost during the transition period from existing power systems.

Chapter 2-2

Large amounts of renewable energy, especially fluctuating renewable energies, such as solar and wind power, have an impact on system operation. A characteristic phenomenon is that solar power generated during the day offsets demand for thermal generation. This can result in curtailment of thermal power plants for significant periods of the day, but requires them to ramp-up and –down rapidly during shoulder periods, which can be difficult for system operators. As the share of renewable, and particularly solar powered, generation increases across APEC, addressing this issue will become a widespread challenge of stability of the power system.

Chapter 2-3

Mass introduction of renewable energy might result in a decline in the utilization of coal and natural gas and a drop in the wholesale electricity market price. These are called compression effects and merit-order effects respectively. This phenomenon results in a decline in the profitability of thermal power plants, making it difficult for power producers to make investment decisions to build new thermal power plants. This in turn will present new challenges for system operators in maintaining the stable supply of electricity in the future.

Chapter 2-4

The development of Information Technology has greatly contributed to the improved efficiency and profitability of the energy industry. However, digitalization has resulted in many incidents of computer network abuse (or cyber-attacks). The energy sector in the United States experienced more cyber threat incidents than any other sector from 2013 to 2015, accounting for 35% of total cyber incidents (796) reported by critical infrastructure sectors.

Chapter 2-5

Natural disasters represent threats to people's lives, personal property and energy facilities. In recent years, the impact of damage to energy facilities has tended to increase as the amount and interconnectedness of energy resources has increased. According to Ernst and Young, business disruption due to catastrophic events, including natural disasters, is the greatest management risk for public utilities, including power generators.

Chapter 2-6

Building energy supply systems take a long time and a huge amount of investment. However, uncertainty around energy policy can impede energy system development. For example, policy can often lag behind changing real world circumstances, and public protests against energy policy and ongoing projects. These uncertainties would not only affect energy system reliability but also hold back investment that is essential to sustain energy supply.

Discussion and conclusion

Chapter 3

An outlook characteristics of each fuel are summarized in the table below.

Characteristics of risks in oil, natural gas/LNG and electricity

	Oil	Gas/LNG	Electricity
3-1-1 Substitution of supply	Middle	**<u>Low</u>**	High
3-1-2 Substitution of end use demand	Middle	High	**<u>Low</u>**
3-1-3 Geographical spread of impact	**<u>Wide</u>**	Middle	Narrow
3-1-4 Risk prospect	Decrease	Middle	**<u>Increase</u>**

* Assessment is relative evaluation rather than absolute evaluation among the energies.

* Results that lead to high risk are in bold and underlined.

Chapter 4

The findings and recommendations from the discussions in Chapters 1 and 2 are summarized.

A) Maintain traditional energy security policy as long as it is still viable. [from Chapter 1.1 – 1.4]
B) Promote more fluid and transparent LNG markets, improve gas market information (e.g. via institutions such as JODI), and develop emergency response mechanisms. [1.5]
C) Provide appropriate investment signals. [2.1]
D) Ensure renewable electricity is developed orderly and invest in power storage technology R&D. [2.2]
E) Introduce innovative new electricity market designs, such as capacity mechanisms. [2.3]
F) Develop cyber security programs for energy system. [2.4]
G) Develop climate adaption programs. [2.5]
H) Build policy on scientific evidence and involve stakeholders in the policy making process. [2.6]

The policy implications for each energy are as follows.

1- Oil

- Help developing economies to adopt necessary policies and investment.
  - Design of policy/regulation.
  - Remove oil price subsidy to make government/company capable of necessary investment.
  - Low interest rate loan for security investment.

2. Gas/LNG

- Analyze the risks and develop contingency plan/mechanism in an economy.
  - Develop common methodology to assess risk.
  - Case study, joint study with an economy those who need a help.
- Start discussing multilateral response mechanism.
  - Identify available gas/LNG supply flexibilities (storage, piped gas, reserve capacity) in a market.
  - Develop rules for flexible use.

3. Electricity

- Analyze the policy/mechanism gap between traditional (centralized & thermal power) and emerging (decentralized and VRE) electric power system in an economy.
- Deeper communication between electric power sector and IT sector.
  - Periodic dialogue to seek better integration of sectors.

Introduction

1. Background to the Report

Since the beginning of the 20th century, oil has been the primary focus of energy security, as the stable supply of oil has been the greatest concern in oil-consuming economies in how they view energy security. This is because around half of global resources is concentrated mainly in the Middle East, and the Middle East has been geo-politically unstable. As such, oil-consuming economies have been proactive in taking measures to keep the oil flowing by engaging in dialogue with oil-producing economies, participating in upstream development projects, securing transportation routes, and stockpiling.

However, as the focus of energy demand expands from oil to other energies, there is also a need for change in the approach to energy security. Natural gas demand has been increasing in the 21st century, but natural gas exists all over the world. Also, with the improvement of shale gas development technology and the emergence of floating storage & regasification units (FSRU), the supply capacity of natural gas is further increasing.

Also, in response to the vigorous rise in the demand for electricity, the use of renewable energy as a measure to combat global warming is advancing. However, there is concern that the rapid increase in the use of renewable energies to produce electricity will affect power generation using existing energy sources (oil, coal, and natural gas). At the same time, the fragmentation of supply chains by natural disasters, cyberattacks, and other events is also becoming a major issue in energy security.

2. Purpose of the Report

Thus, this survey aims to gain insight into new forms of energy security in APEC economies based on the various changes currently seen in the energy market. For this purpose, with reference to the six risks categories (Geological risks、Geopolitical risks、Economic risks、Environmental risks、Technical risks and Intermittency risks) based on "Center for European Policy Studies (CEPS) Working Document" announced in January 2009, we extracted the fossil energy that forms the core of conventional energy and the power that will become important as energy security in the future and the surrounding risks. Ultimately, this report seeks to propose the possibility of a new approach to increase energy security.

Chapter 1 Update of traditional energy security risk for oil and natural gas

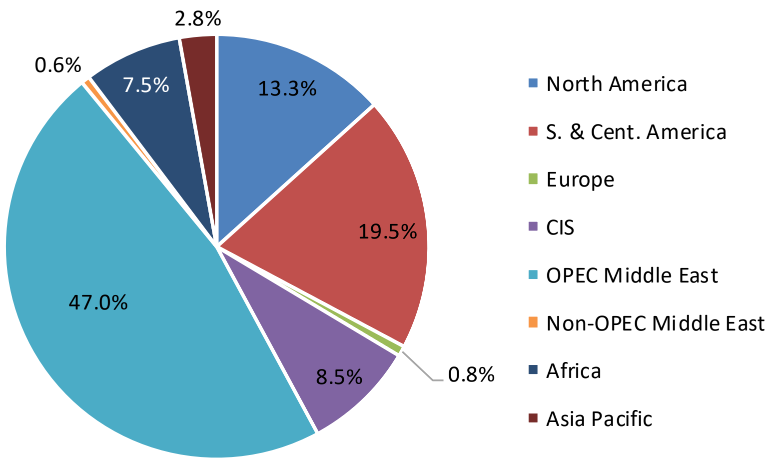
1-1 Geopolitical risk in the Middle East

1-1-1 The uneven distribution of fossil fuel resources

Global crude oil reserves were estimated to be about 170 billion barrels as of the end of 2017 (BP, 2018). Of this, OPEC account for 72% of reserves, or 122 billion barrels, with the remaining 28%, or 48 billion barrels, in non-OPEC producers. Furthermore, almost half of the world's oil reserves (47%), or 80 billion barrels, are located in the Middle East (Figure 1-1).

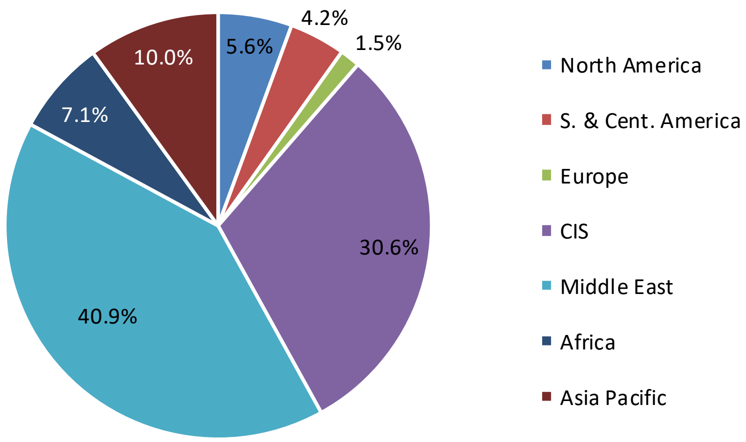
Similar to oil resources, proven reserves of natural gas also tend to be concentrated in the Middle East and Commonwealth of Independent States (CIS) economies (Figure 1-2).

Figure 1-1 World proved reserves of crude oil, 2017



Source: BP (2018).

Figure 1-2 World proved reserves of natural gas, 2017



Source: BP (2018).

1-1-2 Traditional conflicts and rivalries

Long standing instability and geopolitical risk in the Middle East combined with this uneven distribution of fossil fuel resources (i.e. far from traditional demand centers in East Asia, North America and Europe) represents a significant energy security challenge. Some of the more significant regional conflicts and rivalries are listed below.

(1) The Arab-Israeli wars

As oil gradually became the primary energy source of the 20th century, dependence on its supply from the Middle East increased. Against this backdrop, the founding of Israel in 1948 led to several wars between Israel and Arab economies. These were the 1948 Palestine War, the 1956 Suez Canal Crisis, the Six-Day War in 1967 (the Third Arab‑Israeli War), and the 1973 October War (the Fourth Arab-Israeli War). In the Fourth Arab-Israeli War in 1973, Arab oil-producing economies were tempted by the use of the “oil weapon” and put in place an oil embargo (first oil crisis) on economies supporting Israel.

(2) The Iranian Revolution

In Iran, a rebellion against the monarchy began in 1978, resulting in the exile of the monarch of Iran, Mohammad Reza Shah Pahlavi, in January 1979. At the time, Iran was the world’s second-largest oil producer after Saudi Arabia, and its oil interests were controlled by the international oil companies (oil majors). With the collapse of the Pahlavi regime, the revolutionary government nationalized its oil sector and reduced crude oil output in order to protect its resources. OPEC sided with Iran and did not increase output, which triggered a global oil shortage (second oil crisis).

(3) The Iran-Iraq War

The Iran-Iraq War started in 1980 and lasted for eight years. Saddam Hussein of Iraq attributed the cause of the war to conflict over oil resources along the border with Iran and concerns over the Shi'a who were the main actors in the Iranian Revolution. During the war, Iraq bombed the Iranian crude oil terminal on Kharg Island, which led to fears of another oil crisis and resulted in UN intervention and ultimately led to a ceasefire in 1988.

(4) Iraq's invasion of Kuwait

In August 1990, Iraq suddenly invaded Kuwait and quickly took control the entire economy. Iraq argued that Kuwait was part of its territory, and with its domestic economy in shambles from the war with Iran, it hoped to boost crude oil prices. However, Iraq's premise for the invasion was that Kuwait was lowering oil prices and expanding its distribution channels, and the suspicion that it was stealing crude oil from fields near the border between the two economies. Hence, the international community took measures to ban imports of crude oil from both economies, resulting in an oil crisis.

(5) The collapse of the Saddam Hussein regime and the rise of extremist groups

With a dictatorship in Iraq, the international community judged its possession of weapons of mass destruction as a danger, and in March 2003, UN coalition forces launched air strikes on Baghdad. The war ended in May, but subsequent sectarian conflict is ongoing. In particular, the weapons of the Iraqi military made their way into the hands of extremist groups and conflicts broke out in various places. From the conflicts rose organizations such as the Sunni extremist group, the Islamic State in Iraq and the Levant (ISIL). They perpetrated acts of terror in Iraq and Syria which included attacking and occupying oil facilities and affecting Iraq's crude oil production and shipments. Groups such as Boko Haram in Nigeria, Abu Sayyaf in the Philippines, and Al Qaida in the Arabian Peninsula in Yemen are all autonomous groups that pledge their allegiance to ISIL.

1-1-3 The changing dynamics in the Middle East

(1) US foreign policy on the Middle East

- The US is partnering with the Middle East against terrorists

US President Trump delivered a speech to the Arab Islamic American Summit in May 2017. This was one of three summits held on the occasion of the US President Trump's visit to Saudi Arabia. The speech addressed how the US is building partnerships with Middle East economies based on mutual interests by uniting together to confront terrorism. President Trump stated: "We are not here to lecture—we are not here to tell other people how to alive, what to do, who to be, or how to worship. Instead, we are here to offer partnership—based on shared interests and values—to pursue a better future for us all. … This is not a battle between different faiths, different sects, or different civilizations. This is a battle between Good and Evil. … America is prepared to stand with you — in pursuit of shared interests and common security. But the nations of the Middle East cannot wait for American power to crush this enemy for them. The nations of the Middle East will have to decide what kind of future they want for themselves, for their countries, and for their children. It is a choice between two futures —and it is a choice America cannot make for you" (The White House, 2017).

In addition, US signed an agreement with the Kingdom of Saudi Arabia to establish the Terrorist Financing Targeting Center (TFTC) to prevent the financing of terrorism, joined by all the members of the Gulf Cooperation Council. "We must cut off the financial channels that let ISIS sell oil, let extremist pay their fighters, and help terrorists smuggle their reinforcements," stressed President Trump (The White House, 2017).

- Terminating participation in JCPOA

In May 2018, the US terminated its participation in Joint Comprehensive Plan of Action (JCPOA) with Iran and re-imposed sanctions lifted under the deal. The White House stated, "The agreement failed to protect US domestic security interests. … The re-imposed sanctions target Iran's energy, petrochemical and financial sectors. … United States withdrawal from the JCPOA will pressure the Iranian regime to alter its course of malign activities and ensure that Iranian bad acts are no longer rewarded. As a result, both Iran and its regional proxies will be put on notice. As importantly, this step will help ensure global funds stop flowing towards illicit terrorist and nuclear activities" (The White House, 2018).

The US sanctioned more than 700 individuals, entities, aircraft, and vessels after the end of 180-day wind-down period. In addition, the persons and associated blocked property that were on the Executive Order (E.O.) 13599 (E.O. 13599 List) have been moved to the Specially Designated Nationals and Blocked Persons List (SDN List) (U.S. Department of Treasury, 2018). On November 2018, eight oil importing economies[1] were granted a 180-day exemption after the sanctions were re-imposed (Bloomberg, 2018).

(2) The active involvement of Russia and other economies in the Middle East

- Involvement in Saudi Arabia

Russia is increasing its involvement in the Middle East, starting with an agreement at the end of 2016 to cooperate in reducing oil production. In February 2018, the two economies signed joint agreements focusing on oil and gas projects, and announced cooperation that would extend beyond the deadline of the ongoing joint production cuts (end of 2018) (Platts Oilgram News, 2018). The signed agreements include investment from Saudi Arabia to develop Yamal gas, preliminary signing of joint work on Arctic LNG 2 by Saudi Aramco and Novatek, and support from Rosatom to build nuclear power in Saudi Arabia.

In addition, a meeting on a comprehensive agreement on energy cooperation by the energy ministers of the two economies was held in June 2018, and confirmed that Russia was in step with the joint production cuts. These developments and both economies, underlying interest in maintaining oil prices suggest that they will continue to cooperate to control the market, even if the OPEC/non-OPEC oil joint production cut agreement collapses.

- Iraq

In the Iraqi Kurdistan region, ExxonMobil announced its withdrawal from six blocks and Chevron announced a temporary shutdown in two blocks in the fall of 2017. While no reasons were given, it is thought this was done to avoid the risk of litigation from the Iraqi government. On the other hand, some companies intend to start development in the area. Russia’s Rosneft signed a three-year crude oil import contract with the Kurdistan Regional Government in February 2017, and agreed to expand cooperative relations in exploration, production, commerce, and logistics. Given the deteriorating

[1] The eight economies were China, India, Italy, Greece, Japan, Turkey, Chinese Taipei and Republic of Korea.

security environment in the area with the Kurds losing the Kirkuk oilfield and the governments of Turkey and Iraq becoming closer, these developments may be less business decisions than they reflect the intent of Russia “to carve out political influence in the face of waning US influence.”

- Iran

While European and North American foreign capital have announced their departure from Iran because of the trade embargos of the United States, economies such as Russia and China are distancing themselves from the US and deepening their relations with Iran. Recently, the Iranian private oil company, Dana Energy, and the Russian state-owned oil company, Zarubenzhneft, signed an oil development contract for the Aban and West Paydar oil fields in March 2018. In April, the term of the oil for goods program from Iran to Russia was extended. In June, Gazprom of Russia began talks with the Iranian state-owned oil company, National Iranian Oil Company, to increase production in the Azar/Changuleh oil fields.

In addition to Russia, China National Petroleum Corporation took over the interests of France’s Total, which withdrew from developing Iran’s South Pars gas field because of the US trade embargo. It is not known how these changes will affect the region in the future.

1-2 Honeymoon between OPEC and Russia

1-2-1 History of production adjustment

OPEC's first production ceiling allocations date back to the 63rd Meeting of OPEC in March 1982. However, these allocations, which aimed to prop up crude oil prices, were considered to be based on the production capacity of each member economy, with Saudi Arabia acting as the actual adjuster. In 1985, production cuts reached nearly 2 million b/d (mb/d). However, Saudi Arabia was unable to maintain this heavy burden and, as a result of abandoning its role in 1986, crude oil prices plunged from around $28/barrel (bbl) to around $10/bbl. After Saudi Arabia abandoned this role, production ceilings were revised at meetings of OPEC and elsewhere and began again in the middle of 1998.

1-2-2 Joint production cut between OPEC and non-OPEC producers

(1) December 2001 agreement

After the Asian economic crisis in July 1997, OPEC began production adjustments in order to support crude oil prices. As a result, crude oil prices showed signs of recovery, but because of the September 11 terrorist attacks on the United States in 2001 and worsening consumer confidence in major economies economic growth stalled and uncertainty about the future increased. For this reason, in December 2001, five non-OPEC economies, including Russia, also participated in adjusting their production. From January to June 2002, OPEC cut production by 1.5 mb/d, while five non-OPEC economies (Russia, Norway, Mexico, Oman and Angola) cut by 0.46 mb/d.

(2) December 2016 agreement

By the middle of 2016, the crude oil price, which had collapsed in the middle of 2014, showed no signs of recovery. Both OPEC and non-OPEC oil-producing economies depend on revenue from oil prices. Joint production cuts were agreed to between OPEC-members and 11 other economies, including Russia, Mexico, Oman, Azerbaijan and Kazakhstan, for the first time in 15 years. These cuts had a high compliance rate, and along with a recovery in oil demand resulted in falling oil stocks and strengthening crude oil prices. From January to June 2017 (and with a later extension), OPEC cut production by 1.2 mb/d and 11 non-OPEC economies cut by 0.60 md/d.

Subsequently, OPEC and non-OPEC producers agreed to extend the joint production cuts by nine months in May 2017 (July 2017 until March 2018), and then decided to further extend the cuts another nine months in December 2017. In June 2018, production cuts were halted, implying that OPEC become satisfied with their effect on helping the price of crude oil to recover. However, there are doubts as to whether crude oil prices are recovering due to joint production cuts alone.

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1-2-3 How long will the joint production cut between OPEC and Russia last?

Russia is one of the world's largest crude oil and natural gas producers, rivaling Saudi Arabia and the United States in the former, and second only to the United States in the latter. As Russia is highly dependent on income from energy resources. According to fiscal year 2016 data from the Russian Export Center (REC), oil and natural gas and their processed products accounted for approximately 62% of Russia's total exports. This has been the trend over the past several decades, and oil and natural gas continue to be a major export for Russia. The slump in the price of crude oil led to lower export revenues, and the price of natural gas, which is often linked to the price of crude oil, has also stagnated. Russia is therefore similar to most Middle Eastern and OPEC oil-producing economies in that sluggish crude oil and natural gas prices have a major impact on the economy.

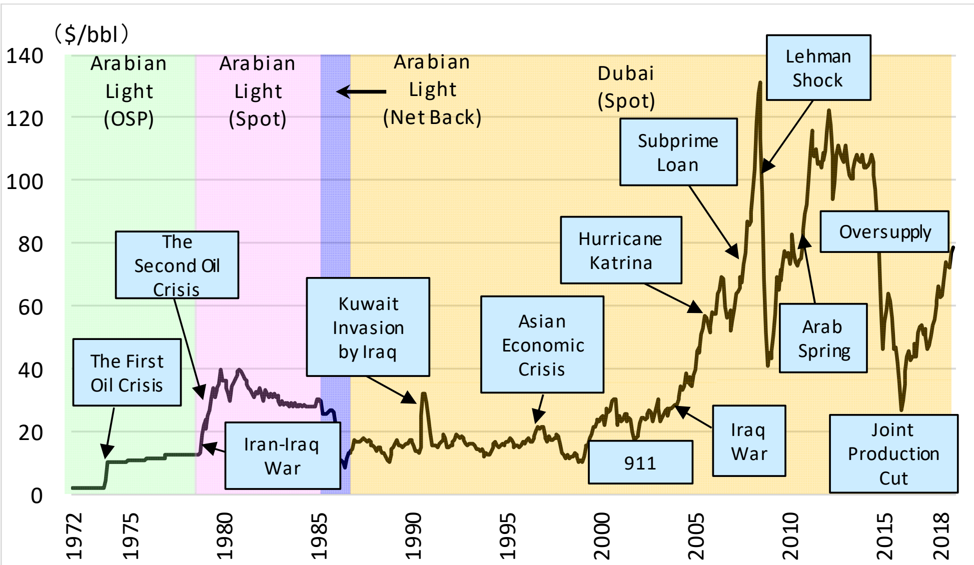
As there is common ground between OPEC and Russia, the joint production cuts are expected to last as long as their interests are aligned. Joint production cuts were once again decided at the Meeting of the OPEC Conference, and at the OPEC and non-OPEC ministerial meeting in December 2018. From January 2019, OPEC decided to cut its production by a total of 1.2 mb/d (OPEC: 800 000 b/d, non-OPEC producers: 400 000 b/d) for six months, compared with production in October 2018. OPEC and non-OPEC producers are planning to evaluate the production cuts in April 2019 based on the state of the global economy and the impact of the trade friction between the United States and China on oil demand. The joint production cuts will continue until at least April 2019, but it will be necessary to carefully monitor the state of compliance with cuts in each economy and the trend of oil demand in the world to see if the joint production cuts will continue.

1-3 Underinvestment and supply crunch risk due to oil price volatility

1-3-1 Oil price volatility

Historically, oil prices have fluctuated due to a variety of factors, including natural disasters, political and social events around the globe, decisions made by producer/consumer economies and organisations, and the availability of other resources. Figure 1-3 illustrates this volatility through the trend in oil price indices since 1972[2], with additional information on the causes of major spikes and dips. For example, the Iran-Iraq war triggered the second oil Crisis in the late 1970s, while hurricane Katrina caused a peak in the late 2000s. Since then, prices have plummeted after the Lehman shock before recovering and through oversupply by OPEC economies.

Figure 1-3. Trend of crude oil price, 1972-2018



Source: Petroleum Association of Japan (2018).

1-3-2 Impact of oil price volatility

(1) OPEC's concerns for underinvestment

OPEC was seriously concerned about the lack of investment caused by low oil prices when the 2nd Technical Meeting was held on 18 July 2016. And, like OPEC, interviews conducted in the United

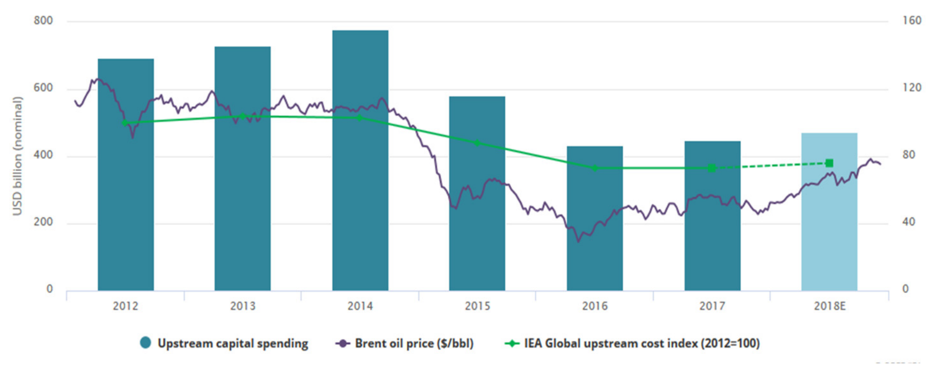
[2] Four different price indices have been used for different periods, as depicted by the coloring of the chart (Arabian Light OSP, green; Arabian Light Spot, pink; Arabian Light Net Back, purple; Dubai Spot, yellow).

States (Washington) and Europe (London) from 13 to 20 November 2016, indicate that some energy experts, government officials and international oil companies are concerned about future supply problems due to the lack of investment (Koyama, 2016). The net profit of the oil majors has been greatly reduced, and they are carrying out large-scale cost-cutting measure and layoffs. Also, in 2015, Saudi Arabia's Minister of Petroleum and Mineral Resources, Ali Al-Naimi voiced concerns that if investment in oil development dries up, the natural depletion of oil fields and annual increase in oil demand may lead to supply shortages in the medium to long term. To respond to natural depletion and increased oil demand, Al-Naimi noted that new production capacity of 5 mmb/d would need to be added every year. To ensure the continued stable supply of crude oil, Al-Naimi estimated that USD 7 trillion would need to be invested over the next 10 years (APERC, 2017).

(2) IEA reported upstream investment collapsed because of low oil prices

World Energy Investment 2018 by the IEA, stated: "Following the peaks in oil and gas upstream investment reached in 2014, investment collapsed abruptly as a result of lower oil prices. 2017 investment rebounded by 2% in real terms, and we estimate the same level of growth for 2018."

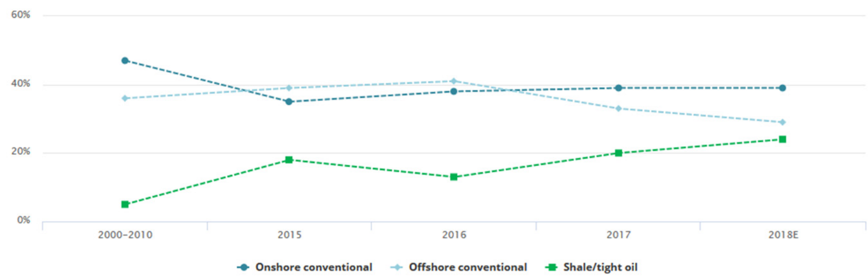
Figure 1-4 Global oil and upstream capital spending, 2012-18



Source: IEA (2018a).

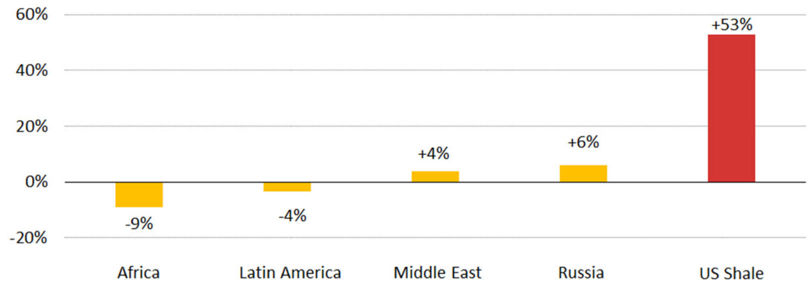
Furthermore, the IEA states the investment situation by asset in the upstream sector of oil and natural gas. Looking at this, investment in non-conventional oil and gas fields in the United States has increased, and investment in offshore conventional oil and gas fields is decreasing.

Figure 1-5 Share of upstream oil and gas investment by asset type



Source: IEA (2018a).

Figure 1-6 Change in upstream investment, 2016 vs 2017



Source: IEA (2017).

1-3-3 Impact of underinvestment in oil and gas upstream

(1) Potential supply crunch due to rising demand in the future

The rate of increase in oil demand has slowed down compared with the latter half of the 1990s. Instead, renewable energy and natural gas are rapidly growing in recent years. This is due to the growing awareness of global environmental problems, but the demand for oil still continues to increase mainly in developing economies in Asia, the Middle East and Africa. The share of fossil fuels in primary energy supply might decline, but the absolute volume is expected to increase. This situation indicates that upstream investment for crude oil production is still necessary, but the recent turbulence in crude oil prices has a big influence on investment in the upstream sector.

The World Energy Outlook 2018 by the International Energy Agency predicts that the world primary energy demand will increase from 13 972 Mtoe in 2017 to 17 715 Mtoe in 2040 in the New Policies Scenario at an average annual growth rate of 1.0%. Of these, coal is estimated to increase from 3 750

Mtoe to 3 809 Mtoe at an average annual rate of 0.1%, petroleum by 0.4% from 4 435 Mtoe to 4 894 Mtoe, and natural gas by 1.6% from 3 107 Mtoe to 4 436 Mtoe. As a result, the proportion of total fossil fuels is 74% even in 2040.

These energy demands do not increase uniformly across the world but depend on economic growth and energy policy of each economy and region. For instance, the demand for coal is expected to decrease in developed economies, and to increase in developing economies. The growth in demand for oil is expected to be driven by developing economies in Asia, the Middle East and Africa. In particular demand in China and India is expected to increase from 16.7 mb/d in 2017 to 24.9 mb/d in 2040 and their share is predicted to increase from 17.6% in 2017 to 23.4% in 2040. Gas demand is expected to increase almost all over the world. In particular, the demand in Asia and the Pacific in 2040 is expected to overtake North America, driven by increased demand in China and India.

(2) Both investment and management are needed to sustain upstream development

In general, maintenance and upgrading of crude oil production are achieved by combining the maintenance of active oil fields with the development of new oil fields. In active-producing oil fields, periodic refurbishment is carried out for each production well to extract the maximum amount of crude oil from underground. To prevent the decline of production from an oil well, continuous investment and management are needed.

1-4 Trade risks caused by choke points

1-4-1 The importance of choke points to oil trade

Crude oil and petroleum products are generally transported by tanker trucks, trains, ships, or pipelines, depending on the place of origin and destination, and the economy. Among them, shipping is the most economical way of transporting large amounts of crude oil and petroleum products, accounting for more than 80% of the global oil trade in 2017 (BP, 2018). However, maritime transport has various dangers and risks.

A choke point is a narrow traffic zone in a sea transportation route. Many vessels transporting goods come and go through a narrow place, so it is a critical point for maritime traffic. There are eight major choke points in the world, and uncertainty about maritime security can lead to international oil price fluctuations. If one of these chokepoints were disrupted, ships may need to travel additional thousands of kilometres on an alternate route, leading to supply delays and higher shipping costs, resulting in higher oil prices.

Table 1-1 Crude oil and petroleum products transported through world chokepoints, 2011-16 (mb/d)

Location	2011	2012	2013	2014	2015	2016
Strait of Hormuz	17.0	16.8	16.6	16.9	17.0	18.5
Strait of Malacca	14.5	15.1	15.4	15.5	15.5	16.0
Suez Canal and SUMED Pipeline	3.8	4.5	4.6	5.2	5.4	5.5
Bab el-Mandab	3.3	3.6	3.8	4.3	4.7	4.8
Danish Straits	3.0	3.3	3.1	3.0	3.2	3.2
Turkish Straits	2.9	2.7	2.6	2.6	2.4	2.4
Panama Canal	0.8	0.8	0.8	0.9	1.0	0.9
Cape of Good Hope	4.7	5.4	5.1	4.9	5.1	5.8
World maritime oil trade	**55.5**	**56.4**	**56.5**	**56.4**	**58.9**	**n/a**
World total petroleum and other liquids supply	**88.8**	**90.8**	**91.3**	**93.8**	**96.7**	**97.2**

Source: U.S. EIA (2017a).

1-4-2 Potential risks and threats to choke points

(1) War

Most crude oil produced in the Middle East passes through the Strait of Hormuz and is exported to Asia. In 2016, 16 tankers per day passed through the Strait, and 21 mb/d petroleum and 4.1 Tcf/year LNG were exported (EIA, 2019).

The Strait of Hormuz has been regarded as a critical point for maritime traffic for a long time, and Iran frequently threatens to blockade the choke point. During the Persian Gulf War in January 1991, Iraq laid mines in the Strait of Hormuz. Floating mines caused restrictions on the navigation of the Strait of Hormuz, and affected the transportation of crude oil, petroleum products and LNG. These type of actions both reduce supply and increase costs. Decline in shipping also occurred because of navigation restrictions, as did a rise in maritime insurance (cargo insurance and hull insurance) rates. Cargo insurance premium rates increased to 2.0%, from 0.05% normally, and hull insurance also increased 10 fold. Thus, in order to secure alternative crude oil supplies, buyers had to pay a market premium, otherwise they had to bear increased fares and insurance burdens.

In the beginning of the 20th century, security concerns surrounding the Strait of Hormuz were again raised during the Iraq war between March and May 2003 and with heightened tensions concerning Iran's nuclear situation in the first half of 2012 and 2018.

This potential supply disruption is also a risk for Middle East oil and gas exporters if they cannot earn oil revenue because exports are impeded. For this reason, the UAE has constructed a pipeline to the export terminal on the side of the Oman bay (Fujairah Terminal) not facing the Strait of Hormuz, and Saudi Arabia has developed and repurposed the Yanbu South Terminal, which was idle on the Red Sea.

(2) Piracy

In the first six months of 2018, there have been 156 attempted and actual attacks by pirates globally, up from 127 in the same time span in 2017 (ICC-IMB, 2018). There were 12 crude oil tanker attacks and 2 were carried out on gas tankers (LNG and LPG) (ICC-IMB, 2018). There were 41 attacks near Nigeria, 31 attacks near Indonesia, and 11 attacks near Bangladesh. About 70% of the attacks were at six major sites, especially in the vicinity of Nigeria, and attacks are increasing. Nigeria, which suffers a vast majority of the attacks in the Gulf of Guinea, has proven to be especially vulnerable to pirates.

Vessels traveling in Sub-Saharan Africa are particularly susceptible to pirate attacks for many reasons, according to Brandon C. Prins, Professor of Political Science Professor at the University of Tennessee. The long coastline with many inlets that make policing difficult is just one of the many challenges that result in increased piracy (Globepost, 2018). On the other hand, the number of attacks in the Malacca Straits has dropped substantially (2016 and 2017 recorded zero attacks) because of the increased and aggressive patrols by the littoral states authorities since July 2005.

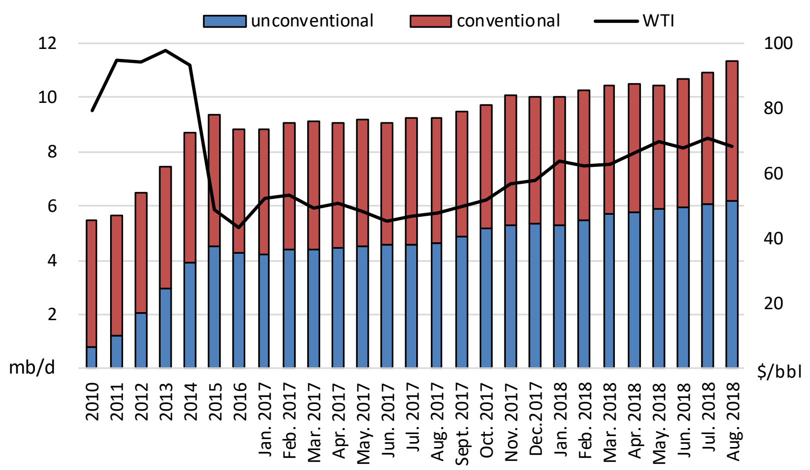
1-4-3 New choke points emerged as US exports surge

(1) US oil production and exports increase significantly

The expansion of shale oil production in the US has radically altered global oil markets and trade patterns. This may alter the energy security risks faced by maritime trade.

In 2017, about 4.7 million barrels per day of crude oil were produced directly from tight oil resources in the United States (Figure 1-7). This was equal to about 50% of total U.S. crude oil production. The EIA expects that U.S. crude oil production will average 10.9 mb/d in 2018, up from 9.4 mb/d in 2017, and will average 12 mb/d in 2019 (EIA, 2018). This rise is being driven by growth in output of light tight oil from U.S. shale oil basins.

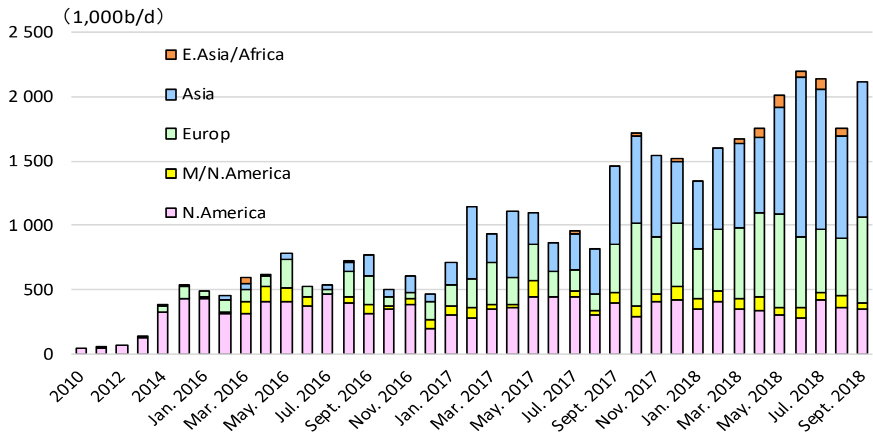
Figure 1-7 Crude oil production in the United States, 2010-18



Source: EIA (2019).

The U.S. is now the world's largest crude oil producer, surpassing both Saudi Arabia and Russia, and of the largest producing OPEC economies, only Saudi Arabia (7 mb/d in 2017) and Iraq (3.8 mb/d in 2017) are exporting more oil than the U.S.

Figure 1-8 Crude oil exports from the United States, 2010-18



Source: EIA (2019).

In late 2015, the U.S. law prohibiting crude oil exports that had been in place since 1975, was lifted. Exports, mainly to Europe and Asia, have grown from 4.9 mb/d in January 2016 to 20 mb/d in May 2018 and are expected to continue to increase in the future. The U.S. became a net oil exporter at the end of November 2018, breaking 75 years of continued dependence on foreign oil and marking a turning point. Furthermore, the IEA predicts that the crude oil production in the United States will increase from 13.2 mb/d in 2017 to 18.5 mb/d in 2025.

Table 1-2 Oil production in the New Policies Scenario (mb/d), 2000-40

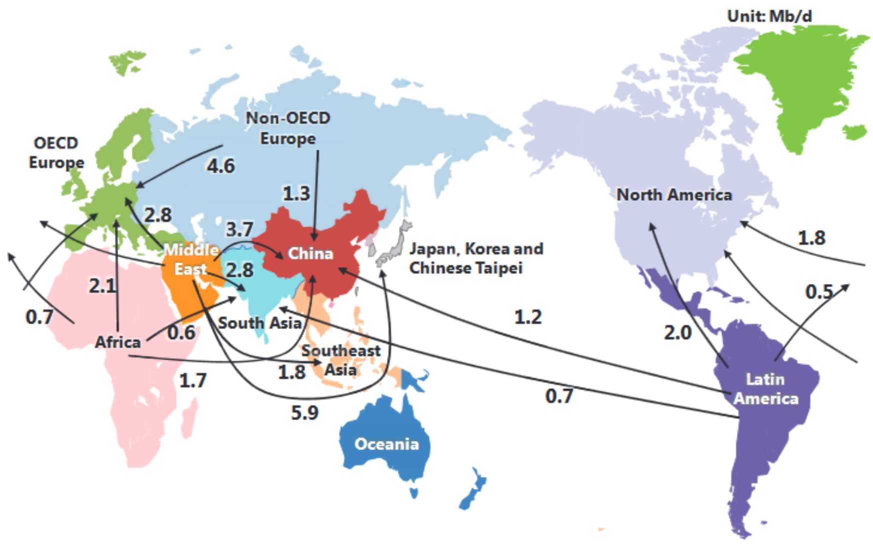
	2000	2017	2025	2030	2035	2040	2017-2040 CAAGR
The United States	8.0	13.2	18.5	18.3	17.5	16.2	0.9%

Source: IEA (2018b).

(2) Prospects for the change in global crude oil trade

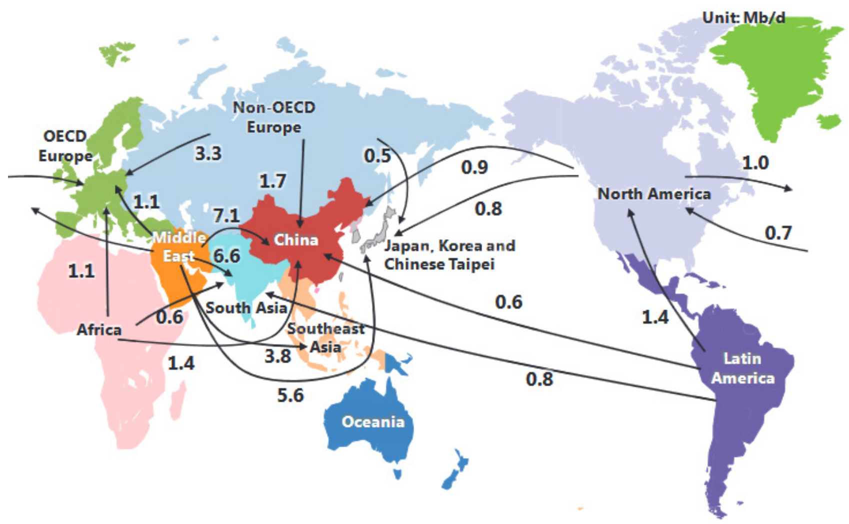
The most visible change in major crude oil trade flows in 2030 compared to 2017 is expected to be the increase in crude oil imports by China and India. Both economies are expected to increase their energy consumption because of continuing economic development, which will increase imports of crude oil.

Figure 1-9 Major crude oil trade flow, 2017



Source: IEEJ (2019).

Figure 1-10 Major crude oil trade flow, 2030



Source: IEEJ (2019).

In addition, US crude oil exports are expected to increase mainly to Northeast Asia (China, Korea, and Japan) and Europe. As a result, the Middle East, which has mainly exported crude oil to these regions, is expected to pivot towards Southeast Asia, China and India by taking advantage of the relatively short distance compared with the United States.

Finally, by 2030 compared with 2017, Africa's crude oil exports are expected to shrink (from 4.1 million barrels to 3.1 million barrels) and South America's from to 4.4 million barrels to 2.8 million barrels. This is because of security of supply issues and reduced exports from these regions to the United States and intensifying competition in supplying other markets among U.S., Middle East and Russian producers.

(3) Impact of changes in trade routes on maritime trade risk

The United States, which was the largest importer of crude oil in the past, is now increasing its share of world oil exports as shale oil production surges. China became the world's largest oil consumer in 2017 and along with the rest of Asia is expected to diversify its crude oil supply sources by expanding imports from Central Asia and North America. However, these regions, along with the Middle East and Africa, will have to compete for oil exports to the growing Asian market as oil demand in Europe is shrinking. Increased production of shale gas/oil in the U.S. is causing changes in trade relations between oil suppliers and consumers and changing the routes for oil movement.

With the recent completion of expansion work, virtually all LNG/LPG transport ships and all but very large crude carriers (which account for the majority of crude trade) can pass through the Panama Canal. As a result, economies in the Far East (China, Korea and Japan) that import U.S. crude oil are starting shipments from the Gulf of Mexico and returning via the Cape of Good Hope, while LNG exports to these economies are increasingly coming through the Panama Canal. U.S. shale gas and tight oil production is changing the supply and flow of crude oil around the world and increasing the importance of the Panama Canal to global energy markets.

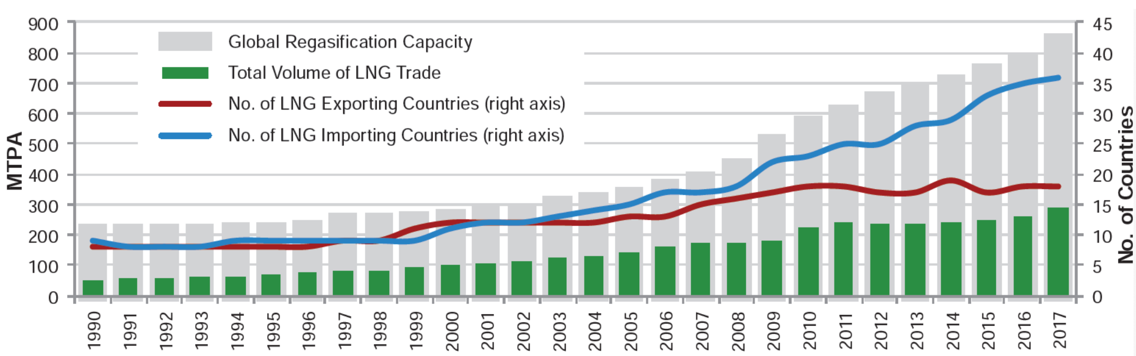
1-5 Potential risks in the LNG market

1-5-1 LNG market development

When LNG was introduced in the late 1960s, it was not regarded as a commonly used fuel because of the huge investment requirements and the long period needed to build LNG facilities through the whole LNG value chain compared with other energy sources. There were very few economies able to use LNG because of the commitment needed to 20 or more year long-term contracts and the expense of bearing all the costs of the whole LNG value chain. The lack of economies capable of underwriting these type of contracts and the scale of the market prevented LNG from being traded like other energy commodities such as crude oil and coal.

Since the mid-2000s, change has come to the LNG market. Europe needed to diversify its supply sources in the face of high reliance on Russian piped gas, Southeast Asia needed to replace declining natural gas production, technical innovation in horizontal drilling and hydraulic fracturing led to US LNG exports, and global environmental efforts to reduce CO_2 emissions highlighted the importance of gas as both a source of peaking power to respond to intermittent renewables and a lower emissions alternative to coal. The conjunction of technical innovation, falling oil prices (to which many LNG contracts are linked) and an LNG supply glut resulted in LNG prices plummeting from 2016. In this market situation, the number of LNG importing economies has almost doubled to 36 economies in 2017 from 20 economies in 2005 (IGU, 2018).

Figure 1-11 LNG imports, trade and regasification capacity, 1990-2017

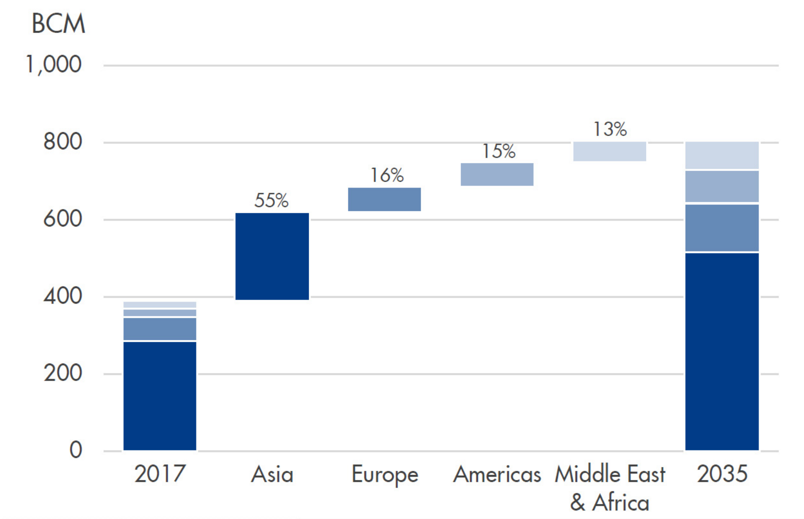


Source: IGU (2018).

(3) Prospect of LNG market expansion

Although most economies have focused on preparing for the expected increase of LNG demand driven by economic growth, growing natural gas production, diversification of natural gas supply sources, tightening global environmental standards and low LNG prices are also expected to stimulate LNG demand. Other tailwinds for LNG demand include shifting oil and coal demand in transportation and other sectors for environment policy reasons.

Figure 1-12 LNG imports outlook by region, 2017-35



Source: Shell (2018).

1-5-2 Risks associated with expanding LNG market

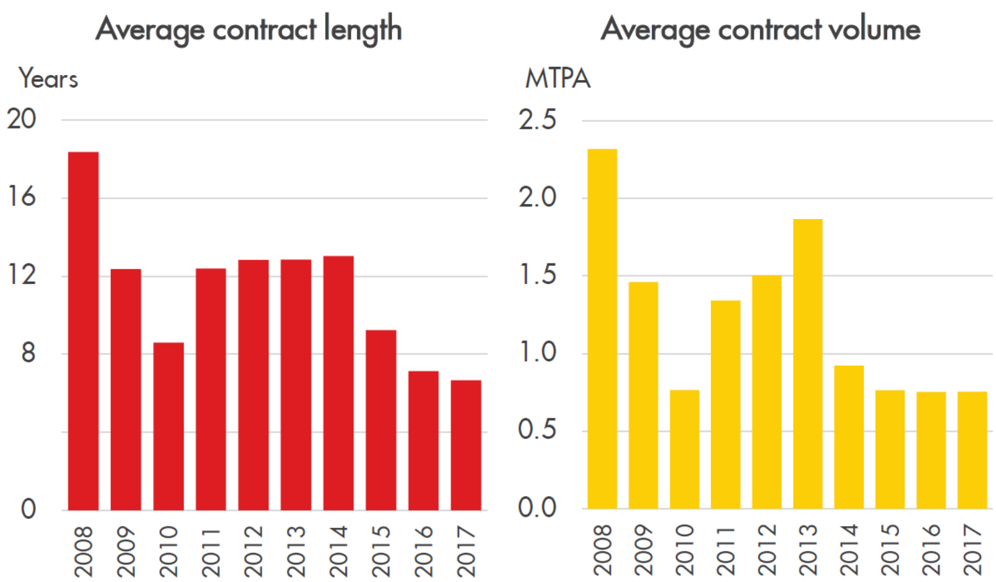
(1) The uncertain LNG market

Economies currently importing and planning to import LNG, face an uncertain LNG market. While LNG is the most probable substitution option of oil and coal, its position is threatened by the rapid progress of renewable energy. In this light, LNG contracts are becoming more flexible with less LNG contractual volume, shorter contract terms and rising LNG trading volume.

(2) The change in LNG contract types

LNG buyers are showing increasing interest in the flexibility offered by commodity markets, rather than handling unforeseen risks with inflexible contracts. Major LNG buyers have changed their procurement strategy to shorter period terms and less LNG volume, and have altered their LNG supply portfolios to raise the portion of spot or short-term contracts. Further, they have worked to develop overseas LNG outlets as a way to avoid unexpected imbalances in LNG supply and demand. This should help them optimize their LNG supply by increasing the diversity of sources.

Figure 1-13 LNG trading volume, 2008-17



Source: Shell (2018).

(3) Market barriers

However, consistent market practices may not to allow the LNG market to move to a flexible market easily in a short period. After the JFTC`s recent ruling against destination clauses in LNG contracts, Japanese buyers have tried to eliminate restrictive destination conditions, but very few sellers have shown interest in fair competition.

As the major LNG consumer, the Asia Pacific region lacks a widely-used liquid and transparent LNG pricing benchmark like Henry Hub (HH) or National Balancing Point (NBP) (U.S. EIA, 2017b). They are racing to the goal, and some of them have already introduced new platforms with benchmark prices However, these are not attractive enough for LNG players to participate. Transaction records are rarely seen on those platforms. LNG players, including those who wish the LNG market was more flexible and transparent, still seem more likely to continue bilateral negotiation in secret, in order not to reveal their position to other competitors and LNG market.

The LNG market is shifting toward to a commodity market with the hope that more flexibilities will avoid supply security uncertainties. In the current market situation abundant LNG can be procured with a less effort than the past without fear of LNG supply disruption. However, the market situation changes periodically depending on the supply and demand balance, resulting in some voices fearing a supply deficit as investments in LNG supply decline as in tandem with prospects for a demand increase.

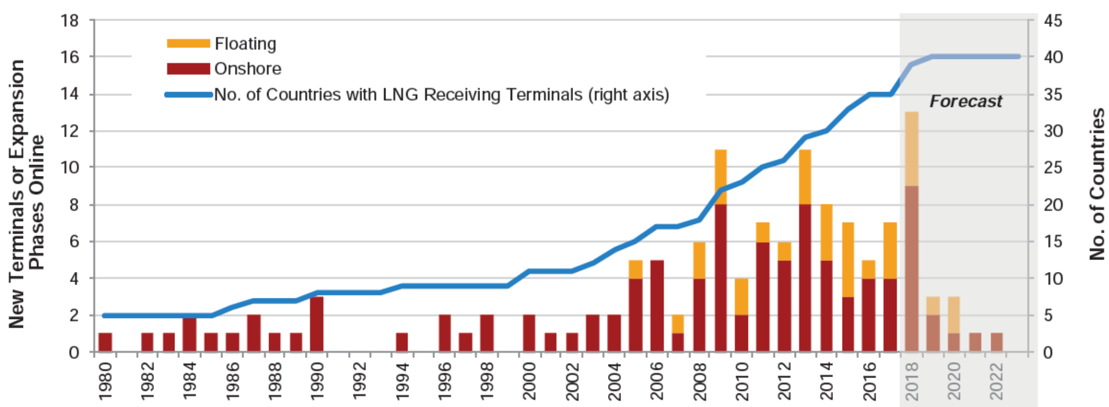
Even though the LNG market is expected to be as flexible as the oil market, progress is sluggish and various voices are not reaching to consensus in whole LNG market. In this light, various measures for LNG supply security should be considered during the current transition period to a commodity market.

1-5-3 Preparedness for LNG imports in emerging markets

(1) Emerging LNG markets trying to succeed in LNG imports within a short period

Since the mid-2000s, as the number of emerging LNG importing economies rises, the number of FSRUs (Floating Storage and Regasification Unit) has risen. As LNG began to play a major role, each economy was eager to find a short cut to deploy LNG importing facilities in a rapid and economic way. FSRUs were utilized for periodic peak demand shaving or temporarily bridging the period to complete onshore facilities. Introduction of FSRU helped them realize their plans within a relatively short period.

Figure 1-14 Starts-ups of LNG receiving terminal, 1980-2022



Source: GIIGNL (2018).

Currently the economies seeking to develop LNG imports, are almost all developing economies in Southeast Asia with high dependency on indigenous gas in the past. They are selecting the option of

LNG to supplement the shortage from the declined production of indigenous natural gas considering the current favorable economics of LNG, which compel them to facilitate LNG imports with FSRUs in a short period.

(2) Needs to consider LNG supply security from the overall standpoint

LNG requires a value chain connecting supply to demand of LNG facilities, which makes it difficult to avoid risks inside the chain particularly with legacy contract market practices. LNG players who may be sellers or buyers, therefore, tend to regard the safety and credibility of LNG facilities as a prerequisite for transactions between each other. Especially for buyers the safety and operational credibility of the LNG receiving terminal was treated as the most considerable requirements for LNG imports. In this light, every economy with a long history of importing LNG, has tried to bolster the safety and operational credibility of its facilities. Major LNG importing economies, Japan and Korea, also have a well-organized distribution system with measures to mitigate supply disruption, particularly in case some parts of the supply system are damaged. In 2011 LNG receiving facilities in Fukushima prefecture were damaged by a tsunami just after an earthquake and suffered a supply disruption, but well-organized and diversified supply facilities connected to the damaged area managed to help supply natural gas even during the outage of the LNG receiving facilities.

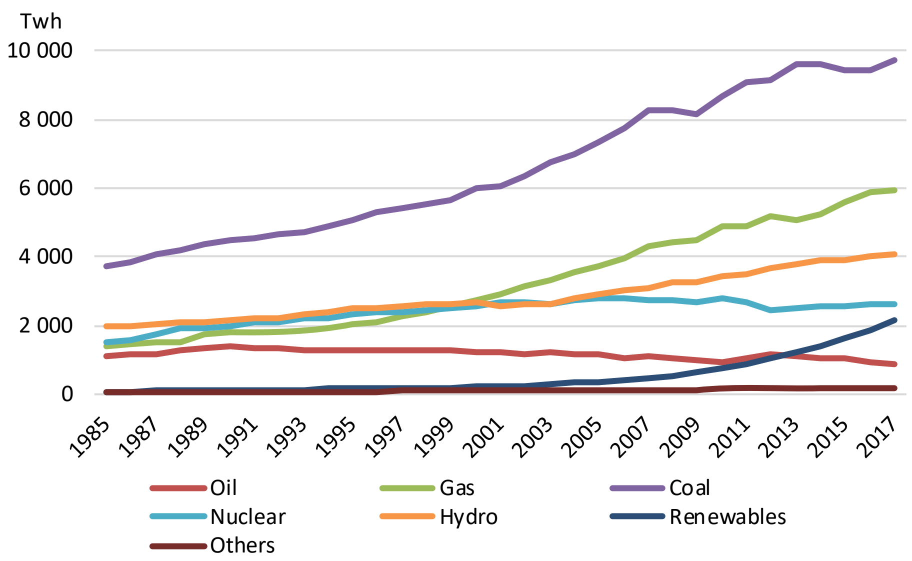
Chapter 2 Emerging energy security risks in power supply market

2-1 Mismatch during transition period between conventional energy and renewable energy

2-1-1 Rapidly growing renewable energy

Recently, renewable energy for power generation has grown rapidly. The Kyoto Protocol to the United Nations Framework Convention on Climate Change adopted in 1997 required economies to take action to control GHG emissions. Economies that ratified the Protocol each set GHG emission goals and devised action plans such as improving energy efficiency and increasing the deployment of renewable energy.

Figure 2-1 Global electricity generation by fuel, 1985-2017

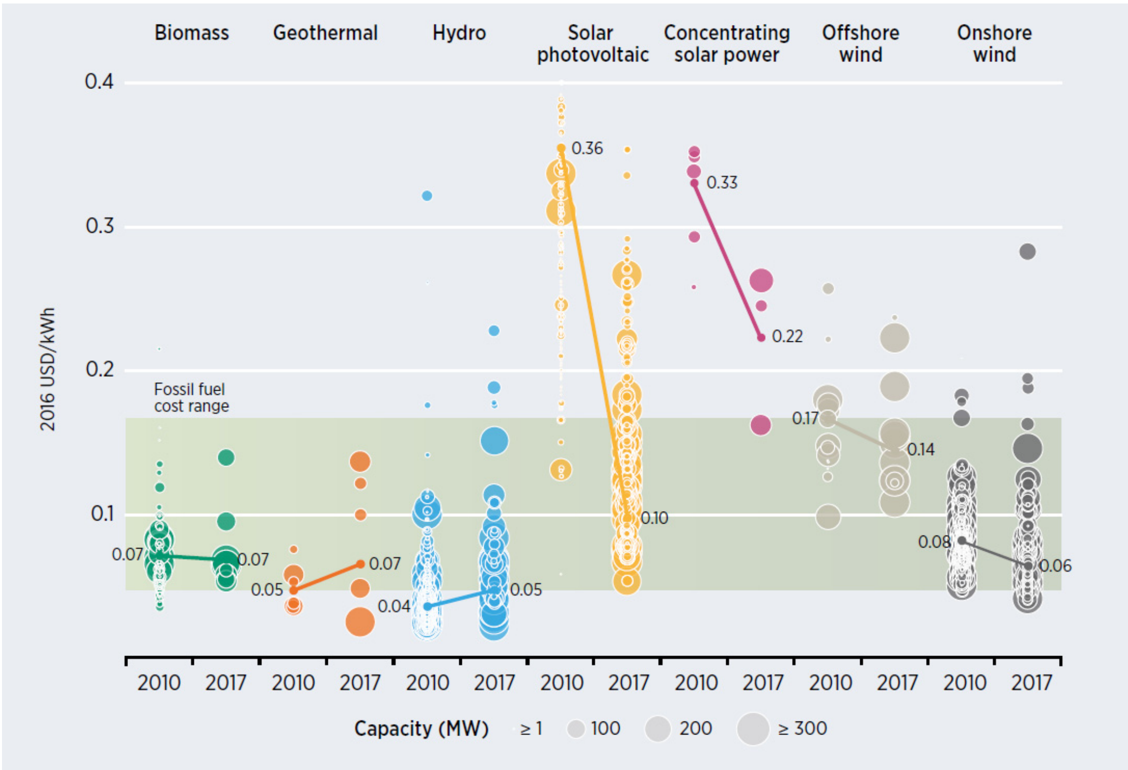


Source: BP (2018).

For energy supply, it was necessary to introduce policies effective to reduce CO_2 emissions. Particularly in power generation, switching from coal and petroleum to other fuels with lower GHG emissions, deploying renewable energy, and utilization of nuclear power generation were expected to be important. As a result of both government support, such as feed-in-tariffs, and technology advancement, renewable-based power generation has been one of the most substantial contributors to the Kyoto goals since 2000.

According to IRENA, “The rapid deployment of renewable power generation technologies, combined with high learning rates, has driven down costs. This trend is projected to continue, making renewables increasingly competitive with fossil fuels in economies across the world and the least-cost option in a growing number of markets. … Further equipment cost reductions can be expected up to 2020, which will lower the weighted average levelized cost of electricity (LCOE) of renewables” (IRENA, 2018a).

Figure 2-2 The cost of renewable energy technology, 2010-17



Source: IRENA Renewable Cost Database.

Note: The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE value for plants commissioned in each year. Real weighted average cost of capital is 7.5% for OECD countries and China and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

Source: IRENA (2018b).

The rapid deployment of solar photovoltaics (PV) has led to dramatic cost declines in the last 10 years. Crystalline silicon (c-Si) PV module prices have fallen by more than 80% since 2010, driving reductions in installed costs. Utility-scale solar PV projects can now provide electricity that is competitive with other grid supply options, without financial support.

Concentrating solar power (CSP) plants are only just beginning to be deployed at scale. Although current costs are high due to the low levels of deployment, significant cost reduction potential still exists. The ability to incorporate low-cost thermal energy storage will make them more important as the share of variable renewables in total power generation rises. The average LCOE of CSP power plants could fall to around USD 0.09/kWh by 2025 (IRENA, 2018b).

The weighted average electricity cost of new onshore wind farms in 2016 was between USD 0.05 and USD 0.12/kWh depending on the region, but costs can be as low as USD 0.03/kWh for the most competitive projects without financial support. Average costs will continue to decline because of continuing pressure on wind turbine prices and continued growth in hub heights and swept areas, which results in higher capacity factors for wind. Offshore wind is considerably more expensive, with costs of between USD 0.10 and USD 0.21/kWh for projects commissioned in 2014–16.

2-1-2 Uncertainty in security on shifting to VRE

The rapid growth in renewable energy in the electricity market is accompanied by security risks during the transition period from existing energy sources.

(1) Impact on energy prices

The rapid growth of renewable energy can lead to a drastic fall in electricity prices in the wholesale market, a drop in the operation ratio of thermal power plants, and failure to cover operating costs for conventional power plants. For instance, at the end of March 2016, German operator E.ON recorded an increase in losses due to the operation of a power plant that had not been fully depreciated. As a result, the company applied to the supervisory authority to suspend units No. 4 and No. 5 (1 400 MW in total) of its natural gas thermal power plant in Irsching, located in the outskirts of Munich.

On the other hand, while renewable energy is becoming cheaper due to governmental support, unconditional support may not mesh with real-world conditions, and plans may suffer from setbacks. Parties responsible for supplying energy, including power companies, need to provide the necessary investment signals for each type of power source. If this process were disrupted, utilities would be forced to utilize whatever power sources are available in order to avoid a power outage, thereby risking a rapid hike in energy costs.

(2) Risk of sudden power source conversion

Some economies are planning to phase out nuclear energy from their energy mix. In Korea and Chinese Taipei, nuclear power and coal-fired power plants will be closed in phases, while LNG and renewable energy will grow to replace them. However, when power demand increases because of unexpected summer heat, there is a risk that supply is unable to catch up with demand because of a slowdown in the introduction of renewable energy. If no adjustments are made to the pace at which VRE is introduced and the pace at which conventional energy is abolished, the risk of a power outage rises.

2-2 Effect of renewable electricity increase on electricity supply security

2-2-1 New challenges arising from the introduction of renewable energy

As described in the previous section (2-1-1), the market share of renewable energy in the power market is growing. However, this brings up new problems for power supply.

(1) Impact on power system operation

Variable Renewables Energy (VRE) mainly refers to wind and solar PV whose output is driven by the weather. Those types of power plants display greater variability and uncertainty than conventional power plants like fossil fuel-fired power plants or nuclear power plants. Such VRE characteristics pose challenges for grid operators. For example, they require additional actions to balance the system.

System operators need to have greater flexibility in the system to accommodate variability and the relationship to generation levels and loads. In cases in which the variable renewable energy generation increases when load levels fall (or vice versa), not only the VRE but also conventional power plants are required to adjust their output to meet electricity demand. System operators also need to ensure they have enough resources to accommodate significant up or down ramps in the VRE generation to maintain system balance including frequency adjustment. In some economies, the grid is not stable at locations where the VRE has largely integrated (Bird et al, 2013). Lack of transmission line capacity causes congestion in the system and has not only economic impacts in the form of possible curtailment or higher local pricing, but also risks to the reliability of the system (IEA, 2018a).

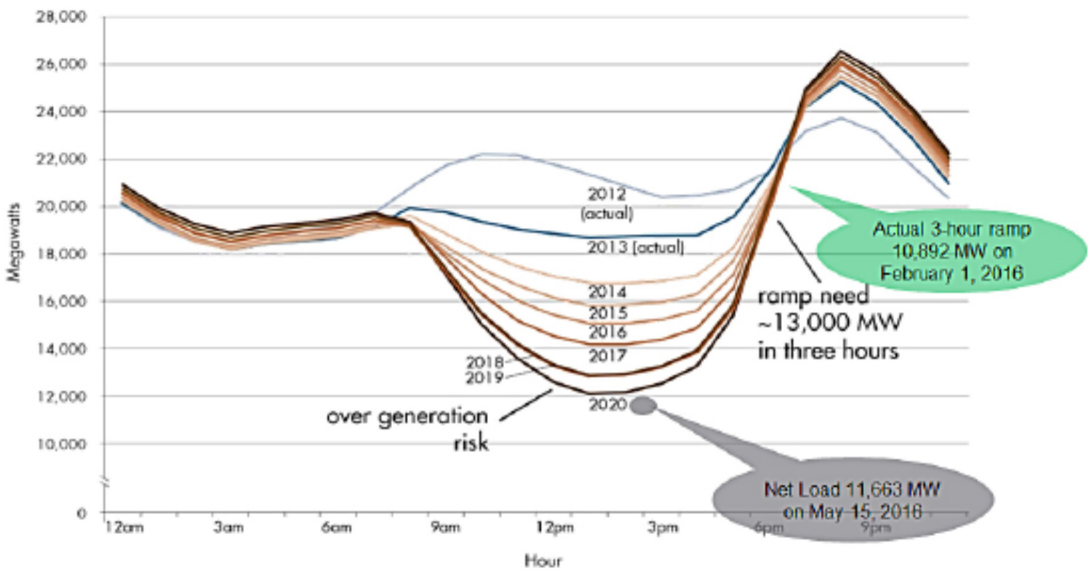
In general, installing battery storage or pumped storage power plants, upgrading and enhancing transmission line facilities and frequency adjustment by using smart meters are some of the options to address the challenges.

(2) Characteristic phenomenon: the Duck Curve

The Duck Curve (Figure 2-3) was first described in a report by the California Independent System

Operator (CAISO), an independent power system operator in California that manages power transmission systems in the state of California. This curve illustrates the changes in real power demand (net load) at different periods of time in the state of California from 2013 to 2020. Net load, shown on the vertical axis, is obtained by deducting photovoltaic power generation output from the overall power demand capacity of electric companies. This makes it possible to see the impact that the growth in the introduction of renewable energy has on the power system (grid). The horizontal axis shows time of day.

Figure 2-3 The Duck Curve shows steep ramping needs and overgeneration risk



Source: CAISO (2016).

The demand curve for 2013, which takes the shape of the duck's back, shifts into the downward-sloping shape of a duck's stomach from 2015 alongside the growth in the introduction of photovoltaic power generation. In 2020, this "stomach" bulges outward, indicating that it has encroached into demand for conventional power supply sources such as thermal power.

Next, while power demand in the state of California increases significantly after 5pm, photovoltaic power output is largely exhausted before that. In short, alongside the growth in the introduction of photovoltaic power generation, the gap between the rise in peak demand and drop in output grows accordingly, resulting in the increasingly long "neck" of the duck.

The Duck Curve phenomenon sheds light on the issues related to system operation.

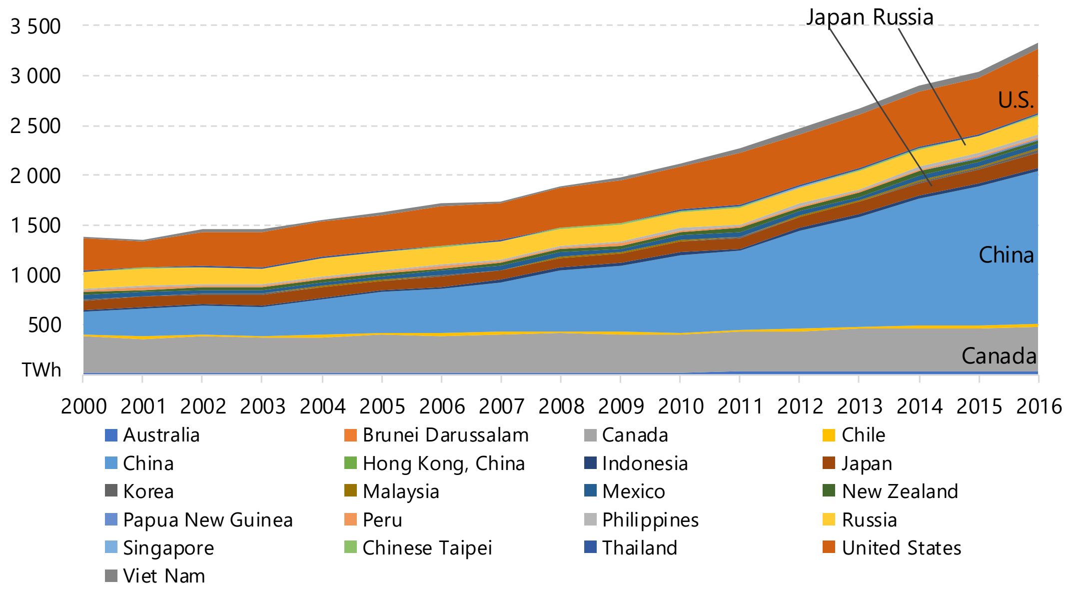
- Power companies supply power as “baseload power” through centralized power plants such as thermal power plants (mainly coal and nuclear), serving as power sources that are able to operate continuously regardless of day or night. However, when photovoltaic power generation increases, power demand during the day falls, and it becomes necessary to make a downward adjustment corresponding to the changes in output. Alternatively, supply may outstrip demand, making it impossible to keep frequency at a certain level. As a result, it becomes difficult to maintain a stable supply of electricity.
- As demand increases in the evening hours, generation from solar PV declines, resulting in a supply-demand imbalance. This gives rise to the possibility that adjustments to power generation will not be able to keep up, making it impossible to keep frequency at a certain level. Alternatively, corresponding to periods of high demand, it will be necessary to secure a large amount storage or peaking capacity (gas or diesel) which output can be adjusted rapidly.

2-2-2 Recent renewable energy developments in APEC

(1) Status of renewable energy introduction in the APEC economies

APEC economies have been proactive in introducing renewable energy over the last decade (Figure 2-4). The biggest contributor to renewable electricity growth in the APEC region has been hydro power, however the percentage of VRE in total electricity generation has been rapidly increasing since 2000 (Figure 2-5).

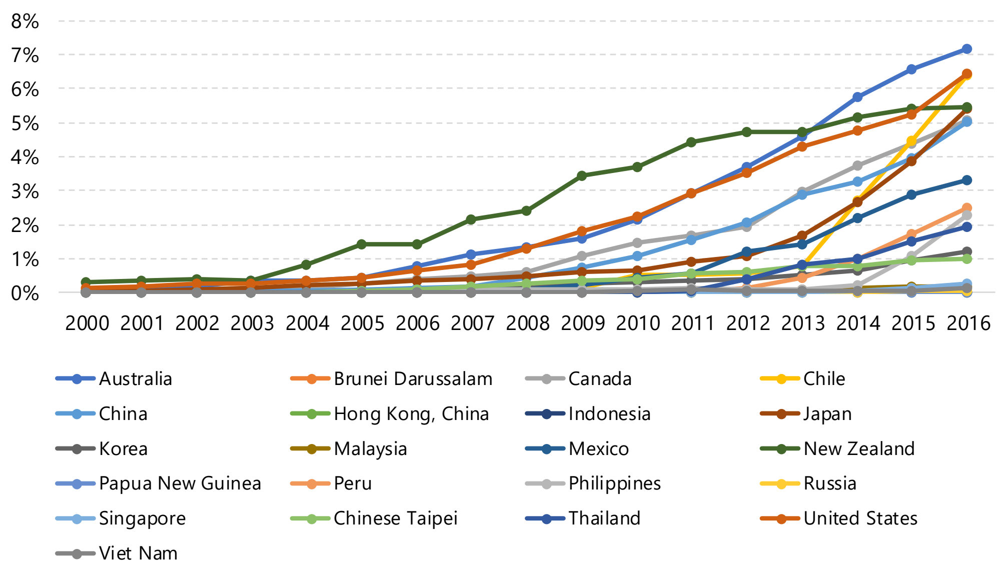
Figure 2-4 Electricity generation from renewable energy resources in APEC economies, 2000-16



Sources: IEA (2018a) and EGEDA (2018).

Note: Renewable electricity resources includes hydro, geothermal, solar PV, solar thermal, wind, biofuels and waste, tide, wave and ocean.

Figure 2-5 Percentage of VRE of total electricity generation in APEC economies



Sources: IEA (2018a) and EGEDA (2018).

2-2-3 Impact of VRE deployment in the APEC region

(1) IEA's research on VRE deployment

The International Energy Agency published a report titled "System Integration of Renewables An update on Best Practice" in 2018. The report defines four phases of VRE deployment on the basis of annual share of total electricity generation. An economy with less than 3% VRE is recognized as in Phase One. 3-15% is in Phase Two, 10-25% is in Phase Three and 25-50% is in Phase Four.

The IEA shows how cost-effectiveness and reliability of the power system differ over the four stages of VRE deployment (IEA, 2018a). This study categorizes APEC economies into four phases based on the IEA report and summarized the measures conducted by the APEC economies. Most of the economies are categorized as Phase One and Phase Two.

Table 2-1 Categorization of APEC economies and characteristic areas

	VRE share of electricity generation	**Economies (VRE share in percentage, year)**
Phase One	<3%	Brunei (0%, 2016), Hong Kong, China (0%, 2016), Indonesia (0%, 2016), Korea (2%, 2017), Malaysia (0%, 2016), Mexico (3%, 2017), Papua New Guinea (0%, 2016), Peru (3%, 2016), Philippines (2%, 2016), Russia (0%, 2016), Singapore (0%, 2016), Thailand (2%, 2016), Chinese Taipei (1%, 2016), Viet Nam (0%, 2016)
Phase Two	3-15%	Australia (8%, 2017), Canada (5%, 2017), China (5%, 2016), Chile (9%, 2017), Japan (6%, 2017), New Zealand (5%, 2017), United States (8%, 2017)
Phase Three	10-25%	Kyushu area (Japan), ERCOT (United States), CAISO (United States)
Phase Four	25~50%	-

Source: IEA (2018b).

(2) Status of APEC economies based on IEA's research

- APEC economies in Phase One

Phase One means the VRE capacity has no noticeable impact on the electricity system (IEA, 2018a). At this stage, the challenges mainly depend on local conditions in the grid. System operators do not need to take immediate actions to accommodate the increase of the VRE. However, it is important to ensure that developers of VRE have sufficient visibility on where they can connect to the grid, and that local conditions are such that new plants can indeed connect (IEA, 2018a). Not only the grid infrastructure but also the technical standards relating to the performance of the first VRE plants, for example connection standards or grid connection codes should be carefully considered. As the very first stage, assessing local grid conditions is critical to ensure that the VRE plants do not have a negative impact on the local quality and reliability of electricity supply. It is also important to consider some alternatives to new grid infrastructure to enhance transmission system capability. Enhancing system controllability using additional transmission system devices such as Flexible AC Transmission Systems (FACTS) and special protection schemes may help. Moreover, having appropriate technical grid connection rules is required when the capacity of VRE increases because the operation of most of the modern wind and solar PV power plants is controlled via software programs.

- APEC economies in Phase Two

Phase Two means the VRE has a noticeable systematic impact on the supply-demand balance of electricity. However, this can be managed quite easily by upgrading some operational practices (IEA, 2018a). At this stage, the concept of net demand (or net load) becomes central. Net demand (or net load) is the demand for power minus the VRE output. In Phase One, there is no relevant difference between load and net load. However, there will be a structural change in the net load curve in phase two. In order to meet electricity demand, other resources on the grid, for example other dispatchable power plants, storage batteries, demand response and interconnections will be needed. IEA stated however, the uncertainty and variability of net load is still slight in Phase Two. So upgrading operational practices by system operators is sufficient for integrating VRE. In Phase Two, the following actions are required to successfully integrate VRE to the grid: developing or upgrading grid connection code, ensuring visibility and controllability of power plants, implementing the VRE production forecast system, improving operation strategies and considering grid expansion, and managing the VRE deployment location and technology mix (IEA, 2018a).

- Thailand, an economy where VRE needs to be managed

The share of VRE is still small in Thailand. However, Thailand's Alternative Energy Development Plan (AEDP2015) suggests that renewables will have potentially large impacts on the future development of the transmission network, as suitable locations for renewables are not always close to load centers (IEA, 2016). Over the course of the development of the AEDP2015, existing network constraints in eastern Thailand led to reductions in the renewable targets, as the system operator claimed that it was not able to both increase imports and integrate significant shares of variable renewables.

2-3 Fixed cost recovery and underinvestment in liberalized electricity markets

2-3-1 Challenges for conventional thermal power plants

The characteristic challenges caused by large deployment of VRE are a decline in the capacity factor and in the wholesale electricity price under liberalized electricity market. Those challenges for conventional thermal power plants have become big issues especially in European economies such as Germany.

(1) Decline in capacity factor of conventional thermal power plants

In the short-term, one of the effects of deploying large deployment of VRE is the reduction of capacity utilization of dispatchable power plants with higher marginal costs such as gas-fired power plants. This is also called compression effect (Frontier Economies, 2016). For example, in Germany, the operating time of natural gas-fired power plants has declined dramatically from 3 400 hours in 2010 to 2 640 hours in 2012. Natural gas-fired power plants in Germany have lost their economic competitiveness because of higher generation cost, and their capacity factor has often been less than 30%. Continuous decline of capacity factors for natural gas-fired power plants is likely to happen until 2025 because natural gas-fired power plants are expected to back up VRE for security of supply at peak demand (METI, 2017).

After the mid-2020s, when Germany will phase out nuclear power, the lack of electricity generation will be compensated for by increasing combined-cycle gas turbine facilities. In that case, capacity factors of natural gas-fired power plants might rise. Not only in Germany, but also in the United Kingdom, capacity factors of gas-fired power plants have significantly decreased from around 60% in

2009 to less than 30% in 2013 because of the large deployment of VRE.

(2) Decline in wholesale electricity price

In general, the electricity price is determined by the merit order in liberalized electricity market, which means the sequence in which power stations contribute power to the market, with the cheapest offer made by the power station with the lowest running costs setting the starting point (Clean Energy Wire, 2018). The marginal cost of VRE is almost zero because it has almost no operating costs. Therefore, when the volume of the VRE increases in wholesale electricity market, existing power plants especially coal-fired or gas-fired power plants are pushed out of the market and some of their volume remains unsold. This is also called merit-order effect (Hirth, 2013). This makes the power companies that own thermal power plants stop their operation. In addition, some economies have priority dispatch rules when electricity supply exceeds demand, and thermal power plants are usually the first generating sources to be curtailed. Additionally, the suppliers of VRE are sometimes guaranteed purchase of electricity at a fixed price for a certain period usually through a feed-in tariff scheme so they continue generating electricity even if the electricity price in a wholesale electricity market becomes negative. This brings further reduction of electricity prices and declines in capacity factor of thermal power plants.

Germany is one of the examples of wholesale electricity price changes due to VRE deployment. In addition to Germany, a report by Lawrence Berkeley National Laboratory summarized the evidence of VRE-induced wholesale electricity price changes in several economies, such as Australia and the United States. It finds that "analyses of wholesale prices in Australia show that the deployment of photovoltaic capacity can lead to price changes: historical capacity additions by 2013 had already eroded a mid-day peak in prices in comparison to 2009 and caused the diurnal price profile to flatten significantly (Seel et al, 2018)."

The report also mentioned the cases in the United States, saying that "Wiser et al (2017) comprehensively review wholesale electricity price data of U.S. independent system operators (ISOs) and find evidence of changed temporal and geographic price patterns in areas with high VRE penetrations. Growth in PV in the California market drove down net-load levels during the mid-day in 2017 relative to 2012 resulting in an associated change in price patterns. In contrast to more even prices over the course of the day in the first half of 2015, the more recent price profile resembled a "duck" in the first half of 2017. … Another example of VRE-induced price changes are low power prices at night in wind-rich areas in Texas that have caused some electricity retailers to offer “free” electricity at night (Seel et al, 2018).”

Furthermore, the report by Lawrence Berkeley National Laboratory found that similar price effects, i.e. the reduction in average annual hourly energy prices, with increasing VRE penetrations across the four regions despite market-specific differences when they compare four ISOs in the United States, NYISO, CAISO, SPP and ERCOT.

Such a decline in wholesale electricity prices makes it difficult for power companies to recover the fixed cost of thermal power plants. When power companies bid into the wholesale electricity market, they usually bid at short-run marginal cost, basically variable cost equivalent amounts, to win an auction in order to keep power plants operating and secure income. However, fixed cost is covered by the incremental difference between market price and short-run marginal cost. If thermal power plants are pushed out of the market and wholesale electricity prices decline because of large integration of VRE, the power companies cannot recoup fixed costs of thermal power plants.

Under such circumstances, thermal power plants’ profitability deteriorates, and it cannot be expected that power companies make new investments to those plants. On the other hand, large deployment of VRE requires backup power supply that can respond to sudden output variability. Thermal power plants can play this role (as can pumped hydro storage, demand response mechanisms or batteries). However, it becomes difficult to build thermal power plants because of their profit deterioration under the current liberalized wholesale electricity market.

In order to secure future electricity supply security, some economies have introduced capacity mechanisms, which ensure the achievement of the desired level of security of supply by remunerating generators for the availability of generation resources. There are several types of capacity mechanisms, and European Parliament gave the following examples; strategic reserve, capacity auction, capacity obligation, reliability options and capacity payments (European Parliament, 2017).

2-3-2 Capacity mechanisms in specific APEC economies

In the APEC region, economies with liberalized power generation sectors include Australia, Canada, Chile, Japan, New Zealand, Russia, Philippines, and 13 states in the United States. However, the wholesale electricity price does not decline if the volume of VRE deployment is limited. For example, Canada, Japan, CAISO and ERCOT in the United States are considering or have introduced capacity mechanisms.

(1) Canada

The government of Alberta, Canada announced that they would transition to a capacity market in November 2016, to be operational in 2021, based on the Alberta Electric System Operator's recommendations (Government of Alberta, 2019). The current energy market in Alberta is an "energy only" market, and the current market relies on the volatility of the market to spend price signals to encourage new investment. The government states that establishing a capacity market aims to protect consumers from volatile price swings, ensure Albertans continue to have a stable, reliable electricity supply, provide the price stability and revenue certainty needed to attract private investment, and support Alberta's transition from coal generation to renewable energy. In a capacity market, private power generators are paid through a mix of competitively auctioned contracts that pay their fixed capital costs and revenue from the spot market.

(2) Japan

Japan has reformed its wholesale electricity market and retail electricity market in a stepwise manner since 1995. After the accident at Fukushima Daiichi Nuclear Power Station in 2011, comprehensive review of Japan's energy policy started, and the Electricity Business Act was amended in 2016 to complete the process of liberalization. In Japan, investment in new power plants was recovered primarily through regulated tariffs under the "costs pass-on to consumers" method, but today under the liberalized market without regulated tariffs, the expected return on investment in power plants is much less and is uncertain. The government thus decided that measures to secure a certain degree of predictability of recovering investment in power supply developments were necessary. One of the government councils recommended that Japan establish a capacity market, the Organization for Cross-regional Coordination of Transmission Operators Japan (OCCTO), to play a certain role as a market manager. Studies on the introduction of a capacity market are being conducted; the specific scheme is yet to be determined.

2-4 Rising cyber threats in energy sector

2-4-1 What is cyber risk?

According to World Energy Council, cyber risk is defined as any risk that emanates from the use of electronic data and its transmission, including technology tools such as internet and telecommunications networks. The risk also includes physical damage that can be caused by cyber-attack, fraud committed by misuse of data, any liability arising from data storage, and the availability, integrity and confidentiality of electronic information – whether it is related to individuals, companies, or governments (WEC, 2016).

Cyber-attack includes physical and non-physical attack. Physical attacks include infection of software and energy operational technology (OT),[3] which leads to breakdown on energy supply disruptions. This can affect assets and information resources, as well as the integrity and availability of OT and data, such as building and physical controls, manufacturing systems, SCADA systems and warehouse systems. Non-physical attacks include data corruption, theft of intellectual property, theft of private/financial data, and extortion (WEC, 2016).

Cyber risks exist in all energy subsectors, especially oil, gas and electricity. However, the impact differs from subsector to subsector. As the oil and gas distribution networks and electric power grid become more tightly integrated owing to increasing use of digital technologies and automated system, such as smart meters and smart sensors, the dependence of homes, communities and industries on these networks grows significantly. The growing dependence on energy networks makes them become an easy and prime target for cyber-attack. It has been shown the energy sector in the United States experienced more cyber threat incidents than any sector from 2013 to 2015, accounting 35% of total cyber incidents (796) reported by critical infrastructure sectors (DOE, 2018).

2-4-2 Background of rising cyber risks

There are several reasons cyber-attack incidents are increasing. The World Energy Council proposed three reasons: (1) the ongoing digitization of energy sector raises its cyber vulnerability; (2) the continuous evolution and sophistication of cyber-attacks presents a highly dynamic threat; and (3) the

[3] In the past, energy control systems operate within the OT environment, and is isolated from information technology (IT) system. But in modern energy systems, OT and IT are connected, allowing cyber-attack to originate from IT to OT.

deepening interconnection between the energy sector and society and the potential cross-over between a cyber-attack and a physical event (WEC, 2016).

Among the reasons proposed, the most influential one is the digitization of the energy sector. Oil and gas companies depend on data networks to manage facilities; electric utilities rely on automated controls to run the grids; transmission companies depend on data networks to manage meters and to analyze their customers' needs. Digitization is also widely used in upstream and downstream, such as production optimization, computer-aided hydraulic fracturing, and supply planning analytics in upstream, as well as supply-demand matching smart grids and trading activities in downstream. The deepening digitization makes the sector more exposed to cyber-attack, and the high volume of data leads to potential data breaches or theft.

The variety of cyber attackers and approaches of attacks are expanding, while the attacks evolve from disruption to destruction. In 2015, a survey showed that more than 75% of energy companies reported an increase in successful cyber-attack, yet only 20% of respondents reported they were confident to detect all cyber-attack, indicating that many attacks are undetected (DOE, 2018).

2-4-3 Cyber threats examples

There have been many cyber-attack incidents in recent years, including:

- 2003, USA, nuclear power plant, malware
  The fastest computer worm in history, "slammer," attacked the private network at an idle nuclear power plant in Ohio, disabling a safety monitoring system for 5 hours. Five other utilities were also affected.

- 2012, Saudi Arabia, oil company, virus
  The Shamoon virus infected 30 000 computers in Saudi Aramco. Some systems were offline for 10 days, and 85% of the company's hardware was destroyed. The entire economy was affected.

- 2013-2015, USA and Canada, power generation, hacking
  The attack happened to a company that operates over 50 power plants in the US and Canada. A contractor stole information and let the hackers steal important power plant designs and system passwords.

- 2014, Germany, steel manufacturing, hacking
  Hackers attacked the business network of a German steel mill, causing massive damage to their industrial equipment. It was the second recorded cyber-attack to affect physical infrastructure.

- 2015, Ukraine, power grid, hacking
  On 23 December 2015, hackers entered the computer and SCADA systems of the Ukrainian electricity distribution company Kyivoblenergo and disconnected seven 110 kV and 23 35 kV substations, causing a 3-hour outage for around 80 000 customers. This attack was the first publicly acknowledged cyber event impacting a country's power supply.

- 2015, Korea, nuclear power plant, hacking
  Hackers attacked Korea Hydro and Nuclear Power Co. in an attempt to malfunction its nuclear reactors. The attacks only succeeded in leaking non-classified documents.

- 2016, Ukraine, power grid, hacking
  Using malware capable of deleting data and causing physical damage to industrial control systems, attackers successfully blacked out a portion of the capital city of Kiev.

2-4-4 Impacts of cyber risks in energy sector

Cyber risk is a common threat for many economic sectors, but attacks here specific impacts and challenges across the extensive energy value chain. The impact can happen from upstream exploration to electricity distribution. Also, within energy sector, the threat can result in physical damage to energy assets or the surrounding environments which leads the energy sector be targeted more.

For instance, in 2014, pipeline transportation encountered the most cyber-attack incidents, followed by support activities for mining, and oil and gas extraction. Furthermore, the rate of cyber-attacks on the energy sector is far higher than other industries (WEC, 2016).

On the other hand, changing energy architecture and management, including the expansion of decentralized renewable generation and smart grids, creates more “exposed and easy” entry points for cyber attackers. The World Energy Council listed six main impacts.

Table 2-2 Impacts of cyber-attack in the energy sector

Impacts	Examples/illustrations
Market disruption	Hacking into company data on reserves could affect derivatives and future markets for oil and gas and may cause industry-wide problems. Accessing company information on coal reserves could include information related to commodity pricing.
Physical infrastructure damage	Attacks on dams and levees could result in massive property damage and compromise water supply. Gaining control of a wind turbine could change the wind vane speed, damaging the equipment.
National security	Attacks on systems of national interest and critical infrastructure could have significant impacts on a country's economy, international competitiveness, public safety, or national defense and security.
Human harm	An attack on nuclear plant equipment could lead to a core meltdown and dispersal of radioactivity. An infiltration of the electric grid that results in blackouts can cut off access to running water, refrigeration or other services dependent on electricity.
Network effects	Breaching a control system at a generating facility could serve as an access point for another facility that has a larger impact, taking large portions of the grid offline. An attack could affect operations of solar panels and cut energy to a given area.
Financial loss, liabilities	Attacks can lead to financial losses including the cost to replace broken equipment and upgrade systems affected by an attack, regulatory fines, loss of business opportunity, and loss of intellectual capital as well as – in a secondary stage – liability of power producers towards manufactures in case of continued business interruption and delays in manufacturing.

Source: WEC (2016).

2-5 Impact of natural disasters on the energy supply-chain

2-5-1 Natural disasters that threaten the lives of human beings

(1) Natural hazards and natural disasters

According to *At Risk: Natural Hazards, People's Vulnerability and Disasters* (Blaikie, Cannon, Davis and Wisner, 2003) "Disasters occur when hazards meet vulnerability." The United Nations Educational, Scientific and Cultural Organization (UNESCO) defines the difference between a disaster and a hazard as follows (UNESCO, 2010):

- Natural hazards: Refers to physical phenomenon that occur in nature, and which are caused by events that hit quickly or slowly on the scale of a solar system, the earth, regions, economies or local districts, as a result of atmospheric, geological or hydrological reasons. Includes earthquakes, volcanic eruptions, landslides, tsunami, floods and droughts.
- Natural disasters: Refers to the result or impact of natural hazards and refers to the collapse of a society's sustainability as well as chaos and confusion in economic and social development.

According to this definition, even when a natural hazard occurs, a natural disaster may not occur if no vulnerabilities exist. In other words, while natural hazards cannot be prevented, natural disasters will not occur if the proper countermeasures are taken. Alternatively, it is possible to minimize the impact of a disaster. In today's environment, energy is integral to all aspects of the economy. Therefore, it is vital to put effort into maintaining the energy supply-chain. In recent years however, natural hazards have tended to become increasingly large-scale, and it is becoming necessary to put in place stronger countermeasures than ever before.

(2) Classifications of natural hazards

- Geological (topographical) disasters
    - Volcanic eruptions: Pyroclastic flows, lava flows, volcanic ash, shutting out of sunlight, etc.
    - Earthquake: Earthquake disaster, landslide disaster, ground subsidence, etc.
- Weather disasters
    - Wind and flood damage caused by hurricanes, typhoons, etc.
    - Other wind and flood damage: Inundation, decrease in daylight hours due to long periods of rain, tornado, gusts of wind, salt damage, etc.
    - Snow damage: Heavy snowfall, snowstorms, etc.
    - Rainfall, temperature: Droughts, forest fires caused by high temperatures, dryness, etc.
- Complex disasters
    - Tsunami brought about by an earthquake
    - Landslip or landslide brought about by torrential rain or long periods of rain, etc.
    - Changes in plant or animal behavior brought about by abnormal weather conditions (grasshoppers, locusts, stomolophus, etc.)

- Astronomical phenomenon
  - Fall of small celestial bodies
  - Communication disturbances caused by solar flares, etc.

(3) Phenomenon that occur during a disaster

When a natural disaster occurs, various supply infrastructure becomes damaged, which in turn cuts off lifelines and causes breakdowns.

- Interruption or restrictions to power, gas, water, or sewerage supply
- Interruption or restrictions to telephone and communication networks or broadcasting services
- Interruption or restrictions to public transportation services and traffic regulations due to the cutting off of roads
- Fuel shortage caused by traffic problems
- Shortage of food, water and daily necessities due to interruption or restrictions to logistic services
- Interruption or restrictions to medical services and public utilities
- Interruption or restrictions to corporate activities due to the cutting off of the supply-chains

2-5-2 Security of energy supply and natural disasters

Some recent examples of the impact of natural disasters on security of energy supply, include:

(1) Hurricanes in the US

The ultra-large-scale hurricane Katrina, which brought about the most severe damage ever recorded in the history in the US, struck the southern states of Louisiana and Mississippi at the end of August 2005. U.S. oil fields in the Gulf of Mexico region were forced to stop operations and a number of oil refineries were damaged by the hurricane. Restoration of the oil refineries took several months. Crude oil prices, which were approximately $60/bbl at the end of July, exceeded $70/bbl at one point immediately after the hurricane struck. In the state of Georgia, which is connected to Louisiana by crude oil pipelines, gasoline prices increased threefold almost instantaneously to $1.6/gallon because of concerns over the shortage of crude oil. In response to the rise in domestic gasoline prices and other conditions, the US Department of Energy decided to loan crude oil from the Strategic Petroleum Reserve (SPR) to oil companies.

Hurricane Harvey, which struck the states of Texas and Louisiana in August 2017, hit denselypopulated areas and led to 68 casualties and damage worth approximately US$125 billion. According to reports from the US Energy Information Administration (EIA), as Hurricane Harvey halted the operation of oil refineries and the loading and unloading of crude oil tankers, gasoline supply was delayed. This interruption to supply led to a 10% increase in the average gasoline retail price in the US to $2.68/gallon one week after Hurricane Harvey.

Hurricane Irma struck the states of Florida, Georgia and South Carolina at the beginning of September of the same year and had a significant impact on the electricity sector. It resulted in power outage for 16 million people and damage of approximately US$49 billion. Due to rainstorms, 15 million people lost their power supply in the state of Florida alone, while about 800 000 people in the state of Georgia and 200,000 people in the state of South Caroline lost their power supply.

(2) Forest fires in the US

The state of California becomes dry from spring to autumn, and experiences strong winds and rising temperatures. Hence, it is a region where fires occur easily. During this period, strong and dry winds known as the Santa Ana winds and “devil winds” (winds that flow from the high pressure on the opposite side of Mount Diablo inland toward the sea) flow inwards, bringing about greater damage and stronger fires. For this reason, about 8 000 forest fires occur every year, and the average area of burnt land in the past 15 years has reached approximately 250 000 ha. Due to such forest fires, in 2013, power companies in San Diego put in place measures to suspend power supply in areas that face extremely high risks of fire.

(3) Coal during torrential rains and flood in Australia

The torrential rains that fell in Queensland, Australia, from December 2010 to January 2011 saw record rainfall of more than 600 mm over a 72-hour period. Australia exports much coal, with annual export value reaching US$55 billion. Much of the coal production in Queensland is carried out in open-pit coal mines. As these mines were inundated by torrential rains, production was halted and the rail network stopped functioning. As a result, there was a sharp decline in coal exports. Hence, when the port of Dalrymple, which is the primary port for the shipment of coal, resumed operations, about 50 vessels were unable to enter the port and had to wait along the coast.

(4) Energy supply-chain loss due to earthquake and tsunami in Japan

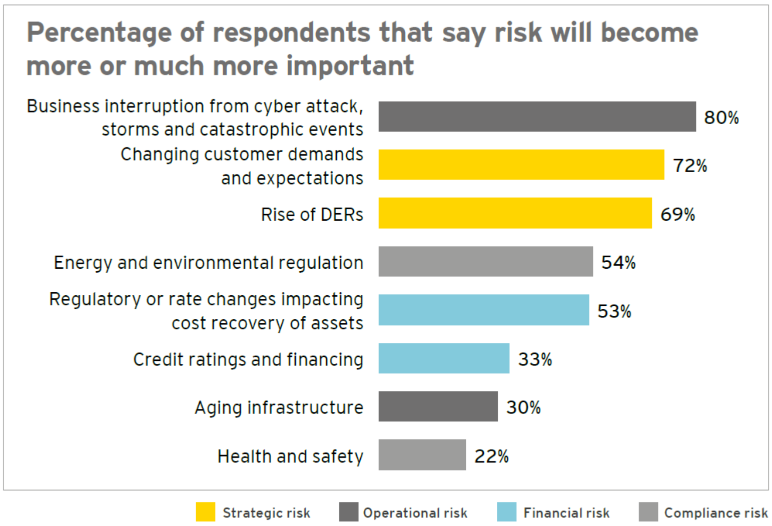
On 11 March 2011, the earthquake and subsequent tsunami that occurred off the Pacific coast of Japan's Tohoku region cut off all energy supply-chains along the Pacific coast in the Tohoku region. Receiving crude oil and LNG and production of petroleum products, as well as power generation, came to a complete stop. As infrastructure for distribution also suffered severe damage, it was not possible to immediately re-establish transportation of petroleum products and natural gas, and the recovery of power transmission services. Furthermore, the accident at Fukushima Daiichi Nuclear Power Station made it necessary not only for Japan, but for economies around the world, to review their energy policies.

2-5-3 Recognition of risks among power and public utility operators

According to a recent survey conducted by Ernst & Young of 50 senior power and utility officers about their sector faces, business disruption caused by catastrophic events including natural disasters, was selected as the greatest risk in management.

While preparations for energy supply problems are progressing, the recognition that natural disasters pose the greatest risk to the energy business remains unchanged. This is because natural hazards occur unexpectedly and tend to have a significant impact on the lives of citizens after they cause damage. Furthermore, as damage is becoming increasingly severe due to the progression of climate change, and natural disasters such as earthquakes have occurred frequently over the past few years, there is growing concern about the potential risk of interruption to energy supply as a result of natural disasters.

Figure 2-6 Survey outcome on the risk in power and utilities



Source: EY (2017).

2-6 Uncertainty of energy policies

Energy supply chains take a long time to develop and consist of a significant amount of expensive investment. Therefore, economies generally formulate energy policies as national guidelines. Energy security, economic efficiency and environment are the basic pillars that many governments establish when formulating energy policies. These are known collectively in Japan as "3E." In recent years, "safety" has been added to the "3E" to make "3E + S."

While energy policies should be consistent and have continuity, they may break down in various ways. An energy policy that lacks continuity brings about confusion in energy supply, which can lead to wasteful investment.

2-6-1 Review of energy policies through change in governing party

A change in the governing party can bring about sudden changes in the direction of policies.

(1) Australia's energy policy

In Australia, as a result of the Federal Elections held in November 2007, the coalition government made up of the Liberal Party and the National Party, which had been the governing party for 11.5 years, was replaced by the Australian Labor Party. Several issues related to energy policy remained consistent even after this change in the governing party, but the new government adopted an opposing position around other issues, particularly relating to the environment.

For example, the coalition government did not ratify the Kyoto Protocol and did not set out clear numerical targets. The Labor Party, however, immediately ratified the Kyoto Protocol, set a numerical target for reduction of CO_2 emissions (60% of 2000 levels by 2050), and established a policy promoting the adoption of renewable energy (20% by 2020). The Labor party also established a carbon price mechanism as a means of reducing economy-wide CO_2 emissions in 2012.

The Labor Party was once again replaced by the Liberal Party as the governing party five years and nine months later in September 2013, and the direction of the energy policy underwent changes such abolishing the carbon price mechanism and advocating new coal-fired power generation.

(2) The US' energy policy

US President Trump, who assumed office in January 2017, signed "the Presidential Executive Order on Promoting Energy Independence and Economic Growth" on 28 March. This Presidential Executive Order required government agencies to review the series of environment policies formulated by the Obama Administration, including the Clean Power Plan with a view to abolishing them. The Order lead to the:

- Suspension, revision, and abolition of the Clean Power Plan
- Suspension, revision, and abolition of CO_2 emission regulations for newly constructed coal-fired power plants
- Review of methane emission regulations for the mining of oil and natural gas
- Invalidation and review of the results of the estimated social cost of climate change
- Rescission of the suspension of new development of coal mines on Federal-owned land
- Review of legal regulations that obstruct energy production and development etc.

In response to this Presidential Executive Order, some state governments enacted their own regulations and appealed to the courts, highlighting the fractured relationship between the federal and some state governments. The difference in federal and state based policies makes it difficult for corporations to make long-term investment decisions and can lead to increased costs in project development (which are passed on to consumers).

Furthermore, on 29 June 2017, President Trump stated in his remarks delivered at the US Department of Energy that the US “will seek not only American energy independence” “but American energy dominance,” that the US is “going to be an exporter (of energy)” and “provide true energy security.”

To that end, he set out six initiatives:

- Revive and expand nuclear energy, which is renewable and has a small impact on the environment
- Eliminate the barriers to the financing of high-efficiency coal power plants overseas by Department of the Treasury
- Approve the construction of a new oil pipeline to Mexico in order to increase energy exports
- Agreement with Sempra Energy to commence negotiations to promote the export of natural gas from the US to Korea
- Approve the applications to export natural gas from the Lake Charles LNG Terminal by Department of Energy
- Allow for the development of 94% of offshore land, which was not permitted under the previous government, and create a lease program for the new development oil and natural gas offshore

Some of the policy changes made through these initiatives that call for judicial ruling on their legality, and corporations face a difficult decision on whether to move forward with projects.

2-6-2 Changes in policy lagging behind changes in circumstances

There are also examples where energy policies are reviewed as a result of changes to the energy environment after the announcement of the energy policy.

(1) Germany’s nuclear power policy

In Germany, based on an amendment to the nuclear power law made by Prime Minister Schröder in 2002, the decision was made to achieve complete denuclearization by 2022. In December 2010 under Prime Minister Merkel, which succeeded Prime Minister Schröder, the schedule for denuclearization was postponed. It was impossible to foresee the amount of power needed to cover denuclearization. So nuclear power generation was positioned as a transitionary measure until renewable energy sources were developed. The nuclear power law was amended to authorize the extension of the transitionary period for nuclear power to a maximum of 14 years.

However, in response to the nuclear accident that occurred in Japan in March 2011, Prime Minister Merkel triggered the nuclear power moratorium immediately, and seven nuclear reactors that commenced operations before 1980 were immediately suspended. Furthermore, all nuclear power stations in Germany were subjected to stress tests by the Reactor Safety Commission (RSK) for their tolerance to earthquakes, floods, loss of external power, airplane crashes, and other events. As a result, RSK drew the conclusion that with the exclusion of airplane crashes, Germany's nuclear reactors have a high degree of tolerance, so there is no need to suspend the nuclear reactors immediately.

However, the Merkel administration acknowledged the growing public concern toward nuclear power in Germany, and accepted the recommendations of the ethics committee that was convened after the accident. In June the same year, the cabinet decided to abolish all nuclear power by 31 December 2022.

Germany is putting effort into the mass introduction of renewable energy and the construction of thermal power plants as an alternative power source for nuclear power. However, new challenges have arisen, including delays in construction and the emergence of power plants with insufficient budget to adopt renewable energy.

2-6-3 Opposing views among the citizens toward ongoing projects

There are also cases where the government is confronted by opposing views among the citizens toward projects that are already ongoing.

(1) Chinese Taipei's nuclear policy

In 2011, the nuclear disaster at Fukushima led to public fears regarding nuclear safety in Chinese Taipei. The government at the time released an energy policy aimed at steadily reducing nuclear dependence by lowering electricity consumption and peak loads and by promoting alternative energy sources to ensure a stable power supply. In 2016, the new elected President Tsai Ing-wen reassured the policy to abolish nuclear power generation by 2025, and to increase the percentage of power generated through renewable energy to 20% (coal 30% and gas 50%). To achieve the 20% share renewable generated power, the government announced new targets for both solar PV and wind power installation capacity, which is to achieve 20 GW for solar PV and 5.5 GW for wind power by 2025.

However, the economy faced tight power supply in the summer of 2017, leading to large-scale power outages across the island. As a result, the opposition party and some financial circles voiced their criticism of the denuclearization policy. In response, a referendum was held in November 2018 to ask voters whether they agree that 'all nuclear-based power-generating facilities shall completely cease operations by 2025'. The referendum found overwhelmingly that voters were against the plan to remove nuclear from the power mix target. About 5.8 million votes were cast in favor of removing the clause, while 4.01 million votes were cast in opposition of the removal.

In respond to the referendum, the government announced a revised energy policy in January 2019, stating that the government will proceed with its plan to phase out nuclear energy because the deadline of nuclear power plants license renewals has passed, along with the opposition for the extended operation from local governments, despite the referendum result against the policy. As the presidential election will be held in January 2020, the nuclear phasing out policy might be changed again if the opposite party win the election, which creates significant uncertainty for Chinese Taipei's energy policy.

(2) Korea's nuclear power policy

The *7th Basic Plan for Long-term Electricity Supply and Demand 2015 - 2029* published by the Ministry of Trade, Industry and Energy (MOTIE) in July 2015 set out the goal to build 47 new power plants by 2029 (13 nuclear power, 20 coal-fired plants, 14 natural gas-fired) to generate a total of about 46.5 GW of power output.

President Moon Jae-in, who assumed office in May 2017, declared a major shift in the economy's energy policy during the ceremony for the declaration of the permanent decommissioning of the first reactor at Kori Nuclear Power Plant in June 2017. Although he did not present a specific timing for the realization of this in his declaration, he stated that a denuclearization roadmap, alongside with a roadmap for moving away from coal power, will be drawn up as soon as possible with the aim of gradually reducing the number of nuclear power plants, through means such as withdrawing plans for the construction of new nuclear power plants.

In response to the denuclearization declaration in June 2017, the construction of reactors 5 and 6 of the Shin-Kori Nuclear Power Plant was temporarily halted. The Public Deliberation Committee, which has been conducting surveys on citizens' opinions, reported in October 2018 that 59.5% of the people were in favor of resuming construction, and submitted a recommendation for resuming construction to the government. In the explanation provided by the Committee, 1.6 trillion won had already been spent on the construction of reactors 5 and 6, and 30% of the construction had already been completed. For this reason, there was strong opposition toward suspending construction. Secondly, there were no clear proposals for a substitute power source that could offer a stable supply of power in place of nuclear power. These two points contributed to the criticism of the denuclearization policy advocated by the Moon administration.

President Moon Jae-in presented a policy that accepted the result and recommendation. However, since as many as 53.2% of the people were of the view that dependence on nuclear power, which makes up 30% of total power generated in the economy, should be reduced, the Moon administration decided to maintain the denuclearization policy itself.

(3) Indonesia's construction of coal-fired power plants

Indonesia announced a plan to increase power generation capacity by 35 GW from 2015 to 2019, based on its experience of 7.1% growth in power demand on average since the 2000s. The plan also took into consideration the shutdown of aging power plants, and the breakdown of the increase in capacity was 52.3% coal, 38.6% natural gas, 6.7% hydroelectricity, 1.6% geothermal power, 0.2% oil, and 0.6% others. For this reason, there was a jumble of scattered construction projects for coal-fired power plants.

The rapid increase in the number of coal-fired power plants over a short period of time developed into a movement among local citizens opposed to their construction. Anxiety and fear about the destruction of villagers' lives and the environment led to demonstrations almost every day, while violent incidents also took place between residents seeking the suspension of construction works and the construction companies. Environmental organizations raised not only environmental issues, but also pointed to the naivety of the government's demand forecasts, promotion of the use of idle facilities, and weakness of the financial constitution of PLN, the state-owned power company. Furthermore, in a lawsuit filed by the residents seeking the withdrawal of environment permits, the local residents won the lawsuits against projects in Cirebon and Indramayu, putting the government in an increasingly difficult position.

Under such conditions, the PLN announced in March 2018 an electricity procurement business plan (RUPTL) spanning 2018 to 2027. Alongside the downward correction of power demand in 2017, the RUPTL set out the average annual growth rate for power demand as 8.3% for 2017. This was revised downward to 6.86% for 2018.

Table 2-3 Construction plans for coal-fired power plants in Indonesia

Power plant	Region	Capacity	Project costs, scheduled start of operation, etc.
Jawa 5	Banten	2 X 1 000MW	Bidding cancelled in September 2016
Java 7	Banten	2 X 1 000MW	US$2 billion, 2020
Java 12	Banten	2 X 1 000MW	
Lontar	Banten	1 X 315MW	US$450 million, 2019
Java 6	West Java	2 X 1 000MW	
Indramayu	West Java	2 X 1 000MW	US$200 million (reactor 1 only), 2021
Java 8	Central Java	1 X 1 000MW	
Java 13	Central Java	2 X 1 000MW	
Central Java	Central Java	2 X 1 000MW	US$4 billion
IPP Cirebon	Central Java	1 X 1 000MW	US$2.18 billion, 2022
Tanjung Jati	Central Java	2 X 1 000MW	US$4.2 billion, 2021
Keban Agung	Sumatra	2 X 135MW	
Kalselteng-2	Kalimantan	2 X 100MW	US$400 million, 2020
Sulsel Barru 2	Sulawasi	1 X 100MW	2021

Sources: Itochu (2017), JOGMEC (2018), KEPCO (2017), MHPS (2017) and Toshiba (2018).

With regard to power generation capacity accompanying the review of power demand, the RUPTL for 2018 set the additional power generation capacity for the next 10 years as 56 GW, marking a 28% decline from the additional capacity of 78 GW set out the previous year. The breakdown for capacity reduction by the type of power source is as follows: coal-fired power 5 000 MW, gas-fired power and combined cycle 10 000 MW, and renewable energy 6 600 MW. As for the initial 35 GW power development plan, the period for commencing the operation of 15 GW of power plants was extended from the initial schedule of 2019 to 2024-25.

(4) Pipeline construction in the US

On 24 January 2017, the Trump administration issued two Presidential Executive Orders pushing for the construction of the Dakota Access Pipeline (DAPL) and the Keystone XL Pipeline. The Obama administration had sought to suspend these in December of the previous year on grounds of protecting the environment.

The Dakota Access Pipeline is a crude oil pipeline extending for about 1,886km from the states of North Dakota to Illinois. The project is worth US $3.8 billion and is owned by Energy Transfer Partners. The construction route passes close to the land of indigenous people in North Dakota (Standing Rock Sioux tribe), and cuts across their water source, the Missouri River. The tribe had been engaged in an opposition campaign since 2016 on grounds that the project would pollute their drinking water as well as the precious assets passed down from their ancestors. For this reason, President Obama decided in December 2016 to temporarily halt the construction. However, the signing of the order by President Trump led to the resumption of construction works, and operation of the pipeline started on 1 June 2017. However, on 14 June, the US District Court acknowledged some of the assertions by the opposition groups, including the Sioux tribe, and judged that the Trump administration's risk assessment was inadequate, but did not shut down the pipeline.

On the other hand, the Keystone XL Pipeline, which plans to connect existing pipelines from Alberta in Canada to the states of Montana, South Dakota and Nebraska in the US, and is owned by Canadian company Trans Canada. In an assessment in 2011, the Department of State requested a change in the route. While this was authorized once in 2013, the authorization was withdrawn in 2014 based on the intentions of the White House. In November 2015, the Obama administration withdrew permission for the construction.

In January 2017, the Trump Administration changed direction. The government approved the construction plans in March 2017, and approval was granted in November 2017 for the construction route by three US states that the pipeline would pass through. In response, environmental NGOs and other parties appealed to the US district court of Montana to carry out an environmental assessment on the entire construction route. In August 2018, the district court issued an order to Trans Canada for an environmental assessment of the entire route. Carrying out an environmental assessment on the entire route would lead to significant delays in the progress of the project.

Chapter 3 Risk Analysis

Chapter 1 examined representative risks relating to traditional forms of energy such as oil and natural gas. Chapter 2 included an examination of risks related to electrical power and various issues in society and the natural world.

3-1 The characteristics of risks related to oil, natural gas/LNG and electricity

Chapter 3 contains an analysis of the characteristics of supply disruptions and differences in risks for traditional forms of energy and for emerging forms of energy. The characteristics of supply disruptions will be shown using the examples of oil, natural gas/LNG and electrical power.

Table 3-1 The characteristics of supply disruption risks related to oil, gas/LNG and electricity

	Oil	**Gas/LNG**	**Electricity**
3-1-1 Substitution of supply	Middle	**<u>Low</u>**	High
3-1-2 Substitution of end use demand	Middle	High	**<u>Low</u>**
3-1-3 Geographical impact	**<u>Wide</u>**	Middle	Narrow
3-1-4 Risk exposure level	Decrease	Middle	**<u>Increase</u>**

Sources: APERC (2019) and IEEJ analysis.
Notes: Assessment is relative evaluation rather than absolute evaluation among the energies. Bold and underlining implies a result that is connected to high risks.

3-1-1 Substitutability of supplies

Substitutability of supplies differs depending on the energy source. For oil and natural gas/LNG the focus is on whether transport methods have a high or low level of substitutability. For electrical power the focus is on the substitutability of sources of power generation.

Transport methods for oil supplies are primarily pipelines and tankers, with the latter accounting for more than 80% of the 67.6 million b/d of oil traded throughout the world in 2017 (BP, 2018). Since the majority of oil is transported via tankers, it is easy for consumers to choose suppliers. Therefore, if a loading port announces a supply disruption for reasons of force majeure, the effects will be minimal if the supply can be switched on other loading port.

Natural gas may be transported as a liquid or gas, with pipelines (65% of the total) accounting for the majority and ship-based transport of LNG (liquid natural gas) accounting for the remainder (35%).

Transport via pipelines means that the supplier and consumer are directly linked, making it difficult to substitute unless it is coming from multiple suppliers. LNG buyers have more flexibility to change suppliers at any time because it is transported via LNG vessels, resulting in minimal impact in supply disruption.

The substitutability of natural gas/LNG, which has a higher ratio of import via pipelines, is lower than that of oil (i.e. it has a higher risk of supplies being disrupted). Although liquefaction plants for LNG are gradually increasing, there are still far fewer than loading ports for oil. This means that oil has more flexibility in regard to suppliers. Access via boat is possible for APEC members that have coastlines. This means that it is important to secure and maintain receiving terminals/ports for import purposes.

Electrical power can be supplied via transmission lines. Typically, these lines are connected to several generators and power plants. Sources of electricity can also include oil, gas, coal, nuclear, hydro, wind and thermal. These sources can be switched to meet demand.

There should be few problems maintaining supply if a disruption is small-scale. However, risks do exist. Several loading ports/liquefaction plants may announce force majeure simultaneously, or some issues may occur in international trading routes such as the Strait of Hormuz. Wide-ranging problems related to sources of electrical production and transmission grids may also reduce substitutability.

3-1-2 Substitutability of Demand

A switch in the source of energy used by consumers is one countermeasure for supply disruptions. For instance, much of the demand for natural gas for electricity production, boilers, heating and food preparation can be substituted with coal, oil, or electrical power. From a historical perspective natural gas has often substituted for coal and oil.

Crude oil is the source of many petroleum products such as LPG, gasoline, jet fuel, kerosene, diesel and heavy oil. Some of these can be substituted for other energy sources according to their use. For example, the kerosene, diesel and heavy oil used to produce electricity for boilers in plants can be substituted with natural gas. Plugin hybrid vehicles can also substitute electrical power for gasoline. At present the substitutability of fuel for vehicles is low. Development of vehicles that can use 100% biofuels, along with aviation biofuels, is proceeding, but there are limits to this kind of substitution.

Devices that require electrical power (motors, lighting, electrical appliances) are unable to substitute this with other sources. Therefore, there are large risks related to electricity supply disruption.

3-1-3 Geographical Spread of Effects

Any number of problems could occur in oil producing economies and along international transport routes to disrupt oil supplies. If this occurs, the effects may be global. The futures market quickly reflects supply disruptions and may create a larger worldwide effect in a shorter period of time then physical disruptions. The financial commodification of oil means that it is now affected by trends in speculative money and financial commodities.

Physical obstructions to natural gas supplies may also affect worldwide markets. However, the supply of natural gas relies more on pipelines. Shipping (liquefaction plants) and receiving (gasification terminals) points for LNG are also limited by contracts, so the geographical spread of effects is more fragmented than that of oil.

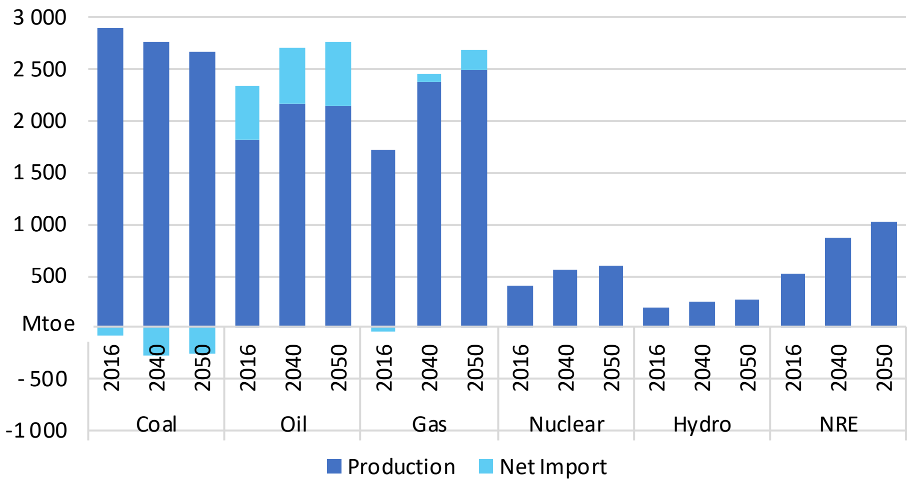
Electrical power on the other hand is supplied primarily through closed systems for each economy or region. Therefore, in many situations effects may be limited to specific economies and areas. In advanced economies where energy transmission systems have been automated, switching between non-functioning circuits is both automatic and immediate, further limiting the scope of effects.

3-1-4 Risk implications

In order to consume energy in the face of these risks, each economy of APEC must recognize the magnitude of risks arising from the amount used and dependency on each energy type. These risks vary from economy to economy. Related to this, based on the "APEC Energy Demand and Supply Outlook 7th Edition" (published in May 2019) the APEC region's energy supply situation and resilience to obstacles in the power generation sector is examined in the following section. The results for each economy are listed in an appendix at the end of this document.

In the projection period, APEC-wide coal self-sufficiency continues, but oil and natural gas are not self-sufficient. An annual breakdown reveals that exports of coal and imports of oil are increasing and that although natural gas was primarily being exported as of 2016, this will change in the future.

Figure 3-1 APEC's overall energy supply, 2016-2050



Source: APERC (2019).

Figure 3.1 shows the amount of primary energy that APEC requires. In order to maintain this supply, a variety of risks need to be mitigated.

The above net import amounts (in light blue) show a high dependence on oil-based energy. This suggests that continued supply assurance for traditional forms of energy is required in APEC.

In recent years, worldwide demand for electrical power has been increasing. A risk analysis for electrical power supplies follows. In Figure 3.2, the vertical axis is the substitutability of electrical generation; the horizontal axis is the self-sufficiency index for energy used to generate electricity.

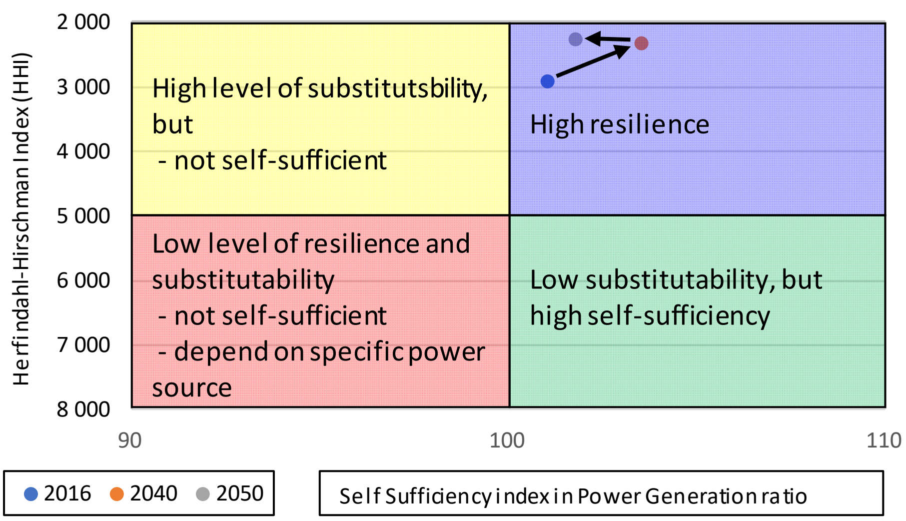
[Vertical Axis]

The Herfindahl-Hirschman Index (HHI) was used to show the substitutability of electrical generation. The HHI is an indicator of the ratio of concentration of companies, and if there are many energy sources that can be selected for electrical generation, this should imply that there's a high level of substitutability. We therefore calculated the ratio of electricity generation for each energy source, squared the ratio and obtained the total sum. As a result, HHI is displayed as a number between 0 to 10 000. The higher figure indicates a monopoly (no substitutability, so low resistance to power supply interruption) and numbers closer to 0 indicate a high level of competition (high level of substitutability, so high resistance to power supply interruption).

[Horizontal Axis]

For the self-sufficiency index for energy used to generate electricity, the input ratio for each energy source is multiplied by the self-sufficiency ratio for each energy source to obtain the total sum. If only self-sufficient energy sources are used, the self-sufficiency index will exceed 100. The more non-self-sufficient energy sources are used, the closer the index will be to 0.

Figure 3-2 APEC's overall resilience for power supply disruption



Source: APERC (2019).

[Estimates of Risks]

To use HHI for analyzing elasticity, two varieties of electricity sources that have a 50% share will be considered as a point of divergence. In this situation if source A becomes obstructed, source B can compensate for a constant amount of electricity. Using the HHI, this would be 5000. As a criterion for the self-sufficiency index, a state where the sum of the input ratio multiplied by the self-sufficiency ratio per source of energy used to generate electricity is 100 (the total energy self-sufficiency rate for electrical power is regarded as 100%) will be considered as a point of divergence. Less than 100 indicates a state where energy for power generation must be imported.

As a result, regardless of the time, the HHI for APEC as a whole is less than 3000 (resistance to power supply interruption is relatively high) and the self-sufficiency index is more than 100 (100% self-sufficient). This indicates that as a collective entity, the promotion of energy cooperation by APEC would be very meaningful.

3-2 Responses to Risks

In the previous section the characteristics of risks and their differences were discussed, this section analyzes possible responses. Based upon these characteristics, the commonalities for responding to risks include diversification, decentralization and redundancy. In the case of oil and LNG, increased diversification of economies that these are being imported from, along with diversification of transport routes, would be effective for increasing decentralization. Even in domestic supply networks, geographically decentralizing oil refineries and storage facilities and increasing redundancy in these networks would lead to increased resistance to disruptions. In the same manner, diversification of fuel used for producing electricity, geographic decentralization of power plants and redundancy in power transmission will all reduce the risks associated with disruption to electrical power and provide an increased ability to respond to any disruptions.

However, diversification and redundancy of infrastructure will also lead to cost increases. So a fine balance needs to be struck between strengthening security and economic rationality. A deregulated market means that corporations attempt to maximize profits, but this behavior can be connected to risks in supply stability. This corresponds with high reliance on specific oil producing economies for oil and natural gas, and high reliance on specific energy sources for electrical power etc. Regulations could be used to maintain diversity in these situations, but it may disrupt market forces. Here, the same dilemma arises regarding strengthening security and economic rationality.

One difference is that oil can be stockpiled for emergency purposes and a collaborative framework has been created among IEA member nations. Oil supplies can also be ensured by supporting stability in the economies of oil producing nations. By comparison there is no system to stockpile electrical power, but there are backup methods of maintaining electrical generating capacity in the event of disruptions to supplies. However, there are not enough systematic safeguards in place for ensuring backup electrical generating capacity. Systems, therefore, need to be created to acquire this backup capacity based around a suitable level of compensation.

Table 3-2 Responses to risks related to oil, gas/LNG and electricity

	Oil	**Gas/LNG**	**Electricity**
Effective policy to address risks	Identified	Identified	**Tested**
Contingency plan/mechanism	Exists	**Under development**	**Under development**

Source: IEEJ analysis

Note: Assessment is relative evaluation rather than absolute evaluation among the energies.

3-2-1 Oil

The risks associated with disruptions to oil supplies have been recognized for many years. For this reason, many economies have prepared effective political measures for reducing risks and there are countermeasures in place for the risks associated with supply being interrupted. These include:

(1)Efficient use of energy

- Improvements in performance of equipment/devices to improve the basic unit of energy consumption, and
- Suppression of consumption, reduction or abolishment of subsidies

(2) Creating a suitable energy mix

- Distribution of an energy consumption composition taking 3E+S (Energy Security, Environmental Protection and Economic Efficiency + Safety) into consideration

(3) Acquisition of direct primary energy sources

- Diversification of suppliers, and
- Acquisition of distribution channels (pipelines and surface transport routes)

Plans for consumer economy groups to collectively avoid risks to supply interruptions and a place where consumer economy groups and oil producing economy groups can deepen mutual understanding have been prepared. These include:

(1) Strategic stockpiling of oil by the IEA

- Possession of strategic oil stockpiles and implementing emergency responses (reducing stockpiled amounts with the inclusion of a time limit etc.)

(2) Continuous dialog between oil producers and consumers

- Both groups are aiming for stability in supply and demand. In response, the International Energy Forum (IEF) was established in 1991 to increase transparency in the marketplace.

3-2-2 Gas/LNG

Many aspects of natural gas and LNG are similar to oil, with the following three countermeasures all being performed:

- Efficient use of energy
- Creating a suitable energy mix, and
- Acquisition of direct primary energy sources.

However, in comparison to oil, security measures through stockpiling and international collaboration could still be improved.

(1) Underground storage of natural gas

Underground storage of natural gas is a technology of temporarily reinjecting and storing natural gas into the underground geological structures (reservoirs layer) and taking it out again when necessary. This is done with the aim of reducing the effects of seasonal changes in demand between winter and summer, as well as those on shorter time scales such as changes in demand throughout a day. By balancing yearly average load factors, improvements in the economic efficiency of natural gas projects can be created. In addition, underground storage acts as a backup in case of a pipeline accident. Primarily, reservoirs in depleted oil and gas fields are used for this purpose. In addition, the use of aquifers, salt caverns and fields that are still being operated are being considered and partially implemented. Underground storage is being performed in more than 600 locations throughout the OECD economies.

(2) Strategic stockpiling of LNG

Even the EU, which has pipeline imports from multiple economies and multiple routes, also imports LNG in order to diversify procurement sources. This may lead to concerns about stockpiling but storing natural gas in its original form requires much more land and larger spaces than crude oil. Storing natural gas underground is one solution, but it requires areas that meet the correct conditions. For this reason, ultra-cold storage of LNG should also being considered. However, the costs associated with creating these facilities and keeping the gas cold are significant, so this approach is generally not affordable.

(3) Mechanisms that allow for multiple economy responses

For natural gas, each economy is gradually progressing with countermeasures independently. However, there are no multi-economy frameworks to respond to natural gas with a stockpiling obligation similar to oil, joint release in emergencies or assistance from economies with available supply capacity.

If demand for natural gas increases in the future, so too will the necessity of a multiple economy mechanism that will provide extra security for supplies. In light of this, an example of an effort between multiple European economies to increase natural gas security will be introduced.

The natural gas conflict that occurred between Russia and Ukraine in 2009 led to the possibility that natural gas supplies from Russia that passed through the Ukraine would be affected. For this reason, the EU amended its natural gas security regulations (No.994/2010 of the European Parliament and of the Council of 20 October 2010 concerning measures to safeguard security of gas supply and repealing Council Directive 2004/67/EC).

The regulation was as follows:

・ Defined responsibilities and collaborative responses at an economy and EU level,

・ The roles of the Agency for the Cooperation of Energy Regulators (ACER) and independent per-economy regulatory agencies in relation to providing a stable supply of natural gas.

Specifically, it made the following three requests to member nations.

- At the point during a peak cold season that only occurs once in 20 years, secure a volume of natural gas that meets N-1 standards

  The N-1 standard states that if a disruption to supply occurs in the primary gas supply infrastructure, the total supply capacity of the remaining infrastructure must be able to exceed peak demand during a peak cold season that only occurs once in 20 years. The supply infrastructure used in the calculations includes the gas production capacity of the economy itself, as well as import and storage capabilities.

- Making reverse flow obligatory at interconnection points

  Reverse flow is the ability for pipelines that are typically used to transport gas from producing economies to consuming economies to send gas in reverse in response to temporary suspensions in supply (reverse compressors are installed).

- A re-organization of the concept behind requiring continuous supply even during absolute peak times for “protected customers (degree of priority)”

Tensions between Russia and Ukraine came to a head following pro-Russian and anti-government demonstrations across eastern and southern Ukraine and the annexation of Crimea in early 2014. This resulted in Russia announcing in May of the same year that unless Ukraine paid the natural gas fees it owed, supplies of Russian-produced natural gas being transported through the Ukraine would be suspended. Almost half of the natural gas being imported to the EU from Russia was being transported via the Ukraine. The EU Commission of European Communities immediately proposed performing a stress test to see how much of an effect a reduction in natural gas supplies would have if things worsened. As well as performing a stress test, the commission also proposed creating a framework to increase natural gas stores in the event of an emergency and introducing methods of suppressing energy consumption. It also suggested cooperating with the IEA to create a shared storage system.

These efforts by the EU can act as a reference for strengthening the security of natural gas supplies in the APEC region.

- Perform stress tests to assess any vulnerabilities in the natural gas supplies of individual economies and regions.

- Create a framework to include the supply capacity of other APEC economies as part of emergency supply capacity.

3-2-3 Electricity

A disruption to electrical power implies a power cut. The causes of power cuts include a lack of fuel to generate power, or generating capacity not meeting demand. There can also be problems with transmission lines caused by natural disasters. In recent years issues have arisen relating to deregulation of electrical power and the promotion of renewable energy as a way to prevent climate change. These include possible damage from natural disasters and new risks caused by cyber attacks.

Table 3-3 Primary disruptions to supply and responses

Sector	Factor of power failure	Measures
Power generation	Lack of power generation facilities	Construction of power plant
	Primary energy supply shortage	Procurement, substitution
Transmission and Distribution	System malfunction	Power accommodation
All	Natural disasters	Localization, fastest restoration

Source: IEEJ analysis.

(1) Traditional responses to supply disruptions

Decentralization of power generation sources, securing backup generation capacity, and increased interconnection between power systems have been made in order to maintain power generation at amounts that meet demand even if there is a disruption to primary sources required for power generation. This response is similar to that which would be performed for disruptions to oil and gas supplies. The causes of the disruption are clear and required countermeasures have been implemented.

- Securing exhaustible energy procurement: Among primary energy sources, exhaustible energy includes fossil fuels such as oil, natural gas and coal, ie. resources that will eventually be depleted if they are used. This is the same as the response for dealing with oil and natural gas procurement.

- Risk reduction through decentralization of fuel used to generate electricity: There are unique risks related to fuel used to generate electricity and there are no fuels in existence without these risks. Therefore, diversification of fuels means that even if these risks arise, the extent of damage will be limited.

- Securing backup sources of electrical power generation: Current technologies mean that electrical power cannot be stored for long periods of time at low costs. This means that backup sources of electrical power generation need to be secured in preparation for unexpected failures in electricity generating equipment that are not detected by inspections and are otherwise unplanned.

- Securing flexibility via interconnection: Interconnecting power between adjacent systems allows for benefits during emergencies through mutual accommodation. It also provides benefits during non-emergencies by reducing standby power generating capacity and allowing for maximum use of supplies of low-cost power.

Table 3-4 Emerging disruptions to supply and responses

Factor	Problem	Measures
1) Lower daily load factor	- Respond to peak demand ⇒ Increase investment for power plant, increase of low operating rate (i.e. high cost) power plant	- Development of storage technology (demand leveling) - Development of energy management system (smart grid, VPP, demand response)
2) Large introduction of renewable energy	- Mismatched power generation (Duck curve phenomenon) - Lower predictability of return of investment ⇒ Dis-incentive for investment	- Development of storage technology (supply leveling) - Introduction of capacity mechanism
1) + 2) + Unexpected natural disaster	- Increasing probability of power outage	- Assessment of supply adequacy - Wider grid connectivity - Decentralized power system
Other	- Electrification of end-use energy ⇒ Rising concern for cyber attack	Measures against cyber attack (e.g. Use of private line)

Source: IEEJ analysis.

(2) New technologies/ideas to prevent supply disruptions

- Storing electrical power

Demand for electrical power fluctuates both seasonally and throughout the day. The use of solar power is progressing, but hourly differences between the demand for electrical power and the electricity supplied by solar panels are inconsistent. This means that there is an oversupply during the day and a lack of supply at night. As a result, the electrical output of baseload power must be adjusted downwards during the day and increased at night. However, adjustments cannot be performed quickly enough, meaning it is difficult to maintain a consistent frequency. This inconsistency between supply and demand for electrical power is sometimes known as the duck curve.

Significant construction investments must be made in order to secure power generation and power transmission facilities to cover the maximum net load (total demand excluding the output of variable renewable energy) in response to this situation. The utilization rate of the electricity used to meet this peak demand is low, which pushes electricity costs upwards. For this reason, attention is being paid to electricity storage that aims to reduce the scale of investments and provide efficient operation of equipment. In recent years electrical storage is not just being used as an "electricity demand leveling" technology that absorbs demand fluctuation. It is also being used as an "electrical generation amount leveling" technology when producing electricity using intermittent energy such as solar and wind. Progress is also being made on the research and practical application of batteries for storing electrical power (sodium sulfur batteries - NAS batteries, redox flow batteries) and systems for storing electrical power using hydrogen.

- Energy management systems

Recently there have also been high expectations for energy management systems that incorporate computer networks.

- Smart grids: Currently electricity is supplied in one direction to homes and businesses. By allowing electricity to flow in both directions, smart grids allow surplus clean energy produced by households and businesses through solar panels etc. to be supplied to areas where it is needed. Experimental smart meter installation is also being performed to allow for demand data to be analyzed in the hopes of realizing electricity supply with less waste.

- Virtual power plants (VPP): Involves controlling multiple small power plants and electrical power demand management systems and treating them as though they were a single power plant. Companies involved in creating VPPs are beginning to arise in Europe, where electrical power is being both deregulated and decentralized. Linking small-scale power generation facilities and control systems using cutting edge IT technologies makes it possible to optimize the supply-demand balance of the power grid. It is also economical because it allows for the efficient operation small-scale power generation facilities. These require less capital investment and fewer construction costs. They are also relatively easy to maintain.

- Demand response (DR): Involves power companies generating surplus power by encouraging consumers to conserve electricity. Consumers are then compensated for energy savings. For power companies, this has the benefit of suppressing power generation that requires the use of costly energy sources. There are two control methods 1) Raising electricity fees (electricity prices are raised during times when electricity demand peaks, thereby causing consumers to use less) and 2) Negawatt trading (involves having the consumer sign a contract with the power company to save electricity in advance, with the consumer receiving a benefit for saving electricity at the company's request).

(3) Capacity mechanisms in a deregulated market

In February 2016, the IEA announced its "Re-powering markets, market design and regulation during the transition to low-carbon power systems" report. It contains an analysis of the challenges faced by the OECD economies related to the mass introduction of renewable energy to its electrical systems. It also discusses how a restructuring of the electricity market will be required to switch to low carbon power systems. The effectiveness of "capacity mechanisms" for avoiding stagnation in willingness to invest in sources of electricity is also examined.

The report mentions that the background to the situation is deregulation of electricity retailing leading to changes in ways of thinking regarding cost recovery for electricity generation. Before deregulation, electricity prices were based on generating costs, but after deregulation these prices were based on trading in the wholesale electricity market. This led to a decrease in the predictability of investment recovery. In addition, feed-in tariff (FIT) systems led to wholesale electricity prices declining because of an influx of renewable energy that wasn't based on market principles. Decreased income from selling electricity also led to a decline in predictability.

These changes are likely to result in a decline in a willingness to invest in electricity supply equipment by electric power companies. There are concerns that this will result in stagnation when it comes to purchasing new equipment or replacing equipment and may lead to the closure of existing power plants, eventually creating electricity supply shortages and causing electricity prices to remain high.

This led to a proposal to introduce capacity mechanisms. Essentially, this means that payments are made according to electricity generation capacity (kW), rather than generated amounts (kWh). By maintaining the ability to reliably generate electricity when supply capacity is needed, a certain level of income is obtained regardless of whether electricity is generated or not. It's also possible to obtain a level supplementary income by selling electricity (kWh). This will result in increased predictability for recovery of investment costs when purchasing equipment for electricity generation.

Each economy's circumstances vary and there is no specific method that could be referred to as an international standard, but consideration of this matter will continue.

(4) Methods for responding to emergencies that are currently under construction

- Level of sufficiency of equipment (appropriateness of the N-1 standard)

Electrical power systems are tightly interconnected. If a disruption occurs to a section of the system - including the generator, transmission lines and source of demand - without affecting the system, the supply reliability of the electrical system can be said to be high. In other words, even if one unit supplying power becomes unavailable or an accident occurs in the transmission lines, redundancy in the system through multiple lines – thereby ensuring that the entire system is not affected - allows for supplies of backup electricity to be secured.

For example, even if one transmission line fails, there are mechanisms in place to prevent power cuts by allowing the electricity to pass through a different line. These ideas are all based on the "N-1 Standard" which has been adopted widely throughout the world. To realize this, there always needs to be available capacity in transmission lines. For instance, if there are only two simple transmission lines, as a general rule one of these lines being used means that 50% of the line capacity is being used. This is the maximum capacity that can be used during non-emergencies.

Under the N-1 standard, N-2 (where two transmission lines are broken) allows for power cuts. It is worth considering measures to prevent power cuts even in the case of N-2, especially considering the tendency of energy demand to be converted to electrical power and the level of damage that can be caused by power cuts. However, it's also self-evident that increasing the number of backups also increases cost. So, we need to discuss the balance between the importance of securing electrical power and costs.

- Wider grid connectivity

Strengthening power transmission connections and broadening the scope of control of systems can be beneficial. If there is extra capacity for generating electricity in an adjacent system and enough power transmission capacity to accept this power, the supply stability of the system will increase. As an example, the United Kingdom and Ireland have introduced a system called "Connect & Manage." This is to allow more electricity to be transmitted by making use of emergency capacity, as well as using capacity when it happens to be available.

- Geographic decentralization of power plants

Having power plants close to areas of demand allows for transmission loss to be reduced thus increasing energy efficiency. However, there are limits on areas where they can be built, and they may be more expensive than building large-scale energy systems. Recently however, small-scale independent distributed energy systems are beginning to emerge, while at the same time progress is being made in electricity storage technologies. This will allow for electricity to be locally produced for local consumption and will increase the efficiency of energy usage during non-emergencies. In addition, it's expected that this will provide stable electric power even when other electrical systems can't be used because of disasters or accidents. They are expected to complement the weaknesses of large-scale energy systems.

- Responding to cyber attacks

In recent years the number of sudden risk factors in supply chains is increasing. These include unexpected natural disasters and cyber attacks. Although it's not possible to prevent natural disasters, efforts are being made to minimize their damage by automating transmission and distribution and improving backup systems.

In the past, acts of terrorism such as cyber attacks were aimed at exploiting information, but in recent years the risk of actual physical damage to social infrastructure such as electrical power has increased. In fact, a cyber attack was responsible for a major power outage in the Ukraine in 2015. It lasted up to six hours and affected tens of thousands of households.

For this reason, groups such as the United Nations, OECD and APEC are holding specialized multilateral and bilateral meetings to share information related to protecting important infrastructure and incidents that have occurred. Many national and private organizations are also considering ways to improve their cyber security.

Chapter 4 Implications

4-1 Comparison for the events extracted in Chapter 1 and 2

The items discussed in Chapter 1 and Chapter 2 can be summarized as follows.

Table 4-1 Summary of discussed items

Risk		Reason/cause	Effect	Likelihood	Impact
Traditional Risk	Geopolitical risk in the Middle East	Traditional conflicts	Supply disruption	Frequent	Supply shortage, High price
	Honeymoon between OPEC and Russia	Change of market condition	Market control	Occasional or Remote	High price
	Underinvestment and supply crunch risk due to fluctuating oil price	Low predictability of market	Supply shortage	Probable	High price, Shift to other energies
	Trade risk	Geopolitical conflicts	Cost rise, Unable to transport	Frequent	High price Supply disruption
	Potential risks in the LNG business	Rigid trade practice	Low liquidity of transaction	Probable	Supply-demand gap, Growth inhibition
Emerging Risk	Mismatch during transition period from conventional to VRE system	Increase of renewable energy	Low profitability of fossil power plants	Occasional	Low reserve margin, blackout
	Side-effect of increasing variable renewable electricity in power supply	Uncontrollable power output	Complicated grid operation	Frequent	Low-quality electricity, blackout
	Fixed cost recovery and underinvestment in liberalized electricity market	Decline of capacity factor and wholesale electricity price	Low profitability of fossil power plants and no new investments	Frequent	Weakened security of supply
	Rising cyber threats in energy sector	Act of terrorism	Collapse of energy production and supply activities	Probable	Supply shortage, High price
	Effect of natural disaster by climate change on energy supply chain	Natural hazard	Shredding of supply chain	Frequent	Crisis of life, Discontinue of business operation
	Uncertainty of the energy policy	Regime change, public opinion	Stagnation of infrastructure construction	Probable	Supply shortage, High price, Blackout

Source: IEEJ analysis.

Notes: Likelihood: Likelihood means the probability of occurrence. “Frequent” indicates occurrence on a daily basis. “Probable” indicates that there is a high possibility of occurrence. “Occasional” indicates that it may occur occasionally. “Remote” indicates that the probability of occurrence is low.

4-2 Recommendations for the events extracted in Chapter 1 and 2

The region /economy is recommended:

(1) To maintain traditional energy security policy. [for 1.1 – 1.4]

- The Producing Economies in a Changing Energy World conference held by the IEA in April 2018 identified great uncertainty in the future of oil demand because of issues such as peak demand and the strengthening of climate change measures. As such, the proportion of oil in the primary energy supply is expected to decrease. This does not mean, however, that oil demand will suddenly disappear. Even if drivers switch to EVs, the change will gradually take place over the next 30 years or more. Aiming for a low-carbon society over the long term and immediate oil demand and supply security are separate issues. In addition, the same IEA conference recognized that stability in the Middle East will continue to be the key to international energy markets and global energy security. Because of this, stability in the Middle East is an extremely important issue for Asia as it deepens its interdependence.
- The large swings in the price of crude oil encourage output coordination between OPEC/non-OPEC producers, so price stabilization is being sought. If the period of low oil prices continues for a long time, there is a concern that the willingness to invest in upstream development will decline and supply shortages may occur in the future. Even at a meeting with OPEC in October 2018, the importance of investment in upstream development was brought up in addition to discussion about peak demand. Oil-consuming economies, along with oil suppliers, must make sustained investment in upstream development.
- The emergence of a new oil-exporting economies creates new trade (sea commerce, pipeline trade) routes. Just like existing trade routes, it is necessary to secure the safety of those new routes.
- The risk to oil supply will continue until the day when the demand for oil is completely gone. As such, traditional energy security policies will be necessary for energy consuming economies.

(2) To promote more fluid and transparent LNG market, to enrich gas market information (e.g. JODI), and to create emergency response mechanism. [for 1.5]

- The aforementioned IEA conference found that while gas markets are currently oversupplied globally, gas security may emerge as an important issue if the future LNG market sees a tighter supply and demand due to increased demand in China, India, and Southeast Asia, and increased demand due to policies abandoning nuclear power. As a result, the need for an energy security policy for natural gas (including LNG) will increase.

- Improving the mobility and transparency of natural gas trade will be effective from the perspective of short-term security. This implies that it is necessary to enhance tools such as JODI Gas.
- At the IEA conference, concern was expressed about the uncertainty of final investment decisions (FID) for the construction of new LNG terminals. However, it was pointed out that the problem with this is whether it will result in excess supply, or whether it will create a more balanced supply and demand environment. If the role of natural gas/LNG further increases in the future, it is possible that it may be time to seriously consider stockpiling, even though there is no enthusiasm for this because of its current high cost.

(3) To provide appropriate investment signals. [for 2.1]

- The 41st IAEE International Conference held in June 2018 under the overarching theme of transforming energy markets toward a low carbon/carbon-free society, discussed movement toward a low-carbon society with "energy transition" as one of the keywords. This movement has raised the difficulty of forecasting the demand for fossil energy, and the uncertainty of recovering investments made in fossil energy.
- Investment in fossil energy resources and the construction of energy infrastructure generally requires a long investment recovery period due to its scale. Crude oil development, for example, requires 5‑10 years from exploration to the start of production, and then more than 10 years to recover the investment. Similarly, coal-fired power plants take 2-3 years to plan, 2-5 years to build, and 10 years to recover the investment. Therefore, an appropriate demand signal is needed for investment.
- On the other hand, since there are strict needs for oil demand and cheap power, suppliers need to respond to this. In other words, unless there is an adequate investment signal to respond to the "demand existing now," there will be a large gap in supply and demand or increased risk of a sharp rise in energy costs in the future while aiming for a low-carbon society in the long-term.
- As the environment drastically changes, market prices are insufficient as a long-term investment signal, and a role is needed for policies (for example, to share future investments between exporting and importing economies, or to share future investments between governments and

industry).

- In addition, the November 2018 meeting of European energy businesses raised the question of how to deal with discontinuity in future forecasts. Discontinuity is difficult to capture in the regular long-term outlook, but in some cases, it can have enough impact to change the direction of the energy market. The emergence of shale oil is one example. We must recognize that it is basically impossible to incorporate such elements as such a game changer into the long-term outlook.

(4) To control of renewable electricity and to promote R&D of necessary technologies. [for 2.2]

- The proportion of renewable energy in primary energy is increasing in the power supply. However, since renewable energy depends on weather conditions, the duration and amount of power generated are not constant (variable renewable energy, or VRE), which makes it difficult to use baseload power sources such as fossil fuel and nuclear power.
- There are numerous supply and demand adjustment technologies, some already available and some still concepts. However, at present, the introduction of VRE is generally making inroads, but implementation of measures to absorb fluctuations are lagging. Therefore, if the timing of introducing VRE and implementing control measures is not aligned, the stability of the power supply will be affected and there is a possibility for confusion.
- It is necessary to research and construct mechanisms to solve these problems. In addition, introducing VRE that exceeds fluctuation absorbing capacities should be avoided. It is necessary to review the fluctuation absorption capacity of the system and allowable VRE capacity, and manage the rate at which VRE is introduced.

(5) To introduce new electricity market design such like capacity mechanisms. [for 2.3]

- Currently there is rapid growth of renewable energy with zero marginal cost that was not anticipated when existing thermal power plants were built. This has led to an unexpected decrease in the operating rate of existing thermal power--in other words, uncertainty in the recovery of the investment.
- If renewable energy has priority in a wholesale electricity market, the wholesale electricity price may fall below the marginal cost of thermal power (or there is a possibility of it happening in the future) and the recovery of investment in existing thermal power becomes uncertain. There are cases in Europe where the survival of existing thermal power has been in danger.

- On the other hand, renewable energy cannot be used 24 hours a day, 365 days a year, and without energy storage technology it is essential to maintain thermal power that is equivalent to peak demand. This means it is necessary to maintain high-cost thermal power generation in order to maintain a stable supply of electricity.

(6) To develop cyber security program for energy system. [for 2.4]

- The perception of what is the most important and serious problem/risk changes with the times and occasionally depends on the political and economic environment and the state of the energy market. In a June 2018 energy security meeting in the United States, many energy issue experts and energy industry personnel showed interest in issues concerning the stable supply of power and cybersecurity.
- With the electrification of energy use progressing in all fields in recent years, electrification has spread to the automotive field. There have also been efforts to connect everything to the Internet and create new value and services.
- In such a world, maintenance of the electricity supply network and the Internet becomes a life and death problem, and conversely, can become the target of crime and terrorism. For example, a server attack by someone with malicious intent may stop the operation of and destroy a power plant.
- Although these risks are being discussed, systematically-built comprehensive measures have not been taken and urgent action is required.

(7) To develop a climate adaption program. [for 2.5]

- The impact of climate change has led to frequent disruptions in energy supply chains-namely, the effects of drought on hydroelectric power generation and the effects of tsunamis and floods on power generation facilities and transmission systems.
- As such, both energy suppliers and consumers must work together in an interdependent relationship on energy security and climate change measures.

(8) To build policy on scientific evidence and to involve stakeholders in the policy making process. [for 2.6]

- It may be impossible to smoothly carry out policies in the face of citizen opposition. The same applies to energy security policies (Japan’s nuclear power, Canada’s crude oil pipeline, Thailand’s coal-fired power, etc.).

- Energy security cannot be completely entrusted to companies and markets, and a certain amount of intervention by the government is necessary.
- Enforcement of top-down energy security policy should be avoided as much as possible, and it is necessary to construct policies that take into account scientific evidence, discussion, and stakeholders.

4-3 Policy implications for each energy type

In conclusion, policy recommendations for each energy type are summarized.

4-3-1 Oil

- Help developing economies to adopt necessary policies and investment.
    - Design of policy/regulation.
    - Remove oil price subsidy to make government/company capable of necessary investment.
    - Low interest rate loan for security investment.

4-3-2 Gas/LNG

- Analyze the risks and develop contingency plan/mechanism in an economy.
    - Develop common methodology to assess the risk.
    - Case study, joint study with an economy which needs help.
- Start discussing multilateral response mechanism.
    - Identify available gas/LNG supply flexibilities (storage, piped gas, reserve capacity) in a market.
    - Develop rules for flexible use.

4-3-3 Electricity

- Analyze the policy/mechanism gap between traditional (centralized and thermal power) and emerging (decentralized and VREs) electric power system in an economy.
- Deeper communication between electric power sector and IT sector.
    - Periodic dialogue to seek better integration of sectors.

Appendix

Data source: APEC Energy Demand and Supply Outlook 7th Edition

【Location of data】

Factor	A:Primary Energy Supply			B:Production (Mtoe)			C:Net Import (Mtoe)			D:Electricity Generation Input Fuel (Mtoe)			E:Electricity Generation Output by Fuel (TWh)		
Location	Sammary Table			Sammary Table			Sammary Table			Electricity Generation			Electricity Generation		
	2016	2040	2050	2016	2040	2050	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	AJ50	BH50	BR50	AJ28	BH28	BR28	AJ36	BH36	BR36	-AJ64	-BH64	-BR64	AJ685	BH685	BR685
Oil	AJ51	BH51	BR51	AJ29	BH29	BR29	=AJ37+AJ38+AJ43+AJ44			-AJ65	-BH65	-BR65	AJ691	BH691	BR691
Gas	AJ52	BH52	BR52	AJ30	BH30	BR30	AJ39	BH39	BR39	-AJ66	-BH66	-BR66	AJ694	BH694	BR694
Nuclear	AJ53	BH53	BR53	AJ31	BH31	BR31		replaced by BH for Oil	replaced by BR for Oil	-AJ67	-BH67	-BR67	AJ699	BH699	BR699
Hydro	AJ54	BH54	BR54	AJ32	BH32	BR32				-AJ68	-BH68	-BR68	AJ701	BH701	BR701
NRE	AJ55	BH55	BR55	AJ33	BH33	BR33				-AJ69	-BH69	-BR69	AJ700-AJ701		

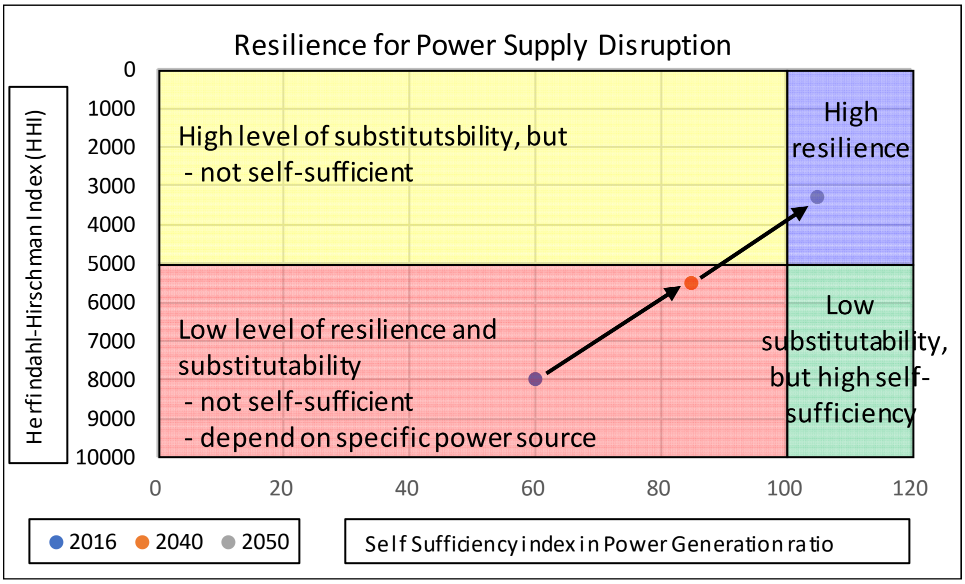
【Calculated data】

Calcurated	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	=AJ28/AJ50			=AJ64/Total input x F			=AJ685/Total output x100		
Oil		=BH29/BH51			=BH65/Total input x F			=BH691/Total input x100	
Gas			=BR30/BR52			=BR66/Total input x F			=BR694/Total input x100
Nuclear									
Hydro		B/Ax100							
NRE									
Total				SSI 2016			HHI 2016		

* SSI 2016 is a sum from Coal to NRE

* HHI 2016 is a sum total of the squared power generation ratio by energy source

【How to read chart "Resilience for Power Supply Disruption"】



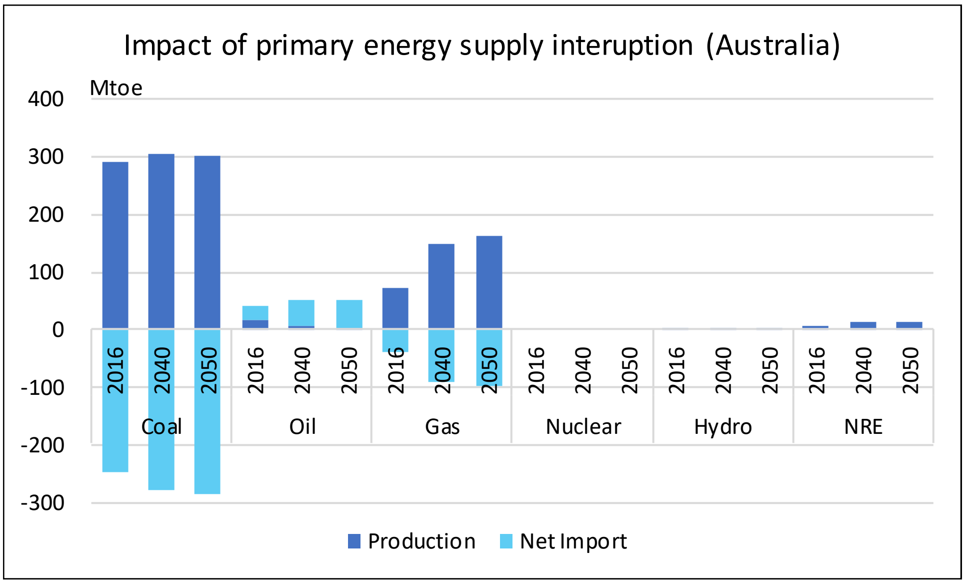
The separation line 5000 in HHI is not an indication of safety if it is within the range (0-5000). HHI 5000 means that there are two power generation sources with equivalent capabilities. The smaller the HHI, the more power generation sources are meant. That is, a small number of HHI means that the resilience is high.

The separation line 100 at the self-sufficiency index indicates a situation where self-sufficiency can be achieved if it is in the range above 100. The state of the four quadrants is not separated by the boundary line. In fact, that tendency will gradually become stronger.

Therefore, the direction of the arrow is important. That is, it is important that the arrow heads to the upper right zone. Based on this recognition, please look at the chart.

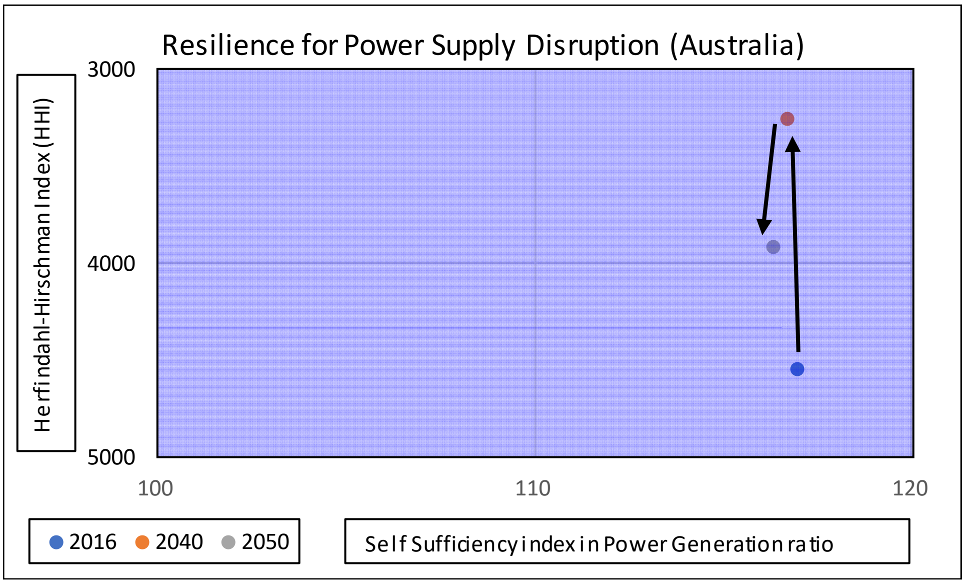
1 Energy supply situation in Australia

1-1 Primary energy supply balance



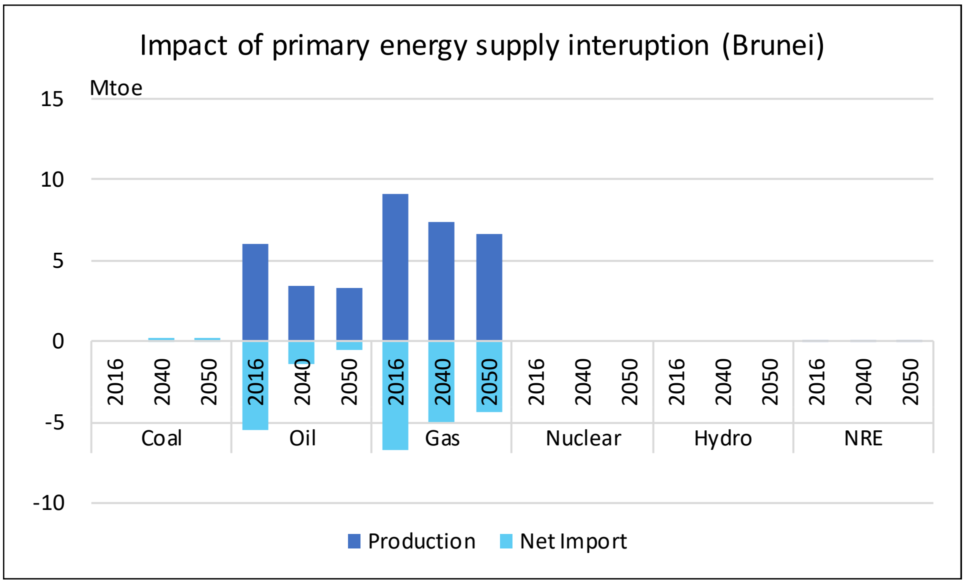
1-2 Resilience for power supply disruption

Australia	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	120.0	120.0	120.0	83.9	50.9	27.4	63.6	30.0	14.9
Oil	39.5	11.2	8.0	0.8	0.0	0.0	2.2	0.3	0.1
Gas	120.0	120.0	120.0	25.6	51.3	71.1	19.8	43.1	54.9
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	100.0	100.0	100.0	2.3	2.3	2.4	5.9	4.7	4.4
NRE	100.0	100.0	100.0	4.3	12.1	15.4	8.6	22.0	25.8
Total				117.0	116.7	116.3	4546	3259	3917



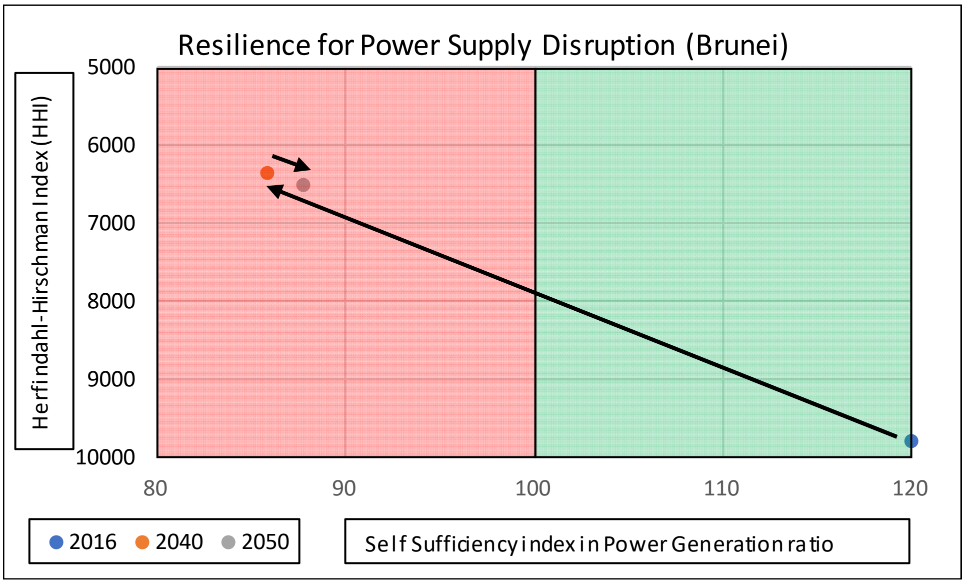
2 Energy supply situation in Brunei Darussalam

2-1 Primary energy supply balance



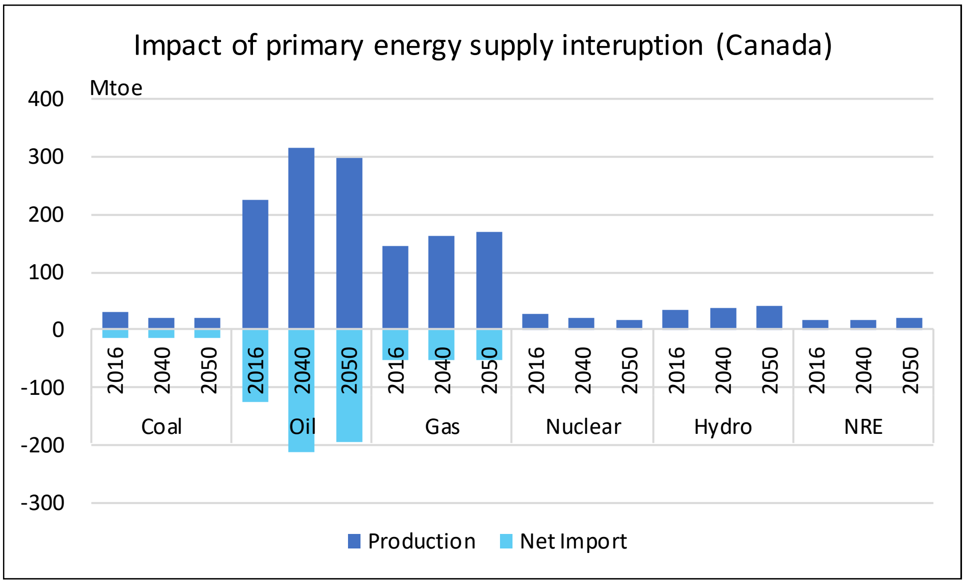
2-2 Resilience for power supply disruption

Brunei	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.7	22.3
Oil	120.0	120.0	120.0	1.2	0.0	0.0	1.0	0.0	0.0
Gas	120.0	120.0	120.0	118.8	85.8	87.7	98.9	76.2	77.6
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NRE	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.1	0.1
Total				120.0	85.9	87.7	9788	6371	6523



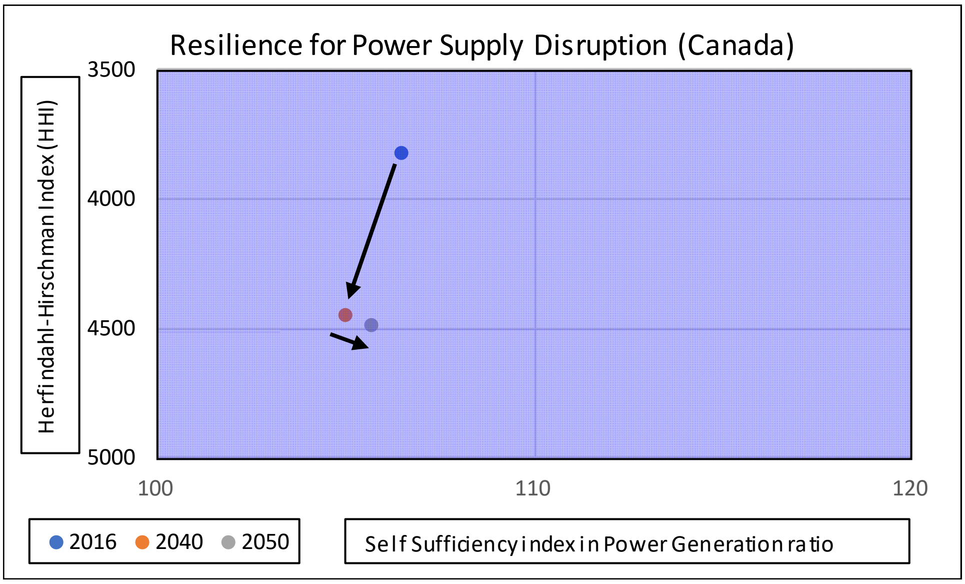
3 Energy supply situation in Canada

3-1 Primary energy supply balance



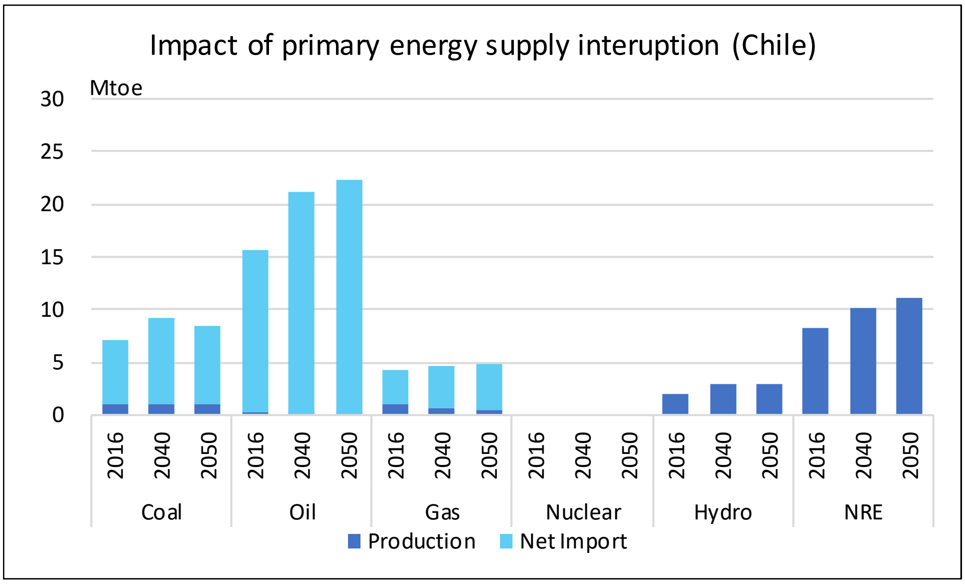
3-2 Resilience for power supply disruption

Canada	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	120.0	120.0	120.0	17.9	3.1	3.8	9.3	1.2	1.4
Oil	120.0	120.0	120.0	2.7	2.8	2.8	1.2	1.1	1.1
Gas	120.0	120.0	120.0	18.2	24.1	27.4	9.2	11.4	13.3
Nuclear	100.0	100.0	100.0	27.2	23.4	18.6	15.2	11.6	9.1
Hydro	100.0	100.0	100.0	34.3	42.2	43.4	58.1	63.7	64.0
NRE	100.0	100.0	100.0	6.2	9.4	9.7	7.0	10.9	11.0
Total				106.5	105.0	105.7	3825	4448	4485



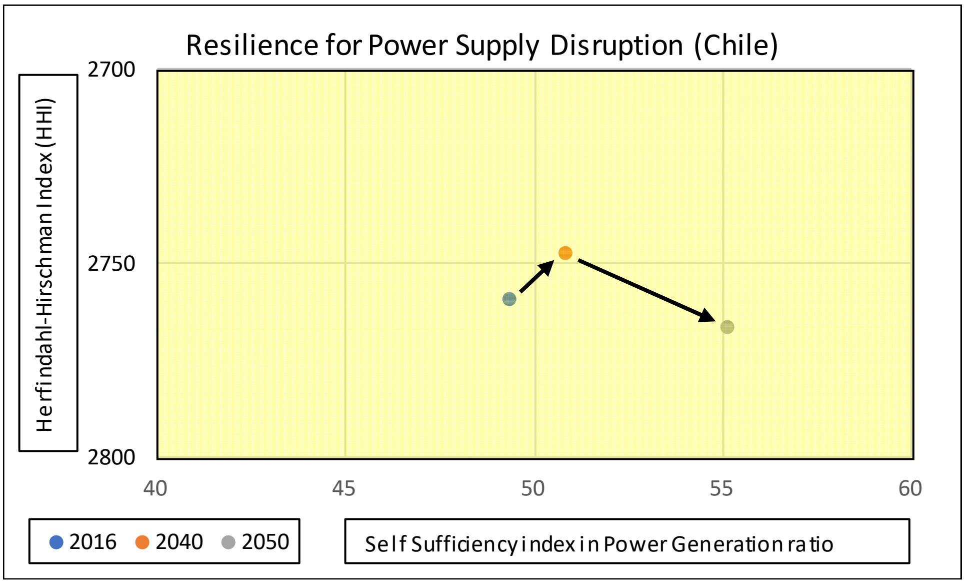
4 Energy supply situation in Chile

4-1 Primary energy supply balance



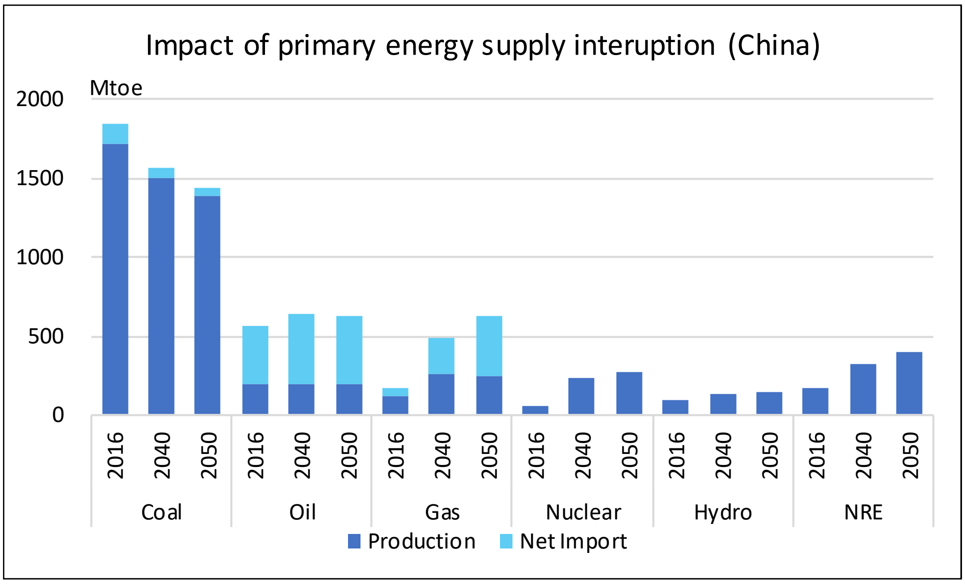
4-2 Resilience for power supply disruption

Chile	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	14.3	11.0	11.9	6.1	4.8	4.6	38.2	33.4	28.4
Oil	1.6	0.1	0.0	0.1	0.0	0.0	3.7	1.3	1.2
Gas	23.5	12.1	9.9	3.0	1.2	1.0	15.0	10.5	9.3
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	100.0	100.0	100.0	12.2	14.7	14.9	29.6	30.4	29.0
NRE	100.0	100.0	100.0	27.9	30.1	34.6	13.5	24.4	32.1
Total				49.3	50.8	55.1	2759	2747	2766



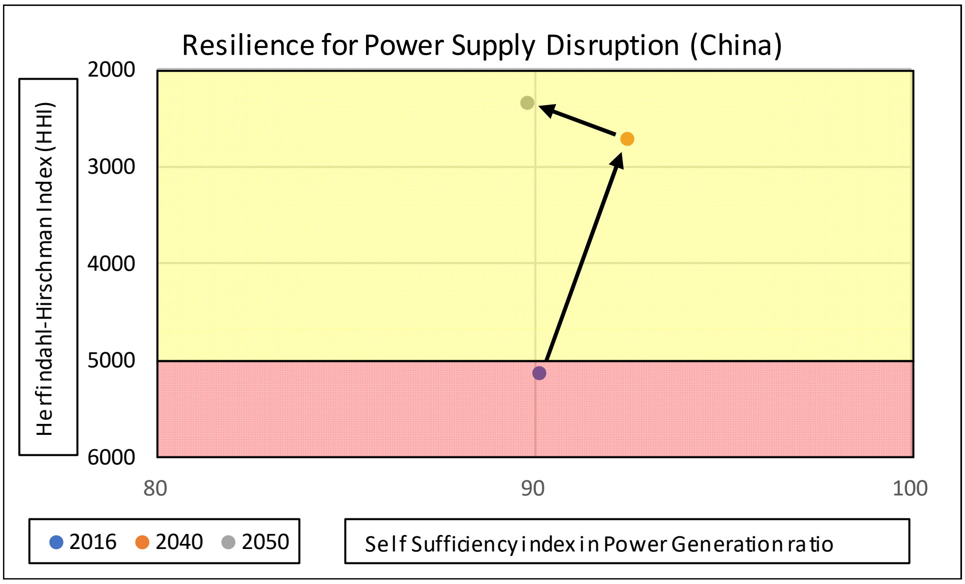
5 Energy supply situation in China

5-1 Primary energy supply balance



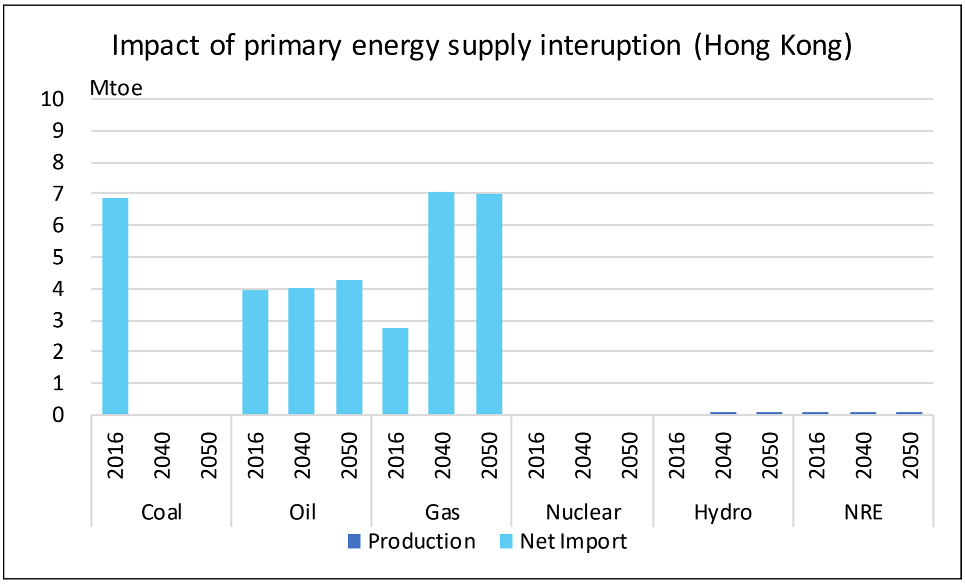
5-2 Resilience for power supply disruption

China	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	89.3	95.3	96.4	72.1	53.2	45.8	68.8	42.8	35.1
Oil	36.5	29.4	30.4	0.2	0.1	0.1	0.2	0.1	0.0
Gas	67.7	52.6	40.4	1.8	5.2	5.6	2.8	10.9	15.3
Nuclear	100.0	100.0	100.0	4.3	13.5	15.0	3.4	9.9	10.8
Hydro	100.0	100.0	100.0	7.8	7.8	7.7	18.8	17.3	16.6
NRE	100.0	100.0	100.0	3.9	12.8	15.6	6.1	18.9	22.1
Total				90.1	92.5	89.8	5136	2710	2350



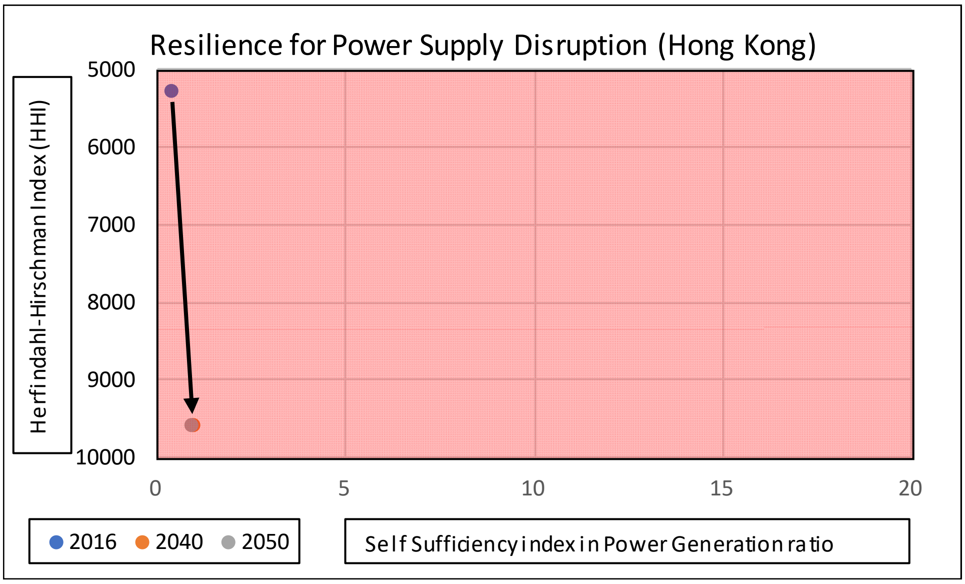
6 Energy supply situation in Hong Kong, China

6-1 Primary energy supply balance



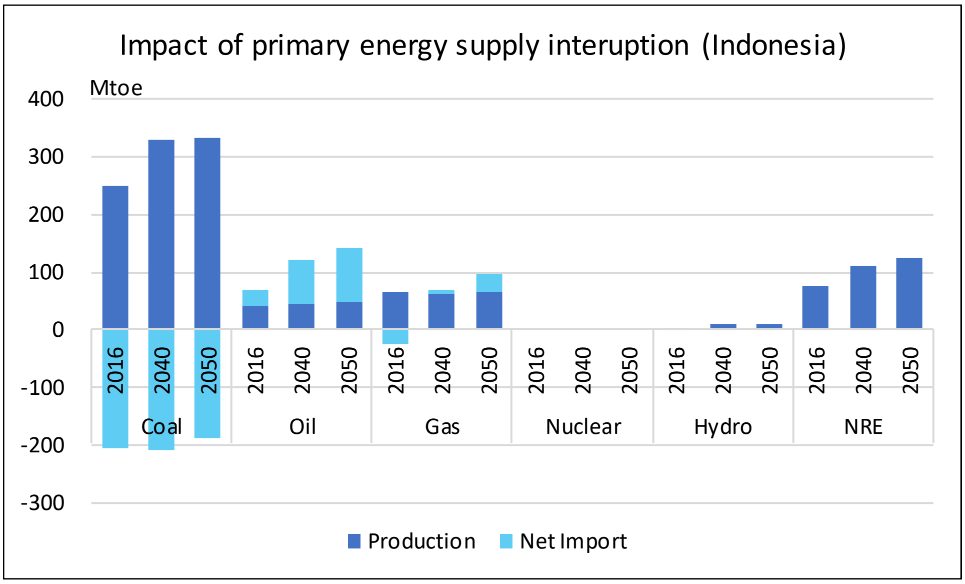
6-2 Resilience for power supply disruption

Hong Kong	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	0.0	0.0	0.0	0.0	0.0	0.0	63.7	0.0	0.0
Oil	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.9	0.9
Gas	0.0	0.0	0.0	0.0	0.0	0.0	35.1	97.9	97.9
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	0.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
NRE	100.0	100.0	100.0	0.3	0.9	0.9	0.3	1.2	1.2
Total				0.3	0.9	0.9	5286	9585	9587



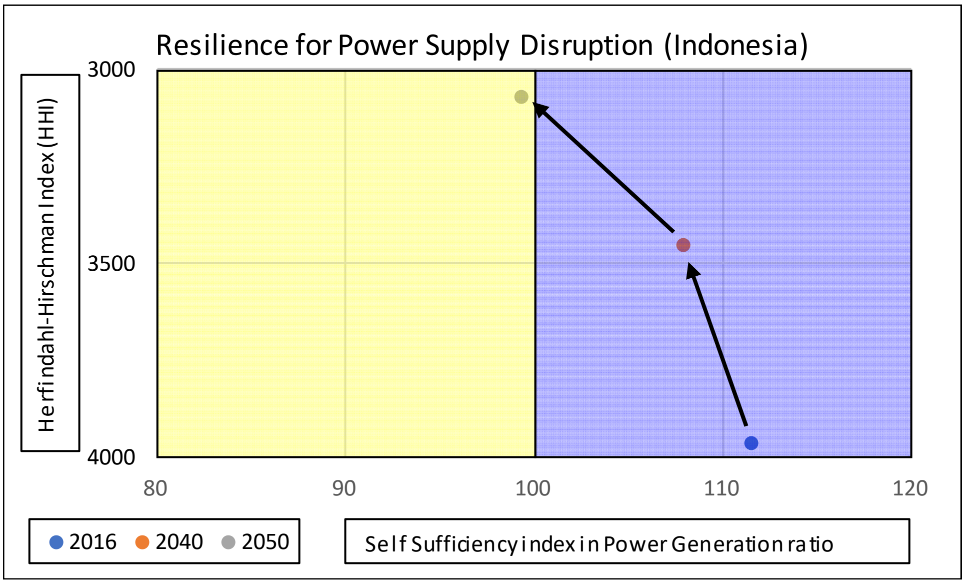
7 Energy supply situation in Indonesia

7-1 Primary energy supply balance



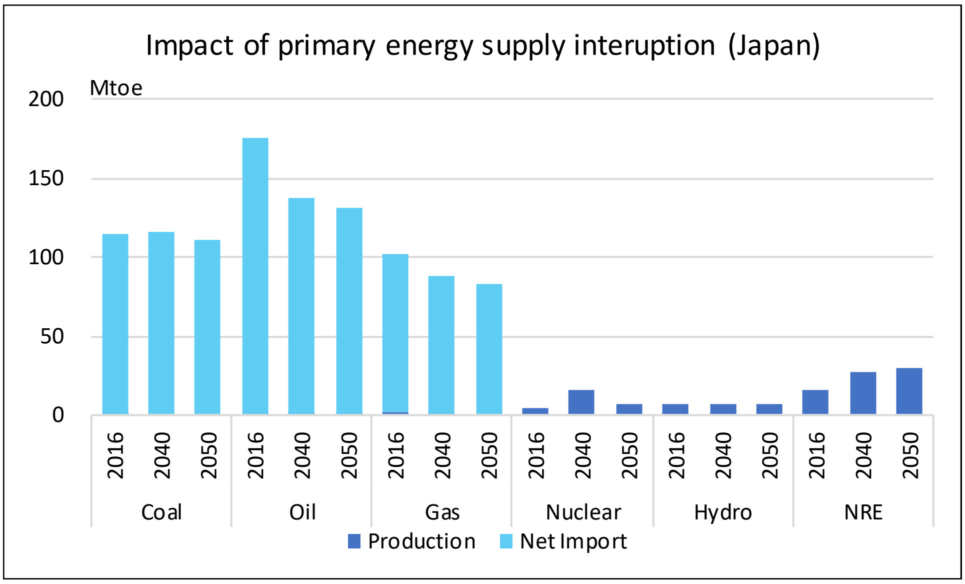
7-2 Resilience for power supply disruption

Indonesia	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	120.0	120.0	120.0	59.1	59.8	50.2	56.8	50.7	42.7
Oil	57.3	33.2	29.5	2.8	0.1	0.0	6.0	0.2	0.1
Gas	120.0	90.3	65.3	22.5	17.9	16.9	25.0	23.7	29.3
Nuclear	0.0	0.0	0.0				0.0	0.0	0.0
Hydro	100.0	100.0	100.0	2.2	5.1	5.5	7.4	12.9	12.9
NRE	100.0	100.0	100.0	24.8	25.0	26.7	4.8	12.6	15.0
Total				111.5	107.9	99.3	3965	3451	3070



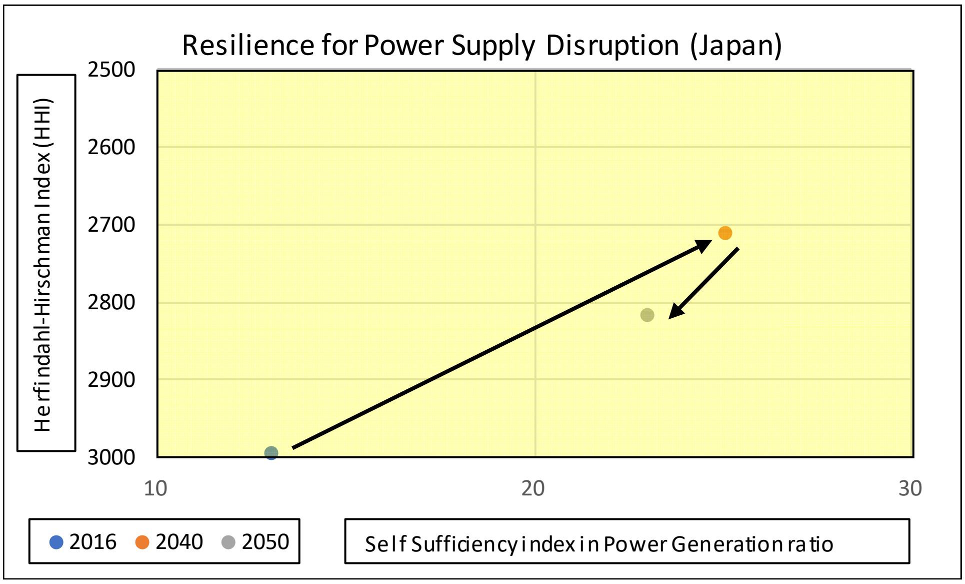
8 Energy supply situation in Japan

8-1 Primary energy supply balance



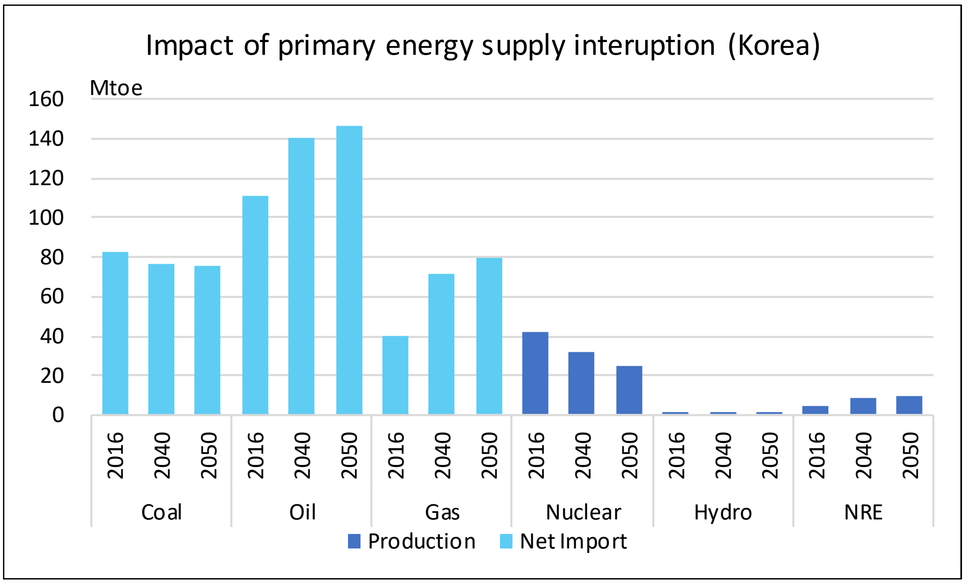
8-2 Resilience for power supply disruption

Japan	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	0.6	0.0	0.0	0.2	0.0	0.0	33.8	37.1	37.8
Oil	0.3	0.2	0.2	0.0	0.0	0.0	8.7	0.9	0.7
Gas	2.3	0.0	0.0	1.0	0.0	0.0	40.8	30.5	29.9
Nuclear	100.0	100.0	100.0	2.5	8.9	4.2	1.7	6.0	2.7
Hydro	100.0	100.0	100.0	3.6	3.9	4.3	7.6	8.1	8.5
NRE	100.0	100.0	100.0	5.8	12.2	14.6	7.4	17.4	20.4
Total				13.0	25.0	23.0	2995	2709	2816



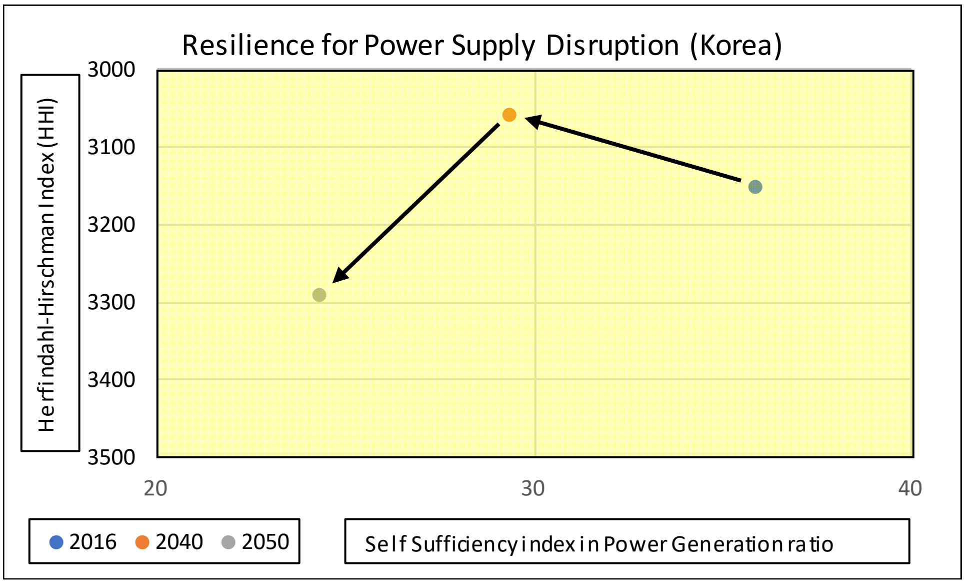
9 Energy supply situation in Korea

9-1 Primary energy supply balance



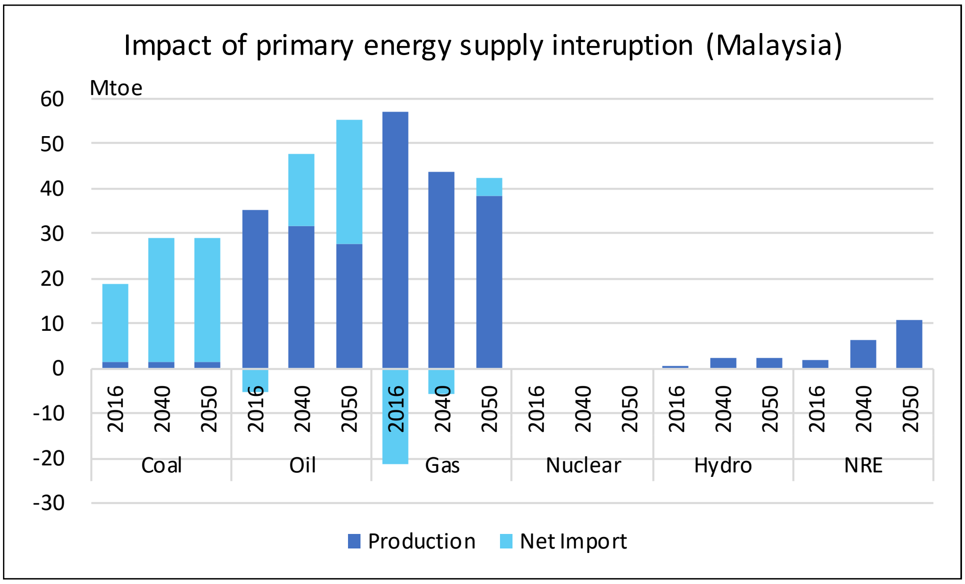
9-2 Resilience for power supply disruption

Korea	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	0.9	1.0	1.0	0.4	0.4	0.4	42.1	34.5	32.5
Oil	0.6	0.0	0.0	0.0	0.0	0.0	3.2	0.1	0.1
Gas	0.3	0.0	0.0	0.1	0.0	0.0	22.8	38.2	44.4
Nuclear	100.0	100.0	100.0	33.4	24.0	18.4	29.0	18.4	13.7
Hydro	100.0	100.0	100.0	0.2	0.2	0.2	0.5	0.5	0.4
NRE	100.0	100.0	100.0	1.8	4.8	5.3	2.3	8.3	8.9
Total				35.8	29.3	24.3	3152	3057	3290



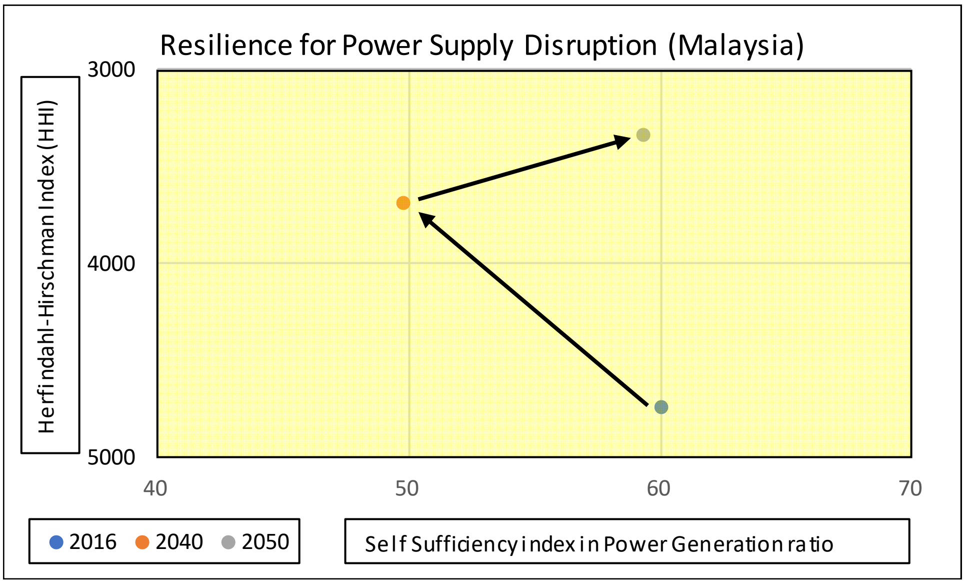
10 Energy supply situation in Malaysia

10-1 Primary energy supply balance



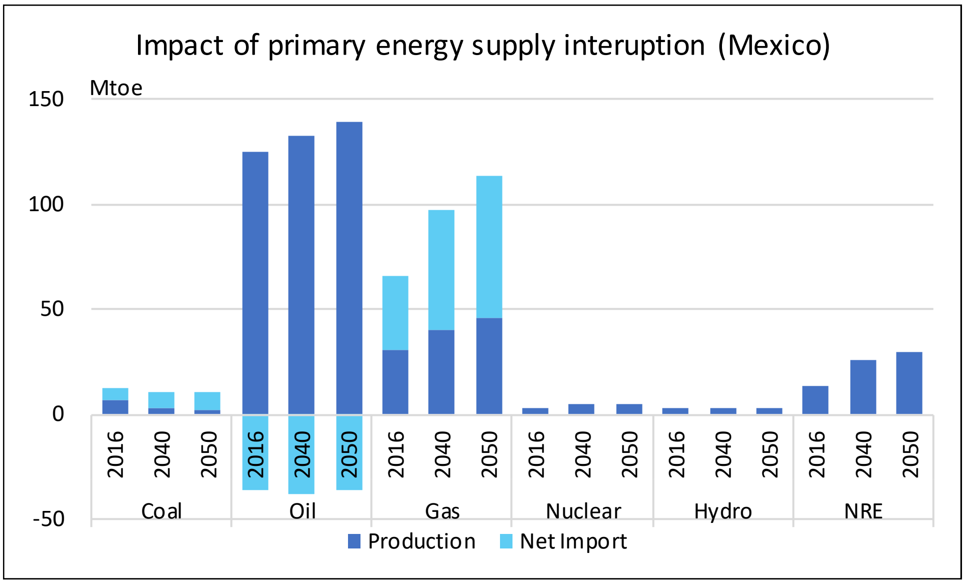
10-2 Resilience for power supply disruption

Malaysia	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	7.6	4.9	4.9	4.0	2.9	2.4	50.1	51.3	43.7
Oil	116.3	65.0	49.3	1.3	0.3	0.0	0.9	0.3	0.0
Gas	120.0	120.0	120.0	53.4	30.0	34.6	47.3	29.6	34.4
Nuclear	0.0	0.0	0.0				0.0	0.0	0.0
Hydro	100.0	100.0	100.0	0.4	4.6	4.3	1.2	11.2	10.5
NRE	100.0	100.0	100.0	0.8	12.0	18.0	0.6	7.7	11.4
Total				60.1	49.7	59.3	4745	3692	3332



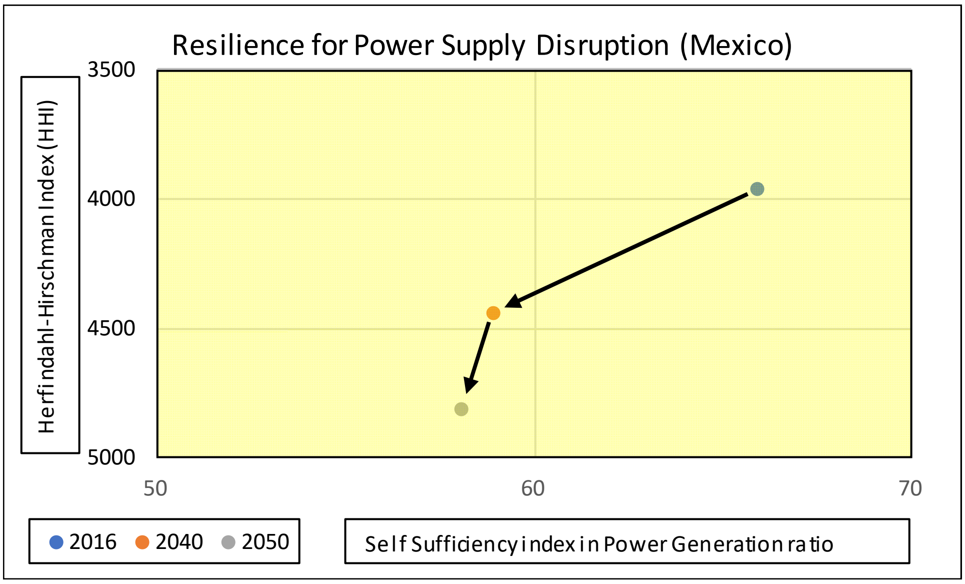
11 Energy supply situation in Mexico

11-1 Primary energy supply balance



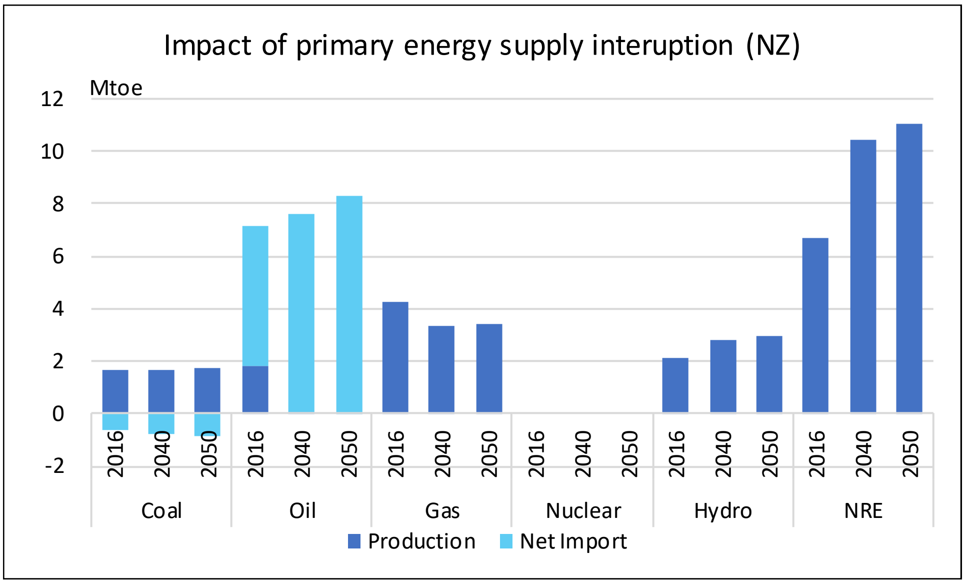
11-2 Resilience for power supply disruption

Mexico	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	56.2	27.4	19.0	7.8	2.1	1.3	10.8	5.6	4.7
Oil	120.0	120.0	120.0	15.2	2.0	1.7	10.7	1.0	0.9
Gas	45.6	40.3	40.0	25.6	24.2	24.5	60.0	63.2	66.4
Nuclear	100.0	100.0	100.0	4.2	5.8	5.0	3.3	4.1	3.5
Hydro	100.0	100.0	100.0	4.1	3.5	3.0	9.6	7.6	6.5
NRE	100.0	100.0	100.0	9.0	21.3	22.5	5.7	18.5	18.0
Total				65.9	58.9	58.0	3961	4441	4813



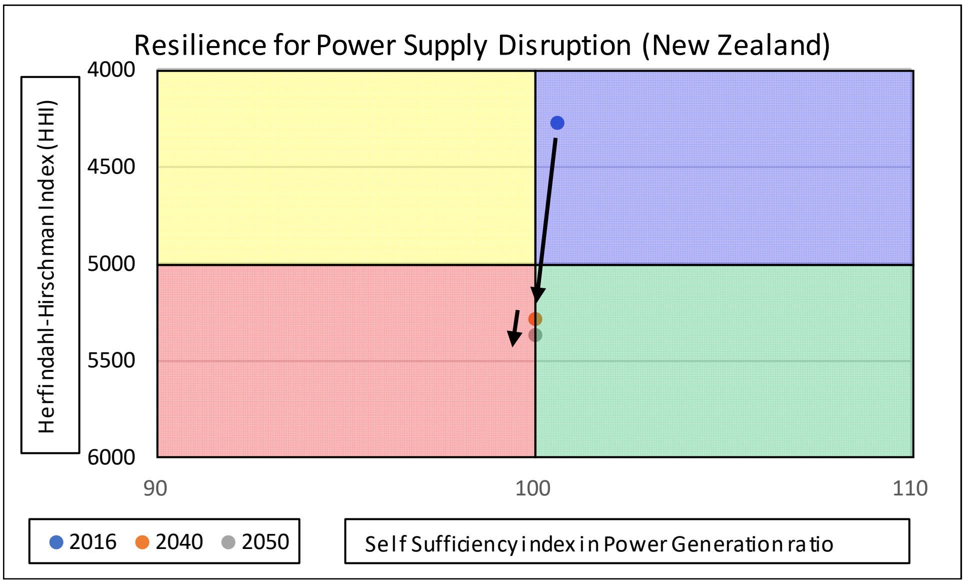
12 Energy supply situation in New Zealand

12-1 Primary energy supply balance



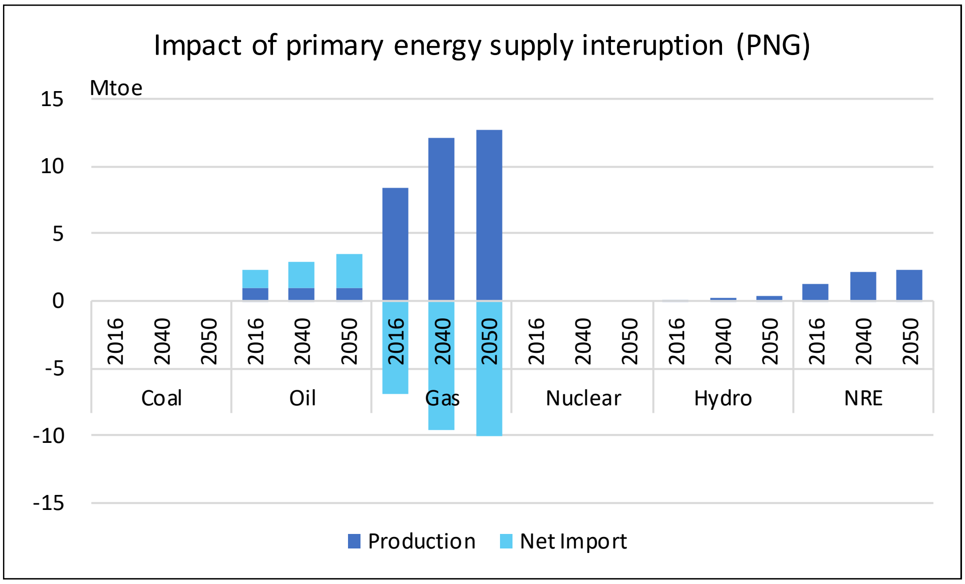
12-2 Resilience for power supply disruption

New Zealand	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	120.0	120.0	120.0	3.5	0.0	0.0	2.3	0.0	0.0
Oil	27.7	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Gas	100.7	100.4	100.4	12.7	0.0	0.0	14.7	0.0	0.0
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	100.0	100.0	100.0	24.7	24.5	25.1	58.9	61.9	63.5
NRE	100.0	100.0	100.0	59.6	75.5	74.9	24.1	38.1	36.5
Total				100.6	100.0	100.0	4272	5284	5366



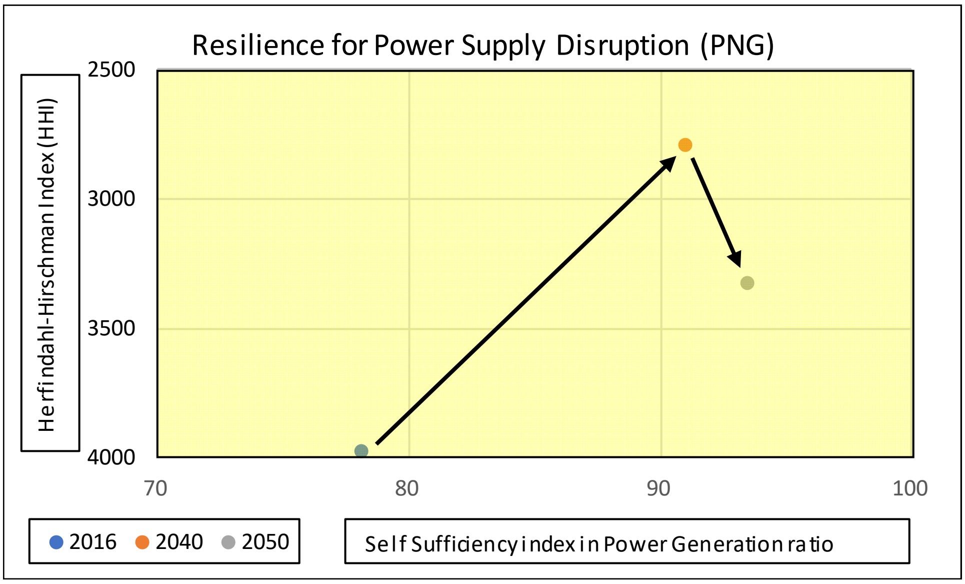
13 Energy supply situation in Papua New Guinea

13-1 Primary energy supply balance



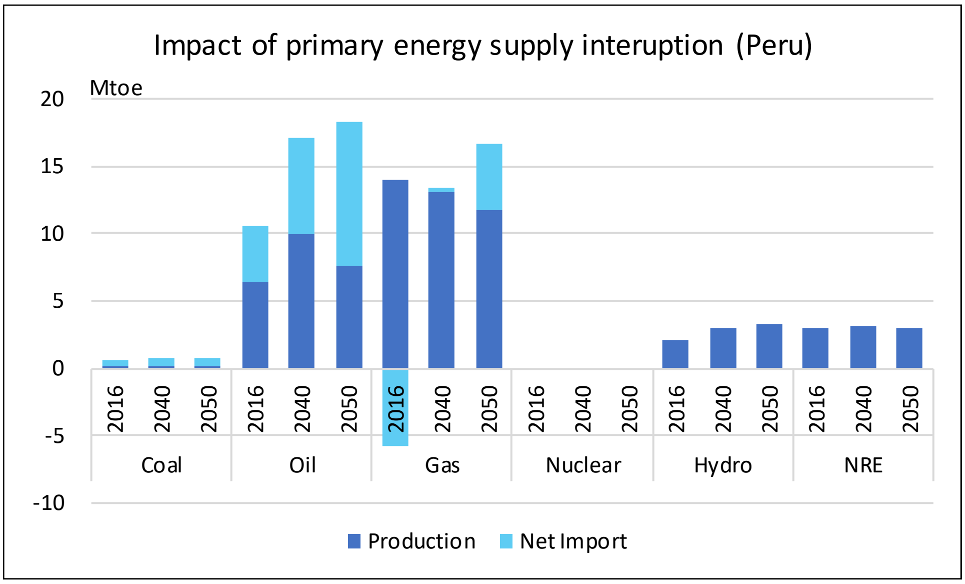
13-2 Resilience for power supply disruption

PNG	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil	54.1	35.2	28.8	28.2	6.5	3.8	57.1	22.9	12.7
Gas	120.0	120.0	120.0	12.9	18.2	17.0	10.8	17.3	12.6
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	100.0	100.0	100.0	7.1	11.0	17.0	22.6	39.3	47.7
NRE	100.0	100.0	100.0	29.9	55.3	55.7	9.5	20.5	27.1
Total				78.1	91.0	93.5	3976	2789	3325



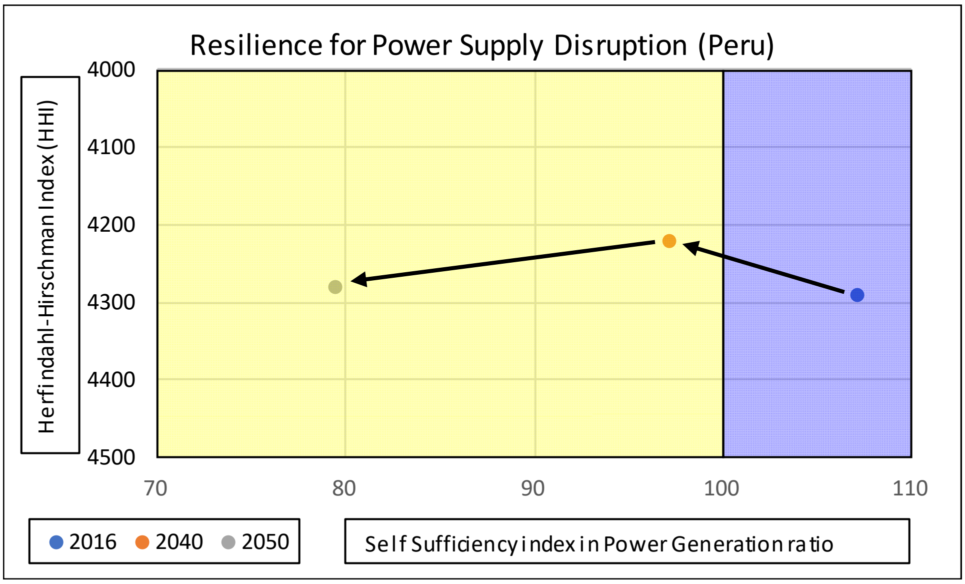
14 Energy supply situation in Peru

14-1 Primary energy supply balance



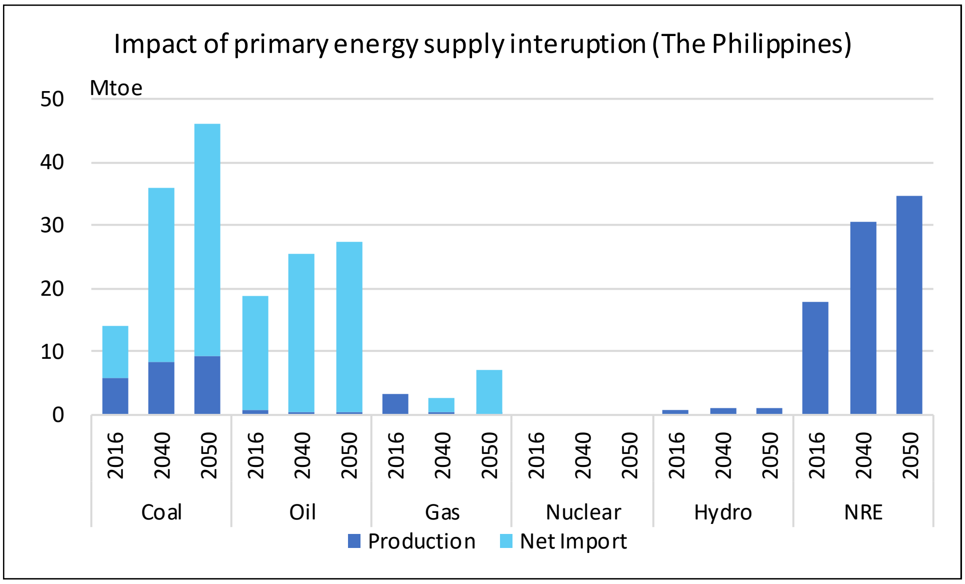
14-2 Resilience for power supply disruption

Peru	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	20.3	22.8	20.9	0.8	0.0	0.0	1.6	0.0	0.0
Oil	62.7	69.9	46.8	3.3	2.8	1.7	2.3	1.6	1.4
Gas	120.0	97.4	70.6	72.5	60.0	45.0	45.8	45.3	48.2
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	100.0	100.0	100.0	26.3	29.7	28.3	46.6	46.0	43.7
NRE	100.0	100.0	100.0	4.2	4.6	4.4	3.7	7.2	6.7
Total				107.1	97.2	79.4	4291	4221	4280



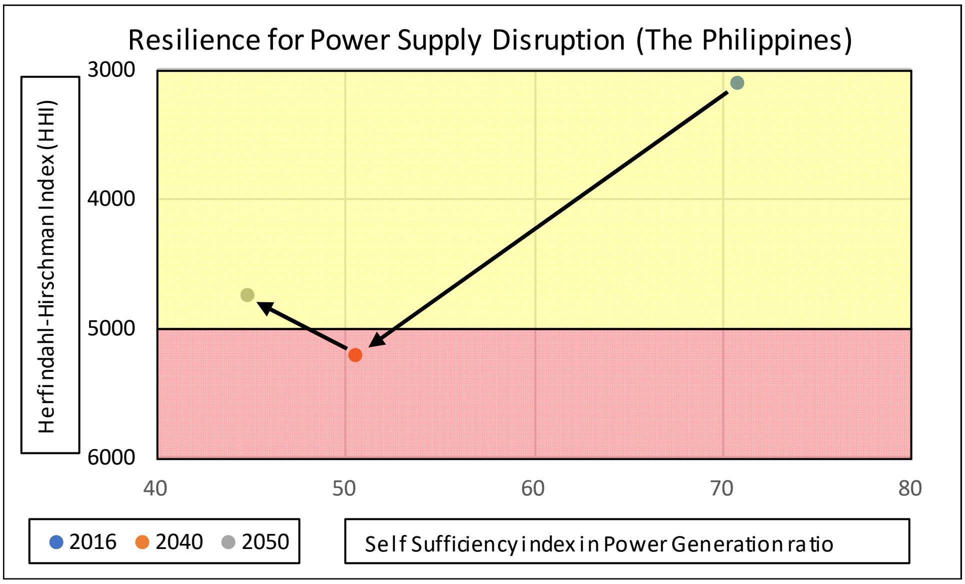
15 Energy supply situation in the Philippines

15-1 Primary energy supply balance



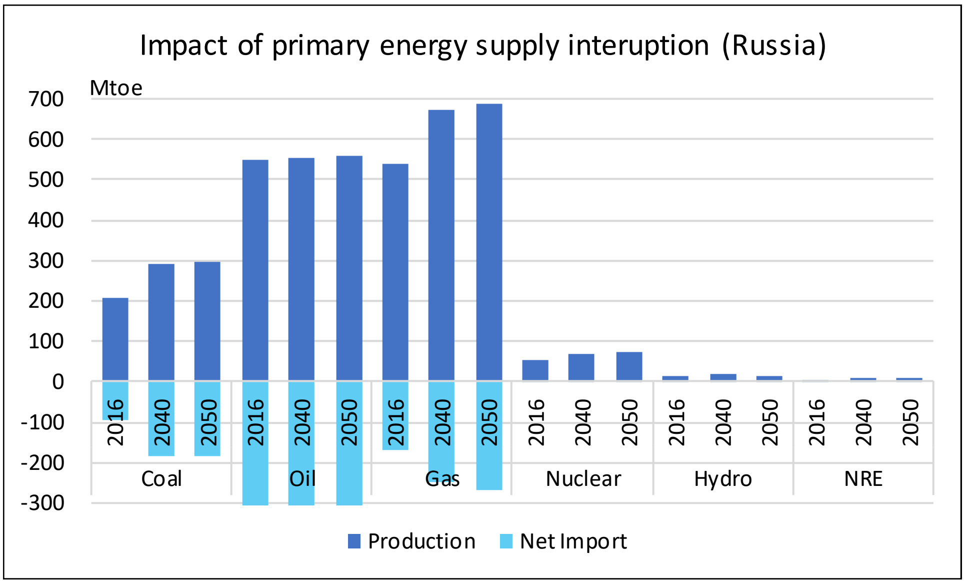
15-2 Resilience for power supply disruption

The Philippines	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	41.6	22.9	20.5	17.6	13.6	12.1	47.7	69.6	65.5
Oil	4.1	1.8	1.3	0.2	0.0	0.0	6.2	0.4	0.0
Gas	100.0	13.5	3.8	11.9	0.5	0.3	21.9	6.6	14.6
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	100.0	100.0	100.0	2.7	2.1	1.8	8.9	6.2	5.0
NRE	100.0	100.0	100.0	38.3	34.3	30.6	15.3	17.2	14.9
Total				70.7	50.5	44.8	3105	5215	4747



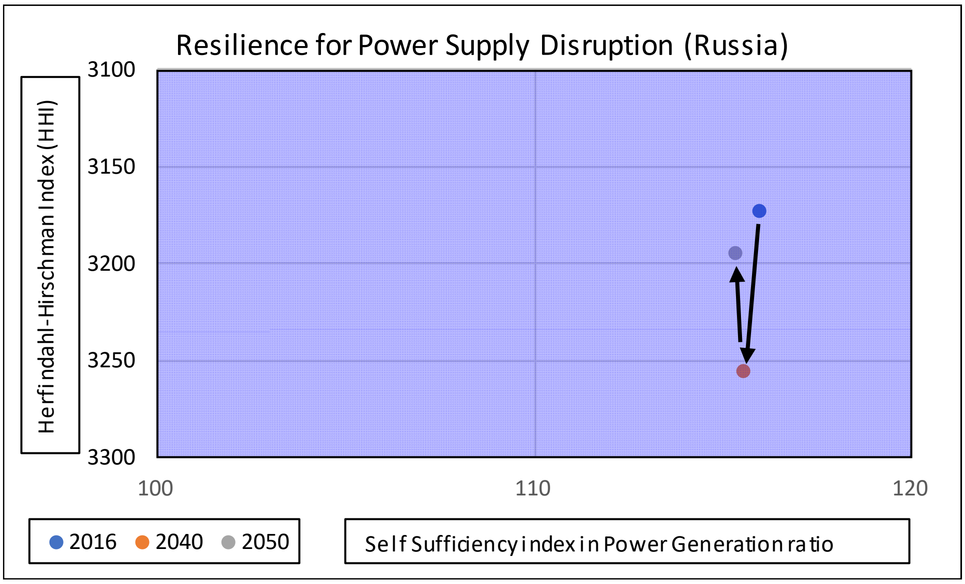
16 Energy supply situation in Russia

16-1 Primary energy supply balance



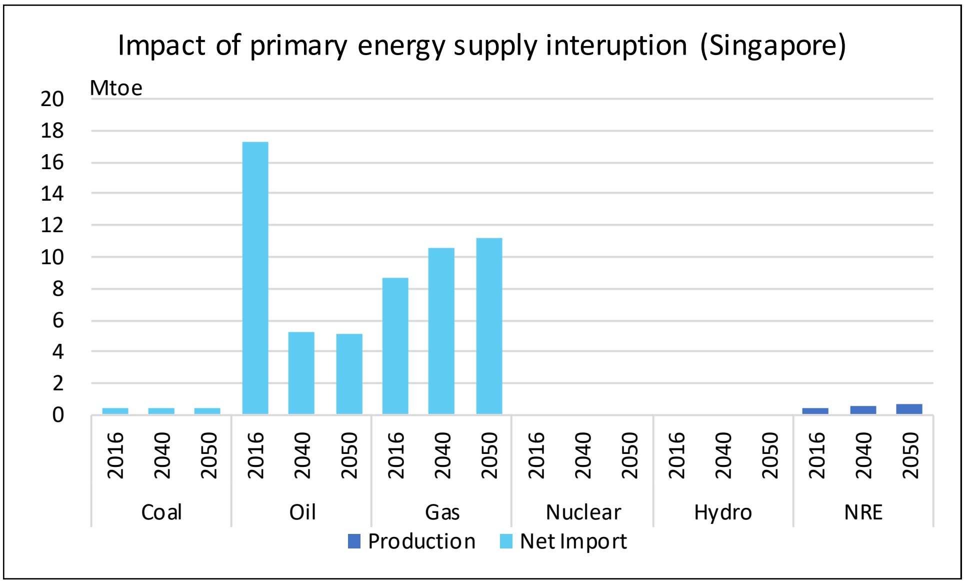
16-2 Resilience for power supply disruption

Russia	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	120.0	120.0	120.0	21.8	17.4	17.1	15.8	12.4	12.4
Oil	120.0	120.0	120.0	2.4	2.3	2.3	1.0	0.8	0.8
Gas	120.0	120.0	120.0	71.4	73.4	72.5	48.0	49.6	48.6
Nuclear	100.0	100.0	100.0	15.4	16.7	17.7	18.1	19.8	21.2
Hydro	100.0	100.0	100.0	4.7	4.3	4.1	17.0	15.7	14.9
NRE	100.0	100.0	100.0	0.2	1.3	1.6	0.1	1.7	2.1
Total				115.9	115.5	115.3	3173	3256	3194



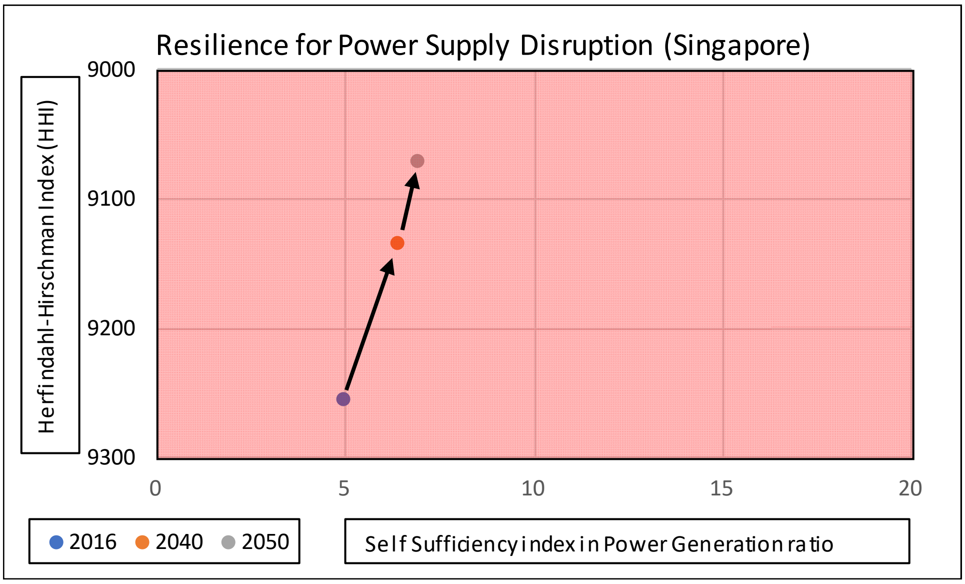
17 Energy supply situation in Singapore

17-1 Primary energy supply balance



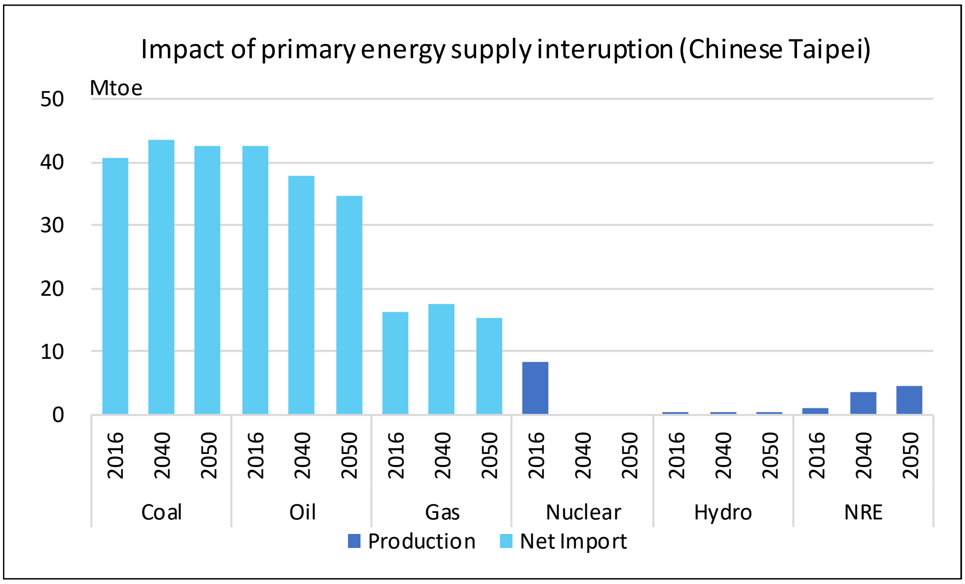
17-2 Resilience for power supply disruption

Singapore	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.0	1.0
Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.6	0.6
Gas	0.0	0.0	0.0	0.0	0.0	0.0	96.2	95.5	95.2
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NRE	100.0	100.0	100.0	4.9	6.4	6.9	1.9	2.9	3.3
Total				4.9	6.4	6.9	9254	9134	9071



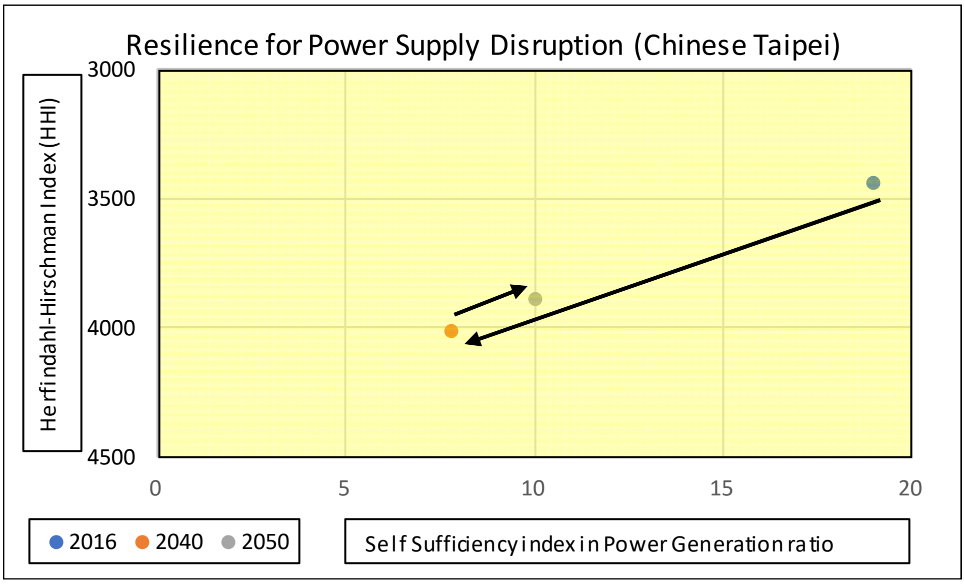
18 Energy supply situation in Chinese Taipei

18-1 Primary energy supply balance



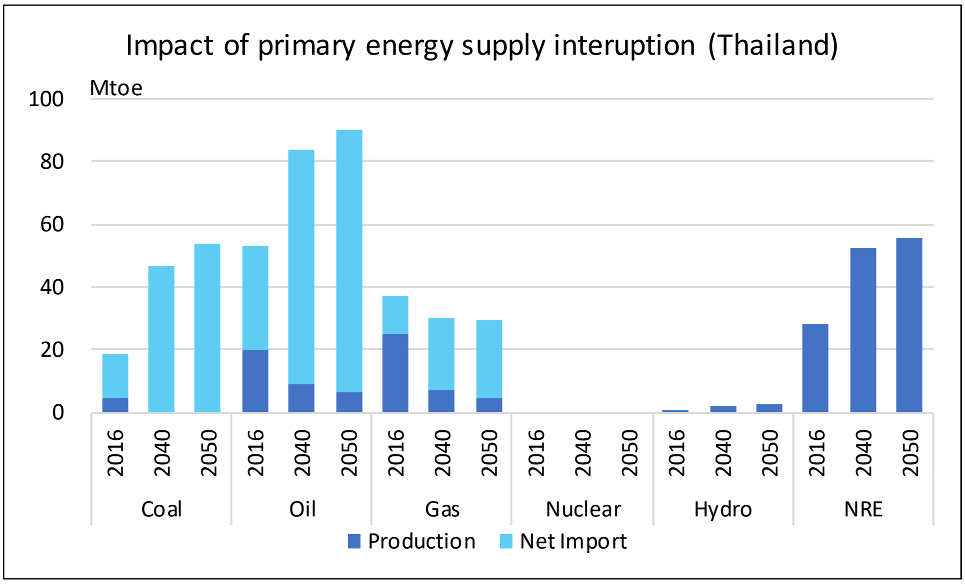
18-2 Resilience for power supply disruption

Chinese Taipei	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	0.0	0.0	0.0	0.0	0.0	0.0	47.2	52.1	52.9
Oil	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.9	0.9
Gas	1.5	0.3	0.2	0.4	0.1	0.1	32.1	34.4	29.7
Nuclear	100.0	100.0	100.0	15.7	0.0	0.0	12.1	0.0	0.0
Hydro	100.0	100.0	100.0	1.1	1.2	1.2	2.5	2.4	2.5
NRE	100.0	100.0	100.0	1.8	6.5	8.7	1.7	10.2	14.0
Total				19.0	7.8	10.0	3435	4009	3886



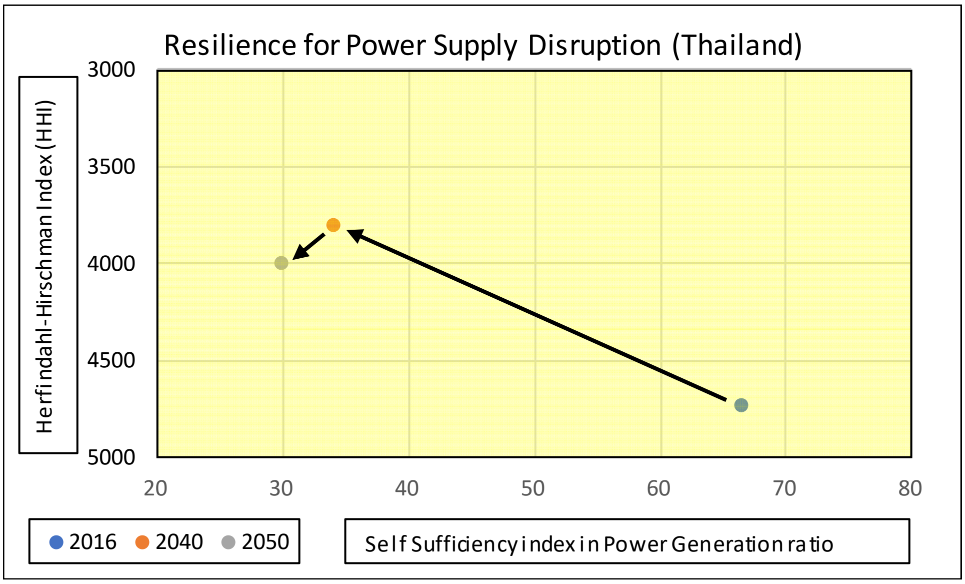
19 Energy supply situation in Thailand

19-1 Primary energy supply balance



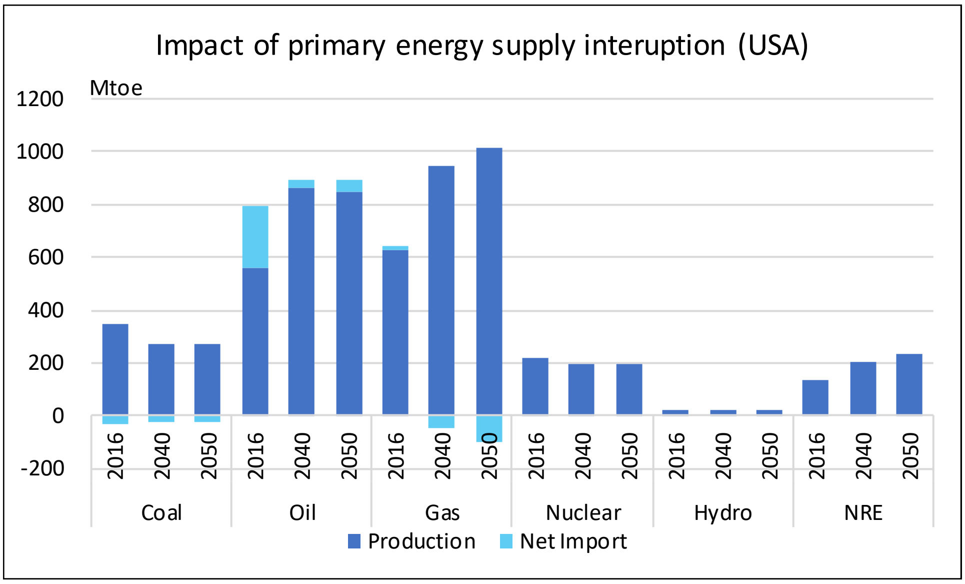
19-2 Resilience for power supply disruption

Thailand	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	26.6	0.3	0.3	6.3	0.1	0.1	20.8	52.8	56.3
Oil	35.9	11.0	7.4	0.1	0.0	0.0	0.3	0.0	0.0
Gas	69.1	24.7	15.0	35.8	5.6	3.1	64.6	28.7	25.7
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	100.0	100.0	100.0	1.4	2.6	2.9	3.6	6.8	7.5
NRE	100.0	100.0	100.0	22.9	25.6	23.6	10.7	11.6	10.6
Total				66.5	34.0	29.8	4727	3800	3995



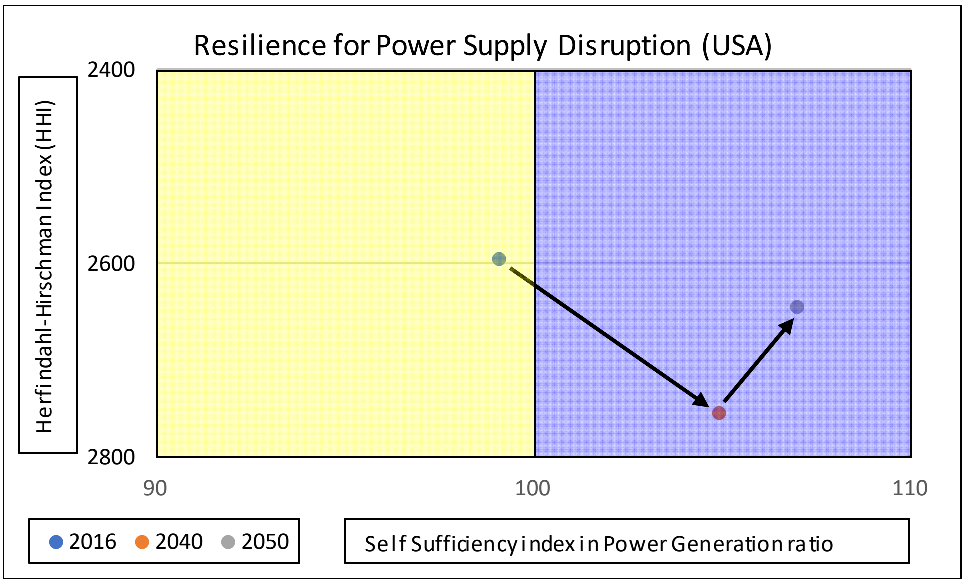
20. Energy supply situation in the United States

20-1 Primary energy supply balance



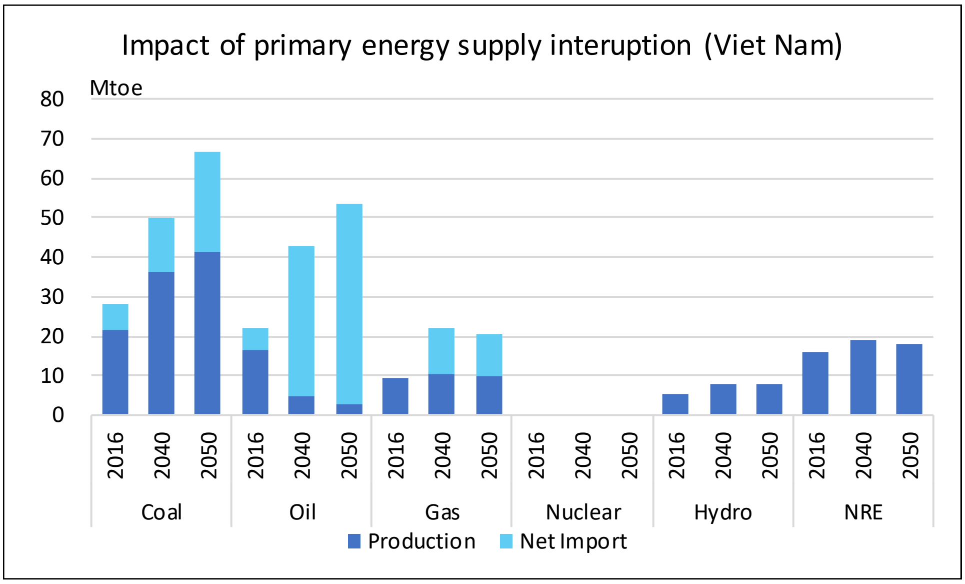
20-2 Resilience for power supply disruption

USA	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	101.1	108.3	108.7	37.3	26.7	26.0	31.8	19.7	18.7
Oil	70.4	113.5	109.9	0.6	0.9	0.9	0.8	0.7	0.7
Gas	96.3	106.9	112.5	27.4	42.8	43.3	33.0	43.0	40.5
Nuclear	100.0	100.0	100.0	25.3	20.8	20.7	19.6	14.8	14.4
Hydro	100.0	100.0	100.0	2.7	2.5	2.5	6.3	5.3	5.2
NRE	100.0	100.0	100.0	5.8	11.2	13.6	8.6	16.6	20.5
Total				99.1	104.9	107.0	2595	2755	2646



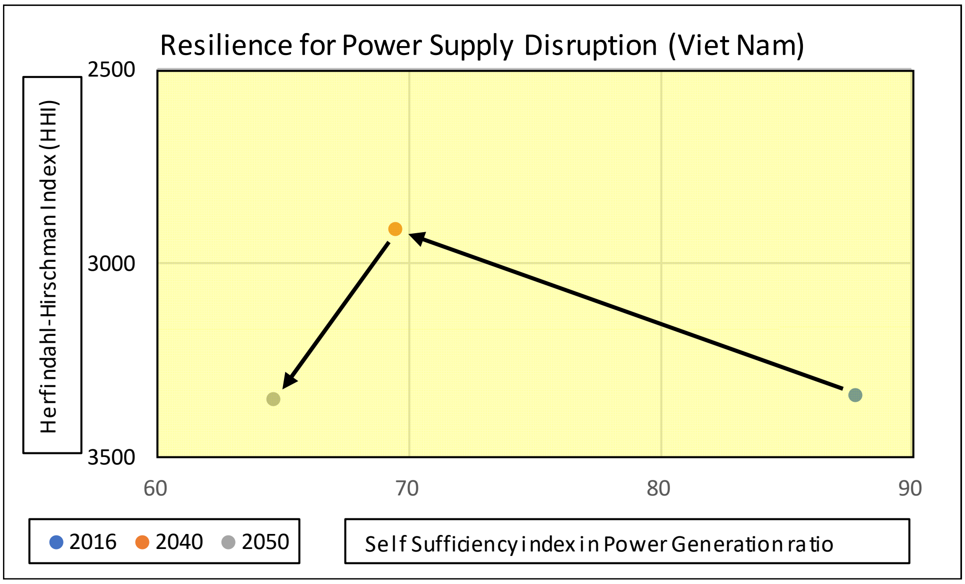
21 Energy supply situation in Viet Nam

21-1 Primary energy supply balance



21-2 Resilience for power supply disruption

Viet Nam	F:Self-sufficiency rate (Maximum value:120)			G:Input(D)-based Self-Sufficiency Index			H:Output(E)-based HHI		
	2016	2040	2050	2016	2040	2050	2016	2040	2050
Coal	78.0	72.8	62.2	38.1	34.0	36.7	32.6	36.2	47.7
Oil	76.1	10.7	5.1	1.1	0.0	0.0	0.7	0.1	0.0
Gas	96.0	47.7	47.9	28.0	16.1	12.0	27.7	26.7	21.2
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	100.0	100.0	100.0	20.4	14.4	11.8	38.9	28.7	24.0
NRE	100.0	100.0	100.0	0.1	4.9	4.1	0.2	8.4	7.0
Total				87.8	69.4	64.6	3341	2911	3351



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