Data Collection Survey Report on Energy Security in Asian Countries

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Abbreviations

ADGSM	The Australian Domestic Gas Security Mechanism
APS	Alternative Policy Scenario
ASEAN	Association of South - East Asian Nations
BAU	Business As Usual
BECCS	Bio Energy Carbon Capture and Storage
CAMMESA	Compañía Administradora del Mercado Eléctrico Mayorista S.A.
CBM	Coal Bed Methane
CCS	Carbon Capture and Storage
CCUS	Carbon dioxide Capture, Utilization and Storage
CDM	Clean Development Mechanism
CES	Clean Energy Scenario
CNG	Compressed Natural Gas
CNOOC	China National Offshore Oil Corporation
CNPA	Cambodian National Petroleum Authority
CNPC	China National Petroleum Corporation
COP	Conference of the Parties
COVID	Coronavirus Disease
DACS	Direct Air Capture and Storage
DEEP	Discovery of Efficient Electricity Price
DG	Distributed Generation
DOE	Department of Energy
EAC	Electricity Authority of Cambodia
EDC	Electricite du Cambodge
ENTSO	The European Network of Transmission System Operators
EOR	Enhanced Oil Recovery
EPE	Empresa de Pesquisa Energética
EPTC	Electric Power Trading Company
ERC	Energy Regulatory Commission
ERIA	Economic Research Institute for ASEAN and East Asia
EU	European Union
EVN	Vietnam Electricity
FIT	Feed-In Tariff
FIT-CfD	Feed in tariff – Cash for Difference
FSRU	Floating Storage and Regasification Unit
GCA	Global Climate Action
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HHI	Herfindahl and Hirschman Index:
Hz	Hertz
IEA	International Energy Agency:

INDC	Intended Nationally Determined Contribution
IPP	Independent Power Producer:
ISO	Independent System Operator
JSC	Joint Stock Company
LED	Light Emitting Diode
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MJ	Mega Joule
MME	Ministry of Mines and Energy
MOF	Ministry of Finance
MOIT	Ministry of Industry and Trade
MONRE	Ministry of National Resources and Environment
MOST	Ministry of Science & Technology
MPI	Ministry of Planning and Investment
mtoe	million tons of oil equivalent
MW	Mega Watt
NERC	North American Electric Reliability Corporation
NGCP	National Grid Corporation of the Philippines
NLDC	National Load Dispatch Center
NPC	National Power Corporation
NPTC	National Power Transmission Corporation
NREB	National Renewable Energy Board
OECD	Organisation for Economic Co-operation and Development
PAT	Perform Achieve and Trade scheme
PDP	Power Development Plan
PNOC	Philippine National Oil Company
PNOC-EC	PNOC Exploration Corporation
PPA	Power Purchase Agreement
PSC	Production Sharing Contract
PtX	Power to x
PVEP	PetroVietnam Exploration and Production
RES	Reference Scenario
RoCoF	Rate of Change of Frequency
ST	Sustainable Transition
STATCOM	Static Synchronous Compensator
TPES	Total Primary Energy Supply
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan
UNFCCC	United Nations Framework Convention on Climate Change
VAEI	Vietnam Atomic Energy Institute
VRE	Variable Renewable Energy

Summary

Concept of Energy security

In this study, the concept of energy security is defined as "a sufficient amount of energy supply is stably secured for the countries' economic activity".

Energy security is composed of five elements. One of the most important elements of energy security is self-sufficiency. This can be rephrased as low (or ideally, no) import dependence. In order to secure a stable supply of energy, it is desirable to supply energy within the border of the country as much as possible and not to depend on other countries.

The second is diversification. Ensuring diversity in energy supply (decentralization of supply sources) is as critical as self-sufficiency to ensure energy security. Ensuring diversity is important because it has a large impact when the supply from its largest energy source is cut off.

The third element is resilience. Resilience is a concept that has become popular in recent years as a component of energy security. It is the ability to minimize the impact of energy supply problem and to recover it in a short period when energy supply problem occurs. Supply resilience can be further broken down into two components: "mitigation of damage" and "swift recovery". "Mitigation of damage" is to create a system in advance so that even if a supply problem occurs, the impact will not have a significant impact on socioeconomics while the "swift recovery" is to restore the pre-disruption status in as short period as possible.

The fourth element is (low) geopolitical risk. If the energy supply depends on imports from other countries, the level of geopolitical risk in the exporting country is also an important component of energy security. For example, when diversifying energy supply sources, if energy is additionally imported from a geopolitically unstable country, the diversity will increase, but the stability of supply itself will decrease and energy security becomes rather worse.

The fifth element is accurate and timely information. Providing accurate information on energy supply and demand is an important component of energy security. When an energy supply problem occurs in foreign country, it is necessary to obtain accurate and timely information on what caused the problem and how long it will take to recover. Such detailed information will also help to avoid panic activities by people.

Energy security in Asian countries

In evaluating energy security in developing Asian countries, the three components of self-sufficiency rate, diversity, and supply resilience can be verified by the available data among the above five elements. First of all, regarding the self-sufficiency rate of primary energy supply, the rate is 50% or more in all case countries, which is relatively

desirable at present. The self-sufficiency ratio of the total primary energy supply (TPES) is above 50% in all case countries (Figure 0-1). However, it is not necessarily guaranteed that Asian countries can maintain this state in the future. Energy demand is expected to continue to grow in many Asian countries, but it is uncertain whether domestic energy supply (fossil fuels or renewable energy) can be increased to meet that demand.

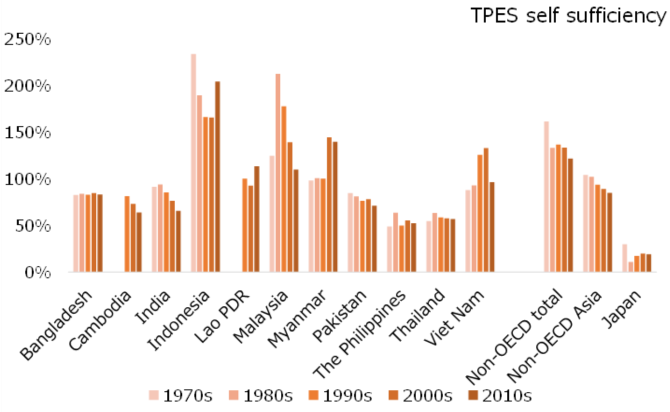

Figure 0-1 Self-sufficiency rate of Asian countries

Source: International Energy Agency, *Energy Balances of the World 2020 edition*

Next, regarding the diversity of total primary energy supply (TPES), the Herfindahl-Hirschman Index (an index to measure the degree of diversity) of primary energy supply shows that the supply sources are well diversified in most countries except for Bangladesh (Figure 0-2). In many of Asian countries, oil used to a major source of energy in the past, but with the increasing use of other energy sources such as coal, natural gas and hydropower, the dependence on oil has gradually decreased and the energy mix became more diversified. In the future, since many countries have a high share of traditional biomass in primary energy supply, which is highly likely to be substituted by other commercial energy sources, depending on which is energy is chosen, the relatively high diversity may be undermined.

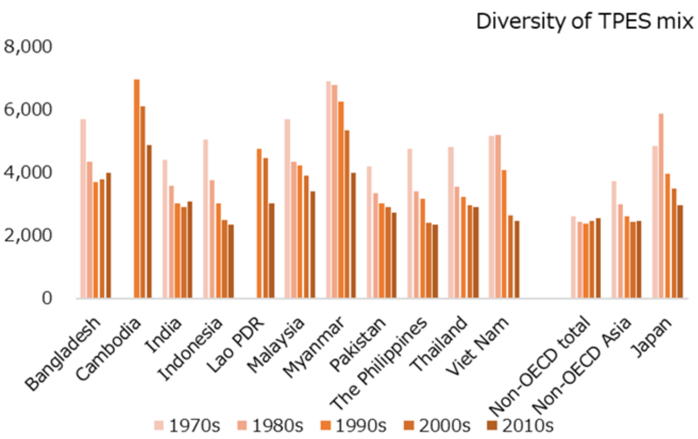

Figure 0-2 Diversity of total primary energy supply of Asian countries

Note: The number of the figure is Herfindahl Hirschman Index, which suggests a lower score shows a larger diversity.

Source: International Energy Agency, *Energy Balances of the World 2020 edition*

The energy intensity of GDP, which indicates how much energy is required for conducting to generate a unit economic value added, is an effective index for resilience in the event of an unexpected supply disruption. The energy intensity of GDP has improved in many Asian developing countries (Figure 0-3). However, when looking at the data, it is necessary to pay attention to the difference in industrial structure. In countries where the proportion of manufacturing industries that consume a lot of energy is high, the figures tend to be poor, and conversely, in countries where the service industry is the mainstream business, the figures look good. In Asia, many countries have introduced reporting obligations and energy manager systems for energy-intensive industries, energy consumption standards and labeling systems for buildings and equipment, energy conservation education, etc. These efforts have contributed to the recent improvement of energy intensity.

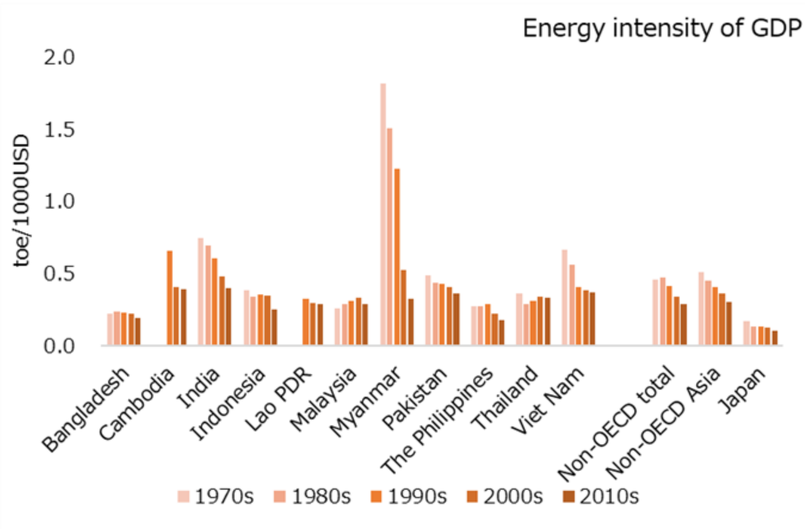

Figure 0-3 Energy intensity of GDP of Asian countries

Source: International Energy Agency, *Energy Balances of the World 2020 edition*

Evaluation of Energy mix in Asia

In this study, energy mix of Asian countries is evaluated by ten indices, namely, 1) TPES self-sufficiency, 2) oil self-sufficiency, 3) natural gas self- sufficiency, 4) coal self-sufficiency, 5) electricity self-sufficiency, 6) diversity of TPES mix, 7) diversity of power generation mix, 8) access to electricity, 9) energy intensity of GDP, 10) CO2 intensity of GDP. The study selects eleven countries (Cambodia, India, Lao, Thailand, Bangladesh, Pakistan, Myanmar, the Philippines, Malaysia, Indonesia, and Vietnam. Indices are scored from 1 to 10 scale depending on the relative position of evaluated country in the range of the lowest and the largest score in the world.

Table 0-1 shows the summary of ten evaluation benchmarks of the above 11 countries. The first finding is that, each Asian country has high self-sufficiency rate of primary energy supply and natural gas and electrification rate compared to other regions in the world. However, the high self-sufficiency rate derives from the fact that conventional biomass is still widely used in many Asian countries. The self-sufficiency rate is likely to decline with expanding use of commercial energy in the future. The second finding is that self-sufficiency ratio of oil and coal and diversity of power generation sources are at a low level. Increasing self-sufficiency ratio of oil and coal is difficult through policy measures because is largely determined by the size of domestic resources. Therefore, each Asian country is set make efforts to improve diversification of supply sources in the future. Particularly, the effective use of natural gas and introduction of renewable energy will be a meaningful countermeasure.

Among Asian countries, Indonesia and Vietnam are the ones whose scores are high in most evaluation benchmarks, suggesting that the countries have a well-balanced and preferable energy mix. Many of the other countries have different scores in each evaluation benchmark.

Table 0-1 Points in Evaluating Energy Mix in Each Country as of the 2010s

	BGL	CAM	IND	IDN	LAO	MAL	MYA	PAK	PHI	THA	VTN
TPES self sufficiency	8.3	6.4	6.5	10.0	10.0	2.0	10.0	7.1	5.2	5.7	9.6
Oil self sufficiency	0.6	0.0	2.1	5.8	0.0	10.0	1.9	1.8	0.5	3.7	8.9
Gas self sufficiency	10.0		6.0	10.0		10.0	10.0	8.9	10.0	7.1	10.0
Coal self sufficiency	3.0	0.2	7.0	10.0	10.0	1.0	7.9	2.5	3.7	2.8	9.9
Power self sufficiency	9.5	6.6	7.0	10.0	10.0	10.0	9.5	10.0	10.0	8.9	9.7
Diversity of TPES mix	6.1	5.2	7.0	7.8	7.1	6.7	6.1	7.3	7.7	7.2	7.6
Diversity of power gen. mix	3.3	6.1	4.5	6.5	3.3	6.2	5.1	7.3	7.1	5.0	6.7
Access to electricity	7.5	4.9	7.9	8.8	9.1	10.0	3.0	7.3	9.0	9.9	9.9
Energy intensity of GDP	8.3	6.1	6.0	7.6	7.2	7.2	6.8	6.4	8.5	6.7	6.3
CO2 intensity of GDP	8.3	7.9	4.1	7.2	6.8	6.3	8.5	7.1	8.3	6.9	5.4
Total	**64.9**	**43.4**	**58.1**	**83.7**	**63.4**	**69.3**	**68.7**	**65.8**	**70.0**	**63.8**	**84.1**

Note: BGL: Bangladesh; CAM: Cambodia; IND: India; IDN: Indonesia; LAO: Lao PDR; MAL: Malaysia; MYA: Myanmar; PAK: Pakistan; PHI: The Philippines; THA: Thailand; VTN: Vietnam. The blank part in the table is the place where the index could not be calculated due to data constraints.
Source: The Institute of Energy Economics, Japan

In this study, not only the current energy mix but also the outlook for the future energy mix is evaluated. For the outlook figures, the study refers to the figures in "Energy Outlook and Energy Saving Potential in East Asia 2020" prepared by the Economic Research Institute for East Asia and ASEAN (ERIA). The reason for adopting this Outlook is that it is a highly reliable outlook that more appropriately reflects each country's economic and policy factors because it was created with the participation of government officials from each country. Since the outlook shows the supply and demand outlook up to 2050, the values of the outlook for 2040 and 2050 are adopted. Since this outlook is prepared only for East Asia Summit countries, the outlooks for Bangladesh and Pakistan are not included. In addition, the outlook will be evaluated in four categories: Diversity of TPES mix, Diversity of power generation mix, Energy intensity of GDP, and CO2 intensity of GDP due to the constraints of available supply and demand outlook data.

Table 0-2 Scores of case countries' future energy mix (APS in the 2050s)

	CAM	IND	IDN	LAO	MAL	MYA	PHI	THA	VTN
Diversity of TPES mix	7.6	7.5	7.3	7.5	6.6	6.8	7.7	6.7	7.4
Diversity of power gen. mix	6.7	6.8	7.1	5.3	6.2	6.4	7.1	5.5	6.0
Energy intensity of GDP	7.7	9.0	9.1	8.6	8.0	9.4	9.2	8.7	7.5
CO2 intensity of GDP	7.4	8.7	8.9	8.0	7.6	9.3	8.9	8.8	6.2
Total	**29.4**	**32.0**	**32.4**	**29.4**	**28.4**	**31.9**	**32.9**	**29.6**	**27.1**

Note: CAM: Cambodia; IND: India; IDN: Indonesia; LAO: Lao PDR; MAL: Malaysia; MYA: Myanmar; PHI: The Philippines; THA: Thailand; VTN: Vietnam. Green-colored column shows the score at above 8.0. Bangladesh and Pakistan are not included. Figures of APS in the 2050s except for Indonesia, which refers to "Low Carbon Scenario Compatible with Paris Agreement target" of "Long-Term Strategy for Low Carbon and Climate Resilience 2050."

Source: The Institute of Energy Economics, Japan

The summary of scores of the future outlook for each country's primary energy supply mix is shown in Table 0-2. In most countries, the diversity in the primary energy supply and power sectors is generally scored at 6 to 7 range, which suggests that their degree of diversity are expected to converge to a similar level in the future. Among them, the scores for Laos and Thailand are relatively low, as the share of hydropower in Lao and gas-fired power sources in Thailand is projected to exceed 60% by 2050 in these countries. On the other hand, the energy intensity and carbon intensity of GDP are expected to improve significantly in the future in all countries. Among the case countries, Vietnam has a relatively low carbon intensity value (high CO2 emissions) as it is assumed that coal will still account for 11% of the total primary energy supply as of 2050.

Next, looking at each country, the Philippines has the highest total score, followed by Indonesia, India, and Myanmar. The Philippines is scored at high because its diversities in primary energy supply and power supply are high. Indonesia also has a well-balanced outlook for diversity, energy intensity and CO2 intensity. For India and Myanmar, expected improvements in energy efficiency and CO2 intensity contribute to the high scores.

It is in fact difficult to develop an energy mix which has very high scores in all of the benchmarks. The energy security scores in this section nonetheless can quantify each country's energy mix, identify the relative fallacies of specific country's energy mix compared to others, and brings some useful policy implications to improve its energy mix.

Issue Analysis and Cooperation Projects with Vietnam

The study analyzes energy mix of Vietnam, Cambodia, and the Philippines more in detail and extracts several potential items of international cooperation with Japan.

Overviewing the energy supply status of Vietnam, the study identifies three issues in the current and future energy mix of Vietnam. The first issue is to reduce the dependence on coal in a realistic manner. Vietnam's dependence on coal is high among the three case countries analyzed in this study. Coal is widely used not only in the power generation sector but also in the industrial and the commercial sectors. In the future, coal may not be allowed to use as intensively as today to reduce greenhouse gas emissions, but the rapid phase out of coal-based energy supply infrastructure may cause great loss to the Vietnamese economy. Therefore, as a realistic solution, encouraging the conversion from coal to natural gas, at least during the phase of the energy transition, is a viable and acceptable measure for reducing the current high dependence on coal. One of the pillars of the collaboration between Vietnam and Japan should be to promote the replacement of coal with natural gas.

The second issue is to develop a more detailed energy policy in the non-power sector. In Vietnam, a detailed power development plan has been prepared for the power sector, but for the other non-power sectors, long-term plans have not been necessarily sufficiently developed. In the future, Vietnam will need a well-balanced energy mix of 3Es by ensuring economically rational and stable energy supply and promoting climate change countermeasures. A similarly detailed roadmap of energy supply and infrastructure development for the non-power sectors will help such efforts.

The third issue is to build a competitive and highly transparent energy industry structure. In Vietnam, system reforms have already been carried out in the electricity market, which has effectively functioned in securing a stable and transparent supply of electricity while securing investments. On the other hand, the system reform of the gas market relatively lags behind, and the reform equivalent to the electric power market may worth considering to ensure efficient natural gas supply to Vietnam. Specifically, it is desirable to set clear rules regarding the industrial structure in the gas market, the division of responsibilities of the government, state-owned entities, and private companies, and the method of determining the electricity and gas prices for the final consumers based on the imported natural gas. Such system reforms will also be important in securing investment in future gas supply infrastructure development.

Based on these three objectives, the study proposes i) LNG value chain study, ii) technological cooperation for LNG adoption and utilization, and iii) gasification road map in the non-power sectors.

(1) LNG value chain study

The objective of this cooperation project is to ensure stable and economic LNG supply to achieve sustained economic growth with competitive and low-carbon energy supply.

The specific items in the study are composed of the following three. The first is elaboration of the dynamics of international LNG market. In evaluating the optimal business model of LNG, external factors that may have an impact the Vietnam's LNG procurement needs to be well understood. Such external factors include transaction forms in the international LNG market, contract trends, technology development trends, future supply and demand outlook, and the technologies to lower greenhouse gas emissions in the supply chain of LNG.

The second item is to examine an optimal business model. By reviewing the relevant value chain cases related to LNG import and utilization in other major LNG importing countries, plausible options of LNG business models that can be considered in Vietnam to government and state-owned enterprises such as MOIT and PV Gas will be provided. And then, the most preferred mode is identified based on various factors including the consistency of the political, economic and energy situation in Vietnam and the existing legal system. In order to promote the development of the LNG industry in Vietnam, domestic political, economic, and energy environment, operational and commercial risks, and technical issues related to LNG will be examined in the identification process.

The third item is an analysis of domestic natural gas and LNG industrial policies. As the use of natural gas and LNG expands in the future, demarcation of the business scope of existing state-owned enterprises and private players need to be clarified. An independent regulator may also better to be established, and legal and regulatory systems related to the import and utilization of LNG have to be developed and refined. Based on Vietnam's unique conditions as well as the learning from other LNG importing countries' experience, required policy menu for sound development of LNG utilization will be provided in this project.

(2) Technological cooperation for LNG adoption and utilization

This cooperation project is to enable the Vietnamese government or state-owned oil companies obtain comprehensive knowledge on the receiving and utilization of LNG. Acquiring LNG-related knowledge through the capacity building of these government's and state-owned oil companies' officials will lead to seamless and efficient receiving and utilization of LNG.

Specific action in this project is providing training programs to the targeted group of officers at the Vietnamese government and state-owned enterprises. The following items can be considered as specific contents of the training program:

- Law and regulatory frameworks for LNG receiving business including safety, environment, health issues
- LNG / natural gas applications for power generation, industrial use, consumer use, transportation
- LNG receiving / utilization infrastructure finance
- Procurement contract with LNG seller
- Training programs, manuals, and exercises for operation at LNG receiving terminals and related equipment
- Construction contract for LNG regasification facility, operation contract with terminal operator

In addition to the above items, the legal and operational issues related to third-party access to the natural gas related infrastructure may be included to expand the business opportunities of natural gas supply in Vietnam. Also, in order to utilize the LNG receiving terminal, utilization of cold heat of the terminal may be included in the training program.

(3) Gasification road map in the non-power sectors.

The purpose of this roadmap development is to ensure a stable supply of natural gas in the industrial, transportation, residential, and commercial sectors of Vietnam to ensure a balanced energy supply structure of the entire Vietnamese economy.

The first item of the roadmap is market development plan for the industrial sector. In order to promote the use of natural gas in non-power sectors. The industrial sector is the most important sector because its demand potential is large and can efficiently gain large demand with a relatively small amount of supply infrastructures. Demand development in the industrial sector will include policy support for infrastructure development and switching to natural gas from other furls. Since the industrial sector consumes more energy than other sectors, it is expected that the promotion of conversion to natural gas will greatly contribute to the reduction of GHG emissions in Vietnam.

The second item is natural gas supply plan for the transportation sector. Land transportation and shipping sectors are expected to switch from the current petroleum-based fuels such as gasoline, diesel oil and fuel oil to natural gas. Among them, the use of liquefied natural gas (LNG) or compressed natural gas (CNG) vehicles in the land transportation sector can be a potential option for the long-distance transportation. In these days, LNG-fueled vessels also gain industrial attention as the regulations of carbon emission from vessels are being discussed at international organization such as International Maritime Organization. By switching from existing petroleum-based fuels to natural gas fuels, it is also possible to reduce hazardous materials such as sulfur oxides and nitrogen oxides besides CO2.

The third item is demand development plan for the residential and commercial sectors. This study project will particularly feature the demand potential in the commercial sector and considers various policy menu to encourage gasification in the commercial sector including energy efficiency standard or subsidy system for fuel switching.

Issue Analysis and Cooperation Projects with Cambodia

Overviewing the energy supply status of Cambodia, the study identifies two issues in the current and future energy mix of the country.

The first is to secure a stable and commercial energy supply to the people of Cambodia. Cambodia still highly relies on conventional biomass fuels, and its electrification rate is relatively low. In the future, in order to improve the standard of living of the people of Cambodia, development of the commercial energy supply system and investment for required energy infrastructure while meeting other important challenges such as long-term GHG emissions reduction goal, will be a primary energy policy goal of the Cambodia's energy policy. A clear roadmap for such long-term energy supply and infrastructure development plan while meeting long-term carbon neutrality requirement will be an important item for the collaboration between Cambodia and Japan.

The second is to develop a realistic roadmap to lower carbon emissions, and eventually achieve carbon neutrality of Cambodia. The introduction of coal-fired power generation is currently progressing in the Cambodia's power generation sector, and the demand for oil is expected to increase mainly in the transportation sector in the future. On the other hand, in order to promote climate change measures on a global scale, it is certain that Cambodia will be required to make concrete efforts toward carbon neutrality in the future. Identification of renewable energy resources in Cambodia will be certainly an important task, and, expanding the use of natural gas in the sectors that are not easily substituted by renewable energy are important step to reduce carbon emissions. Although natural gas is not currently consistently used in Cambodia, the introduction of natural gas will improve energy security by diversifying the primary energy sources. Joint development of the future carbon emissions reduction plan between Cambodia and Japan will be another item of the bilateral collaboration.

Based on the above objectives, two projects for international cooperation, namely, the development of master plan toward energy transition and the technical cooperation project for LNG utilization are proposed as meaningful activities for the bilateral cooperation between Cambodia and Japan.

(1) Master plan toward energy transition

The purpose of this collaboration is to formulate a master plan for energy transition in Cambodia. Four research items are included in the study. The first is the development of long-term energy and natural gas demand outlook. In considering the life of infrastructure investment that will last for several decades, a long-term outlook for energy demand with a view to 2040 or 2050 is indispensable. In this cooperation project, such a long-term energy demand outlook will be prepared first with detailed analyses of natural gas demand trends in each demand sector.

The second item is the planning of infrastructure development to realize the envisaged energy transition after the long-term future demand outlook is developed. Major components of the plan include the scheduled time table of the development of natural gas-fired power generation, LNG receiving facilities, and domestic pipeline network development, and so on.

The third is dentification of prioritized infrastructure. Specifically, during the transition period, natural gas-fired power generation, LNG receiving facilities, and domestic pipeline network development, will be included as the contents of the plan. In the long term, identification of domestic renewable energy supply sources, transmission and distribution network development from the identified sources, and distribution network development are needed as required infrastructure.

The fourth is providing policy proposals. The proposals include the development of various legal and regulatory systems including the business law for natural gas supply and distribution, investment-related frameworks, various policy menu to promote natural gas use in each demand sector, and the establishment of a new government organization for gas-related businesses including domestic gas-fired power generation for the transitional period. The road map will also include specific policy items to make renewable energy as the primary generation sources. The roadmap will include demand structure and infrastructure development plans in the benchmark years such as 2030 and 2040, with a target of 2050.

(2) Technical cooperation project for utilization of natural gas/LNG

This cooperation project aims to transfer required knowledge and expertise to facilitate the adoption of natural gas and LNG in Cambodian energy and power generation mix.

The first item included in this project is the transfer of knowledge on the overall natural gas and LNG utilization. Such transfer includes fundamental policy issues of natural gas utilization, preferred demand sectors of natural gas use, infrastructure development requirement, setting tariff of natural gas supply, technologies in natural gas utilization, and safety, health, and environment (SHE) issues in natural gas use.

The next item is to assist the development of legal and regulatory systems in natural gas use. Since the Cambodian government will need to provide specific legal and regulatory framework as its use of natural gas expands, the international cooperation project will be consulted by the Cambodian government officials who are in charge of such legal / regulatory developments and provide a template for such systems.

Finally, the third item is the developments of technical and SHE standards. Because there is no current use of natural gas in Cambodia, it is necessary to establish such standards from scratch. The company that conducts the business is primarily responsible for the operational issues, but the government officials are preferred to acquire knowledge about how natural gas-related operations are conducted. Such operational and technical expertise are important for more effective and efficient policy planning and elaboration.

Issue Analysis and Cooperation Projects with the Philippines

Overviewing the energy supply status of the Philippines, the study identifies three issues in the current and future energy mix of the country.

The first is to secure alternative supply of depleting domestic natural gas, which is expected to cease the production in 2024, as relatively a short-term issue. Most of the gas produced from the domestic gas field is used for power generation, but considering the period until the production stoppage and the reduction of greenhouse gas emissions, the introduction of imported LNG seems a practical solution. Collaborating in assisting smooth and efficient introduction of LNG as a substitution of the domestic natural gas supply as well as utilization of imported LNG to other energy applications such as industrial fuels will be of higher needs for the Philippines.

The second is to reduce the dependence on coal in a realistic manner. The demand for coal has increased 2.6 times in the Philippines due to the significant increase in demand for power generation in the last 10 years. Most of the new thermal power sources committed at this time, furthermore, are also coal-fired. Such coal-biased power development is not very preferable not only from the climate action's perspective but also from the energy security perspective. Therefore, in order to reduce the dependence on coal, a realistic path needs to be drawn and LNG will play a key role in the reduction actions.

The third is to show a clear path of long-term introduction of renewable energy and achieving carbon neutrality. As mentioned above, it is expected in the government's outlook that the introduction of fossil fuels such as coal will progress in the Philippines in the mid-term. Even in the government's energy demand scenario that assumes least dependent on fossil fuels, the share of fossil fuels as of 2040 is 68%, which is almost the same as the current level. Since the share of hydroelectric power generation is low in the Philippines and the development of geothermal power generation is stagnant, domestic wind power, solar power generation, nuclear power generation, and hydrogen including ammonia will need to be used to reduce the dependence on fossil fuels in the future. A long-term supply and demand plan for utilization of such zero-emission energy sources will an important collaboration item.

Based on the above three objectives, this study proposes three support projects: a natural gas utilization master plan, a technical cooperation project for LNG utilization, and the creation of a net zero scenario.

(1) Natural gas utilization master plan

Based on the above background, this study proposes to prepare for a master plan for expanding the use of natural gas as one of the future international cooperation with the Philippines. The plan will promote the use of natural gas in a systematic manner and ensure the Philippines to access to economic, environmentally friendly, and reliable energy and power supply.

This cooperation project will have four specific items. The first is long-term energy / power generation demand and supply scenarios with a view to 2050. In these scenarios, it is assumed that different degree of advancements of energy and environment technologies can cause different future scenarios of energy and power generation supplies, and different energy and power supply paths toward 2050 will be provided. Quantitative model analyses in accordance with the different scenarios will also be provided.

The second is infrastructure development plan. Based on the specific scenarios and associated demand projections of natural gas, infrastructure required to enable such scenarios will be identified. Such infrastructure plan will include the development of LNG receiving facilities (floating storage and regasification unit (FSRU) or onshore receiving terminals), port facilities required to accommodate LNG import vessels, pipeline network to consumers, gas-fired power generation facility, and natural gas pipeline network to the Manila area as needed. Depending on the projection of natural gas demand in remote areas, small-scale LNG delivery facility (LNG Hub) may also be included.

The third is a blueprint of system reform of natural gas market. In order to promote the use of natural gas, it is desirable that there is vibrant natural gas industry that are responsible for the expansion of such businesses. Excessive market liberalization, however, may inflate the future business uncertainty and curb investments. The project therefore will include the appropriate market design of natural gas industry to facilitate infrastructure developments and the use of natural gas in the Philippines.

The fourth is a roadmap for expanding the use of natural gas in the Philippines in the future and policy recommendations to the Philippine government and state-owned enterprises such as the Philippines National Oil Corporation (PNOC) will be provided. Regarding the roadmap, based on the demand outlook for natural gas obtained, the demand patterns of natural gas in the Philippines as of 2030, 2040, and 2050 will be shown, and the menu of required policies and the expected infrastructure development to accommodate the forecasted demand will be clarified.

(2) Technical cooperation project for LNG utilization during the transition period

This project aims to share the knowledge of LNG receiving and utilization between the Philippines and Japan to ensure smooth adoption and demand development of LNG in the Philippines.

This project includes three items. The first is the sharing the knowledge and expertise of LNG with the officials of the Philippine government (mainly the Department of Energy) and the state-owned oil company (PNOC). Through the capacity building program of the Philippines government and the PNOC officials, the Philippines can more smoothly pursue its LNG adoption and develop the LNG demand.

The second is the assistance to develop legal and regulatory system for LNG. There are still many policy and regulatory issues that may not have been sufficiently cleared when introducing LNG, such to what extent the government needs to monitor the procured prices of LNG or how to reflect the imported LNG price to the domestic market. This cooperation project will first present a draft framework of the LNG Business Law (tentative name), which summarizes the provisions regarding the import of LNG. It is important to promptly develop various regulations under the jurisdiction of the government organization related to LNG while maintaining consistency with the current judicial and regulations regarding the supply and use of domestic gas.

The third is the assistance to set standards of safety, health, and environment. Various technical and operation standards need to be developed to ensure safety, health, and environment (SHE). Since LNG is a product that needs to be treated with care, it is not easy for operators who do not have sufficient operational knowledge to carry out the LNG handling operations. This cooperation project assists to prepare for such standards on safety, health, and environment and to prepare for a manual on actual operational know-how.

(3) Net-zero scenario in the Philippines

This project provides multiple scenarios to realize net zero for the Philippines and presents an idea for the international net zero pledge which will not excessively burden on the macro economy and the energy supply for the Philippines.

The first item in the scenario study the presentation of two or three scenarios to reach net zeros under different time axes and preconditions related to energy and environmental technology. As a candidate of such scenario determinant, two variables are assumed: 1) the time axis for achieving net zero (2050, 2070, etc.) and 2) the degree of cost reduction of energy and environmental technologies. Then, create multiple scenarios by combining the different variables.

The second item is calculation of economic costs required to achieve each net zero scenario. Each scenario will take a different path of GHG emissions reduction and selected energy portfolio, and will require a different level of carbon price (or marginal emissions reduction cost). Economic costs of each scenario will be compared based on the calculated carbon prices in each scenario. The study then suggests an optimal emissions reduction path with particular time frame and technological assumptions.

The third item is to identify international cooperation items between the Philippines and Japan to realize the net zero emission based on the optimal reduction path. While the candidate areas for such international cooperation will be extensive, this project will identify prioritized ones that will bring large reduction effects while the need for international technical and financial cooperation is large.

1. Concept of Energy Security

1.1 Definition and Importance

1.1.1 Definition

In this study, the concept of energy security is defined as "a sufficient amount of energy supply is stably secured for the countries' economic activity".[1] Energy security is a concept with various definitions. Elements included in the content are also multiple.[2] For example, energy security has a definition that includes reasonable level of energy prices as well as stable energy supply.[3] Given the importance of climate change measures in recent years, there is an argument that inclusion of non-fossil fuel energy in energy security should be a critical element of energy security.[4] However, these additional elements may have conflict with energy supply and stability, a core element energy security and inclusion of non-fossil energy can be covered by an index of diversity. Therefore, in this study, the two points of energy supply such as "quantity" and "stability" are considered as components of energy security.

On the other hand, in recent energy security debates, there is also a debate that includes the concept of fairness in energy security requirements, whether energy is equally supplied to people of various levels in the country.[5] The main target countries of this survey are developing countries in Asia. The issue of energy access in the country is also one of the important policy goals for securing energy supply. Therefore, the issue of energy access will be included as part of the issue of the amount of energy security.

1.1.2 Importance

Energy security is one of the important prerequisites for the economic management of the country. The reason why energy security is important in national policy is due to the characteristics of energy supply. Many energy products (coal, oil, natural gas, LNG, etc.) have a character of market commodity traded at international markets. This means that there is a place where an incremental supply is secured at least if a certain level of price can be paid.

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[1] Jonna Nyman, "Red Storm Ahead: Securitization of Energy in U.S. - China relations," *Millennium - Journal of International Studies*. Vol. 43. p. 44; Congressional Budgetary Office, *Energy Security in the United States*. (Washington D.C.: Congress of the United States, 2012); Christian Winzer, "Conceptualizing Energy Security," *Energy Policy*. Vol. 46., No. 1 (2012). p. 36, etc.

[2] Christian Winzer, "Conceptualizing Energy Security," *Energy Policy*. Vol. 46., No. 1 (2012). pp. 42-43

[3] Daniel Yergin, "Ensuring energy security," *Foreign Affairs*. (2006) Vol .85, No. 2. p. 69 etc.

[4] Benjamin K. Sovacool and Ishani Mukherjee, "Conceptualizing and measuring energy security: A synthesized approach," *Energy* (2011) Vol. 36, No. p. 5343; Bert Kruyt, D.P.vanVuuren, H. J.M. de Vries, ad H. Groenenberg, "Indicators for Energy Ssecurity," *Energy Policy*, Vol. 37, No. 6 (2009). pp. 2169-70 etc.

[5] Benjamin K. Sovacool, "An International Assessment of Energy Security Performance," *Ecological Economics* Vol. 88 (2013). p. 150.

On the other hand, energy products often have a character that a substitutable product is limited and the price elasticity to the demand is low. For example, when the power supply is cut off, it is very difficult to secure alternative product that can provide the same services that electricity provides, such as lighting, air conditioning, and cooking, in the short term. Moreover, a person who usually commutes by private car may find it difficult to change its way of commuting to public transportation just because of the gasoline price rise unless such public transportation is available. Even though the price of gasoline significantly rose, therefore, the commuter is forced to pay for a high-priced gasoline. Energy products can certainly be procured with money, but they also have the character as a strategic goods in the sense that it is difficult to substitute even if supply and demand are tight and prices rise significantly, and sometimes such inability of substitution can cause significant damage to the economy. This is a major reason why ensuring a stable supply of energy is an important policy goal for governments.

As efforts to achieve carbon neutrality are expected to progress, risks of energy security may become more diversified. Since fossil fuels are expected to play an important role at least during the transitional period, fundamental elements will not significantly change. Yet, as electrification in the energy mix progresses, the share of variable renewable energy (VRE) will increase in the power supply mix. In such condition, how to address the intermittency of VRE, the decrease in inertial force in the power generation, and securing a low-carbon base load power source will be regarded as additional energy security concern. In order to manage such variable supply, therefore, investments and research and development for the transmission and distribution network and storage technologies such as battery and hydrogen will be a more important counter measure for energy security.

In addition to these “known” issues, furthermore, various “unknown” issues may emerge, as the world will adopt VRE up to an unprecedented level. Keeping an eye on the latest development, continuous research and development, sharing best practices to manage such future tasks will become more important.

1.2 Components of Energy Security

Energy security is composed of particular elements, this section discusses five such elements: self-sufficiency, diversity, supply resilience, low geopolitical risk, and availability of information.

1.2.1 Energy Self-sufficiency Rate

One of the most important components of energy security is self-sufficiency. This can be rephrased as low (or ideally, no) import dependence. In order to secure a stable supply of energy on a country basis, it is desirable to supply energy within the border of the country as much as possible and not to depend on other countries. Among the self-sufficiency rates, the increase in the self-sufficiency rate of oil has been often regarded as a major energy security issue in the world. Since the oil crisis of the 1970s, many countries have sought to reduce their dependence on oil imports by developing domestic energy resources as well as promoting energy conservation.[6] Since the 1980s, international crude oil prices have been low and stable for a long time due to the drastic easing of oil supply and demand, the so-called "reverse oil shock." With widespread recognition that oil can be procured most efficiently by the international markets, self-sufficiency became regarded less important in energy security policy. However, the self-sufficiency rate in energy security seems to be becoming more important in recent years because of the increased geopolitical risk in oil producing regions in Middle East.

Specific measures to raise the self-sufficiency rate are to promote energy conservation to reduce energy demand and to promote development of domestic energy resources such as renewable energy and nuclear power. The development of these non-fossil energies is expected to contribute also to climate change countermeasures.

1.2.2 Diversity

Ensuring diversity in energy supply (decentralization of supply sources) is as critical as self-sufficiency to ensure energy security. Ensuring diversity is important because it has a large impact when the supply from its energy source is cut off. In fact, ensuring the diversity of energy sources is another cornerstone of energy security. Before the start of World War I, it is widely known that Winston Churchill, British Navy Minister stated that it is safe and certainty in oil lie in "variety and variety alone."[7] The "N-1 Principles" adopted in the EU power supply risk scenario (to be explained later) are also basically considered as one criterion for ensuring diversity.

As an index for evaluating the diversity, Herfindahl and Hirschman Index (HHI) is often used. This is the sum of the squared share of each energy source. Theoretically, it ranges from zero to a maximum of 10,000 (in the case of a monopoly). Diversity can be secured when it is close to zero. An actual example will be described later.

There are several "layers" of diversity to ensure in energy security. The first layer is the kind of primary energy source. For example, countries that are highly dependent on oil are vulnerable to unexpected oil supply disruptions and sharp rises in oil prices. In power supply, for example, in a country that relies heavily on hydropower, the stability of power supply depends on the amount of rainfall. Ensuring diversity based on the characteristics of each primary energy supply is one of the most important components

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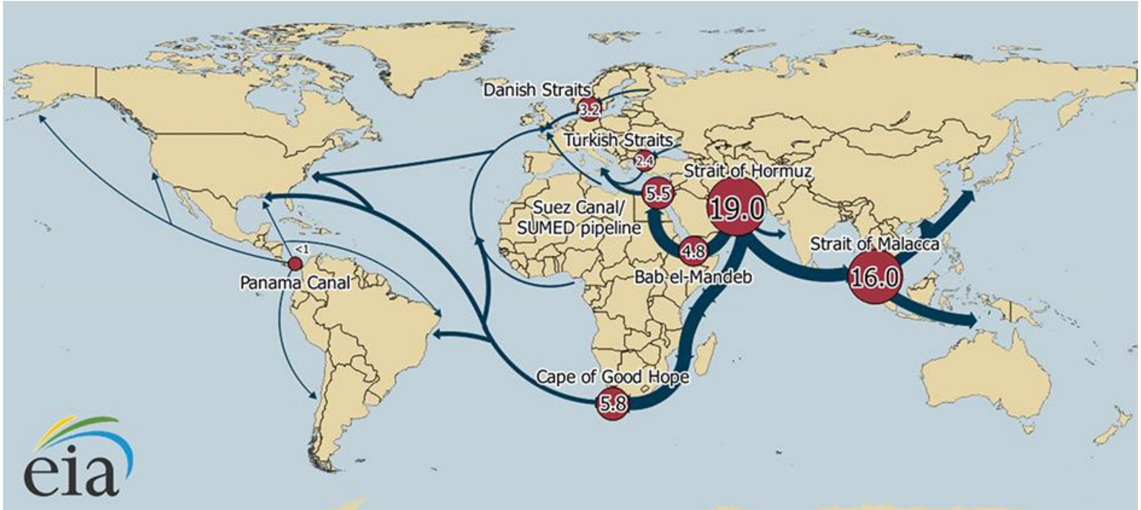
[6] The Agency for Natural Resources and Energy, https://www.enecho.meti.go.jp/about/whitepaper/2010html/1-1-3.html. Accessed on 8 January 2021.
[7] Daniel Yergin, "Ensuring energy security," *Foreign Affairs*. (2006) Vol .85, No. 2. p. 69.

in energy security.

The second layer of diversity is the geographical source of supply. For example, there are two types of oil imports. One is that all oil is supplied from a single source. Another is supplied from multiple sources. In this case, the latter can be said to be a more stable supply because even if one of the sources is interrupted, the supply from the other sources is secured. In recent years, the EU has called on its member states to expand their interconnection with other countries. Establishing such a system not only promotes the integration of energy markets in the region, but also enhances mutual energy security by diversifying the geographical sources of each member country. In addition, securing a variety of sources is an advantageous factor for energy buyers in negotiating more economically desirable procurement conditions.

The third layer of diversity is diversity in transportation and logistics. Ships are often used to transport energy. Among the routes used to transport energy, there are strategically important marine waterways such as the Suez Canal and the Strait of Hormuz, so-called choke points (Figure 1-1). Some of these choke points are politically unstable. In order to ensure stable energy transport, it is desirable to reduce the dependence on choke points.

From the perspective of diversity in the transportation of oil and natural gas, there is transportation by international pipeline or by ship. The initial investment of the pipeline is costly, but once it is constructed, the operating cost can be greatly saved. However, if the supply of the pipeline is interrupted for some reason, it is difficult to transfer to another supply method compared with the supply by ship. Since the choice of transportation depends largely on the geographical conditions of the country and the economics of infrastructure development, it is difficult to determine which option is more desirable. But in terms of energy security, countries that depend both on pipelines and maritime supply will be more flexible by securing alternative supply systems.

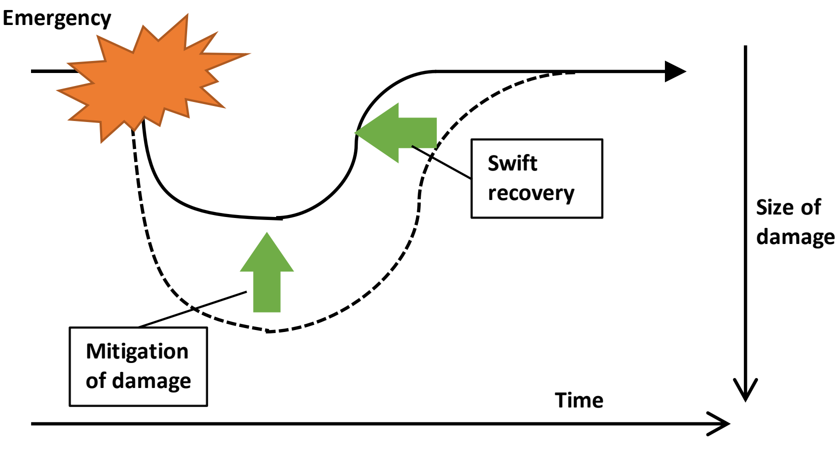


Note: The values in the figure are actual oil transportation volume in 2016 (unit: million b/d)
Source：U.S. Information Administration, "WORLD OIL TRANSIT CHOKEPOINTS." 25 January 2017.

Figure 1-1 Choke points in the World

1.2.3 Supply Resilience

Resilience is a concept that has become popular in recent years as a component of energy security. Resilience is the ability to minimize the impact of energy supply problem and to recover it in a short period when energy supply problem occurs, rather than completely preventing it. (Figure 1-2).



Source: The Institute of Energy Economics, Japan

Figure 1-2 Resilience Image

Supply resilience can be further broken down into two components: "mitigation of damage" and "swift recovery". "Mitigation of damage" is to create a system in advance so that even if a supply problem occurs, the impact will not have a significant impact on socioeconomics.

Energy conservation is important in this system. If the energy demand required for economic activities is small, when the energy supply is interrupted, the adverse effect on the domestic economy will be small. As a specific index showing the degree of such energy conservation, the GDP intensity of energy (energy demand per GDP) is often used. Energy conservation tends to be relatively neglected as an energy security measure, as it is not a “conspicuous” measure compared to securing new alternative sources or developing domestic energy. However, promotion of energy conservation is an energy security measure should be prioritized because it essentially a domestic effort that can be undertaken readily and also can be applied in all energy consumption sections. Best practices in individual fields for energy conservation are also readily available for use. In emerging countries where energy demand continues to grow, there is large potential for energy conservation.

Another important measure to minimize the impact is to ensure redundancy (surplus capacity). Even if a problem occurs on the supply side, if there is a "surplus capacity,” the impact of the problem can be mitigated by utilizing the surplus capacity. The most typical countermeasure in the surplus capacity is to secure stockpiles. Although various energy sources can be stockpiled, oil is the most stockpiled energy source. Oil can be stockpiled relatively easily and at low cost if storage facilities can be developed. Crude oil stockpiling also has the advantage that its quality does not easily deteriorate even if it is stored for a long time. If there is a refinery with sufficient capacity in the country, it is more desirable to stockpile with crude oil. On the other hand, natural gas is difficult to stockpile unless geological conditions are met. However, some countries, such as Finland, have the energy-equivalent amount of oil stockpiling instead of natural gas stockpiling. Also, it is desirable that redundancy is ensured in all supply chains. For example, it is desirable that there is surplus capacity for storage, pipeline capacity, the number of tankers and trucks in the case of petroleum product. In the case of electric power, the reserve ratio in power generation capacity and surplus capacity of the transmission are also desirable. On the other hand, these surplus capacities are used only in an emergency, and thus having such unused surplus capacity normally is not desirable in terms of ensuring economic efficiency. Therefore, in order to secure such surplus capacity, the government often maintains its own surplus capacity as a policy like the national oil stockpiling. Alternatively, it is necessary to oblige the business operator to secure surplus capacity as a regulation.

Minimizing the impact also includes countermeasures to further strengthen the energy supply infrastructure itself. As seen in the case of Japan, measures to improve resilience include strengthening the power grid, improving the earthquake resistance of gas pipelines to natural disasters, and disaster countermeasures for supply infrastructure in coastal areas such as refineries. Especially in developed countries, the infrastructure built in the past is aging, and it is important to strengthen such fragile infrastructure.

Along with minimizing the impact, swift recovery which is another component of supply resilience, mainly includes "soft" capabilities such as emergency response planning and actual emergency response capabilities through regular training. In general, when an emergency occurs, the energy supply decreases sharply, while the additional energy demand increases due to emergency response. Emergency response is also required to establish standards and decision-making systems that prioritize the timely supply of energy to consumers who need the most energy. Although it is difficult to quantify and evaluate such measures, it is one of the indispensable elements when considering energy security.

1.2.4 Geopolitical risks

If the energy supply depends on imports from other countries, the level of geopolitical risk in the exporting country is also an important component of energy security. For example, when diversifying energy supply sources, if energy is imported from unstable countries in addition to politically stable countries, the diversity will increase, but the stability of supply itself will decrease and energy security becomes rather worse.

The country risk assessment published by the OECD is often used for the quantitative assessment of such geopolitical risks.[8] However, since analyzing geopolitical risks requires a deep understanding of the political, economic, and social conditions of the country, it is desirable to conduct a professional analysis of individual countries and regions for the evaluation.

In addition, although it is different from general geopolitical risk, if the energy supply country is internationally isolated, the supply may be restricted by imposing economic sanctions by the United States, EU, etc. For example, Iran has a relatively stable domestic political situation and has sufficient capacity for oil exports. However, the United States has imposed economic sanctions on Iran's nuclear technology development. As a result, third-party countries are also unable to import crude oil from Iran. In addition to Iran, the United States has imposed similar sanctions on Venezuela. Countries procuring oil from Venezuela are under pressure from the United States to relocate their sources.[9] These US sanctions are affecting not only US companies but also

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[8] Organization of Economic Cooperation and Development, "Country Risk Classifications of the Participants to the Arrangement on Officially Supported Export Credits." 16 October 2020. http://www.oecd.org/trade/topics/export-credits/documents/cre-crc-current-english.pdf. Accessed on 3 January 2021.

[9] Clare Ribando Seelk, "Venezuela: Overview of U.S. Sanctions," *In Focus*. 30 October 2020. https://fas.org/sgp/crs/row/IF10715.pdf. Accessed on 5 January 2021.

the business activities of other countries because the US government has restricted access to US financial markets to third countries that have economic deals with Iran and Venezuela. Companies in these third countries are forced to comply with U.S. sanctions because they will not be able to use the dollars needed for international payments if they are not allowed to access to U.S. financial markets. Therefore, from the perspective of geopolitical factors that affect the stable energy supply, it is necessary to consider the possibility of secondary sanctions by the United States and the EU.

1.2.5 Correct and timely of information

Providing accurate information on energy supply and demand is also an important component of energy security. When energy supply problems occur in foreign country, it is necessary to obtain accurate and timely information on what causes the problem and how long it will take to recover. It is also important to take appropriate measures to deal with the problem.

Even if a problem occurs domestically, it is necessary to promptly grasp the situation (cause of the problem, degree of damage to infrastructure, etc.) in the area and the situation of energy supply and demand. Especially when the power is cut off, the communication tools that use the power may also be cut off. This may not provide sufficient information in areas that require the most energy supply to energy providers. To prevent such a situation, various communication and information sharing systems must be prepared.

The first step in increasing the availability of such information is to expand the ability to collect information. To develop an international information gathering system, it is conceivable to strengthen the information sharing system through international organizations, as well as to expand the so-called intelligence capabilities that each country individually develops through the expansion of functions such as diplomatic missions abroad. In energy sector, the International Energy Agency has mainly functioned as an information sharing mechanism among developed countries. In the future, as energy demand in emerging countries increases, it is necessary to develop a more comprehensive international information sharing mechanism including new energy consuming countries.

One of the domestic activities is to improve the statistical system. Accurate and timely statistical data on energy supply and demand is extremely important for making accurate policy decisions. Moreover, such accurate information needs to be widely shared with the public. If accurate supply and demand information is not shared, false information, speculation, or rumors can lead panic among consumers.

The above are the five main elements that make up energy security. However, these elements may conflict with each other. For example, the pursuit of primary energy diversity may lead to increased reliance on imported energy, which is negative for improving self-sufficiency. In addition, one element may include another. For example, both ensuring diversity and improving self-sufficiency will have the effect of improving supply resilience. The important thing in improving energy security is to *balance each element* rather than thoroughly pursuing only one of these elements. It means considering what is the "optimal" balance is a critical core of energy security discussions.

1.3 Energy Security Policy in selected countries

To ensure the energy security, this section shows an overview of policies in major developed countries.

1.3.1 Japan

In traditional Japanese energy security policy, the main concern was to ensure the stability of imported oil. During World War II, Japan was imposed oil embargo sanctions by the Allies. There is historical experience that this caused enormous economic and security damage. In addition, after World War II, oil production began in various countries in the world and the oil supply capacity increased dramatically. As a result, the "fluid energy revolution" occurred in which the raw materials for chemical industries and fuel for power plants and industrial plants are converted from coal to petroleum products. Domestic oil demand in Japan increased dramatically in the early 1970s. In particular, oil demand from 1960 to 1970 increased by 1.5 times.

The increase in oil demand was mainly covered by imports from the Middle East countries. Since the latter half of the 1960s, both the establishment of oil stockpiling (ensuring redundancy) and the development of oil fields in overseas by Japanese companies (ensuring supply resilience and to some extent self-sufficiency) were recognized as the main measures to ensure energy security. The need for oil stockpiling was triggered by an oil embargo by Arab oil-producing countries on Western countries during the Third Middle East War in 1967. In 1972, the private oil stockpiling system that obliged private oil companies to stock a certain amount of oil started. In 1973, at the first oil crisis, Japan's oil dependence on total primary energy supply was 75% and the share of oil-fired power generation was 73%. Since the oil crisis was occurred, the main focus of Japan's energy security policy from the 1980s to the 1990s was to reduce this high dependence on oil and to diversify energy source. In December1975, the Oil Stockpiling Law was enacted to expand the existing private oil stockpiling. In addition, bases for national oil stockpiling were constructed in 10 locations in Japan under the initiative of the Japan National Oil Corporation. Such an oil stockpiling system was also promoted as emergency response system[10] established by the International Energy Agency (IEA) that was founded after the oil crisis. Foundation of IEA was also an effort to sure information availability.

The national stockpiling in Japan is not only for oil, but also for liquefied petroleum gas (LPG). This is because LPG plays an important role as household energy, especially in rural areas, and has a large impact on people's lives in the event of a supply cut-off. National LPG stockpiling started in 2007 and LPG stockpiling for 50 days (1.4million tons) was completed in 2012.[11]

Contrary to oil and LPG, natural gas has no institutional stockpiling system. Power companies and/or city gas companies only have their own commercial inventory for several weeks. Japan imports most of its natural gas as in the form of liquefied natural gas (LNG). LNG is difficult to store for a long time. This because the specific gravity of natural gas is very light, and a certain ratio of gas is continuously released into the atmosphere even if it is liquefied and stored at an ultra-low temperature. Coal, on the other hand, is not stockpiled due to the low geopolitical risk of major exporting countries (Australia, Canada, Indonesia, etc.).

After two oil crises in the 1970s, along with the development of stockpiling system, a policy to diversify the sources of oil imports from outside the Middle East countries was promoted. Oil companies in Japan jointly procured crude oil from China and Mexico to increase supply sources outside the Middle East countries. As a result, dependence on the Middle Eastern oil dropped to 68% in 1986 as shown in Figure 1-3. In the 1990s, however, as the international oil price fell and maintained low level for a long period of time, interest in diversifying sources at additional cost receded and the dependence on the Middle East rose to nearly 90% again. In recent years, exports of Russian crude oil have been started, and the dependence on the Middle East has temporarily declined to the low 80% range. After that, it rose again to 88% in 2019.

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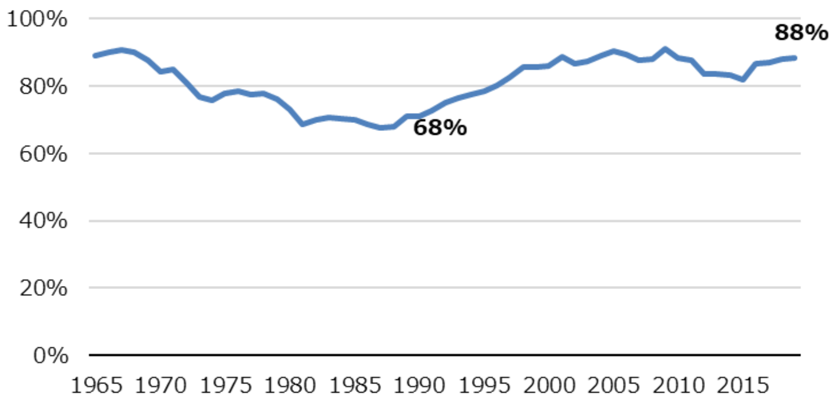
[10] The emergency response system is that the member countries of the IEA maintain oil reserves of the specified scale in normal times and release the oil reserves when there is a disruption in oil supply among the member countries.

[11] https://www.meti.go.jp/press/2017/11/20171102002/20171102002.html



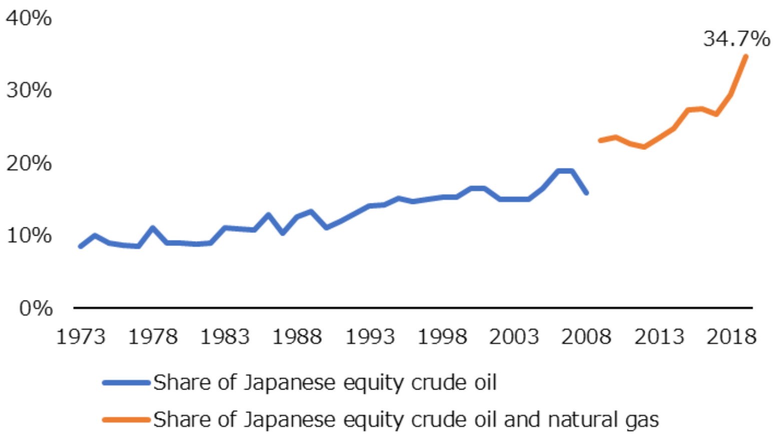
Source: Ministry of Finance, "Japan Trade Statistics"

Figure 1-3 Middle East Dependence on Japan's Crude Oil Supply

In Japan's energy security policy, securing self-developed crude oil is also a major policy goal (self-developed crude oil is crude oil produced from oil fields owned by Japanese companies). Having a large number of self-developed crude oils makes it possible to preferentially supply oil to Japan in the event of a supply cut-off in the international oil market, without depending on supply from foreign companies. In addition, by having self-developed crude oil, it is possible to strengthen relations with the resource-holding countries and provide closer cooperation for the stable political and economic management. Furthermore, by securing own wells and having positions to sell crude oil, it is possible to partially offset the increase in prices even in the event of a sudden increase in crude oil prices. [12]

With regard to securing self-developed crude oil, a numerical target was set in 1967 to secure 30% of imports by 1985. However, this target was not achieved. When the Basic Energy Plan was revised in 2010, the target was modified to secure 40% of oil and natural gas imports combined by 2030. Figure 1-4 shows the ratio of self-development oil and the ratio of self-development oil and natural gas since the 1970s. In recent years, the ratio of self-development has risen to 34.7% in 2019 due to the decrease in domestic oil and gas demand and the increase of LNG projects by Japanese companies.

[12] This effect is said to be the natural hedging effect in vertical integration.



Note: The ratio after 2009 is the total ratio of oil and natural gas.
Source: Agency for Natural Resources and Energy website

Figure 1-4 Trends in Japan's Self-Development Ratio

Recent energy security policies have been focused on ensuring resilience of domestic energy supply. This is due to natural disasters, such as large earthquakes and severe typhoons, cut off the energy supply in recent years. As for resilience measures, specific measures have been taken for each energy supply. In the discussions on the review of the Basic Energy Plan scheduled in 2021, the following issues will be discussed.

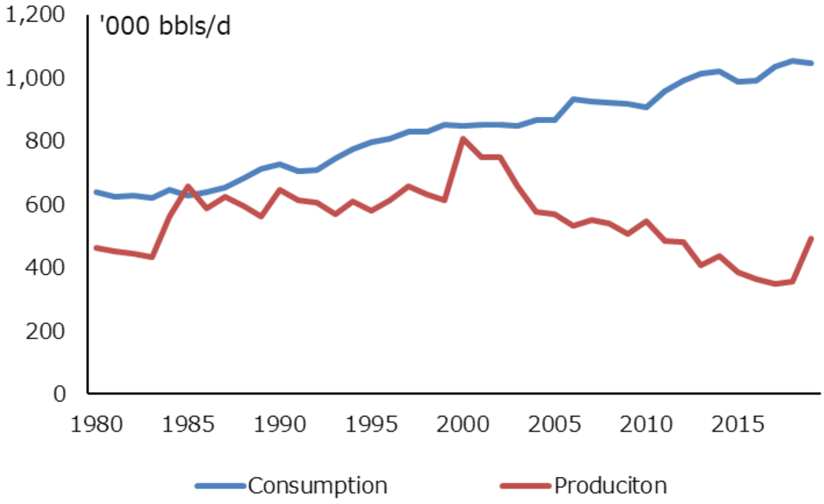
Power sector:	Strength of interconnection lines and investment of power generation and transmission
Gas sector:	Improving the earthquake resistance of low-pressure gas pipeline
Oil sector:	Preparations for heavy rains and storm surges such as strengthening the drainage capacity of refineries and seawalls, fuel stockpiling at the evacuation stations.[13]

1.3.2 Australia

Australia is one of the most abundant natural resource holding countries among the developed countries. Therefore, they have not necessarily been interested in energy security like other energy-importing developed countries. Since Australia is the world's largest exporter of coal and LNG (as of 2019) and a net export country of energy, energy security was also of a strong interest in ensuring stable export demand rather than supply security. However, in recent years, a concern about stable energy supply became apparent in both oil and natural gas sectors, and thus Australia has also shown policy interest in energy security as security of supply.

[13] Agency for Natural Resources and Energy, "Toward a Review of the Basic Energy Plan", Comprehensive Resource and Energy Research Committee Basic Policy Subcommittee Handouts (13 October, 2020) pp. 37-42.

As for oil, Australia is an oil-producing country, but its production has continued to decline since 2000 (Figure 1-5). Production is expected to increase in 2019, but much of the increase in production is very light oil called natural gas liquid (NGL). NGL is produced as a by-product from LNG plants, and most of the production is exported directly to foreign countries from LNG plants. Domestic oil demand, meanwhile, continues to increase year by year. As the result, oil imports are also increasing. Australia is an exporter of coal and natural gas, but is an importer of oil and its import dependence is rising.



Source: BP, Statistical Review of World Energy 2020 edition

Figure 1-5 Oil Production and Consumption in Australia

In the oil product supply, several refineries in Australia closed in recent years amid rising oil import dependence. There were eight refineries in Australia, but the closure of refineries in Australia has continued due to the deterioration of the domestic market conditions and the strategic decision of international oil company (oil major) who operated refining business in Australia. There are only four refineries as of the end of 2020, one of which is now under consideration for closure.[14] Although refinery is a facility that produces oil products from crude oil, as long as the import of oil products are secured, refinery is not a necessary facility for energy supply security. However, the presence of domestic refineries is preferable for energy security because it can bring two oil product supply options: 1) the production of petroleum products by refining crude oil, and 2) the import of petroleum products.

In addition, the advantages of domestic refineries are: 1) Since large tankers can be

[14] Sonali Paul, "BP to close Australian oil refinery, losses seen outlasting pandemic," *Reuters*. 30 October 2020.

used for crude oil imports, transportation costs can be reduced 2) Having a refinery makes it easier to control the quality of petroleum products 3) It is desirable for energy security to have a domestic refinery because the quantity of domestic oil inventories will increase if refinery exist and it becomes possible to have stockpiling in the form of crude oil. Stockpiling of crude oil is more preferable than stockpiling products because quality management is easier. For this reason, the idea that the consuming (importing) country should have a refinery in the country is called “refining at home” policy.

In response to the closure of domestic refineries, the Australian government has launched a policy called “Fuels Security Program” that contained the following four points: 1) construction of $ 200 million storage facility for diesel oil, 2) introducing stockpiling obligations to domestic oil companies, 3) financial support for domestic refinery business, 4) revisions to the legal system for developing a response system in the case of supply cut-off.

Regarding the oil stockpiling facility, a new storage facility of 780,000 kl is planned. Regarding the stockpiling obligation, it is expected that the existing inventory level will be raised by 40% by 2024. Financial support for the refinery will be provided as a subsidy of 1 Australian cent per litter for gasoline, diesel oil, and jet fuel with a total of $83.5 million allocated as a budget for the subsidy in 2020.

In recent years, there have been supply concerns in Australia not only for petroleum products but also for natural gas.

Australia's LNG exports are mainly done from offshore gas fields in the north-west of the country. In 2010, an LNG export project using coal bed methane produced from the coal seams in the northeastern part of the country started, and LNG exports began in 2016.

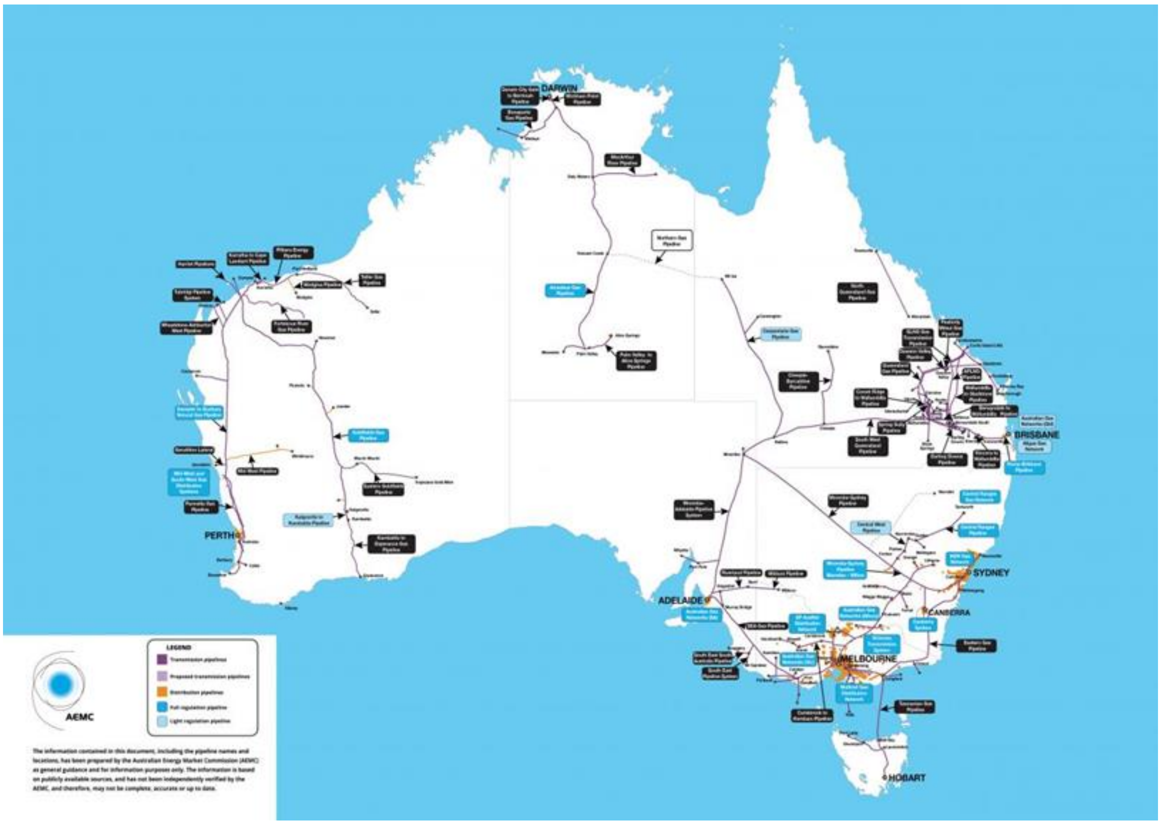
However, when this export was launched, some developers were unable to secure enough coal bed methane to produce the LNG. So, they took action to procure large quantities of gas from the domestic wholesale market and export it. As a result, domestic gas price soared over a wide area from the eastern part to the southern part of Australia.

As the eastern and southern regions in Australia are connected by pipelines, tight gas supply and demand in the northeast has a direct impact on urban areas in the southeast (Figure 1-6). Since the northwestern part where is Australia's main LNG export area is not connected to the southeastern part by a pipeline, the gas balance between supply and demand in that area did not directly affect the gas price in the southeastern part.

In response, the Australian government introduced a policy called The Australian Domestic Gas Security Mechanism (ADGSM)[15] in June 2017 to ensure the stability of

[15] Australian Department of Industry, Science, Energy and Resources, “Australian Domestic Gas Security Mechanism” 8 December 2020. https://www.industry.gov.au/regulations-and-standards/australian-domestic-gas-security-mechanism. Accessed on 4 January 2021.

domestic gas prices. Under this system, the Ministry of Industry, Science, Energy and Resources forecasts the balance of natural gas supply and demand the following year from September to November every year. If supply and demand is expected to be tight, the ministry will notify domestic gas market (mainly companies), and if there is an actual tightness, the ministry will restrict LNG exports. However, there have been no cases in which this system was actually activated so far.



Source：Australian Pipelines and Gas Association

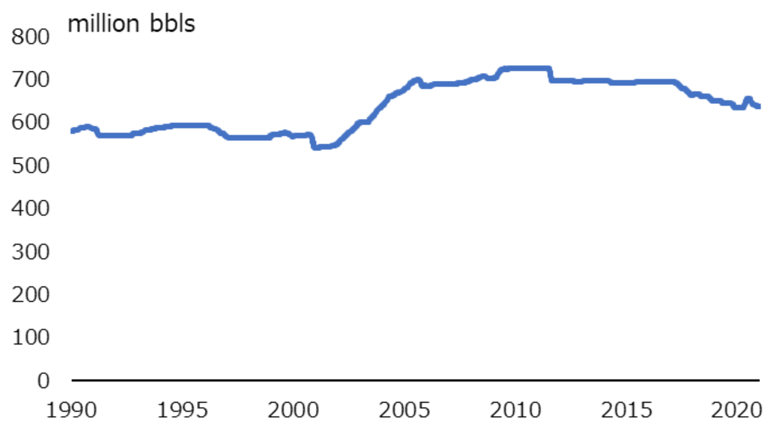
Figure 1-6 Gas Pipeline Network in Australia

In this way, Australia did not put much effort into energy security policies in the past as a measure to secure a stable supply as an exporter of energy resources. However, Australia began to take policy measures to ensure a stable domestic energy supply due to changes in the domestic oil and gas supply and demand situation in recent years.

1.3.3 United States

For the United States, which is the largest oil consumer in the world, a primary energy security concern was to secure stable oil import. Because the society of the United States is highly dependent on the automobile for transportation, the level of gasoline prices greatly affects the life of the U.S. citizens. The US Congress report released in 2012 also states that ensuring a stable supply of oil is an essential issue for US energy security.[16] "Energy Independence," or a status where energy supply does not depend on import from overseas, was proposed by President Nixon in November 1973 after the oil crisis and has been advocated by all presidents including the President Trump who stepped down in January 2021.[17] It is listed as one of the important goals in energy policy.

As a policy of the US government to the stable supply of oil, the development of oil stockpiling is known as a major initiative. In addition, there are also policies that encourage domestic oil and natural gas development by taxation benefits. US oil stockpiling is mainly stored at four oil stockpiling bases in the southern part of the country. US oil reserves have been maintained at 500 million barrels level since the 1990s. After that, the Bush administration which was inaugurated in 2001, raised to 700 million barrels because of the increased uncertainty of the situation in the Middle East. However, in the 2010s, US oil imports began to decline due to the increase in domestic production by the shale revolution. Therefore, the reduction of oil reserves has been discussed. In 2015, the Congress decided that the federal government could sell its crude oil reserves if certain conditions were met. Based on this decision, the US Department of Energy sold some of its crude oil reserves and the volume of oil stockpiling was 638 million barrels as of the end of 2020 (Figure 1-7).



Source: U.S. Energy Information Administration website

Figure 1-7 U.S. Oil Stockpiles

Previously, only crude oil was stockpiled in the United States, but since the 2000s, petroleum products have also been stockpiled. The government rented tanks from

[16] Congressional Budgetary Office, "Energy Security in the United States." May 2012. Washington D.C: Congress of the United States

[17] Charles Homans, "Energy Independence: A short History," *Foreign Policy*. 3 January 2012. https://foreignpolicy.com/2012/01/03/energy-independence-a-short-history/ (Accessed on 4 January 2021)

private oil companies on the east coast of the United States to store gasoline and low-sulfur diesel oil. In addition, the United States took a policy of increasing domestic oil and gas production in order to enhance its energy supply. These policies include lowering royalties on US federal land and tax credits for the introduction of a technology called the Enhanced Oil Recovery. In natural gas sector, a tax credit system for the development of unconventional natural gas was introduced by the Windfall Profits Tax Act of 1980. It is said that this system played a role in realizing the shale revolution. In the United States, Republicans have traditionally taken policies that are friendly to the oil industry. President Trump who retired in January 2021 has also taken support measures such as promoting domestic infrastructure development to promote domestic oil and natural gas development.[18]

A strong concern in energy security in the United States in recent years has been cyber defense against energy supply infrastructure. In May, 2021, an oil pipeline that transports petroleum products from Gulf of Mexico to East coast in the United States was attacked by hacking organization and the price of petroleum products such as gasoline rose.[19] As the economy becomes more digitalized and electrified in the future, it is important to protect against cyber-attacks on power supply systems.

1.3.4 European Union

Since the European Union (EU) is also a net importer of energy, its energy security policy is mainly focused on ensuring a stable supply of energy.

Regarding oil, the EU has its own oil stockpiling regulations. Member States are required to hold a stockpile of either 90 days of net imports per day or 61 days of consumption, whichever is greater.[20] Many EU member states are also members of the International Energy Agency and establish the oil stockpiling system required by the agency. Regarding securing electricity and gas supply, the development of supply networks (transmission networks and gas pipeline networks) and the diversification of supply sources are set as policy goals for ensuring energy security. In particular, it aims to expand the interconnection between member countries and between member countries and foreign countries, and to maintain and expand the mutual energy interchange system using the interconnection. In addition, in the decentralization of supply sources, promotion of renewable energy such as solar power and wind power is

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[18] The White House, “Executive Order on Promoting Energy Infrastructure and Economic Growth” 10 April 2019. https://www.whitehouse.gov/presidential-actions/executive-order-promoting-energy-infrastructure-economic-growth/ (Accessed on 4 January 2021)
[19] Christopher Bing and Stephanie Kelly, “Cyber attack shuts down U.S. fuel pipeline ‘jugular,’ Biden briefed,” *Reuters*. 8 May 2021. https://www.reuters.com/technology/colonial-pipeline-halts-all-pipeline-operations-after-cybersecurity-attack-2021-05-08/. Accessed on 16 August 2021.
[20] European Commission, “EU Oil Stocks” 17 March 2020. https://ec.europa.eu/energy/topics/energy-security/eu-oil-stocks_en. Accessed on 7 January 2021.

recommended not only for climate change countermeasures but also for expansion of energy security supply options.[21]

In the power sector, the EU has asked the European Network of Transmission System Operators (ENTSO) which consists of Transmission System Operator (TSO) in each country, to create risk scenarios related to power supply and to prepare countermeasures for the risk scenarios. It is important to develop countermeasures against the interruption of energy supply due to natural disasters and to secure supply based on the concept called "N-1" principle. The N-1 principle is a rule that obliges a country to ensure a status where alternative supplies can be secured even if the largest source of supply is disrupted.[22]

It is certain that digitization will progress in the EU as well as in the United States. There is great interest in ensuring cybersecurity for critical infrastructure in power supply. In April 2019, the European Commission announced a cybersecurity recommendation[23] on energy infrastructure with the following measures: A supply system to continue with alternative infrastructure even if a specific infrastructure becomes unavailable due to a cyber-attack. A communication system for member countries to prevent chain reactions caused by the same supply network. Introduction of the latest technology.

In terms of the diversification of geographical sources of energy supply, the EU is also showing great interest in introducing LNG because some of EU member countries are concerned about the dependence on the pipeline natural gas supply from Russia. In the 2000s, Russian gas accounted for the first half of 20% of the EU's total natural gas demand. After that, due to the decrease in gas production in the North Sea, the ratio of Russian gas has risen to the latter half of 30% in recent years (Figure 1-8). Under these circumstances, the European Commission created the "EU Strategy for Liquefied Natural Gas and Gas Storage" in February 2016, taking into account factors such as the dramatic expansion of LNG supply capacity due to the US shale revolution.[24] In this strategy, the utilization of LNG is regarded as one of the effective measures for diversifying gas supply sources, and the following measures are shown: construction of LNG receiving facilities and improved access to existing gas pipeline networks and storage facilities in the EU; promoting integration of gas markets and strengthen gas

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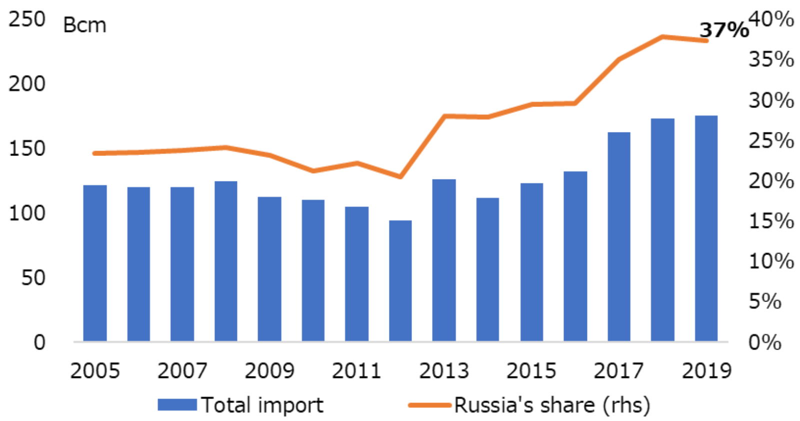
[21] European Commission, “In focus: Energy security in the EU.” 27 April 2020. https://ec.europa.eu/info/news/focus-energy-security-eu-2020-avr-27_en. Accessed on 2 January 2021.
[22] European Commission, “Critical infrastructure and cybersecurity.” 19 October 2020. https://ec.europa.eu/energy/topics/energy-security/critical-infrastructure-and-cybersecurity_en. Accessed on 2 January 2021.
[23] European Commission, “Cybersecurity in the energy sector.”19 October 2020. https://ec.europa.eu/energy/topics/energy-security/critical-infrastructure-and-cybersecurity_en#cybersecurity-in-the-energy-sector (Accessed on 4 January 2021).
[24] European Commission, “EU strategy for liquefied natural gas and gas storage”

trading hub functions in the EU; dialogue with LNG supplying countries such as Qatar, Nigeria and Egypt; and cooperation with other LNG importing countries such as Japan and China.



Source: BP Statistical Review of World Energy 2020 edition

Figure 1-8 EU Imports of Russian Gas to Their Overall Gas Demand

1.3.5 United Kingdom

The UK was a member state of the EU until January 2020, but it also had its own energy security policy apart from the EU's energy security policy. The Department of Energy and Climate Change in the UK created the Energy Security Strategy in November 2012. Among them, two requirements to be ensured in energy security are 1) securing services provided by energy supply to the people and 2) suppressing excessive fluctuations in energy prices.

Six major policies are shown as specific measures. The first measure is to secure the resilience of energy supply. The measure includes the creation of Contingency Plan in the event of any supply problem, the securing of alternative fuels and alternative power sources for power generation in case of unexpected events, and the maintenance of oil and natural gas stocks. The second measure is to promote energy conservation such as creating a mechanism to encourage the sharing of information on energy conservation among consumers. The third measure is to maintain and expand domestic oil and natural gas production, including tax support for domestic resource development. The fourth measure is to secure the functions of the international market. The UK depends on imported energy and the normal functioning of the international market is a major premise for a stable energy supply. Measures for the functioning of international market include policy dialogues with oil-producing and gas-producing countries and support for upstream technology development. The fifth measure is to improve the reliability of the domestic energy supply network. Under the deterioration of the domestic supply infrastructure, measures such as evaluation of its reliability and promotion of necessary investment are required. Finally, the sixth measure is to promote decarbonization. By promoting renewable energy, oil and natural gas imports from overseas will be reduced and supply vulnerabilities will be improved. These are divided into two categories: One is oil and natural gas logistics and domestic electricity and gas trading which depend on the market mechanism. Another is the maintenance and operation of stockpiling, promotion of investment in upstream and supply networks, and introduction of renewable energy promoted by the government. The UK Government will provide policy support in each sector if necessary.

1.4 Assessment and Risk of Energy Security Policies in Asian Countries

The components of energy security described in section 1.3 are the general ones for various countries including developed countries. This section examines particularly important factors considering energy security in Asian developing countries and evaluates the energy security situation in Asia.

1.4.1 Energy Security Evaluation Criteria in Asian Countries

(1) Index

The essence of energy security is the same regardless of economic development or region, and the evaluation criteria described in section 1.3 can be directly applied to the consideration of energy security issues in Asian countries. However, the availability of statistical data has an important influence in the selection of evaluation criteria when assessing the state of energy security in Asian countries. In some countries, energy statistics are not sufficiently collected and it may not be possible to calculate the indicators required for evaluation. In addition, in the evaluation of energy security, it is one of the important evaluation approaches to make an international comparison. However, if the data processing method differs depending on the statistical methodologies of each country, there is a difference in the data in the international comparison, and the result may be misinterpreted. Considering these conditions and restrictions, this study adopts the indicators shown in Table 1-1. Analysis for geopolitical risks and information availability should be undertaken. But, as for geopolitical risk, historical statistical data for import sources of fossil fuel imports for all of the sample countries is not available. As for the information availability, there is no reliable and objective data to measure the availability. Thus, these elements of energy security are not included in the analysis of this section.

Table 1-1 Evaluation Index for Energy Security

Indicator	Description
1) TPES self sufficiency	Represent total sufficiency including non-fossil energies.
2) Oil self sufficiency	Represent risk status of each fossil fuels supply. Higher self-sufficiency rate means lower exposure to external risks.
3) Natural gas self sufficiency	
4) Coal self sufficiency	
5) Power self sufficiency	
6) Diversity of TPES mix	Represent risk status of energy mix. Diverse energy mix have higher resilience against supply shock.
7) Diversity of power generation mix	
8) Access to electricity	Represent status of national energy system. Higher access rate means more robust energy system.
9) Energy intensity of GDP	Represent energy efficiency of economy. Lower intensity means higher resilience of economy against energy supply shock.

Note: TPES = total primary energy supply
Source: The Institute of Energy Economics, Japan

(2) Statistics

All eight extracted indicators represent one aspect of energy security. These can be calculated by common statistics with high transparency. The statistics used to calculate each indicator are shown in Table 1-2.

Table 1-2 Statistical Data used for Index

Indicator	Statistics
1) TPES self sufficiency	IEA, World Energy balances 2020 edition
2) Oil self sufficiency	IEA, World Energy balances 2020 edition
3) Natural gas self sufficiency	IEA, World Energy balances 2020 edition
4) Coal self sufficiency	IEA, World Energy balances 2020 edition
5) Power self sufficiency	IEA, World Energy balances 2020 edition
6) Diversity of TPES mix	IEA, World Energy balances 2020 edition
7) Diversity of power generation mix	IEA, World Energy balances 2020 edition
8) Access to electricity	IEA, SDG7: Data and projections, Access to electricity
9) Energy intensity of GDP	IEA, World Energy balance 2020 edition

Note: IEA (International Energy Agency) SDGs (Sustainable Development Goals)
Source: The Institute of Energy Economics, Japan

(3) Target Year for Evaluation

All indicators except access to electricity can be calculated annually from existing statistics. However, the purpose of this evaluation is not a short-term factor analysis. For example, a temporary economic recession could lead to a decline in energy demand and reduce dependence on imports. The decline in dependence on imports is a desirable change for energy security, but if the cause is a recession, the effect is temporary. In this analysis, from the viewpoint of analyzing changes in energy indicators from a long-term perspective, 10 years is regarded as one unit and the average value during the period is used for the analysis (Table 1-3). According to the IEA's energy statistics, data on developing countries can only be obtained after 1971. Statistics for Cambodia and Laos can only be obtained after 1995. The latest statistics available as of January 2021 are 2018 statistics.

Table 1-3 Time Periods and Target Years

Estimation period	Covered calendar year
1970s	1971 – 1980
1980s	1981 – 1990
1990s	1991 – 2000
2000s	2001 – 2010
2010s	2011 – 2018

Source: The Institute of Energy Economics, Japan

(4) Method for calculating indicators

The calculation method for each index in Table 1-2 is shown below.

1) to 5) Self sufficiency

The self-sufficiency rate, which indicates how much of the energy required in a country is covered by domestic production, is one of the most basic indicators of the country's energy security. In this analysis, both the self-sufficiency rate of each fossil fuel and the overall self-sufficiency rate including non-fossil fuels are adopted as indicators. In Asian countries, the ratio of non-fossil fuels to primary energy supply is generally high. All countries are highly dependent on oil for transportation energy. However, regarding power generation, the energy selected for power generation is different because the available amount of domestic energy resources is different in each country. Some of the sample countries such as Thailand, Vietnam, Cambodia, and Lao have grid connections and export/import electricity.

In recent years, the use of renewable energy such as solar and wind power has tended to increase due to the response to air pollution and climate change issues. Renewable energy is domestic energy and in this sense is desirable energy from the point of security. Therefore, in order to include such renewable energy in the risk assessment, both fossil fuel and non-fossil fuel are adopted as an index of the self-sufficiency rate of the total primary energy supply. Indigenous production includes nuclear power generation. Nuclear power generation is treated as semi-domestic energy because once uranium fuel is loaded into the reactor, it can continue to operate for a long time and uranium does not need to be imported frequently.

The calculation formula of the index is shown below.

$$Oil\ self\ sufficiency\ = \frac{Indigenous\ oil\ production}{Oil\ supply} \times 100$$

$$Natural\ gas\ self\ sufficiency\ = \frac{Indigenous\ natural\ gas\ production}{Natural\ gas\ supply} \times 100$$

$$Coal\ self\ sufficiency\ = \frac{Indigenous\ coal\ production}{Coal\ supply} \times 100$$

$$Power\ self\ sufficiency\ = 1 - \frac{Net\ import\ of\ electricity}{Total\ final\ consumption\ of\ electricity} \times 100$$

$$TPES\ self\ sufficiency\ = \frac{Total\ indigenous\ production}{TPES\ supply} \times 100$$

TPES = total primary energy supply

6) to 7) Diversity

Each energy has different characteristics in terms of quantity, trade, price, and CO2 emissions. Since there is no perfect energy source in all metrics, it is important to utilize each characteristic and use energy properly in a well-balanced manner. If the supply of one energy is cut off or the price rises, the impact can be reduced if it can be substituted with other energy. By diversifying energy sources, the merits of each energy can be enhanced. At the same time, the disadvantages and risks of each energy can be reduced

The Herfindahl-Hirschman Index (HHI) is an oft-used index to measure the level of diversification. HHI is usually used to assess the degree of competition in a certain product's market. The index is calculated as the sum of the squares of the shares (%) of each energy source. If the energy is dominated by a single element, HHI is the maximum value of 10,000 (100[%] * 100[%] = 10,000). HHI decreases when the energy share is dispersed. The analysis classifies energy types into seven categories: coal, oil, natural gas, nuclear power, hydro, renewable energy (solar, wind, geothermal), and others (biofuels and waste, etc.).

$$HHI = \sum_{1}^{n} (share\ of\ energy\ \text{"n" in TPES or electricity [\%]})^2$$

n = represent seven different energy sources.

TPES = total primary energy supply

8) to 9) Supply resilience

The final stage of the energy supply chain is the supply to end users. Energy security is guaranteed by domestic supply infrastructure. Improving access to electricity is one of the highest priorities for energy policies in many Asian developing countries. This is the first step in building an important supply infrastructure.

As an evaluation in this analysis, the access rate to electricity is adopted as an index. There are two statistics on the access rate to electricity, IEA and the World Bank. However, there are significant differences between the two statistics in some countries. Since IEA statistics are used for other indicators in this analysis, IEA statistics are also used here for the access rate to electricity.

As another indicator of the evaluation, energy consumption per GDP is adopted. High energy efficiency can reduce the amount of energy required without reducing economic activity. In the case of energy importing countries, higher energy efficiency can reduce energy imports and reduce the energy security risks. In the evaluation of indicators, it should be noted that the relationship between energy consumption and GDP depending on the economic structure. For example, the balance between energy consumption and GDP differs between countries where energy-consuming industries such as the steel industry are the center of economic activity and countries where service industries such as finance and tourism are the center of economic activity. In the former industrial structure, the energy consumption per GDP tends to be large. On the other hand, in the latter industrial structure, it tends to be small. According to IEA statistics, the maximum energy intensity (worst performance) is 0.947 toe / 1000 USD in Ukraine and the minimum energy intensity (best performance) is 0.033 toe / 1000 USD in Switzerland from 2000 to 2018.

$$Energy\ intensity\ of\ GDP\ = \frac{TPES}{GDP} \times 100$$

TPES = total primary energy supply

1.4.2 Energy Security Assessment and Risks in Asia

This section analyzes the energy security status of the target countries for each of the nine indicators. The case countries are ASEAN countries excluding Brunei and Singapore[25]. In addition, estimation results of the non-OECD average, non-OECD Asia excluding China, and Japan are also shown for comparison.

(1) Self-sufficiency rate of total primary energy supply

The self-sufficiency rate is above 50% in all case countries (Figure 1-9). However,

[25] In the OECD Development Assistance Committee's list of eligible countries, Brunei and Singapore are not eligible for assistance.
http://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/daclist.htm

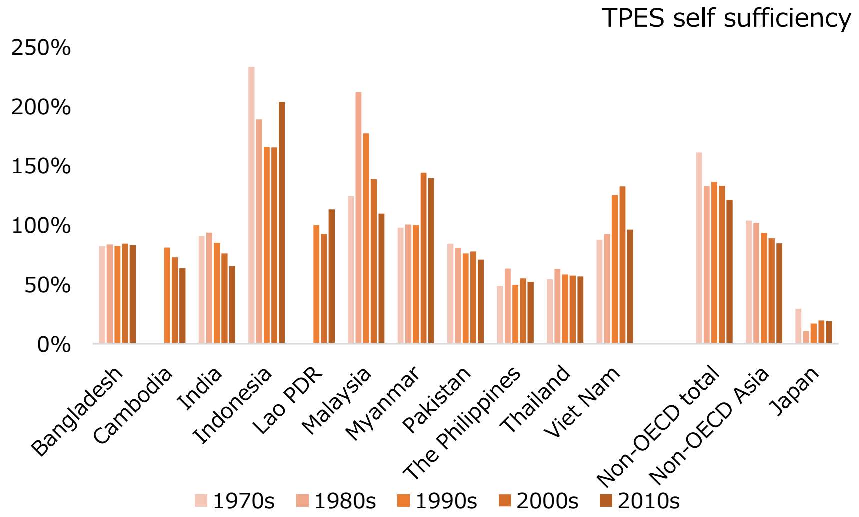
considering Japan's experience of significantly decreasing its self-sufficiency rate due to changing its main energy from coal to oil after World War II, it is not always possible for Asian countries to maintain the existing relatively high self-sufficiency rate in the future. Energy demand is expected to continue to grow in many Asian countries, but there is a risk that domestic fossil energy production cannot be increased due to the following factors.

- Constraints on the existing resources
- Constraints on the domestic resource development (Cheap import energy)
- Investment competitions with other rich resource countries
- Energy selection from environmental consideration

As a measure to address these risks of fossil energy, many countries are aiming to expand renewable energy including hydro-electricity. Countries like Laos, Cambodia, Myanmar and places like Kalimantan (Borneo) island are said to have a large potential for hydropower development. Both Laos and Cambodia are located in the waters of the Mekong River, but the supply of river water may not be guaranteed depending on the use of the water in the upstream of the river in China. Moreover, dam-type hydroelectric power generation may require the relocation of residents and the destruction of the environment, and thus agreements with residents, financing, and long lead times may become a hurdle for further development of the dam-type hydroelectric power plant.

In renewable energy other than hydro power, there is a high expectation for solar power generation because relatively favorable solar radiation conditions exist in the case countries. On the other hand, with regard to wind power generation, it is considered that there is smaller potential than solar power because the areas with good wind conditions are limited. In addition, as many of the case countries have mild and rainy climates, some countries are aiming to expand the use of biofuels by taking advantage of the rapid growth of plants. Subsidies for petroleum products are a major financial issue in many countries. The introduction of biofuels is also expected to have the effect of reducing the issue of such subsidies

In India, the ratio of nuclear power generation to the primary energy supply is small about 1%, but nuclear power generation is also one of the measures to improve the self-sufficiency rate. Bangladesh also has a plan to introduce a nuclear power plant. Indonesia, the Philippines, and Thailand have also considered to introduce nuclear power in the past, but no progress has been seen in recent years except for the Philippines. Vietnam and Malaysia also had plans to introduce nuclear power but canceled the plans in 2016 and 2018, respectively.

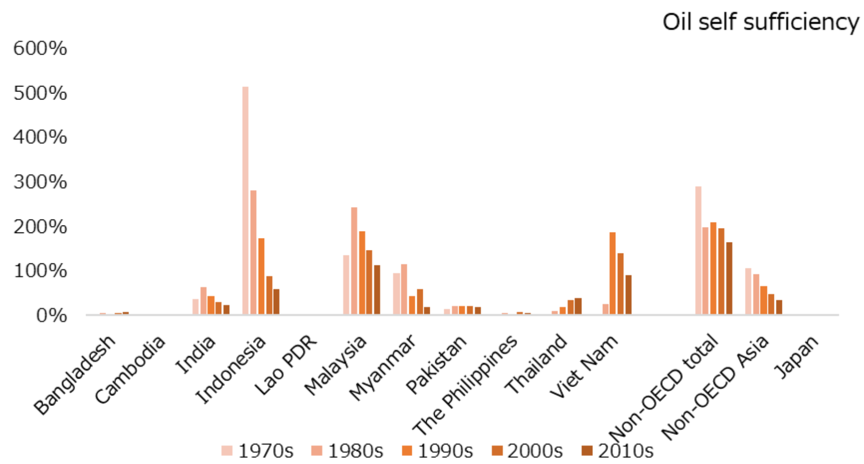


Source: IEA, *World Energy Balances 2020 edition*.

Figure 1-9 Self-Sufficiency Rates in Primary Energy Supply in Asian Countries, 2011

(2) Self-sufficiency rate of oil

Self-sufficiency rate of oil has decline in almost all countries (Figure 1-10). This is clearly because oil demand has grown in those countries as the demand has increased greatly with the progress of motorization while their domestic oil supply has not caught up with the demand growth. Unfortunately, the endowment of oil resources in Asia is low, and the likelihood of discovery of large-scale oil resources is also less likely, and thus the self-sufficiency rate is expected to continue to grow in the future.



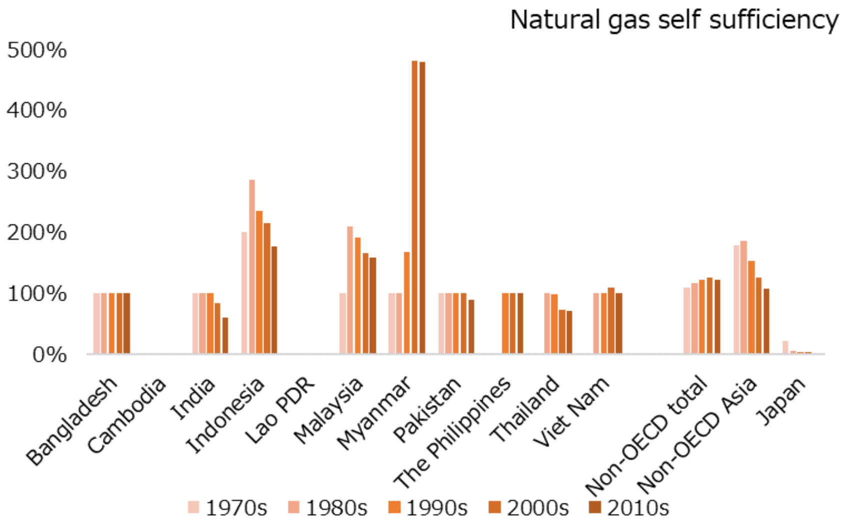
Source: IEA, *World Energy Balances 2020 edition*.

Figure 1-10 Self-Sufficiency in Oil Supply in Asian Countries, 2011

(3) Self-sufficiency rate of natural gas

Among the case countries, India, Indonesia, Malaysia, Pakistan and Thailand have experienced the declining self-sufficiency (Fig. 1-11). Imports of natural gas began in India in 2003 and Thailand in 1998. Both countries are proceeding with the opening of exploration acreage and encourage oil companies to explore domestic resources. However, since the prospect of additional resource potential is not large in these countries, and it seems not easy to increase the production in accordance with the demand growth. Malaysia is a net exporter of natural gas, but, due to the distance between the natural gas production area and the demand area, the country started to import liquefied natural gas (LNG) in 2013. Indonesia is characterized by a large geographical area in the east and west, and also has a geographical mismatch between natural gas supply and demand. Despite its continuous LNG production and exports, therefore the country diverted the Arun liquefaction terminal in the northern part of Sumatra into LNG receiving facilities, and adopted floating LNG receiving facilities to manage the geographical demand-supply gap.

According to IEA statistics, Bangladesh[26], the Philippines and Vietnam maintained 100% natural gas self-sufficiency as of 2018. Myanmar has significantly increased its net exports since the 2010s. However, these countries will not be able to maintain their natural gas self-sufficiency system in the near future due to resource constraints, the growing demand, and existing export contractual obligation, which urges the countries to prepare for LNG import.



Source: IEA, *World Energy Balances 2020 edition*.

Figure 1-11 Self-sufficiency rate of natural gas supply in Asian countries

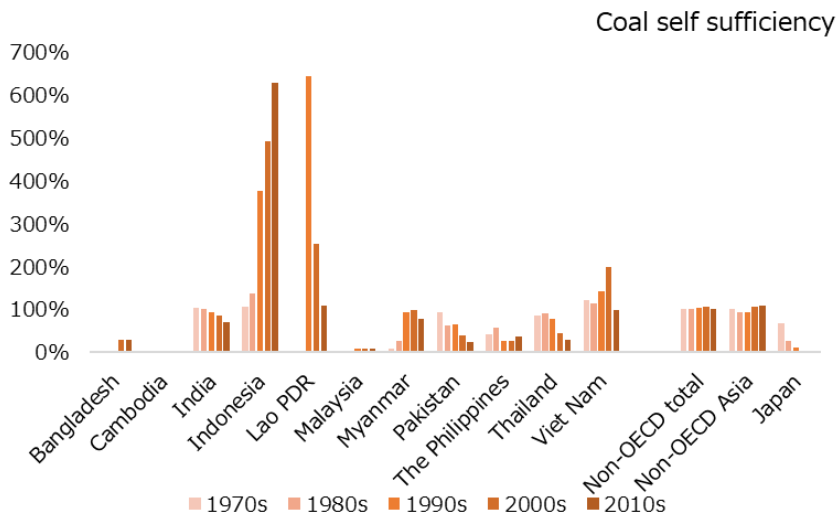
[26] Bangladesh started importing LNG since August 2018. Jessica Jaganathan and Ruma Paul, "Bangladesh starts operations at country's first LNG terminal," *Reuters*, 20 August 2018. https://www.reuters.com/article/bangladesh-lng-terminal-idUSL3N1VB1ZM. Accessed on 25 January 2021.

(4) Self-sufficiency rate of coal

Asia has abundant coal resources. Indonesia, in particular, has vast coal resources and are in a net export position of coal (Figure 1-12). Indonesia requires a certain percentage of production to be supplied for domestic coal-fired power generation (Domestic market obligation). However, actually, coal export has increased significantly as a result of large coal production and sluggish domestic coal demand.

Lao PDR exported most of the coal and consumed the rest at domestic brick factories. In 2009, a joint venture company was established with a private company in Thailand. The company started a project to develop the Hongsa coal deposit (lignite) in western Laos and to construct mine-mouth coal-fired power plant. The coal-fired power plant started in 2016. As a result, domestic production and consumption are roughly balanced. Most of the electricity generated is exported to Thailand. Laos intends to increase the capacity of coal-fired pawer plant to supplement hydropower which fluctuates with rainfall. Expanding the capacity of coal-fired power plant and coal production will be the key to securing power supply in the future.

On the other hand, the self-sufficiency rate is declining in India, Pakistan and Thailand. India has abundant coal resources, but due to delays in coal mine development, the supply has not been able to meet demand. Therefore, in addition to the development of coal mines, India plans to invest to improve the coal self-sufficiency rate by improving transportation efficiency and disseminating high-efficiency utilization technology. Although coal production is increasing in Pakistan, coal demand exceeds production, and the self-sufficiency rate is declining.

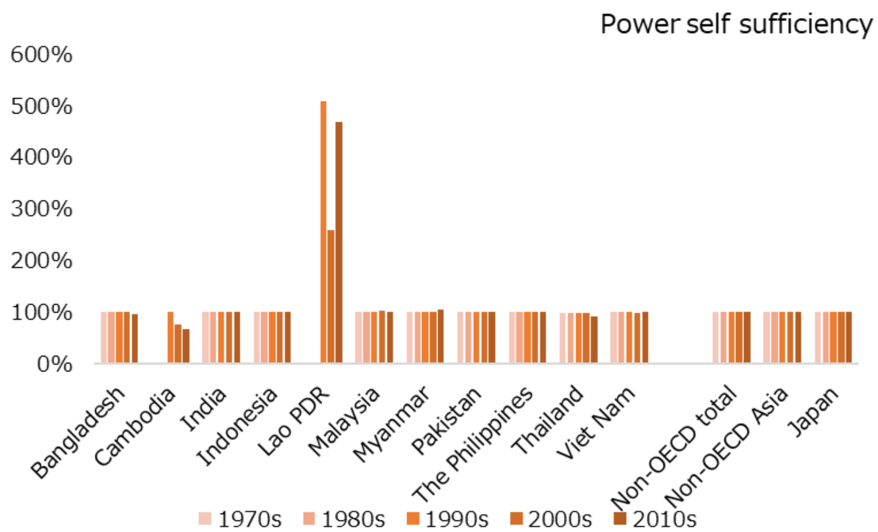


Source: IEA, *World Energy Balances 2020 edition*.

Figure 1-12 Self-Sufficiency Rate in Coal Supply in Asian Countries, 2011

(5) Self-sufficiency rate of power

Self-sufficiency rate for power has been at 100% in many of the case countries (Figure 1-13). Of particular note is Lao PDR, which has consistently maintained its net exporter position since the 1990s when its data is available. Countries whose self-sufficiency rate is below 100% are Bangladesh, Cambodia, Thailand and Vietnam. Bangladesh imports electricity from India and the latter three from Laos. In particular, Cambodia's dependence on imports fluctuates greatly due to the operating rate of domestic hydroelectric power. From the perspective of energy security, the need to develop domestically produced power sources is high for the country.

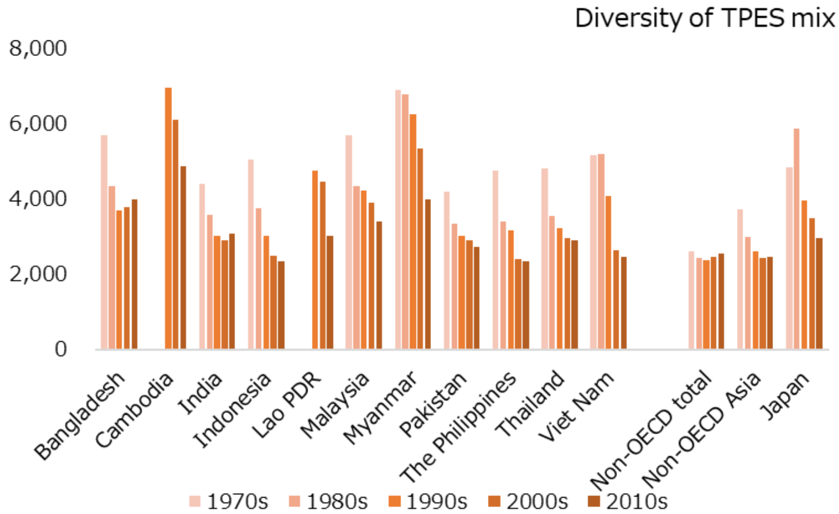


Source: IEA, *World Energy Balances 2020 edition*.

Figure 1-13 Self-Sufficiency Rate in Power Supply in Asian Countries, 2011

(6) Diversity of total primary energy supply mix

In all case countries except for Bangladesh, the total primary energy supply (TPES) is relatively well diversified (Figure 1-14). Oil was a major source of energy in the case countries in the past, but its dependence on oil gradually declined due to the use of coal, natural gas, hydro, and renewable energy. Some countries show a high performance in terms of diversity of primary energy supply. However, it may change in the future. For example, Indonesia, the Philippines, and Vietnam, which perform better at this stage, have a higher share of conventional biomass in total primary energy supply at 15%, 14%, and 11% respectively as of 2018. This will, however, soon be replaced by commercial energy, and the diversity may be worsened depending on the energy selected.



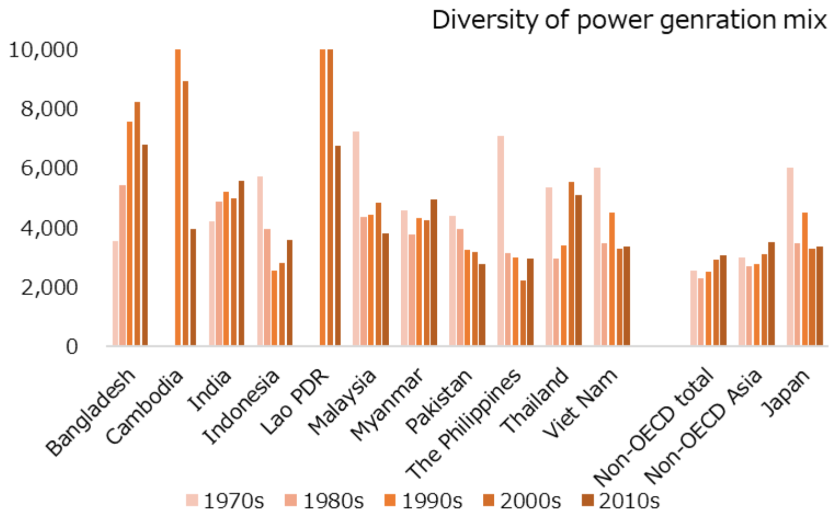
Note: Figures indicate the value of HHI, and lower numbers are more diversified, which is desirable for energy security.
Source: IEA, *World Energy Balances 2020 edition*.

Figure 1-14 Diversity in Primary Energy Supply in Asian Countries

(7) Diversity of power generation mix

The diversity of power generation mix has worsened in some of the case countries. India, Indonesia, and the Philippines are increasingly dependent on coal, while Thailand is more relying on natural gas, and Myanmar on hydropower likewise (Figure 1-15). However, these power generation mixes were formed so as to utilize their domestic natural resources and thus contributed to self-sufficiency for the fuel for power generation. The implication of the low diversification therefore needs to be evaluated with caution. If cheap resources are abundant in the country, such as coal in India and Indonesia, the increase in dependence on coal will also contribute to the economics of power supply.

Nonetheless, too much dependence on a particular power supply source still poses a high risk for stable power supply as the interruption of the power generation would seriously hurt the country's energy supply and economic activities. For instance, it cannot be denied that supply problems may occur due to events caused by domestic factors such as the submergence of coal fields due to heavy rain and the accident of coal transportation. Furthermore, in case of coal power generation, there is also the risk that domestic coal-related assets will become stranded assets if pressure to respond to climate change issues rises rapidly.



Note: Figures indicate the value of HHI, and lower numbers are more diversified, which is desirable for energy security.
Source: IEA, *World Energy Balances 2020 edition*.

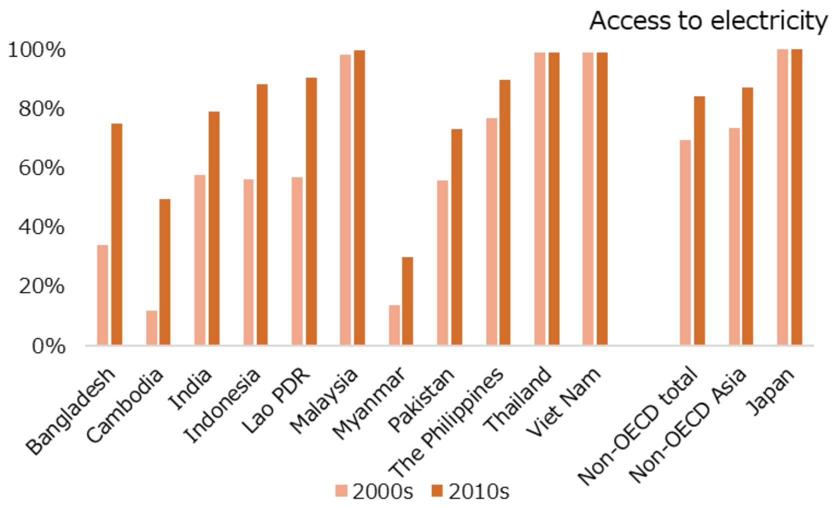
Figure 1-15 Diversity in Power Generation in Asian Countries

To diversify power generation mix, all countries should expand the use of renewable energy. This is because renewable energy is domestic energy, and installation costs drastically declined in recent years, and it is also effective in reducing the greenhouse gas emissions. Such installation of renewable energy however, may require large integration costs to the existing grid and thus its marginal cost of installation need to be monitored closely.

Compared to other sectors, the power generation sector is easier to use different fuels. If there are a lot of power plants using various energy, the supply system has a higher flexibility based on the availability of fuel. This flexibility is also a key element to energy security.

(8) Access to electricity

Access to electricity in the case countries significantly improved over the past 20 years. Although not shown in Figure 1-16, according to IEA statistics, access to electricity exceeded 95% in India, Indonesia, Laos, Malaysia, the Philippines, and Thailand as of 2019. Other areas such as Bangladesh (87%), Cambodia (75%), Myanmar (51%) and Pakistan (79%) also improve rapidly.



Note: Figures are shown only after 2000 due to data availability constraints.
Source: IEA, *SDG7 Data and Projections: Access to Electricity*; World Bank, *World Bank Open Data: Access to electricity*

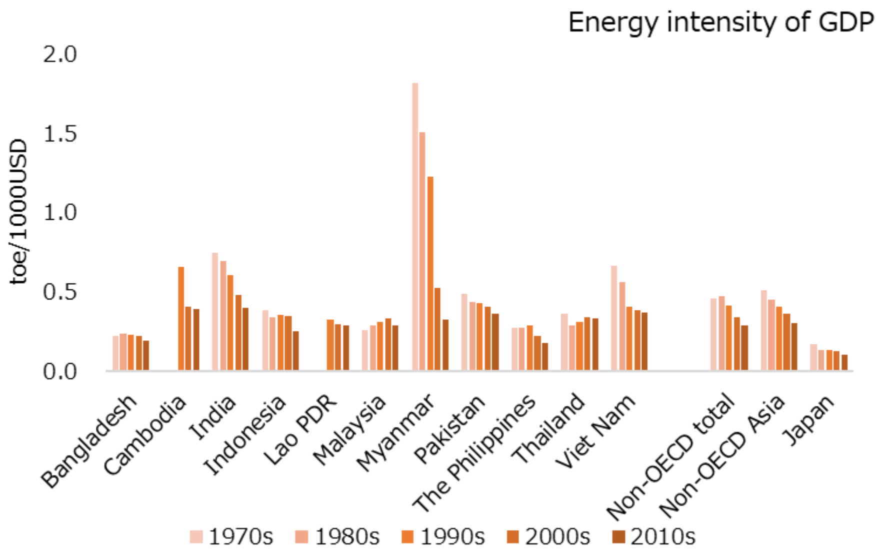
Figure 1-16 Access to Electricity in Asian Countries, 2011

(9) Energy intensity of GDP

The energy intensity of GDP continued to improve in many case countries (Figure 1-17). However, the outcome should be interpreted considering the differences in the industrial structure of each case country. Countries with a higher proportion of manufacturing industries that consume more energy tend to have relatively worse outcome whereas countries based on service industries tend to show better performance.

In Asia, many countries refer to Japan's energy conservation system. Many countries have introduced mandatory reporting to energy-intensive industries, an energy manager system, energy consumption standards and labeling systems for buildings and equipment, energy conservation education, and so on. India's Perform Achieve and Trade scheme (PAT) is an effective system for energy conservation in this aspect. Energy conservation targets can be set for each factory in the energy consuming industry and the excess achieved can be sold to unachieved factories. By introducing such a system, it will be provided an incentive to further promote energy conservation. Similarly, as an example of India, replacement with LED bulbs is being promoted as a policy.

One issue for the future is domestic energy prices, which have been kept low by subsidies in many countries. Domestic energy prices in developing countries do not reflect international energy prices, and thus many countries have not been able to provide sufficient energy conservation incentives to energy-using industries and consumers. In addition, due to low energy price, the economic benefit of switching to energy-saving equipment is also small. High initial investment also hinders to purchase efficient equipment and to renovate equipment efficiency. In the future, it will be important to introduce an energy price system that can provide the benefits of energy conservation. It is also important to remove the constraints in terms of funding for investment of energy conservation.



Note: The dollar value of GDP is real value as of 2015.
Source: IEA, *World Energy Balances 2020 edition*.
Figure 1-17 Energy Efficiency of Asian Economies

2. Energy and Power Mix Assessment

2.1 Criteria for evaluating energy and power mix

2.1.1 Energy mix policies around the world

This section elaborates on the energy mix policies of major countries, the EU, the United Kingdom, Germany, and the United States.

In the EU, decision to target a specific energy mix is made by individual member states, and the EU institutions such as European Commission does not have an authority to direct a specific energy mix. One exception is the target rate of renewable energy. In June 2018, the European Parliament and the European Commission agreed that in the EU, as a whole, renewable energy adoption target would account for more than 32% of final energy consumption by 2030. [27] EU has an EU-wide target of renewable energy and set a specific target for each member state in consultation with them. The allocation of targets takes into account each state's resource endowment, the existing energy supply and demand structure, and the ability to bear costs. European Commission published its proposal to raise the targeted share of renewable energy as of 2030 from the existing 32% to 40% in July 2021.[28] The proposal will be reviewed and discussed at the European Council and the European Parliament for finalization.

What is notable about the EU's energy mix is that they have overall achieved a well-balanced energy mix, even though the choice of non-renewable energy is left to the member states (Figure 2-1). Each member of EU is connected by natural gas pipeline and electricity grid, and EU functions as if it were a single country. Such cross-border infrastructure is utilized for commercial purpose in ordinary times, but is utilized as back-up facility in case of emergency. Forming such close interconnectedness, EU maintains a highly resilient energy supply system which an individual member country cannot achieve. EU's energy security policy therefore emphasizes increased connectivity, and the EU continued to expand its connectivity capacity by addressing weak parts of its network.

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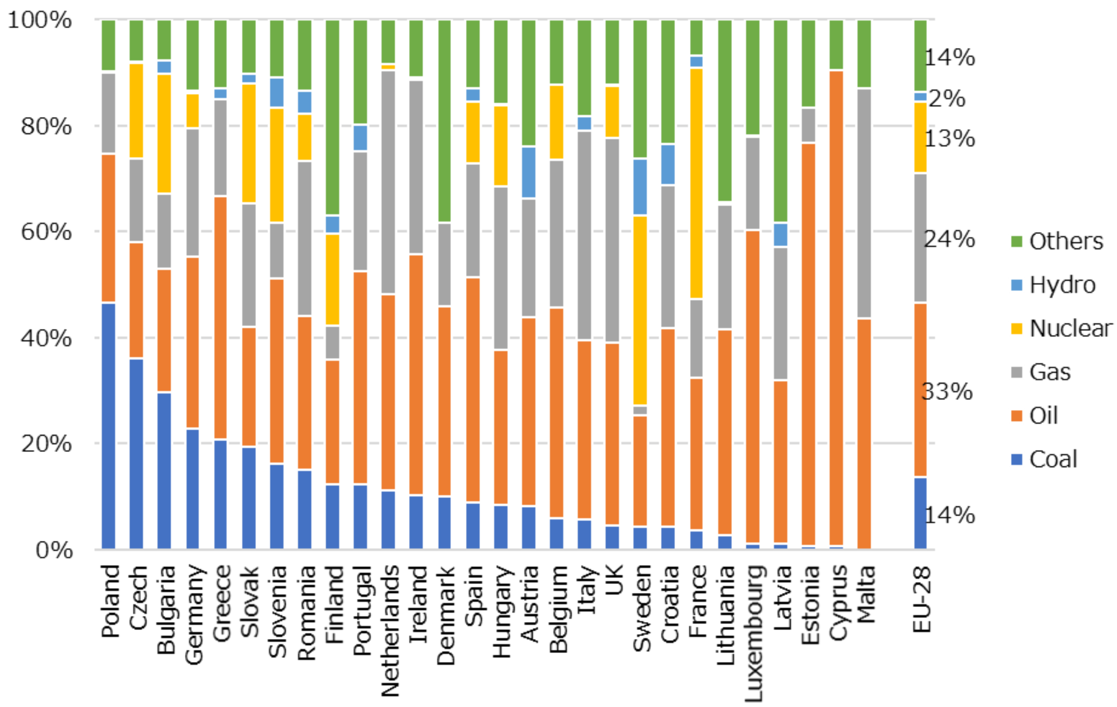
[27] European Parliament, "Energy: new target of 32% from renewables by 2030 agreed by MEPs and ministers" 14 June 2018. https://www.europarl.europa.eu/news/en/press-room/20180614IPR05810/energy-new-target-of-32-from-renewables-by-2030-agreed-by-meps-and-ministers. Accessed on 25 January 2021.

[28] European Commission, "Commission presents Renewable Energy Directive revision," 14 July 2021. https://ec.europa.eu/info/news/commission-presents-renewable-energy-directive-revision-2021-jul-14_en. Accessed on 10 August 2021.



Note: UK: United Kingdom. Figures as of 2018. The UK is included in the EU-28.
Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-1 Primary Energy Supply Composition of 28 EU Countries

(1) United Kingdom

The energy mix of the United Kingdom is closely affected by the status of domestic energy production. Since the latter half of the 18th century, domestic coal was a driving force of the Industrial Revolution and played a central role in the British energy supply. With the discovery of a large oil and natural gas field in the North Sea in the mid-1960s, the United Kingdom switched the town gas that was produced from coal to natural gas produced from the discovered North Sea gas fields. After that, the rise in oil prices due to the oil crisis in the 1970s, the development of natural gas pipeline network in the Britain, and the decline of domestic coal production in the 1990s promoted the shift from oil and coal to natural gas, particularly in the power generation sector. In this way, the UK energy mix has changed largely reflecting the status of its domestic energy production.

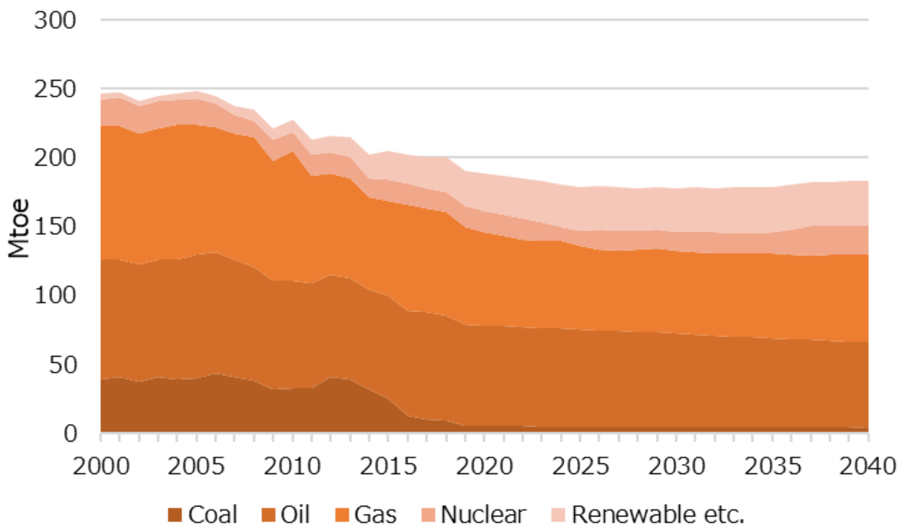
Nuclear power also plays an important role in ensuring diversity. Britain began to utilize nuclear power in the 1950s, but the last nuclear power plant was built in 1995, or more than 25 years ago. While many nuclear reactors are approaching the end of their lifespan, new build has not progressed and the operation of existing units has been extended. The UK government has a policy of promoting nuclear power generation from the perspective of stable power supply and climate change measures, and is considering applying a favorable tariff model to new nuclear power generation plans. UK is a country that possesses nuclear weapons and has an incentive to maintain nuclear power generation also from the military perspective.

In terms of the environment, the United Kingdom is one of Europe's most proactive countries to pursue climate change actions. Supply of renewable energy in the UK has increased significantly in recent years. Solid biomass (8.0Mtoe), wind power (6.5Mtoe), and biogas (2.8Mtoe) are major source of such renewable energy supply. Solid biomass, which is the largest source of supply, has been increasingly used for power generation under the government's support measures, but in recent years nearly half of its supply depends on imports. Competitions with food supply as well as deforestation also became negative factors for solid biomass. On the other hand, because it is basically a domestic energy source and its cost becomes lower, wind power, particularly offshore wind, has gained growing interests in the UK.

In terms of energy system redundancy, the UK has the advantage of connecting gas pipelines and transmission lines between the North Sea oil and gas fields and continental Europe. In addition, as decarbonization progresses in the future, it is expected that the demand for oil and natural gas from the North Sea oil and gas fields will decline. This also means that the amount of these unproduced resources can be maintained as a stockpiling in a sense. The energy infrastructure that connects to continental Europe, furthermore, will also serve as a backup energy supply source in case of emergency.

In the energy selection of the future, environmental factors, namely reduction of CO2 emissions, will be a major determinant. The Department for Business, Energy and Industrial Strategy (BEIS) of the United Kingdom announced the "Energy and Emission Projection" every year since 2013, which shows the outlook for future energy supply and demand and CO2 emissions under multiple scenarios.[29] According to the projection, the amount of primary energy supply will remain almost flat through 2040 because the decline of demand in the industry and transportation sectors will be offset with the increase in the residential and commercial sectors. The energy mix shows no significant changes other than a slight increase in the use of nuclear power (Figure 2-2). On the other hand, the power generation sector is expected to make steady changes toward decarbonization, such as the abolition of coal-fired power generation and a significant increase in renewable energy (Figure 2-3).

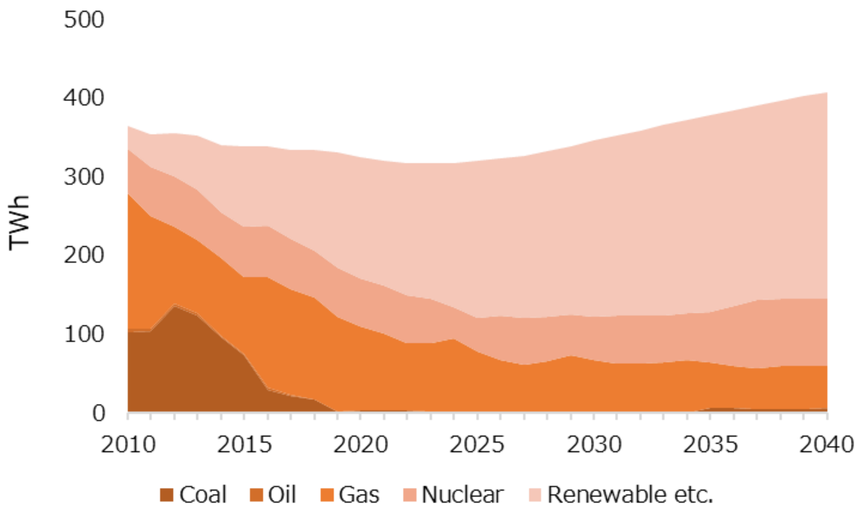
[29] The analysis of the projection was done in March 2020 and thus does not reflect the impact of coronavirus.



Note; Figures of Reference scenario. Renewable etc. include import of electricity.

Source: Department for Business, Energy & Industrial Strategy (BEIS), *Updated energy and emissions projections: 2019*

Figure 2-2 Outlook of primary energy supply in the United Kingdom



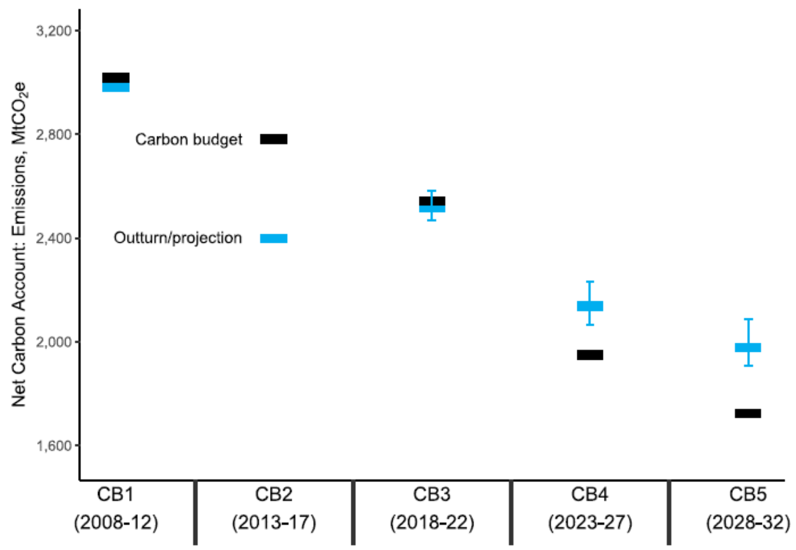
Note; Figures of Reference scenario. Renewable etc. include import of electricity.

Source: Department for Business, Energy & Industrial Strategy (BEIS), *Updated energy and emissions projections: 2019*

Figure 2-3 Outlook of electricity generated in the United Kingdom

Considering these factors, the decarbonization of heat demand is behind the target. In fact, the Updated Energy and Emission Projection 2019 compares the carbon budget for

2050 carbon neutrality [30] and the CO2 emission forecast, and predicts that in the 4th period (2023-2027) and in the 5th period (2028-2032), emissions will exceed the carbon budge (Figure 2-4). The UK announced in November 2020 that it would ban the sale of new gasoline and diesel vehicles in the country in 2030. This target setting can be one of attempts to contain the emissions below the carbon budget as automobiles uses large amount of heat as the industrial sector and the electrification of automobile may contribute to the control of the entire emissions amount.



CB = carbon budget

Source: BEIS, *Updated energy and emissions projections: 2019*

Figure 2-4 Outlook of Carbon budget and CO2 emissions in the United Kingdom

(2) Germany

The primary energy source of Germany was domestic coal as in the UK. There are abundant lignite resources in Germany, and by making the best use of them in power generation, industry, railways, and buildings, and greatly helped the postwar reconstruction of Germany. The demand growth of oil natural gas then gradually reduced the proportion of coal in the energy mix, but it has remained as one of the key energies, accounting for about 25% of total primary energy supply until 2015. Behind this was consideration for the domestic coal industry, especially the former East German coal industry. At the time of the unification of East and West Germany in 1990, the income disparity (difference in GDP per capita) between East and West Germany was as large

[30] It defines the amount of CO2 that can be emitted over a five-year period and considers it as a "budget. The carbon budget will be gradually devalued toward carbon neutrality in 2050. The government will take measures to ensure that CO2 emissions within the period will be within the budget.

as about four times. Although it has narrowed considerably since then, economic disparity still remains. The abolition of coal use hurts the economy of the former East Germany, and rising unemployment can lead to social and political instability. This is the reason why Germany was unable to solidify its coal-free thermal power policy until 2019, despite being a country enthusiastic about decarbonization.

Like many other countries, oil demand in Germany increased by its industrialization, motorization and improved living standards. The oil demand for the transportation sector continued to increase until 1999, but the demand for industrial and consumer products turned to decline due to the switching to natural gas after the oil crisis in the 1970s. Natural gas demand, which replaced oil outside the transportation sector, increased significantly through the 1990s. Natural gas is mainly imported from Russia by pipeline, but since the 2000s it has experienced several outages of gas supply via Ukraine, which poses a risk to energy supply. In response to this, Germany developed its pipeline capacity directly imported from Russia.

Renewable energy and nuclear power have shown contrasting movements in recent years. As the main energy for decarbonization, renewable energy is steadily increasing thanks to policy arrangement such as feed-in tariff and prioritized access to the power supply. On the other hand, after some twists and turns in policy, it was decided in 2011 that all nuclear power plants would be abolished by 2022 in Germany. The history of the German anti-nuclear movement can be traced back to the 1970s. Germany initially had a plan to promote nuclear power generation in the 1970s, but after the Chernobyl nuclear power plant accident in 1986, it began to take a distancing policy from nuclear. In 2009, the Merkel administration once changed its direction to nuclear power promotion due to the necessity and economic efficiency of fossil fuel substitution, but decided to abolish nuclear power by 2022 following the accident at Fukushima Daiichi Nuclear Power Plant in 2011.

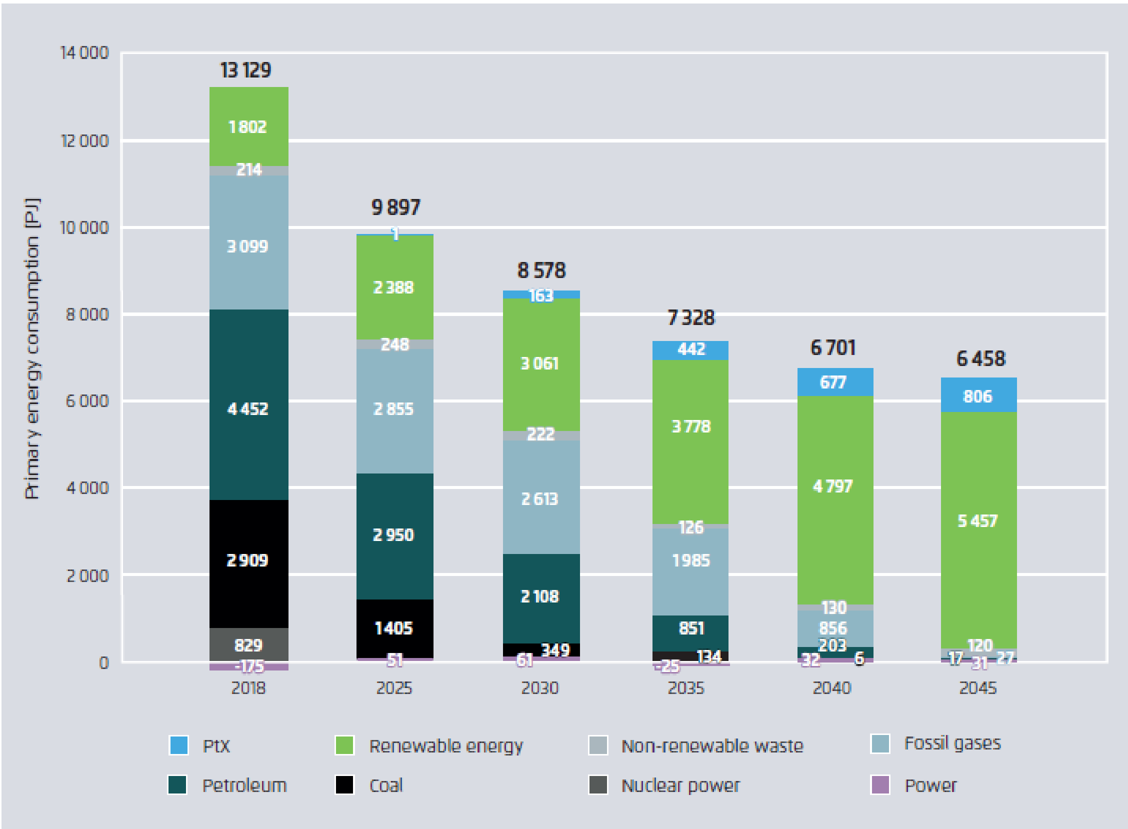
In terms of energy system redundancy, Germany's strength is that it is geographically central to Europe. the close connection of cross-border energy infrastructure is one of the cornerstones of energy security. By connecting to neighboring countries via gas pipelines and power transmission lines, Germany secures flexibility in supply and demand adjustment during normal times and backup supply in emergencies.

As in the UK, CO2 emissions are the most important factor in determining Germany's future energy mix. In June 2021, German Congress passed the revised Climate Action Law, which stipulates that carbon neutrality will be achieved by 2045. [31] The energy supply and demand structure will change dramatically to achieve this ambitious goal.

The German federal government has not published an official energy mix target, so

[31] Clean Energy Wire (2021.6.25), Germany passes new Climate Action Law, pulls forward climate neutrality target to 2045

a think tank analysis is examined here (Agora Energiewende et al., 2021). According to the analysis, Germany's energy mix will undergo a major shift toward a supply structure centered on renewable energy toward 2045 (Figure 2-5). Among renewable energies, it is anticipated that many solar power generation facilities will be added. This is to replace the energy used in all demand sectors including transportation and buildings with electricity from renewable energy. Hydrogen produced by abundant renewable electricity (PtX in the figure corresponds) will also be utilized in the industry and freight vehicles. Germany has decided that nuclear power generation will be abolished by 2022 and coal-fired power generation will be abolished by 2038. In addition to these, natural gas consumption is projected to be significantly reduced in 2045. Currently, natural gas is extensively used for heating, but it will be replaced by electric heat pumps. Fossil fuels will continue to be used in some industries such as cement manufacturing, but CCS will be installed to eliminate CO2 emissions.

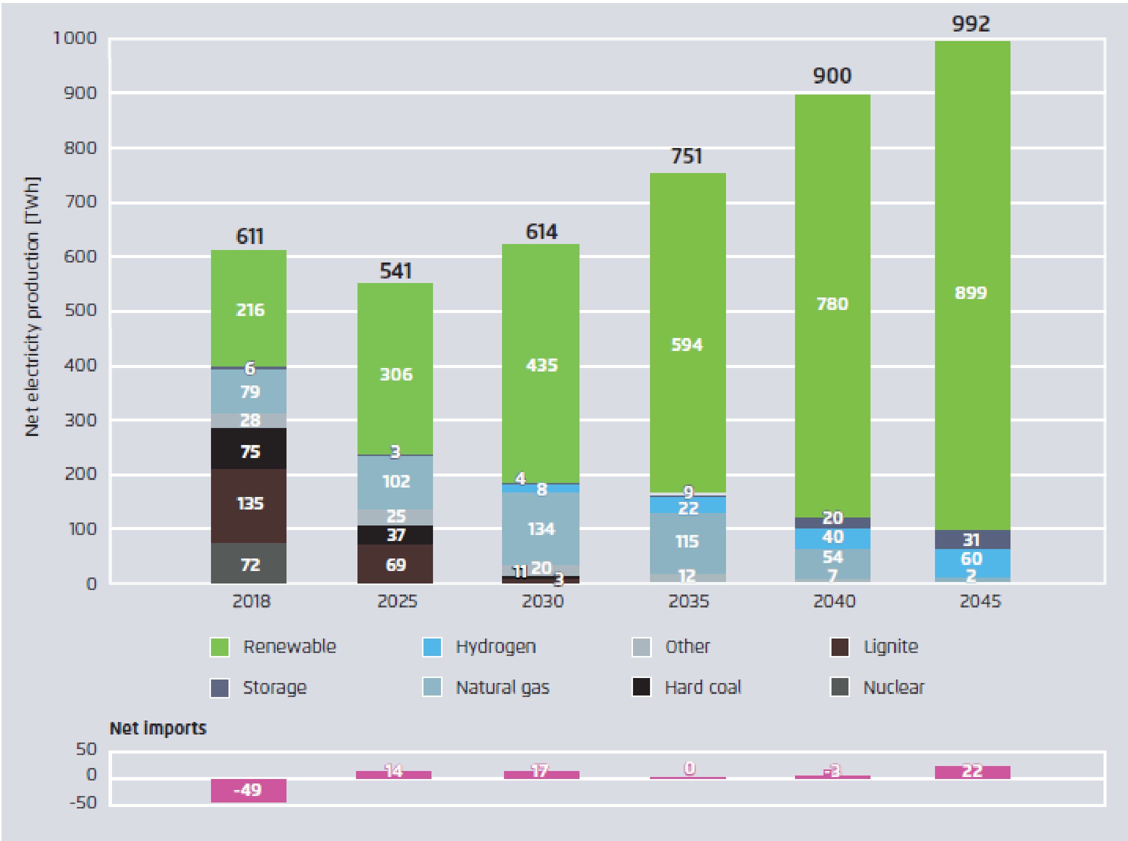


Note: PtX = power to x : various secondary energy produced from renewable electricity

Source: Agora Energiewende (2021.6), Toward a Climate-Neutral Germany by 2045

Figure 2-5 Outlook of primary energy supply in Germany

Regarding electric power, as shown in Figure 2-6, cross border trade of electricity is projected. In expanding the use of variable renewable energy (VRE) with fluctuating output, how to balance supply and demand is a major issue. In the case of Germany, supply and demand adjustment by PtX and various power storage technologies is assumed, but in addition to these, power trade with neighboring countries is also assumed as an effective means. If these energy-power mix of 2050 were realized, Germany will have a strong energy supply and demand structure with a self-sufficiency rate close to 100%. In terms of geopolitical risk, through these increased self-sufficiency of energy supply and utilization of electricity trade with other EU member countries, Germany will be able to reduce geopolitical risks in crude oil imports from Middle East and North African countries and natural gas imports from Russia.



Source: Agora Energiewende (2021.6), Toward a Climate-Neutral Germany by 2045

Figure 2-6 Outlook of electricity supply and net import in Germany

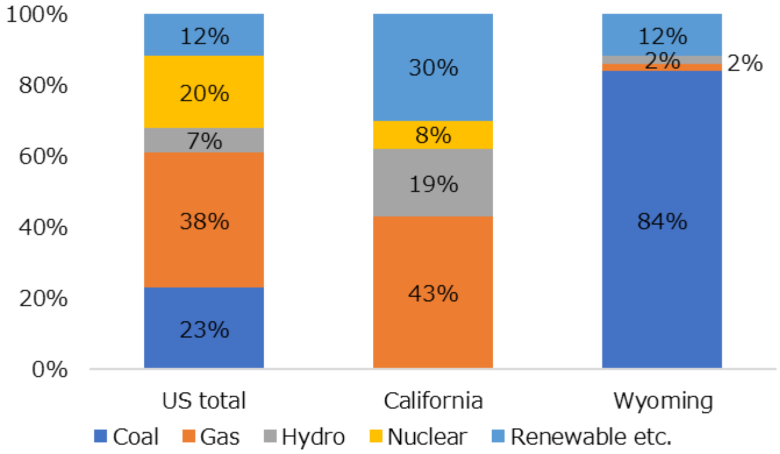
(3) United States

US energy policy has two major characteristics: emphasis on the market functions and dual structure of federal and state governments.

Energy mix target has never been an agenda of energy policy in the United States, at least on the federal level. This is because the United States has abundant fossil energy resources in its land, and, without the involvement by the government, the United States has been able to secure a stable energy supply. An exceptional sector where the federal government engaged in stable energy supply was oil. The U.S. oil self-sufficiency began to decline after the 1970s, reaching 35% in the mid-2000s. As a result, oil security became a central issue for the U.S. energy policy, and strategic petroleum reserves began to be developed from 1975 after experiencing the oil crisis in 1973. Against such development, in the 2000s, the “shale revolution” drastically changed energy security landscape by bringing a significant increase in the U.S. crude oil and natural gas production. Thanks to the shale revolution, all fossil energies achieved self-sufficient as of 2020, and the "Energy Independence" that the United States has long pursued since the oil crisis was finally realized.

It is the electricity market that clearly shows that energy is chosen by market mechanism. In the 2000s, the shale revolution provided abundant supply of cheap natural gas, which made gas-fired power far more cost-competitive. Coal-fired power, which used to account for about 50% of electricity supply, peaked in 2005 and began to decline. Electricity generated by coal decreased by 60% compared from 2005 to 2019, and its share of electricity supply also dropped to 20%. On the other hand, the electricity generated by gas-fired power generation increased 2.1 times from 2005 to 2019, and its share rose rapidly to 39%. The competitiveness of gas-fired power plants has reached a level that cannot be matched by nuclear power generation, and nuclear power plants are being closed due in part to the decline in natural gas prices.

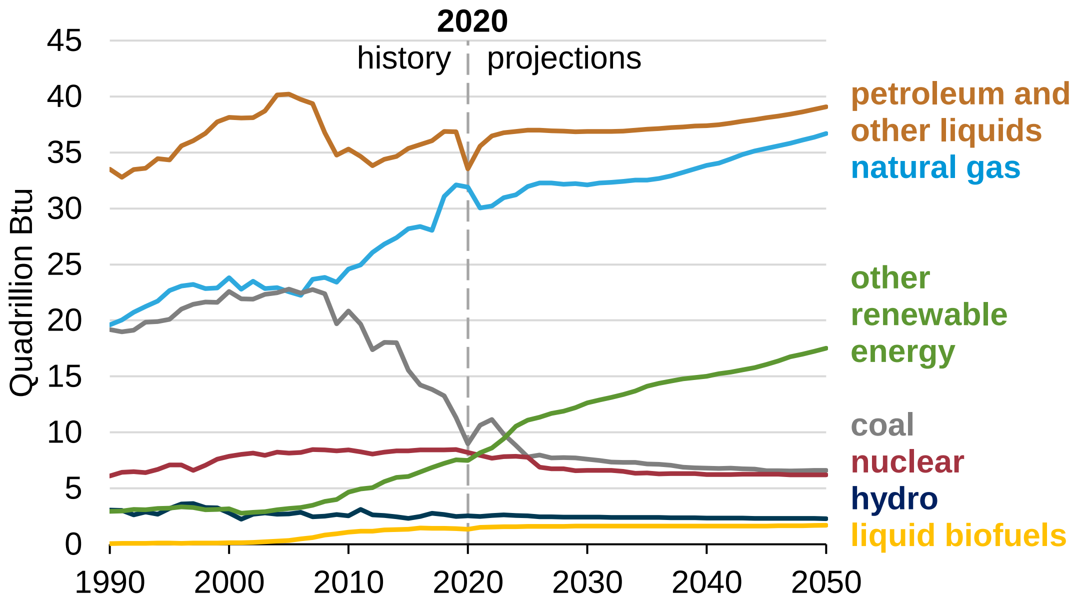
The dual structure of federal and state governments poses another characteristic of the U.S. energy policy. The state government in the United States has strong authority over energy policy and develop their own energy policy. The high degree of independence of the state government is analogized as the independence of each member state government in the European Union. Characteristics of each state most visibly appear in the power generation mix. In the federal power generation mix, the shares of coal, natural gas, hydropower, nuclear power, and renewable energy are composed of 23%, 38%, 7%, 20%, and 12%, respectively (Figure 2-7). By contrast, in the state of California, which aims to decarbonize electricity by 2045, the shares of coal, gas, hydro, nuclear and renewable are 0%, 43%, 19%, 8%, and 30%, respectively. Meanwhile, in the state of Wyoming, which is known as a major coal producing area, those shares are 84%, 2%, 2%, 0% and 12%, respectively. In this way, the electricity mix for each state varies greatly depending on resource availability and policies.



Source: Energy Information Administration, Detailed preliminary EIA-923 monthly and annual survey data

Figure 2-7 Shares of electricity generated in the entire United States, California, and Wyoming as of 2019

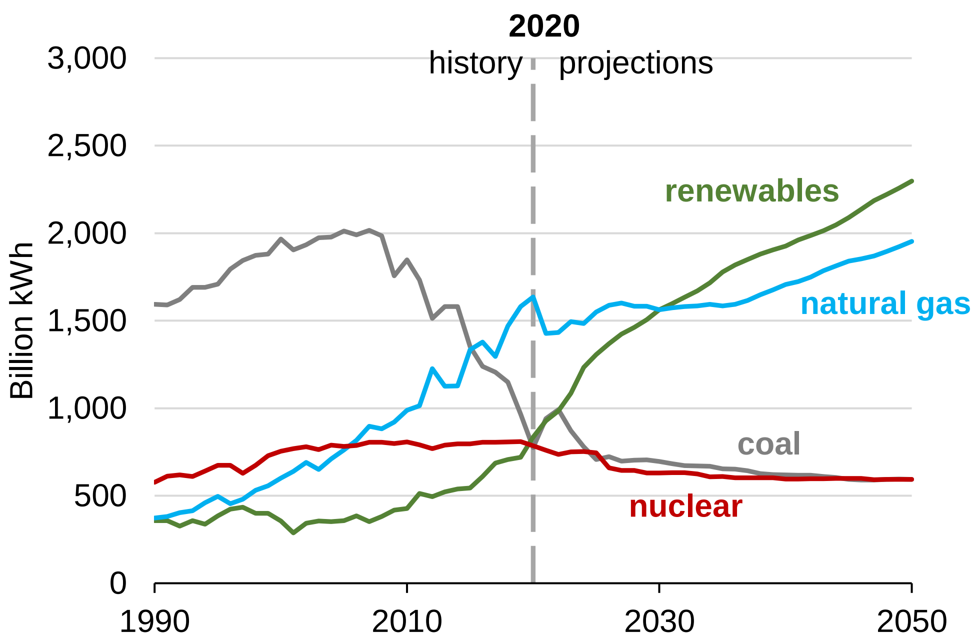
Looking at the future energy mix, according to the Annual Energy Outlook 2021 released by the Energy Information Administration (EIA) in February 2021, although the supply of renewable energy including solar will increase due to cost reduction, oil and natural gas are still expected to remain as the main energies as they are today (Figs. 2-8 and 2-9). Coal and nuclear power will continue the declining trend in all of potential scenarios. This is because in this outlook natural gas will continue to be the most competitive energy in the industrial sector, which will consume the most energy through 2050. In addition, petroleum will continue to be a major energy in the transportation sector as electrification will not progress under the existing policy menu. Although demand for electricity is increasing in the building sector, it does not dramatically change the structure of the two pillars of electricity and natural gas.



Note: the figures shown are those of Reference Case; Quadrillion = 10^15, Btu = 1.05506 kJ

Source: Energy Information Administration, *Annual Energy Outlook 2021*

Figure 2-8 Outlook of primary energy supply in the United States



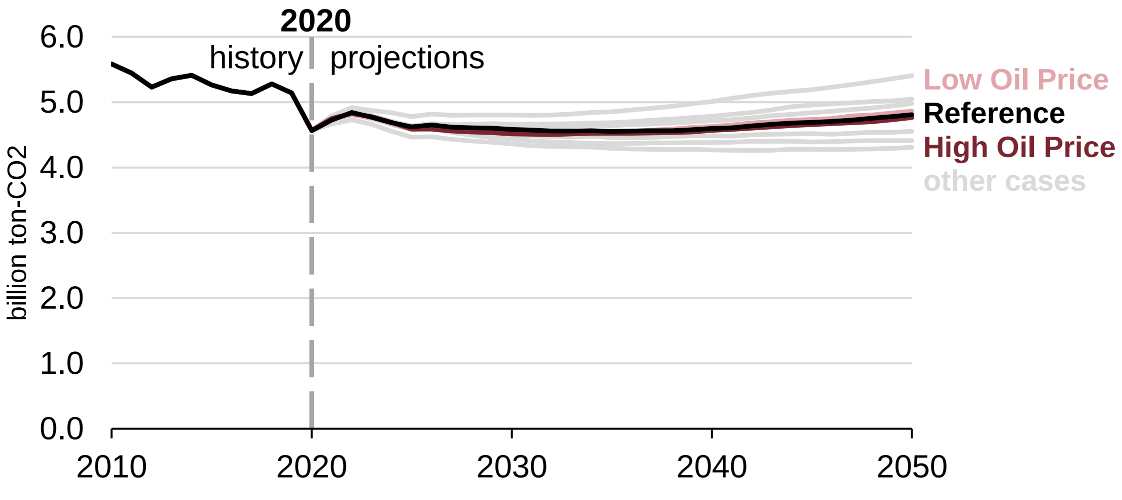
Note: the figures shown are those of Reference Case; Quadrillion = 10^15, Btu = 1.05506 kJ

Source: Energy Information Administration, *Annual Energy Outlook 2021*

Figure 2-9 Outlook of electricity generated in the United States

CO_2 emissions are expected to remain almost flat as total energy demand increases while the carbon intensity of energy supply gradually improves (Figure 2-10). It should be noted that the EIA outlook cited here was published in February 2021, and thus the analysis work was carried out under the previous Trump administration, which was not very positive to climate actions. In April 2021, President Biden announced the U.S. Nationally Determined Contributions (climate target) that the United States would reduce its emissions amount by 50-52% from 2005 to 2030. There exists a large gap between the pledged NDC and the outcome of EIA's analysis. Therefore, the Biden administration's new policies on the future energy mix will be reflected in the next outlook published in 2022.

In the United States, meanwhile, it is not uncommon that the direction of energy and environment policy sways from one administration to another, while such political fluctuations did not cause significant influence on the actual energy selection in the end. This is because energy industry by nature requires long-term investment planning, and the four- or eight-year presidential / administrative changes are difficult to align with the long investment cycle of energy infrastructure. For this reason, it is better to think that market principles and state government policy based on the local resource endowments will have more influence in the future of the US energy mix rather than the federal energy and environment policies.



Source: Energy Information Administration, *Annual Energy Outlook 2021*

Figure 2-10 Outlook of CO2 emission in the United States

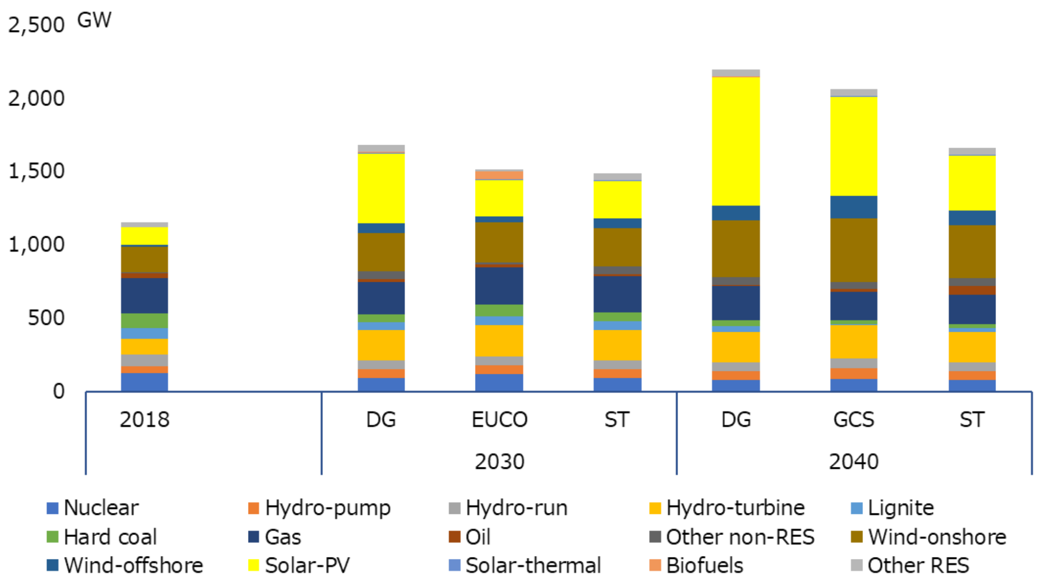
2.1.2 Power mix policies around the world

(1) Power Mix Policy in Developed Countries

1) Europe

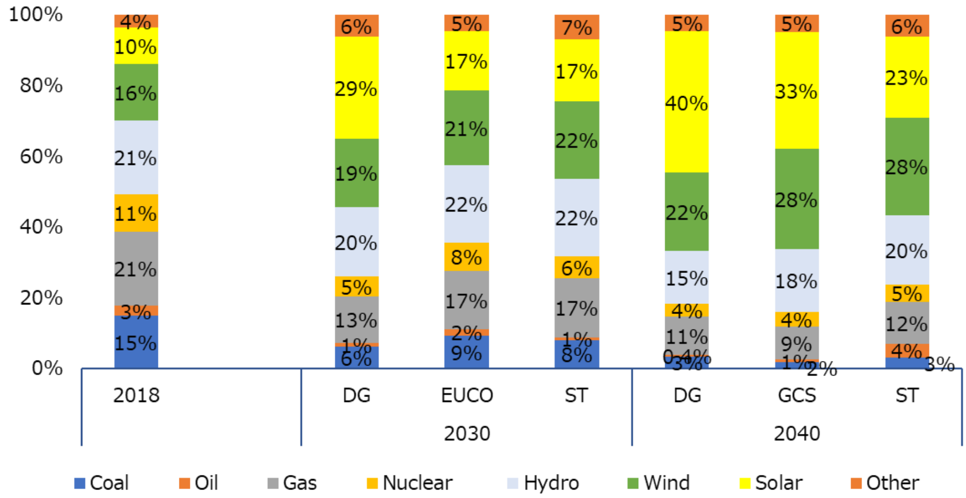
In many of developed countries, investments in the power generation sector have been liberalized, and the government no longer publishes policies of a particular power mix, except to set targets for expanding the adoption of renewable energy generation. On the other hand, since the transmission sector requires a certain amount of time for acquisition of land to build power transmission facilities, governments have created and announced the assumption of future power supply mixes for the purpose of identifying required power transmission facilities.

In Europe, ENTSO-E (the European Network of Transmission System Operators) has announced a power transmission facility plan called the Ten-Year Network Development Plan (commonly known as TYNDP) every two years, and has published several power configuration scenarios as a precondition for its power transmission development plan. The outlook includes three scenarios: 1) Sustainable Transition (ST) scenario (achieving climate change targets through national regulations, emissions trading, and subsidies to make the best use of existing infrastructure), 2) Distributed Generation (DG) scenario (centered on prosumer for small-scale power generation, storage batteries and fuel switching), and 3) The Global Climate Action (GCA) scenario (global decarbonization actions and large-scale renewable energy development in both power and gas sectors). The outlook of power generation capacity as of 2030 and 2040 under each scenario are shown in Figures 2-11 and 2-12.



Note: EUCO: European Commission 2030 scenario based on energy outlook for 2030 adopted by the European Commission in 2014
Source: ENTSO-E, Made by "ENTSO Scenario 2018 Generation Industries" 2018

Figure 2-11 ENTSO-E Power Configuration Outlook



Source： ENTSO-E, Made by "ENTSO Scenario 2018 Generation Industries" 2018

Figure 2-12 ENTSO-E Power Configuration Share Outlook

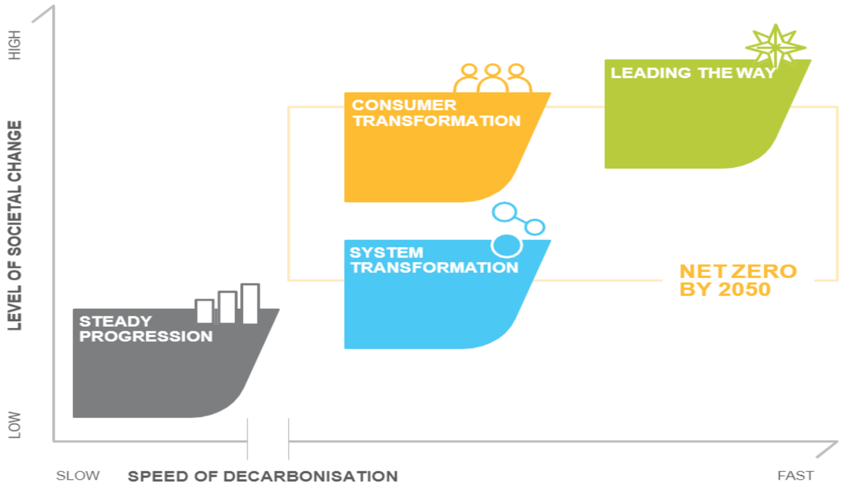
The EU regulation (Regulation on the internal market for electricity (EU) 2019/943) provides that adoption of capacity mechanism is allowed only when the European Resource Adequacy Assessment finds insufficient supply capacity. The adequacy assessment is conducted for the next 10 years by ENTSO-E. The methodology of assessment was just approved by ACER (European Union Agency for the Cooperation of Energy Regulators: an organization composed of independent regulators of Europe) on October 2, 2020, and the first assessment is scheduled to be published in the end of 2021. According to the approved system, the adoption of capacity mechanism may last 10 years if the assessment finds it necessary, although unconditional participation of coal-fired power generation to the capacity mechanism is permitted only until July 2025. From July 2025, the participation of coal-fired power generation is restricted so as not to exceed the 350kg emissions of CO_2.

One of recent cases of capacity mechanism adoption is the Italian case where the European Commission permitted to adopt the capacity mechanism in February 2018, and the adoption was finalized by the Ministerial Decree of June 28, 2019. The first auction for capacity mechanism was conducted in November 2019, and the capacities of year 2022 and 2023 were transacted. Coal-fired power generation was not included in these transactions.

2) United Kingdom

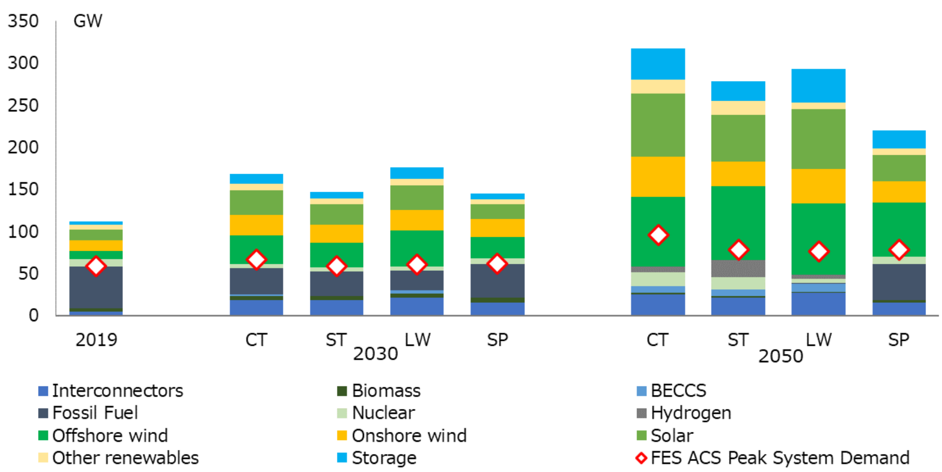
Similar power configuration prospects have been made in European countries. In the United Kingdom (UK), National Grid ESO (Electricity System Operator), a transmission system operator of the UK, publishes future scenarios called "Future Energy Scenarios" every year, and makes a plan for building transmission facilities based on each scenario and provides transmission facilities owners with information utilized for their investment decisions.

The Future Energy Scenario of 2020 are based on two axes: social structure transformation and decarbonization progress. In the document, four scenarios are provided, namely Consumer Transformation Scenario, System Transformation Scenario. Leading the Way Scenario, and Steady Progression Scenario (Figure 2-13). The scenarios also had their power supply configuration plans by 2050 (Figure 2-14).



Source: National Grid ESO, "Future Energy Scenario Framework", June 2020

Figure 2-13 Future Energy Scenario Framework by National Grid



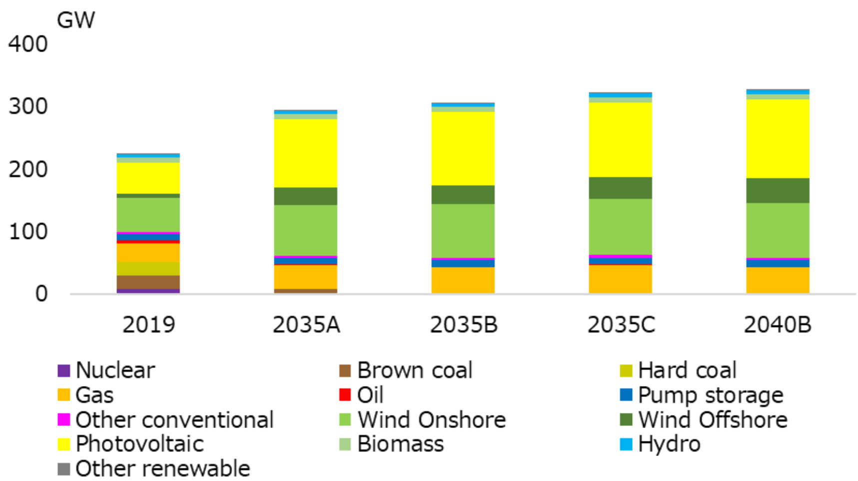
Note: CT: Consumer Transformation Scenario; ST: System Transformation Scenario; LW: Leading the Way Scenario; SP: Steady Progression Scenario

Source: National Grid ESO, "Future Energy Scenario 2020", June 2020.

Figure 2-14 UK Power Configuration Outlook

3) Germany

In Germany, power supply mix scenarios are formulated also as a reference for power transmission investments. The scenarios are formulated based on discussions with various stakeholders hosted by the Federal Network Agency and is updated annually. Based on different climate action scenarios, the power configuration scenario formulated in June 2020 assumes three power configurations for 2035 and one power supply configuration for 2040 (Figure 2-15). These scenarios are based on the Federal Climate Protection Act's renewable energy expansion targets in Germany and the CO2 reduction targets of the Climate Protection Program 2030, and reflect the phase out law for coal-fired power that was enacted in August 2020.



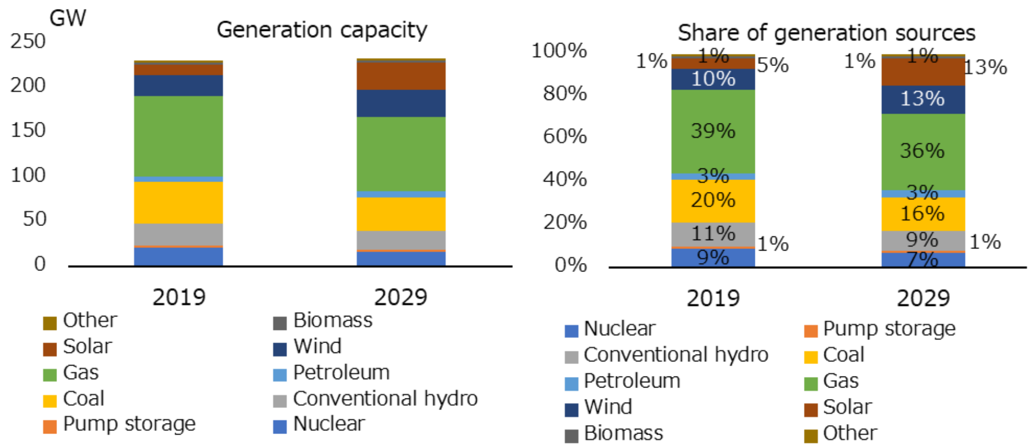
Note: The alphabet after the number of years refers to the type of scenario.
Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railways, "Approval of scenario framework 2021-2035", June 2020

Figure 2-15 German Power Configuration Scenarios

4) United States

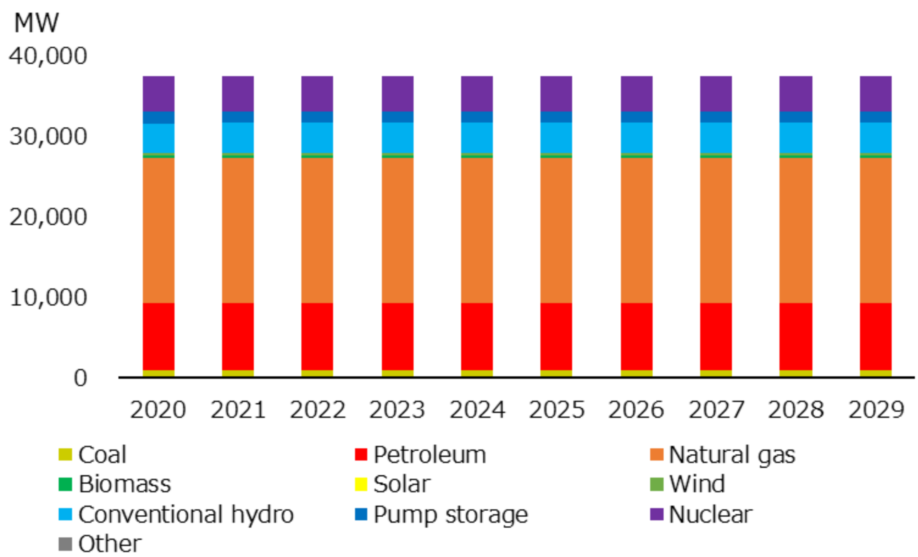
In the United States, North American Electric Reliability Commission (NERC) annually publishes "Long-Term Confidence Assessment Report." The report assesses the adequacy of generation capacity over the next decade and shows the power configuration outlook (Figure 2-16). NERC made its assessments based on reliable information sources submitted by relevant agencies in each regional market. In some markets, however, high uncertainties exist because the markets are liberalized. Depending on the degree of certainty, therefore, capacity assessments are made for four categories; 1) existing capacity, 2) capacity under construction and approval (Tier 1 capacity addition), 3) decommissioned capacity (officially approved for decommissioning) and planned and applied but not-yet approved capacity (Tier 2 capacity addition), and 4) abolished capacity.

Because of the high degree of uncertainties, some regional power markets such as New England, PJM,[32] and ERCOT,[33] provide simplified capacity assumptions just by adding new capacities and detract to-be-abolished capacity in the next few years and put the capacity level at flat. As an example of such simplified assumption, Figure 2-17 shows the power configuration outlook for New England, and Figure 2-18 shows the power configuration outlook for major regional power transmission authorities in the United States.



Source: NERC, "2019 Long-Term Reliability Assessment" December 2019

Figure 2-16 Outlook for North American (U.S.-Canada) Power Supply Configuration

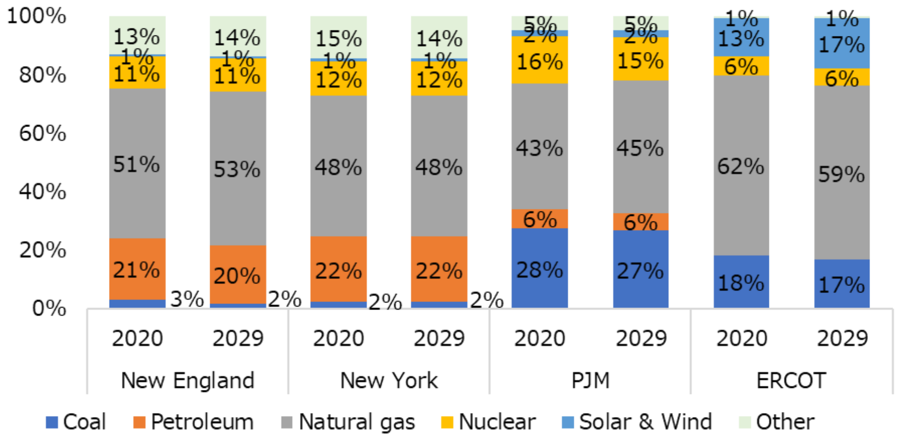


Source: NERC, "2019 Long-Term Reliability Assessment" December 2019

Figure 2-17 New England Power Configuration Outlook for 2020 and 2029

[32] PJM is the power market in the states of Pennsylvania, New Jersey, and Maryland

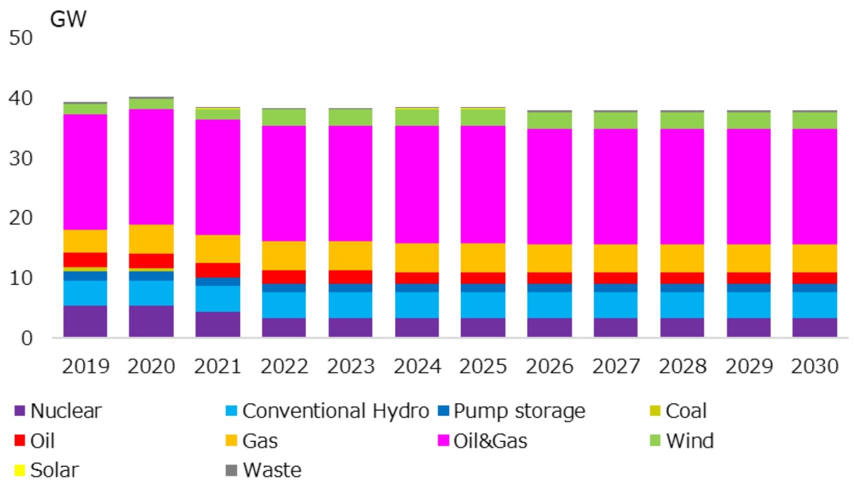
[33] ERCOT (Electric Reliability Council of Texas) is the power market in the state of Texas.



Source: NERC, "2019 Long-Term Reliability Assessment" December 2019

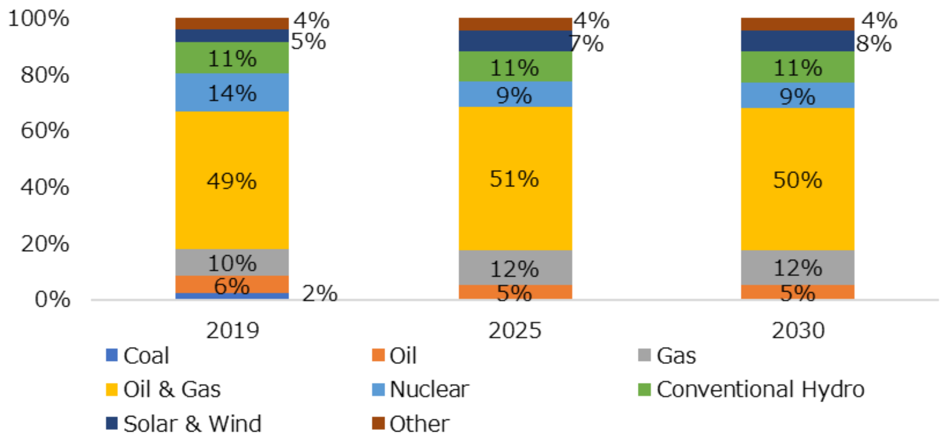
Figure 2-18 Power Share Outlook for Major Regional Transmission Engines (RTO)

The power configuration outlook prepared and published by each regional market organization is different from the one submitted to NERC for the above reasons. Figures 2-19 and 2-20 show power configuration (in the summer period) for the next ten years published by New York ISO. Whereas the share of coal-fired power is assumed at 2% as of 2029 in the report submitted to NERC, the published forecasts suggests that coal-fired power capacity will be gone after 2021. Furthermore, although the report submitted to NERC says that the share of wind power generation will be flat after 2021, the published configuration forecasts that the share of wind power will increase until 2024. Since power configuration in the future has uncertainty in the liberalized market, it should be noted that forecast will differ depending on the precondition of probable investment and abolishment of power capacity.



Source: New York ISO, "Gold Book", April 2020.

Figure 2-19 Outlook for Power Configuration in summer by New York ISO "Gold Book"

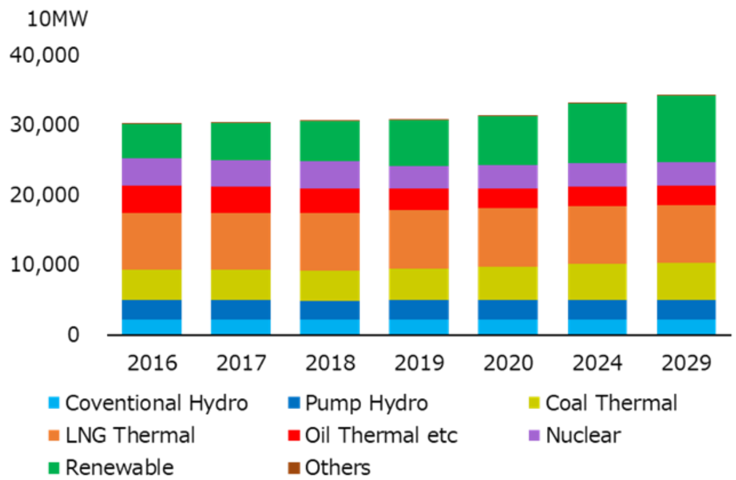


Source: New York ISO, "Gold Book", April 2020.

Figure 2-20 Outlook for share in Power Configuration in summer by New York ISO "Gold Book"

5) Japan (Organization for Cross-regional Coordination of Transmission Operators)

In Japan, retail electricity company and power generation company are obliged to submit the power supply and demand outlook for the next 10 years to the Organization for Cross-regional Coordination of Transmission Operators (OCCTO), Japan, in conformity with the regulation of the Electricity Business Act. Based on these submitted plans, OCCTO publishes "Aggregation of Electricity Supply Plan" every year, which shows the power supply configuration for the next 10 years (Figure 2-21). The supply plan is also used to assess the future supply-demand balance and is also utilized by the Committee on Cross-regional Coordination of Transmission to determine whether or not to build main transmission capacity.



Source: "Aggregation of Electricity Supply Plan for FY 2020", Organization for Cross-regional Coordination of Transmission Operators

Figure 2-21 Outlook for Power Supply Configuration in Japan

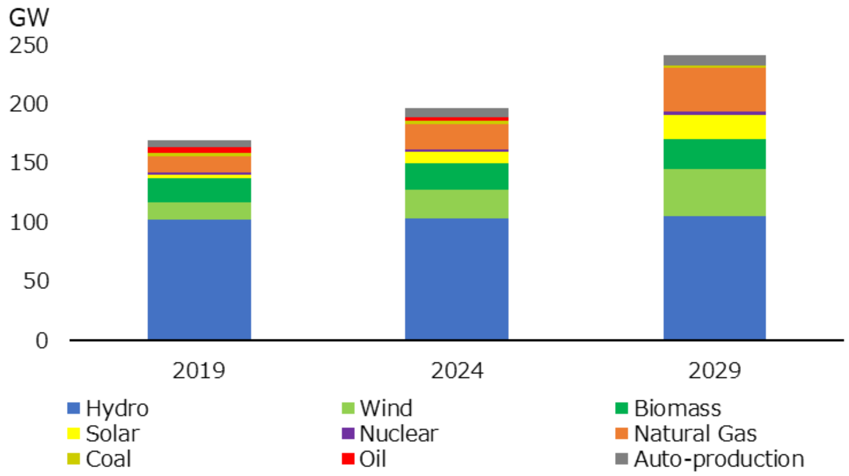
(2) Power Mix Policy in Developing Countries

In developing countries where electricity demand continues to increase, medium- to long-term power supply configuration forecasts have been made to ensure investment in supply power. In these forecasts, the government usually takes the lead in establishing future power supply configurations in consideration of the availability of fuels and the supply capacity such as renewable energy generation. In recent years, the World Bank and other financial institutions often demand structural reforms of the electricity market as a condition for financing power source development, and the increasing number of developing countries have introduced independent power producer (IPP) systems. For this reason, the forecast for power supply composition in developing countries, which used to have strong implications for the country's power development plan, has gradually become an indicator of facilitating private-sector investment in power generation. Since power mix policies in developing countries in Asia will be covered in the following chapters, this section features the policies of Brazil and Argentina, two emerging countries in South America, where relevant English materials are available.

1) Brazil

In Brazil, power system reforms have already been done, and investments in the power generation sector is basically determined through auction. The auction is to be held four and six years before the start of operation respectively. Contract is concluded between a distribution company responsible for power supply and a competitive retail company

In Brazil, Empresa de Pesquisa Energética, a state-owned think tank under the Brazilian Ministry of Mines and Energy, develops a ten-year Energy Expansion Plan (Figure 2-22). The plan is developed in cooperation with the government and takes account of future energy development and procurement. The power development plan for the next six years is completed through the actual auctions, so the power configuration outlook is updated based on the results of the auctions and the power decommissioning plans in light of the increase in power demand. Since hydroelectric power generation requires the acquisition of water rights and a long period for development, outlook for power supply configuration has been made with some estimates on the start of the operation (Table 2-1, Figure 2-23). Outlook for other power source is made based on build-up plan for transmission capacity and location potential.



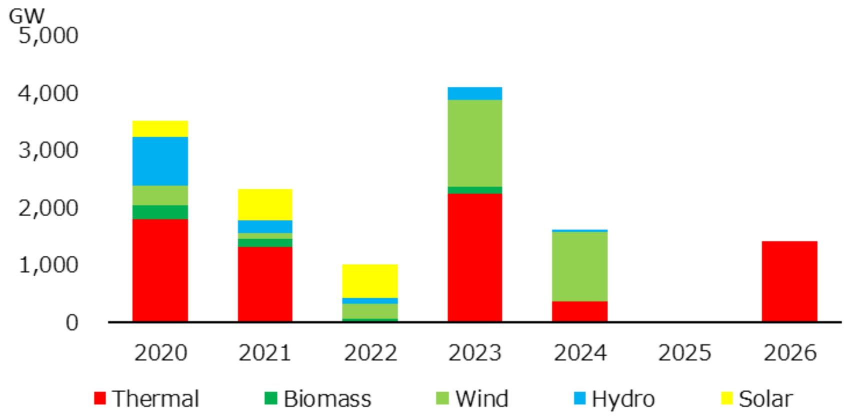
Source: Enpressa de Pesquisa Energetica, "Ten-Year Energy Expansion Plan 2029", June 2020.

Figure 2-22 Brazil Power Supply Configuration Outlook

Table 2-1 New Hydroelectric Power Generation Projects in Brazil

Site name	Installed capacity (MW)	Year of start of operation
Telemaco Borba	118	2026
Tabajara	400	2027
Apertados	139	2027
Andrcilandia	87	2027
Bin Qurer	650	2028
Castanheira	140	2028
Comissario	140	2029

Source: Energy Requisition Company, "Ten-Year Energy Expansion Plan 2029" June 2020.



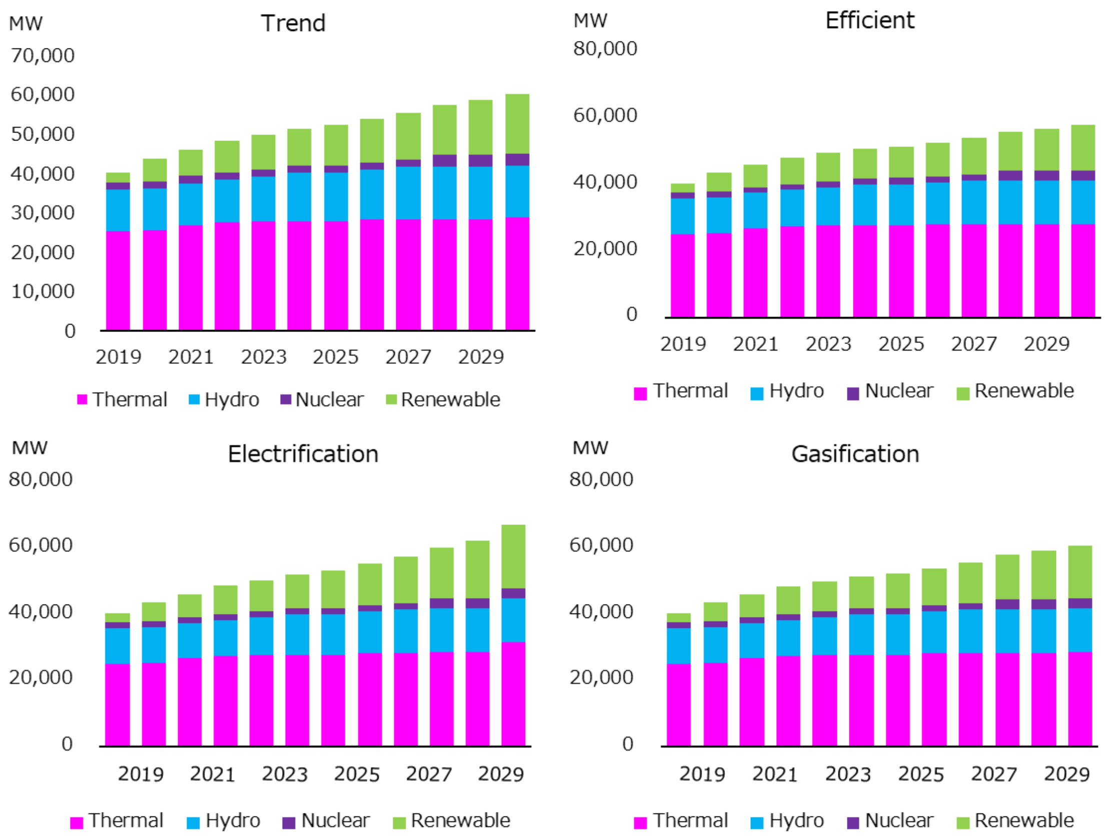
Source: Energy Purchasing Company, "Ten-Year Energy Expansion Plan 2029" June 2020.

Figure 2-23 Brazil's Power Development Plan to 2026 (Contracts through 2019)

2) Argentina

Power system reforms have been done also in Argentina, and the wholesale electricity market is operated through a spot market called CAMMESA (Compañía Administrator dora del Mercado Eléctrico Mayorista S.A.

Unlike Brazil, Argentina does not have an auction system that guarantees long-term contracts, and renewable energy generation is traded through an international tender system. Therefore, power supply configuration in the future contains high uncertainty, and Argentina has prepared multiple scenarios of outlook to accommodate such uncertainties. Argentina. The scenarios which Argentina develops are "Trend Scenario" and "Efficiency Scenario," both of which reflect the existing policies. "Industrialization by Gasification Scenario" and "Electrification Scenario" are developed as alternative scenarios (Figure 2-24).



Source: Secretariat of Energy Planning, "Escenarios Energéticos 2030", November 2019

Figure 2-24 Argentina Power Configuration Scenarios to 2030,

(3) Evaluation criteria for power mix in developed countries and emerging countries in South America

Table 2-2 summarizes the evaluation criteria utilized to develop power configuration outlook in the preceding paragraphs. In developed countries, there is no significant increase in electricity demand, and thermal power generation will be on a downward trend in the future, so factors related to energy security tend not to be seriously considered. Since the electricity market has already been liberalized in developed countries, furthermore, factors of economic efficiency are also out of the scope of evaluation. NERC of the United States and Canada and OCCTO of Japan develop the future power generation plan by referring to the existing investment plans while in Europe the power generation plan is developed by referring to the required carbon emissions reduction rather than the existing investment plans. With regard to environmental factors, while CO2 emissions reductions are adopted as the main criteria in Europe and NERC (a confidence agency in the United States and Canada), Japan evaluates sufficiency of supply capacity based on the highly reliable supply capacity plan submitted by each power generation company. The United State, Canada and Japan put emphasis on sufficiency of supply capacity as to power supply configuration in the future, quite unlike European countries, which put emphasis on CO2 emissions reduction.

In Brazil and Argentina, on the other hand, much of the investment in power generation has been left to private investments after power system reforms. CO2 emissions reduction is a subject for evaluation in addition to conventional power supply evaluation criteria such as changes in future energy demand and the ability of fuel procurement. Overall, since fuel prices have been at a low level in recent years, less and less countries take account of fluctuations in fuel prices in scenarios.

Table 2-2 Evaluation Criteria covered in the document showing the various power configuration prospects

Subject of consideration	Documentation for power configuration outlook	Evaluation criteria
ENTSO-E(EU)	Ten Years Development Plan	• CO2 emissions reduction • Power costs • Amount of renewable energy controlled • Amount of supply disruption
National Grid ESO (UK)	Future Energy Scenario	• CO2 emissions reduction (set up scenarios to maintain confidence) • Elasticity of supply power • Gas and hydrogen procurement volume
Federal Network Agency (Germany)	Scenario framework	• CO2 emissions reduction
NERC (Mi Plus)	Long-Term Reliability Assessment	• Sufficient supply power (confidence) • Elasticity of supply power
Power Wide Area Operation Promotion Organization (Japan)	Summary of supply plan	• Sufficient supply power (confidence)
EPE, Brazil	Ten-Year Energy Expansion Plan	• Elasticity of supply power • Gas procurement, oil procurement, ethanol procurement • CO2 emissions
Secretariat of Energy Planning (Argentina)	Energy Scenarios	• Gas procurement volume, oil procurement volume • Gas prices, oil prices • CO2 emissions

Source: Made by the Institute of Energy Economics, Japan, based on various materials.

Sufficient supply capacity is used as an index for stable supply. Summed capacities of power generation are compared with the expected maximum power generation from the viewpoint of whether sufficient supply capacity can be secured for such peak power generation. In recent years, however, because of the expansion of variable renewable energy power generation, it becomes difficult to make a proper evaluation based on the conventional method. In order to address this problem, probabilistic evaluation is adopted as a mean of such sufficiency evaluation. In Japan, this probabilistic evaluation is used to calculate the required reserve capacity. This method considers probabilistic fluctuations in demand and supply capacity for 8,760 hours a year, and calculates the supply reserve capacity required to meet the standard values for supply reliability (annual power outage time and power outage amount). Similarly, by giving a specific scenario to the power generation pattern of renewable energy power generation based on the future power source composition, the annual power outage time and power outage time are calculated probabilistically. Currently, while the power generation pattern of variable renewable power generation refers to the historical record, the evaluation method is not necessarily well established and, there are still many rooms for improvements.

2.2 Evaluation of energy mix in Asian countries

This section evaluates the energy mix of Asian countries. The analysis is conducted for both historical mixes and the future mixes. In the analysis for future energy mix, this section refers to Energy Outlook and Energy Saving Potential in East Asia 2020, an outlook prepared by Economic Research Institute for ASEAN and East Asia (ERIA). This is because the outlook was prepared by government officials or experts of each analyzed country (there are some exceptions) and well reflects the energy and environment policies of each country. The outlook, however, does not include the outlook for Bangladesh and Pakistan, and thus only historical analyses are made for the two countries.

2.2.1 Evaluation criteria for energy mix in Asian countries

The indicators that this section evaluates are shown in Table 2-3. Calculated indicators are scored from 1 to 10 scale because comparison of different indicators in the same standard is difficult. The higher the value of the self-sufficiency rate, the better the performance in each index. In case of HHI, because the lower figure is preferable, the score is converted and calculated as such. The analysis assumes that the minimum and maximum values of each indicator can take 0 point and 10 points. Each indicator is scored between the minimum of 0 points and the maximum of 10 points on the relative basis. The scored indicator could be less than 0 points and more than 10 points depending on the way of setting of the minimum and maximum values. In these cases, the minimum and maximum values are set as 0 points and 10 points, respectively (Table 2-3).

Table 2-3 Evaluation indicators of energy mix and their range of values

Indicator	Range of value		Description
	Minimum Score=0	Maximum Score=10	
① TPES self sufficiency	0%	100%	
② Oil self sufficiency	0%	100%	
③ Natural gas self- sufficiency	0%	100%	
④ Coal self sufficiency	0%	100%	
⑤ Electricity self sufficiency	0%	100%	
⑥ Diversity of TPES mix	Close to 0*	10,000	
⑦ Diversity of power generation mix	Close to 0*	10,000	
⑧ Access to electricity	0%	100%	
⑨ Energy intensity of GDP	0.947	0.033	The best and the worst in 2018 (IEA)
⑩ CO_2 intensity of GDP	1.84	0.05	The best and the worst in 2018 (IEA)

* This is theoretical figure. In this analysis, the lowest figure of TPES mix is 2,320 (Indonesia in the 2010s) and the lowest figure of power generation mix is 2,230 (the Philippines in the 1990s).
Source: The Institute of Energy Economics, Japan

This analysis refers to the figures provided in "Energy Outlook and Energy Saving Potential in East Asia 2020" published by Economic Research Institute for ASEAN and East Asia (ERIA) for future energy mix figures. The outlook provides two scenarios: Reference scenario (RES) as the base-case, business-as-usual scenario and Alternative Policy scenario (APS) where progressive energy and environmental policies will be adopted. Since this outlook covers only East Asia Summit countries, the outlooks for Bangladesh and Pakistan are not included. In addition, the outlook will be evaluated only for the following four items due to the constraints of the available supply and demand outlook data.

- Diversity of TPES mix
- Diversity of power generation mix
- Energy intensity of GDP
- CO2 intensity of GDP

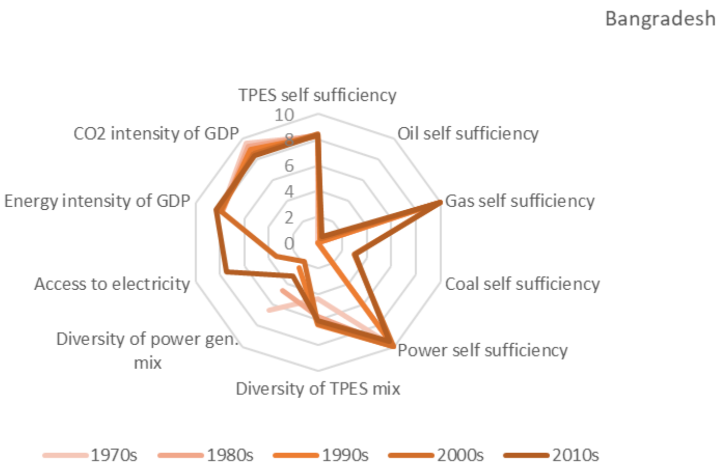
2 2.2 Assessment of energy mix in Asian countries

(1) Bangladesh

Bangladesh has maintained a high natural gas self-sufficiency rate to date. Oil production has also increased so far, but there is a significant shortage to meet the growing demand and thus the import has grown. While the volume of coal production is small, its domestic demand is also small. Overall, Bangladesh is largely dependent on natural gas. Securing natural gas supply, either from domestic production or LNG import, is important to secure energy security.

With regard to energy diversity, the scores of Bangladesh tend to worsen due to the increasing reliance on natural gas in both primary energy and electricity. Especially, natural gas accounted for 81% of the electricity generation (in 2010s) and the disruption of the supply of natural gas can cause significant impacts on the power supply. Since the 2000s, the country has achieved partial diversification of power generation by increasing coal-fired power generation. Given the growing interests on climate change globally, however, it may become difficult to pursue the diversification efforts only by introducing coal. Therefore, ensuring diversification of natural gas supply sources and expansion of use of renewable energy will be important options for Bangladesh.

Access to electricity has steadily improved, reaching at 87.2%as of 2019. Energy intensity of the economy is declining (improving), but the speed of improvement is slow. Carbon intensity worsens consistently throughout the period. This is likely due to the continued shift from traditional biomass to commercial energy, where carbon emissions are inevitable. (Figure 2-25).



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

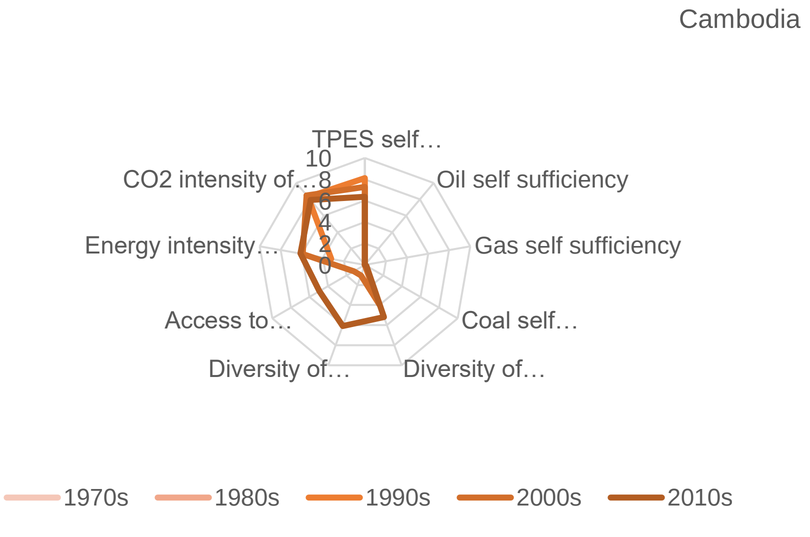
Figure 2-25 Changes in Energy Security Indicators in Bangladesh

(2) Cambodia

Cambodia is not endowed with fossil energy resources. It only produces a small amount of coal in the 2010s. Nonetheless, the overall self-sufficiency rate remained relatively high at 64% in the 2010s, because of the continued use of traditional biomass such as charcoal and firewood. The use of traditional biomass will shrink with economic growth and shift to the use of commercial energy such as electricity and oil. As a result, self-sufficiency rates are likely to decline in the future, and energy security risks will increase. The self-sufficiency rate for power, meanwhile, has continued to drop to 66% in the 2010, which is the lowest among the case countries. Developing its own domestic power generation capabilities and raising the rate of self-sufficiency are of primary energy policy goals for Cambodia (Figure 2-26).

Cambodia has seen significant improvements in recent years in terms of diversifying energy use. The reason is the use of hydroelectric and coal-fired power generation, which began in the 2000s and later. Traditionally, Cambodia's primary energy supply has been dependent only on traditional biomass and oil. In particular, Cambodia used to be almost exclusively dependent on oil for power generation, but diversification of power source has improved due to hydropower and coal-fired power generation.

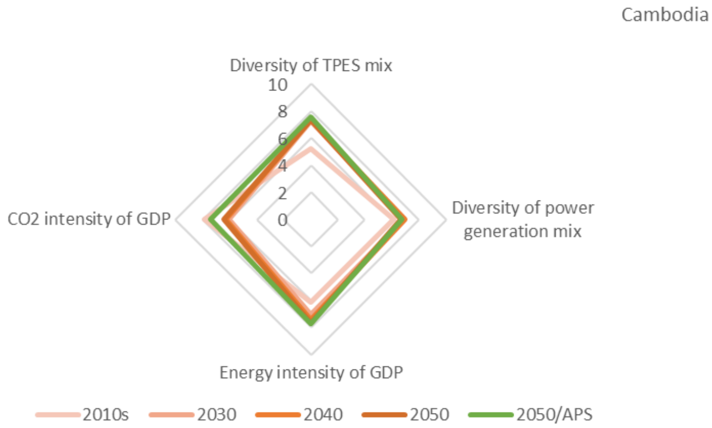
Access to power tends to improve, but its rate was 74.8% as of 2019 (IEA) There is still a lot of room for improvement. While the energy intensity of the economy is steadily declining, the carbon intensity of the economy tends to deteriorate due to the increased use of coal-fired power. The use of coal-fired power is effective in terms of stable supply of energy and control of energy costs, but it is a potential risk amid strengthening measures for climate change in the world.



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-26 Changes in Cambodia's Energy security Indicators

Looking to the future, it is expected that the use of traditional biomass will be replaced by commercial energy, and the amount of natural gas, which is currently little used, will increase. These changes will increase the diversity of primary energy supply, but increasing coal use will worsen the carbon intensity of the economy and may cause environmental problems. Meanwhile, in the APS scenario, which envisions progressive energy and environmental policies are undertaken, promotion of energy conservation and increased use of renewable energy, will improve the carbon intensity of the economy without damaging the other three indicators. It is clear that Cambodia should aim for the direction of the APS scenario assumes (Figure 2-27).



Note: APS: Alternative policy scenario where progressive energy and environment policies such as energy conservation and decarbonization promotions are taken

Source: ERIA, *Energy Outlook and Energy Saving Potential in East Asia 2020* を

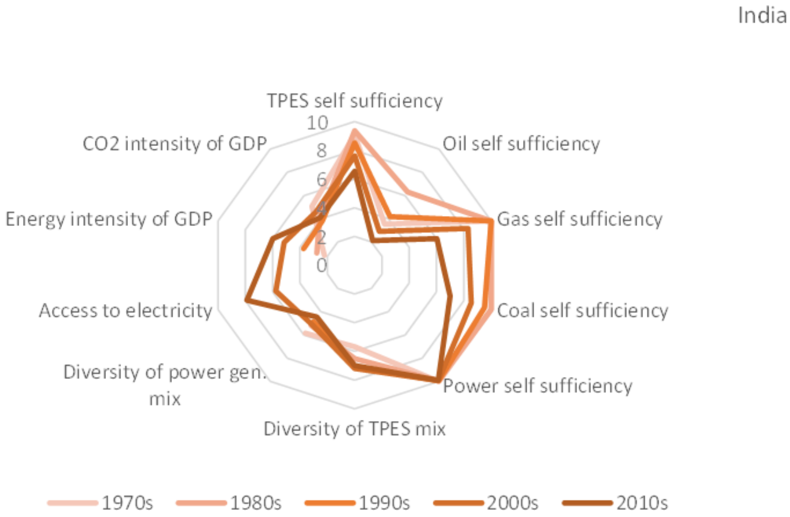
Figure 2-27 Benchmarks for future energy mix of Cambodia

(3) India

India has domestic productions of fossil fuels; oil, natural gas and coal, all of which show a downward trend in self-sufficiency. Domestic demand for oil and natural gas has been increasing, but the domestic production has been sluggish. The increase in domestic coal production also doesn't keep up with increase in domestic demand, Energy security risks are likely to increase in response to the increasing dependence on imports in the future.

The diversity of energy sources worsened from the 2000s to the 2010s, both in terms of primary energy and power generation. The reason is the increase in coal dependence caused by the increase in coal-fired power generation. Especially, in the power generation sector, the dependency on coal-fired power generation is as high as 73% (2010s), which can be a risk in terms of supply stability and environmental impact. Diversification of energy through expanded use of natural gas and renewable energy may address the risk.

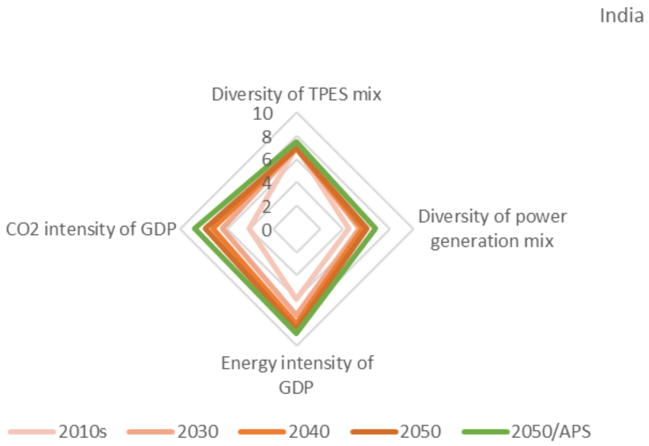
Access to electricity has steadily improved, reaching at 96% as of 2019 (IEA). Energy intensity of economy has been improving, but still marks at high (i.e. inefficient) number. Carbon intensities have been flat or rather worse, because, as mentioned above, coal-fired power is on the rise. Dramatic improvements in this indicator will be difficult unless the current power supply structure, which is overly dependent on coal, will change (Figure 2-28).



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-28 Changes in India's Energy Security Indicators

Looking to the future, renewable energy will replace coal-fired power in the power generation sector. Such replacement will help to improve the diversity of electricity supply, the energy intensity of the economy and the carbon intensity of the economy. In the primary energy supply, however, because of the increase in oil demand, the effect of improved diversity in the power generation sector is canceled out. In order for India to strengthen its energy security, therefore it is important to curb oil demand and promote its conversion to other energies such as gas and electricity (Figure 2-29).



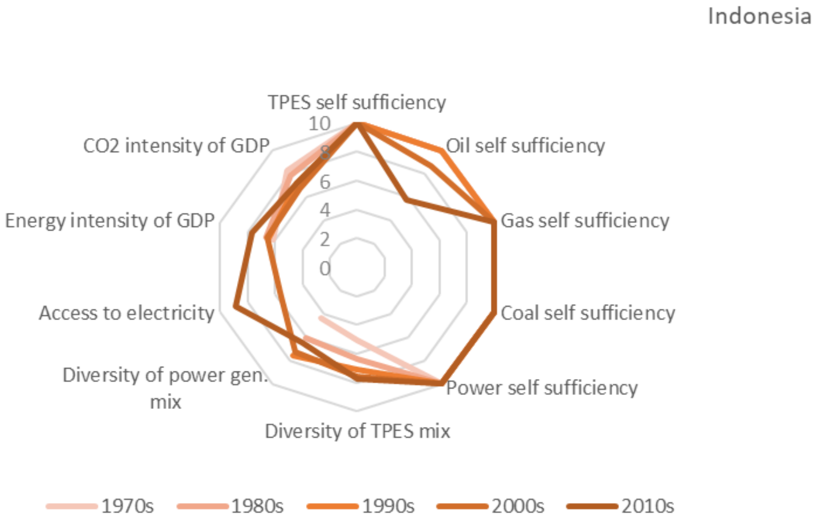
Source: ERIA, *Energy Outlook and Energy Saving Potential in East Asia 2020* を

Figure 2-29 Benchmarks for future energy mix of India

(4) Indonesia

Indonesia has abundant fossil energy resources, but the dependence on imports of oil has increased due to domestic demand growth and declining production. Indonesia has still domestic oil resources, but not all of the resources are easy to develop. Self-sufficiency rate of oil is thus unlikely to improve in the near future. From the viewpoint of ensuring the stability of primary energy supply, oil supply security is the central issue for Indonesia. In terms of diversity, the increased use of coal in the power sector has contributed to improve the diversity although it is note a preferred move from the environment perspective.

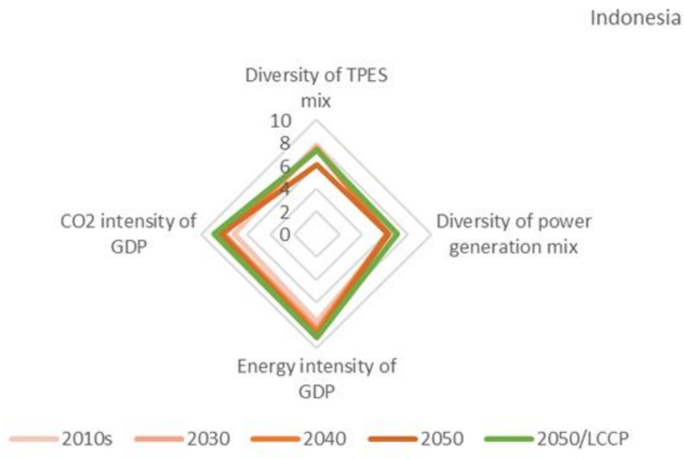
Access to power has improved steadily, reaching at 99.5%as of 2019 (IEA). The energy intensity of the economy improved gradually. On the other hand, the carbon intensity of the economy deteriorated in the past as coal use in power generation increases. The flexibility of power systems and the increased carbon intensity are likely to be future challenges in Indonesia (Figure 2-30).



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-30 Changes in Energy and Security Indicators in Indonesia

Looking to the future, diversity in the power generation sector will gradually improve as the installation of coal-fired power generation will slow down while natural gas-fired power generation capacity will increase significantly. The diversity on a primary energy supply basis is, however, exacerbated by the expected growth of oil demand. On the other hand, the carbon intensity of the economy will decrease (improve) due to the increase in the ratio of natural gas in power generation, and the energy intensity of the economy will also improve due to the progress of energy conservation. In July 2021, the Indonesian government published the "Long-Term Strategy for Low Carbon and Climate Resilience 2050" as its energy supply and demand outlook up to 2050 based on the net zero target as of 2060. In the "Low Carbon Scenario Compatible with Paris Agreement target (LCCP)" of the outlook, the share of renewable energy is expected to increase to about one-third, while the share of coal is expected to be suppressed to about one-third as well. It is expected that the emission of greenhouse gases will be controlled more. (Fig. 2-31).



Source: ERIA, *Energy Outlook and Energy Saving Potential in East Asia 2020*, The Government of Indonesia, *Long-Term Strategy for Low Carbon and Climate Resilience 2050*

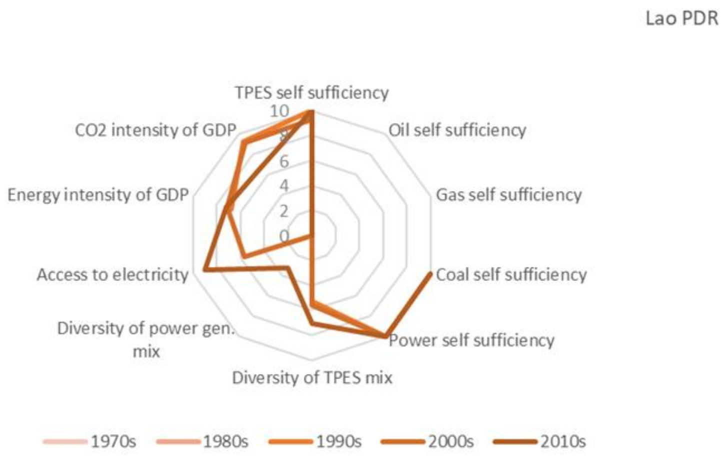
Figure 2-31 Benchmarks for future energy mix of Indonesia

(5) Laos

Laos does not produce oil and natural gas, and their self-sufficiency rate is 0%. Coal has been used significantly in recent years, mainly for power generation, and the country also export coal to neighboring country. Laos also has abundant hydroelectric power generation, and total primary energy is in a net export position due to these two resources.

In terms of diversity, both primary energy and power generation has improved as coal is used more. In the past, the Lao power generation was exclusively dependent on hydropower, the power supply capacity was greatly affected by the change in rainfall between seasons. Therefore, the addition of coal-fired power generation greatly contributed to improving the supply stability of electricity, especially during the drought period.

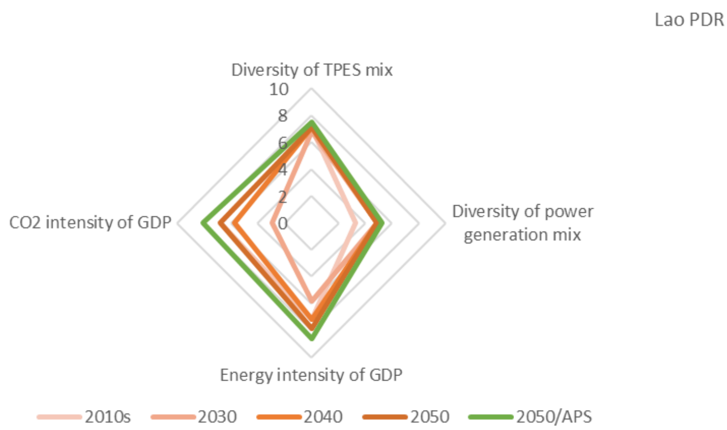
Access to electricity has been improving steadily, reaching at 94.8% as of 2019 (IEA). The energy intensity of the economy improved, but the rate is not necessarily low (i.e. efficient). On the other hand, the carbon intensity of the economy worsened greatly in the 2010s. This is due to the single use of coal-fired power generation. Laos has been able to achieve power supply stability by coal-fired power generation, but on the other hand, it has lost the low-carbon nature of its particularly high-scoring electricity (Figures 2-32).



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-32 Changes in Energy and Security Indicators in Laos

Looking to the future, increasing use of coal-fired power will improve the diversity of electricity supply until the 2030s, but since then there will be no significant change in the electricity mix and improvement is forecasted to stagnate. In the primary energy supply, the overall degree of diversity will not change greatly although the mix and the balance of each energy source will change. Energy efficiency will greatly improve and so will the carbon intensity of the economy (Fig. 2-33). How to sustain the continuous improvement in the power and energy mix in the long run may be a critical element in the Lao energy policy.



Source: ERIA, *Energy Outlook and Energy Saving Potential in East Asia 2020* を

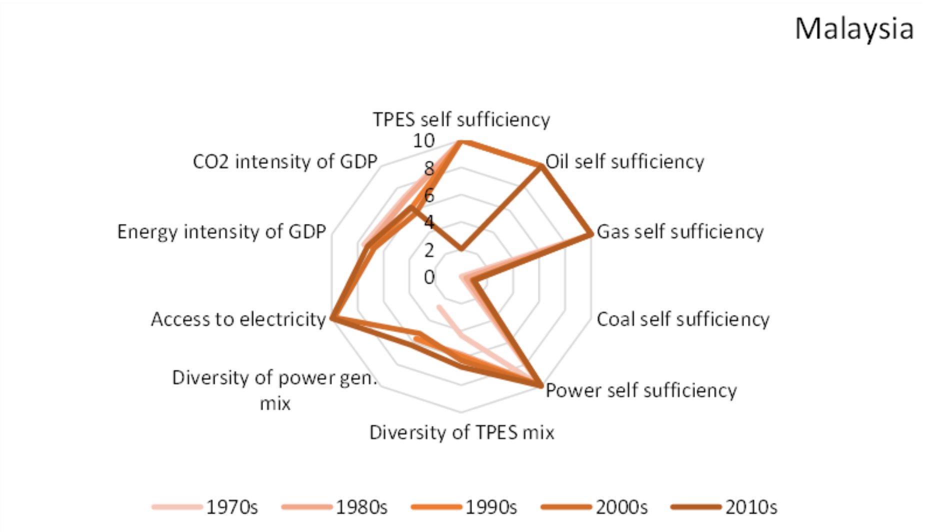
Figure 2-33 Benchmarks for future energy mix of Lao PDR

(6) Malaysia

Malaysia is a net exporter of oil and natural gas, and as a whole achieves a high self-sufficiency rate. However, while population and economic activity are concentrated in the Malay Peninsula, oil and natural gas resources exist in Borneo (Kalimantan). Therefore, there is a geographical mismatch. LNG is exported from Borneo to the Malay Peninsula.

Malaysia was highly dependent on oil in the past. However, Diversification of energy supply sources has improved by gradual increase in the use of natural gas and coal. Improvements have been particularly significant in the power sector, where natural gas and coal accounted for almost half in the 2010s. In the future, fossil energy alone cannot be expected to improve diversity any further, and if we try to improve the numbers further, it is necessary to greatly increase the use of new energy such as renewable energy.

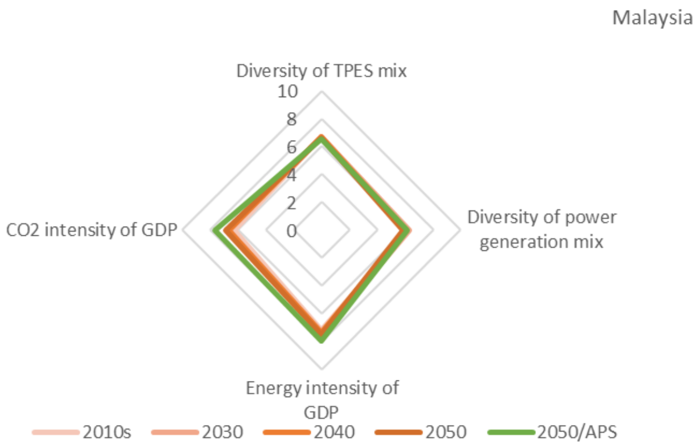
Access to electricity has reached at 100% as of 2019 (IEA). On the other hand, the energy and carbon intensities of the economy have been deteriorating or remain flat. The delayed improvement of effective use of energy and the slow pace of renewable energy use are major reasons. In the future, expanding use of renewable energy in terms of both energy diversity and carbon intensity will be an essential factor in Malaysia's strengthening of energy security in the future (Figure 2-34).



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-34 Changes in Malaysia's Energy Security Indicators

Looking to the future, the diversity of electricity supply will gradually deteriorate as the share of natural gas in power generation increases. In the primary energy supply, the degree of diversity will not change much. On the other hand, the carbon intensity of the economy will improve as the adoption of more natural gas in the power sector (Figure 2-35).



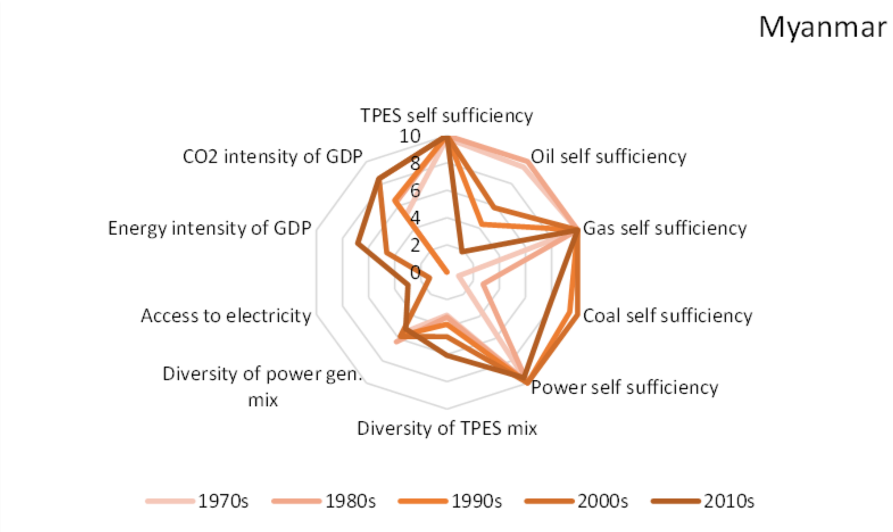
Source: ERIA, *Energy Outlook and Energy Saving Potential in East Asia 2020* を

Figure 2-35 Benchmarks for future energy mix of Malaysia

(7) Myanmar

Myanmar has domestic fossil energy resources, but its self-sufficiency rate varies from resource to resource. As for oil, while domestic demand has been rapidly increasing, production is declining, which causes the rapid decline in its self-sufficiency rate. Similar trends are seen in coal. Natural gas, on the other hand, is in the net export position as of the 2010s. However, Myanmar has a risk of not maintaining self-sufficiency of energy because of the stagnant domestic energy production amid increasing domestic demand. In the diversity of energy sources, there is a change in the different trends in primary energy supply and power generation. In primary energy supply, Myanmar has a balanced mix, shifting from intensive use of oil to more diversified mix with the increased uses of natural gas, hydro and coal. In power generation, by contrast, diversity has receded rather due to the surge in hydropower since the 2000s. In the 2010s, the ratio of hydro power to power generation was 62%, which is desirable in terms of self-sufficiency and CO2 emissions, but changes in river water volume are a major risk to the stable supply of electricity.

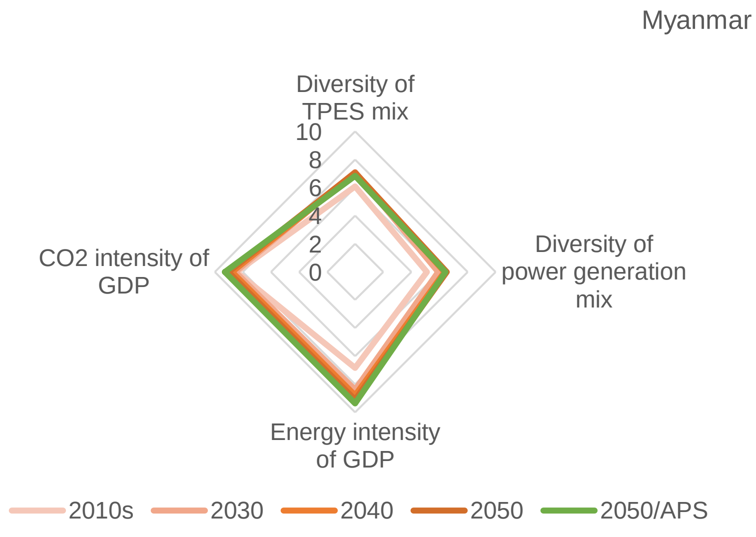
Access to power has improved steadily, reaching still low at 50.6% as of 2019 (IEA) and there is a lot of room for improvement. The energy intensity of the economy has been improved greatly. Carbon intensity has improved, but, after 2010s, the increasing use in coal has hindered its improvement (Figure 2-36).



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-36 Changes in Myanmar Energy and Security Indicators

Looking to the future, the diversity of primary energy supply and electricity supply will improve, mainly by reducing the dependence of power generation on hydropower. While improved energy efficiency reduces the energy intensity of the economy, the carbon intensity of the economy will level off as the increases in natural gas and coal in power generation cancel each other out (Fig. 2-37).



Source: ERIA, *Energy Outlook and Energy Saving Potential in East Asia 2020*を

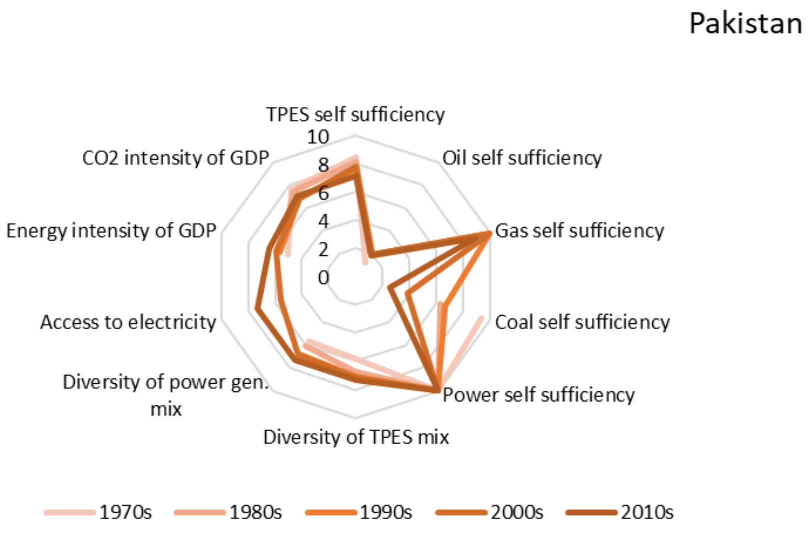
Figure 2-37 Benchmarks for future energy mix of Myanmar

(8) Pakistan

Pakistan has fossil energy resources, among which natural gas is relatively abundant in terms of the size of resources. However, the natural gas production peaked in 2012 and started to decline, and so did the self-sufficiency rate in recent years. Production of coal and oil on the other hand continued to increase throughout the period although the rate of growth has not caught up with the demand growth, which also resulted in a decline in self-sufficiency. As a result, the self-sufficiency of Pakistan, as a whole, exhibits constant decline.

Energy mix of the Pakistan meanwhile became diversified as primary energy supply shifted from conventional biomass energy to commercial energy. Nonetheless, going forward, the progress of diversification of energy source will slow down because the share of fossil fuels will grow from now on. Power generation sources became also diversified by shifting from hydro and natural gas in the past to increased use of coal although the expansion of coal may be capped in the future because of the climate concerns.

Access to power improved steadily, reaching at 79.2% as of 2019 (IEA) although there is still room for improvement. The energy intensity of GDP growth also improved, partly because of the efforts of energy conservation. On the other hand, the carbon intensity of the economy became worsened because of the shift from traditional biomass to commercial energy and the increased use of coal in the power sector. Traditional biomass still accounts for approximately 30% of primary energy supply as of 2018. It is important to determine what kind of energy to choose in the future in terms of energy diversity and carbon intensity of the economy (Figures 2-38).



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-38 Changes in Pakistan's Energy and Security Indicators

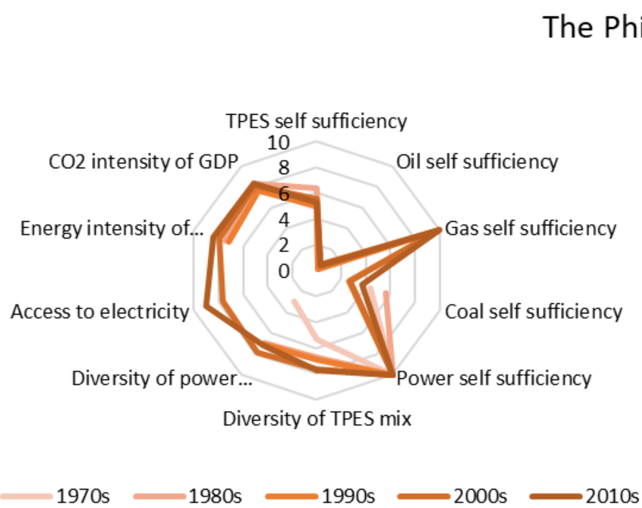
(9) Philippines

The Philippines does not have ample natural resources except for natural gas. While the self-sufficiency rate of oil is less than 5% throughout the period, it is 100% for natural gas because all of natural gas consumed in country is supplied from domestic gas field

(Malampaya). Produced natural gas mainly utilized at the power plants in Batangas, an industrial city south of Manila. Production of natural gas in Malampaya gas field is scheduled to cease in 2024, and the Philippines will lose its sole domestic supply source of natural gas. Domestic production of coal has increased, but as the domestic demand outpaced the production growth, its self-sufficiency rate declined.

As for diversity of energy sources, the high dependence on oil in the past became addressed in recent years. The change is particularly notable in the power generation sector, which significantly lowered the reliance on oil by expanding the use of coal, natural gas and renewable energy. In the power generation sector, the ratio of coal-fired power generation increased to 45%, but if this rate rises further, another risk such as reduced flexibility of power systems and increased environmental impact will become apparent.

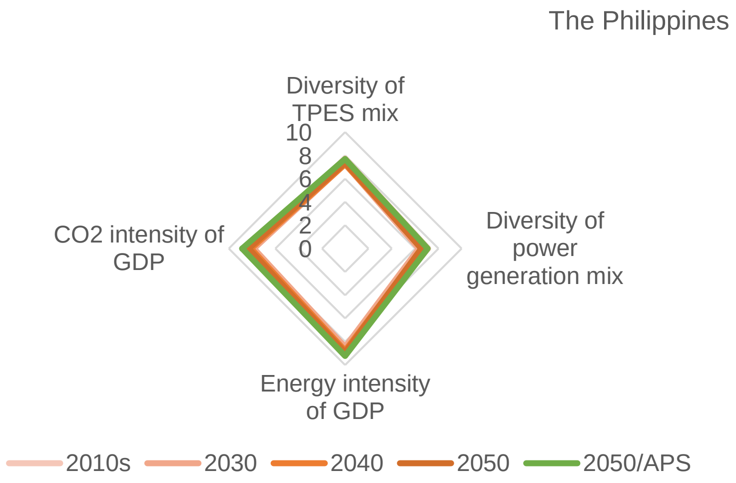
Access to power steadily improved, reaching at 96.4% as of 2019 (IEA). Both the energy and carbon intensity of the economy also showed improvements. Especially, energy intensity performed well, but this may be because of its industrial structure where the share of tertial (services) sector is large (Figure 2-39).



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-39 Changes in Energy and Security Indicators in the Philippines

Looking to the future, although there will be changes in the structure of primary energy supply and electricity supply, it seems not easy to get out of the state of being highly dependent on coal and oil as of the 2010s, and diversity will gradually deteriorate. Energy efficiency improves, but only to a lesser extent (Figure 2-40).



Source: ERIA, *Energy Outlook and Energy Saving Potential in East Asia 2020* を

Figure 2-40 Benchmarks for future energy mix of the Philippines

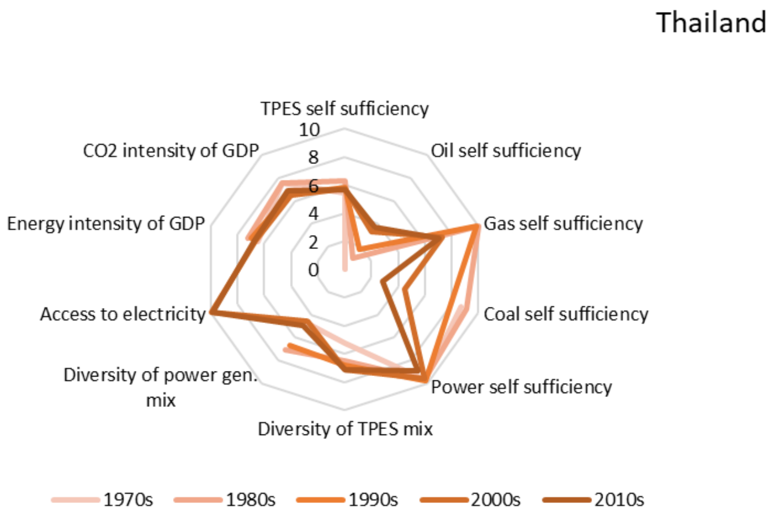
(10) Thailand

Thailand used to be almost self-sufficient in natural gas and coal, but in recent years, import dependence of both energy sources increases as their domestic productions stagnate. It notable that the self-sufficiency rate of oil increased because of the growth of domestic production although the level of self-sufficiency is not necessarily high in absolute terms (37%). Overall, securing stable imports of fossil fuels is an important energy security issue for the country.

Diversification of energy sources improved in primary energy supply but worsened in power generation. In the primary energy supply, it became more diversified because of the growing use of natural gas and coal. In the power generation sector, meanwhile, the dependence on natural gas became high and the generation mix became less diversified. In order to address this issue, the Thai government attempted to install more coal-fired units, but it has run into a major barrier to public consensus building. Therefore, it is important to expand the use of new energy such as renewable energy while maintaining a stable supply of natural gas to ensure diversity in the future.

Access to power was 100% as of 2019 (IEA). Both the energy and carbon intensity of the economy are slow to improve, because renewable energy expansion is likely to be slower than others in addition to the delay in improving efficient use of energy, (Figure 2-41).

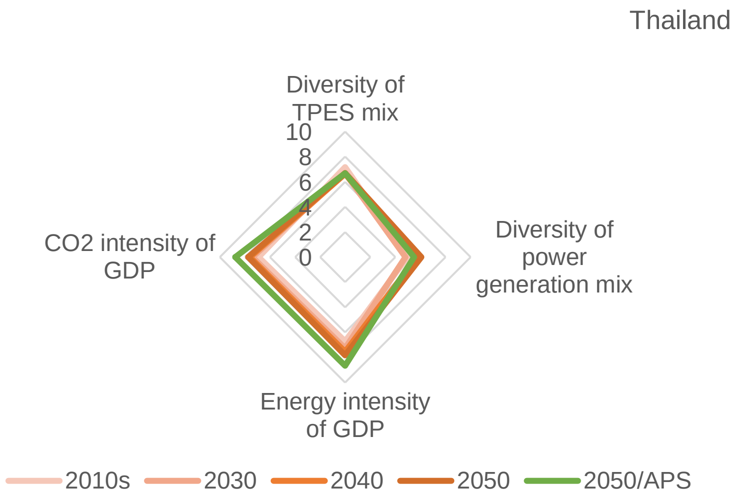
It is notable for Thailand that the import of electricity has grown. The self-sufficiency rate of power in Thailand used to be around 97 to 98 percent until the 2000s. Yet in the 2010, the rate began to decline and the rate of 2019 was down to 87%. The import of electricity itself is not necessarily a serious problem as seen in many European countries such as Germany depends on the electricity import from neighboring countries. Yet, the rapid rise of the import can be problematic because the investment to meet the rapid increase may not catch up. The current rise of electricity import therefore casts potential energy supply security problem to Thailand.



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-41 Changes in Energy and Security Indicators in Thailand

Looking to the future, power generation will reduce its dependence on natural gas due to increased renewable energy and coal, and will improve the diversity of electricity supply. On the other hand, the primary energy supply will become more diverse as oil's share increases further than it does today. By improving energy efficiency, the energy intensity and carbon intensity of the economy will improve. In the APS scenario, which envisions further improvements in energy efficiency and significant restraint on coal-fired growth, the economy's energy and carbon agglomerations can be expected to improve, albeit at the expense of some power mix diversity (Figure 2-42).



Source: Made by the Institute of Energy Economics, Japan, based on ERIA, *Energy Outlook and Energy Saving Potential in East Asia 2020*

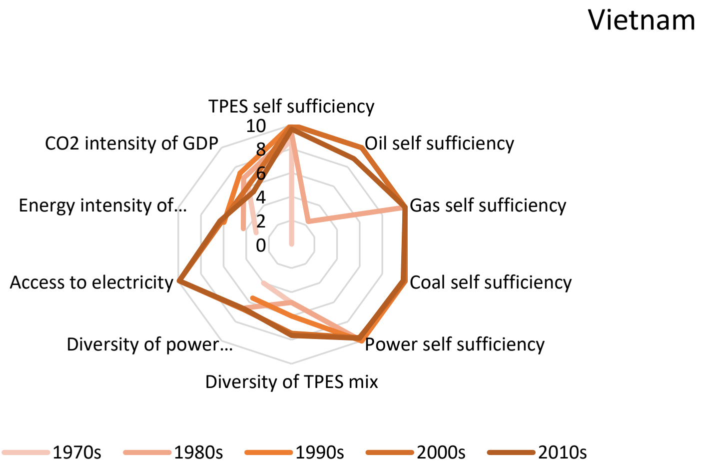
Figure 2-42 Benchmarks for future energy mix of Thailand

(11) Vietnam

Vietnam is endowed with natural resources and has relatively high self-sufficiency rates in oil, natural gas and coal. However, like in other Asian countries, the domestic demand growth will be faster than the production growth and the self-sufficiency rate is set to decline. With regard to coal, the domestic production has maintained its past production volume, but because the pace of increase in demand is fast, dependence on imports will increase rapidly and the vulnerability to external factors will increase.

Diversification of energy sources improved in both primary energy supply and power generation sector. The current diversity of primary energy supply may, however, be a mere transitional state. Conventional biomass still accounts for 20% in primary energy, which shows “apparent” good indicators of diversification of energy sources. However, Vietnam will rely on other fossil fuels more with expanding use of commercial energy. Vietnam has a relatively large population, and the demand for oil in the transportation sector will surely increase in the future. In the power generation sector, on the other hand, the power supply configuration shifted to a well- balanced use of coal and natural gas based on hydropower. In recent years, however, s, coal-fired power generation increased significantly, and if this trend continues, it could lead to a high-risk power generation mix with over-dependence on coal.

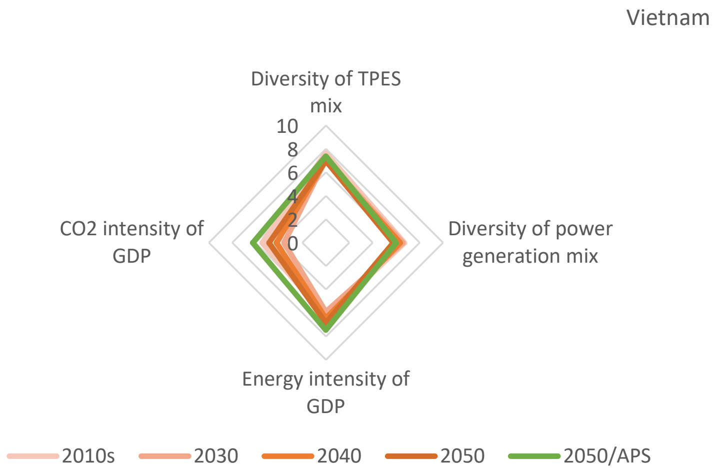
Access to power has improved, reaching at 99.2% as of 2019 (IEA). While the energy intensity of the economy is improving at a moderate pace, carbon intensity is deteriorating due to the increasing use of coal-fired power plants (Figure 2-43).



Source: Made by the Institute of Energy Economics, Japan, based on IEA, *World Energy Balances 2020 edition*.

Figure 2-43 Changes in Energy and Security Indicators in Vietnam

Looking to the future, the level of diversity will worsen in the TPES because the shares of coal and oil will increase, and the level of diversity will also worsen in the power generation because the share of natural gas will increase. Although energy efficiency will improve, the carbon intensity of the economy will worsen in the short term as coal is more intensively utilized. After that, it will gradually improves as the use of natural gas will grow. As a future challenge for Vietnam is therefore to further reduce the dependence on fossil fuels, and, for the sectors that still need to use fossil fuels, to adopt natural gas as the cleanest fossil fuel (Figure 2-44).



Note: APS: Alternative policy scenario that assume enhanced energy conservation and low-carbon policies

Source: Made by the Institute of Energy Economics, Japan, based on ERIA, *Energy Outlook and Energy Saving Potential in East Asia 2020*

Figure 2-44 Benchmarks for Future Energy Mix of Vietnam

(12) Summary

Table 2-4 shows the summary of ten evaluation benchmarks of the above 11 countries. The first finding is that, each Asian country has high self-sufficiency rate of primary energy supply and natural gas and electrification rate compared to other regions in the world. However, as pointed out repeatedly, the high self-sufficiency rate derives from the still widely used conventional biomass in many Asian countries. The self-sufficiency rate is likely to decline with expanding use of commercial energy in the future. The second finding is that self-sufficiency rate of oil and coal and diversity of power generation sources are at a low level compared to other countries in the world. Increasing self-sufficiency rate of oil and coal is difficult through policy measures because is largely determined by the size of domestic resources. Therefore, each Asian country is set make efforts to improve diversification of power generation source in the future. Particularly, the effective use of natural gas and introduction of renewable energy will be powerful countermeasures.

Among Asian countries, Indonesia and Vietnam are the ones whose scores are high in most evaluation benchmarks, suggesting that the countries have a well-balanced and excellent energy mix. Many of the other countries have different scores in each evaluation benchmark. It is in fact difficult to develop an energy mix which has very high scores in all of the benchmarks. The energy security scores in this section nonetheless can quantify each country's energy mix, identify the relative fallacies of specific country's energy mix compared to others, and brings some useful policy implications to improve its energy mix.

The summary of scores of the future outlook for each country's primary energy supply mix is shown in Table 2-5. The scores are those of APS (alternative policy scenario) as of the 2050s, which seems more plausible figures under the growing interests toward more aggressive CO2 emissions reduction.

What is notable is that in most countries the diversity in the primary energy supply and power sectors is generally scored at 6 to 7 range. The scores for Laos and Thailand are relatively low, as the share of hydropower and gas-fired power sources is projected to exceed 60% by 2050 in these countries, respectively. On the other hand, the energy and carbon intensity of the economy is expected to improve significantly in the future in all countries. Among the case countries, Vietnam has a relatively low carbon intensity value (high CO2 emissions) as it is assumed that coal will account for 11% of the total primary energy supply as of 2050.

Table 2-4 Points in Evaluating Energy Mix in Each Country as of the 2010s

	BGL	CAM	IND	IDN	LAO	MAL	MYA	PAK	PHI	THA	VTN
TPES self sufficiency	8.3	6.4	6.5	10.0	10.0	2.0	10.0	7.1	5.2	5.7	9.6
Oil self sufficiency	0.6	0.0	2.1	5.8	0.0	10.0	1.9	1.8	0.5	3.7	8.9
Gas self sufficiency	10.0		6.0	10.0		10.0	10.0	8.9	10.0	7.1	10.0
Coal self sufficiency	3.0	0.2	7.0	10.0	10.0	1.0	7.9	2.5	3.7	2.8	9.9
Power self sufficiency	9.5	6.6	7.0	10.0	10.0	10.0	9.5	10.0	10.0	8.9	9.7
Diversity of TPES mix	6.1	5.2	7.0	7.8	7.1	6.7	6.1	7.3	7.7	7.2	7.6
Diversity of power gen. mix	3.3	6.1	4.5	6.5	3.3	6.2	5.1	7.3	7.1	5.0	6.7
Access to electricity	7.5	4.9	7.9	8.8	9.1	10.0	3.0	7.3	9.0	9.9	9.9
Energy intensity of GDP	8.3	6.1	6.0	7.6	7.2	7.2	6.8	6.4	8.5	6.7	6.3
CO2 intensity of GDP	8.3	7.9	4.1	7.2	6.8	6.3	8.5	7.1	8.3	6.9	5.4
Total	**64.9**	**43.4**	**58.1**	**83.7**	**63.4**	**69.3**	**68.7**	**65.8**	**70.0**	**63.8**	**84.1**

Note: BGL: Bangladesh; CAM: Cambodia; IND: India; IDN: Indonesia; LAO: Lao PDR; MAL: Malaysia; MYA: Myanmar; PAK: Pakistan; PHI: The Philippines; THA: Thailand; VTN: Vietnam. The blank part in the table is the place where the index could not be calculated due to data constraints.

Source: The Institute of Energy Economics, Japan

Next, looking at each country, the Philippines has the highest total score, followed by Indonesia, India, and Myanmar. The Philippines is scored at high because its diversities in primary energy supply and power supply are high. Indonesia has a well-balanced outlook for diversity, energy intensity and CO2 intensity. For India and Myanmar, improvements in energy efficiency and CO2 intensity are expected. The improvement of CO2 intensity is attribute to the introduction of renewable and hydro power..

Table 2-5 Scores of case countries' future energy mix (APS in the 2050s)

	CAM	IND	IDN	LAO	MAL	MYA	PHI	THA	VTN
Diversity of TPES mix	7.6	7.5	7.3	7.5	6.6	6.8	7.7	6.7	7.4
Diversity of power gen. mix	6.7	6.8	7.1	5.3	6.2	6.4	7.1	5.5	6.0
Energy intensity of GDP	7.7	9.0	9.1	8.6	8.0	9.4	9.2	8.7	7.5
CO2 intensity of GDP	7.4	8.7	8.9	8.0	7.6	9.3	8.9	8.8	6.2
Total	**29.4**	**32.0**	**32.4**	**29.4**	**28.4**	**31.9**	**32.9**	**29.6**	**27.1**

Note: CAM: Cambodia; IND: India; IDN: Indonesia; LAO: Lao PDR; MAL: Malaysia; MYA: Myanmar; PHI: The Philippines; THA: Thailand; VTN: Vietnam. Green-colored column shows the score at above 8.0. Bangladesh and Pakistan are not included. Figures of APS in the 2050s except for Indonesia, which refers to " Low Carbon Scenario Compatible with Paris Agreement target" of " Long-Term Strategy for Low Carbon and Climate Resilience 2050."

Source: The Institute of Energy Economics, Japan

2.3 Evaluation of power generation mix in Asian countries

2.3.1 Issues in considering the power mix policies in Asian countries

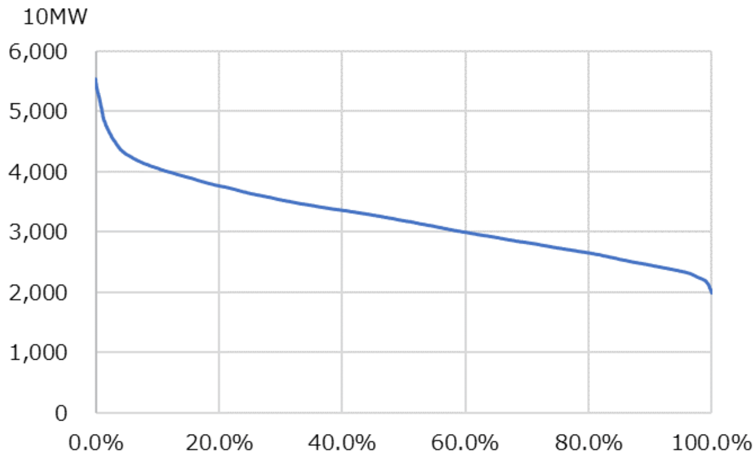
This section evaluates several issues in considering the power supply mix in Asia. After outlining the procedure for formulating a general power supply mix, the section compares the power supply configurations in the power development plans of each Asian country.

Asian countries develop conventional power generation facilities to meet their growing demand. Unlike developed countries, they are required to formulate power generation development plan in consideration of factors such as fuel selection, geographical location of fuel supply, and capacity of transmission lines and their locations.

(1) Procedure for power supply mix outlook

In general, formulating power supply mix outlook is based on three steps: 1) analysis of the power demand load curve, 2) examination of the optimal power supply plan, and 3) estimation of the power supply mix at the minimum cost based on the examination of 2).

Firstly, in the analysis of power demand load duration curve, an hourly power consumption in a year from biggest to smallest is examined (Figure 2-45). In this power demand load duration curve analysis, net load, which deducts estimated output of wind and solar power from power consumption, needs to be calculated as supply capacity of wind and solar power with low load follow-up capability expands. By doing so, necessary additional capacity of base load power supply is estimated.



Source: Made from "System Information Service", by Organization for Cross-regional Coordination of Transmission Operators, Japan.

Figure 2-45 Analysis of Power Demand Duration Curve in TEPCO (2019)

Secondly, in the examination of the optimal power supply plan, the expected changes in fuel prices, lead time to construction of various power supplies, and impacts of environmental policies are evaluated from the viewpoint of primary energy supply. Since coal and gas procurement is related to other energy demands, it is necessary to consider them based on trends in other demand sectors. Especially, as electrification will advance in transportation sector in the future, it is important to examine transportation sector, where power consumption has been small so far. The amount of capital costs for power development needs to be scrutinized to examine whether state-owned enterprises can cover the costs or private capital should be utilized. It should be considered that to what extent the government will target the introduction of renewable energy generation as a countermeasure against climate change.

Finally, in the estimation of the power supply mix at the minimum cost, the minimum cost of power supply operation from expected hourly power demand and configuration of transmission facilities is estimated by setting multiple scenarios centered on specific selection of power source with restrictions of each kind of problem. If power transmission constraints are also expected to occur at a certain point of time, necessary power transmission equipment costs will also be added to the assumptions. Then a necessary amount of whole capital investment is estimated. By examining the power supply configuration by these scenarios, the power supply configuration is determined.

(2) Examples of considerations in setting up a power supply mix

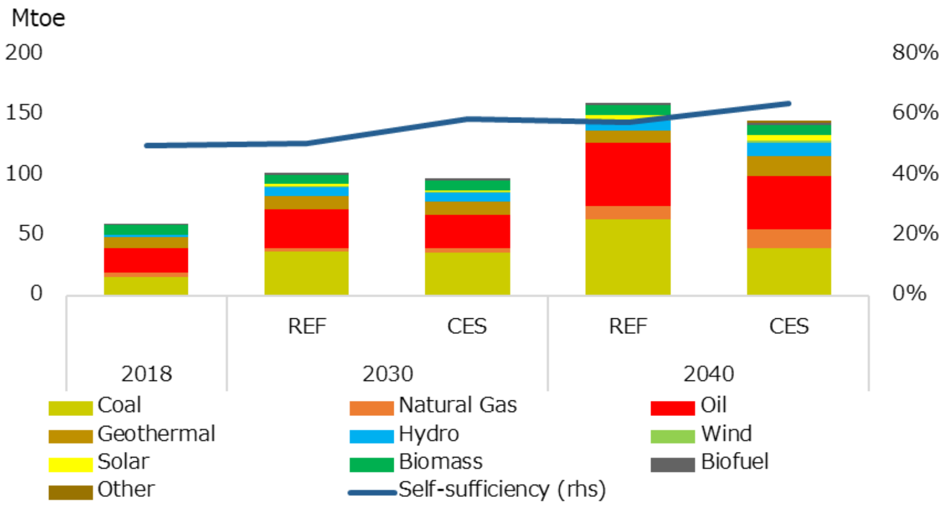
Many Asian countries have adopted the process of formulating the power supply mix outlook set forth in the preceding sub-section. Malaysia has separate power supply system in two regions, Peninsula (Malay Peninsula) and Sabah (Borneo), so they formulate power supply outlook, respectively. The following indicators are used as reference in the formulation of the power mix:

1) Demand forecasts
2) Transmission system reliability criteria
3) Optimal reserve margin
4) COP21 climate change commitment
5) Government instructions (renewable energy 20% target in 2025, energy conservation initiative, reduced coal dependence, no nuclear power)
6) Other technical principles (power source diversity, unplanned outages, fuel pricing policies, etc.) [34]

In the Philippines, the Ministry of Energy has formulated a long-term energy plan, which is also in accordance with the framework set forth in the preceding sub section (Figures 2-46). The 2018-2040 plan made a power supply plan based on the following basic policy [35](Figure 2-47).

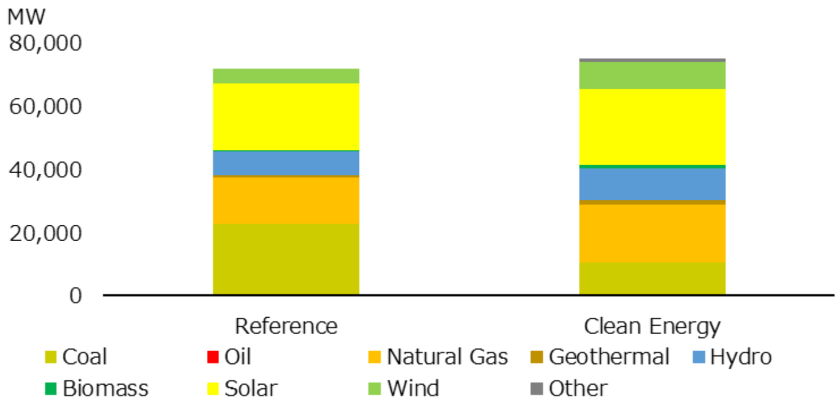
1) Improved access to electricity in all Philippines
2) Adopting a technology-neutral approach for optimal energy mix
3) Improved reliable supply to meet demand through 2040
4) Acceleration of LNG project implementation in consideration of natural gas depletion in Malampaya Gas field
5) Completion of the Mindanao-Visayas connecting line project by 2021 and implementation of a series project of connecting small islands
6) Prosumerization in the power distribution sector
7) Rationalization of domestic policies to reduce domestic bureaucratic formalism
8) Privatization of Power Sector Assets and Liabilities Management Corporation (PSALM)
9) Consumer awareness to promote energy conservation of electricity consumption

[34] Energy Commission, "Sabah Electricity Supply Industry Outlook 2019" February 2020. p.24 https://www.st.gov.my/en/contents/files/download/106/SABAH_ELECTRICITY_SUPPLY_INDUSTRY_OUTLOOK_2019.pdf. Accessed on 21 January 2021.
[35] Department of Energy, "Philippines Energy Plan 2018-2040" p. viii-ix.



Source: Department of Energy Republic of the Philippines, "Philippines Energy Plan 2018-2040"

Figure 2-46 Philippines Primary Energy Supply Outlook to 2040



Source: Department of Energy Republic of the Philippines, "Philippines Energy Plan 2018-2040"

Figure 2-47 New Power Supply Projects in the Philippines by 2040

2.3.2 Evaluation of power mix in Asian countries

(1) Power Mix and Evaluation in Each Country

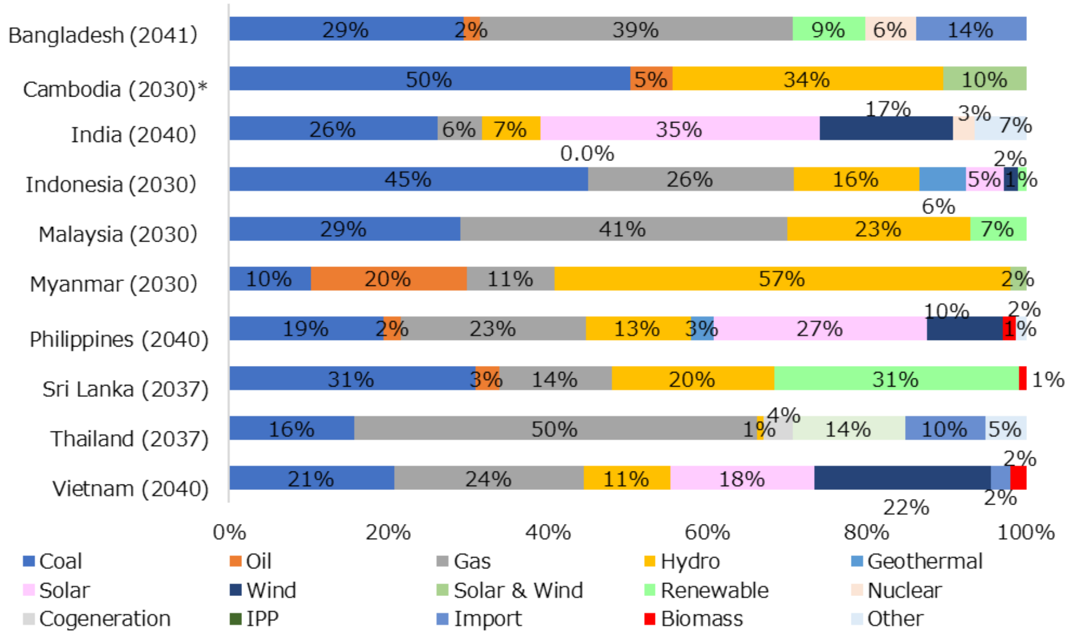
This section evaluates the power mix targets of Asian countries. Ten countries are eligible for the case assessment: Bangladesh, Cambodia, India, Indonesia, Malaysia, Myanmar, Sri Lanka, Thailand and Vietnam. Brunei, Laos, Pakistan, and the Philippines. Singapore is not included because future power generation capacity plans by government or equivalent public authorities are not available. The power mix to be analyzed is the farthest future of the future power generation capacity plans set out in each country's power development plans (or similar policy documents). Some countries have post-2040 goals and others have only pre-2030 goals, but this section does not take the difference of the goal year into consideration this time. Note that the evaluation of the power mix should be evaluated by the amount of power generated, which originally indicates the value of the actual power supply, but since fewer countries have included such a power generation outlook in the plans [36], we prioritize the evaluation of the power supply mix of more countries, and evaluate the mix based on the power generation capacity. Table 2-6 shows the target year and figures for future power generation capacity in the power supply plans of each country to be evaluated, and Figure 2-48 shows the figures converted to shares.

Table 2-6 Power Generation Capacity Plans in Asian Countries

Unit: GW	Bangladesh	Cambodia	India	Indonesia	Malaysia (Share only)	Myanmar	Philippines	Sri Lanka	Thailand	Vietnam
Year	*2041*	*2030*	*2040*	*2030*	*2030*	*2030*	*2040*	*2037*	*2037*	*2040*
Coal	25.5	2.4	330.0	44.7	0.3	1.6	18.2	3.4	9.2	48.4
Oil	1.8	0.3				3.0	2.0	0.3		
Gas	34.0		70.0	25.6	0.4	1.7	21.7	1.5	29.5	55.7
Thermal										
Hydro		1.6	92.0	15.6	0.2	8.8	12.3	2.2	0.5	25.3
Geothermal				5.8			2.8			
Solar			443.0	4.7			25.0			42.3
Wind			210.0	1.8			8.9			51.9
Solar & Wind		0.5				0.3				
Renewable	7.9			1.0	0.1			3.3		
Nudear	5.5		34.0							
Cogeneration									2.1	
IPP									8.3	
Import	12.0								5.9	5.7
Biomass							1.6	0.1		4.5
Other			82.0				1.2		3.0	
Total	**86.7**	**4.7**	**1,261.0**	**99.2**	**1.0**	**15.3**	**93.5**	**10.9**	**58.5**	**233.8**

Note: "Coal" of Cambodia includes gas. This applies also to the following data. "Gas" of Indonesia includes a small amount of oil-fired power generation. In calculating the quantitative benchmark, the internal share of coal and gas is assumed as 50:50.
Source: (Bangladesh) Bangladesh Power Division, "Revisiting Power System Master Plan 2016"; (Cambodia) Ministry of Mines and Energy, "Cambodia Basic Energy Plan"; (India) NITI Aayog, "Draft National Energy Policy" (BAU Scenario); (Indonesia) PLN, "Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) (2021-2030)"; (Malaysia) Energy Commission, "Report on Peninsular Malaysia Generation Development Plan 2019 (2020-2030)"; (Myanmar) National Energy Management Committee, "Myanmar Energy Master Plan"; (The Philippines) Department of Energy, "Philippines Energy Plan 2018-2040"; (Sri Lanka) Ceylon Electricity Board, "Long Term Generation Expansion Plan 2018-2037"; (Thailand) Ministry of Energy of Thailand, "Power Development Plan,2018-2037"; (Vietnam) Ministry of Industry and Trade, The 8th power Development Plan

[36] The target value of the energy mix (actually the power supply mix) in the Basic Energy Plan of Japan is also the target value by the share of the amount of power generated.



Note: Renewable includes hydro, solar and wind power.
Source: Same as Table 2-5

Figure 2-48 Share of Power Generation Capacity in Asia

The power mix in this section is evaluated based on the so-called 3E, economic efficiency, energy security, and environment. This section evaluates economic efficiency based on the theoretical value of power generation costs, energy security based on power supply diversity and import dependence including fuel for power generation, and environment based on CO2 intensity of the power generation configurations.

(2) Economic efficiency

The first benchmark is economic efficiency of the power supply sources. The cost of power supply must be calculated based on the amount of power generated, but this section makes evaluation based on the power generation capacity due to the constraints of data availability. The evaluation is based on unit cost of power supply weighted averaged by the share of each power supply source. The unit price of power generation is based on the unit price made by the Agency for Natural Resources and Energy's Working Group for Power Generation Cost Verification in 2021 (Table 2-7). The reason for adopting the unit price is that various power supply costs including future cost declines are evaluated side by side, and the cost of gas-fired power generation is calculated using imported LNG as fuel, which is expected to be widely used in Asia in the future.

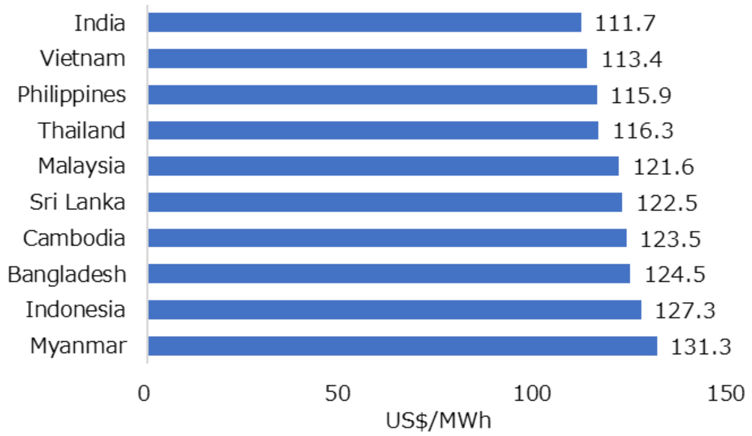
Table 2-7 Unit cost of power generation

Unit: $/MWh

Coal	Oil	Gas	Thermal	Hydro	Geo-thermal	Solar	Wind	Renewable	Co-generation	IPP	Import	Biomass
163.9	238.8	112.4	138.1	93.6	149.8	84.3	98.3	92.1	89.0	101.8	93.6	168.6

Remarks: Unit cost of Thermal is average of coal and gas; unit cost of Renewable is the average of hydro, solar, and wind; unit cost of IPP is the average of gas, solar, and wind; unit cost of Import is assumed as equivalent to hydro;
Source: "Report on Verification of Power Generation Costs, etc. to the Subcommittee on Long-Term Energy Supply and Demand Outlook" by Japan Agency for Natural Resources and Energy, Working Group for Power Generation Cost Verification May 2015.

Generation costs shown in Figure 2-49 are the figures weighted averaged by each country's power mix based on the unit cost shown in Table 2-6. Lower estimated costs of India, Vietnam, and the Philippines suggest that the share of solar is high in the power development plans of these countries. The estimated costs of Myanmar and Indonesia are relatively high because Myanmar is expected to have higher share of oil and the Indonesia is expected have higher shares of geothermal and coal.

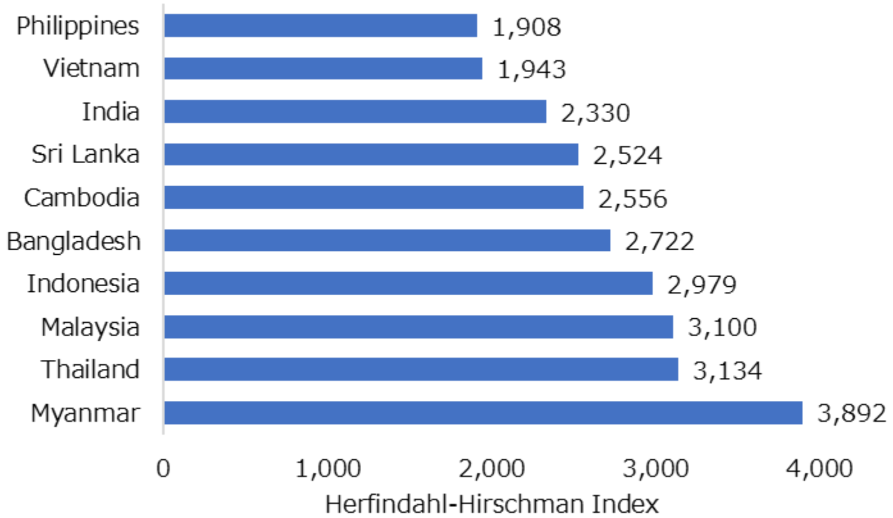


Note: The values in the figure are weighted averages based on the share of power generation capacity, so they differ from actual power generation costs. It does not take country-specific factors that affect the level of unit power generation into account. Imported electricity cost in each country is calculated by the unit price of hydro power generation cost, and renewable energy cost is calculated by simple average value of hydro power, hydro power, and solar power. For Thailand IPP cost is calculated by simple average of gas-fired power generation costs and solar and wind power generation costs, and cogeneration is calculated by the cost unit price of gas cogeneration.
Source: Estimates by the Institute of Energy Economics, Japan

Figure 2-49 Economic Efficiency of Power Mix Targets in Asian Countries

(3) Diversity

Next, we compare the Herfindahl-Hirschman Index (HHI) as an indicator for diversity of energy security. HHI is a commonly used indicator for calculating concentration in the market, but is used here for the purpose of evaluating the degree of diversity of power supplies. The results of the calculation are shown in Figure 2-50. HHI in the Philippines, which is expected to be supplied from a variety of power supplies, is the lowest and thus preferable in terms of diversity. Vietnam also has diversified power development plan. On the other hand, in Myanmar, as the dependence on the largest power supply source (hydro) is high at around 50%, the value of HHI is also high (inferior in terms of diversity).

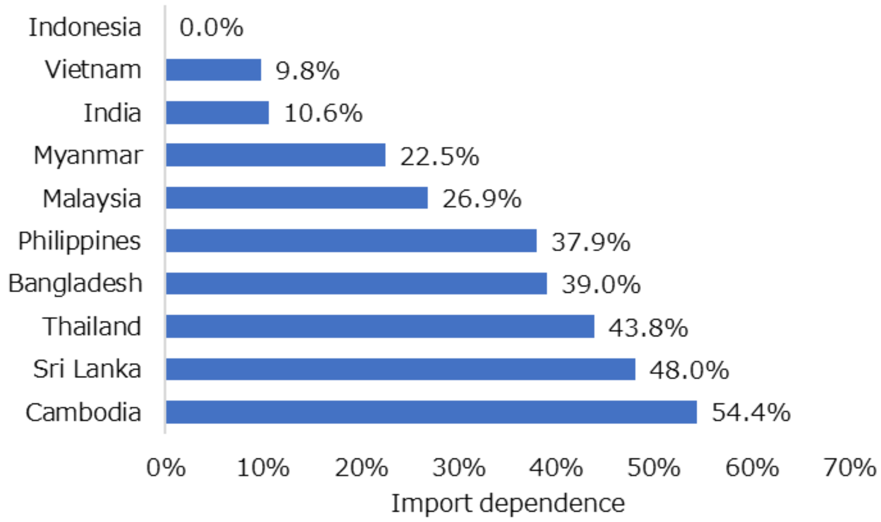


Note: The value in the figure is HHI, and lower values are more diverse and desirable.
Source: Estimates by the Institute of Energy Economics, Japan

Figure 2-50 Diversity in Power Mix Targets in Asian Countries

(4) Import dependence

As an indicator of Energy Security along with diversity, we calculate an indicator of import dependence of electricity. This index is calculated by combining the import dependence of fuel (coal, oil, and gas) in each country on a weighted average of the share of power supplies and the share of imported power supplies when imports from overseas are expected in the power supply plan. In the future, which is assumed in the power supply mix, there is a possibility that the dependence on imports of fuel in each country is changing, but here it is assumed that the dependence on imports is at the same level as the level of the 2018 results. Figure 2-51 shows the results of the calculation, which shows that Indonesia, a net exporter of coal and natural gas, has virtually no import dependence. In reality, a small amount of oil fired power generation will be utilized and thus its import dependence will not be zero, but because of the growth of the domestic renewable energy, its import dependence will be the lowest among the case countries. Vietnam also has low import dependence for power generation fuels. As to India, coal and gas are dependent on imports, but their dependence on imports is not very high (30% and 49%, respectively), and the share of coal and gas-fired power generation in the power supply mix is relatively low (37% and 4%, respectively). Therefore, the overall import dependence rate is calculated as low. Cambodia and Sri Lanka, by contrast, have high import dependence rate. Cambodia is dependent almost totally on import for coal and will have higher share of coal-fired power plants.

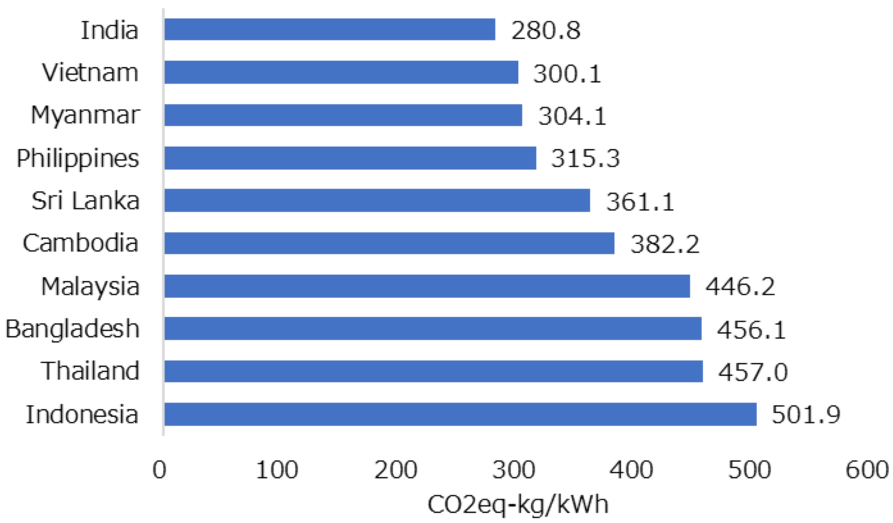


Source: Estimates by the Institute of Energy Economics, Japan

Figure 2-51 Import Dependence of Power Mix Targets in Asian Countries

(5) Evaluation of power mix (CO2 emissions)

Finally, the intensity of CO2 emissions from the power mix is evaluated as an indicator of environment. To calculate the indicator, CO2 emissions per kWh for each power source is weighted averaged by the share of the target power mix. Figure 2-52 shows the results of the calculation. India and Vietnam, both of which plan to have a high solar and wind share, have the lowest degree of CO2 emissions. Myanmar, which plan to have a large hydro share, also has low CO2 intensity. Indonesia, Thailand, and Bangladesh are expected to be more dependent on coal in the future, so the degree of CO2 emissions is also high.



Note: The unit is CO2 emissions per kWh, but the calculation is based on the share of power generation capacity.

Source: Estimates by the Institute of Energy Economics, Japan

Figure 2-52 CO2 Emissions in Asian Power Mix Targets

(6) Summary

Table 2-8 summarized the relative scores of the ten case countries in the four benchmarks. Countries that rank the first to second among the ten countries in total as "A" and the third to the fourth as "B" and the countries that hit the last ninth position as "E" in order to evaluate the relative values of each country. It should be noted that since this ranking is only a relative rating among the ten countries of the subject, the evaluation of "A" to "E" is not necessarily an absolute evaluation. In the table, Vietnam has “A” in all of the four benchmarks, which suggests its power development plan will bring a well-balanced and preferable power generation mix if realized as planned. Likewise, India’s power development is also well designed and balanced by taking either “A” or “B” in all benchmarks.

Table 2-8 Summary of Assessment of Power Mix in Asian Countries

Country	Economic efficiency	Diversity	Import dependence	CO2
Bangladesh	D	C	D	D
Cambodia	D	C	E	C
India	A	B	B	A
Indonesia	E	E	A	E
Malaysia	C	D	C	D
Myanmar	E	E	B	B
Philippines	B	A	C	B
Sri Lanka	C	B	E	C
Thailand	B	D	D	E
Vietnam	A	A	A	A

Note: BGL: Bangladesh; CAM: Cambodia; IND: India; IDN: Indonesia; MAL: Malaysia; MYA: Myanmar; SRI: Sri Lanka; THA: Thailand; VTN: Vietnam
Source: The Institute of Energy Economics, Japan

3. Energy Security Challenges in Major Countries

3.1 Analysis of issues related to stable supply of primary energy

3.1.1 Basic information

Table 3-1 shows basic information for the three targeted countries of this study. The Philippines and Vietnam have large population of almost 100 million. Vietnam has the highest primary energy supply per capita of 0.82 toe/person among the three target countries, and there is no significant difference for the other two countries. Energy-derived CO_2 emissions per capita are high in the Philippines and Vietnam, where coal accounts for a high proportion of primary energy supply. Energy-derived CO_2 emissions per capita is low in Cambodia, which has a high proportion of biomass in primary energy supply and are relatively dependent on hydro power in the power mix.

Table 3-1 Basic Information of the Target Countries

	Cambodia	Philippines	Vietnam
Population (thousand)(2018)	16,250	106,600	94,580
Area (km2)	181,035	299,404	331,230
GDP per capita (US$) (2018)	1,509	3,104	2,551
Real GDP growth (%) (2018)	7.3	6.2	7.1
Total Primary Energy Supply (million toe) (2018)	8	58	78
Total Primary Energy Supply per capita (toe/capita) (2018)	0.51	0.55	0.82
Energy self-sufficiency (%)	58	49	85
CO2 emissions from fuel consumption (Mt) (2018)	10.8	126.5	191.2
CO2 emissions per capita (t/capita) (2018)	0.7	1.2	2.0

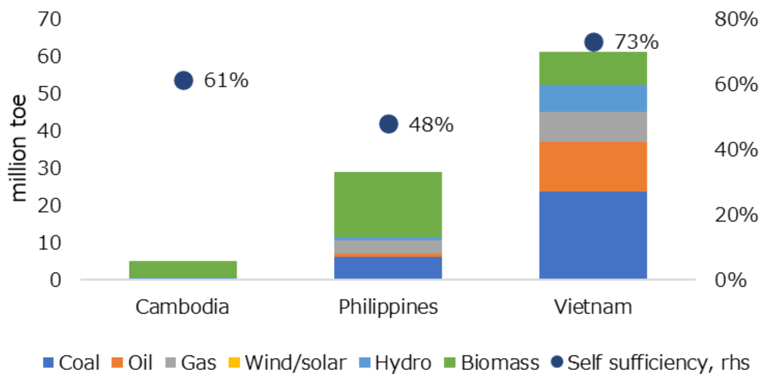
Note: toe: tons of oil equivalent; Mt: million tons
Source: International Monetary Fund, World Economic Outlook Database; International Energy Agency, World Energy Statistics and Balances 2019; International Energy Agency, CO2 Emissions from Fuel Combustion.

3.1.2 Self-sufficiency rate

In terms of energy self-sufficiency, all three countries import energy. Vietnam has a relatively high self-sufficiency rate of 73%, and the energy self-sufficiency rates in Cambodia and the Philippines are 61% and 48%, respectively (Figure 3-1).

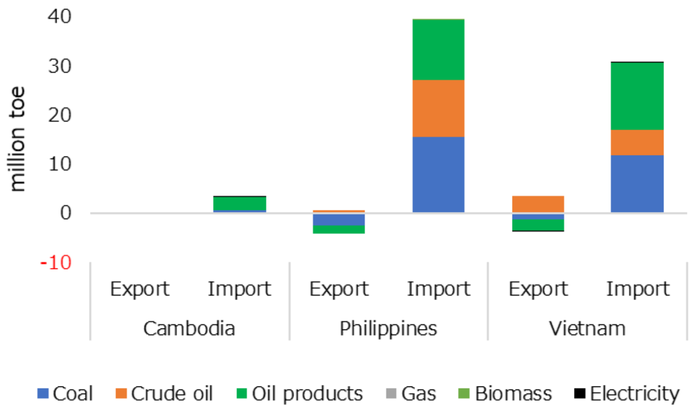
Vietnam has domestic energy resources and produces coal, crude oil and natural gas. Vietnam both imports and exports crude oil because crude oil produced by Vietnam is good in quality (low sulfur content) and can be sold at a high price in international market. Since Vietnam has two new refineries, it can have economic benefits by importing and refining low-quality crude oil produced by Middle Eastern countries instead.

The Philippines produces coal and natural gas, but the self-sufficiency rate of natural gas is likely to decline in the future due to the declining production of the Malampaya gas field. Figure 3-2 shows the energy imports and self-sufficiency rates of the target countries. In each country, the development of domestic resources is sluggish while energy demand is expected to grow in the future. Thus, imported energy will have to cover most of the future growth in demand. Among potential energy sources, LNG, which emits relatively little greenhouse gas among fossil fuels and is considering new projects in various supply sources (North America, Oceania, Southeast Asia, Russia, Middle East, East Africa, etc.) in recent years, will be one the leading options.



Source: IEA, *World Energy Balances 2020 edition*

Figure 3-1 Domestic energy production and domestic energy demand in the surveyed countries (as of 2018)



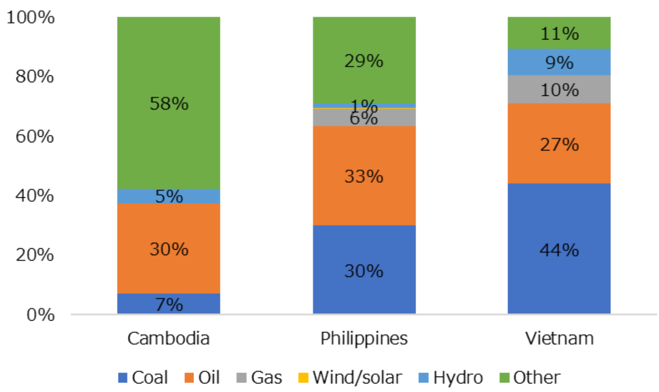
Source: IEA, *World Energy Balances 2020 edition*

Figure 3-2 Energy imports and exports in surveyed countries (as of 2018)

3.1.3 Diversification of energy sources

Figure 3-3 shows the primary energy supply mix of the targeted three countries as of 2018. Energy sources are becoming increasingly diverse in the Philippines and Vietnam.

Cambodia relies on biomass and Vietnam relies on coal for almost half of their energy. Although energy sources are becoming relatively diverse, the Philippines and Vietnam would be able to accomplish more well-balanced energy supply mix by reducing their dependence on oil and coal with introduction of renewable energy and natural gas.

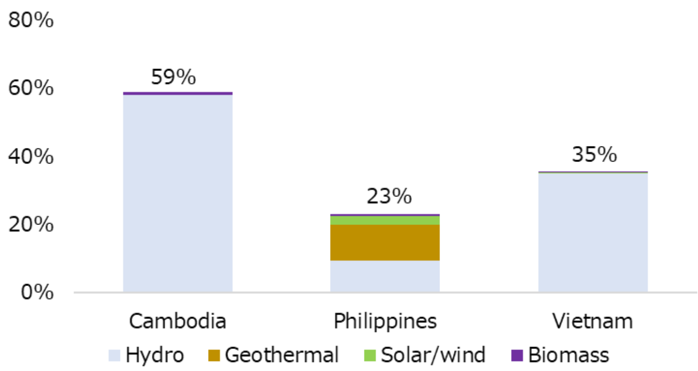


Source: IEA, *World Energy Balances 2020 edition*

Figure 3-3 Primary energy supply mix in the surveyed countries (as of 2018)

3.1.4 Low-carbonization Trends

The share of non-fossil power sources in power supply mix are 25% for the Philippines, the lowest among the target countries. Exception for the Philippines, most of the non-fossil power supplies in all countries are hydropower (Figure 3-4). As domestic electricity demand grows significantly in the future, the share of non-fossil power supplies in each country may decline, as the countries must also depend to a certain extent on thermal power generation using fossil fuels.



Note: The figures in the figure are the sum of the share of power generated by non-fossil power supplies.

Source: IEA, *World Energy Balances 2020 edition*

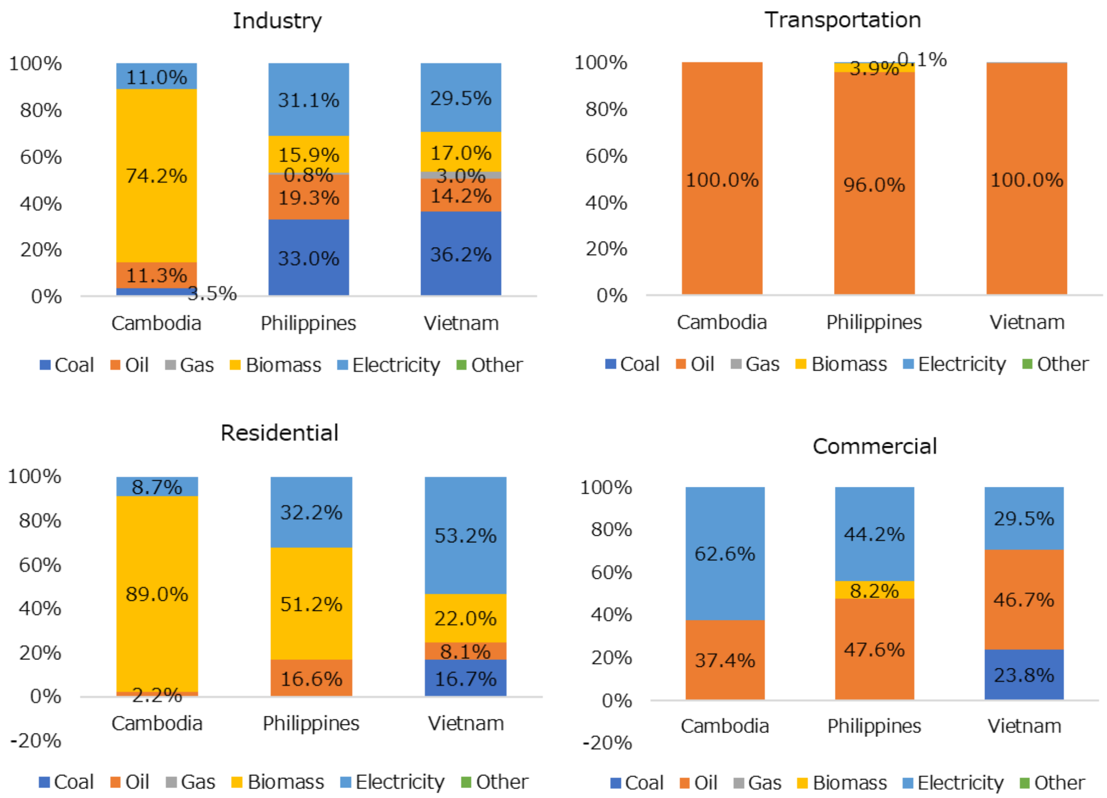
Figure 3-4 Share of non-fossil electricity in the surveyed countries (2018)

Figure 3-5 shows the energy supply mix in the industrial, transportation, residential, and commercial sectors. In the energy supply mix in the industrial sector, the share of fossil fuels (coal, oil and gas) exceeds 50% in Vietnam and the Philippines. Since the industrial sector requires a large amount of heat, it is difficult to promote low carbonization compared to other sectors. However, if coal and oil currently used can be converted to natural gas, CO2 emissions can be reduced relatively. In that sense, there is a lot of room for low-carbonization through gas conversion in the industrial sector in any country.

In the transportation sector, oil has an overwhelming share in all countries. To promote low-carbonization in the transportation sector, it is necessary to promote the electric-powered vehicles such as electric vehicles (EV) and fuel cell vehicles (FCV) and to overcome the problem of relatively high vehicle prices and the development of infrastructure for power and hydrogen supply. It is, however, not always easy to remove oil from the transportation sector and promote low carbonization in these Asian countries in the short term, where its infrastructure to support such low carbonization is still not well developed.

The mix of energy use in the residential sector varies greatly from country to country. In Cambodia, where traditional biomass such as timber and charcoal is still widely used, it will be a priority in energy policy to promote the use of commercial energy, such as electricity or LPG. In the Philippines and Vietnam, where the use of commercial energy is expanding to some extent, it is necessary to gradually curb the use of fossil fuels in the household sector by further promoting electrification to promote low carbonization of the household sector.

Finally, in the commercial sector, as electrification is relatively advanced, if the power supply mix can be low-carbonized, it will greatly contribute to the low carbonization of energy supply mix throughout the commercial sector. In addition, although all three countries are relatively highly dependent on oil. Oil is assumed to be much used as a cooking fuel. Therefore, if this can be converted to gas, the effects of lower carbonization can be further accumulated.



Note: The share of biomass in the industrial sector may seem large in the referred IEA's statistics. According to the estimate in Economic Research Institute for ASEAN and East Asia (ERIA), the estimated share is 58%. Economic Research Institute for ASEAN and East Asia (2016), *Cambodia National Energy Statistics*. p.31 and p.44

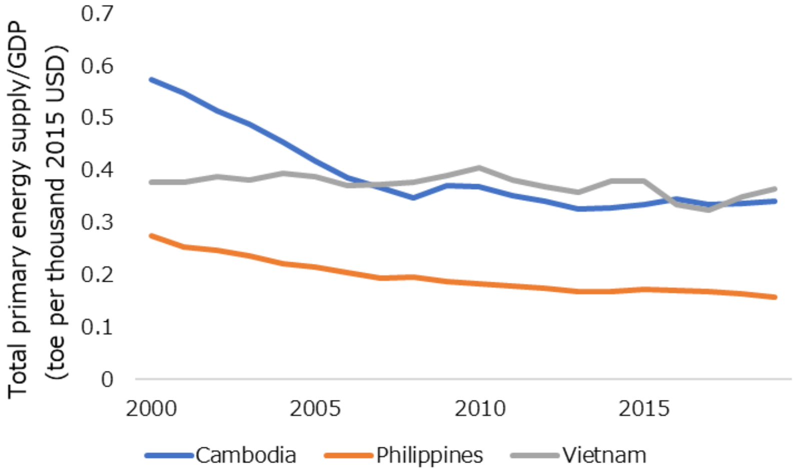
Source: IEA, *World Energy Balances 2020 edition*

Figure 3-5 Energy supply share in non-power sectors in surveyed countries (as of 2018)

As described above, from the perspectives of diversity, self-sufficiency, and low carbonization, besides expanding the use of renewable energies such as wind power and solar power, natural gas will have a great potential to contribute to ensuring energy security in these three countries as a fuel in the transition period toward more drastic reduction of carbon emissions.

3.1.5 Energy intensity

Finally, an overview of the energy intensity of the countries is provided. The Figure 3-6 shows the changes in the energy intensity of each case country. In terms of the absolute figure, the Philippines has the lowest figure, which suggests the highest energy efficiency among them. Regarding Cambodia and Vietnam, the figure was high in the past, but in recent years, it declined and reached almost the same level as Vietnam. Looking at historical development, while the Philippines has consistently achieved the improvement, Vietnam has not seen a significant progress since 2000. Improvements were seen in Cambodia until around 2008, but it has stagnated since then.



Source: IEA, *World Energy Balances 2020 edition*

Figure 3-6 Energy intensity of the three surveyed countries (as of 2018)

By country wise, the level of intensity in Cambodia has been stagnant since 2008, but this period coincides with the period when the use of fossil fuel began to increase in Cambodia. In Cambodia, the share of fossil fuels in primary energy demand increased from 21% to 28% from 2000 to 2008, but the pace of the increase was accelerated since then and the share rose to 49% in the following ten years to 2018. This may suggest that the increase in fossil fuels, particularly the use of coal, negatively affected the entire efficiency of energy use in Cambodia. Improving energy efficiency, meanwhile, has been regarded as an important policy issue, and in 2013, in cooperation with the EU, the National Policy, Strategy, and Action Plan on Energy Efficiency was published.[37] In 2020, furthermore, Energy Efficiency and Conservation Master Plan was developed in collaboration with ERIA.[38]

In the Philippines, steady improvement in energy utilization efficiency has been observed, presumably because the energy markets in the Philippines have been liberalized and domestic energy prices are determined based on the market mechanism, incentivizing the consumers to use energy more efficiently. In addition, the Philippine government's efforts to improve energy efficiency functioned effectively. The government released the "Philippine Energy Efficiency Roadmap" in 2013, setting a goal of reducing

[37] Royal Government of Cambodia, *National Policy, Strategy, and Action Plan on Energy Efficiency in Cambodia*. May 2013. https://data.opendevelopmentcambodia.net/laws_record/national-policy-strategy-and-action-plan-on-energy-efficiency-in-cambodia/resource/649b99b2-4c59-484f-97f6-06cb88e22922. Accessed on 28 November 2021.

[38] Economic Research Institute of ASEAN and East Asia, *Energy Efficiency and Conservation Master Plan in Cambodia*, July 2020. https://think-asia.org/bitstream/handle/11540/12326/Energy-Efficiency-and-Conservation-Master-Plan-of-Cambodia.pdf?sequence=1. Accessed on 28 November 2021.

final energy consumption by 10% between 2011 and 2030. [39] The Road map also sets a goal of improving energy intensity by 40% by 2030 in industrial, transportation, commercial building and household sectors. Specifically, it includes policies such as vehicle fuel efficiency standards, road toll taxes, and industrial equipment utilization efficiency standards. Policy initiatives such as these roadmaps and action plans enabled a solid improvement in energy intensity in the Philippines.

In Vietnam, the improvement in the degree of consolidation since 2000 is small compared to the other two countries. This may be due to the large use of inefficient coal in the power generation sector and the industrial sector such as steel and cement. There is also a view that the fact that companies in such industries are state-owned caused a delay in the introduction of energy-saving technologies. [40] As a policy initiative, the Vietnam National Energy Efficiency Program was formulated in 2006, and the program has been revised thereafter (the latest version was revised in 2018).

3.2 Potential issues related to stable supply of electricity in Asia

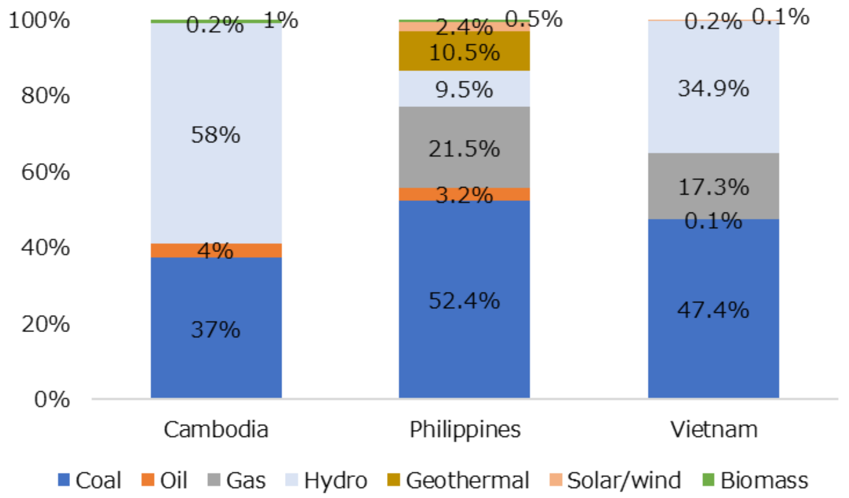
This section summarizes the factors related to the stable supply of electricity in the three case countries.

3.2.1 Diversification of power supply configurations

Figure 3-7 shows the mix of the power generated in the target countries as of 2018. Since all of the three countries rely on the largest power generation source for more than 40%, they commonly have a problem of diversification of power generation mix. The Philippines relies on coal for half of its power generation but has a balanced power generation source for the remaining supply. On the other hand, In case of Cambodia, the summed share of the largest and second largest power supply sources exceeds 90%. Particularly, since hydro power generation tend to be fluctuate depending on the amount of rain fall and has seasonal variations, the diversification of power supply source is more acute.

[39] Department of Energy of the Philippines, *Philippine Energy Efficiency Roadmap*. December 2013. https://policy.asiapacificenergy.org/sites/default/files/energy_efficiency_and_conservation_roadmap2014-2030.pdf. Accessed on 28 November 2021.

[40] Nikos Tsafos and Lachlan Karey, Energy Transition Strategies Vietnam's Low-Carbon *Development Pathway*. July 2020. https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/200731_EnergySecurity_Vietnam_FullReport_v4_WEB%20FINAL_1.pdf. Accessed on 28 November 2021.



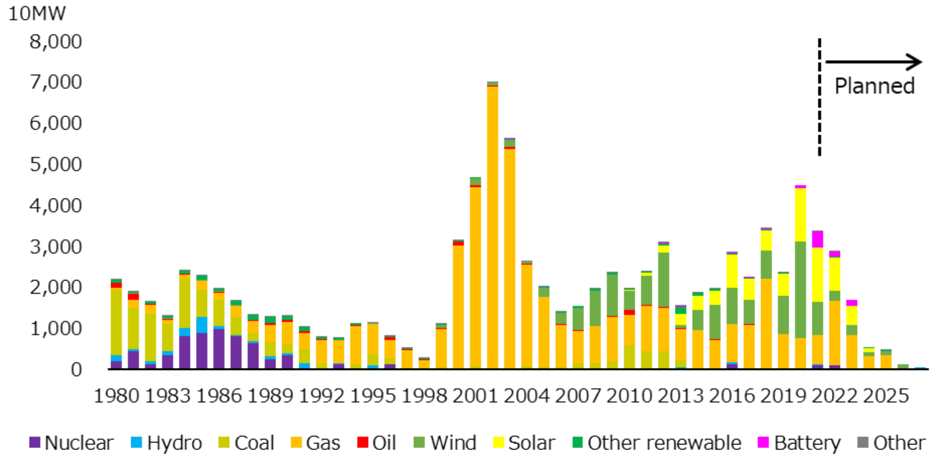
Source: IEA, *World Energy Balances 2020 edition*

Figure 3-7 Power Generation in the Countries Surveyed (as of 2018)

In many Asian countries, more and more countries are reforming their power supply systems. In such environment, only a limited types of power sources can be profitable, and investment of power generation may be concentrated on such specific profitable generation sources. For example, in the early 2000s, many developed countries made large investments to gas-fired generation capacity, which was called "Dash for Gas." After that, the demand for electricity became sluggish after the international financial crisis in 2008, and the government's policy to promote renewable energy power generation caused large investments in renewable power generation. Figure 3-8 shows the status of new power generation by power source type in the United States. In the first half of the 2000s, most of the investment in power generation was gas-fired.

As another example, in Singapore, which adopted the liberalization of the wholesale electricity market, conversion from oil-fired power generation to gas-fired power generation progressed, and as a result, the utilization of each gas-fired generation unit fell because of the rapid capacity expansion, and many gas-fired power plants had difficulty to secure even fixed costs. When power system reforms are implemented in these three countries in the future, it will be a major issue to take care not to concentrate investment on a particular power generation source.

In the UK, which puts a high priority to cut carbon emissions, FIT-CfD (Feed in tariff – Cash for Difference) is used to ensure a certain level of capacities of nuclear power generation in consideration of the decrease in inertial force and the role as a stable power source due to the expansion of the introduction of asynchronous renewable energy power generation. Electricity has various "values" which are not properly appreciated. Such unappreciated values include elasticity of supply and voltage stabilization It is therefore very important to ensure diversity of power generation sources so as to these values are counted in the power generation mix. In other words, the level of price per kWH is an important benchmark but should not be too much emphasized.



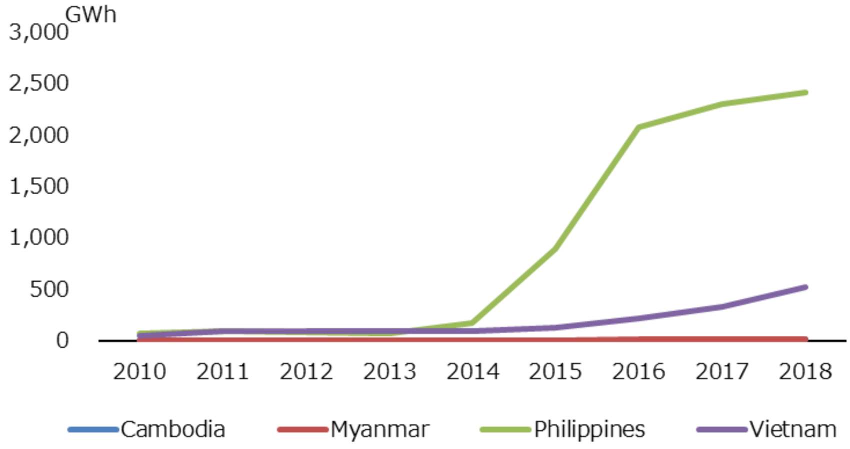
Source: U.S. Energy Information Administration, "Preliminary Monthly Electric Generator Inventory" August 2020

Figure 3-8 Power generation capacity addition by fuel in the United States (Actual and expected)

3.2.2 System stability due to increased variable renewable energy

(1) Introduction status of variable renewable energy

Figure 3-9 shows the trends in the amount of power generation by so-called variable renewable energy in the three targeted countries. Since the mid-2010s, power generation volumes in the Philippines have shown significant growth due to the introduction of Feed-in tariff (FIT) in July 2012. In other countries, introduction of the amount power generation by renewable energy is still sluggish as of 2018.



Source: IEA, "Energy Balances of the World 2020"

Figure 3-9 Electricity Volume of Variable Renewable Energy (Wind and Solar) in the case countries

(2) Conditions for grid management

It is important to maintain system integration requirements for frequency maintenance and voltage stabilization for introduction variable renewable energy for power generation. When the frequency declined in the system failure in Japan in 2016, the width of frequency gap was relatively large for the scale of the system failure. This incident occurred because some solar power generators dropped out from the power system in response to slight frequency drop. This is a problem of the setting value for frequency drop relay. In this case, regulation of technical requirements was set as the value with width, not necessarily as the lower limit value.

For this reason, the regulation was revised in May 2019. Each power generation facility is required to adapt for the setting value for frequency drop relay by each region. Furthermore, the Organization for Cross-regional Coordination of Transmission Operators, Japan (OCCTO) started reconsideration of the system integration requirements for asynchronous renewable energy for power generation in September 2020.

In Europe, where renewable energy for power generation has already been widely introduced, the EU Commission Regulation (EU) 2016/631 was provided as a network code on requirements for grid connection of generators. Each EU member country adopts the regulation and provided its own law based on the regulation. The EU Commission Regulation stipulates ten required items, namely, 1) operating range (frequency and voltage), 2) power quality (voltage flicker, higher harmonic wave, voltage fluctuations), 3) invalid power supply for voltage control, 4) frequency control, 5) behavior in the event of a system failure (protection function, operation continuation function in the event of accidents), 6) effective power change limit (especially after parallel and before analysis),

7) providing simulation model (for response transient in the event of system failure), 8) effective power management (for supply and demand adjustment and system stabilization), 9) data transmission (monitoring, effective power control, adjustment force command), 10) protection function (power generator protection and prevention of accident spread to the system).

In the United States, regulations on the sophistication of variable renewable energy are being developed, The Order No. 827[41] announced by the Federal Energy Regulatory Commission (FERC) in June 2016 stipulated requirements of the invalid power requirements for asynchronous generators. The "Order No. 842" [42] announced in February 2018 stipulated that providing primary frequency response. In California, where the introduction of renewable energy power generation is progressing, "Rule21"[43] was provided as the requirements for connecting a series of inverter-type equipment, In Phase-I, which began to be applied in September 2017, mandatory use of smart inverters certified by UL standard UL1741 (protection function, voltage ride-through, flicker requirement, frequency ride-through, current harmonic distortion rate, DC current injection limit, power factor control, voltage and invalid power control, ramp rate control) was stipulated. Phase-II, which began to be applied in January 2020, communication protocols and cyber security for remote control were stipulated. Phase-III is considered to have an advanced function. In February 2019, frequency-watt and voltage-watt control began to be applied in January 2020, included provisions for data monitoring functions, remote control of reclosing/parallel off and the maximum effective power limit function.

These functional arrangements for variable renewable energy for power generation will be needed in a certain stage of introduction of renewable energy for power generation. It can be introduced in Asian countries because it has already been implemented in several countries.

(3) Response to decreased inertia

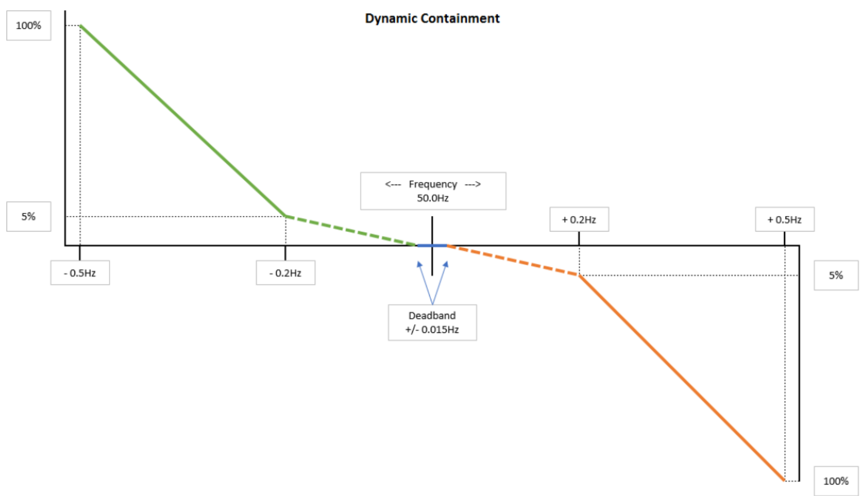
Ireland, UK, ERCOT in Texas, Northern European countries and Australia have a problem of decreased inertia by growing introduction of asynchronous renewable energy for power generation. These countries and regions have a higher risk of massive blackout. They have a small-scale of synchronous power system and the increase in asynchronous renewable energy for power generation causes a bigger decreasing rate of change of

[41] Federal Energy Regulatory Commission, "Order No. 827" 16 June 2016. https://www.ferc.gov/sites/default/files/2020-04/E-1_68.pdf. Accessed on 17 January 2021.
[42] Federal Energy Regulatory Commission, "Order No. 842" 15 February 2018. https://www.ferc.gov/sites/default/files/2020-06/Order-842.pdf. Accessed on 17 January 2021.
[43] California Public Utility Commission, "Rule 21 Interconnection" 13 July 2017. https://www.cpuc.ca.gov/rule21/. Accessed on 17 January 2021.

frequency (RoCoF) with a system failure. Then, the frequency will go beyond the setting value of RoCoF relay (If the rate of change of frequency becomes larger than a certain amount of value, RoCoF relay will automatically stops power generator) equipped with power generator. This RoCoF relay is usually set to around 2 Hz/s, but in the UK, the RoCoF relay of the old in-house power generation facility is 0.125Hz/s (currently 1Hz/s). The RoCoF relay was set to 0.5Hz/s in Ireland (currently changed to 1 Hz/sec), so the problem became apparent in an early stage.

There are many island countries in Asia, and the system scale in each country is small. If the introduction of asynchronous renewable energy power generation expands in such countries and regions, the problem of inertia may become apparent in the same way. Countermeasures against this inertia are difficult to be taken. If a decrease in inertia is expected in advance, it is necessary to establish the purchase conditions for renewable energy power generation or prepare otherwise responsive storage batteries so that asynchronous renewable energy generation can be easily controlled.

In the UK, a frequency response called "Dynamic Maintenance" started in October 2020, which requires deadbands to be set to ±0.015Hz, maintaining 5% of the registered output at ±0.2Hz, and responding in full in up to one second when it reaches±0.5Hz (response starts in 0.5 seconds at the latest). The frequency measurement interval must be 0.05 seconds. The National grid ESO, which currently purchases 250,000kW of power, has indicated that it will expand purchasing to 1 million kW of power by 2021. So far, only storage batteries have responded to Dynamic Container (Figure 3-10).



Source: National Grid ESO, " EBGL Article 26: Proposal for Defining and Using Specific Products for balancing energy and balancing capacity"

Figure 3-10 Dynamic Container Response Design

Synchronous phase modifiers and phase modifying equipment (STATCOM, etc.) can be installed as a countermeasure against the decrease in inertia. But the equipment is utilized for voltage countermeasure and needs to be designed to effectively cope with the inertia problem, which is regarded as difficult even in developed countries. There is only one actual case: a six-year contract of plural usage for maintaining inertia, voltage control and maintaining system stability in Stability Pathfinder Project in UK in January 2020. [44]

This problem of inertia reduction has not yet been fully recognized, especially in Asia. In promoting renewable energy, therefore, it is necessary to refer to the preceding experiences in developed countries where the adoption of variable renewable energy progresses and take appropriate measures to address the potential problem.

3.2.3 Mitigation of risks from the viewpoint of international power interchange

There are several advantages to connecting different countries and regions by integration lines. In case of power sources development of coal-fired and nuclear power plants, which have economies of scale, the power sources development will advance more smoothly if multiple countries and regions share the power plants. The gas-fired power plants also benefit from economies of scale by adding the number of gas-fired power generators which are equipped with LNG facilities. In addition, renewable energy for power generation, of which power output fluctuates depending on the weather conditions, would reduce power output fluctuation by enlarging scale of system for receiving power capacity.

On the other hand, if a country is heavily dependent on imported fossil fuels and the purchase price of fossil fuels is more expensive than in other countries, increasing the capacity of the international connecting line may increase the amount of electricity imported, which would result in a management squeeze on the domestic power industry. For example, Italy is dependent on imported fossil fuels and faces higher gas imported price than other countries, since it is located far from gas-producing countries, However, since there are no tariffs or additional consignment fees for the import of electricity via international connecting lines, it is cheaper for Italy to import electricity from gas power generation in other countries than to utilize gas for power generation in Italy. As a result of the liberalization of electricity, Italy's dependence on electricity imports increased. However, Italy experienced blackout in 2003 because of large power outage of international connecting lines amid growing electricity imports. In that sense, it should be noted that the security of power supply has become more fragile by international connecting lines. In Italy, since then the dependence on electricity imports has declined slightly. Italy prevented cheap importing electricity price from spreading nationwide by

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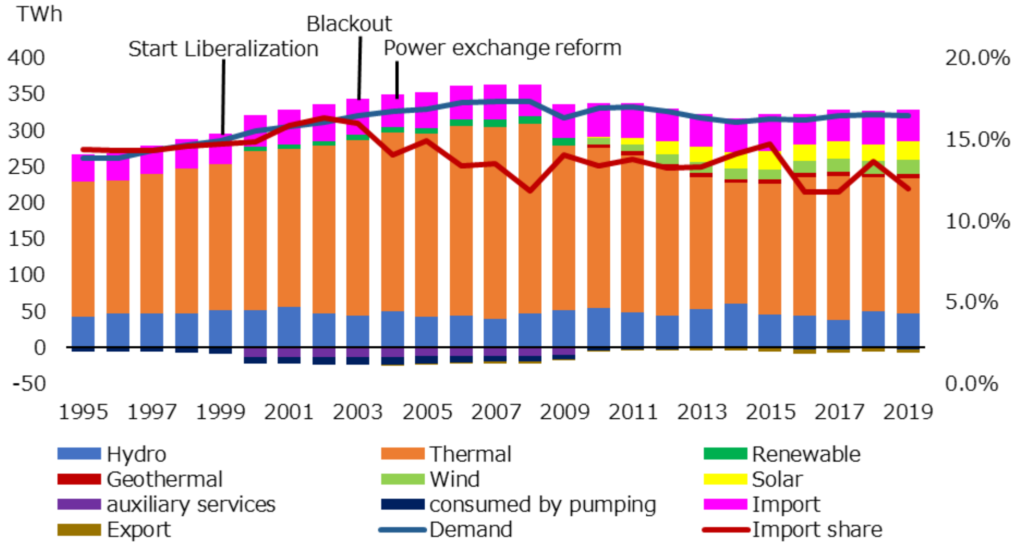
[44] Drax Generation Enterprise, Rassau Grid Services, Deeside Power (UK), Uniper and UK, Statkraft UK were awarded.

segmenting regional wholesale pricing through revision of trading system and introduced solar power generation domestically (Figure 3-11).



Note: We do not have Report for 2013. Net imports from 2000 to 2003
Source: Terna, "Provisional Data on Operation of the Italian Power System" for each year.

Figure 3-11 Power Generation and Power Consumption in Italy

When countries and regions adopt different wholesale electricity trading mechanisms, international connectivity need to be developed with caution. For example, in Finland, its power grid is connected with Russia electricity used to be imported from Russia. However, Finland turned to be in exporting balance to Russia as a result of liberalization of international electricity trade. Before the Finnish liberalization, Russia had liberalized electricity market and had capacity market. But because Finland did not have such capacity market, the Finish power generators could receive not only electricity sales per kWh sold but also capacity value per kW by exporting electricity to Russia. This somewhat skewed economics made Finland better positioned and become a net exporter of electricity to Russia. In the context of Asia, since international electricity trade tends to be done by state-owned power utility based on bilateral contract, such kind of problem caused by such differed market systems is not likely to occur. However, going forward, when international wholesale electricity transactions will be liberalized in Asia, similar problem may arise.

3.2.4 Problems associated with coal-fired power generation

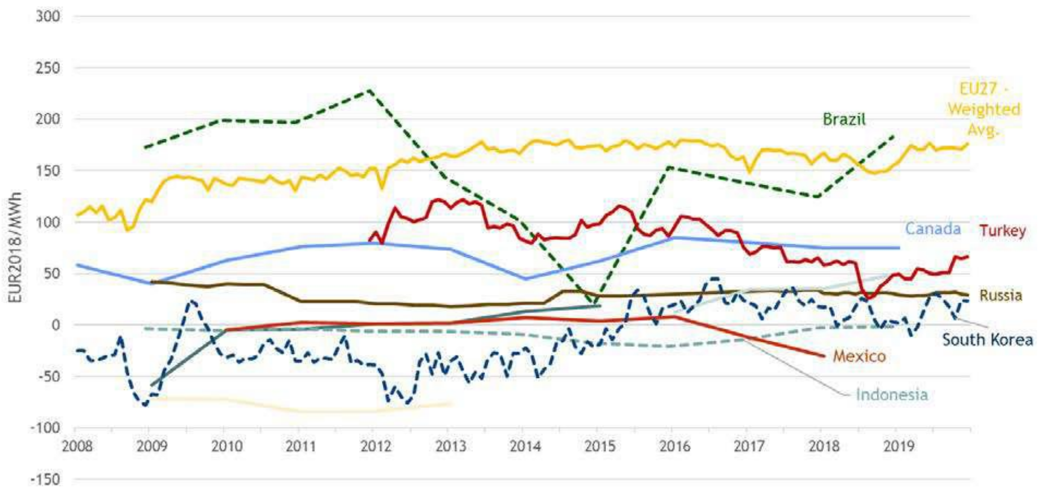
Many Asian countries have plans to invest in coal-fired power generation, which can procure low-cost fuel. On the other hand, a growing number of financial institutions are cautious about financing investments in coal-fired power generation. More and more reports indicate higher risks for investing in coal-fired power generation due to local opposition risks and improved cost competitiveness of renewable power generation [45]. Therefore, even if the optimal power supply configuration with coal-fired power generation is identified based on the method described earlier, more and more countries will change their policies and reduce the ratio of coal-fired power generation from the optimal configuration and increase the introduction of renewable energy. In Europe and the United States, an increasing number of countries and regions have set the system-based requirements for renewable energy power generation as requirements that contribute to system stabilization, but such requirements have not been introduced in Asian countries. For this reason, in many Asian countries, kWh costs are compared without evaluating the system stabilization function (frequency stabilization or voltage stabilization) of coal-fired power generation as a value. Therefore, in introducing renewable energy power generation, additional system countermeasure costs such as installation of voltage adjusters needs to be included.

Furthermore, the increase in power generation costs by reducing the dependence on coal-fired power generation will also be a major issue. Figures 3-12 and 3-13 analyze the price difference between residential electricity prices and wholesale electricity prices in major countries and regions. In China and Indonesia, the difference between residential electricity prices minus wholesale electricity prices is negative (residential rates are cheaper than wholesale prices) because residential electricity prices are set cheaply. Other Asian countries are on a similar trend, and if the cost of power generation rises due to “de-coalization” in the future, it will further worsen the overall balance of the electricity business. For this reason, in reducing the dependence on coal-fired power generation, reform of electricity pricing and fee systems have to be also implemented so as to reflect the cost of supply. South Korea for instance traditionally set electricity prices for residential use cheaply, but the unbalance has been gradually modified, and similar responses will be needed in Asian countries.

[45] For instance Influence Map "Analysis of Investment Risks in Coal-Fired Power Plants in Asia"2019 年
10Months)https://influencemap.org/site/data/000/420/%E3%82%A2%E3%82%B8%E3%82%A2%E3%81%AB%E3%81%8A%E3%81%91%E3%82%8B%E7%9F%B3%E7%82%AD%E7%81%AB%E5%8A%9B%E7%99%BA%E9%9B%BB%E6%89%80%E3%81%B8%E3%81%AE%E6%8A%95%E8%B3%87%E3%83%AA%E3%82%B9%E3%82%AF%E3%81%AE%E5%88%86%E6%9E%90.pdf. Accessed on 17 January 2021.

Source: European Commission, "Study on energy prices, costs and their impact on industry and households," p. 75

Figure 3-12 Difference between Residential Electricity Prices and Wholesale Prices in the EU, Japan, the United States, and China

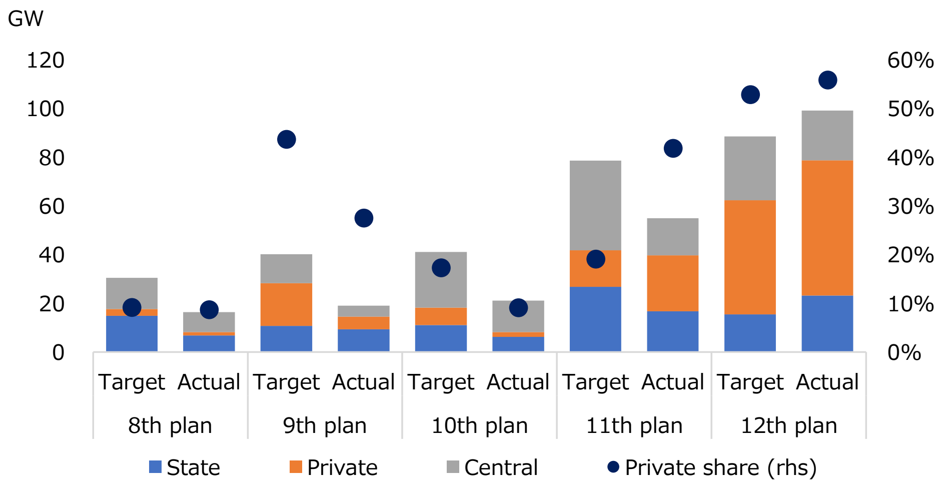


Source: European Commission, "Study on energy prices, costs and their impact on industry and households," p. 76

Figure 3-13 Difference between Residential Electricity Prices and Wholesale Prices in the EU and Other G20 Countries, 2011

3.2.5 Planning and reality

In Asian countries, an increasing number of countries are adopting analytical methods for making optimal power supply configuration prospects through international cooperation. However, even though such an optimal power supply configuration outlook is made, realizing the outlook in another problem. For example, India has developed a five-year plan to identify power generation and transmission investments for the next five years, but the previous five-year plan shows that many of the actual power investments realized were significantly lower than the target value (Figure3-14). In fact, the disparity between the plan and the actual caused power shortage. In India, power system reforms allowed the separation of transmission and distribution sectors and open access to transmission and distribution networks. The power generation sector signs purchase agreements with distribution companies for more than seven years. Distribution companies procure power generation for one to five years supply contract through tenders called "Discovery of Efficient Electricity Price (DEEP)". The contract for less than one year can be signed through bilateral transactions and trading at wholesale markets, such as India Energy Exchange and Exchange India Limited. Since the discrepancies of the procurement cycle of power supply and investment cycle can cause serious power shortage, ensuring proper designing of the market and sufficient investments in power generation capacity is an important issue for the government.



Source: Central Electricity Authority, "Draft National Electricity Plan (Volume 1) Generation", December 2016

Figure 3-14 Goals and Implementation Status of India's Five-Year Plan

4. Issue Analysis and Cooperation Projects with Vietnam

4.1 Energy Supply and Demand Overview

4.1.1 Primary energy supply

(1) Total supply

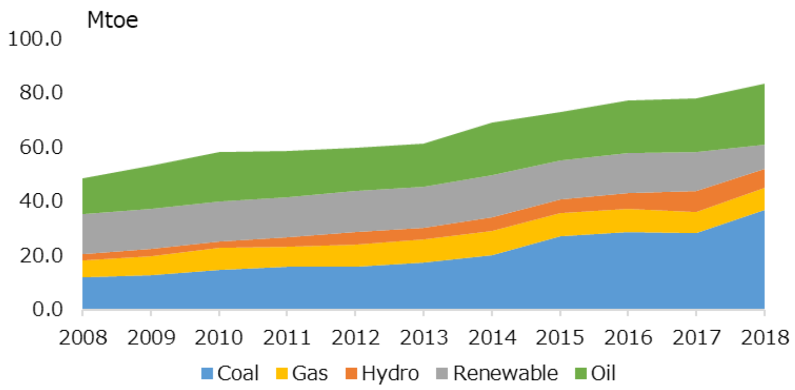
Vietnam's primary energy supply in 2018 was 83 million tonnes of oil equivalent (mtoe), an increase by 60% over the previous decade compared to the supply of 49 mtoe in 2008. (Table 4-1 and Figure 4-1). As of 2018, coal had the largest share by energy source at 44%, followed by oil at 27%, and renewable energy at 11%. Natural gas accounts for 10%, but there are no imports because the entire amount is covered by its own domestic production. However, since domestic natural gas demand is expected to increase, particularly in the power sector in the future and production of domestic gas has stagnated from around 2015, Vietnam plans to import LNG.

Table 4-1 Primary Energy Supply in Vietnam

Unit: mtoe

	Coal	Oil	Gas	Hydro	Renewable
2008	11.7	13.4	6.4	2.2	14.7
2009	12.6	15.8	7.1	2.6	14.7
2010	14.7	18.3	8.1	2.4	14.7
2011	15.6	17.0	7.6	3.5	14.9
2012	15.8	16.0	8.3	4.5	15.0
2013	17.2	15.9	8.5	4.5	15.2
2014	19.9	19.2	9.1	5.1	15.3
2015	26.8	18.0	8.8	4.9	14.4
2016	28.5	19.5	8.8	5.7	14.7
2017	28.2	19.8	7.8	7.7	14.4
2018	36.7	22.5	7.9	7.2	9.0

Source: International Energy Agency (IEA), World Energy Balances 2020 edition



Source: IEA, *World Energy Balances 2020 edition*

Figure 4-1 Primary Energy Supply in Vietnam

(2) Oil

Vietnam produced 13.2 mtoe of crude oil in 2018, of which 2.5 mtoe was exported. The production volume turned to decline since 2015 because of the depletion of the producing oil fields.

Crude oil imports were on an increasing trend with the start of operations at the country 's second refinery in 2018. Crude oil import of Vietnam was 7.6 mtoe in 2019 (up 47.1% from previous year). Nghi Son refinery imports Kuwaiti crude oil supplied by Kuwait Petroleum Corporation. Since Nghi Son refinery began operation in 2018, Vietnam's imports of petroleum products have declined, from 15.2 mtoe in 2017 to 9.8 mtoe in 2019. The main sources of imported petroleum products are Malaysia, South Korea, Singapore, Thailand, and China.

Vietnam has two refineries in Dung Quat and Nghi Son. The start of the operation of the country's first Dung Quat refinery, was 2009 with the capacity of 145,000 barrels per day (B/D). The Dung Quat refinery has a capacity expansion plan to 190,000 B/D with the investment of USD 1.8 billion. The construction work is scheduled to start in August 2021. The Dung Quat refinery processes mainly domestic Bach Ho crude oil, while the other Nghi Son refinery refines crude oil imported from Kuwait. With the start of operations at the Nghi Son refinery of 200,000 B/D in 2018, Vietnam's petroleum products import has been on the decrease, although the import has not declined to zero as the domestic oil demand still is larger than the combined production capacities of the two refineries.

(3) Natural gas

Vietnam produced 7.9 mtoe of natural gas domestically in 2018. Like the oil production, natural gas production also continued to decline from 2015 as most of the production is associated gas produced from oil fields Vietnam. Domestic gas-fired power plants consumed 87% of the total produced gas and industry sector (mainly petrochemical sector) consumed the rest. Natural gas is transported by pipeline from offshore gas fields. The gas-fired power plants are located in Vung Tau, Ca Mau, Dong Nai and Can Tho in southern Vietnam, and has a total domestic gas-fired power generation capacity of 7.7 GW. According to the progress report of the seventh power supply development plan, 6.8G W has been approved as agas-fired power plant, and 18.4 GW has been planned. [46]

[46] Ministry of Industry and Trade, "Report on the Implementation of Progress of Power projects in the Revised Power Development Plan7,"4 June 2019. http://vepg.vn/wp-content/uploads/2019/06/MOIT_Report_58_BC_BCT.pdf. Accessed on 20 January 2021.

(4) Coal

Vietnam produced 21.4 mtoe (about 32 million tons of coal equivalent: tce) of anthracite (hard coal) in 2018. Unlike the productions of oil and natural gas, the coal production in Vietnam achieved constant growth since the early 2010s. Vinacomin, a state-owned mining company, produces coal mainly in red river Delta Coal Basin in northern Vietnam, where Japan provides safety and technical cooperation

Vietnam imported 2.3 mtoe (about 3.7 million tce) of anthracite and 5.4 mtoe (about 8.7 million tce) steam coal (thermal coal) and exported 1.1 mtoe (about 1.7 million tce) in 2018. Domestic coal-fired plants consumed 48% of totally supplied coal and coal accounted for 34% in power generation mix.

4.1.2 Power generation mix

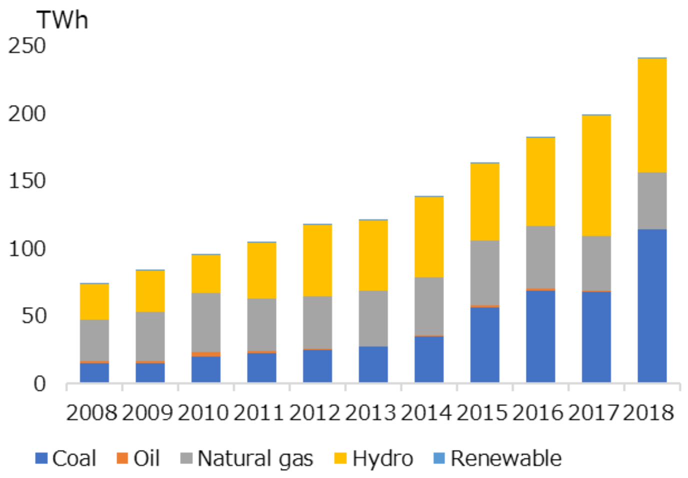
Vietnam generated 241 TWh of electricity in 2018, increasing by 2.3 times over the past decade compared to 73 TWh in 2008. Coal accounts for about half (47%) of the total power generation mix, followed by hydro (35%) and natural gas (17%). In 2018, as the demand for electricity in Vietnam increased rapidly, and the power generation of hydroelectric power generation, which is the main power source, decreased due to the decrease in water level. The power generation mix changed significantly compared to 2018 due to the increased use of coal-fired power generation to secure electricity supply. Renewable energy (solar and wind), meanwhile, accounted for only 0.3% as of 2018. (Table 4-2 and Figure 4-2).

Table 4-2 Vietnam Annual Electricity Statistics

Unit: GWh

	Coal		Oil		Gas		Hydro		Renewable		Total	
2008	14,723	20.1%	1,569	2.1%	31,062	42.3%	25,986	35.4%	56	0.1%	73,396	100%
2009	14,979	18.0%	1,785	2.1%	36,358	43.7%	29,981	36.0%	72	0.1%	83,175	100%
2010	19,690	20.7%	3,410	3.6%	44,148	46.5%	27,550	29.0%	105	0.1%	94,903	100%
2011	22,429	21.6%	1,749	1.7%	38,827	37.3%	40,924	39.3%	142	0.1%	104,071	100%
2012	24,855	21.1%	372	0.3%	39,426	33.5%	52,795	44.9%	143	0.1%	117,591	100%
2013	27,192	22.6%	424	0.4%	40,862	33.9%	51,955	43.1%	144	0.1%	120,577	100%
2014	34,602	25.0%	515	0.4%	43,263	31.3%	59,841	43.2%	145	0.1%	138,366	100%
2015	56,469	34.6%	1,293	0.8%	48,147	29.5%	57,174	35.0%	194	0.1%	163,277	100%
2016	68,211	37.4%	1,910	1.0%	46,055	25.3%	65,722	36.1%	286	0.2%	182,184	100%
2017	67,558	34.0%	700	0.4%	41,020	20.6%	88,982	44.8%	399	0.2%	198,659	100%
2018	114,182	47.4%	258	0.1%	41,729	17.3%	84,125	34.9%	646	0.3%	240,940	100%

Source: IEA, World Energy Balances 2020 edition



Source: IEA, *World Energy Balances 2020 edition*

Figure 4-2 Trends in Power Generation in Vietnam

4.1.3 Initiatives for climate change action

As a policy document for climate actions, Vietnam approved "The National Target Program to Respond to Climate Change" in December 2008, "The National Climate Change Strategy" in December 2011, and "The National Green Growth Strategy" in September 2012. In September 2015, Vietnam submitted its INDC (Intended Nationally Determined Contributions) to the UNFCCC Secretariat. The Vietnam's INDC goal is to reduce greenhouse gas emissions by 25% compared to BAU by 2030 with international assistance (an 8% reduction if international assistance is not available). As of June 2015, Vietnam had 254 Clean Development Mechanism (CDM) projects certified by the CDM Board of Directors. Vietnam ranks fourth in the world in terms of the CDM projects, with total GHG savings of approximately 137.4 million tons of CO2 equivalent during the credit period. Of the 254 projects, 87.6% were energy projects, 10.2% were waste disposal, 0.4% were reforestation and afforestation, and 1.8% were other projects.

4.2 Ministries and Agencies in charge of energy policy

All energy industries, including electricity, new and renewable energy, coal, and oil and gas, are overseen by the Ministry of Industry and Trade (MOIT). MOIT is responsible for developing laws, policies, development strategies, master plans and annual plans for these energy industries, as well as submitting, issuing and authoring them to the Prime Minister, as well as mentoring and managing the energy sector. In addition to MOIT, representative energy-related ministries and agencies are as follows:

- Ministry of Planning and Investment: MPI
  - The ministry has an authority to coordinate the allocation of investment funds

of the government for projects submitted by other ministries and agencies. The ministry is also in charge of introduction of foreign capital.

- Ministry of Natural Resources and Environment: MONRE
  - MONRE is responsible for research and development on environmental regulations, energy and environmental protection.
- Ministry of Finance (MOF)
  - MOF has an authority to set energy-related tariffs and levies.
- Ministry of Science and Technology (Ministry of Science & Technology: MOST)
  - MOST oversees relevant agencies related to nuclear energy technologies such as the Vietnam Atomic Energy Agency (VIETNAMATOMIC ENERGY AGENCY), the Vietnam Atomic Energy Institute (VAEI), and the Vietnam Agency for Radiation and Nuclear Safety.

Source: Ministry of Industry and Trade, "Organizational Chart of Ministry of Industry and Trade" https://moit.gov.vn/web/web-portal-ministry-of-industry-and-trade/organization. Accessed on 20 January 2021.

Figure 4-3 Organization Chart of the Ministry of Commerce and Industry of Vietnam

4.3 Energy suppliers

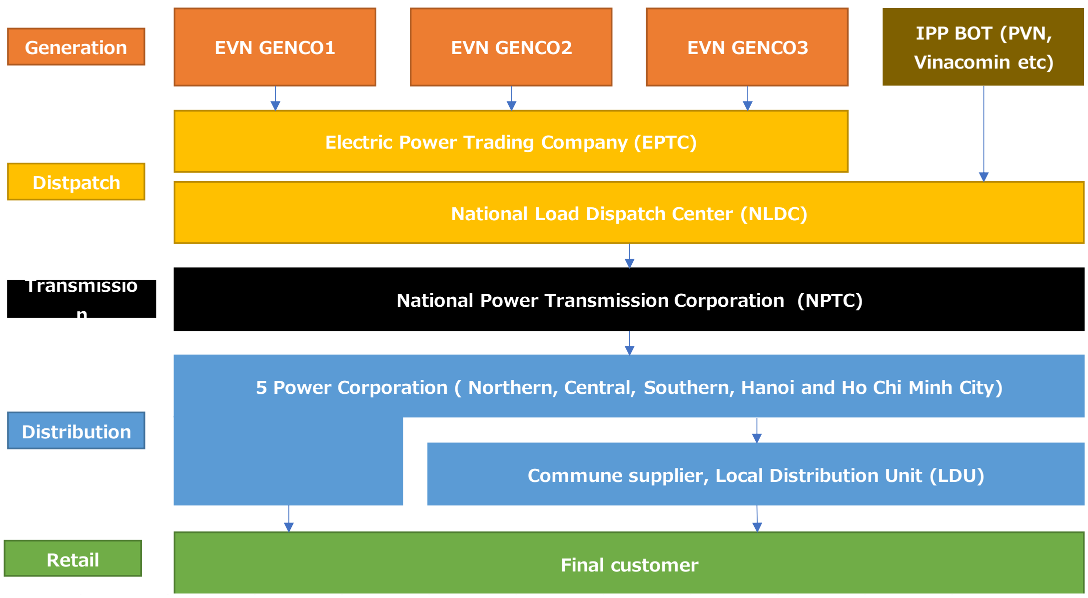
4.3.1 Power

The Vietnam Electric Power General Public Corporation (EVN) owns and manages major power plants, power supply command stations, transmission companies, and power distribution companies as holding companies. Subsidiaries include those of "directly under the control" of EVN, which are 100% owned by EVN and allocated budget, "independent profitable enterprise" (GENCO1-3, etc.), which is 100% owned by EVN but in an independent profitable format, and "Joint Stock Company (JSC)" co., Ltd., which EVN partially owns. (Figure 4-4).

- Power Trading Company (ELECTRIC Power Trading Company: EPTC)
  - EPTC, a company under the direct control of EVN, is responsible for EVN power

transactions, including finalizing of power sales contracts (PPA).

- National Load Dispatch Center: NLDC
  - NLDC, a company under direct control of EVN, operates the system while coordinating with regional power supply command stations in the northern, central, and southern regions. The main business is 110kV, 220kV, 500kV system operation and operation directive to power plant, and it is the key to supply and demand adjustment throughout Vietnam.
- National Power Transmission Corporation (NPTC)
  - NPT, an EVN independent management company, maintains and manages 220-500 kV transmission facilities throughout Vietnam, and also undertakes construction investments such as plans to expand and enhance transmission facilities.
- Power Distribution and Retail (Power Corporation: PC)
  - Five PC independent management companies ((1) Northern Distribution Company, (2) Southern Distribution Company, (3) Central Distribution Company, (4) Ho Chi Minh City Distribution Company, and (5) Ha Noi City Distribution Company) exist in each region to supply power to local consumers and Commune operators. The five companies also operate and maintain transmission and distribution lines of 110 kV or less, sales operations such as fee collection, and local electrification.



Source: Overseas Electric Power Research Committee, "Electricity Business in Overseas Countries Vol.2 2020 Edition"

Figure 4-4 Structure of Electricity Business in Vietnam

4.3.2 Oil

The Vietnam Oil and Gas Group (Petro Vietnam), a state-owned oil company, plays a central role in oil supply in Vietnam. The company operates extensively in the value chains of oil in Vietnam. It explores, produces, stores, refines and transports oil, gas and coal bed methane gas (CBM), manufactures petrochemicals, imports, exports and markets petroleum products, and has subsidiaries in the upstream and downstream divisions, respectively.

In Vietnam's upstream sector (oil development and production), Petro Vietnam Exploration and Production (PVEP) operates by forming a joint venture with foreign companies and concluding a product sharing agreement (Production Sharing Contract: PSC). Since the end of the 1990s, the company has expanded into upstream business overseas, and has also operated in neighboring countries in Asia, as well as in South America, the Middle East, and Africa.

In the refining sector, Petro Vietnam Oil Corporation (PV Oil) imports and sells crude oil and petroleum products in Vietnam's downstream sector. In the refining sector, Idemitsu Kosan of Japan, together with Petro Vietnam, Kuwait Petroleum Company, and Mitsui Chemicals of Japan, form a joint venture to operate the Nghi Son refinery since December 2018.

In the product sales sector, not only PV Oil but also another state-owned oil company, Vietnam National Petroleum Group (no equity relationship with Petro Vietnam), imports, exports, sells petroleum products and petrified products. In May 2016, Japan's ENEOS Holdings of Japan invested 8% in the company.

4.3.3 Gas

The Petro Vietnam plays a major role also in the gas business in Japan. Upstream natural gas production is mainly from offshore in the southeastern part of the country, but the production has been sluggish in recent years. Petro Vietnam Gas Joint Stock Corporation (PV Gas) is responsible for supply, logistics, and sales of gas in Vietnam.

In July 2017, Petro Vietnam announced the Basic Plan for The Development of the Gas Industry through 2025 and the Policy to 2035. The government set out a direction to combine the gas industry with the country's electricity development strategy and effectively use it as clean energy with low greenhouse gas emissions and will expand domestic efforts and international cooperation to do so. Especially, in the power generation sector, interest in LNG thermal power generation has been increasing as domestic natural gas production has stagnated, and construction of LNG receiving bases is being considered mainly in the northern and southern regions of Japan (Table 4-3). Furthermore, at the Japan-U.S. Strategic Energy Partnership (JUSEP) held in December 2020, there was a lively exchange of views on LNG value chain development in Vietnam, and future progress will be noted.

Table 4-3 Plan for LNG Receiving Terminals in Vietnam

Name of receiving base (construction site)	Gasification capacity(1 million ton)	Scheduled start of operation
FSRU LNG terminal	0.2～0.5	2026-2030
Hai Phong LNG Terminal (Cat Hai)	1～3	2030-2035
Binh Thuan LNG Terminal (Son My)	6	2022-2025
Khanh Hoa LNG Terminal (My Giang)	3	2030-2035
South East LNG Terminal	4～6	2022-2025
Vung Tau LNG Terminal (Thi Vai)	1～3	2020-2022
South West LNG Terminal	1	2021-2030

Source: Ministry of Industry and Trade, "Vietnam Gas Industry Master Plan" July 2018. https://www.jccp.or.jp/country/docs/4_CPJ-5-18_MOIT.pdf. Accessed on 20 January 2021.

4.3.4 Renewable energy

The PDP8 (8th National Electricity Master Plan), formulated in 2021, set the target ratio for renewable energy in power configurations is above 50% as of 2040 on capacity basis (11% for hydro, 18% for solar, 23% for wind, and 2% for biomass). The National Energy Development Strategy, published in February 2020, also emphasizes rapid and sustainable energy development, and the development of renewable and clean energy is a priority. The strategic policy set a target ratio of renewable energy to the total primary energy supply of 15 to 20 percent as of 2030 and 25 to 30 percent as of 2045. In Vietnam, a fixed-price purchase system (FIT) has been introduced as a policy to promote renewable energy generation.

(1) Solar power generation

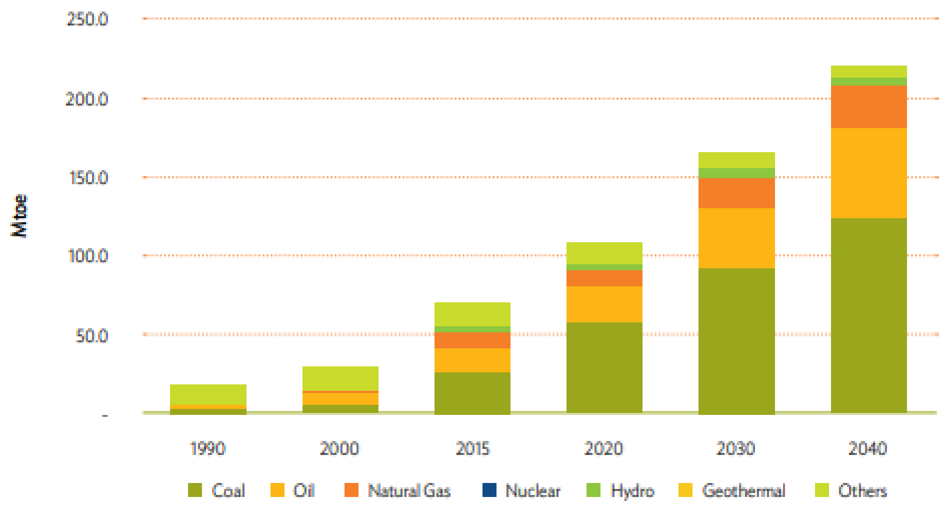
In July 2019, MOIT approved a plan to promote the development of roofed solar power from 2019 to 2025. The goal is to install and utilize 100,000 sets of roof-top solar power generation equipment, equivalent to 1,000 MW of installed capacity, nationwide by the end of 2025. Solar power generation is actively promoted in the central and southern regions, which have a geographical advantage in solar radiation and hours of sunshine, The installed capacity of solar power as of 2019 was 5,695MW (up 5,589 MW from the previous year) and is rapidly expanding afterward.

(2) Wind power generation

In April 2020, MOIT announced plans to install a little under 12 GW of wind power by 2025. In October 2020, the Company signed an agreement with the Danish Energy Agency to develop offshore wind power. Overseas companies have also expressed high interest in wind power generation in the country. Wind power is expected to have a high potential, especially on the coastline of the south-central part of the country and inland mountainous areas, and a 7GW wind power project was approved in June2020. As of the end of 2019, the installed capacity of on-land wind power generation was 275MW (up 138 MW from the previous year), and the installed capacity of offshore wind power generation was also 99 MW.

4.4 Energy Mix and Power Mix Goals

The Vietnamese government has not released any formal energy mix targets. Vietnam's primary energy supply will increase to 219.9mtoe in 2040 in the baseline scenario, according to energy outlook and Energy Saving Potential in East Asia 2019, a Long-Term Outlook released by the Economic Research Institute of ASEAN and East Asia[47](ERIA). Coal will grow the fastest, from 35.9% in 2015 to 56.2% in 2040. On the other hand, natural gas is expected to decrease from 13.7% to1 2.1%, and hydro power from 7.8% to 3.1% (Figure 4-5).



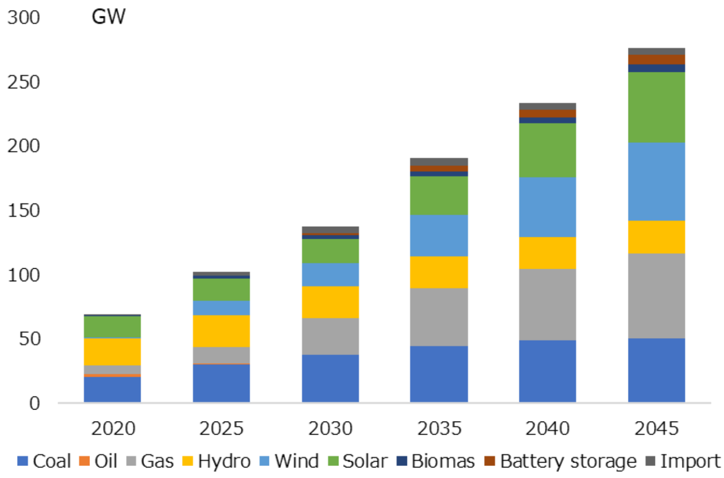
Source: ERIA, Energy Outlook and Energy Saving Potential in East Asia 2019

Figure 4-5 Outlook for Vietnam's Primary Energy Supply

The 8th Power Development Plan (PDP8) of 2021 sets a mix target based on power generation capacity (Figure 4-6). The total installed capacity is targeted at 143GW in 2030 and 282GW in 2045. Compared to PDP7 (7th National Power Development Plan) prepared in 2016, the installation of low-carbon power sources was revised upward. The share of gas-fired power generation as of 2030 was revised rom from 15% to 21%, the share of renewable energy is revised from 21% to 29%, while the share of coal-fired power

[47] Economic Research Institute of ASEAN and East Asia (ERIA), *Energy Outlook and Energy Saving Potential in East Asia 2019.* 22 February 2019. https://www.eria.org/research/energy-outlook-and-energy-saving-potential-in-east-asia-2019/. Accessed on 18 January 2021.

generation was revised downward from 43% to 27%.



（出所）8th Power development plan

Figure 4-6 Outlook for Vietnam's Power Generation Capacity

4.5 Effects of COVID-19

4.5.1 Effects on the supply chain

In Vietnam, there is no significant impact of coronavirus disease 2019 (COVID-19) on the energy and power supply chain. Vietnam's primary energy supply in 2020 saw a 3% year-on-year decline. By energy source, oil demand decreased most by 11.9% year-on-year and natural gas demand decreased by 11.8%, while electricity demand increased by 2.3% year-on-year. The decline in demand for oil and natural gas was due to a decline in economic activities and movement of people. Regarding electric power, judging from the fact that the demand is steadily increasing even under the COVID-19, it is presumed that the electric power supply itself was continued without any problems.

4.5.2 Effects on capital expenditure, operation, and maintenance

Although no significant impact on the existing supply chain has been observed, capital investment plans in the energy sector had some impacts by COVID-19. Investment project in wind power was delayed because of the suspension of production activities by foreign equipment manufacturers of wind power generation appliances.[48] For the same reason, it seems that new investment in the power transmission and distribution sectors under EVN is also delayed from the original plan.[49]

[48] *Viet Nam News* (2020-05-11) "Investors concern about wind power development" https://vietnamnews.vn/economy/716482/investors-concern-about-wind-power-development.html. Accessed on March 29, 2021.

[49] *Vietnam Energy* (2020-05-07) "Many power grid projects are behind schedule due to the impact of

4.5.3 Issues in the recovery from COVID-19 impacts

The electricity demand in Vietnam has not been significantly affected by COVID-19. But the corporate revenues of the National Electric Power Company (EVN) were temporarily deteriorated in the first half of 2020 due to the introduction of measures such as reduction and exemption of electricity tariff for certain groups of consumers, such as lower-income households. However, in the entire year of 2020, the corporate income improved. Revenues increased by 3% and net income increased by 49% to 14.48 trillion dong (US $ 630 million) compared to 2019. Therefore, it can be said that the influence of the COVID-19 on the balance sheet of the electric power business was at manageable level.[50] Regarding the impact on capital investment and operation and maintenance expenses (O&M), financial difficulty was not an issue for EVN, and thus the need for international financial assistance cooperation on the impact of COVID-19 seems limited.

4.6 Proposed projects for international cooperation

Based on the above analysis, the following three objectives will be set to consider future collaboration items with Vietnam.

The first is to reduce the dependence on coal in a realistic manner. As seen in this chapter and the previous chapter, Vietnam's dependence on coal is remarkably high among the three case countries analyzed in this study. Coal is widely used not only in the power generation sector but also in the industrial and the commercial and the residential sectors. In the future, coal will not be used as intensively as today to reduce greenhouse gas emissions, but the rapid phase out of coal-based energy supply infrastructure may cause great loss to the Vietnamese economy. Therefore, as a realistic solution, encouraging the conversion from coal to natural gas, at least during the phase of the energy transition, is a viable and acceptable measure for reducing the current high dependence on coal. One of the pillars of the collaboration between Vietnam and Japan should be to promote the replacement of coal with natural gas.

The second is to provide more detailed sector-specific support for the use of natural gas. In the Vietnamese electricity sector, a power development plan has been periodically prepared, and, as noted in the previous chapter, the planned power generation mix in the plan has a well-balanced power development plan from the view point of preferable energy mix. In the non-power sectors of Vietnam, however, long-term plans have not been prepared with the same preciseness and periodical interval as the power sector..

COVID-19 pandemic" http://nangluongvietnam.vn/news/en/electricity/many-power-grid-projects-are-behind-schedule-due-to-the-impact-of-COVID-19-pandemic.html. Accesssed on March 29, 2021.

[50] Anh Minh, "EVN Posts 49pct Profit Rise," *VN Express*, July 5, 2021. https://e.vnexpress.net/news/business/companies/evn-posts-49-pct-profit-rise-4304586.html. Accessed on August 19, 2021.

Therefore, there is a room for collaboration between Vietnam and Japan in jointly developing a long-term plan for energy supply policies and infrastructure development in the non-electric power sectors.

The third is to build a competitive and highly transparent energy industry structure. As mentioned above, in Vietnam, system reforms have already been carried out in the electricity market, which has effectively functioned in securing a stable supply of electricity and securing investment. On the other hand, the system reform of the gas market relatively lags behind, and the reform equivalent to the electric power market may need to be considered. Specifically, it is desirable to set clear rules regarding the industrial structure in the gas market, the division of responsibilities of the government, state-owned enterprises, and private companies, and the method of determining the electricity and gas prices for the final consumers. Such system reforms will also be important in securing investment in future gas supply infrastructure development.

Based on these three objectives, the study proposes i) LNG value chain study, ii) technological cooperation for LNG adoption and utilization, and iii) gasification road map in the non-power sectors.

4.6.1 LNG Value chain study

(1) Background

Vietnam's GDP growth rate in 2020 was 2.9%, somewhat lower than the historical level due to the large impact of the spread of COVID-19. However, given the negative growth in Indonesia (-2.1%), Singapore (-5.4%), Malaysia (-5.6%) and Thailand (-6.1%) in surrounding countries, the Vietnamese economy performed very well. According to the Asian Development Outlook released by the Asian Development Bank in July 2021, Vietnam's GDP growth rate in 2021 is expected to be 5.8%. [51]

Vietnam's domestic electricity demand is expanding rapidly along with economic growth. Vietnam used to utilize hydroelectric power as its main power source, but in recent years coal-fired power has expanded its market share as an inexpensive power source due to the decrease in hydro power because of low water level. The share of coal-fired power in the power mix was 20.1% in 2008, but expanded sharply to 47.4% in 2018. Going forward, because climate change action and reduction of carbon emissions becomes recognized as an acute issue, increasing reliance on coal-fired power will not be likely. According to the draft of the 8th Power Development Plan (PDP8) announced by the Ministry of Industry and Trade (MOIT) in 2021, the share of coal-fired power will decrease in the future, while the shares of gas-fired and renewable power will grow.

[51] Asian Development Outlook July 2021
https://www.adb.org/sites/default/files/publication/715491/ado-supplement-july-2021.pdf

Vietnam produces natural gas domestically, and about 90% of its produced gas is used as a fuel for power generation. In the future, however, as additional gas-fired power generation is installed as assumed in PDP8, it will be difficult to cover the additional fuel from domestic production, and thus it will be necessary to import it as LNG from overseas. For this reason, LNG receiving terminals by companies such as PV Gas are currently being planned and constructed, and the country's first LNG cargo will be scheduled to arrive as early as 2022.

While interests in LNG adoption are increasing in Vietnam, since there is only limited expertise about LNG acceptance and utilization in Vietnam at this stage, it is necessary to develop a new business model for accepting and utilizing LNG in a smooth and effective manner for Vietnam. LNG requires a huge upfront investment and requires different risk management than oil and coal. Therefore, as an international cooperation project with Vietnam, it is conceivable to investigate the business model for optimal LNG acceptance based on Vietnam's political economy and social environment.

(2) Objective

The objective of this cooperation project is to ensure stable and economic LNG supply to achieve sustained economic growth with competitive and low-carbon energy supply.

(3) Expected outcomes

This project aims to bring the following three outcomes.

a) Outcome-1: Understanding of the dynamics of international LNG market

In evaluating the optimal business model of LNG, external factors that may have an impact the Vietnam's LNG procurement needs to be well understood. Specific examples of such factors include transaction forms in the international LNG market, contract trends, technology development trends, future supply and demand outlook, and the introduction of decarbonization technology.

b) Outcome-2: Provision of plausible LNG business models

The second expected outcome is designation of optimal business model. By reviewing the relevant value chain cases related to LNG import and utilization in other major LNG importing countries, plausible options of LNG business models that can be considered in Vietnam to government and state-owned enterprises such as MOIT and PV Gas will be provided. And then, the most preferred outcome is identified based on various factors including the consistency of the political, economic and energy situation in Vietnam and the existing legal system. In order to promote the development of the LNG industry in Vietnam, domestic political, economic, and energy environment, operational and commercial risks, and technical issues related to LNG will be examined in the designation process.

c) Outcome-3 Policies for natural gas and LNG industry and market

The third expected outcome is an analysis of domestic natural gas and LNG industrial policies. As the use of natural gas and LNG expands in the future, demarcation of the business scope of existing state-owned enterprises and private players need to be clarified. An independent regulator may also better to be established, and legal and regulatory systems related to the import and utilization of LNG have to be developed and refined. Based on Vietnam's unique conditions as well as the learning from other LNG importing countries' experience, required policy menu for sound development of LNG utilization will be provided in this project.

(4) Required actions for expected outcomes

a) Actions for Outcome-1 (Understanding of LNG market dynamics)

As the actions for the expected outcome-1, the study will analyze the latest information on the market's supply and demand, technological development, and contract trends in the international LNG market, and exchange opinions with stakeholders such as the Vietnamese government, state-owned oil companies, and state-owned electric power companies. International LNG market is highly dynamic and the meeting with stakeholders will be held multiple times during the survey period.

b) Actions for Outcome-2 (designation of LNG business models)

In order to present plausible business models, evaluation of various business models of other countries that have already started to use LNG and have will be an important to step to start. Vietnam is unique among many LNG importing countries in the sense that it has a certain amount of natural gas production in the country, but there is no gas pipeline connection with neighboring countries, and the domestic gas pipeline network exists only in the south surrounding the domestic natural gas fields. For this reason, there is no perfect example that Vietnam can refer to, and the study will need to extract implications from various preceding LNG receiving cases abroad. Comprehensive review of such foreign cases, particularly those in Europe and Asia because of its accessibility of information, will be conducted in the study. The research will be made basically through literature survey, but interviews to industrial players who actively develop LNG markets in emerging countries as well as research institute or consultancies that analyzes the natural / LNG market structures globally.

In order to designate the most preferred business model in Vietnam, collected plausible models extracted from the previous action will be classified into several groups. As one possible way of classification is whether the model is "integrated" or "disintegrate" depending on the degree of integration of each value chain. In the integrated model, a single operator develops and operates the entire value chain, while in the disintegrated model each value chain is developed and operated by different entities. Advantages and disadvantage of each mode is summarized in the Table 4-4. What is important for the government to develop a particular business model is to specify which risks in the entire LNG value chains is taken by whom. In other words, determining what are the government's responsibility and what are the industry's responsibility is important, and differed business models may affect the way of government's degree of involvement in the LNG business. In addition, it is also important to consider the efficiency of administration as integrated model will help to enhance the efficiency of administration.

Table 4-4 Pros and cons of different business models

	Integrated model (Gas & power)	Disintegrated model
Pros	• Simple administration (single project company) • Low "project on project" risk (coordination among value chain) • Higher interests from foreign investors and lenders	• Selecting the best (cost competitiveness and operational expertise) contractors for each value chain. • More transparent cost structure
Cons	• Cost structure of each value chain may not be as clear as disintegrated model. • Less consistent with the Vietnamese regulatory requirement (procurement authority, share of foreign ownership, etc.)	• Each value chain has to be developed simultaneously. • Additional coordinating burden among project companies and contractors • Complicated administration by government for each value chains' activities • Fallacy of composition, or partial optimization may not always result in total optimization

Source: The Institute of Energy Economics, Japan

In examining the business model, it is necessary to coordinate with stakeholders to realize a designated business model smoothly. In coping with this task, a working group such as the Business Model Review Committee will be set up in this study and sharing of study findings and discussions for a preferable business model for Vietnam will be made.

c) Actions for outcome-3 (natural gas and LNG industrial policy)

In Vietnam, Petro Vietnam is in charge of natural gas development, and PV Gas, a subsidiary of Petro Vietnam, is in charge of gas distribution and marketing business.

State-owned enterprises play a major role in the natural gas business in Vietnam. However, inviting private investments and the participation of private businesses to the domestic natural gas industry may be needed to further develop natural gas market in Vietnam. Developing a business model in Vietnam is thus important from industrial policy perspective. Starting from the current status of the Vietnam's natural gas market and industry, this study will analyze what kind of market system is desirable and feasible, and what should be the division of roles between state-owned enterprises and private enterprises. Based on that analysis, the study will also present specific measures such as the third-party access system to LNG receiving terminals and the formation of a wholesale natural gas market.

4.6.2 Technological cooperation project for LNG utilization

(1) Background

As mentioned above, interest in LNG is increasing as production has stagnated after peaking around 2015. Since domestically produced natural gas has been used in Vietnam so far, knowledge on the handling of natural gas has been accumulated in Vietnam. However, since Vietnam has no experience in importing LNG from overseas, it is necessary to acquire specialized skills and knowledge, including the physical characteristics of LNG and international commercial transactions. Regarding the status of LNG-related regulations and administrative procedures, although there are some regulations and standards have already been established in the past, there are new development under the current market conditions, such as the emergence of FSRU as a cost competitive way of LNG receiving. Thus, the previously provided regulations may need to be updated to reflect the latest development of LNG business

While such knowledge sharing about the acceptance of LNG can be broadly divided into technical and regulatory sharing segment and commercial and operational segment. Since the former segment (technical and regulatory) has already been started in a separate truck, this study will focus on the commercial and operational sides. In particular, in this cooperation project, comprehensive technical cooperation on the acceptance and utilization of LNG will be provided in order to realize a seamless acceptance and utilization of LNG. The target of technical cooperation is the staff of MOIT and Petro Vietnam.

(2) Objective

The main purpose of this cooperation project is to have the Vietnamese government or state-owned oil companies trained comprehensive knowledge on the receiving and utilization of LNG. Acquiring LNG-related knowledge through the capacity building of these government's and state-owned oil companies' officials will lead to seamless and efficient receiving and utilization of LNG.

(3) Expected outcomes

a) Outcome-1: Enhancing the capability to plan and operate integrated natural gas/LNG network operations

The first expected outcomes of this cooperation project is to equip the officials of the Vietnamese government (MOIT) and the state-owned oil company (Petro Vietnam) with comprehensive knowledge about LNG. These officials have sufficient knowledge and expertise in handling natural gas itself, and regulations on safety, environment, and hygiene have already been established for natural gas supplied by pipeline. Yet, as noted repeatedly, there is no sufficient knowledge about the handling of ultra-low temperature substances such as LNG at -162 ° C in Vietnam. Learning appropriate operations in safety, environment, and health-related practices related to LNG receiving, regasification, and sending the regasified gas will ensure safety from the initial stage.

b) Outcome-2: Provision of draft legal and regulatory framework for third-party access

The next expected outcome is the efficient use of LNG receiving terminals using the third-party access system. If many LNG receiving terminal construction projects are realized in the future, third-party access to LNG receiving terminals may become a policy issue from the perspective of expanding the use of natural gas in Vietnam. While third-party access is expected to have the effect of encouraging new entrants in the natural gas supply business, it may discourage investment in the receiving terminal itself, depending on how the system is operated. In this cooperation project, while referring to the cases of third-party access systems in other countries, while maintaining consistency with the current laws and regulations regarding domestic gas, we will present a draft of a third-party access system that can be considered in Vietnam.

c) Outcome-3: Provision of marginal business plan that utilizes the LNG receiving terminal

The third expected outcome is the presentation of peripheral projects that utilize LNG receiving terminals. In Vietnam, the legal system and regulations for accepting LNG are currently in the process of being developed, and the construction of infrastructure is also underway at the same time. The acceptance of these LNG is planned to be promoted mainly for natural gas-fired power generation applications, which has been in line with the purpose of utilizing natural gas as domestic resources. Yet, the cold energy that LNG has is not planned to be utilized. In this cooperation project, by providing a draft business model that is used in Japan using cold energy, it will be possible to further increase the added value at the LNG receiving terminal.

(4) Required activities for expected outcomes

a) Actions for outcome-1 (the capability to plan and operate integrated natural gas/LNG network operations)

Activities to achieve the first expected outcome will focus on providing training programs to the targeted group of officers at the Vietnamese government and state-owned enterprises. The following items can be considered as specific contents of the training program:

- Law and regulatory frameworks for LNG receiving business including safety, environment, health issues
- LNG / natural gas applications for power generation, industrial use, consumer use, transportation
- LNG receiving / utilization infrastructure finance
- Procurement contract with LNG seller
- Training programs, manuals, and exercises for operation at LNG receiving terminals and related equipment
- Construction contract for LNG regasification facility, operation contract with terminal operator

b) Actions for outcome-2 (draft legal system and regulatory framework for introduction of third-party access to gas-related facilities)

Next, as an activity required for the second expected outcome, it is necessary to set up a similar format of training program as the activity for the first outcome. The purpose of this training is to have the targeted government and state-owned companies' official to obtain knowledge about the detailed regulatory system and contract details for using third-party access system, and other natural gas market systems related to infrastructure use. The following items can be considered as specific contents of the training program:

- Business law that governs the use of LNG receiving terminals by third parties (licenses for businesses, government's responsibilities on the terminal operations, responsibilities fulfilled by industry, etc.)
- A regulatory agency / department that has jurisdiction over the use of third-party access system
- Gas contract manufacturing agreement (cooperation between LNG receiving terminal and gas retail business)
- Other relevant issues such as fees for third-parry use, and security precautions when a third-party uses the terminal, surplus regasification capacity (method of

determining equipment surplus capacity, disclosure of surplus capacity information), usage fee (charge calculation method, disclosure of fee information), information required for usage application, etc.

c) Activities required for outcome-3 (providing a business model utilizing LNG receiving terminals

LNG terminal provides a potential marginal business that utilizes its cold energy. Normally, most of the cold energy of LNG is conducted to heating fluids such as seawater and air, and when re-gasifying 1 ton of LNG, energy of up to about 48 MJ (about 20,000 kcal) is released. This cold energy is often under-utilized. There are two types of cold heat utilization methods: direct use, which uses the cold heat of LNG as it is, and indirect use, which involves the generation of liquid nitrogen. Specific examples include cold power generation, freezing warehouse, air liquefaction separation, and dry ice production for direct use, and low-temperature crushing of food and metal scrap, and production of frozen food for indirect use. The following items can be considered as specific contents of the training program:

- Law and regulations related to businesses using LNG cold heat (Business Law, related regulations, safety / environment / hygiene)
- Capacity improvement program for cold heat management (cold heat sales contract, cold heat related equipment)
- Training and practical training with the cooperation of LNG cold heat utilization companies

In addition, this project will assist to prepare for draft operation manuals and draft training programs for staff engaged in the acceptance and utilization of LNG.

4.6.3 Gasification of non-power sectors

(1) Background

Vietnam is a natural gas producing country, and about 90% of its production is supplied to existing gas-fired power plants and consumed for power generation. In order to meet the expansion of energy demand accompanying the growth of its economy, expansion of natural gas use gains increasing attentions. Growing interest about climate change also adds another motivation to utilize natural gas not only in the power sector but also in non-power sectors, such as the industrial sector and the commercial sector. In these sectors, large amount of carbon intensive energy sources such as coal and oil products are used, and switching them with natural gas will bring significant carbon emissions reduction effects.

In addition to the relatively low greenhouse gas emissions, natural gas also has an advantage over other fuels in terms of safety. While petroleum products can cause soil and water pollution when leaked, natural gas is lighter than air and diffuses upward without staying on the ground like liquid fuel, preventing or reducing unexpected accidents. In addition, since the lower explosion limit of natural gas is higher than other fuels, and the ignition point temperature is also high, natural gas contributes to the improvement of safety in each sector of energy use.

In order to continuously import stable and competitive LNG, not only the demand in the power sector but also the demand in the non- power sectors needs to be created to secure the bargaining power against suppliers. This cooperation project will provide various inputs such as policy support and development plans to expand the use of natural gas in non-power sectors.

(2) Objectives

The main purpose of this cooperation project is to ensure a stable supply of low-carbon energy in the industrial, transportation and consumer sectors that support Vietnam's economic growth.

(3) Expected outcomes

a) Outcome-1: Market development plan for the industrial sector

In order to promote the use of natural gas in non-power sectors. The industrial sector is the most important sector because its demand potential is large and can efficiently gain large demand with a relatively small amount of supply infrastructures. Demand development in the industrial sector will include policy support for infrastructure development and switching to natural gas from other furls. Since the industrial sector consumes more energy than other sectors, it is expected that the promotion of conversion to natural gas will greatly contribute to the reduction of GHG emissions in Vietnam.

b) Outcome-2: Market development plan for the transportation sector

The second outcome is a demand development plan in the transportation sector. In the transportation sector, the land transportation, shipping and aviation sectors are expected to switch from the current petroleum-based fuels such as gasoline, light oil and fuel oil to natural gas. Among them, the use of liquefied natural gas (LNG) or compressed natural gas (CNG) vehicles in the land transportation sector can be a potential option for the long-distance transportation. In these days, LNG-fueled vessels also gain industrial attention as the regulations of carbon emission from vessels are being discussed at international organization such as International Maritime Organization. By switching from existing petroleum-based fuels to natural gas fuels, it is also possible to reduce hazardous materials such as sulfur oxides and nitrogen oxides besides CO2.

c) Outcome-3: Market development plan for the commercial sector

The third outcome is demand development plan in the consumer sector. While the consumer sector includes the residential sector and the commercial sector, this study project will feature the demand potential in the commercial sector and considers various policy menu to encourage gasification in the commercial sector including energy efficiency standard or subsidy system for fuel switching.

(4) Required actions for expected outcomes

a) Actions for outcome-1 (market development in the industrial sector)

In the industrial sector of Vietnam, coal, oil, and biomass account for 67% of the energy supply composition, and thus there is a large potential to switch them to natural gas. In such fuel switching, boilers and industrial furnaces are expensive equipment, and the cost of capital investment for the switching is sometimes prohibitively high. Therefore, it is necessary for the national and local governments to consider assisting part of such capital investments by subsidies or other incentive mechanisms. Furthermore, it may also be a policy option to set a higher efficiency standard to encourage fuel switching from other fossil fuels to natural gas to meet the standard.

In addition to the above policy measures, logistical infrastructure development may also be developed to supply industrial users in remote locations. Possible gas supply options are pipeline supply and satellite supply using LNG trucks. Since the initial investment for new pipeline construction is larger than that for satellite supply infrastructure formation, economic efficiency is calculated from the relationship between demand and transportation distance, and appropriate supply methods and infrastructure equipment will be chosen. For the purpose of infrastructure development that enables efficient use, including the natural gas use from the stage of design when a new industrial zone is planned.

b) Actions for outcome-2 (market development in the industrial sector)

In the transportation sector, the number of automobiles has increased significantly in Vietnam due to recent economic development, and air pollution may become a serious problem in the future. In particular, Ho Chi Minh City, Vietnam's largest city, is regarded as one of the most suffering cities from air pollution in the world, and as a mean to address the problem, the trial introduction of CNG buses was started in 2011[52]. In 2019,

[52] Vietnam News (2019/07/24) https://vietnamnews.vn/society/523062/cng-buses-in-hcm-city-could-lose-fuel-supply.html

out of about 2,457 buses operating in Ho Chi Minh City, 20% of 428 buses was replaced with CNG buses. Also in the capital city of Hanoi, CNG buses were introduced on three routes from July 2018, and the effects have been confirmed in terms of lowering running costs and improving the air environment compared to existing diesel fuel. Since the application of CNG vehicles is still limited to some large cities and small number of routes, how to efficiently expand the application of CNG vehicles to other cities and routes needs to be examined in this cooperation project.

In addition to the above-mentioned natural gas vehicles, the development of hydrogen infrastructure may worth considering in the long run. Development of a hydrogen pipeline network that takes into account the conversion from the existing natural gas pipeline may be effective way to develop hydrogen supply network. Since the pipeline network can be utilized for decades once it is built, an optimal supply infrastructure network needs to be designed and implemented for hydrogen utilization.

c) Actions for outcome-3 (market development in the consumer's sector)

In the commercial sector of Vietnam as of 2018, the energy supply composition was oil (46.7%), electricity (29.5%) and coal (23.8%), and no natural gas was used . This means that a large potential of fuel switching remains, and it is possible to develop demand for such uses as air conditioning, heat pump, cooking for business (including restaurant) and gas cogeneration. In order to realize these potential gas demand, adoption of energy conservation regulations for new and existing commercial buildings may be an option. By setting rigorous energy-saving standards for commercial buildings, switching to natural gas will be encouraged. In addition, establishing a new subsidy system for the above measures, as well as regulation to use oil and coal may be another policy option. In terms of infrastructure development, when local governments and private businesses develop urban planning, natural gas infrastructure may be integrated into the plan.

4.7 Roadmap toward Net-zero

Finally, Figure 4-7 shows a roadmap for reducing greenhouse gas emissions to net-zero in Vietnam in the future. This roadmap was developed by a "back cast" approach from the current energy demand in Vietnam, assuming that it will reach net zero by 2060.[53]

The path to net zero is roughly composed of i) promotion of electrification by renewable energy, ii) introduction of other non-fossil fuel energy in the demand sectors that cannot be electrified, and iii) utilization of offset arrangements or negative emission technology

[53] It should be noted that the cost and technical feasibility required to realize are not rigorously verified.

for the remaining use of fossil fuels that cannot be completely eliminated. In the electrification process, it is desirable to convert coal-fired power generation plans to natural gas-fired power generation or renewable energy power generation, except for those whose investment decision has been done in the 8th Electric Power Development Plan. On top of that, as of 2030, new coal-fired power generation plan should be fully abolished, and co-firing of fuel ammonia should be started as a decarbonization measure for existing coal-fired power generation units. Initially, the co-firing will start with 10% share, and by 2050, the share will be raised to about 60% for all coal-fired power plants. In Vietnam, the share of electricity in the final energy consumption is relatively high at present, but it will be gradually increased to 40% in 2040 and 50% in 2050, and further increase toward 2060.

As for the development of new power generation sources, the introduction of renewable energy is, of course, the highest priority. Currently, Vietnam has a share of nearly 35% of renewable power sources in terms of electricity generated, but most of them are hydroelectric power generation, and the relative share will decrease as domestic electricity demand increases in the future. Therefore, the main renewable energies in the future will be wind power and solar power, and the share of renewable power sources including hydropower will be raised to 50% in 2040 and about 70% in 2060. Considering Vietnam's geographical factors and industrial structure, it is difficult to make the power source completely renewable energy, and it is thought that about 30% will be thermal power generation with hydrogen (ammonia) and CCUS.

Along with the introduction of renewable power sources, decarbonization of thermal power generation will be promoted at the same time. Regarding coal-fired power plants, all coal-fired power plants will be shut down in 2060. Gas-fired power plants will continue to be used from the perspective of resilience such as backing up renewable energy and securing inertial force in the power source composition. As a decarbonization measure, 20% of gas-fired power plants will equip CCUS facility as of 2050, and all of the gas-fired units will have CCUS as of 2060.

Regarding the non-electricity sector, in the industrial sector, as a short-term measure, decarbonization plan will be developed. The plan will include the stringent energy efficiency standards fuel switching from coal and oil that currently take a half share of the total industrial energy demand. Regarding energy efficiency standards in the industrial sector, it will be regularly reviewed and revised to achieve more energy saving. In addition, by 2040, all industrial facilities will be required to be able to be ready for net zero with specific plan. Furthermore, adoption of non-fossil fuels such as renewable electricity or hydrogen will be rigorously examined and used, and CCUS facilities that recovers all the emitted CO2 and / or negative emission technologies will be installed where it is possible. By 2060, at least 80% of industrial facilities will be virtually zero.

In the transportation sector, electrification will be a primary measure for decarbonization. For transportation means in which electrification is difficult, such as long-distance shipping and aviation, alternatives fuels such as hydrogen or synthetic fuels will be introduced. What should be done first is promoting strict fuel efficiency standards. Regulations may be set so as to incentivize consumers to choose electric vehicles or other zero-emission vehicles such as fuel-cell vehicles or hydrogen vehicles. The share of next-generation vehicles (electric vehicles, fuel cell vehicles, hydrogen engine vehicles, etc.) over the total new sales will be gradually increased, and as of 2050 all newly sold vehicles will be zero-emission vehicles. In addition, transportation means such as aircraft and ships that are difficult to electrify will be converted to hydrogen from around 2040, and by 2060, all means of transportation will be driven by electricity or hydrogen (or other zero-emission fuel).

In the residential and the commercial sector, similar steps will be taken from the energy efficiency improvement to electrification. For the residential sector, energy efficiency standard for the residential building will be introduced and construction of energy-efficient homes will be promoted. In addition, in rural areas, commercial energy supply and decarbonization will be realized simultaneously by promoting decentralized power sources such as solar power and wind power from traditional biomass. From 2030 onward, some hydrogen application may be introduced, and by 2060 net-zero emission will be achieved in at least 80% of the residential sector.

In the commercial sector, by applying energy-efficiency standards for new construction, and electrification will be promoted. Infrastructure of shopping malls will be developed so as to be easily decarbonized. From 2040 onward, new buildings will be required to be constructed on the premise of electrification, and as of 2060, the sector will be as close to zero as possible.

Finally, regarding negative emission technology, investigation of the CO2 storage potential in Vietnam will be undertaken. Since there are many depleted gas fields in the country, evaluation of such former gas reservoirs will the first step. CCS-EOR, which uses CO2 for enhanced oil recovery, will be applied to oil fields where it is possible as an economic way to pursue CCS. Also, the evaluation CCU technologies such as methanol production or mineralization will be started in around 2030, and as of 2050, a study on the possibility of introducing Direct Air Capture and Storage (DACS) or Bio Energy Carbon Capture and Storage (BECCS) technology, which combines direct air capture or domestic biofuel use with CCS, will be started in 2060 to offset the residual CO2 emissions.

Year	2022	2030	2040	2050	2060
Power sector Elec gen in GWh	Switch planned but unconfirmed coal units to gas	No new coal power plants is permitted Introduce fuel NH3 to the existing coal units	All new power generation units are net-zero ready Share of renewable power at 50% 40% of total final consumption is electrified.	20% of LNG power plants are equipped with CCUS Share of renewable power at 60% 60% NH3 mixed combustion at the existing coal units 50% of total final consumption is electrified.	Phase out of coal power plants Share of renewable power at 80% All LNG power plants are equipped with CCUS
Non-power sector Industry in ktoe	Providing long-term net-zero emission plan Start to switch coal/oil to gas , electricity, or renewable Setting efficiency standards	Mandate to adopt all available efficiency technologies Monitoring and tightening the efficiency standards	Obligation all new industrial sites to be net-zero ready	30% of industrial sites are net-zero (electrified or with CCUS)	80% industrial sites are net-zero (electrified or with CCUS)
Transportation in ktoe	Efficiency standard incentive policy to encourage EV adoption	25% passenger car sale is Next-gen vehicle* All vehicles for public service is Next-gen vehicle*	75% of passenger car sale is Next-gen vehicle* Half of HDV sale is Next-gen vehicle* Start conversion to H2 in air and maritime transportation	All new sale is Next-gen vehicle*	All vehicles on road are Next-gen vehicles* No fossil fuels in air and marine transportation
Residential in ktoe	Adoption of strict efficiency standard for new building Accelerate conversion from biomass to electricity	Promotion of distributed power supply based on solar/wind	All new buildings are net-zero ready	50% of existing buildings are retrofitted to zero-carbon ready	80% of buildings are electrified with renewable power supply
Commercial in ktoe	New building is recommended to be fully electrified. Adoption of strict efficiency standard for new building	Reduce 75% of oil consumption in the sector	All new buildings are net-zero ready Monitoring and tightening the efficiency standards		80% of buildings are electrified with renewable power supply
Negative emissions	Study for CCS potential in Vietnam	Pilot project for CCU (C1 chemical, mineralization, etc.) Apply CCS-EOR to the existing oil producing fields	First BECCS or DACS pilot projects		BECS and DACS operation commercialized

Source: The Institute of energy Economics, Japan

Figure 4-7 Roadmap toward net-zero in Vietnam

5. Issue Analysis and Cooperation Projects with Cambodia

5.1 Energy Supply and Demand Overview

5.1.1 Primary energy supply

(1) Total supply

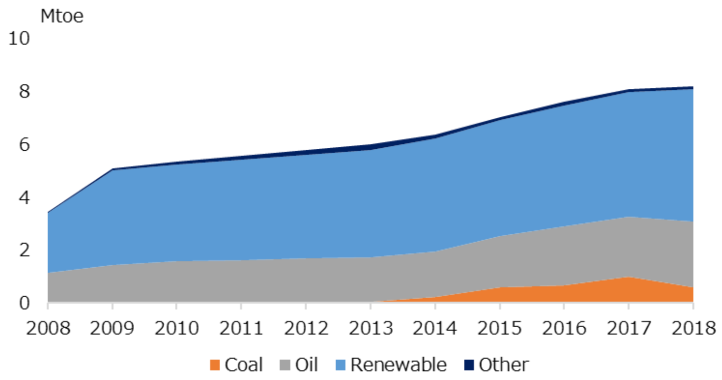
Primary energy supply in Cambodia as of 2018 was 8 million tons oil equivalent (toe). Although the size of demand is not large, its annual growth rate since 2008 is very high at 9%. The share of renewable energy is the largest at 61%, mostly traditional biomass such as wood and charcoal, followed by oil at 30%. There is no use of natural gas in the period 2008-2018 as shown in Table 5-1 and Figure 5-1.

Table 5-1 Primary Energy Supply in Cambodia

Unit: ktoe

	Coal	Oil	Gas	Renewable	Other	Total
2008	0	1,142	0	2,279	24	3,445
2009	8	1,412	0	3,604	62	5,086
2010	13	1,580	0	3,622	117	5,332
2011	15	1,592	0	3,795	141	5,543
2012	16	1,662	0	3,933	180	5,791
2013	52	1,655	0	4,078	195	5,980
2014	242	1,708	0	4,260	156	6,366
2015	587	1,928	0	4,391	131	7,037
2016	679	2,202	0	4,572	136	7,589
2017	1,009	2,252	0	4,701	127	8,089
2018	589	2,473	0	5,008	134	8,204
2018 share	7%	30%	0%	61%	2%	100%

Source : International Energy Agency (IEA), *World Energy Balances 2020 edition*



Source : IEA, *World Energy Balances 2020 edition*

Figure 5-1 Primary Energy Supply in Cambodia

(2) Oil

Cambodia did not have domestic oil production. Kris Energy of Singapore had a plan to develop offshore Block A , but after the company found that it could secure sufficient volume of production, it ceased the development.[54]

Cambodia has no refinery and imports all petroleum products. Cambodia imported 2.4 million toe of petroleum products in 2018. Main imported petroleum products are diesel oil and gasoline, and the import sources are Singapore, Thailand, and Vietnam. Since Cambodia has a liberalized oil market and oil products are sold at a higher price compared with neighboring countries, it is said that there are smuggled products that do not show up in the statistics.

As for future oil-related infrastructure investments, an oil refinery is being constructed between southern part of Kampot province and Preah Sihanouk province. The capacity of this refinery is 100,000 B/D. The project is conducted by a joint venture between Cambodian Petrochemical Company (CPC) and Northeast Refining and Chemical Engineering under China National Petroleum Corporation (CNPC). The investment cost is US$ 620 million. Construction began in May 2017 and was scheduled to be completed in early 2019. However, due to weather conditions and changes in equipment specifications, the project is currently scheduled for completion in 2022[55]. The refinery is designed to refine imported crude oil and is not compatible with light crude oil from oil field. Crude oil from Apsara field will be exported.

(3) Coal

In 2018, Cambodia's coal production was 29 ktoe. The production scale is not enough to distribute coal throughout the country. Most of the coal consumed in Cambodia is imported from abroad.

5.1.2 Power Mix

Power generation of Cambodia in 2018 was 8,172 GWh, which increased by 5.5 times from 2008. Oil used to primary power generation fuel in Cambodia, but the first coal-fired power plants began its operation in 2009, and the generation from renewable energy (hydropower) increased in 2010s. As of 2018, the share of hydropower generation was 59%, coal was 37%, and the share of oil-fired power was reduced to 4% as shown in Tables 5-2 and 5-3.

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[54]Kevin Foster, “Singapore’s Kris collapses as Cambodia oil falls short,” *Argus Media*. 7 June 2021. https://www.argusmedia.com/en/news/2222136-singapores-kris-collapses-as-cambodia-oil-falls-short. Accessed on 27 November 2021.

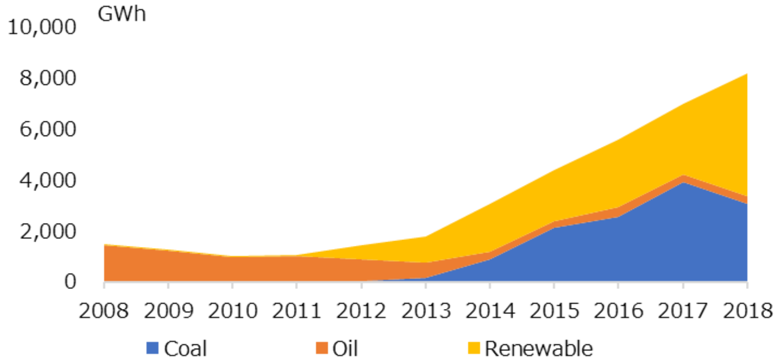
[55] Jason Boken, “Oil refinery project on hold again,” *Khmer Times*. 10 December 2020. https://www.khmertimeskh.com/50791450/oil-refinery-project-on-hold-again/. Accessed on 14 January 2021

Table 5-2 Composition of Power Generation in Cambodia

Unit: GWh

	Coal	Oil	Gas	Renewable	Total
2008	-	1,417	0	65	1,482
2009	28	1,170	0	68	1,266
2010	31	914	0	55	1,000
2011	34	951	0	75	1,060
2012	37	857	0	540	1,434
2013	169	579	0	1,030	1,778
2014	863	327	0	1,872	3,062
2015	2,128	228	0	2,041	4,397
2016	2,551	379	0	2,664	5,594
2017	3,911	297	0	2,790	6,998
2018	3,057	299	0	4,816	8,172
2018 share	37%	4%	0%	59%	100%

Source : IEA, *World Energy Balances 2020 edition*



Source : IEA, *World Energy Balances 2020 edition*

Figure 5-2 Trends in Power Generation in Cambodia

5.1.3 Initiatives for Low Carbon

In Cambodia, the Ministry of the Environment, Royal University of Agricultural, Cambodia, Kyoto University in Japan, Institute for Global Environmental Strategies, and National Institute for Environmental Studies jointly formulated "Low Carbon Development Strategy for Cambodia toward 2050". It is aimed at Cambodia's sustainable strategy of reducing GHG emissions, economic growth and environment. Joint research has identified the following four policies.

- Policy 1: Green Environment
- Policy 2: Harmonization of Green Economy, Society and Culture
- Policy 3: Blue Economy
- Policy 4: Eco-Village

Policy 1, "Green Environment" consists of three strategies: a forest management strategy for forest conservation, a waste management strategy for reducing waste, and an agricultural management strategy for improving eco-agriculture and harvest rates. Policy 2, "Harmonization of Green Economy, Society and Culture" consists of three strategies: a traffic management strategy for reducing transport energy, an energy management strategy for encouraging renewable energy and energy conservation, and a travel management strategy for reducing energy and waste on travel. Policy 3, "Blue Economy" has a marine and sustainable coastal management strategy for managing the oceans. Policy 4, "Eco-Village" consists of two strategies: a low-carbon infrastructure development strategy for improving roads and a building design and construction strategy for energy-saving buildings.

5.2 Ministries and agencies for Energy Policy

The Ministry of Mining and Energy (MME) is in charge of formulating energy policies, power development plan, power technology, safety, and environmental standards. Main departments are General Department of Energy and General Department of Petroleum. General Department of Energy is responsible for the plan and data collection of energy and power sectors and consists of Energy Development Department, New and Renewable Energy Department, Nuclear Energy Technology Department, Thermal Power Generation Department, Technology and Energy Business Policy Department, and Hydropower Department. Energy Development Department is responsible for formulating energy strategies and implementing policies, while Energy Planning Office in the Department is responsible for energy policy formulation and planning. As a separate organization from the ministry, Electricity Authority of Cambodia (EAC) is responsible for the business licenses, management, guidance, and coordination of electric power sector operators.

General Department of Petroleum, on the other hand, is responsible for oil industry in Cambodia, including overseeing Cambodian National Petroleum Authority (CNPA), a state-owned oil company in Cambodia.

5.3 Energy industry

5.3.1 Power

Electricite du Cambodge (EDC) is the only entity in Cambodia that has an integrated license for power generation, transmission and distribution. Most power generation businesses are carried out by Independent Power Producers (IPP). IPPs often take the form of joint ventures between Cambodian and foreign companies such as China Huadian Corporation, Power Construction Corporation of China, China National Heavy Machinery Corporation, Leader Energy (Malaysia), and Marubeni.

5.3.2 Oil

Oil supply is mainly provided by the state-owned CNPA, which was established in 1998. The upstream sector in Cambodia (exploration, development, and production) is open for direct investment by foreign companies. In 2004, Chevron and Mitsui Oil Exploration discovered the oil field. Since then, Chevron's state was taken over by Kris Energy, but as noted above, Kris Energy liquidated the development business.

In the downstream sector (refining, distribution, and marketing), in 2017, Cambodia Petrochemical Company and a subsidiary of China National Petroleum Corporation (CNPC) began construction of Cambodia's first refinery. However, construction has been suspended due to financial difficulties in December 2020[56].

The import and sale of petroleum products in Cambodia has been liberalized, and foreign companies such as Chevron, Total, and PTT (Thailand) have entered the market and are selling their products at gas stations.

5.3.3 Gas

As of November 2021, Cambodia does not use natural gas, but Cambodian Natural Gas Corp was established in 2015 for a future gas industry. The Company is exclusively granted licenses from the government for its natural gas, including LNG imports, the construction of LNG receiving terminal, the operation of domestic natural gas pipelines, the supply of city gas, and the setting of domestic gas-related standards[57].

5.4 Energy Mix and Power Mix Goals

According to the Cambodia Basic Energy Plan, prepared by Ministry of Minerals and Energy in March 2019, Cambodia's primary energy supply will increase to 12.67 million toe in 2030 in case of reference scenario (Business as usual: BAU), but in case of alternative policy scenarios to strengthen climate change countermeasures (Alternative policy Scenario: APS), primary energy supply will remain at 10.46 million toe in 2030[58]. Although primary energy supply composition is mainly biomass, BAU scenario shows a significant increase in oil and coal demand. As a result, the share of oil and coal in BAU scenario will reach 60% by 2030. In this plan, natural gas is considered to be important as well as hydro and coal from the viewpoint of ensuring diversity in energy sources, but in both scenarios, natural gas demand is not appeared in 2030 as shown in Figure 5-3.

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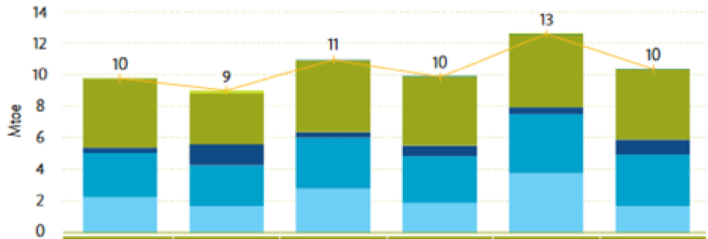
[56] https://www.nna.jp/news/show/2128950 Accessed on 9 January 2021.

[57] Cambodian Natural Gas Corp, "CNGC Profile." http://www.cngc-kh.com/About_Us/CNGC_Profile/. Accessed on 9 January 2021.

[58] Ministry of Mines and Energy, *Cambodia Basic Energy Plan*. March 2019. https://www.eria.org/uploads/media/CAMBODIA_BEP_Fullreport_1.pdf. Accessed on 9 January 2021.



	2020		2025		2030		2030年シェア	
	BAU	APS	BAU	APS	BAU	APS	BAU	APS
Electricty	0,01	0,19	0,00	0,02	0,01	0,00	0%	-
Other renewable	0,01	0,01	0,03	0,04	0,03	0,06	0%	1%
Biomass	4,41	4,24	4,55	4,34	4,66	4,46	37%	43%
Hydro	0,33	0,34	0,35	0.69	0,38	0,95	3%	9%
Oil	2,83	2,56	3,26	2,96	3,78	3,28	30%	31%
Coal	2,25	1,73	2,82	1,93	3,81	1,70	30%	16%
Total	9,84	9.08	11,02	9,98	12,67	10,46	100%	100%

Source: Ministry of Mines and Energy, Added to IEEJ, Cambodia Basic Energy Plan. p. 97

Figure 5-3 Cambodia Primary Energy Supply Outlook, 2011

Cambodia's power generation capacity will expand from 2.5GW in 2020 to 4.8 in 2030 and the increase in coal/gas is the largest[59]. On the other hand, as of 2020, the power generation capacity of oil-fired power generation is expected to be no increase or decrease until 2030 as shown in Table 5-3.

Table 5-3 Cambodia Power Generation Capacity Outlook, 2011

Capacity (MW)\year	2020	2025	2030	2030年シェア
Coal/gas	873	1,773	2,373	6%
Oil	251	251	251	5%
Hydro	1,330	1,506	1,602	34%
Renewable energy (biomass, solar, wind)	72	281	490	10%
Total capacity	2,526	3,811	4,716	100%
Peak demand +20% margin	2,017	3,214	4,776	
Required capacity	0	0	60	

Source: Ministry of Mines and Energy, Added to IEEJ, Cambodia Basic Energy Plan. p. 19

[59] Considering that demand for natural gas is not expected in the above energy outlook, "gas" LPG There is a possible.

5.5 Effects of COVID-19

5.5.1 Impacts to supply chain

In Cambodia, the impact of the coronavirus disease 2019 (COVID-19) on the energy supply chain was not clearly be confirmed. At each power plant, the operation itself was ongoing without any problem or disruption, and many power plants are taking strict infection control measures such as thorough hygiene management in offices and dormitories, frequent temperature measurement, and obligation to wear masks. It seems that these measures effectively worked and contributed to stable electricity supply in the country. [60]

5.5.2 Impacts to capital expenditures and operations and management

Capital expenditures in the power sector were somewhat affected COVID-19. This is due to problems such as stagnation of logistics, delays in delivery of equipment from foreign countries, and the inability of foreign manufacturers to dispatch specialists to construction sites. Specifically, in the LNG-related areas, delays were observed in activities such as importing LNG from China using ISO containers, construction of new LNG receiving facilities, and demand development for LNG. In the suburbs of Phnom Penh, the construction of waste-to-power plants was also reported have delayed. Given the large presence of Chinese firms in the Cambodian power sector, it seems what became most problematic in the capital expenditures is the delay in goods and engineers from China is large.[61] In terms of operation and maintenance, no significant impact or problem has been confirmed. [62]

5.5.3 Issues as countermeasures against COVID-19

The first concern about the effects of the COVID-19 is the financial deterioration of electric power company in Cambodia. The Cambodian government has announced plans to reduce electricity prices for five months starting in June 2020 for companies in four major sectors: manufacturing, agriculture, commerce and services, as a compensation package to its economic sectors. In addition, Cambodia has announced measures to reduce or exempt electricity tariff for low-income households. All of these arrangements are considered to negatively affect the financial condition of the power industry. As of

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[60] "China-constructed hydroelectric station powers Cambodia's development against COVID-19," *Global Times*, May 17 ,2020. https://www.globaltimes.cn/content/1188560.shtml . Accessed on September 3, 2021.

[61] C. Vannak, "New power supply will miss dry season because of virus," *The Khmer Times*, March 26, 2020. https://www.khmertimeskh.com/705761/new-power-supply-will-miss-dry-seaon-because-of-virus/. Accessed on March 31, 2021.

[62] H. Pisei, "COVID delays WtE power plant," *The Phnom Penh Post*, March 9, 2020. https://www.phnompenhpost.com/business/COVID-delays-wte-power-plant. Accessed on March 30, 2021.

writing this report, EDC (Electricite du Cambodge), the Cambodian Electric Power Company, has not issued financial statements for FY2020, so although the financial impact of Corona has not been confirmed, there may be a need for financial support in the Cambodian Electric Power Sector.

Meanwhile, under the COVID-19 wreck, Chinese companies are aggressively investing in Cambodia's electricity sector. The main investment projects of Chinese companies since March 2020, when the spread of the new coronavirus began to worsen, are as follows.

- In March 2020, the Cambodia International Investment Development Group and Huadian Sihanoukville Power Generation obtained approval for constructing a coal-fired power plant with a power output of 700 MW from the Cambodian government.
- In October 2020, China National Heavy Machinery obtained approval for constructing 150 MW hydroelectric power plant form the Cambodian government.
- In December 2020, Chinese-affiliated Rise Energy raised US $ 45 million to develop a 60 MW solar power plant in Battambang.
- In March 2021, Shanxi Electric Power Engineering began operation of 39 MW solar power plant in Banteay Meanchey province

In this way, while there are concerns about the weakening of the financial structure of Cambodia's electric power companies themselves, Chinese companies are actively entering the electric power market in Cambodia to make up for such financial shortfalls. Given the potential of future demand growth, however, there is still a strong need for international cooperation from Japan, particularly in an effort to realize climate action and power supply capacity development simultaneously.

5.6 Proposed projects for international cooperation

Based on the above-mentioned energy supply and demand situation in Cambodia, the following two objectives will be set for providing specific support in the future.

One is to secure a stable and commercial energy supply to the people of Cambodia. As mentioned above, Cambodia still high relies on conventional biomass fuels, and its electrification rate is relatively low. In the future, in order to improve the standard of living of the people of Cambodia, development of the commercial energy supply system and investment for required energy infrastructure while meeting other important challenges such as long-term carbon neutrality goal, will be a primary energy policy goal of the Cambodia's energy policy. A clear roadmap for such long-term energy supply and infrastructure development plan while meeting long-term carbon neutrality requirement will be an important item for the collaboration between Cambodia and Japan.

The second is to collaborate to lower carbon emissions, and eventually achieve carbon neutrality of Cambodia. As mentioned above, the introduction of coal-fired power generation is currently progressing in the Cambodia's power generation sector, and the demand for oil is expected to increase mainly in the transportation sector in the future. On the other hand, in order to promote climate change measures on a global scale, it is certain that Cambodia will be required to make concrete efforts toward low carbonization and carbon neutrality in the future. Identification of renewable energy resources in Cambodia will be certainly an important task, and, expanding the use of natural gas in the sectors that are not easily substituted by renewable energy are important step to reduce carbon emissions. Although natural gas is not currently consistently used in Cambodia, the introduction of natural gas will improve energy security by diversifying the primary energy sources. Joint development of the future carbon emissions reduction plan will be another item of the bilateral collaboration.

Based on the above objectives, two projects for international cooperation, namely, the development of master plan toward energy transition and the technical cooperation project are proposed as meaningful activities for the bilateral cooperation between Cambodia and Japan.

5.6.1 Master plan toward energy transition

(1) Background

In the electricity supply, the access to electricity in Cambodia has improved significantly, with the electrification rate reaching 74.8% in 2019, from 22.9% in 2010. [63] But at the same time, the import dependence on electricity supply remains high for Cambodia and securing a stable power supply through steady power development therefore will continue to be a major policy task for Cambodia

Coal-fired power has so far played a major role in the development of power sources in Cambodia so far and will continue to play an important role in Cambodia's electricity mix as a competitive and reliable power source. Considering the environmental burden such as greenhouse gas (GHG) emissions, however, it may be difficult for Cambodia to continue to increase dependence on coal-fired power.

With regard to other power sources, the Cambodia Basic Energy Plan provides that hydropower generation capacity will account for 34% as of 2030, but the risk of stable

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[63] International Energy Agency, *SDG7 Data and Projections: Access Electricity.* https://iea.blob.core.windows.net/assets/93fd1a56-5c8f-4209-ba6e-7f6ff9fffb19/WEO2020-Electricityaccessdatabase.xlsx. 2021 年 11 月 28 日アクセス

power supply due to drought cannot be eliminated. the Plan assumes that renewable power sources such as biomass, solar power, and wind power will account for 10% of the power source mix as of 2030. The development of these renewable power sources should be further promoted in the future, but the increase in variable renewable power sources such as sunlight wind conditions can be a potential risk factor for stable power supply.

Based on the observations above, it becomes clear that there is a need to adopt lower or zero emissions power generation in Cambodia, and Japan can cooperate and facilitate to adopt renewable energy sources as the primary power generation source in the long term and introduce LNG and natural gas in Cambodia in the short to mid-term by providing a comprehensive master plan for energy transition.

(2) Objective

The purpose of this cooperation project is to formulate a master plan for energy transition in Cambodia. In the long term, the plan aims to make renewable energy the main power source, and in the transition period, the plan aims to promote the utilization of natural gas in order to ensure the balance of future economic growth and the stable electricity supply.

(3) Expected outcomes

The following four outcomes are expected.

a) Outcome-1: Demand outlook for energy and natural gas

The first expected outcome is the development of energy and natural gas demand outlook. The current energy master plan in Cambodia has a supply and demand outlook up to 2030, but does not have a longer term outlook beyond 2030. In considering the life of infrastructure investment that will last for several decades, however, a longer-term outlook for energy demand with a view to 2040 or 2050 is indispensable. In this cooperation project, a long-term energy demand outlook will be prepared first, and in particular, natural gas demand trends will be prepared for each section.

b) Outcome-2: Infrastructure development plan

The second expected outcome is the planning of infrastructure development to realize the envisaged energy transition after the long-term future demand is provided. Major components of the plan include the scheduled time table of the development of natural gas-fired power generation, LNG receiving facilities, and domestic pipeline network development, and so on.

c) Outcome-3: Identification of prioritized infrastructure project

When the infrastructure plan is developed, identify prioritized infrastructure development projects that play a critical role in the future energy transition and require large funding needs. Specifically, during the transition period, natural gas-fired power generation, LNG receiving facilities, and domestic pipeline network development, will be included as the contents of the plan. In the long term, identification of domestic renewable energy supply sources, transmission and distribution network development from the identified sources, and distribution network development are needed as required infrastructure. Regarding the domestic natural gas infrastructure plan, in fact, a Chinese company has already considered the development of infrastructure in Cambodia, but it will be prepared with consideration for consistency with the development plan.

d) Outcome-4: Policy proposal and Roadmap

As a result of formulating this master plan, policy proposals and a roadmap for energy transition will be provided. Policy proposals include the development of various legal and regulatory systems including the business law for natural gas supply and distribution, investment-related frameworks, various policy menu to promote natural gas use in each demand sector, and the establishment of a new government organization for gas-related businesses including domestic gas-fired power generation for the transitional period. The road map will also include specific policy items to make renewable energy as the primary generation sources. The roadmap will include demand structure and infrastructure development plans in the benchmark years such as 2030 and 2040, with a target of 2050.

(4) Required actions for the expected outcomes

a) Activities for outcome-1 (demand outlook for energy and natural gas)

As for the demand outlook as the first expected outcome, multiple scenarios may be provided depending on the variable about the degree of economic growth (eg, high growth and low growth) or the degree of climate change countermeasures (eg, BAU, low carbon technology progress, net zero). Based on each scenario, the energy and natural gas demand outlook will be calculated using macroeconomic models and energy supply and demand models. The outcome of analyses will be shared with the Cambodian government officials for close discussions and feedback for refinements

As for the demand development of natural gas in Cambodia, the demand for the residential and commercial sector may be limited, considering that electricity prices in Cambodia are kept low by regulations. The major target of natural gas demand development is likely to be for industrial use. Cambodia's industrial energy demand, however, is not large at 1,470 ktoe (about 1.25 million LNG equivalent tons) as of 2018.

Since it is technically difficult to convert all industrial energy demand to natural gas due to demand patterns, cost competitiveness, and infrastructure constraints, the industrial natural gas demand potential will be at most hundreds of thousands of tons per year. Therefore, although it is not realistic to launch an LNG import project with industrial demand as major demand component, it can provide additional demand to the anchor demand in the power sector and thus is important to steadily develop industrial heat demand such as boilers and industrial furnaces.

b) Activities for outcome-2 (infrastructure development plan)

The above energy demand outlook will be subdivided into different sector and region in consultation with the Cambodian government, taking into consideration the population and industrial distribution, power generation plant construction sites, etc. After that, infrastructure development plan will be provided for LNG receiving terminals, pipelines, LNG satellite terminals, for the transitional period, and relevant power supply network such as grid capacity expansion or storage facility to accommodate the adoption of renewable power supply. As for the development of natural gas-related infrastructure, the ongoing infrastructure development by Chinese firms will be reflected in the planning to avoid redundant planning (Table 5-4) [64]

Table 5-4 Ongoing infrastructure plans in Cambodia

Phase 1 (2019-2020)	**Phase 2 (2021-2023)**	**Phase 3 (2024-2029)**
Start import LNG by ISO containers	Gas-fired power plant (3.6GW) FSRU (FSRU 550,000 tons per annum)	Onshore receiving terminal (3.0 million tons per annum)

Source: Khmer Times, *CNOOC Gas & Power sizing up entry into new Cambodia LNG import terminal*, July 3, 2021, https://www.khmertimeskh.com/50886168/cnooc-gas-power-sizing-up-entry-into-new-cambodia-lng-import-terminal/

As a recent development, in January 2020, LNG in ISO containers was shipped from Guangxi Province, China to Sihanoukville of Cambodia. [65] However, exports by this ISO container are not constant, and it is considered that they are provided on a small scale according to the needs of the demand side.

[64] Khmeer Times, *CNOOC Gas & Power sizing up entry into new Cambodia LNG import terminal*, 2021 年 7 月 3 日, https://www.khmertimeskh.com/50886168/cnooc-gas-power-sizing-up-entry-into-new-cambodia-lng-import-terminal/

[65] IHS Markit, *China launches small-scale LNG exports to Cambodia: Is there room for growth?*, January 14, 2020. https://ihsmarkit.com/research-analysis/china-launches-smallscale-lng-exports-to-cambodia.html Accessed on July 26, 2021.

c) Activities for outcome-3 (Identification of prioritized infrastructure project)

Based on the infrastructure development plan, specific development projects will be identified. Such project will be those playing a pivotal role in the demand development in Cambodia and requiring a large amount of investment capital that cannot be met only with private capital. According to media reports, the capacity of currently planned gas-fired power generation capacity is 3,600 MW, and if this is achieved, a maximum LNG demand of about 2.3 million tons / year will be generated. Cambodia Basic Energy Plan, on the other hand, assumes that the total power generation capacity as of 2030 will be 4,716 MW. The additional gas-fired power generation capacity will need to be introduced in a phased manner, and the LNG demand will also be gradually increased.

d) Activities for outcome-4 (Policy proposal and Roadmap)

Based on a) to c) above, particular policies necessary for the energy transition will be proposed. Experiences of natural gas introduction in other developing countries will also be referred and useful cases for natural gas introduction to Cambodia will be extracted.

5.6.2 Technical cooperation project for natural gas/LNG

(1) Background

Cambodia plants introduce natural gas into its energy and power mix. However, in Cambodia, where there is no demand for natural gas as of today, expertise and operational experience to utilize natural gas and LNG is limited. Capacity development in the government and companies is indispensable for implementing large-scale infrastructure development such as LNG receiving terminals and gas-fired power plants.

(2) Objectives

This cooperation project aims to transfer required knowledge and expertise to facilitate the adoption of natural gas and LNG in Cambodian energy and power generation mix.

(3) Expected outcomes

There are three expected outcomes.

a) Outcome-1: Knowledge transfer of LNG and natural gas utilization

The first expected outcome is the transfer of knowledge on the overall natural gas and LNG utilization. Such transfer includes fundamental policy issues of natural gas utilization, preferred sectors of natural gas use, infrastructure development requirement, setting tariff of natural gas supply, technologies in natural gas utilization, and safety, health, and environment (SHE) issues in natural gas use.

b) Outcome-2: Legal and regulatory system development

The next expected outcome is to assist the development of legal and regulatory systems in natural gas use. Since the Cambodian government will need to provide specific legal and regulatory framework as its use of natural gas expands, the international cooperation project will be consulted by the Cambodian government officials who are in charge of such legal / regulatory developments and provide a template for such systems.

c) Outcome-3: Expertise in safety, health, and environment (SHE)

Finally, the developments of technical and SHE standards will be assisted. Because there is no current use of natural gas in Cambodia, it is necessary to establish standards from scratch. The company that conducts the business is primarily responsible for the operational issues, but the government officials are preferred to acquire knowledge about how natural gas-related operations are conducted. Such operational and technical expertise is important for more effective and efficient policy planning and elaboration.

(4) Required actions for the expected outcomes

a) Activities for outcome-1 (Knowledge transfer of LNG and natural gas utilization)

Since natural gas can be utilized in various sectors, a comprehensive knowledge transfer in the energy sectors and the potential use of natural gas has to be included in the entire cooperation program. In particular, in the context of Cambodia, the power sector and the industrial sectors will have more weight in the program. The entire technical cooperation project will be designed to meet specific needs in each of government sections and officials to realize fruitful knowledge transfer from Japan to Cambodia. Depending on the progress of the control of COVID-19 and vaccination, training program in Japan that includes lecture-style studies as well as various site visits to natural gas applications will be conducted.

b) Activities for outcome-2 (Legal and regulatory system development)

In newly introducing natural gas and LNG to its energy and power generation mix, it is necessary to develop specific laws, regulations, and contract systems with foreign and private players in the natural gas businesses. First of all, it is necessary to develop a business law that regulates the framework of natural gas and LNG business, and provides fundamental authorities of the government and the responsibilities of firms that conduct actual natural supply and distribution businesses.

In addition, since various contracts are generated when actually receiving and utilizing LNG, specialized knowledge about the contents of those contracts need to be accumulated at the government. Such specific contracts will include construction of gas infrastructure such as LNG receiving terminals and gas-fired power plants, import contracts for LNG procurement, operation service contracts with gas infrastructure operators, and power sales contracts between gas-fired power plants and Cambodia Electric Power Corporation. The technical cooperation project will also propose a specialized government section / department who oversees natural gas/ LNG issues.

c) Activities for outcome-3 (Expertise in safety, health, and environment (SHE))

Since Cambodia has little experience in using natural gas, it is necessary to develop safety, health, and environment (SHE) -related standards from scratch. Setting of effective standards and government office that monitors the issue are needed to ensure safe and reliable energy supply based on natural gas and LNG import. In particular, LNG is extremely cold material and requires careful handling of boil-off gas, the flow rate, and the pressure of the pipeline for safe use. In this regard, in order to acquire specialized knowledge on these operations, maintenance, and management, the technical cooperation project will formulate operation manuals for professional staffs at the natural gas handling sites and provide a training program for field operators. As part of the training program, those officers and operators will be invited to Japan to tour LNG receiving terminals, gas-fired power plants, gas transportation and distribution networks, gas consumers, and gas equipment manufacturers for their professional education.

5.7 Roadmap toward net-zero

Finally, Figure 5-4 shows a roadmap for reducing greenhouse gas emissions to net-zero in Cambodia in the future. This roadmap was created by a "backcast" approach from the current energy demand in Cambodia, assuming that it will reach virtually zero by 2060.[66]

As noted already in the previous chapter, the path to net zero is composed of i) promotion of electrification by renewable energy, ii) introduction of non-fossil fuels in demand sectors that cannot be electrified, and iii) offset by negative emission technology of CO2 emissions that cannot be completely eliminated.

First, in the electric power sector, the share of electric power in final energy consumption of Cambodia was only 10% as of 2018, and this ratio must be raised with addition of renewable energy. The targeted share of electricity over total final energy consumption needs to be raised to 30% in 2040 and finally to 50% in 2060. As for renewable energy, as of 2018, about 60% of domestic electricity is covered by hydropower, but it is highly likely that this share will gradually decline due to the increase in the total electricity demand with the country's economic growth. Therefore, the introduction

[66] It should be noted that the cost and technical practicality required to realize it are not rigorously examined.

of renewable power sources such as solar and wind is indispensable, and the share of renewable power sources including hydropower needs to be increased to 60% in 2040 and 90% in 2060. The remaining 10% as of 2060 is expected to be natural gas fired with hydrogen or CCUS.

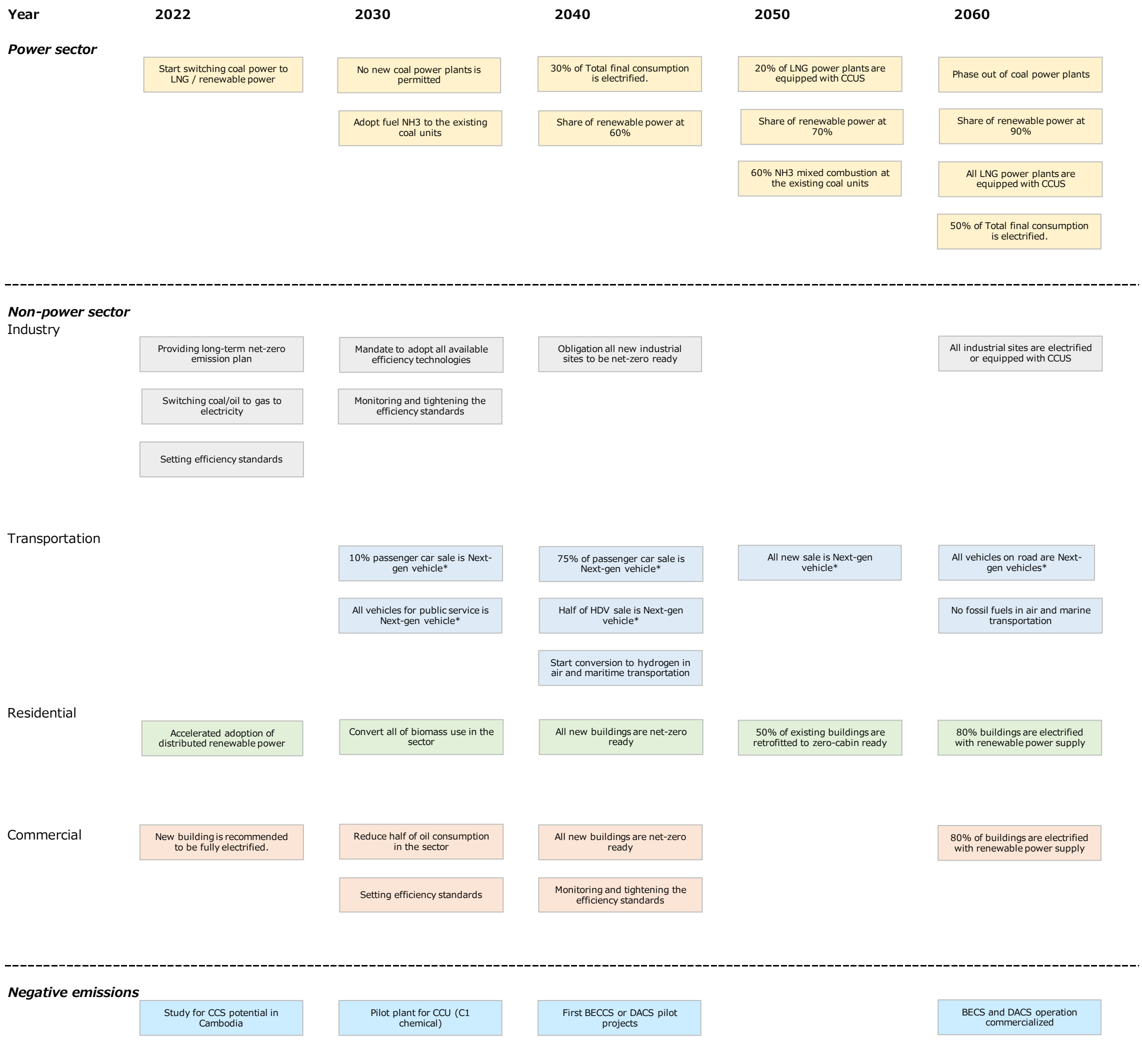
Regarding the thermal power generation, the first action to be taken is to convert the currently planned of coal-fired power generation to natural gas or renewable energy, except for those for which investment decisions have already been made. Furthermore, by 2030, new coal-fired power plants should be banned, and co-firing of fuel ammonia should be started as a decarbonization measure for existing coal-fired power plants. For coal-fired power, to achieve the 60 percent co-combustion of ammonia in all of the existing coal-fired to the prospect of the 2040 year, and in 2060 the use of all the coal-fired power plants will be banned. It is desirable that gas-fired power generation will be continuously used from the viewpoint of resilience such as backing up renewable energy and securing inertial force in the power source composition, but as a decarbonization measure for that purpose, 20% of the gas -fired power generation capacities will install CCUS capacities as of 2050, and all gas-fired power plants will have CCUS facilities as of 2060.

In order to achieve net-zero, non-power sectors have to overcome more difficult challenges than the electric power sector. First, in the industrial sector, as short-term countermeasures, every industry in Cambodia will formulate decarbonization plans and introduce strict energy-efficiency standards in the future. The industry will switch from fossil fuels to electricity or renewable energy where it is technically feasible. Energy-efficiency standards in the industrial sector will be strengthened step-by-step afterward, As of 2040, all the industrial facilities are expected to have concrete plan for their decarbonized operation. Specifically, plans to use non-fossil energy such as renewable electricity or hydrogen, installation of a carbon capture facility, and/or negative emissions arrangements will be included into such plan. Realizing these plans will help the sector to decarbonize as much as possible as of 2060.

In the transportation sector as well, the use of electrification or hydrogen is basically the way to go. The share of next-generation vehicles (electric vehicles, fuel cell vehicles, hydrogen engine vehicles, etc.) will be raised gradually in the domestic sales of new vehicles, and by 2050, all new vehicle sales will be such next-generation vehicles. Vehicles in the public transport sector, which are relatively easy to convert due to government policy, will be converted at an earlier stage. Furthermore, for transportation means such as aircraft and ships that are difficult to electrify, the conversion to hydrogen will be promoted from around 2040, and as of 2060, hydrogen is expected to be a primary fuel for such transportation means.

In the residential and commercial sectors, energy conversion and electrification will be a primary action toward decarbonization. In the residential sector, distributed electrification by solar power and wind power from traditional biomass will also be pursued in rural areas. In addition, after 2030, further utilization of renewable and, where it is feasible, the use of hydrogen will be started. Until 2060, it is desirable to achieve net-zero in 80% of the residential sector. In the commercial sector, similar approach will be taken. Currently oil is one of major fuels in the sector, but this will be gradually switched to natural gas as a transition fuel and eventually to renewable or hydrogen. Furthermore, after 2040, new buildings will be required to be constructed on the premise of electrification, and as of 2060, the sector's net emissions will be as close to zero as possible.

Finally, regarding negative emission technology, investigating the CO2 storage potential in Cambodia will be started as a short-term response. Since there are no depleted gas fields in the country, the storage potential in the aquifer will be explored. Furthermore, to the possibility of introducing the CCU, a pilot project of CCU technologies applications, such as mineralization, will be conducted to examine the feasibility in Cambodia. When the evaluation of CO2 storage potential is completed, after 2030, adoption of Direct Air Capture and Storage (DACS) or Bio Energy Carbon Capture and Storage (BECCS) technologies will be examined toward 2050 in aiming to achieve commercial operations as of 2060.



Source: The Institute of Energy Economics, Japan

Figure 5-4 Roadmap toward net-zero in Cambodia

6. Issue Analysis and Cooperation Projects with the Philippines

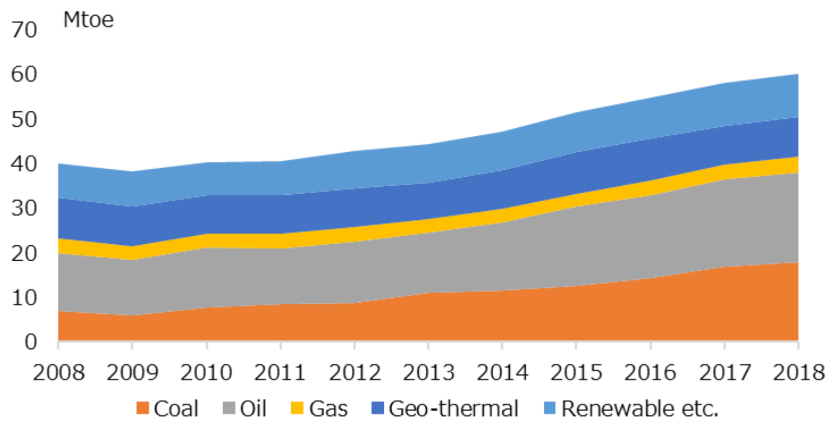
6.1 Energy demand and supply

6.1.1 Primary energy supply

The Philippines' primary energy supply is 60 million toe (mtoe) as of 2018, and the average demand growth rate for 10 years since 2008 is 4.1%. In the early 2010s, the economic growth rate was unstable and the rate of increase in energy demand was relatively low, but since the middle of the 2010s, the economic growth rate has been stably sustained at 6% per annum, and so has been the growth rate of the total primary energy supply. In the primary energy supply mix as of 2018, oil had the highest share, followed by coal and renewable energy (mainly traditional biomass). In terms of growth rate, coal had the highest rate, with supply increasing 2.6 times from 2008 to 2018. This increasing supply of coal was met by both an increase in imports and domestic production. As of 2018, 71% of the domestically supplied coal is imported coal. Most (83%) of the coal consumed domestically is used as fuel for power generation (Figure 6-1; Table 6-1).

Oil demand had the next highest growth rate from 2008 to 2018. Most of the demand growth was observed in the transportation sector, which reflected the growth of movement of people and goods accompanying the activated economic activities. In recent years, moreover, the demand for the commercial sector has increased remarkably.

All of the natural gas in the Philippines is supplied from the Malampaya gas field in the southern part of Luzon Island, and almost all of the produced natural gas is used for power generation. Production from the gas field is currently scheduled to cease in 2024, when the operating contract with the operating oil company will expire. It is therefore an urgent task to secure an alternative natural gas supply as described later. Overall, fossil fuel reliance is high as the share of fossil fuels in primary energy supply has risen from 58% to 69% between 2008 and 2018.



Source： IEA, *World Energy Balances 2020.*

Figure 6-1 Primary energy supply of the Philippines

Table 6-1 Primary energy supply of the Philippines

(Unit: ktoe)

	Coal	Oil	Gas	Geo-thermal	Renewable etc.	Total
2008	6,937	12,984	3,192	9,220	7,776	40,109
2009	6,021	12,251	3,214	8,877	7,827	38,190
2010	7,631	13,602	3,051	8,537	7,580	40,401
2011	8,341	12,718	3,294	8,549	7,768	40,670
2012	8,799	13,774	3,158	8,813	8,212	42,756
2013	10,891	13,711	2,908	8,259	8,510	44,279
2014	11,643	15,064	3,059	8,863	8,620	47,249
2015	12,637	17,679	2,875	9,496	8,835	51,522
2016	14,301	18,547	3,294	9,518	9,149	54,809
2017	16,827	19,649	3,250	8,831	9,569	58,126
2018	17,937	19,991	3,628	8,973	9,523	60,052
Share as of 2018	30%	33%	6%	15%	16%	100%

Source: International Energy Agency (IEA), *World Energy Balances 2020 edition*.

6.1.2 Power generation mix

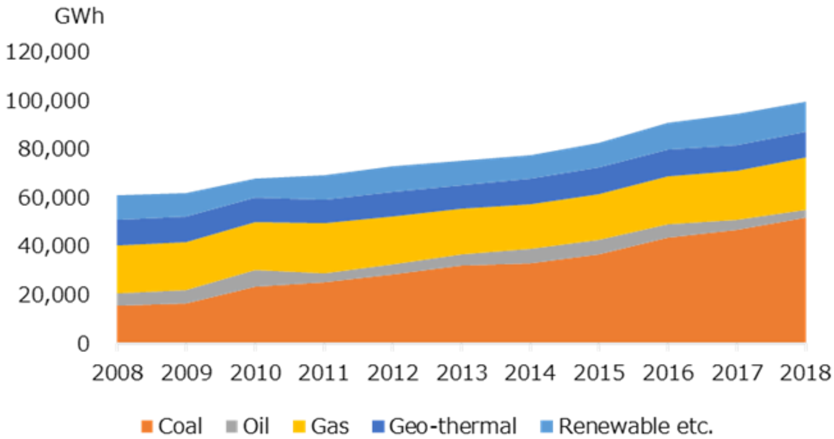
The amount of electricity generated in 2018 was 99,192GWh, which grew by 1.6 times in the 10 years from 2008. The rate of growth was a relatively low among other emerging countries in Asia. The main power source is coal-fired power, which accounts for more than half of the total electricity generated as of 2018, followed by natural gas, renewable energy (mainly hydropower), and geothermal power. The highest growth rate in the last 10 years is observed in the coal-fired power. Most of the electricity demand growth in the Philippines in the last decade has been met by the growth of coal fired power generation. Other power sources have not seen significant growth in renewable energy, except for the increase in solar and wind power generation. Oil-fired power has been declining in recent years (Table 6-2; Figure 6-2).

Table 6-2 Power generation mix in the Philippines

(Unit: GWh)

	Coal	Oil	Gas	Geo-thermal	Renewable etc.	Total
2008	15,749	4,868	19,576	10,723	9,905	60,821
2009	16,476	5,381	19,887	10,324	9,853	61,921
2010	23,301	7,101	19,518	9,929	7,893	67,742
2011	25,342	3,398	20,591	9,942	9,903	69,176
2012	28,265	4,254	19,642	10,250	10,510	72,921
2013	32,081	4,491	18,791	9,605	10,298	75,266
2014	33,054	5,708	18,690	10,308	9,502	77,262
2015	36,686	5,886	18,878	11,044	9,919	82,413
2016	43,303	5,661	19,854	11,070	10,909	90,797
2017	46,847	3,787	20,547	10,270	12,919	94,370
2018	51,932	3,173	21,334	10,435	12,318	99,192
Share as of 2018	52%	3%	22%	11%	12%	100%

Source： IEA, *World Energy Balances 2020.*



Source： IEA, *World Energy Balances 2020.*

Figure 6-2 Power generation mix in the Philippines

6.2 Government offices for energy policy

The Department of Energy (DOE) is the primary government organization to oversee energy policies in the Philippines. The department formulates, implements and manages all plans in the domestic energy sectors, and promotes the exploration, development and utilization of energy resources. The department also oversees the energy conservation issues in the country.

In the electric power sector, there is the National Electrification Administration as an organization that promotes local electric power. In addition, the Energy Regulatory

Commission (ERC) monitors the electricity market, regulates electricity prices, and licenses electricity businesses. ERC regulates not only electricity but also domestic gas prices. National Renewable Energy Board (NREB) promotes the introduction of renewable energy in the private sector, the utilization of clean development mechanism (CDM), and research and development in the renewable energy technologies. The Department of Environment and Natural Resources is tasked with policies on the environment and natural resources to realize balanced development of environmental management and sustainable economic development.

6.3 Energy industry

6.3.1 Electricity

In the Philippines, the National Power Corporation (NPC) used to be a monopoly entity in the power generation and transmission sectors, but it was unbundled by the electricity business reform that took place in 2001, and since then the power generation business in the Philippines has been undertaken by NPC and independent power producers (IPP). NPC is responsible for the operation of existing power plants built before the system reform and Small Power Utilities Group that electrifies areas far from the power transmission and distribution networks. As of 2019, NPC operated 139 power generation units and managed the operation of power transmission and distribution assets in remote areas.

In the transmission sector, the National Transmission Corporation (TransCo) manages the operation of the domestic power grid system. National Grid Corporation of the Philippines (NGCP), a private corporation, also manages state-owned transmission assets. The power distribution business is also unbundled, with the private power distribution company Manila Electric Company (Meralco) operating in the Manila metropolitan area.

As a measure against the COVID-19, the Philippine government issued a requests to state-owned and private power companies for deferral pf payment of electricity bills for 30 days in March 2020.

6.3.2 Petroleum

In the upstream sector of the Philippine oil industry, the state-owned oil company Philippine National Oil Company (PNOC) is a major player, and by partnering with foreign companies, conducts domestic exploration and development activities. The main producing asset in the Philippines is the Malampaya reservoir found beneath the Malampaya gas field,. The production operation is undertaken by a joint venture of Shell (45%, operator), Chevron (45%) and PNOC (10%). Crude oil is produced as an associated products of natural gas, as of 2018, but the production volume was as low as 643 tons of oil equivalent (ktoe), which is only about 3.2% of domestic oil demand.

In the oil refining sector, two companies, Pilipinas Shell Petroleum and Petron, operated refineries in Tabango and Limay counties, respectively. But Shell stopped the refinery's operation due to a decrease in oil demand caused by the COVID-19 and closed the refinery in August 2020. The company plans to convert the closed refinery into an import terminal and shift its domestic petroleum product supply to import products. Philippines' oil imports are made in both in the form of crude oil and petroleum products. More than half of the imports is supplied from three countries, namely Saudi Arabia, Kuwait and the UAE. Petroleum products are imported mostly from China and South Korea.

In the domestic oil retail market, the number of retailers is increasing along with the expansion of demand for petroleum products. As of 2018, the number of retailers was 325, 14% increase from the previous year. These businesses are engaged in businesses such as fuel retailing and transportation, operation of oil depots, and refueling.

After the enforcement of the Petroleum Downstream Industry Deregulation Law in March 1998, the petroleum product market in the Philippines has been liberalized, and many foreign and private companies such as PTT, Petronas, and Total have entered the petroleum product market. Domestic oil product prices are priced linked to international price benchmarks in Singapore, as most of them are covered by product imports.

6.3.3 Gas

In the Philippines, as of 2018, 92% of the gas produced domestically is consumed at power plants at Batanbas, so major companies in the gas industry in the Philippines are the three natural gas field operating companies, Shell, Chevron, and PNOC. Natural gas from the gas field is supplied via the submarine pipeline (Malampaya-Batangas, 504km) to three power plants, Ilijan (1,000MW) and Santa Rita (1,000 MW), supplied to San Lorenzo (560 MW). The Philippine government is attracting foreign capital to promote the development of domestic offshore oil and natural gas resources, but significant progress has been made.

Liquefied natural gas (LNG) import projects are under consideration to supplement the natural gas supply from the Malampaya gas field, which will cease its operation in 2024. Initially, an onshore LNG receiving terminal was considered, but as of April 2021, all LNG receiving projects are based on Floating Storage and Regasification Unit (FSRU). As of 2019, the amount of natural gas produced from the Malampaya gas field is about 3.1 million tons in terms of LNG, but there are currently six import plans planned, and the total import capacity is 20 million tons (Table 6-3).

Table 6-3 LNG Receiving terminal projects in the Philippines

Proponent	Partner	Capacity (million tons per annum)	Estimated start up	Supply direction
FirstGen	Tokyo Gas	5.26	Q3 2022	Power generation
Atlantic Gulf & Pacific	Osaka Gas	3.00	Q2 2022	Power generation
Excelerate	Toplne Energy & Power Dev Corp	4.40	Q3 2022	Small scale LNG, whole sale by third-party access
Shell Energy	-	3.00	Q3 2022	Power generation, industry
Energy World Gas Operations	-	3.00	Q4 2022	Power generation
Bataangas Clean Energy	LCT Energy and Resources	3.00	Q4 2025	Power generation, industry

Source: Department of Energy, "Developments of LNG Infrastructure in the Philippines," April 2021.

6.4 Energy mix and power generation mix targets

6.4.1 Energy mix

The Philippines government publishes the outlook of primary energy supply mix and power generation mix until 2040. In the outlook, the government publishes two different scenarios: Reference Scenario (RES) and Clean Energy Scenario (CES) (Table 6-4)

Table 6-4 Two scenarios and numerical targets in the scenarios

	Reference Scenario (RES)	Clean Energy Scenario (CES)
Demand	• Assumes the implementations of the domestic infrastructure ("Build, Build, Build") and long-term economic development plan (" AmBisyon Natin 2040") • 2% blending of biofuel to diesel oil and 10% blending bioethanol to gasoline	• 10% electric vehicles in the road sector until 2040 • Natural gas demand will grow by 3.0% per annum from 2018 to 2040 • 5% energy efficiency improvement in the oil and power consumptions until 2040
Supply	• Implement the committed power generation capacity development as of 2018 • At least 20GW renewable power generation capacity until 2040 • Raising the share of renewable in the power generation mix 35% by 2030 • Ensuring 25% reserve margin. • 70% utilization in the total domestic power generation	• Introduction of high-efficiency generation units • Additional 10GW renewable power generation capacity until 2040 • Additional 1,200MW generation capacity until 2035

Source: Department of Energy, Philippine Energy Plan 2017-2040, p26

The outlook of primary energy supply in the two scenarios is shown in Table 6-5 and

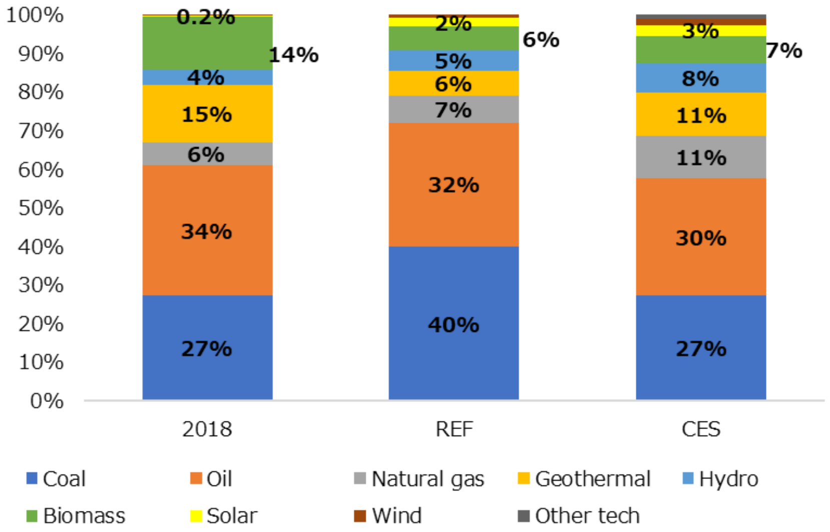
Figure 6-3. In RES (Reference scenario), which is the reference case, the overall primary energy supply will increase 2.7 times from 2018 to 2040, but in CES (Clean Energy scenario) the increase will be slightly suppressed to 2.4 times. As of 2018, oil was the largest energy source with a 34% share of the total, but in the RES scenario, coal will be the largest with 40% of the total as of 2040. On the other hand, in CES, the increase in coal market share will be suppressed by the progress of energy saving and the introduction of renewable energy, and oil will continue to be the largest energy source.

Table 6-5 Outlook of primary energy supply in the Philippines

Unit: million tons oil equivalalent (MTOE)

	Actual	Reference (REF)		Clean Energy (CES)	
	2018	2030	2040	2030	2040
Coal	16.35	38.10	64.17	35.84	39.77
Oil	19.99	32.69	51.78	28.20	44.19
Natural gas	3.60	2.92	11.19	3.91	15.88
Geothermal	8.97	10.62	10.18	11.04	16.38
Hydro	2.34	7.95	8.67	7.19	11.11
Biomass	8.20	9.01	9.96	8.76	10.48
Solar	0.11	1.84	3.47	1.56	3.96
Wind	0.10	0.55	1.29	0.64	2.32
Other tech					1.63
Total	59.66	103.68	160.71	97.14	145.72
Self sufficiency	50.2%	55.3%	40.4%	58.0%	63.5%

Source: Department of Energy, Philippine Energy Plan 2017-2040, p26



Source: Department of Energy, Philippine Energy Plan 2017-2040, p26

Figure 6-3 Outlook of primary energy supply in the Philippines

In CES, the energy intensity (energy consumption per unit of GDP) is expected to improve from 6.4 tonnes of oil equivalent / GDP of 1 million pesos in 2018 to 3.0 in 2040 because of the adoptions of energy conservation technologies and improved energy efficiency. Meanwhile, due to the economic growth and the expanded use of commercial energy, energy consumption per capita is expected to increase from 0.6 tonnes of oil equivalent in 2018 to 1.0 tonnes of oil equivalent in 2040.

Regarding energy self-sufficiency, different trends are predicted in both scenarios. In RES, the self-sufficiency rate of 50.2% as of 2018 will improve to 55.3% as of 2030 due to the development of domestic hydropower resources, but after that, the import of coal, oil and natural gas will increase, and as of 2040, the self-sufficiency will drop to 40.4%. In CES, on the other hand, the amount of domestic renewable energy introduced such as solar power and wind power is expected to grow, and the domestic energy saving is assumed to progress. Thus, the self-sufficiency rate will continuously improve to 58.0% in 2030 and 63.5% in 2040. With regard to the dependence on oil imports, the policies to promote biofuels and electric vehicles in order to curb oil consumption are assumed.

6.4.2 Power generation mix

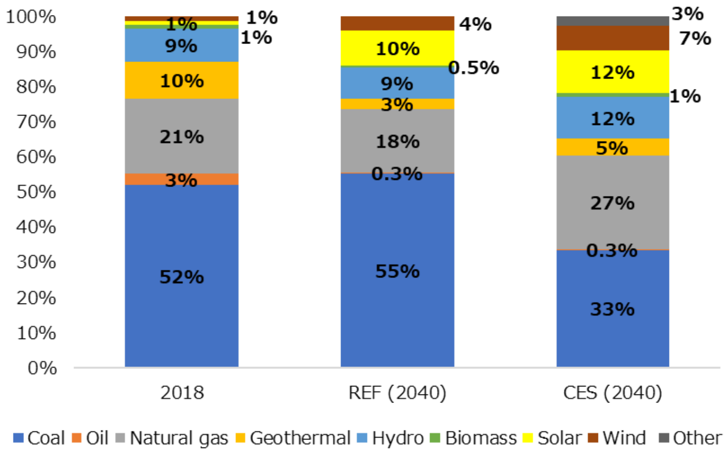
The Philippine government published the outlook for its power mix as well as a primary energy supply outlook (Table 6-6, Figure 6-4). Due to economic growth and electrification, electricity demand in the Philippines is expected to grow at high rate in the future. In RES, domestic electricity demand will be about 4.0 times from 2018 to 2040, and in CES it will be about 3.8 times. In the power supply mix, coal-fired power accounts for more than half of the current situation in RES, followed by gas-fired power. With regard to renewable power generation, on the other hand, the amount of power generated by geothermal power generation will be almost the same in 2040 with declined share, and the share of solar power will increase from 1% in 2018 to 10% in 2040 thanks to the accelerated development in coming years. In CES, the promotion of energy conservation and the introduction of renewable energy is expected to reduce dependence on the coal-fired power generation, whose dependence is assumed to fall to 33% in 2040. On the other hand, the combined share of solar and wind power will increase from 2% in 2018 to 19% in 2040. In addition, 3% of all "other" power sources are expected to be introduced by 2040.

Table 6-6 Outlook of power generation mix (electricity generated)

U: TWh

	Actual	Reference (REF)		Clean Energy (CES)	
	2018	2030	2040	2030	2040
Coal	51.93	129.63	218.34	121.13	126.39
Oil	3.17	1.35	1.23	1.35	1.23
Natural gas	21.33	18.28	71.14	24.40	100.78
Geotherma	10.44	12.35	11.84	12.84	19.05
Hydro	9.38	31.92	34.82	28.89	44.64
Biomass	1.10	1.81	1.81	1.48	4.15
Solar	1.25	21.39	40.35	18.19	46.11
Wind	1.15	6.39	14.99	7.41	26.96
Other					9.49
Total	99.75	223.12	394.52	215.69	378.80

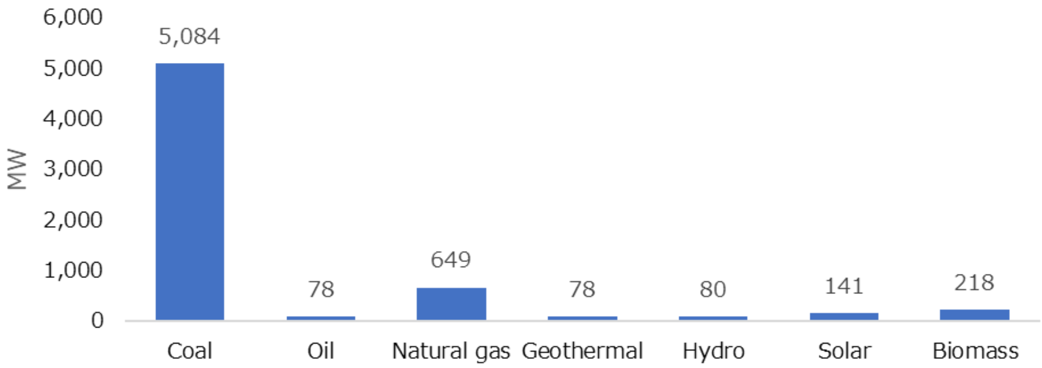
Source: Department of Energy, Philippines Energy Plan 2017-2040, p219-220



Source: Department of Energy, Philippines Energy Plan 2017-2040, p219-220

Figure 6-4 Outlook of power generation mix (electricity generated)

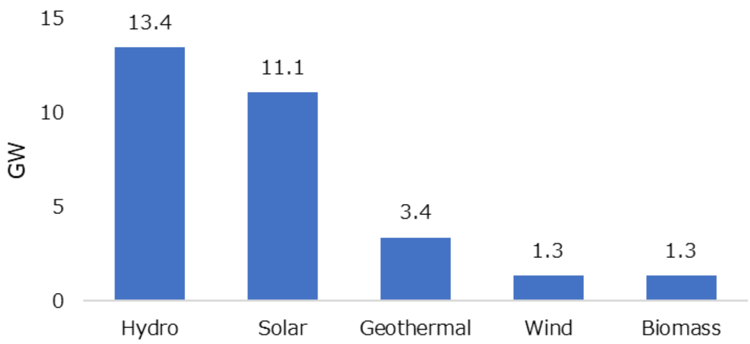
The power demand outlook in RES is based on already committed power development plans, most of which are coal-fired (Figure 6-5). The next largest is natural gas-fired power generation, which is planned in conjunction with LNG imports. Fossil fuel-based thermal power generation is the main axis of power development in RES.



Source: Department of Energy, Philippine Energy Plan, p114

Figure 6-5 Power development plan of already committed capacity development (as of December 2018)

Regarding the introduction of renewable energy into the power mix, RES assumes that 50% on a capacity basis and 33% on a power generation basis will be covered by renewable power as of 2040. CES, on the other hand, assumes that 54% on a capacity basis and 37.3% on a power generation basis will be covered by renewable energy sources. The "National Renewable Energy Program (NREP)", which is currently being drafted, will include the goal of introducing a renewable energy power source of 30 GW or more between 2020 and 2040 (Figure 6-6). For renewable energy, the figures in CES is becoming a more plausible numbers than the figures in RES.



Source: Philippines Energy Plan 2017-2040, p102

Figure 6-6 Planned capacity addition assumed in NREP (2020-2040)

As for "other" power sources in CES, which was no specific power source is designated, nuclear power and hydropower are possible supply sources. Regarding nuclear power, there is already a Bataan nuclear power plant that was almost completed in the 1980s, but the operation has been postponed due to the Chernobyl nuclear accident that occurred in 1986. In October 2020, President Duterte instructed the Department of Energy to start reevaluating the possibility of nuclear power generation, and attention is focused on future development in nuclear power in the Philippines.

Regarding hydrogen, the Department of Energy signed a memorandum of understanding with Australian private company Star Scientific Limited in January 2021 regarding the studies of the future use of hydrogen in the Philippines, and plans to use the company's hydrogen technology for power generation.[67] The hydrogen assumed to utilize in this memorandum is so-called “green” hydrogen produced by electrolysis by solar and wind power. Utilization of hydrogen to coal-fired power generation is also studied in the study.[68]

6.5 Effects of COVID-19

6.5.1 Effects on electricity supply chain

In the Philippines, like the previous two countries, no significant adverse impacts by of the COVID-19 on the energy supply chain has been observed. The country’s total primary energy supply declined by 9.7% in 2020. By energy source, oil demand decreased by 17.7%, natural gas demand decreased by 9.1%, but the electricity demand declined only by 0.9%. During the peak of infection, there was a speculation that Meralco, the largest power marketer in the Philippines, may announce force majeure because of the rapid demand decline, but it was not actually invoked. Other power companies in the Philippines continued to operate normally even under lockdown, resulting in a stable energy supply without major disruption due to the COVID-19.

6.5.2 Effects on capital expenditure and operation and maintenance

Regarding the effects on capital expenditures in the power sector, delays have been seen in some projects because foreign contractors and workers could not be secured at construction sites. Another problem is that the decline in global industrial production activities has delayed the delivery of imported equipment and parts required for construction. Reflecting such circumstances, Meralco announced that capital spending on infrastructure projects in 2020 will be reduced from the originally planned 17.8 billion pesos at the beginning of the year to 9.3 billion pesos (US $ 183.38 million). [69] In the operation and maintenance side of the Philippine’s power industry, there is no noticeable impact by COVID-19 reported.

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[67] Department of Energy, Philippine Energy Plan 2017-2040. p 169

[68] Star Scientific Limited Press Release, January 2021. (https://starscientific.com.au/star-scientifics-cutting-edge-hydrogen-innovation-to-help-drive-philippines-sustainable-economic-development/) Accessed on 2 May 2021.

[69] A. Calonzo, “Manila Electric Halves Spending as Lockdown Weakens Power Demand,” *Bloomberg*, April 27, 2020. https://www.bloomberg.com/news/articles/2020-04-27/manila-electric-halves-spending-as-lockdown-weakens-power-demand . Accessed on March 31, 2021.

6.5.3 Issues as countermeasures against COVID-19

As mentioned above, the electricity demand in the Philippines decreased slightly from the previous year, and the profits of electric power companies shrank due to the reduction and exemption of electricity charges for consumers affected by COVID. For example, in the case of Meralco, its net profit decreased by about 9%, and in the case of First Gen, the profit decreased by 15%. On the other hand, the demand for electricity in the Philippines is showing signs of recovery, and the deterioration of business performance in 2020 are not likely to have a persistent impact on future capital investment and operations. The delay in capital investment is not so much a financial constraint as it is a matter of availability of materials and equipment and human resources. It is likely that if the coronavirus is successfully contained, it will return to its previous state. Therefore, from the viewpoint of the response to COVID, urgent needs for international cooperation seem not very high.

6.6 Proposed projects for international cooperation

Based on the above energy supply and demand observations in the Philippines, the following three objectives will be set for providing specific support in the future.

The first is to support the securing of alternative supply of depleting domestic natural gas, which is expected to cease the production in 2024, as relatively a short-term issue. Most of the gas produced from the domestic gas field is used for power generation, but considering the period until the production stoppage and the reduction of greenhouse gas emissions, the introduction of imported LNG seems a practical solution. Collaborating in assisting smooth and efficient introduction of LNG as a substitution of the domestic natural gas supply as well as utilization of imported LNG to other energy applications such as industrial fuels will be of higher needs for the Philippines.

The second is to reduce the dependence on coal in a realistic manner. As mentioned above, the demand for coal has increased 2.6 times in the Philippines due to the significant increase in demand for power generation in the last 10 years. Most of the new thermal power sources committed at this time, furthermore, are also coal-fired. Such coal-biased power development is not very preferable not only from the climate action's perspective but also from the energy security perspective. Therefore, in order to reduce the dependence on coal, a realistic path needs to be drawn and LNG will play a key role in the reduction actions.

The third is to show a clear path of long-term introduction of renewable energy and achieving carbon neutrality. As mentioned above, it is expected in the government's outlook that the introduction of fossil fuels such as coal will progress in the Philippines in the mid-term. Even in the government's CES scenario that is least dependent on fossil fuels, the share of fossil fuels as of 2040 is 68%, which is almost the same as the current level. Since the share of hydroelectric power generation is low in the Philippines and the development of geothermal power generation is stagnant, domestic wind power, solar power generation, nuclear power generation, and hydrogen including ammonia will need to be used to reduce the dependence on fossil fuels in the future. A long-term supply and demand plan for utilization of such zero-emission energy sources will an important collaboration item.

Based on the above three objectives, this study proposes three support projects: a natural gas utilization master plan, a technical cooperation project for LNG utilization, and the creation of a net zero scenario.

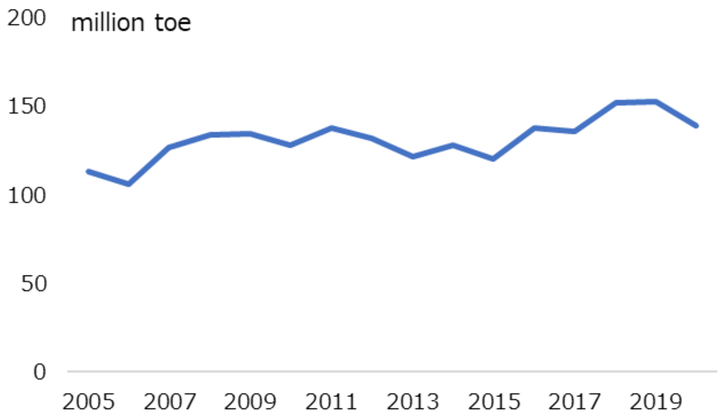
6.6.1 Natural gas utilization master plan

(1) Background

The Philippines is currently highly dependent on coal, with more than half of its power source mix and about 30% of its primary energy supply dependent on coal. In light of such high demand for coal, the existing power development plan plans to expand the power generation capacity of gas-fired power generation in the future. It is necessary to proceed with the introduction of gas-fired power generation in the optimum form, taking into consideration various factors such as geographical distributions of natural gas infrastructure, potential necessity to function as a backup power source for intermittent renewable energy sources, and the overall generation cost to the final consumers.

In the remote islands of the Philippines, oil-fired power generation is used as the main power source, and most of these are considered to be small-scale thermal power generation using diesel oil. In general, such small-scale power generation is often not a favored generation source in terms of both economic efficiency and greenhouse gas emissions. This is because petroleum products tend to be expensive and the heat efficiency of oil-fired power generation is often hot high. Converting such oil-fired power to gas-fired power generation based on LNG is expected to address these inherent issues in the oil-fired power generation.

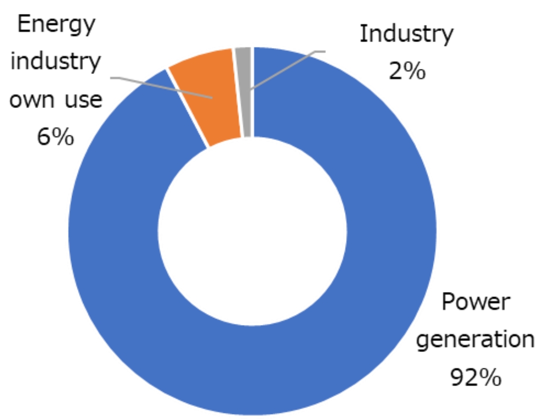
The use of natural gas in the Philippines, on the other hand, has remained stable so far, despite the fact that total energy demand continues to increase (Figure 6-7). This is because of the supply of natural gas in the Philippines has been limited to a particular natural gas field. The Philippines is a country surrounded by sea without international natural gas pipeline connection and has never imported natural gas.



Source: IEA, Energy Balances of the World 2020 edition

Figure 6-7 Natural gas demand in the Philippines

In the Philippines, as of 2018, 92% of natural gas supply was used for power generation, the remaining 6% was own-use by the energy industry (mostly considered as fuel for natural gas production), and only 2 % is used as fuel for industry in the vicinity of Batangas in southern Luzon (Figure 6-8). No natural gas is used in other non-electricity sectors in the Philippines, which suggests that there is a large potential for expanding the use of natural gas in the Philippines.



Source: IEA, Energy Balances of the World 2020 edition

Figure 6-8 The demand component of natural gas in the Philippines as of 2018

The expansion of the use of LNG and natural gas in the Philippines is expected to bring multiple benefits from the viewpoints of diversification of power supply sources, lowering GHG emission, and reliable energy supply to back up the intermittent renewable power generation. Formulation of a master plan to facilitate such natural gas and LNG adoption thus is expected to greatly contribute the future energy supply of the

Philippines.

(2) Objective

Based on the above background, this study proposes to prepare for a master plan for expanding the use of natural gas as one of the future international cooperation with the Philippines. The plan will promote the use of natural gas in a systematic manner and ensure the Philippines economic, environmentally friendly, and reliable energy and power supply.

(3) Expected outcomes

This cooperation project will have four expected outcomes.

a) Outcome-1: Scenarios for energy and power generation mix

First, the major outcome obtained by this project is a long-term energy / power generation demand and supply scenarios with a view to 2050. In these scenarios, it is assumed that different degree of advancements of energy and environment technologies can cause different future scenarios of energy and power generation supplies, and different energy and power supply paths toward 2050 will be provided. Quantitative model analyses in accordance with the different scenarios will also be provided.

b) Outcome-2: Infrastructure development plan

Second, this project aims to provide an infrastructure development plan. Based on the specific scenarios and associated demand projections of natural gas, infrastructure required to enable such scenarios will be identified. Such infrastructure plan will include the development of LNG receiving facilities (floating storage and regasification unit (FSRU) results or onshore receiving terminals), port facilities required to accommodate LNG import vessels, pipeline network to consumers, gas-fired power generation facility, and natural gas pipeline network to the Manila area as needed. Depending on the projection of natural gas demand in remote areas, small-scale LNG delivery facility (LNG Hub) may also be included. The infrastructure plan will also include the estimated amount of investment that require international financial cooperation.

c) Outcome-3: System reform of natural gas market

Third, in order to promote the use of natural gas, it is desirable that there is vibrant natural gas industry that are responsible for the expansion of such businesses. Excessive market liberalization, however, may inflate the future business uncertainty and curb investments. The project therefore will include the appropriate market design of natural gas industry to facilitate infrastructure developments and the use of natural gas in the

Philippines. The analysis will be conducted so as to reflect specific socioeconomic factors in the Philippines and refer to other countries' experience of natural gas market developments including Japan.

d) Outcome-4: Roadmap and policy proposals

Fourth, a roadmap for expanding the use of natural gas in the Philippines in the future and policy recommendations to the Philippine government and state-owned enterprises (PNOC) will be provided. Regarding the roadmap, based on the demand outlook for natural gas obtained, the demand patterns of natural gas in the Philippines as of 2030, 2040, and 2050 will be shown, and the menu of required policies and the expected infrastructure development to accommodate the forecasted demand will be clarified. In addition, the demand for funds required the plan will be presented to attract investment from international donors and private investors.

(4) Required actions

In order to realize the four expected outcomes, the following actions will need to be taken.

a) Activity for outcome-1 (Scenarios for energy and power generation mix)

First of all, using the method of "scenario planning," this project provides two or three future scenarios by identifying critical determinants that can cause different scenario developments in the future. This scenario is not only created by a consultant, but also by having local government officials in the Philippines participate in the discussion and expressing their own concerns about the future energy issues, so that the actual situation in the Philippines can be further reflected.

Likely candidates of such critical determinants are fossil fuel prices (oil and natural gas), renewable energy costs including integration costs such as storage batteries and grid management arrangements, availability of nuclear energy, and the development of international carbon credit system. Considering the potential impacts of these determinants to the future Philippines energy and power generation mix, this project will develop multiple qualitative scenarios with close discussions with the government officials with the Philippines.

After such scenario planning is completed, quantitative analyses for the future energy demand and supply will be conducted. Computer-based models will be utilized for such quantitative analysis (a simplified method such as Simple-E may also be acceptable). Analysis for the natural gas demand and supply in particular will be done in a detailed manner for each demand sector as well as geographical analyses for each region.

When such qualitative scenarios and the quantitative outlook is completed, a review committee will be set up with the government officials and state-owned enterprise officials, and the appropriateness of the created scenario and the contents of the supply and demand outlook will be evaluated. Through this consulting process, awareness of the role of natural gas and its preferred sectors of use will be shared with the Philippines government.

b) Activity for outcome-2 (Infrastructure development plan)

Regarding the infrastructure development plan, the quantitative demand analysis for natural gas obtained in a) provides detailed figures for natural gas demand in each sector and geographical region so that required infrastructure can be identified. Development of infrastructure to meet the future demand is summarized as a plan of infrastructure. Infrastructure that will be included in the plan are:

- LNG receiving facility (FSRU or onshore terminal)
- Natural gas fired power generation plant
- Domestic natural gas distribution network
- LNG distribution facility to remote islands (LNG hub)
- LNG truck distribution system and its satellite terminals, etc.

c) Activity for outcome-3 (System reform of natural gas market)

Currently, natural gas supply in the Philippines is mainly supplied by the Philippines National Oil Company (PNOC), a state-owned oil company. In order to expand the use of natural gas in the Philippines in the future, it may be important to attract private investment and the entry of private businesses to activate the natural gas market. But at the same time, the use of natural gas requires the development of large-scale infrastructure, and excessive market liberalization may not secure sufficient investments. The role of the government and state-owned enterprises needs to remain in this regard. The project will analyze what kind of market system is desirable for such a natural gas industry in the Philippines, and what kind of division of roles should be made between the government and private businesses.

Also, in order to expand the use of LNG, an energy supply source that the Philippines has never utilized, this project will propose what kind of organization should be established as a government regulator to oversee the adoption and expanded use of LNG.

d) Activity for outcome-4 (Roadmap and policy proposals)

Finally, this project will create a roadmap. The contents of the roadmap are qualitative scenarios, quantitative supply and demand analysis, infrastructure development plans, and the ideal industrial structure of the market (degree of liberalization, private sector companies). The time frame of the roadmap is until 2050, but if necessary, longer-term supply and demand targets and policy responses beyond 2050 can be included in the roadmap.

6.6.2 Technical cooperation project for LNG utilization during the transition period

(1) Background

In pursuing the adoption of LNG, one of critical issues is to secure capable human resources. Capacity building therefore is important in advancing the introduction and expansion of LNG. In particular, considering the facts that the Philippines is composed of islands with various sizes, numerous natural disasters such as typhoons can occur, and no domestic natural gas supply is available after the production of exiting field ceases its operation, its natural gas supply system will make a fundamental shift from domestic production-based to LNG imposed-based. In this sense, the conditions of the Philippines will have much more in common with the Japanese conditions, and the Japanese natural gas supply system from supply and demand planning, infrastructure development and management, domestic natural gas logistics, natural gas trading market and industrial structure, to price determination will bring rich policy implications to the Philippines. Also, operational issues, such as mechanical and maintenance operations, and the practices to ensure operational safety, health, and environment will be a useful expertise which Japan can provide the Philippines. Capacity development in the adoption of LNG therefore can be a valuable item for the future international cooperation between the Philippines and Japan.

In this project, comprehensive technical cooperation on the import and utilization of LNG will be implemented. The target of technical cooperation is the staff of the Ministry of Energy of the Philippines and the Philippine Petroleum Corporation (PNOC).

(2) Objective

This project aims to share the knowledge of LNG receiving and utilization between the Philippines and Japan to ensure smooth adoption and demand development of LNG in the Philippines.

(3) Expected outcomes

This project expects the following three outcomes.

a) Outcome-1: Capacity building of the government and state-owned entities officials

First, the most important outcome of this cooperation project is to share the knowledge and expertise of LNG with the officials of the Philippine government (mainly the Department of Energy) and the state-owned oil company (PNOC). Through the capacity building program of the Philippines government and SOE officials, the Philippines can more smoothly pursue its LNG adoption and develop the LNG demand.

b) Outcome-2: Assistance to develop legal and regulatory system for LNG

The next important outcome is to assist the development of legal and regulatory system required for the government to administer LNG import businesses. There are still many policy and regulatory issues that may not have been sufficiently cleared when introducing LNG, such as whether or not the government needs to monitor the procured prices of LNG or how to reflect the imported LNG price to the domestic market. This cooperation project will first present a draft framework of the LNG Business Law (tentative name), which summarizes the provisions regarding the import of LNG. It is important to promptly develop various regulations under the jurisdiction of the government organization related to LNG while maintaining consistency with the current judicial and regulations regarding the supply and use of domestic gas.

c) Outcome-3: Standards of safety, health, and environment

Besides the above outcome of b) on legal and regulatory system development, various technical and operation standards need to be developed to ensure safety, health, and environment (SHE) Since LNG is a product that need to be treated with care, it is not easy for operators who do not have sufficient operational knowledge to carry out the LNG handling operations. This cooperation project assists to prepare for such standards on safety, health, and environment and to prepare for a manual on actual operational know-how.

(4) Required actions to realize the above outcomes

a) Actions for outcome-1 (Capacity building of the government and state-owned entities officials)

In order to realize the expected capacity building, establishing and implementing a systematic training program for the targeted officials will be a primary action. In implementing such a training program, the detailed professional-level programs and instructors are required. If an electric power company or gas company that is already accepting LNG can serve as a consultant for this case, it may be possible to utilize its own in-house education program. If other businesses serve as consultants for this matter, by creating a training program that includes the following items, comprehensive LNG knowledge will be done.

- Potential items of training program
  - Comprehensive overview of LNG supply chain
  - Utilization of LNG in the power, industrial, residential and commercial, and transportation sectors

- Receiving operation of LNG at FSRU and onshore terminal
- Analysis of the world LNG demand and supply
- LNG utilization of other countries
- Financing of infrastructure of LNG receiving
- Contracts in the LNG businesses
- Legal and regulatory framework of LNG businesses
- Safety, health, and environment standards in the LNG business, etc.

b) Actions for outcome-3 (Assistance to develop legal and regulatory system for LNG)

Next, as an activity required for outcome b), a training program will be set up and carried out basically in the same way as outcome a). However, the purpose of this training is to absorb more specialized knowledge and expertise in the legal and regulatory system. Thus, in this training program, the instructors will be invited from practitioners of the relevant departments of the Japanese government.

Specific items in the training program will include the followings:

- Business law that oversees the LNG business (authority to permit the LNG business, government's authority and companies' obligation in the LNG business, government's organization for the LNG issues, etc.)
- Case studies of other countries that have adopted LNG, such as Europe, Japan, Korea, etc.
- Organization that oversees LNG business (independent regulator or a particular organization within the Department of Energy; what king of authority will be delegated to the organization, etc.)
- Practical issues in the LNG business contracts in construction of LNG regasification facility, LNG sales-purchase contract with the LNG seller, operation contracts with the LNG receiving terminal operator, Power purchase agreement with the power generation company; wholesale natural gas supply contract with industrial user, etc.

c) Actions for outcome-3 (Standards of safety, health, and environment)

Regarding the standards on safety, health, and environment, the Philippines has many years of experience in handling natural gas itself, and the standards for natural gas operations are already in place. Thus, the cooperation project focuses on LNG in particular for providing or modifying the existing standards to handle LNG, The responsibility of safe operation primarily belongs to the operators who receives the utilize LNG, but it is desirable for the government officials to accumulate sufficient knowledge and expertise in this regard for its effective policy making and potentially in preparing for some emergencies at the LNG receiving cites.

It is necessary to establish standards in the following fields and thus these subjects will be included in the training program:

- Fundamental concepts of SHE in the LNG value chain
- Safety standards for the LNG unloading
- Procedures from the measurement of unloaded LNG cargo to verification of quantity, to custom clearance
- SHE standards for regasification processes and LNG storage facilities
- Operational manuals for LNG unloading and regasification operations
- Periodical maintenance of the LNG facilities

6.6.3 Net-zero scenario in the Philippines

(1) Background

Since the Paris Accord was agreed in 2015, the so-called net zero target to achieve long-term greenhouse gas emissions to virtually zero has gained global attentions and has been pledged by more countries (Table 6-7). Among ASEAN countries, Indonesia stated in April 2021 that it would aim to achieve net zero by 2070 in the long-term strategy that Minister of Environment and Forests Siti Nurbaya Bakar plans to submit to the United Nations Framework Convention on Climate Change (UNFCCC). As these movements to announce net zero target expands internationally, it is necessary for ASEAN countries other than Indonesia to seriously consider ways to virtually eliminate long-term greenhouse gas emissions in the future.

Table 6-7 Net zero targets by selected countries

Country	Net zero target year	Target by 2030	Announced date
UK	2050	68% reduction from 1990	26 Jun 2019
Germany	2050	65% reduction from 1990	23 Sep 2019
France	2050	40% reduction from 1990	08 Nov 2019
EU	2050	55% reduction from 1990	06 Mar 2020
China	2060	60-65% reduction of CO2 intensity from 2005	22 Sep 2020
Japan	2050	46% reduction from 2013	26 Oct 2020
Korea	2050	24.4% reduction from 2017	28 Oct 2020
Brazil	2050	43% reduction from 2005	09 Dec 2020
United States	2050	50-52% reduction from 2005	27 Jan 2021
Indonesia	2060	29-42% reduction compared to BAU	12 Apr 2021
Russia	2060	70% reduction from 1990	13 Oct 2021
Saudi Arabia	2060	Reduction of 278 million tons of CO2	25 Oct 2021
India	2070	Reduction of CO2 intensity of GDP by 33%-35% from 2005	02 Nov 2021

Note: Announced date is that of net zero announcement.

Source: Made by IEEJ based on various government and media materials

On the other hand, there is a large difference in the difficulty of achieving net zero emissions between Western countries and emerging countries including ASEAN countries. In many developed countries, energy demand is mature and is unlikely to see a large increase in the future. In these countries, furthermore, the average income is also high, and the people have more capacity to bear the additional costs for climate change such as carbon prices. On the other hand, in many emerging countries, the first priority is to secure physical volume of energy to meet the growing energy demand. What is more important is that, because of the relatively lower personal income, the energy supplied has to be priced at affordable level. For this reason, many emerging countries have less "luxury" to narrow down the energy options for climate action purpose like in developed countries do, and in that sense, it is far more difficult to achieve net zero. Therefore, when considering the path to net zero in emerging countries, the same goals as in developed countries may not be set uniformly; instead, stepwise and realistic approach should be taken.

In this cooperation project, multiple net-zero scenarios will be provided considering such differed conditions between developed and emerging countries. Specific conditions of the Philippines, such as resource endowments, social and economic conditions will also be reflected. After that, the optimal scenario for the Philippines will be identified through sufficient dialogue with the Philippine government officials, and the infrastructure development plan will be presented necessary for its realization of the scenario with the specific infrastructure projects that Japan can cooperate.

(2) Objective

This cooperation project provides multiple scenarios to realize net zero for the Philippines and present an idea for the international net zero pledge which will not excessively burden on the macro economy and the energy supply for the Philippines.

(3) Expected outcomes

a) Outcome-1: Multiple net zero scenarios

The main outcome expected in this cooperation project is the presentation of two or three scenarios to reach net zeros under different time axes and preconditions related to energy and environmental technology. As a candidate of such scenario determinant, two variables are assumed: 1) the time axis for achieving net zero (2050, 2070, etc.) and 2) the degree of cost reduction of energy and environmental technologies. Then, create multiple scenarios by combining the different variables.

b) Outcome-2: Economic costs analysis and an optimal reduction path

The second expected outcome is calculation of economic costs required to achieve each net zero scenario. Each scenario will take a different path of GHG emissions reduction and selected energy portfolio, and will require a different level of carbon price (or marginal emissions reduction cost). Economic costs of each scenario will be compared based on the calculated carbon prices in each scenario. The study then suggests an optimal emissions reduction path with particular time frame and technological assumptions.

c) Outcome-3: Specific project for international cooperation to realize net-zero

The third expected outcome is to identify international cooperation items between the Philippines and Japan to realize the net zero emission based on the optimal reduction path. While the candidate areas for such international cooperation will be extensive, this project will identify prioritized ones that will bring large reduction effects while the need for international technical and financial cooperation is large.

(4) Required activities

a) Activity for outcome-1 (Multiple net zero scenarios)

As an activity required to realize the outcome-1, firstly the target year of net-zero achievement will be set with close discussions among the government officials, JICA, and its consultants. Through the discussions, both an importance to achieve net-zero and potential constrains particular to the Philippines will be shared among the relevant parties. Based on such exchange of opinions, once the specifications for realizing the scenario (target achievement year and other important scenario variables) are decided, back cast-based quantitative analysis will be conducted to realize net zero in the future. Quantitative representation of the primary energy-supply composition, power source composition, and greenhouse gas (CO_2) emissions in each base year (2030, 2040, etc.) will be provided based on the scenario assumptions.

b) Activity for outcome-3 (Economic costs analysis and an optimal reduction target)

As a benchmark to compare economic costs of multiple scenarios, carbon price as marginal emissions reduction cost will be calculated. In order to realize the final net zero status, a certain degree of carbon price will be required. This is because even if the cost of various different CO_2 emission reduction technologies such as renewable energy drops significantly in the future, that alone is unlikely to be sufficient to replace the use of existing fossil fuels, especially in the so-called "hard-to-abate" sectors such as heavy industry and long-distance transportation. In each scenario, the economic cost required to realize the scenario is calculated based on the carbon price.

The optimal long-term net zero target for the Philippines is determined based on various political, economic and social conditions. In this cooperation project, the above economic cost assessment will be referred to as one of such determinants to finalize the net-zero target by the Philippines.

c) Activity for outcome-3 (Specific project for international cooperation to realize net-zero)

The project will also identify areas for international cooperation to achieve net zero, particularly in the infrastructure and technology developments. Candidates for such cooperation include storage technologies for renewable energies such as storage batteries and hydrogen, technologies that enable effective utilization of existing fossil fuel-related infrastructure such as fuel ammonia, and international transfer of CCUS technologies and CO2 transportation. Financial support required for such cooperation will also be analyzed.

6.7 Roadmap to Net-zero

Finally, Figure 6-9 shows a roadmap for reducing greenhouse gas emissions to net-zero in the Philippines. Like the previous two cases, this roadmap was created by a back cast approach, and the cost and technical feasibility required to realize it are not rigorously examined.

First, in the power sector, its share of final energy consumption will be raised from 21% in 2018 to 30% in 2030, and then to 50% in 2060. As a required action in the power development, the first priority is to introduce renewable energy, and introduction of nuclear power may be seriously considered as a zero-emission base-load power generation source. As of 2018, the share of renewable power sources in the Philippines was 23%, about half of which is geothermal. In the future, due to restrictions on suitable locations, it is expected that their relative share of geothermal will decline, and power sources such as solar and wind power will be intensively introduced. The share of renewable power sources in the power source composition is expected to be 40% in 2040 and 80% in 2060. From the viewpoint of the need for a backup power source and geographical factors for renewable energy, the remaining 20% will be thermal power generation centered on natural gas with CCUS or hydrogen.

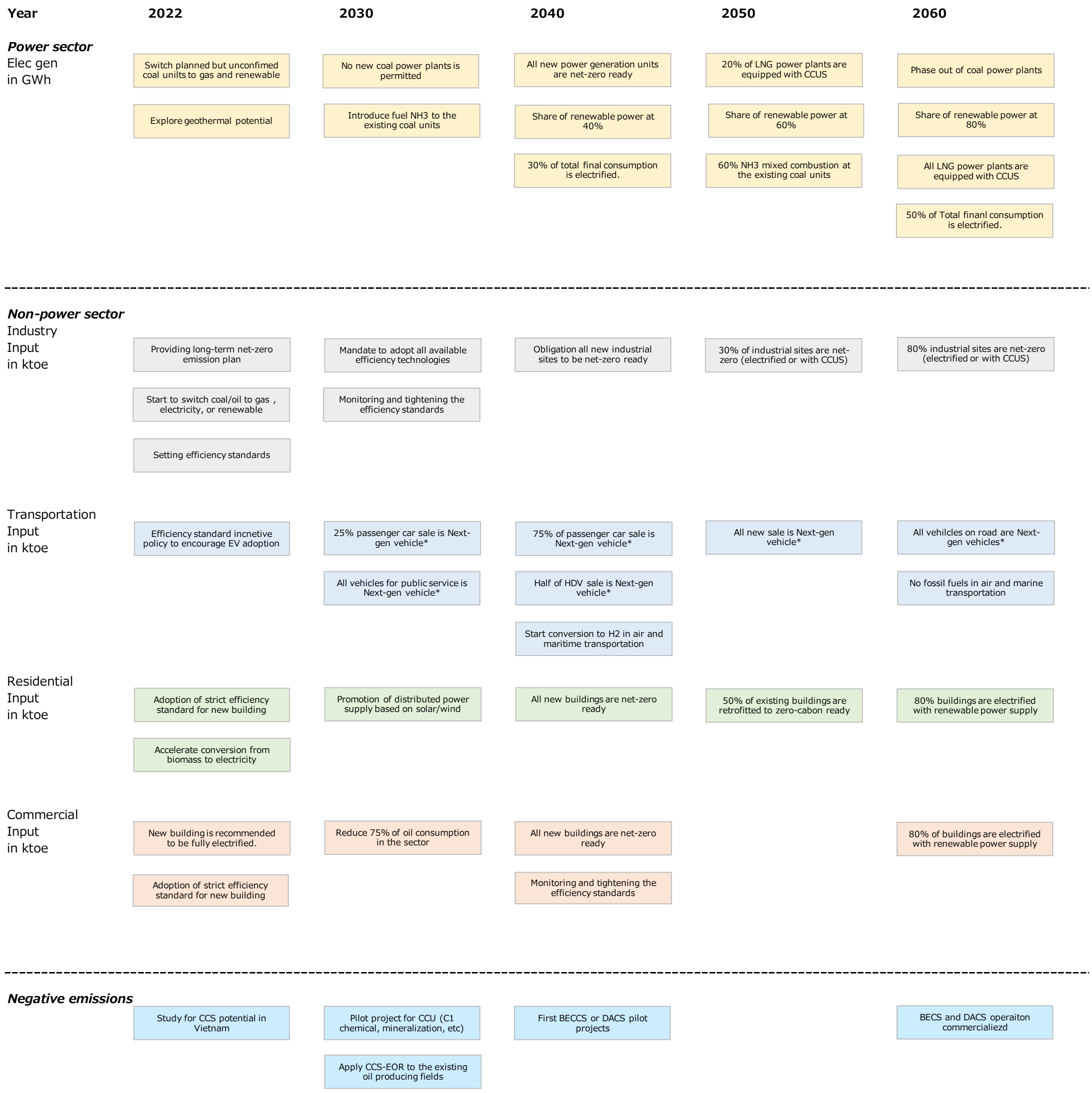
Regarding thermal power generation, new development of coal-fired power generation other than those whose investment decisions have already been mad will be converted to other low-carbon power generation sources such as natural gas-fired power generation or renewable energy power generation. Plan of new build of coal-fired power generation will be abolished as of 2030 and the facility for co-firing of fuel ammonia will be installed. As of 2050, the rate of ammonia co-firing will be raised to 60%, and as of 2060, all coal-fired power plants will be shut down while naturas gas-fired units will remain operated by installing CCUS facilities.

Regarding the non-power sector, as in the two countries mentioned above, in the industrial sector, as a short-term countermeasure will be to formulate an action plan by each industry to achieve net-zero in the long run. Sharing a common vision for net-zero through such planning activities will be the first task to work on. At the same time, strict energy efficiency standard will be adopted, and fuel switching from oil to natural gas (LNG) and electricity will be pursued. As of 2040, all new industrial facilities are ideally "net-zero ready" where each facility has a specific and concrete roadmap to achieve net zero by 2060. Specifically, as in the case of the two countries mentioned above, the introduction of renewable electricity or other non-fossil fuels, the installation of carbon recovery equipment to recover the emitted CO_2, and the combined use of negative emission technology will be major action menu in such plans. By introducing such countermeasures, by 2060, at least 80% of industrial facilities will be net zero.

In the transportation sector, the Philippines will also promote electrification and hydrogen substitution. First, while promoting the introduction of strict fuel efficiency standards, incentive mechanism to introduce electric vehicles such as taxation will be adopted. From around 2030, furthermore, the share of next-generation vehicles (electric vehicles, fuel cell vehicles, hydrogen engine vehicles, etc.) in the domestic new vehicle sales will be gradually raised by regulation, and all new vehicle sales will be zero-emission vehicles as of 2050. In addition, transportation means such as aircraft and ships that are difficult to electrify will be converted to hydrogen from around 2050, and by 2060, all means of transportation will be electricity or hydrogen (or other zero-emission fuel).

As for the residential and commercial sector, as in the transportation sector, energy efficiency improvement and electrification will be promoted as the initial action. Energy-efficiency standards will be introduced for the residential sector and newly built building will be required to ensure a high level of efficiency and electrified. In rural areas, commercial energy supply and decarbonization will be realized at the same time by promoting decentralized renewable power sources such as solar and wind power from traditional biomass. By at least 80% of housing will achieve net-zero. In the commercial sector, energy-efficiency standards will also be applied and new building will be electrified. Furthermore, oil, which is currently the largest energy source for commercial use, will be converted to renewable energy and electricity. From 2040 onward, new buildings will be required to be constructed as "net-zero" ready, and as of 2060, the sector will be as close to zero as possible.

Finally, regarding negative emission technology, the first required activity will be to investigate CO_2 storage potential in the Philippines. The storage potential in the Malampaya gas field in the country and the storage potential in other aquifers will be explored and investigated in detail. On the other hand, the evaluation and future utilization of CCU technologies at the existing industrial complex for producing methanol or mineralization by 2030 for CCU. As of 2050, a study on the possibility of introducing Direct Air Capture and Storage (DACS) or Bio Energy Carbon Capture and Storage (BECCS) technology, which combines direct air capture or domestic biofuel use with CCS, will be started for extensive application as of 2060.



Source: The Institute of Energy Economics, Japan

Figure 6-9 Roadmap toward net zero in the Philippines