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Decarbonisation of Thermal Power Generation in ASEAN Countries

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Decarbonisation of Thermal Power Generation in ASEAN Countries

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This report was prepared by the Working Group for the Decarbonisation of Thermal Power Generation in ASEAN Countries under the Economic Research Institute for ASEAN and East Asia (ERIA) Energy Project. Members of the Working Group discussed and agreed to utilise certain data and methodologies.

Foreword

In recent years, decarbonisation of the power generation sector in East Asia Summit (EAS) countries has steadily progressed. Biomass, hydrogen, and ammonia are considered to be important technological options for EAS countries in their efforts to achieve decarbonisation to mitigate the effects of climate change – if these are coupled with low-carbon power generation sources.

In view of the future expansion of hydrogen and ammonia, policymakers in the EAS region will have to prepare the necessary policies, programmes and plans, economic incentives, and focused infrastructure expansion to support the hydrogen and ammonia fuels, thereby accelerating power sector decarbonisation.

This report provides an assessment of the potential for reducing carbon dioxide emissions through power generation with ammonia fuel. It identifies the strengths, weaknesses, opportunities, and threats related to the decarbonisation of the power generation sector in selected ASEAN countries. The report also includes a cost analysis of coal–ammonia mixed combustion.

I hope the report will provide ASEAN countries with a good basis for understanding necessary policies and measures, as well as business and infrastructure development for ammonia fuel.



Professor Hidetoshi Nishimura

President

Economic Research Institute for ASEAN and East Asia (ERIA)

October 2022

Acknowledgements

This analysis was carried out by a working group under the Economic Research Institute for ASEAN and East Asia (ERIA), comprising members from Indonesia, Malaysia, the Philippines, Thailand, and Viet Nam, and The Institute of Energy Economics, Japan (IEEJ). We would like to acknowledge the support provided by everyone involved. We especially want to express our gratitude to the members of the Working Group.

ASEAN member countries supported us in collecting plans and related information on the power generation outlook in ASEAN countries. Each country's experts supported this step to estimate the effects of CO₂ reduction by ammonia mixing in coal-fired power generation.

ASEAN member countries presented policies and power development and decarbonisation plans in two workshops. Each country representative actively reviewed and commented on our report.

Valuable insights were obtained from several government officials and analysts who were an integral part of implementing this study.

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List of Abbreviations and Acronyms

ASEAN	Association of Southeast Asian Nations
BAU	business-as-usual scenario
CCS	carbon dioxide capture and storage
CCUS	carbon dioxide capture, utilisation, and storage
CO ₂	carbon dioxide
COP	Conference of the Parties
DOE	Department of Energy
EAS	East Asia Summit
EOR	enhanced oil recovery
ERIA	Economic Research Institute for ASEAN and East Asia
ETM	Energy Transition Mechanism
EV	electric vehicle
GDP	gross domestic product
GHG	greenhouse gas
HHV	higher heating value
IEA	International Energy Agency
IEEJ	The Institute for Energy Economics, Japan
LCCP	Low-carbon Scenario Compatible with the Paris Agreement Target
LCOE	levelised cost of electricity
LNG	liquefied natural gas
METI	Ministry of Economy, Trade and Industry, Japan
NDC	nationally determined contribution

NH ₃	ammonia
NRE	new and renewable energy
NREP	National Renewable Energy Program (Philippines)
PDP	power development plan
PEP	Philippine Energy Plan
PV	photovoltaic
REF	Reference Scenario
USC	ultra-supercritical

Executive Summary

This analysis contains the following four parts.

Firstly, we collected plans and related information on the power generation outlook in ASEAN countries concerning the national power development plans and other elements. We also collected climate change policies. ASEAN countries aim to adopt decarbonisation as a long-term strategy. It is important for each country to adopt related policies such as climate change, energy security, energy mix, renewable energy, and coal. To achieve decarbonisation, policy and technology development is necessary. Each country expert supported this step.

Secondly, we collected ammonia market information and experiences regarding fuel ammonia worldwide. We estimated the potential for ammonia cost and production in ASEAN and other countries as well as ammonia import to ASEAN countries. We also considered the possibility of technology innovation for ammonia production and utilisation of existing facilities to deliver and store ammonia.

Thirdly, we estimated the effects of carbon dioxide (CO₂) reduction by ammonia co-firing in coal-fired power generation. The CO₂ reduction potential was estimated using the power plant database to select ammonia co-firing plants. For this estimation, the ammonia co-firing ratio, capacity factor, and efficiency are set as parameters. This estimation has two cases: (i) low scenario (~2030: all capacity under construction phase, 2031~: no additional capacity) and (ii) high scenario (~2030: all capacity under construction and project phase, 2031~: no additional capacity).

Finally, we identified barriers to the decarbonisation of thermal power generation such as ammonia co-firing in coal-fired power generation and the creation of ammonia supply chain amongst Japan and ASEAN countries.

We conducted two workshops to share the results of this study with Indonesia, Malaysia, the Philippines, Thailand, and Viet Nam. Each member country participated in the workshop and was advised to actively improve this study.

Chapter 1

Decarbonisation Initiatives of ASEAN Countries

Overview

Amidst the global movement towards carbon neutrality, ASEAN countries are also being urged to abolish coal-fired thermal power decarbonisation. However, with coal power accounting for, e.g. around 60% of the power supply structure in Indonesia and about 50% in Viet Nam, and with energy demand anticipated to rise further with economic growth, the efficient use of coal-fired thermal power will remain indispensable as a stable power source in the future. Meanwhile, since countries may face difficulties in financing unless they decarbonise earnestly, each ASEAN country should start formulating a road map based on the concept of transition, in which decarbonisation efforts are implemented in phases according to the country's situation, beginning by the introduction of relatively affordable low-carbon technologies.

Given each country's energy mix and potential to introduce renewable energy, covering all additional electricity demand entirely with renewable energy is not realistic. Thus, it will be important to pursue realistic pathways in line with the supply and demand and each country's industrial structure.

Given these issues, we will explore in depth the anticipated challenges in pursuing decarbonisation. First, we examine the current power supply structure and future power development plans of five key ASEAN countries (Indonesia, Malaysia, the Philippines, Thailand, and Viet Nam) and their status in introducing climate measures and renewable energy capacity, and any decarbonisation efforts.

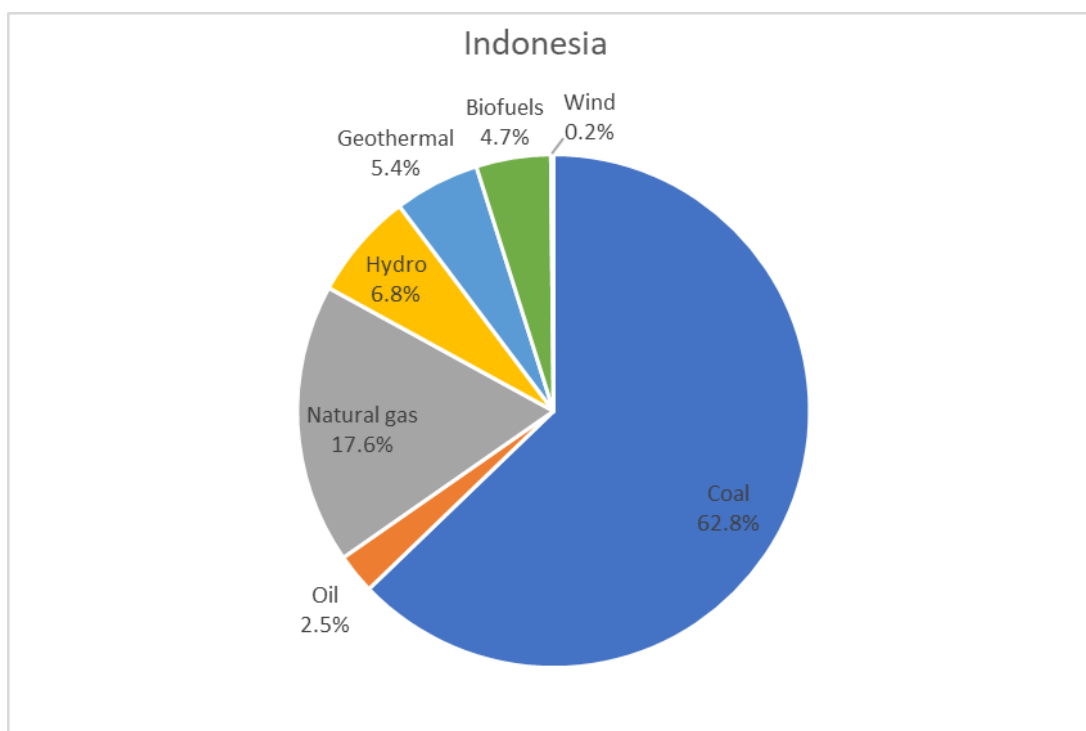
1. Indonesia

1.1. Current power supply structure

Indonesia is the fourth most populous country in the world and the largest amongst ASEAN countries. It continues to achieve stable growth, with a gross domestic product (GDP) growth rate of around 5% before the pandemic. However, its dependence on coal power is an issue. With its national greenhouse gas (GHG) emissions accounting for roughly half of the total for ASEAN countries, Indonesia must act to remain on a path of sustainable growth.

Indonesia's current power supply structure is shown in Figure 1.1. Coal power accounts for the largest share at 62.8%, followed by natural gas power at 17.6%. In 2019, the country had a total power output of 288 TWh.

Figure 1.1. Current Power Supply Structure in Indonesia (2019)



Source: IEA (2021a).

1.2. Power development plan

Indonesia's power development plan is under discussion. The country's nationally determined contribution (NDC) submitted in July 2021 states that it will follow its National Energy Policy¹ stipulated in 2014, its latest policy statement.

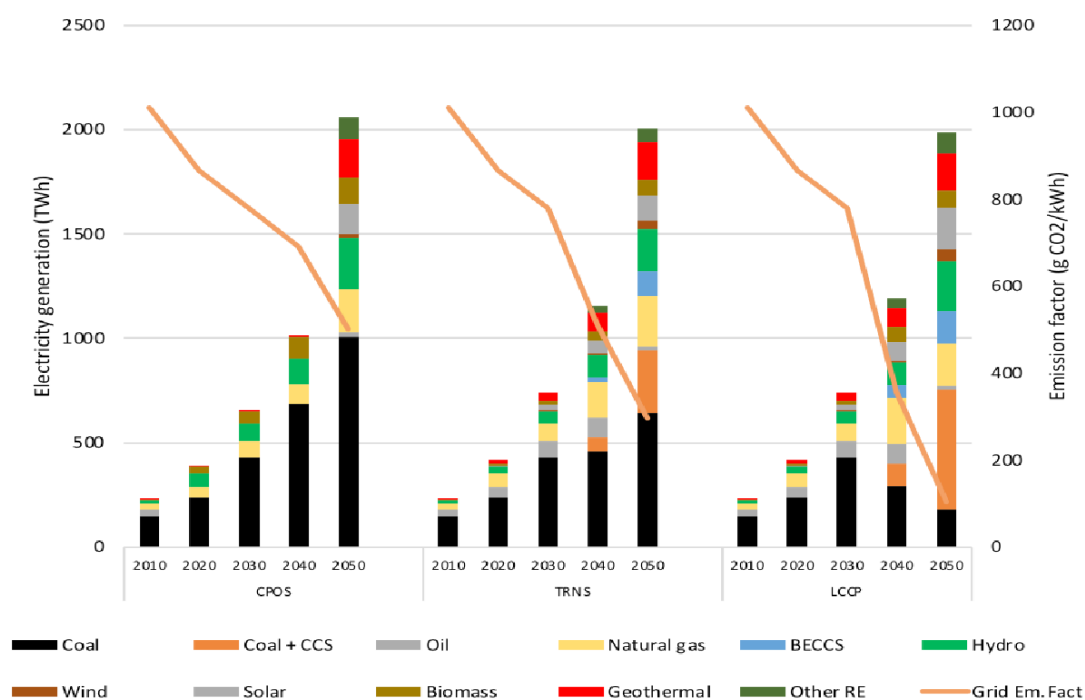
To shift to clean energy sources, the National Energy Policy sets the following targets for 2025 and 2050:

- 1) a share of at least 23% for new and renewable energies (NREs) in 2025 and 31% in 2050
- 2) a share of 25% or less for oil in 2025 and 20% or less in 2050
- 3) a share of 30% or less for coal in 2025 and 25% or less in 2050
- 4) a share of 22% or less for gas in 2025 and 24% or less in 2050

Furthermore, Indonesia's the Long-Term Strategy for Low Carbon and Climate Resilience 2050 (LTS-LCCR 2050) submitted to the United Nations in July 2021 predicts the country's power supply structure based on three scenarios: the Current Policy Scenario (CPOS), the Transition Scenario (TRNS), and the Low-carbon Scenario Compatible with the Paris Agreement Target (LCCP). The LCCP, the scenario with the highest degree of decarbonisation, predicts a power supply composition in 2050 of 43% NREs, 38% coal, 10% natural gas, and 8% bioenergy with carbon capture and storage (CCS), with roughly 76% of all coal power plants adopting CCS to achieve zero emissions. However, the power source plan in this scenario is a forecast rather than a backcast. All scenarios in the LTS-LCCR 2050 predict that coal power will remain in use in 2050.

¹<https://policy.asiapacificenergy.org/sites/default/files/Government%20Regulation%20No.%2079%3A2014%20of%202014%20%28EN%29.pdf>.

Figure 1.2. Power Supply Mix and Projected Grid Emission Factors



BECCS = bioenergy with carbon capture and storage, RE = renewable energy.

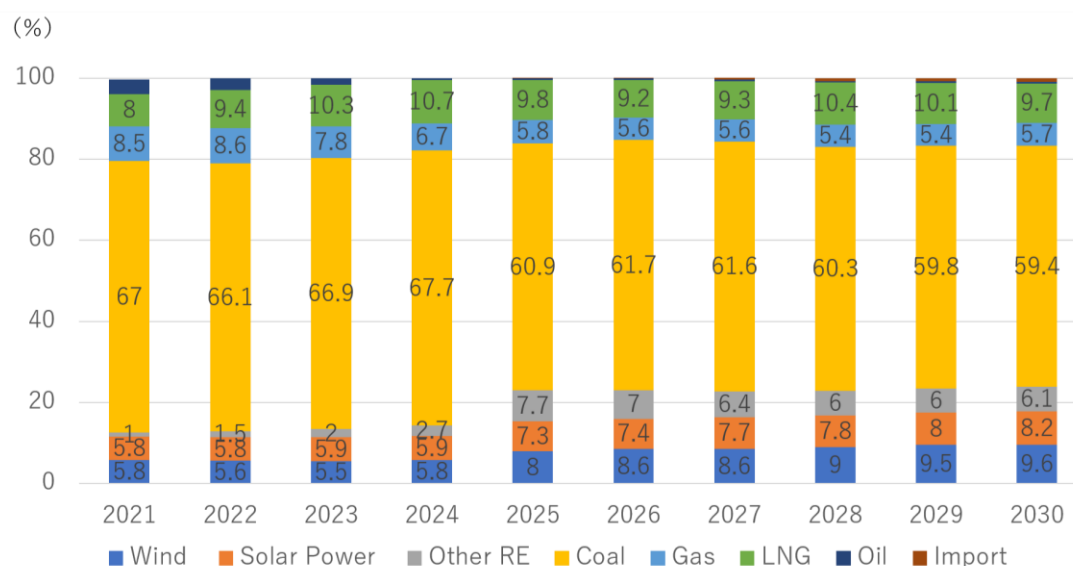
Source: Government of Indonesia (2021).

Meanwhile, in October 2021, the Ministry of Energy and Mineral Resources announced the power supply business plan (*Rencana Usaha Penyediaan Tenaga Listrik: RUPTL*)² of Indonesia's state-owned power company, PLN. According to the plan, the country will phase out its coal power plants from 2025, starting with the least efficient ones, and will not build new plants in 2025 and beyond unless a contract has already been signed.

Furthermore, PLN's 2021–2030 supply plan anticipates average annual growth of 4.9% in electricity output over the next 10 years. PLN's power supply plan is shown in Figure 1.3. Coal accounts for 60.9% and NREs for 23% in 2025 and 59.4% and 23.9%, respectively, in 2030.

² <https://web.pln.co.id/statics/uploads/2021/10/ruptl-2021-2030.pdf>

Figure 1.3. Electricity Supply Planning in the PLN



LNG = liquefied natural gas, RE = renewable energy.

Source: PLN (2021).

1.3. Climate change policy (NDC)

Indonesia submitted its updated NDC and Long-Term Strategy for Low Carbon and Climate Resilience 2050 (LTS-LCCR 2050) to the United Nations in July 2021.

In the updated NDC, Indonesia raised its 2030 GHG emission target from the previous target of 26% of business-as-usual scenario (BAU) figures to 29% and an ambitious level of up to 41% if international support is provided.

In the LTS-LCCR 2050, the country pledges to reach peak GHG emissions in 2030 and achieve net-zero emissions in 2060 or earlier.

Table 1.1. Outline of Nationally Determined Contribution

Target	Target Value	Target Year	Base Year	Basis Law
GHG Emissions	<p>▲ 29%</p> <p>(▲ 41%: with international support)</p>	2030	BAU	NDC

Source: UNFCCC (2021).

1.4. Outlook for coal

At the Conference of the Parties (COP26) held in November 2021, Indonesia signed the Global Coal to Clean Power Transition Statement, albeit with conditions.³ The country plans to phase out coal by 2056 and accelerate the timeline to the 2040s if international financial and technical assistance is provided.

In November 2021, the World Bank's Climate Investment Funds announced the launch of the \$2.5 billion Accelerating Coal Transition⁴ (ACT) programme to help India, Indonesia, the Philippines, and South Africa, accelerate the shift from coal power to clean energy. The four countries collectively account for 15% of the world's coal-related GHG emissions. ACT was approved⁵ by the G7. The programme seeks to assist the energy transition of coal-dependent countries and transform them into sustainable economies.

1.5. Outlook for renewable energy

Indonesia's installed renewable energy capacity was 49 TW in 2020, accounting for 17% of its total power output. It comprises 6.8% hydropower, 5.4% geothermal power, 4.7% biomass power, and 0.2% wind power.

As for the country's renewable energy outlook, the Ministry of Energy and Mineral Resources has revealed that a road map for achieving carbon neutrality by 2060 is being drawn up.⁶ The road map contains the following preliminary capacity targets for renewable energy:

- 2022: NRE law enacted
- 2025: NREs expanded to 23%
- 2030: NREs expanded to 42%
- 2035: NREs expanded to 57%
- 2040: NREs expanded to 71%
- 2050: NREs expanded to 87%

³ <https://ukcop26.org/global-coal-to-clean-power-transition-statement/>

⁴ <https://www.climateinvestmentfunds.org/news/cif-begins-historic-25b-coal-transition-pilot-four-developing-countries>

⁵ <https://www.climateinvestmentfunds.org/news/statement-g7-endorsement-climate-investment-funds>

⁶ <https://www.esdm.go.id/en/media-center/news-archives/road-map-to-carbon-neutrality-is-being-prepared-says-energy-minister>

- 2060: NREs expanded to 100%

The upcoming road map is expected to present an updated power supply structure.

1.6. Recent moves towards decarbonisation

• Carbon pricing

Indonesia aims to establish an emissions trading market by 2023. In March 2021, a trial of emissions trading began for the electricity subsector as a pilot project.⁷ In this project, participants were allowed to purchase credits for a maximum of 70% of the gap with their emission allowance. They must cover the remaining portion through other emission reduction and carbon offset activities, such as building renewable power plants. Participating in the project to gain expertise in CO₂ emissions trading are 80 coal power plants, including 59 owned by the state power company PLN.

From April 2022, a CO₂ emission quota was to be introduced in the power sector and a carbon tax was to be imposed on excess emissions with a very low tax of Rp 30,000 (\$2)/t-CO₂⁸.

However, the Ministry of Finance has twice postponed the introduction of the carbon tax due to the uncertain outlook caused by inflation due to rising fuel costs, and the timing of the introduction of the carbon tax is currently undecided.

• Energy Transition Mechanism by ADB

At COP26, held in November 2021, the Asian Development Bank (ADB), Indonesia, and the Philippines announced a partnership to establish the Energy Transition Mechanism (ETM).⁹ The mechanism aims to retire existing coal power plants ahead of schedule and replace them with clean power plants. When the ETM involving Indonesia, the Philippines, and possibly Viet Nam becomes fully operational, aiming to retire 50% of the total coal power output of 30 GW over the next 10 to 15 years, the parties believe it could cut 200 million tonnes of CO₂ emissions per year. The Japanese government has announced an aid of \$25 million for the

⁷ [https://www.esdm.go.id/en/media-center/news-archives/uji-coba-perdagangan-karbon-diikuti-80-pembangkit-](https://www.esdm.go.id/en/media-center/news-archives/uji-coba-perdagangan-karbon-diikuti-80-pembangkit)

⁸ <https://www.esdm.go.id/en/media-center/news-archives/energy-ministry-disseminates-carbon-tax-policy-in-electricity-subsector>

⁹ <https://www.adb.org/news/adb-indonesia-philippines-launch-partnership-set-energy-transition-mechanism>

ETM partnership.¹⁰

- **Japan–Indonesia memorandum of understanding (MOU) for achieving energy transition**

Japan and Indonesia signed an MOU on a phased transition towards net-zero emissions.^{11,12}

The parties recognise the important role of fuel ammonia in achieving a hydrogen energy society not only as a hydrogen carrier but also as a zero-emission fuel. Therefore, they will cooperate on the future development of the hydrogen and fuel ammonia markets. Examples of the technologies referred to in the MOU include hydrogen; fuel ammonia; carbon recycling; CCS/carbon capture, utilisation, and storage (CCUS); and enhanced oil/gas recovery. One project currently making progress is a joint study by the Mitsubishi Heavy Industries and Indonesia's Research and Development Center for Oil and Gas or LEMIGAS on the co-combustion of fuel ammonia in a coal power plant. The study aims to assess the technological and economic feasibility of partially substituting coal with ammonia to maintain the operating life of coal power plants.

2. Malaysia

2.1. Current power supply structure

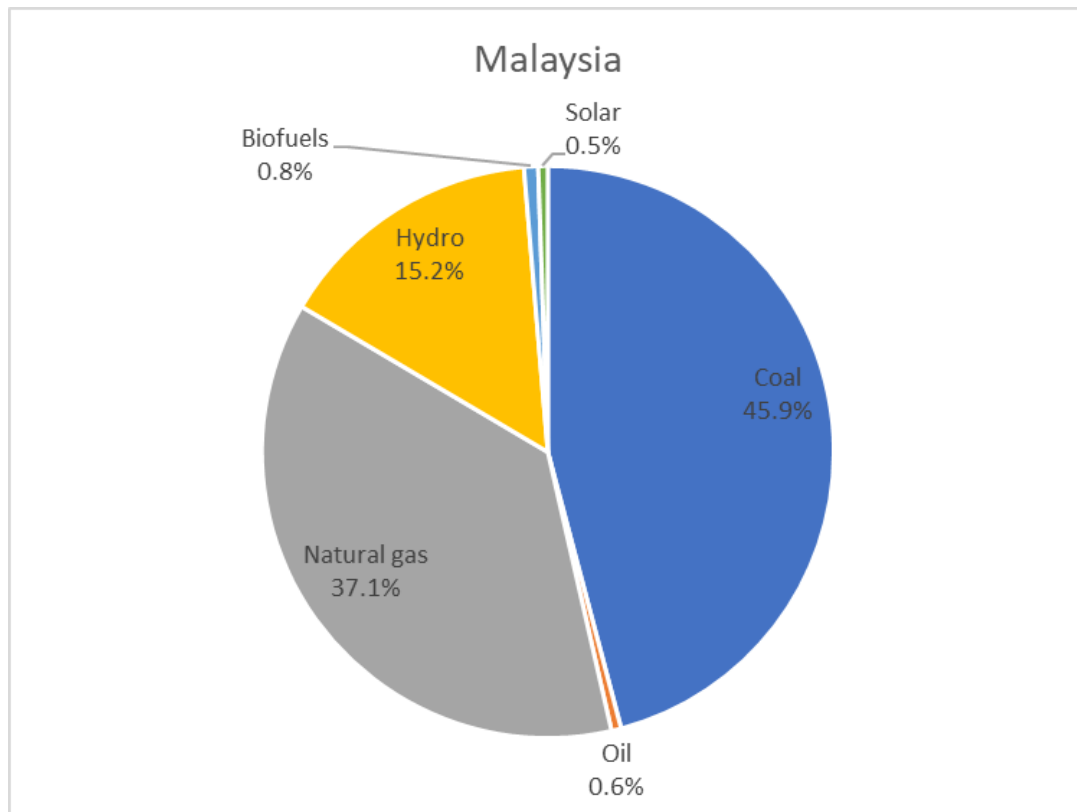
Malaysia's power supply structure consists of 45.9% coal power, 37.1% natural gas power, and 16.5% renewable electricity (including hydropower).

¹⁰ <https://www.adb.org/id/news/japan-announces-25-million-adb-led-energy-transition-mechanism-southeast-asia>

¹¹ <https://www.esdm.go.id/en/media-center/news-archives/indonesia-jepang-teken-kerja-sama-transisi-energi>

¹² <https://www.meti.go.jp/press/2021/01/20220113003/20220113003-1.pdf>

Figure 1.4. Current Power Supply Structure in Malaysia (2019)



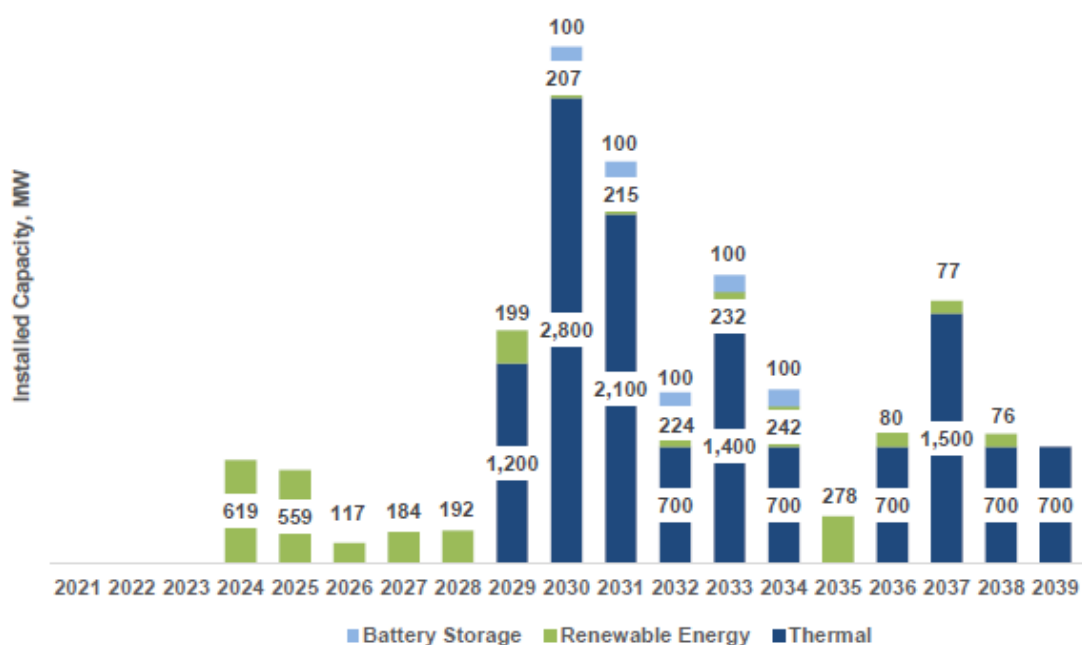
Source: IEA (2021a).

2.2. Power development plan

As for the development of coal power plants, according to the Report on Peninsular Malaysia Generation Development Plan 2020 (2021–2039) published by the Energy Commission (2021), there are plans to abolish 2,100 MW of coal power plants in 2031 and 1,400 MW in 2033. Meanwhile, there are two new build projects in 2021–2039: one 1,400 MW plant in 2031 and one 700 MW plant in 2037. In his speech on the national development plan (Malaysia Plan) on 27 September 2021, Prime Minister Ismail Sabri bin Yaakob stated that the government would build no new coal power plants (Economic Planning Unit, 2021).

There are no plans to build new thermal power plants until 2028, even though closing plants will be replaced (with 1,200 MW of new thermal power plants (combined cycle gas turbine) capacity in 2029 and 2,800 MW in 2030).

Figure 1.5. Power Supply Plan for Peninsular Malaysia (2021–2039)



Source: Energy Committee (2021),

2.3. Climate change policy (NDC)

Malaysia's NDC aims to reduce the national GHG emissions per unit GDP by 45% from 2005 levels by 2030. This is 10% higher than the target registered when Malaysia ratified the Paris Agreement on 16 November 2016. The government intends to draw up an NDC road map to formulate concrete mitigation actions to fulfil the Paris Agreement and to present clear reduction targets for each key GHG emission sector (Economic Planning Unit, 2021).

Table 1.2. Outline of Nationally Determined Contribution

Target	Target Value	Target Year	Base Year	Basis Law
GHG emissions intensity of GDP	▲ 45%	2030	2005	NDC

Source: UNFCCC (2021).

2.4. Outlook for coal

Malaysia does not have a national policy on coal production. However, coal is one of the key energies alongside oil, natural gas, and hydropower based on the Four-Fuel Diversification Policy¹³ (policy for fuel diversification using the four fuels), and the construction of coal power plants has been pursued since the 1980s.

Malaysia began to produce coal to supply its coal power plants in 1988 in the state of Sarawak. The country produced 350,000 tonnes of coal in 2000, 2.4 million tonnes in 2010, and 2.98 million tonnes in 2020 (IEA, 2021d).¹⁴

Meanwhile, coal consumption has increased with the construction of coal power plants. It rose from 410,000 tonnes in 1988 to 3.66 million in 2000; 23.16 million in 2010; and as much as 34.08 million in 2020. Coal imports grew from 410,000 in 1988 to 3.08 million in 2000, surpassed 20 million tonnes in 2010 with 20.74 million, and reached 31.10 million in 2020 (IEA, 2021d).¹⁵

The Energy Commission provides a forum for sharing information on facility planning and coal import and supply, as well as discussing the future coal-sourcing strategy. Its policy is to use mainly coal imported from Indonesia.

The Malaysian government plans to increase the share of renewables to 31% of its power source structure in 2025. It expects the installed capacity of coal power plants to decrease from 37% in 2021 to as low as 22% in 2039. Accordingly, coal consumption is expected to decrease gradually.

2.5. Outlook for renewable energy

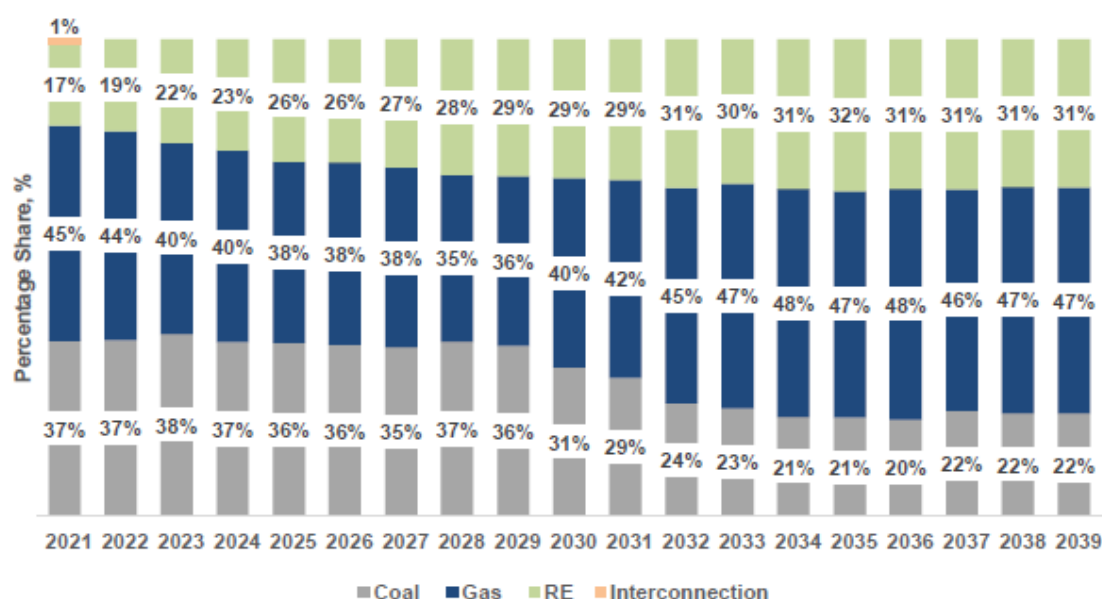
The government plans to increase the national target share of renewable capacity (including hydropower) to 31% in 2025 from the previous target of 20% (to 26% for the Malay Peninsula). The Malay Peninsula is slated to introduce an additional renewable energy capacity of 1,178 MW (including 1,098 MW of solar photovoltaic (PV) plants). Accordingly, the transmission network infrastructure is expected to be strengthened using highly needed technological solutions such as energy storage systems.

¹³ In 1999, the Five-Fuel Diversification Policy, which included renewable energy, entered into effect.

¹⁴ 2020 output is an estimate.

¹⁵ 2020 consumption and imports are estimates.

Figure 1.6 Prospects for the Power Supply Capacity Mix in the Malay Peninsula



Source: Energy Committee (2021).

2.6. Recent moves towards decarbonisation

a) The Twelfth Malaysia Plan

The current Malaysia Plan, the twelfth (2021–2025), aims to promote green growth by implementing a clean, green, and resilient development agenda through a nationwide approach. It sets the following strategic objectives:

- accelerate the transition to a circular economy
- promote green and resilient cities and townships
- strengthen green mobility
- increase low-carbon energies
- strengthen mineral resource management
- improve resilience against climate change and natural disasters

Furthermore, Malaysia plans to strengthen the development and utilisation of renewable energy resources. The country will also focus on using other renewable resources, such as biomass and biogas, as well as large-scale hydropower and solar PV. By utilising existing and

new technologies such as cogeneration, solar heat energy, and fuel cells, it seeks to provide the industry with more alternatives. Further, the plan refers to accelerating the introduction of energy storage systems and other new technologies to resolve the intermittency of solar power.

Regarding energy policy, the plan states that the growth potential related to energy will be studied, particularly new energies that use clean and sustainable resources, especially hydrogen.

Malaysia plans to use domestic gasoline and diesel oil, encourage high-value investment in the petrochemical industry, and expand the use of biofuels to ensure the development and sustainability of the domestic oil and gas industries.

b) Moves to adopt carbon pricing

Malaysia is also expected to conduct a feasibility survey on carbon pricing measures such as a carbon tax and emissions trading system (Economic Planning Unit, 2021). In his speech on the Malaysia Plan on 27 September 2021, Prime Minister Ismail Sabri bin Yaakob declared that Malaysia will become carbon neutral by as early as 2050.

c) Efforts towards decarbonisation

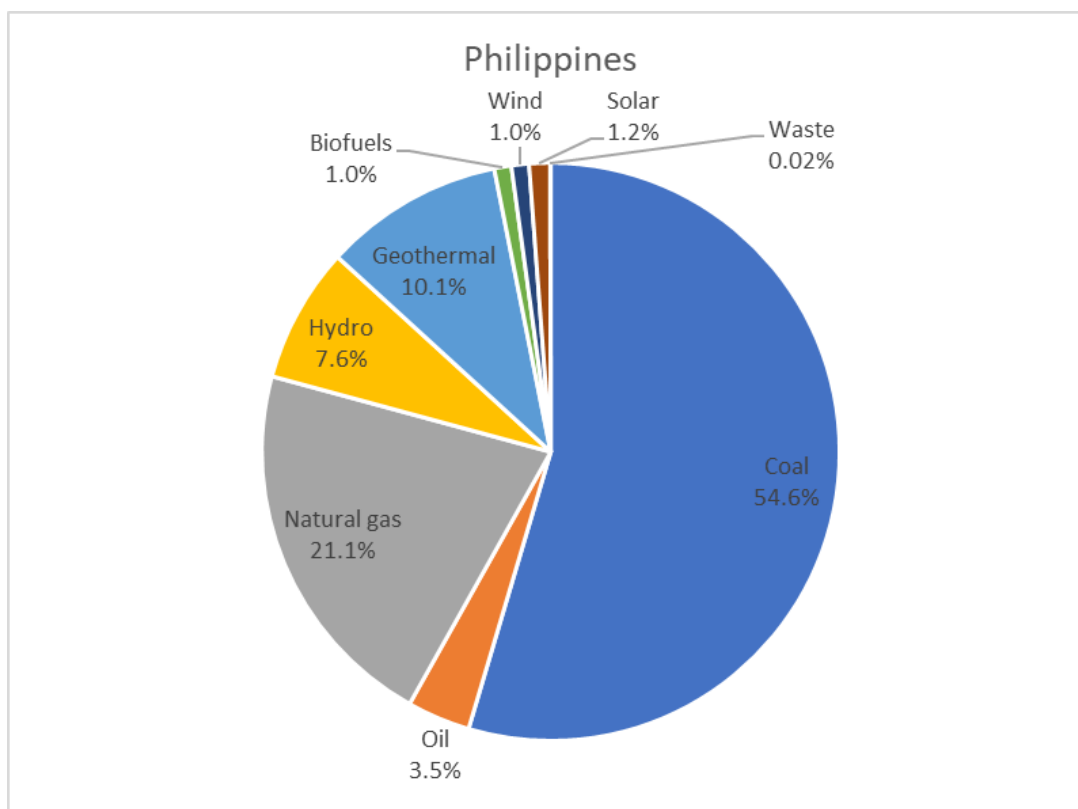
Malaysia's decarbonisation efforts include a technical and economic feasibility study on a business model conducted with subsidies from Japan's Ministry of Economy, Trade and Industry (METI) under its FY2021 feasibility studies on the overseas deployment of high-quality infrastructure (METI, 2021a). The project aims to significantly reduce CO₂ by adding an ammonia-biomass co-firing facility to an ultra-supercritical (USC) coal power plant (METI, 2021b).

3. Philippines

3.1. Current power supply structure

The power supply structure of the Philippines consists of 54.6% coal power, 21.1% natural gas power, and 20.7% renewable electricity (including hydropower).

Figure 1.7. Current Power Supply Structure in the Philippines (2019)

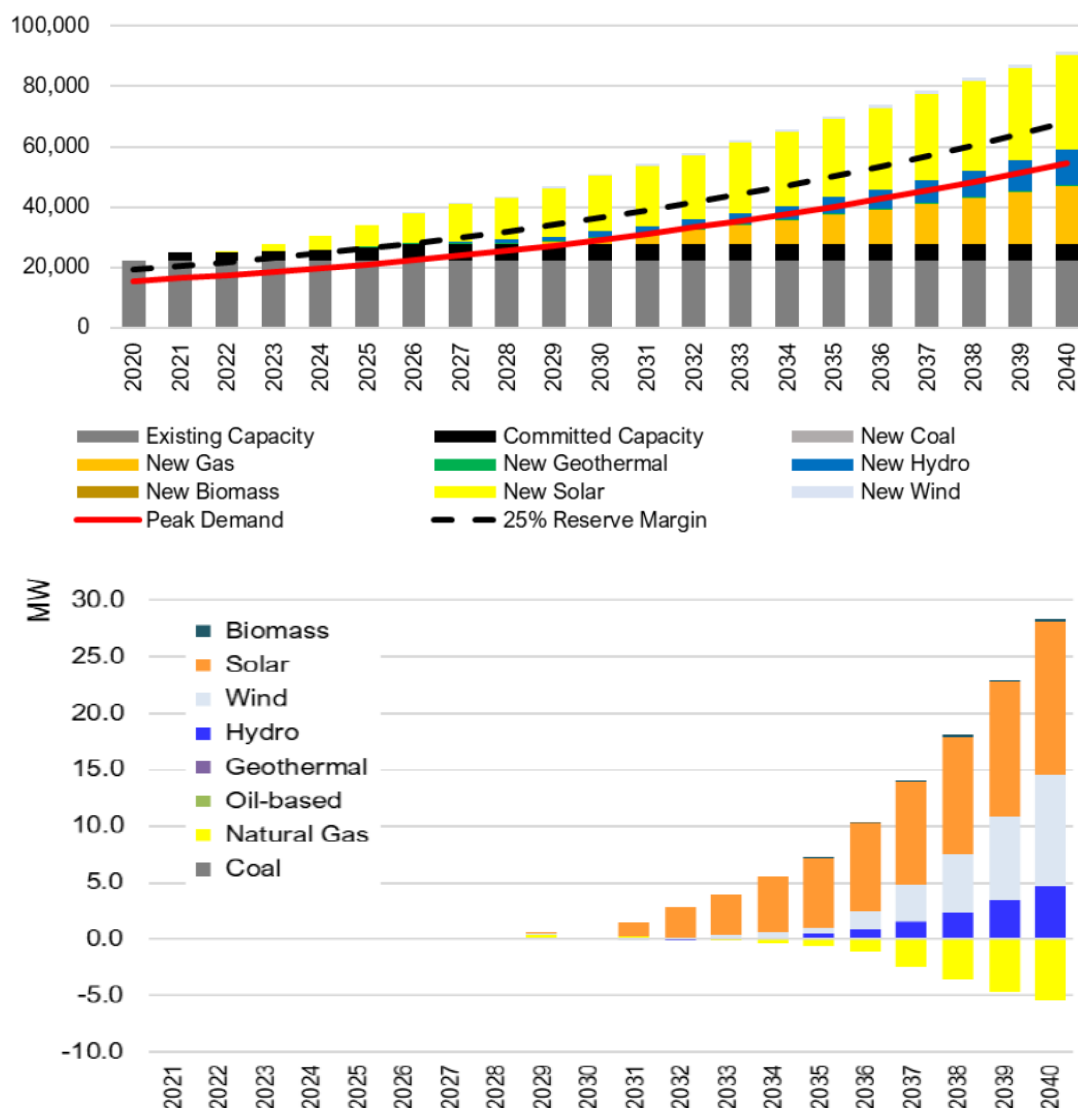


Source: IEA (2021a).

3.2. Power development plan

The Department of Energy (DOE) is responsible for preparing, integrating, coordinating, supervising, and regulating the Philippine government's energy-related plans and activities. In 2021, DOE unveiled the Philippine Energy Plan (PEP) 2020–2040, which presents the national energy supply–demand outlook up to 2040 (Department of Energy, 2021a). Future estimates are based on the Reference Scenario (REF) and the Clean Energy Scenario (CES). CES considers the expanded use of renewable energy, natural gas, and low-carbon, high-efficiency technologies in its estimate.

Figure 1.8. Future Power Supply Structures



Note: Upper figure (REF); Lower figure (CES - REF).

Source: Department of Energy (2021a)

In October 2020, DOE announced the suspension of the development of all new coal power plants apart from those that have already obtained a permit (Philippine News Agency, 2020). PEP 2020–2040 (released in October 2021) estimates that the coal power plant capacity will be 10.944 GW in 2020, 13.585 GW in 2030 and 2040, thus remaining flat from the 2030s. This is common to both the REF and CES scenarios.

The 2030 forecast for total power output under REF is 194 TWh, with coal accounting for a large percentage at 45.2%, followed by natural gas at 19.3%.

The 2040 forecast for total power output under CES is 350 TWh, anticipating a sharp increase in power output. Natural gas will have a higher share than coal, with 26.6% for the former and 23.1% for the latter.

Meanwhile, the 2040 forecast for total power output under REF is 364 TWh, with natural gas accounting for 40.3%, followed by 24.6% for coal, with natural gas having a larger share than coal. This presumably is because natural gas, which is more flexible as a fuel than coal, will contribute to the growth of solar PV, wind power, and other renewable energies. However, the Philippines will need to import liquefied natural gas (LNG) to meet its fuel demand in the future because of the depletion of the Malampaya gas field (Department of Energy, 2021a).

Table 1.3. Power Supply Capacity Outlook (2020, 2040) (REF)

(MW)

Fuel Type	Total Capacity		Capacity Additions				Total Capacity	
	2020		2021-2030		2031-2040		2040	
	Levels	% Shares	Levels	%	Levels	% Shares	Levels	% Shares
Coal	10,944	41.69	2,641	9.23	0	-	13,585	14.20
Natural Gas	3,453	13.15	381	1.33	0	-	24,263	25.36
Oil	4,237	16.14	3,570	12.48	17,240	42.24	4,618	4.83
Renewable	7,617	29.02	22,014	76.96	23,574	57.76	53,205	55.61
Geothermal	1,928	7.35	400	1.40	80	0.20	2,408	2.52
Hydro	3,779	14.40	1,987	6.95	9,660	23.67	15,426	16.12
Wind	443	1.69	216	0.75	90	0.22	2,027	2.12
Solar	1,019	3.88	18,639	65.16	12,932	31.69	32,590	34.07
Biomass	447	1.70	772	2.70	812	1.99	753	0.79
Total	26,250	100	28,606	100	40,814	100	95,670	100

Note: 'Total' may not equal the sum of each item due to decimal point processing

Source: Department of Energy (2021a).

Table 1.4. Electricity Generation Outlook (2040) (REF and CES)

(TWh)

Source	2020		2040				% Pts Diff in Shares CES vs REF
	Actual		REF		CES		
	Levels	% Shares	Levels	% Shares	Levels	% Shares	
Coal	58.18	57.17	89.72	24.62	80.83	23.09	-1.53
Natural Gas	19.50	19.16	146.86	40.30	93.24	26.63	-13.67
Oil-based	2.47	2.43	0.28	0.08	0.52	0.15	0.07
Renewable	21.61	21.24	127.54	35.00	175.49	50.13	15.13
Geothermal	10.76	10.57	16.18	4.44	16.18	4.62	0.18
Hydro	7.19	7.07	51.55	14.15	63.14	18.03	3.89
Wind	1.03	1.01	5.12	1.41	21.77	6.22	4.81
Solar	1.37	1.35	53.06	14.56	72.01	20.57	6.01
Biomass	1.26	1.24	2.39	0.66	2.39	0.68	0.24
Total	101.76	100	364.40	100	350.07	100	

Note: 'Total' may not equal the sum of each item due to the decimal point processing

Source: Department of Energy (2021a).

3.3. Climate change policy (NDC)

The Philippines' NDC aims to reduce GHG emissions by 75% from BAU levels by 2030. Of this reduction, 72.29% is conditional on the implementation of policies and initiatives that require aid and means made available based on the Paris Agreement.

Table 1.5. Outline of Nationally Determined Contribution

Target	Target Value	Target Year	Base Year	Basis Law
GHG emissions	▲ 75%	2030	BAU	NDC

Source: UNFCCC (2021).

3.4. Outlook for coal

The Philippines is reported to have 361 million tonnes of coal reserves (215 million tonnes of hard coal and 146 million tonnes of brown coal) (BGR, 2020). However, the country's production has recently remained at 14 million tonnes, mainly produced on Semirara Island.

PEP 2020–2040 sets targets for the exploration and production of coal to maintain and expand supplies for power plants. The exploration targets are 65 million tonnes of additional

reserves from 2020 to 2022; 223 million tonnes for the 18 years from 2023 to 2040; and explorable reserves of 766 million tonnes by the end of 2040. The production targets are 52 million tonnes from 2020 to 2022 and 282 million tonnes over the 18 years from 2023 to 2040.

The Annex to PEP 2020–2040 estimates that under the REF case, coal production will increase from 6.84 Mtoe in 2020 to 18.43 Mtoe in 2040 and that net imports will increase from 10.5 Mtoe in 2020 to 18.53 Mtoe in 2030. It will then decrease to 14.63 Mtoe in 2040.

3.5. Outlook for renewable energy

The Philippines has an abundance of suitable sites for renewable energy development. According to the National Renewable Energy Program (NREP) (Department of Energy, 2021b), the country has set a target (Department of Energy, 2021c) of increasing renewable power from 7.2 GW in 2018 to 15.3 GW by 2030 (output capacity basis). As of March 2021, the NREP was being revised to ramp up this target to 34 GW by 2040 (Department of Energy, 2021d).

Meanwhile, the renewable energy capacity targets under PEP 2020–2040 are 53 GW for REF and 81 GW for CES, both on an installed capacity basis.

Figure 1.9. Promising Candidate Sites for Renewable Energy



Source: Department of Energy (2021a).

3.6. Recent moves towards decarbonisation

a) Temporary freeze on construction permits for coal power plants

Even during the transition towards carbon neutrality, a certain amount of coal power is expected to remain in use to ensure the effective use of domestic resources. However, DOE has imposed a temporary freeze on construction permits for coal power plants, and there are no plans to build new ones.

Further, the need to build a carbon recycling platform is expected to increase. Financing will be a major issue in creating such a platform, but the prospects are uncertain because major banks have announced decisions to suspend loans for coal power plants (RCBC, 2020).

Finance Secretary Carlos G. Dominguez III had expressed support for abolishing coal power plants early on. He suggested that foreign governments purchase stocks held by Philippine coal power plant operating companies and donate the proceeds based on the Energy Transition Mechanism (ETM) initiative of the Asian Development Bank (Philippine Department of Finance, 2021). Meanwhile, Energy Secretary Alfonso G. Cusi is reluctant to abolish coal power plants in the near future, emphasising that energy security is paramount (Department of Energy, 2021e) because energy transition is a means to improve people's lives and enhance the country's economic development. However, views are divided on the overall direction within the country.

b) Issuance of \$500 million of green bonds

In February 2022, in an interview with US media, Secretary Dominguez stated that the government is considering issuing green bonds worth \$500 million to fund climate change mitigation projects.

c) Decarbonisation by conglomerates

Ayala Corporation announced that it will aim to achieve net-zero emissions group-wide by 2050 (including Scopes 1 to 3). Further, conglomerate San Miguel Corporation announced its withdrawal from the coal power business.

d) Efforts towards decarbonisation

Amongst technical and human resource assistance to decarbonise the Philippines are high expectations for using the Coal and Clean Coal Technology Programme led by the ASEAN

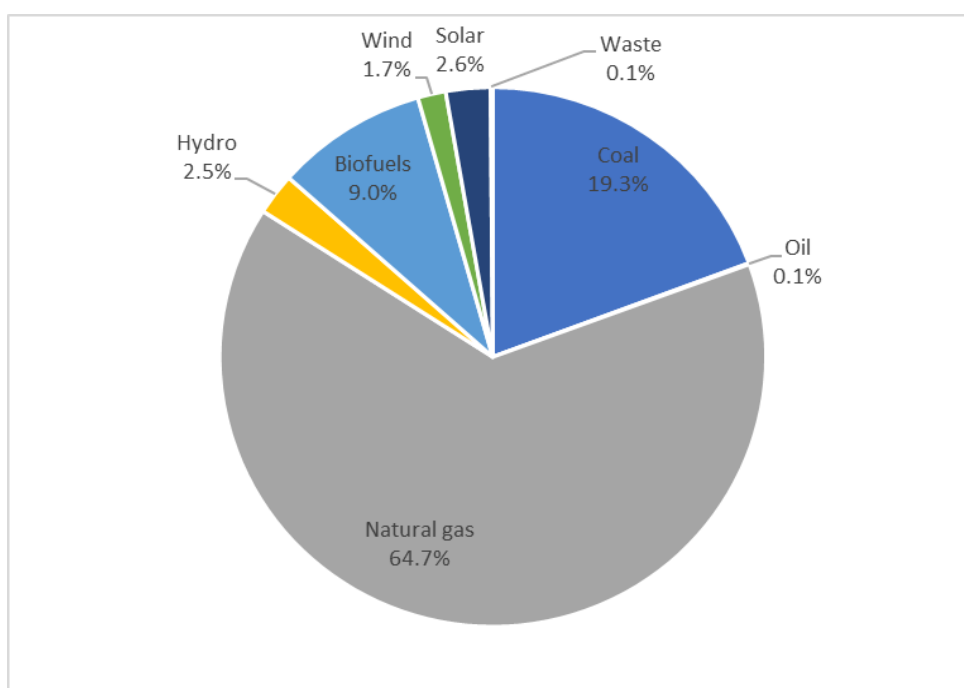
Forum on Coal and expanding its functions. Cooperation on using clean coal technology in the energy transition phase is anticipated, including human resource development through research on CCS and other technologies headed towards decarbonisation.

4. Thailand

4.1. Current power supply structure

Thailand's power supply structure comprises 64.7% natural gas power, 19.3% coal power, and 15.9% renewable electricity (including hydropower).

Figure 1.10. Current Power Supply Structure in Thailand (2019)



Source: IEA (2021a).

4.2. Power development plan

In April 2019, the cabinet of Thailand approved the Power Development Plan 2018–2037 (PDP 2018). As the plan aims to expand the total generation capacity to 77 GW in 2037 from 46 GW in 2018, and shut down 25 GW of power plants by the end of 2037, 56 GW of additional capacity will be necessary to achieve the capacity target. The additional capacity will comprise

the following: 20.7 GW of renewable energy, 0.5 GW from hydropower plants, 2.1 GW from cogeneration plants (which supply both heat and electricity), 13.1 GW from combined cycle plants, 1.7 GW from coal power plants, 5.8 GW purchased from other countries, 8.3 GW purchased from independent power producers (IPPs), and 4.0 GW from other sources.

In 2037, natural gas will account for 53% of the total power generation fuels; renewable energy, 20%; coal, 12%; and hydropower purchases from other countries, 9%. Nuclear power, which accounted for 5% of the total power capacity in PDP 2015, was removed from PDP 2018.

The installed capacity of coal power plants is expected to decrease from 6.1 GW in 2018 to 5.4 GW in 2037. The Electricity Generation Authority of Thailand plans to build two plants (1.2 GW in total) to replace the Mae Mo coal power plants in Northern Thailand, which are scheduled to be retired due to ageing.

Table 1.6. Total Capacity under PDP 2018 (MW)

Power Capacity	PDP2018
Installed capacity (2018–2037)	46,090
Retired capacity (2018–2037)	-25,310
New capacity (2018–2037)	56,431
Total capacity as of 2037	77,211

Source: EPPO (2018).

Table 1.7. Share of Fuel Used in Power Generation (%)

Fuel Type	PDP2015	PDP2018
Natural gas	37	53
Coal	23	12
Imported hydro	15	9
Renewable energy	20	20
Nuclear	5	0
Energy saving	0	6

Source: EPPO (2015, 2018).

4.3. Climate change policy (NDC)

In October 2015, the Thai government announced its NDC that aims to reduce GHG emissions by 20% from BAU levels by 2030. It also announced that the target may be raised to 25% if it gains sufficient international support. The NDC was later updated in October 2020. While no numerical reduction targets were changed, it included plans to formulate the Long-term low greenhouse gas emission development strategy to serve as the base for future NDC enhancements. The NDC update also stated that forest absorption is excluded from the country's NDC.

Thailand formulated the Climate Change Master Plan (Ministry of Natural Resources, 2015) to achieve sustainable, low-carbon growth and build resilience against climate change. The plan names six focus sectors for climate adaptation: (i) water resources management, (ii) agriculture and food security, (iii) tourism, (iv) public health, (v) natural resource management, and (vi) human security. The country's energy efficiency plan targets reducing energy intensity by 30% in 2036 from 2010.

Table 1.8. Outline of Thailand's Nationally Determined Contribution

Target	Target Value	Target Year	Base Year	Basis Law
GHG emissions	▲ 20% (▲ 25%: with international support)	2030	BAU	NDC

Source: UNFCCC (2021).

4.4. Outlook for coal

Thailand does not have a national policy on coal production. The country previously had plans for coal mine development, but there has been no progress. The country will produce coal from the Mae Moh coal mine to meet the demand from the neighbouring Mae Moh brown coal power plant. This plant plans to abolish Unit 8 in 2022, Units 9–11 in 2025, and Unit 12 in 2026, and to operate replacement plants for Units 8 and 9. Brown coal production is estimated at 14 million tonnes in 2022, falling to as low as 6 million tonnes in 2025 and remaining flat after that.

Meanwhile, Thailand's coal imports come mainly from Indonesia. In 2020, 8.47 tonnes were used for power generation (including 6.31 million tonnes by independent power producers (IPPs) and 15.27 million tonnes for the industry. According to the power source development plan, imported coal consumption by the IPPs will remain at the current level of approximately 6 million tonnes until 2031. Thereafter, BLCP Power Units 1 and 2 are scheduled to be abolished in 2032, and replaced by a new imported coal-fired power plant (1,000 MW) in 2033 and 2034, respectively. If things go as planned, imported coal consumption will be around 8 million tonnes in 2034 and beyond. However, the public has not accepted these new imported coal-fired power plants. The plan also indicates a possible switch to other fuels. In that case, imported coal consumption would be around 2 million tonnes in 2032 and beyond.

4.5. Outlook for renewable energy

Thailand's installed renewable capacity was 11.9 GW in 2019, with biomass power capacity having the largest share (28.8% of the total installed capacity), followed by hydropower (both large and small), solar PV, biogas, and waste.

Table 1.9. Number of Plants and Installed Capacity of Renewable Energy

Renewable Source	Number of Plants	Installed Capacity (MW)		Growth Rate (%)
		2018	2019	2018–2019
Biogas	175	505.2	530	4.9
Biomass	205	3,410.1	3,410.1	1.1
Hydro (small & large)	50	3,107.4	3,107.5	0.1
Solar	538	2,962.5	2,982.6	0.7
MSW	30	317.8	314.7	-1.0
Wind	26	1,102.8	1,506.8	36.6

Source: Department of Alternative Energy Development and Efficiency (2019).

The Thai government has formulated a plan for developing alternative energies (Department of Alternative Energy Development and Efficiency, 2019), announced the country's renewable-related power plan for up to 2037, and set a goal of increasing alternative energies to at least 30% of the total energy consumption. The target installed capacity for key power sources is as follows.

- Solar PV: 15.6 GW
- Biomass: 5.8 GW
- Wind power: 3.0 GW
- Hydropower: 3.0 GW
- Waste: 0.9 GW

4.6. Recent moves towards decarbonisation

a) Moves to adopt carbon pricing

Thailand is considering introducing carbon pricing as part of its climate change countermeasures. It introduced a voluntary emissions trading system or V-ETS in October 2014 and implemented pilot emissions trading projects targeting industry, including the electricity, cement, paper and pulp, steel, and petrochemical sectors. However, the electricity sector later left the pilot project as it did not function well under a regulated electricity market.

In a recent move, the Ministry of Finance announced that it is considering introducing a carbon tax on GHG emissions from industry. The government has set a target of electrifying 30% of new cars produced in Thailand by 2025. The introduction of the carbon tax is believed to be motivated by the decrease in the excise tax on fossil fuels in response to the increase in electric vehicles (EVs). When the carbon tax is introduced, the excise tax system for EVs is also planned to be revised. Discussions are underway on setting a lower excise tax rate for EVs than fossil fuel-powered cars.

b) Efforts to achieve carbon neutrality

In August 2021, the National Energy Policy Committee (chaired by Prime Minister Prayuth) approved the National Energy Plan. The plan includes a policy of transitioning to clean energy in stages and achieving carbon neutrality between 2065 and 2070, or the next 50 years. In addition, the plan pledges to work on the following energy areas to realise a low-carbon economy and society:

- to raise the percentage of renewable electricity to at least 50% (considering long-term battery system costs)
- to improve energy efficiency by employing innovative technologies
- to restructure the energy industry based on the 4D1E principles:
 - decarbonisation: reduce CO₂ emissions in the energy sector
 - digitalisation: adopt digital systems for energy management
 - decentralisation: decentralise power generation and infrastructure
 - deregulation: relax energy-related regulations

- electrification: use electricity to the maximum in place of fossil fuels

Later, at the COP26 held in November 2021, Prime Minister Prayuth announced that Thailand would strive to reach carbon neutrality by 2050 and net-zero emissions by 2065.

c) Efforts towards decarbonisation

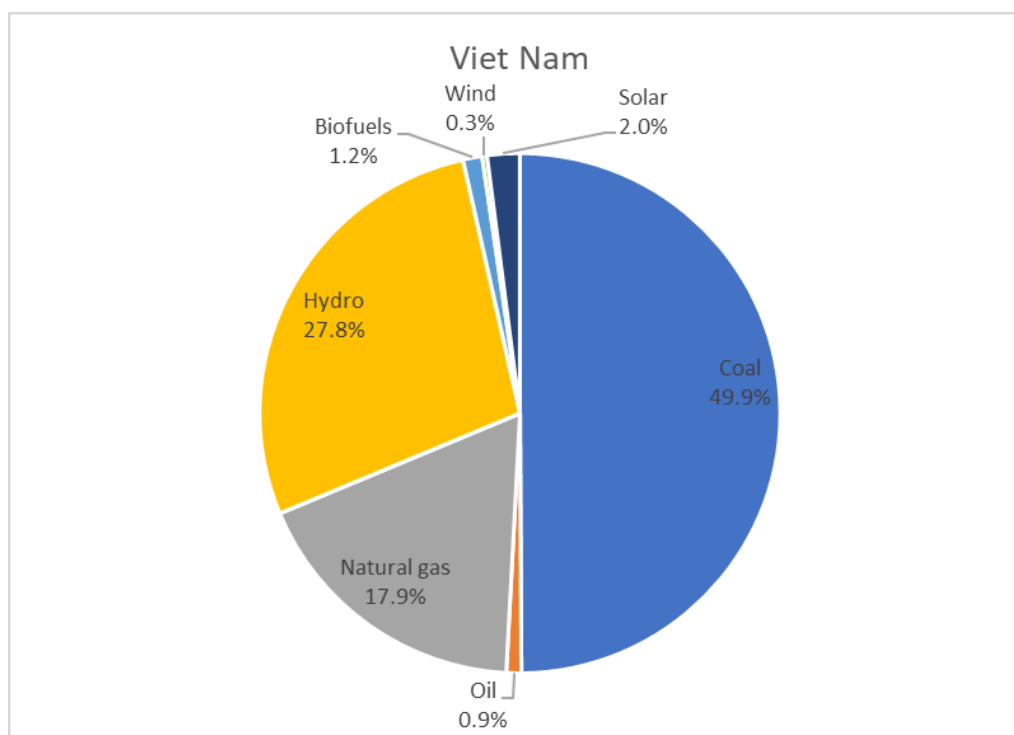
Thailand's decarbonisation efforts include building a platform to make Thailand a decarbonised society through the Clean Development Mechanism and Joint Crediting Mechanism (JCM), in which carbon credits are created using Japan's low-carbon technologies (technologies, products, systems, services, and infrastructure). For example, for the JCM, 32 model projects were in progress as of August 2020, consisting mainly of energy efficiency projects for air-conditioners and renewable energy projects for solar PV. This is the second-largest number of projects, only following Indonesia with 34 projects.

5. Viet Nam

5.1. Current power supply structure

Coal power accounts for 49.9% or roughly half of Viet Nam's power supply structure, followed by 27.8% of hydropower, 17.9% of natural gas power, and 3.5% of renewable power (excluding hydropower).

Figure 1.11. Current Power Supply Structure in Viet Nam (2019)



Source: IEA (2021a).

5.2. Power development plan

In March 2021, Viet Nam published the first draft of the National Power Development Plan (PDP) for 2021–2030 with a vision to 2045 (PDP8), presenting the country’s power development policy. The PDP was in its last stage of finalising.

Currently, Viet Nam has no specific data (share and capacity). So, the following data were under discussion in December 2021.

While discussions on a review are still in progress, according to an announcement¹⁶ by the Ministry of Industry and Trade, Viet Nam forecasts an installed generation capacity of 130,371 MW–143,839 MW in 2030. The share of coal power – so far the country’s main power source – accounts for 28.3%–31.2%, while gas power (including LNG), a low-carbon thermal power, accounts for 21.1%–22.3%. Large, medium, and pumped-storage hydropower accounts for 17.73%–19.5%, renewable energy sources (wind and solar PV) for 24.3%–25.7% aiming to reach carbon neutrality, and imported electricity for 3%–4%. Meanwhile, in 2020, the total installed capacity was 69,258 MW, and each power source’s share was 29.5% for coal power,

¹⁶ <https://moit.gov.vn/tin-tuc/phat-trien-nang-luong/nhung-diem-nhan-trong-quy-hoach-dien-viii.html>

10.3% for gas power, 29.9% for hydropower, 25.8% for renewable energy, and 1.7% for imported electricity.

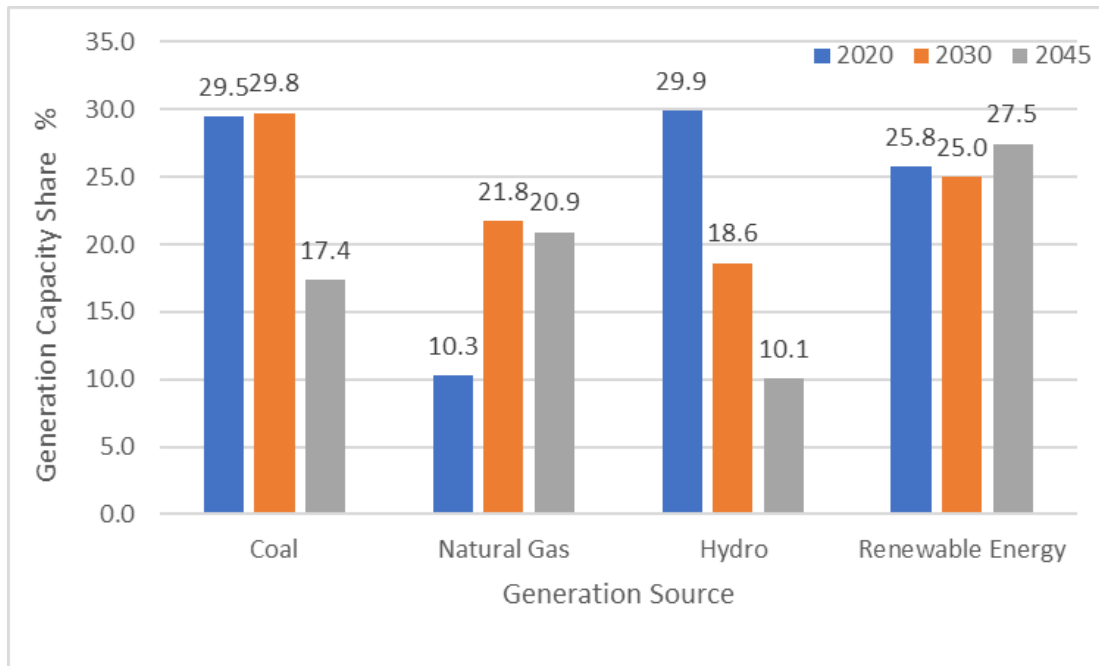
A comparison of the installed capacity–basis power mix in 2030 with that of 2020 shows that the share of coal power will be almost the same, gas power will be nearly double, hydropower will decrease, and renewable power will stay mostly unchanged. Further, a comparison of the 2045 power mix with that of 2020 indicates that coal power will decrease sharply by around 40%, gas power will double, hydropower will account for about one third, and renewable power will remain unchanged. As for the construction of new coal power stations, the policy states that those included in the revised PDP7, the precursor to PDP8, will be built as planned, but not those that are yet to gain approval or excluded in the plan.

The ongoing revision enhances measures to achieve carbon neutrality. Given that the policy declares the accelerated introduction of renewable energy, the ongoing review will strengthen this policy. Meanwhile, according to the plan, some coal will continue to be used even in 2045, so measures will need to be put in place.

During COP26 held in 2021, Viet Nam announced its participation in the Global Coal to Clean Power Transition Statement,¹⁷ a joint statement pledging to phase out coal power stations and end support for new ones.

¹⁷ <https://ukcop26.org/global-coal-to-clean-power-transition-statement/>

Figure 1.12. Share of Power Generation Capacity (2020/2030/2045)



Source: MOIT (Draft) (2021).

5.3. Climate change policy

Viet Nam submitted its first NDC to the United Nations Framework Convention on Climate Change secretariat in November 2016. It later updated and resubmitted its NDC in July 2020. The updated NDC kept the target year and reference year unchanged but raised the target value. As with the previous one, two target values were set: -9% (-8% before the update) for reduction with domestic efforts only, and -27% (from -25%) with international support.

Table 1.10. Outline of Viet Nam's Nationally Determined Contribution

Target	Target Value	Target Year	Base Year	Basis Law
GHG emissions	<p>▲ 9% (Reduction: 83.9 Mt-CO₂)</p> <p>▲ 27%: with international support (Reduction: 250.8 Mt-CO₂)</p>	2030	BAU	NDC

Source: UNFCCC (2021).

5.4. Outlook for coal

The Vietnamese government formulated a development plan for the coal industry to utilise coal, presenting policies on domestic coal development and production. The master plan for the coal industry was prepared in January 2012¹⁸ and was revised in March 2016.¹⁹ According to the revised plan, 40 projects are underway to develop new coal mines and expand existing ones, with plans to launch another 31 projects by 2030. Seven of these are for new development, and the rest are for expansion of existing mines.²⁰

Although Viet Nam is a coal-producing country, it exports its premium domestic coal to match the needs of the domestic market. Instead, it supplies the domestic market with coal that meets its needs using imported and domestically produced coal. The government has permitted to export 2 million tonnes of coal yearly until 2030.²¹

¹⁸ Adjusted Master Plan on Development of Vietnam's Coal Industry through 2020, No. 403/QD-TTg.

¹⁹ Master Plan on Development of Vietnam's Coal Industry through 2020, with the Prospects toward 2030 Taken into Consideration, No. 60/QD-TTg.

²⁰ FY2020 Overseas Coal Development Support Project, Overseas Coal Development Enhancement Survey 'FY2020 World Coal Survey', March 2021, JOGMEC.

²¹ Ibid.

5.5. Outlook for renewable energy

The Vietnamese government plans to increase renewable energy to reach carbon neutrality. The revisions to PDP8 currently being discussed may increase renewable power generation even further.

A substantial increase in the total power output is anticipated towards 2045. Renewable energy share is planned to be maintained, and its amount is set to increase in line with the growth in electricity demand.

Further, as a policy to accelerate the increase in renewable energy, a feed-in-tariff (FiT) system has been launched. The launch of the FiT system for solar PV in 2017 increased solar power generation sharply and resulted in more solar power being generated than planned. Viet Nam also anticipates investment in renewable energy by foreign capital.

The renewable energy potential varies by region, as Viet Nam is geographically very long and narrow. Solar PV potential tends to be high in the southern and central parts of the country, with abundant sun throughout the year, but lower in the mountainous north. Meanwhile, wind power has potential mainly in the southern and central coastal and mountainous areas. However, an issue with connecting capacity in the mountains to the grid must be resolved to realise the potential.

5.6. Recent moves towards decarbonisation

Viet Nam and Japan issued the Joint Statement for Cooperation on Energy Transition to Carbon Neutrality,²² in which Japan announced that it would provide financial and technical assistance to support Viet Nam's efforts towards carbon neutrality. The countries agreed that the keys to success are reducing the costs of renewable energy and the energy storage system, introducing state-of-the-art energy efficiency technologies, and decarbonisation technologies such as hydrogen, ammonia, and CCUS/carbon recycling.

The countries also announced in the Joint Cooperation Plan on Climate Change towards Carbon Neutrality by 2050 that they will step up collaboration to enable Viet Nam to reach carbon neutrality by 2050. This cooperation plan was agreed upon between Japan's Minister of the Environment and Viet Nam's Minister of Natural Resources and Environment. The

²² <https://www.meti.go.jp/press/2021/11/20211125005/20211125005-2.pdf>

ministers will strengthen cooperation to accelerate the transfer of advanced decarbonisation technologies from Japan to Viet Nam under the Joint Crediting Mechanism, including hydrogen and CCUS/carbon recycling.

Vietnam Electricity, which generates, transmits, supplies, and trades electricity, held a clean coal workshop²³ in February 2022 with Japan's METI, the New Energy and Industrial Technology Development Organization, and the Japan Coal Frontier Organization.

One of the workshop objectives is to facilitate technical exchange between Viet Nam and Japan to advance the introduction of renewable energy and share clean coal technologies, aiming to fulfil Viet Nam's 2050 carbon neutrality commitment. Specifically, information was shared on biomass combustion, the use of ammonia in coal power, and environmental protection measures.

Aiming to reach carbon neutrality by 2050, Viet Nam is strengthening cooperation with Japan as described above. However, no specific activities have been announced regarding the use of low-carbon/decarbonisation technologies, such as hydrogen and mixed combustion of ammonia and CCUS/carbon recycling.

²³ <https://moit.gov.vn/tin-tuc/phat-trien-nang-luong/evn-trao-doi-ve-cong-nghe-than-sach-voi-cac-doi-tac-nhat-ban.html>

Chapter 2

Utilisation of Ammonia for Decarbonisation

1. World Ammonia Market

Ammonia is an internationally traded commodity and has an established global market. As a primary feedstock for urea and fertiliser, ammonia has a global supply chain from upstream production to the pipeline, maritime loading infrastructure, tankers, unloading infrastructure, storage tanks, and downstream processing units to convert ammonia into final products. It has also established commercial practices such as supply contracts and pricing schemes. Since ammonia's quality as a fuel is the same as ammonia as a chemical product, the existing infrastructure can be utilised as a supply chain for ammonia as fuel without significant modification. A global market infrastructure greatly helps lower the initial hurdle of adopting ammonia as a fuel for power generation.

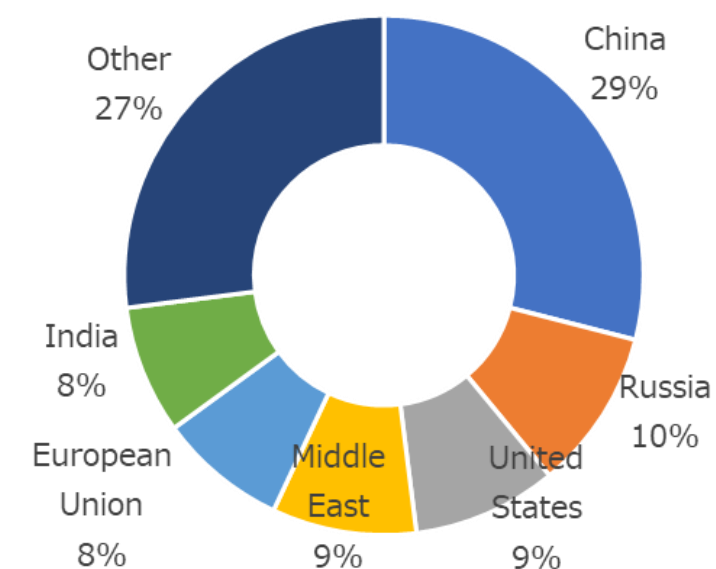
The global ammonia production as of 2019 was approximately 180 million tonnes per year. The volume is indeed one of the largest amongst various chemical products. Ammonia has a large production volume because it is a major fertiliser feedstock. Approximately 80% of the world's ammonia production is processed into urea and then into chemical fertiliser. Because fertiliser is critical for the agriculture sector, its demand also exists in almost every corner of the world. Besides as a fertiliser feedstock, the remaining 20% of the global ammonia production is utilised as various chemical products. Ammonia can be used as a feedstock of plastic, melamine resin, synthetic fiber (nylon), and synthetic rubber. It can also be used as an absorbent of nitrogen oxide (Nox), a pollutant emitted from the combustion of fossil fuels, such as coal and petroleum products.

Most of the world's ammonia is produced from a well-known chemical process named Haber-Bosch process, named after German scientists who found and established the production of ammonia from nitrogen and hydrogen. This innovative process significantly expanded the supply of ammonia and fertiliser that uses ammonia as feedstock. Most of the world's ammonia production facilities are integrated into urea and fertiliser production facilities.

Hence, most ammonia is locally produced and consumed.

While ammonia production facilities exist globally, almost half the global production capacities exist in Asia, particularly in East Asia (Figure 2.1). China is the largest ammonia producer worldwide, and its share of production capacity is approximately 30% as of 2019 (IEA, 2021b). The second-largest supply region is Eurasia, where Russia is a core producer. Thanks to its vast natural gas reserves, Russia can produce hydrogen, an ammonia feedstock, at a competitive cost. Backed by such cost competitiveness, Russia is the largest ammonia exporter globally. Likewise, the Middle East is another major ammonia production and export region. For many Asian countries, the Middle East is a primary ammonia exporter because of its relative geographical proximity and large production capacity.

Figure 2.1. World Ammonia Production

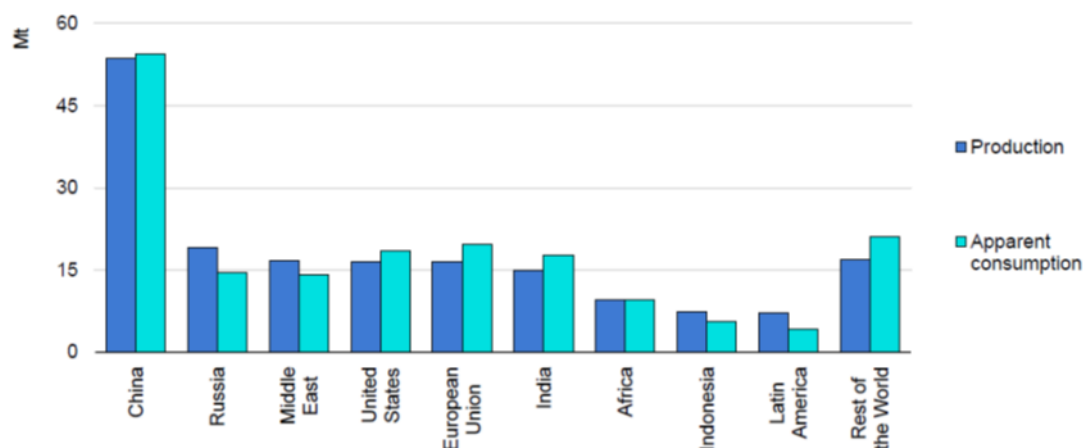


Source: IEA (2021b, p. 23)

The geographical distribution of ammonia demand is similar to that of production (Figure 2.2). Most ammonia production capacities are integrated into urea and fertiliser production facilities. Only a limited capacity is devoted to ammonia production without its downstream processing units. Region-wise, China is by far the largest demand location, followed by the European Union and the United States (US), where the population is large, and so is the

feedstock demand for fertiliser. India, which has 1.3 billion people with growing income and food consumption, has increased its fertiliser and ammonia demand in recent years.

Figure 2.2 World Ammonia Supply and Demand



Source: IEA (2021c, p. 24).

The traded volume of ammonia is approximately only 10% of the world's total production. This is because, as noted above, most ammonia production is integrated into urea and fertiliser production. The largest exporter of ammonia as of 2019 was Russia, followed by Trinidad and Tobago. Middle Eastern countries also significantly contribute to supplying ammonia to the international market. On the other hand, major ammonia importers comprise developed countries, most notably the European Union and the US. India, which has a large population but lacks competitive natural gas feedstock, is also a major importer of ammonia. Russia has been known as a stable exporter of ammonia until today. Because of the war in Ukraine and related economic sanctions on Russia, uncertainties have grown about Russia's exports as of the writing of this report in April 2022.

2.2. Fuel Use of Ammonia

Ammonia's physical properties

The ammonia molecule is represented by the chemical formula NH_3 , composed of nitrogen and hydrogen atoms, and is a colourless gas at room temperature and pressure. In 1906, German scientists Fritz Haber and Karl Bosch developed the Haber-Bosch process, a technique for artificially synthesising ammonia from hydrogen and nitrogen in the air. This

enabled humankind to produce useful nitrogen-containing compounds, such as nitrogen fertilisers and explosives.

As of 2021, the major use of ammonia includes chemical fertilisers, raw materials for chemical products such as synthetic fibres and explosives, and as an agent to reduce nitrogen oxides (Nox) in the exhaust from thermal power plants to harmless nitrogen and water vapour. Current global production is approximately 180 million tonnes/year, about 80% of which is used for chemical fertilisers. Ammonia is an international commodity whose price is determined by the market, and a global supply chain has already been established. About 10% of the total world production is traded internationally.

Ammonia reacts with oxygen and decomposes into nitrogen and water (steam) based on the following chemical reaction formula, $2\text{NH}_3 + 1.5 \text{O}_2 \rightarrow \text{N}_2 + 3\text{H}_2\text{O}$. Because of this property, ammonia can be used as fuel like natural gas or petroleum.

Here the authors compare the physical properties of ammonia with methane, the main component of natural gas, which is also a gaseous fuel and still widely used today, and hydrogen, which like ammonia is expected to become popular as a non-carbon fuel.

Table 2.1. Comparison of Ammonia, Methane, and Hydrogen

Physical Properties	Ammonia	Methane	Hydrogen
Condition at room temperature and pressure	gas	gas	gas
Molecular weight	17.030	16.041	2.016
Boiling point (under ambient pressure)	-33°C	-162°C	-253°C
Volumetric energy density (HHV) MJ/Nm ³	17.0	39.8	12.8
Gravimetric energy density (HHV) MJ/kg	22.0	55.5	142.0

Density (gas) kg/m ³	0.771 (standard condition)	0.717 (standard condition)	0.090 (standard condition)
Density (liquid) kg/m ³	603.0 (25°C, 10 atm)	442.5 (-162°C, saturated state)	70.8 (-253°C, saturated state)
Liquefaction by compression at room temperature	Yes (20°C, 8.46 atm)	No (Critical temp.: -82°C)	No (Critical temp.: -253°C)
Toxicity	Toxic, corrosive	None, but may cause asphyxiation if inhaled in large quantities	None, but may cause asphyxiation if inhaled in large quantities
Combustion speed (air combustion) m/s	0.08~0.09	0.37~0.40	2.91
Combustible concentration (mixing rate with air, % by volume)	15.5~27	5~15	4~75
Ignition point (°C)	651	580	572

Source: IEEJ's compilation based on publicly available information.

All three fuels are liquefied for transport by containers. But while methane and hydrogen must be kept at extremely low temperatures to liquefy, ammonia liquefies by compression at ambient temperature. Ammonia is a non-carbon fuel that is relatively easy to transport.

Regarding combustion characteristics, ammonia's flame speed is only one-fourth of methane during air combustion. It also has a higher ignition point than hydrogen or methane. Because of these properties, ammonia is a fuel difficult to ignite and burn stably.

Almost all fuels produce nitrogen oxides (Nox), which are air pollutants, by oxidising nitrogen

in the air during combustion. In addition, ammonia requires special consideration for combustion because its molecules contain nitrogen, which can also be a source of Nox.

Because of its high toxicity and the need for qualified personnel to control it as a toxic substance, under Japanese law, it is not likely to be used for consumer purposes like other hydrocarbon fuels, such as city gas and liquified propane gas.

Fuel use of ammonia

Examples of ammonia fuel use include its use as an alternative fuel for transit buses during World War II and the flight of US experimental aircraft with liquid ammonia-fueled rocket engines in the 1950s and 1960s.

As of 2021, the use of ammonia as fuel was considered a countermeasure to tackle climate change. Two types of ammonia combustion methods are considered: mixed combustion, in which ammonia is mixed with other fuels, and dedicated combustion, in which ammonia is the only fuel, and the choice depends on the application and scale.

Gas turbine combustion

A combustion property of ammonia, difficult to burn, will require larger combustors when used in gas turbines. Therefore, large gas turbines that use multiple combustors in a single turbine may require major design changes from gas turbines that use natural gas. In ammonia co-firing in gas turbines, it has been pointed out that a phenomenon known as combustion oscillation may occur due to significant changes in the properties of the fuel, and countermeasures are needed. The generation of Nox from fuel components, which does not occur when natural gas is used as fuel, also requires countermeasures. In addition, ammonia combustion produces nitrous oxide N_2O , which has a greenhouse effect 298 times greater than CO_2 . At present, there is no N_2O decomposition catalyst, so it is necessary to establish a combustion technology that can control N_2O production. The following summarises the technological trends in ammonia combustion in gas turbines when this report was written.

Operation with 100% ammonia had been achieved in a small gas turbine with 50 kW power

output.²⁴ This operation reached a Nox concentration of 25 ppm after passing through the Nox reduction catalyst, compared to a Nox concentration of 164 ppm at the turbine outlet.

A gas turbine with 300 kW power output operates at rated power with a fuel composition of 82.4% ammonia and 17.6% methane and achieves a Nox concentration of 2 ppm after passing through a Nox reduction catalyst. When the turbine was operated with 89.7% ammonia and 10.3% methane, the power output dropped to 261 kW, and the Nox concentration after passing through the catalyst increased to 43 ppm.

Mitsubishi Power announced that it is developing a 40 MW class ammonia-dedicated combustion gas turbine for power generation.²⁵ For large gas turbines in the several hundred MW class, ammonia could be decomposed, and fuel gas, consisting of hydrogen and a small amount of ammonia, could be burned in a hydrogen-fired gas turbine.^{26,27} This method is said to allow the use of ammonia from existing gas turbines with minimal modifications required.

Combustion in burners and boilers

The first fuel use of ammonia in boilers for thermal power generation is co-firing with coal (discussed in detail in section 4).

Specific research and development of 100% ammonia-fired boilers for power generation do not appear to have been conducted due to concerns about the generation of N₂O mentioned above and the fact that gas turbine–combined cycles are more efficient in burning liquid and gaseous fuels.

²⁴ Toyota Energy Solutions Inc., SIP (Strategic Innovation Program), Subject name 'Energy Carrier', Research and Development Theme, 'Ammonia Direct Combustion', Research Title: 'Ammonia Combustion Micro Gas Turbine', Completion Report, 2019, 3 (in Japanese).

²⁵ Nikkei XTECH/Nikkei Electronics, 40 MW class ammonia dedicated-fired thermal power generation, Mitsubishi Power to launch in 2025, Nikkei XTECH, 2021.03.02, <https://xtech.nikkei.com/atcl/nxt/news/18/09771/> (accessed January 2021) (in Japanese).

²⁶ Mitsubishi Hitachi Power Systems Corporation, SIP (Strategic Innovation Program), Subject name 'Energy Carrier', Research and Development Theme 'Ammonia Direct Combustion', Research Title 'Technical Development of Ammonia Utilisation Gas Turbine (System and Combustor)', Completion Report, 2019, 3 (in Japanese).

²⁷ Mitsubishi Heavy Industries Engineering Corporation, SIP (Strategic Innovation Program), Subject name 'Energy Carrier', Research and Development Theme 'Ammonia Direct Combustion', Research Title 'Technical Development of Ammonia Utilisation Gas Turbine (Examination of Ammonia Decomposition Equipment)', Completion Report, 2019, 3 (in Japanese).

Ammonia is also envisioned for use in industrial burners.²⁸ The studied applications include industrial furnaces for steel plate degreasing²⁹ and cement firing furnaces.³⁰

Combustion in reciprocating engines

In ammonia combustion in spark-ignition reciprocating engines, co-combustion with methane and dedicated combustion have been studied.³¹ Results show that reciprocating engines can be operated using existing combustion control technology. However, it is difficult to change the power output, and fixed-point operation at a high load is required. On the other hand, the combustion efficiency is lower than methane combustion, and further analysis of basic combustion phenomena is required.

2.3. Outlook of Fuel Ammonia Production

As earlier noted, today's major ammonia producers are China, Eurasia, and the Middle East. But as fuel demand gains extensive attention, several projects to construct a new ammonia production capacity have been announced in various parts of the world. Amongst them, the Middle East has the largest planned capacities. Saudi Arabia, for instance, is set to become the largest fuel ammonia exporter in the near future. Saudi Aramco, the country's state-owned oil company, plans to develop specific natural gas fields in Saudi Arabia's eastern province exclusively for 'blue' ammonia production combined with carbon capture and storage arrangements (Davis, 2021). The production capacity may be expanded to as large as 10 million tonnes per year. Saudi Arabia also pursues another ammonia production project based on 'green' hydrogen, which is produced from water electrolysis by renewable energy. The Haber-Bosch process converts hydrogen from renewable energy into fuel. NEOM, the country's giant project to develop a world-class hub of renewable energy in the country's

²⁸ Taiyo Nippon Sanso Corporation, SIP (Strategic Innovation Program) Subject name 'Energy Carrier', Research and Development Theme 'Direct Ammonia Combustion', Research title 'Technical Development of Ammonia Combustion Furnace Completion Report, 2019, 3 (in Japanese).

²⁹ Nisshin Steel Corporation, SIP (Strategic Innovation Program), Subject name 'Energy Carrier', Research and Development Theme 'Direct Combustion of Ammonia', Research title 'Technical Development of Ammonia Mixed Combustion Impingement Jet Flow Degreasing Furnace', Completion Report, 2019, 3 (in Japanese).

³⁰ Ube Industries, Ltd, SIP (Strategic Innovation Program), Subject name 'Energy Carrier', Research and Development Theme 'Direct Combustion of Ammonia', Research title 'Technological Development of Ammonia-Mixed Cement Kiln', Completion Report, 2019, 3 (in Japanese).

³¹ Toyota Central R&D Labs Corporation, SIP (Strategic Innovation Program), Subject name 'Energy Carrier', Research and Development Theme 'Ammonia Direct Combustion', Research title 'Development of Combustion Technology for Ammonia Reciprocating Engine', Completion Report, 2019, 3 (in Japanese).

western region, plans to produce and export such green ammonia. NEOM, along with ACWA Power and Air Products as joint venture partners, plans to produce 1.2 million tonnes of green ammonia annually (Darasha, 2021).

Abu Dhabi of the United Arab Emirates also plans to build a new blue ammonia plant for export. The production capacity is much smaller than that of Saudi Arabia at 1 million tonnes per year. A unique aspect of this blue ammonia project is that it will be integrated with enhanced oil recovery (EOR), which captures CO₂ to increase crude oil production. Unlike CCS, which injects and stores CO₂ underground, EOR can generate profits by realising improved crude oil production efficiency. Because the production entity can expect additional revenues from EOR by increasing crude oil production, the project owner can expect higher revenues and profit (ADNOC, 2021).

Australia hosts numerous fuel ammonia projects of both green and blue hydrogen. As for the blue ammonia, Woodside, an Australian oil and gas major, plans to produce blue ammonia in Western Australia utilising natural gas feedstock. Their initial production capacity is 1,500 tonnes per day (Matsumoto, 2021), but the capacity will likely be expanded depending on the development of final demand in Asia. Mitsui & Co, a Japanese trading house, also plans to develop another fuel ammonia project with support from the state-owned Japan Oil, Gas, and Metals National Corporation (JOGMEC, 2021). In addition to such blue ammonia projects are more than 10 green ammonia projects.³² Some of them are planned on Tasmania Island, which has favourable wind power generation conditions. Australia also has good solar power generation resources, and such renewable energy is planned to be used as a source of green ammonia production.

The US may not be considered a major fuel ammonia exporter. However, given its abundant natural gas resources with CCS and EOR capacities, it is well-positioned to be a significant blue ammonia producer. Also, it has great onshore wind energy resources that can be utilised to produce green hydrogen and ammonia. Mitsubishi Corporation, a Japanese trading house, is currently exploring the potential to commercialise blue ammonia production and export projects in the Gulf of Mexico region (Mitsubishi Corporation, 2021). Furthermore, because the US has a federal tax credit system for domestic CCS and EOR projects, a blue ammonia production and export project may benefit from such a preferred taxation system.

³² Authors' count based on publicly available media sources.

Latin America, most notably Chile, is known for its competitive renewable energy resources. One preferred location for wind power generation is in the southern end of the South American continent (Patagonia region), where the capacity factor exceeds 60% (IEA, 2021c). Taking advantage of these very competitive renewable energy resources, Chile plans to reinvent itself from an importer of hydrocarbon energy resources to an exporter of green hydrogen and its derivative products, including green ammonia.

In addition to the above export projects, several plans to build fuel ammonia plants were pursued in Russia, one in Siberia, and the other in the Yamal Peninsula. But as the war in Ukraine rages and the US, the European Union, and other countries have imposed economic sanctions on Russia, prospects of such fuel ammonia project have become increasingly invisible.

2.4. Potential (Future) and Challenges of Ammonia Co-firing in Thermal Power Generation (Coal Fired)

Coal-fired power plants are a type of steam-powered power plant in which high-temperature, high-pressure steam produced by a boiler is blown into a turbine, which rotates to generate electricity by turning a generator. Unlike gas turbines used in natural gas-fired power plants, the gas produced by combustion does not directly contact the turbine. Usually, coal is fed to the boiler after it has been crushed into small pieces. Therefore, ammonia in liquid or gaseous form is supplied to the boiler by mixing with air for combustion.

Since coal-fired power generation has higher carbon content in its fuel than natural gas, replacing a portion of the coal with a non-carbon fuel significantly reduces CO₂ emissions intensity. Ammonia is considered a non-carbon fuel for this mixing. The fact that thermal power plants have facilities that handle ammonia for denitrification (removal of nitrogen oxides) of exhaust gas is one of the reasons ammonia is being considered for use. The co-firing ratio is generally 20% on a calorific value basis. A Japanese power generation company, JERA's Hekinan Thermal Power Plant, is planning to conduct a 2-month power generation demonstration test using 20% ammonia mixed with coal, the main fuel, in FY2024.³³

The CO₂ emission reduction effect of this 20% ammonia co-combustion with coal is about 1 million tonnes per year for a 1,000 MW class power plant. If this were done at all coal-fired

³³ https://www.jera.co.jp/english/information/20210524_677.

power plants in Japan, annual CO₂ emissions would be reduced by 40 million tonnes, or approximately 10% of Japan's 400 million tonnes/year of CO₂ emissions, from the power generation sector.

Japan's domestic demand for ammonia is said to be about 1 million tonnes per year. If a 1,000 MW coal-fired power plant were to co-fire ammonia at 20% of its calorific value, annual ammonia consumption would be approximately 500,000 tonnes. If all coal-fired power plants in Japan were to co-fire 20% ammonia, annual ammonia consumption would reach 20 million tonnes. As seen above, even a 20% coal–ammonia co-firing system, if implemented on a large scale, would require far more ammonia in the power generation sector than the current total demand for ammonia in Japan. Procuring this at a low cost and in a stable manner will be a challenge for the practical application of coal–ammonia co-firing. In addition, for this technology to contribute to the decarbonisation of society, the life cycle CO₂ emissions of the ammonia used must be reduced, and the integration of technologies for making ammonia from hydrogen derived from renewable energy sources and CCS into the production of ammonia from fossil fuels is needed.

2.5. Cost Analysis of Coal–Ammonia Mixed Combustion

Assumptions

In general, ammonia price is higher than coal's, so ammonia co-firing in coal-fired power plants increases the cost of power generation. Here, we will conduct a quantitative evaluation to determine the extent to which ammonia co-firing increases the cost of power generation.

Under the assumption that coal-fired power plants are operated in Japan, we calculate the approximate economics of ammonia co-firing in coal-fired power plants. Two types of co-firing ratios are assumed here: 20% and 50% on a calorific value basis. Therefore, the authors set the following three cases for this analysis:

- BAU case: Normal coal-fired power plant
- Ammonia-20 case: Co-firing of 20% ammonia on a calorific value basis in a coal-fired power plant in the BAU case
- Ammonia-50 case: Co-firing of 50% ammonia on a calorific value basis in a coal-fired power plant in the BAU case

This study uses the levelised cost of electricity (LCOE) as a cost index. This index is based on the study of the Power Generation Cost Verification Working Group of the Agency for Natural Resources and Energy, Japan,³⁴ which is regarded as a standard for evaluating power generation costs in Japan. This evaluates the cost of power generation for a given operating period and is calculated by dividing the net present value of all costs required within the operating period by the net present value of generated electricity. The unit of measure is the unit cost of electricity generated (e.g. yen (¥)/kWh or US\$/kWh).

The exchange rate is assumed to be ¥110/US\$. The facility is assumed to operate for 40 years in all three cases. The discount rate for present value conversion is assumed to be 3% per year, and fuel calorific value and efficiency are calculated based on the higher heating value (HHV).

Table 2.2 shows the assumptions regarding capital and operation and maintenance costs. The basic condition settings follow the assumptions of the Power Generation Cost Verification Working Group.³⁵ Capital costs for ammonia co-firing facilities are based on the assumptions of J-Power Corporation.³⁵ The ammonia co-firing facility is assumed to be able to co-fire 20% to 50% on a calorific value basis in the same facility.

Table 2.2. Assumptions about Capital and O&M Costs

Item	Value	Unit
Equipment capacity	700	MW
Capacity factor	70	% per year
Internal rate	5.5	%
Power generation efficiency	43.5	% (HHV basis)
Construction cost per unit capacity	24.4	¥10 ⁴ /kW
Cost of equipment	1,708	¥10 ⁸

³⁴Agency for Natural Resources and Energy, Advisory Committee on Natural Resources and Energy, Power Generation Cost Verification Working Group (8th Meeting) Document 3: List of Specifications of Power Sources, 2021, 9 (in Japanese).

³⁵ J-Power Corporation, SIP (Strategic Innovation Program), Program Name 'Energy Carrier,' Research and Development Theme 'Development of Ammonia Production, Storage, and Transportation Technologies Using CO₂-Free Hydrogen', Research Title: 'Technical Study of CO₂ Free Ammonia Supply Chain as a Fuel for Thermal Power Generation', Completion Report, 2019, 3 (in Japanese).

Facility decommissioning cost ratio (vs. construction cost)	5	%
Personnel expenses	4.4	¥10 ⁸ /year
Repair cost ratio (vs construction cost)	2.4	% per year
Miscellaneous expenses ratio (vs construction cost)	2.2	% per year
General management expenses ratio (vs direct cost)	12.20	% per year
Ammonia co-firing facility cost	278	¥10 ⁸
Ammonia co-firing facility decommissioning cost ratio (vs construction cost)	5	%
Fuel miscellaneous expenses	0.077	Yen/MJ-fuel

HHV = higher heating value, O&M = operation and maintenance.

Sources: Agency for Natural Resources and Energy, Advisory Committee on Natural Resources and Energy, Power Generation Cost Verification Working Group (8th Meeting) Document 3: List of Specifications of Power Sources, 2021, 9 (in Japanese); J-Power Corporation, SIP (Strategic Innovation Program), Program Name 'Energy Carrier,' Research and Development Theme 'Development of Ammonia Production, Storage, and Transportation Technologies Using CO₂-Free Hydrogen', Research Title: 'Technical Study of CO₂ Free Ammonia Supply Chain as a Fuel for Thermal Power Generation', Completion Report, 2019, 3 (in Japanese).

Table 2.3 shows the assumptions about coal. These assumptions refer to the Japanese government's material for generation cost calculation.³⁶

³⁶ Agency for Natural Resources and Energy, Advisory Committee on Natural Resources and Energy, Power Generation Cost Verification Working Group (8th Meeting) Document 3: List of Specifications of Power Sources, 2021, 9 (in Japanese).

Table 2.3. Assumptions about Coal

Item	Value	Unit
Calorific value	26.08	MJ/kg
Price	108.58	\$/t
Price per calorific value	0.458	Yen/MJ
CO ₂ emission factor	89.1	g-CO ₂ /MJ

Source: Agency for Natural Resources and Energy, Advisory Committee on Natural Resources and Energy, Power Generation Cost Verification Working Group (8th Meeting) Document 3: List of Specifications of Power Sources, 2021, 9 (in Japanese).

Assumptions regarding ammonia are shown in Table 2.4. These assumptions are based on a study by The Institute of Energy Economics, Japan (IEEJ). The CO₂ emission factor of ammonia is 0, namely, ammonia in this study is so-called blue ammonia or green ammonia.

Table 2.4. Assumptions about Ammonia

Item	Value	Unit
Calorific value	17.0	MJ/Nm ³
Density (gas)	0.77	kg/Nm ³
Price	338.5	\$/t-NH ₃
Price per calorific value	1.69	Yen/MJ
CO ₂ emission factor	0	g-CO ₂ /MJ

Sources: Agency for Natural Resources and Energy, Advisory Committee on Natural Resources and Energy, Power Generation Cost Verification Working Group (8th Meeting) Document 3: List of Specifications of Power Sources, 2021, 9 (in Japanese); J-Power Corporation, SIP (Strategic Innovation Program), Program Name 'Energy Carrier,' Research and Development Theme 'Development of Ammonia Production, Storage, and Transportation Technologies Using CO₂-Free Hydrogen', Research Title: 'Technical Study of CO₂ Free Ammonia Supply Chain as a Fuel for Thermal Power Generation', Completion Report, 2019, 3 (in Japanese).

6. Result

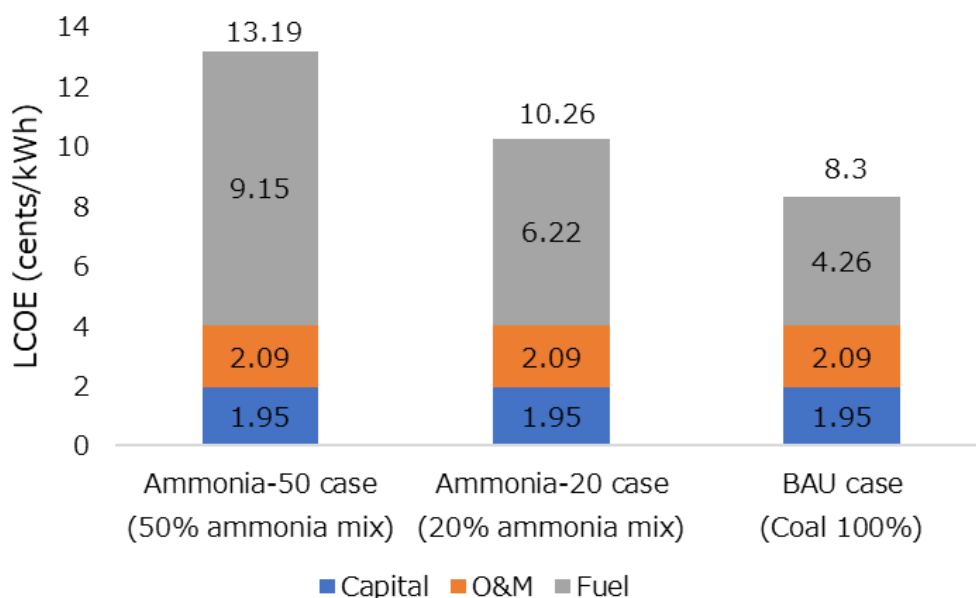
Figure 2.3 shows the calculated LCOE. The LCOE of the Ammonia-20 case is 128% of BAU; that of Ammonia-50 case is 164%. The breakdown shows that this increase is largely due to the increased fuel cost caused by ammonia, which is more expensive than coal.

The present value equivalent investment and generated electricity, the numerator and denominator of the LCOE, are shown in Table 2.5.

Figure 2.4 indicates that CO₂ emissions over 40 years of operation decrease in proportion to the co-firing rate. The original coal-fired power plant emits 127 million tonnes of CO₂ during its 40-year-long operating period. CO₂ emission reduction effects are 26 million tonnes/40 years by 20% mixed combustion and 64 million tonnes/40 years by 50% mixed combustion.

These results indicate that the incremental power generation cost required to reduce CO₂ emissions by 20% and 50% through ammonia co-firing in coal-fired power plants is 2.23 cents/kWh and 5.16 cents/kWh, respectively.

Figure 2.3. Levelised Cost of Electricity



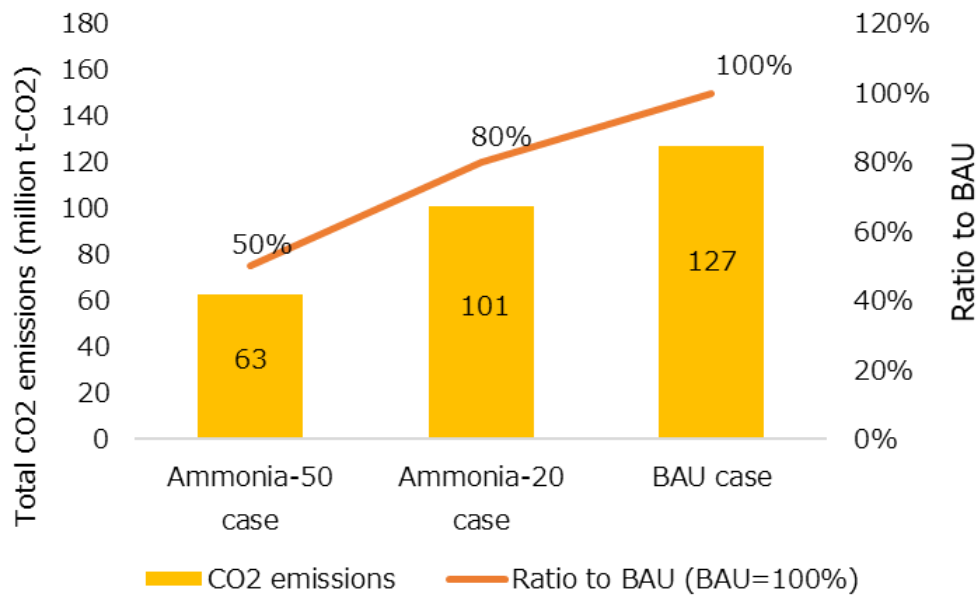
Source: IEEJ's estimate based on Tables 2.2, 2.3, and 2.4.

Table 2.5. Discounted Total Cost and Generated Power

Discounted Total Cost (million US\$)	Ammonia-50 Case (50% ammonia - mix)	Ammonia-20 Case (20% ammonia - mix)	BAU Case (100% Coal)
Capital	1,833	1,832	1,576
Coal-fired power station	1,553	1,553	1,553
NH ₃ mixer	253	253	0
Demolition	27	26	23
O&M	1,956	1,956	1,956
Fuel	8,579	5,828	3,993
Fuel	8,004	5,253	3,419
Fuel misc.	575	575	575
Total	12,368	9,615	7,525
Discounted generated power (GWh)	93,761	93,761	93,761

Source: IEEJ estimate based on the assumptions of Table 2.2, 2.3, and 2.4.

Figure 2.4 CO₂ Emissions during the 40-year-long Operating Period



Source: IEEJ estimate based on the assumptions of Table 2.2, 2.3, and 2.4.

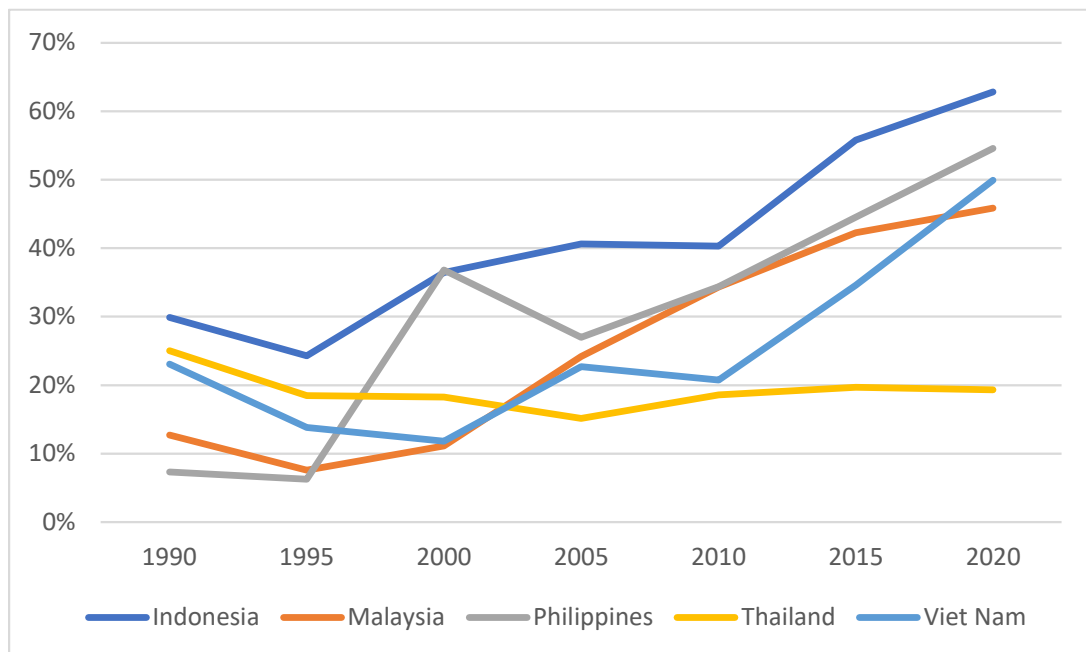
Chapter 3

Potential of Ammonia Co-firing in ASEAN Countries

1. The Necessity for Coal–Ammonia Co-firing

Coal power is facing difficulties under the climate mitigation requirements. COP26 referred to the phasedown of unabated coal power, and the voluntary group comprising over 190 countries and businesses has committed to the phaseout of unabated coal power. However, coal power is currently one of the essential sources of electricity in ASEAN (Figure 3.1). Therefore, reducing emissions from existing coal power is an important step to decarbonising ASEAN pragmatically. This work evaluates the potential of coal–ammonia co-firing in ASEAN 5 countries – Indonesia, Malaysia, the Philippines, Thailand, and Viet Nam.

Figure 3.1. Share of Coal Power Generation in ASEAN 5 Countries



Source: IEA (2021c).

2. Precondition for the Calculation

The coal power unit database developed by Enerdata³⁷ and other country-specific and technology-specific data were used to estimate the potential of coal ammonia co-firing (Figure 3.2).

Coal power capacity

Two scenarios were assumed for additional coal power capacity in the future (Table 3.1). In the ‘low’ scenario, all capacity under the construction phase will be operational by 2030. In the ‘high’ scenario, all capacity under the construction and project phases will be operational by 2030. No additional capacity was assumed after 2031 for both scenarios. Although database information, such as commissioning and decommissioning years, was used to judge the operation status of the unit in the target year, the default lifetime of 40 years was also used in case of lack of such information.

Table 3.1. Scenario for Additional Coal Power Capacity

Scenario	Additional Capacity
Low	~2030: All capacity under construction phase 2031~: No additional capacity
High	~2030: All capacity under construction and project phase 2031~: No additional capacity

Source: Author.

Ammonia co-firing ratio

All coal power units with over 10 years of residual life are assumed to have a co-firing ratio of 20% after 2035³⁸ and 50% after 2045. In this work, no technological or geographical constraints were considered for introducing ammonia.

³⁷ <https://www.enerdata.net/research/power-plant-database.html>

³⁸ 5 years later than Japan’s target shown in the Green Growth Strategy.

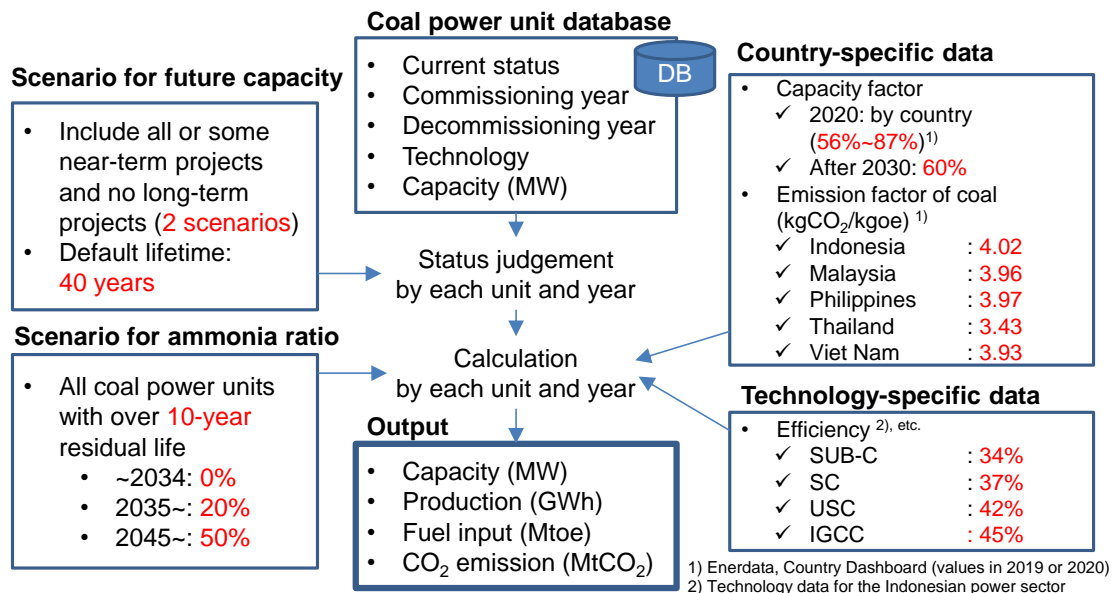
Capacity factor

The future capacity factor of power plants is highly uncertain. Here, 60% was simply assumed for all five countries after 2030. Note that the actual capacity factor of coal power was used for each country in 2020.

Efficiency

Technology data for the Indonesian power sector (Danish Energy Agency, 2021) was used for the efficiency of each technology. In case of lack of technology information in the database, subcritical and ultra-supercritical (USC) were assumed for existing and planned power plants, respectively. A study (CRIEPI, 2019) showed that the efficiency of coal power plants could be lowered by 3.7% point (HHV) by mixing ammonia at 20%. However, it also pointed out that efficiency can be improved by additional plant refurbishment or optimisation of various combustion parameters. Therefore, this study does not assume any drop in efficiency by mixing ammonia in the future.

Figure 3.2. Overview of Methodology

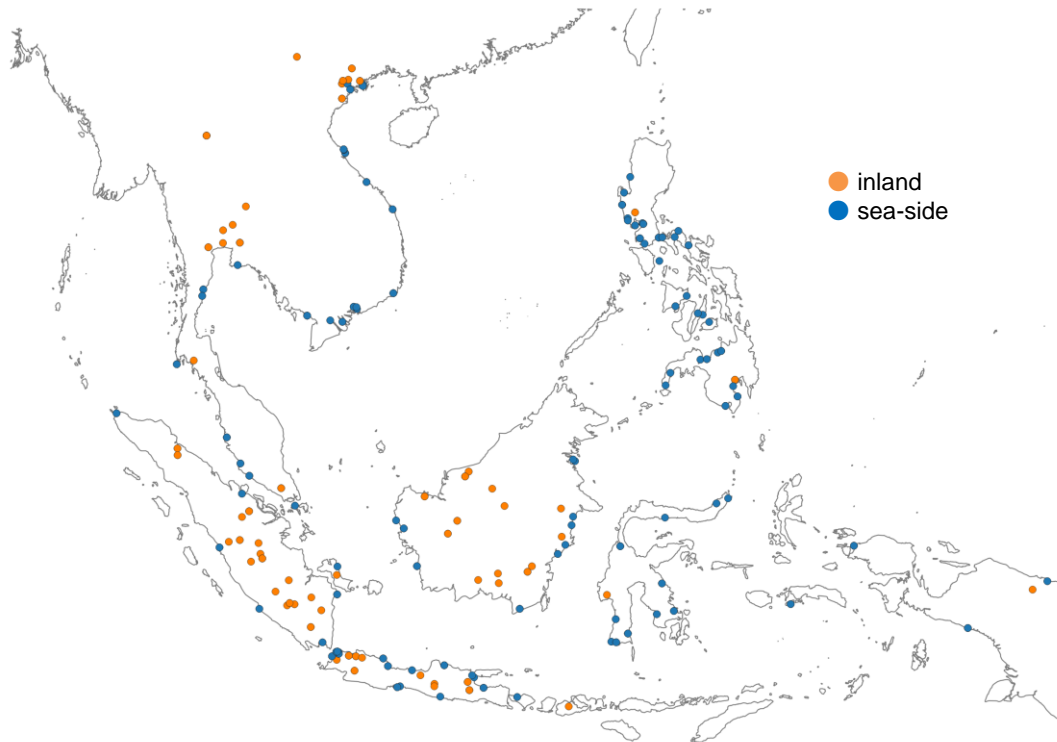


IGCC = integrated gasification combined cycle, SC = supercritical, SUB-C = subcritical, USC = ultra-supercritical.

Source: Author.

Since the database also includes the latitude and longitude of the power plants, they can be plotted on the map with Geographical Information System (Figure 3.3). Considering importing ammonia by ship, sea-side plants might be suitable for co-firing. However, as already stated, the geographic constraints were not considered in this analysis.

Figure 3.3. Location of Coal Power Plants in Five Countries



Note: Plants under construction or development are also included.

Source: Author, based on Enerdata.

3. Estimation of Coal–Ammonia Co-firing Potential

3.1. Coal power capacity

Figure 3.4 shows the coal power capacity by 2050. In short, the capacity would increase dramatically by 2030 in Indonesia, the Philippines, and Viet Nam if all projects were successfully developed, while it would decrease significantly by 2040 in Malaysia and Thailand. Note that our estimation with Enerdata’s database is not necessarily consistent with government plans. In addition, some countries are currently developing their new power development plans (PDPs), including the outlook of coal power.

For Indonesia, coal capacity would be doubled by 2030 in the high scenario. Although the government plan is close to the low scenario in 2030, the plan seems to assume a more aggressive retirement of coal towards 2050. With technology, the proportion of high-efficiency plants is expected to increase. However, the technology types of many planned power plants are unknown, and they are assumed to be USC in this analysis.

The Philippines also has a lot of additional capacity by 2030 in the high scenario. But this might be overestimated, considering DOE's declaration of coal moratorium. The predicted capacity by the government would be 13.6 GW in 2030 and 2040, between the low and high scenarios. By technology, subcritical would increase towards 2030 in the high scenario. As a result, the average efficiency would not improve very much.

Viet Nam would experience increased coal capacity more than any of the other four countries in the high scenario. The capacity would be 56 GW by 2030 in the high scenario, 10 GW of which is already being constructed. The government plan is estimated to be around 40 GW³⁹ by 2030. Much of the additional capacity would be supercritical rather USC.

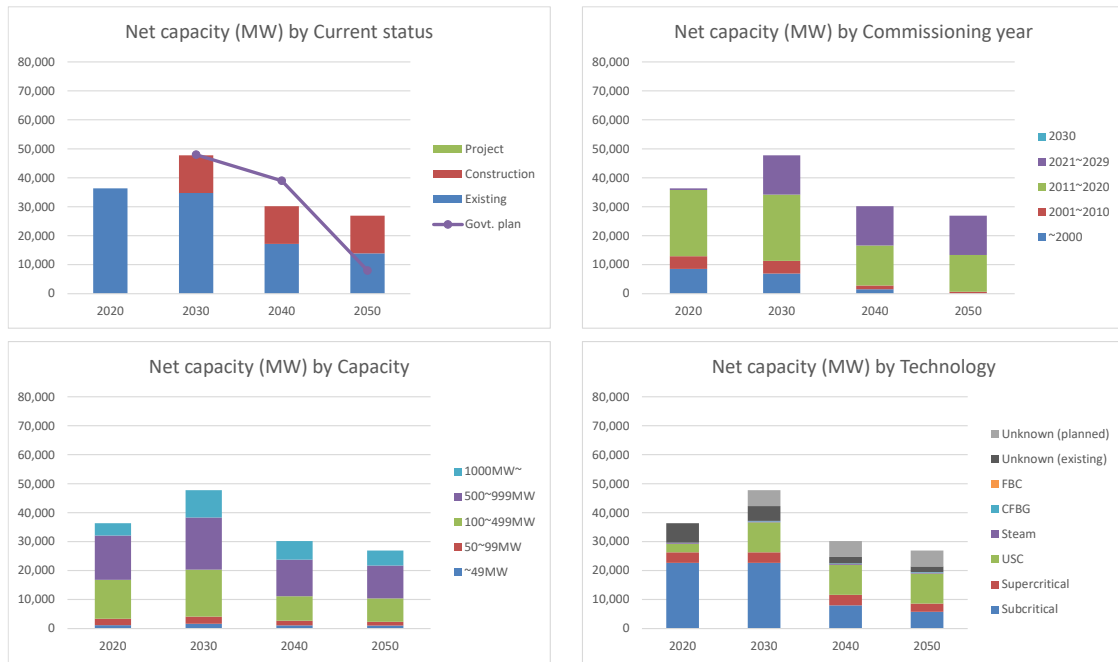
In Malaysia and Thailand, on the other hand, the limited additional capacity would be operational by 2030, according to the database. As a result, coal capacity in these two countries would significantly decrease by 2040 without any long-term projects or lifetime extensions for existing plants. Note that the governments predict more capacity than our estimation by 2040, implying that some additional plants are not included in the database⁴⁰ and/or lifetime extension.

³⁹ Coal power accounts for 28.3% to 31.2% in the total capacity of 130 GW to 144 GW in 2030.

⁴⁰ In Thailand, the replacement of Mae Moh 4-7 is not included in the database.

Figure 3.4. Coal Power Capacity by 2050 (Indonesia)

[Low scenario]



[High scenario]



Source: Author.

Figure 3.5. Coal Power Capacity by 2050 (Malaysia)

[Low / High scenario]



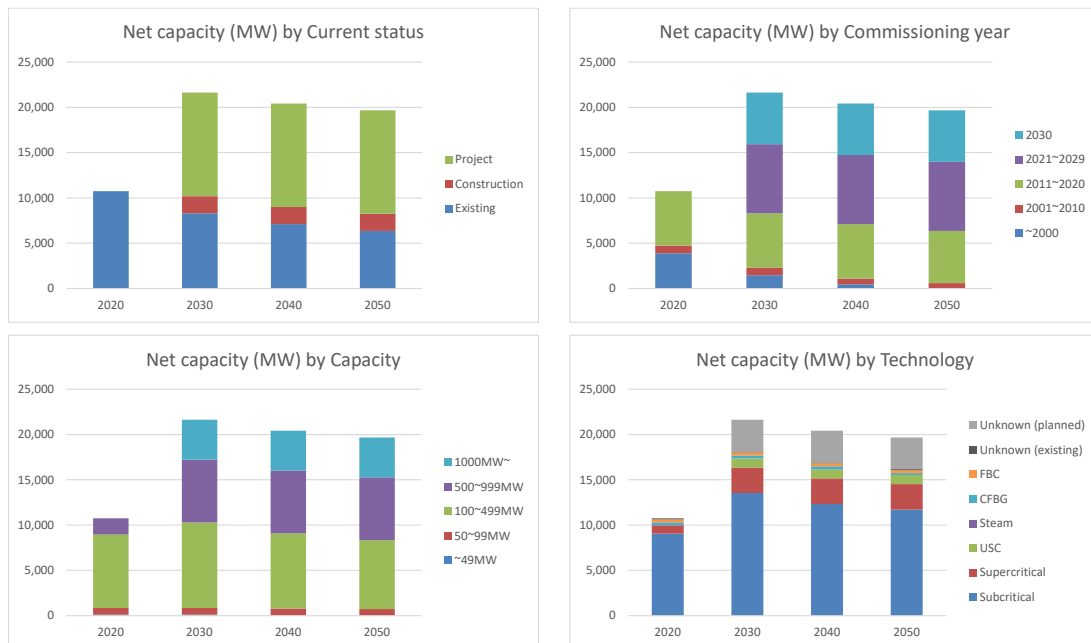
Source: Author.

Figure 3.6. Coal Power Capacity by 2050 (Philippines)

[Low scenario]



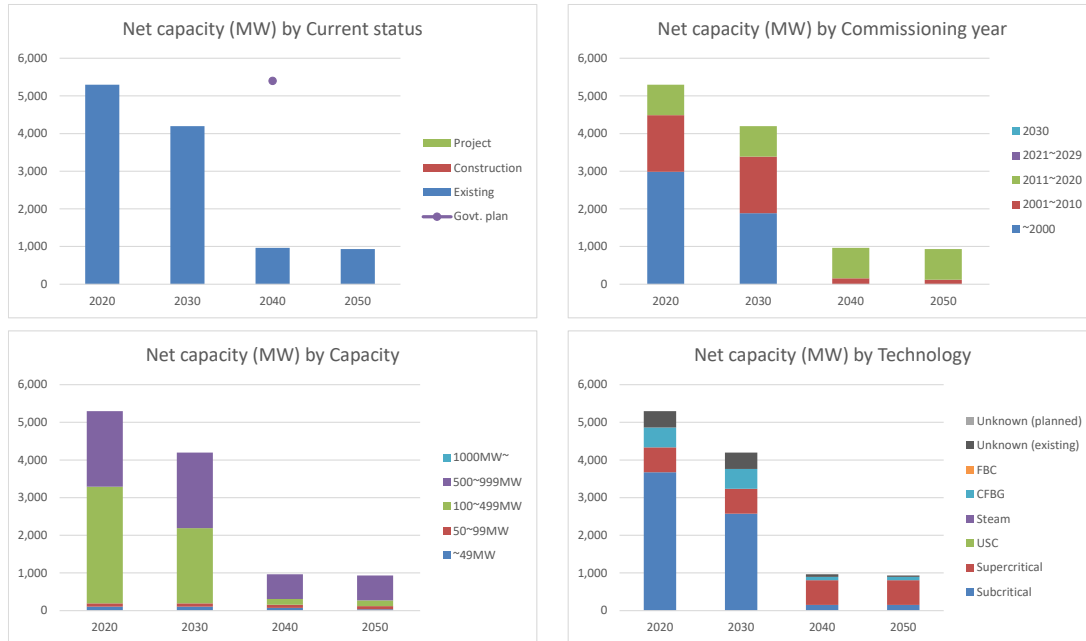
[High scenario]



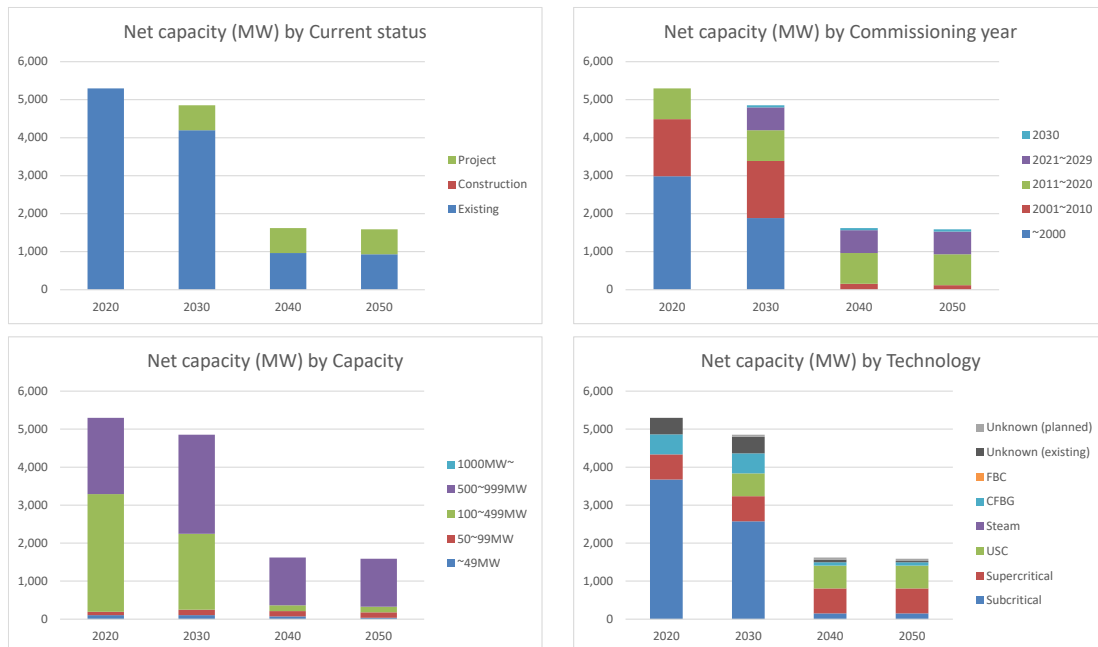
Source: Author.

Figure 3.7. Coal Power Capacity by 2050 (Thailand)

[Low scenario]



[High scenario]



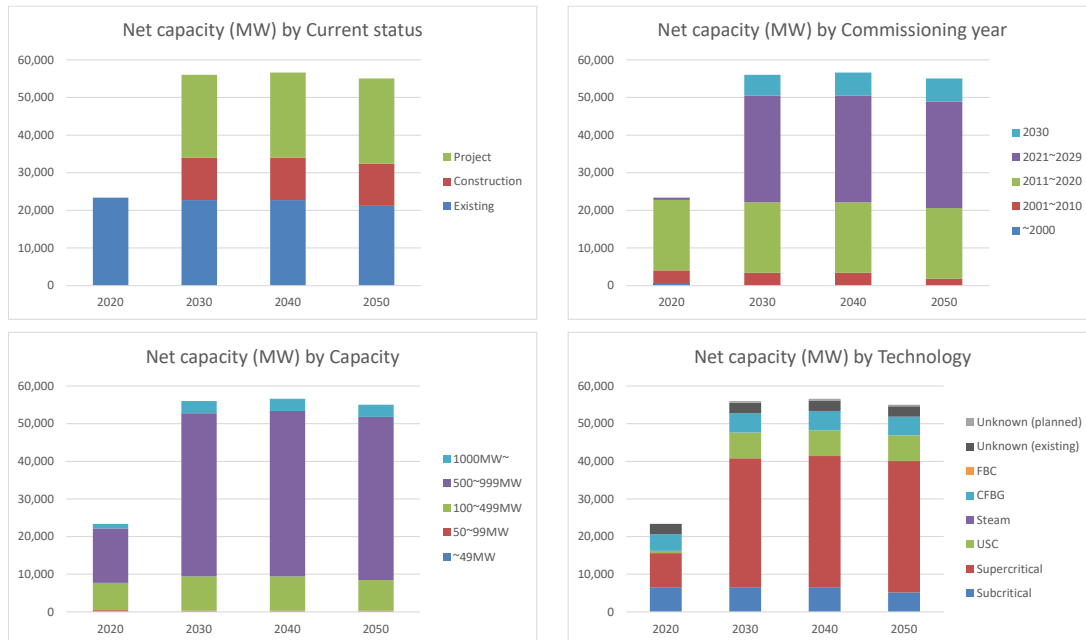
Source: Author.

Figure 3.8. Coal Power Capacity by 2050 (Viet Nam)

[Low scenario]



[High scenario]



Source: Author.

3.2. Fuel input and CO₂ emission

In addition to the low and high scenarios, the PDP scenario, which reflects each country's government plan, was added here for reference. Note that bottom-up estimation using the database was not conducted for the PDP scenario, so the average efficiency and ammonia ratio under the PDP were simply assumed at 40% and 50%, respectively.

In ASEAN 5 countries in 2050, as much as 147 MtCO₂ to 283 MtCO₂ emissions could be avoided from coal power plants by making the most of ammonia co-firing potential (Table 3.2 and Figure 3.9). These figures are equivalent to 10%–18% of total energy-related CO₂ emissions in 2019. The ammonia demand would be 83 Mt to 160 Mt (37 Mtoe to 71 Mtoe) in 2050, which is a considerable volume compared with the current global ammonia demand of 200 Mt (mainly for fertiliser). How to supply this amount of blue or green ammonia is the key.

Table 3.2. Reduced CO₂ and NH₃ Demand by Coal Ammonia Co-firing in 2050

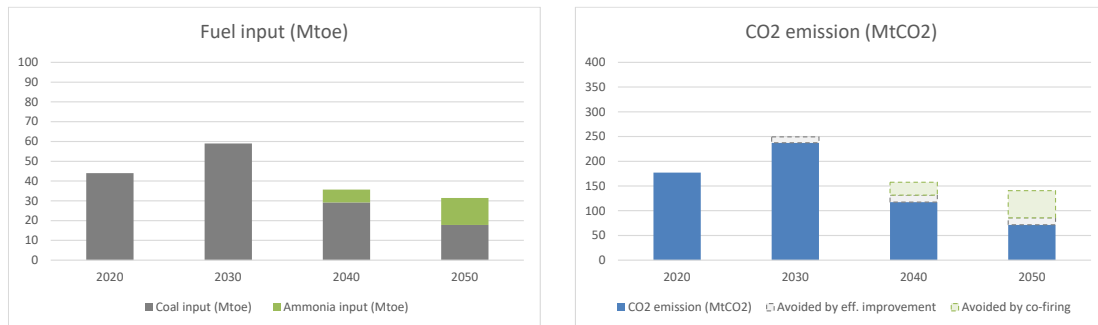
Scenario	Item	IDN	MYS	PHL	THA	VNM	Total
Low	Capacity [GW]	27	3	8	1	32	71
	CO ₂ reduced [Mt]	55	6	19	1	67	147
	NH ₃ demand [Mt]	31	3	11	1	38	83
PDP (ref.)	Capacity [GW]	8 (2050)	8 (2040)	14 (2040)	5 (2037)	41 (2030)	76
	CO ₂ reduced [Mt]	18	18	30	10	91	168
	NH ₃ demand [Mt]	10	10	17	7	52	96
High	Capacity [GW]	52	3	20	2	55	131
	CO ₂ reduced [Mt]	110	6	46	2	119	283
	NH ₃ demand [Mt]	61	3	26	1	68	160

Note: A 40% efficiency and ammonia ratio of 50% are assumed for calculating the PDP scenario.

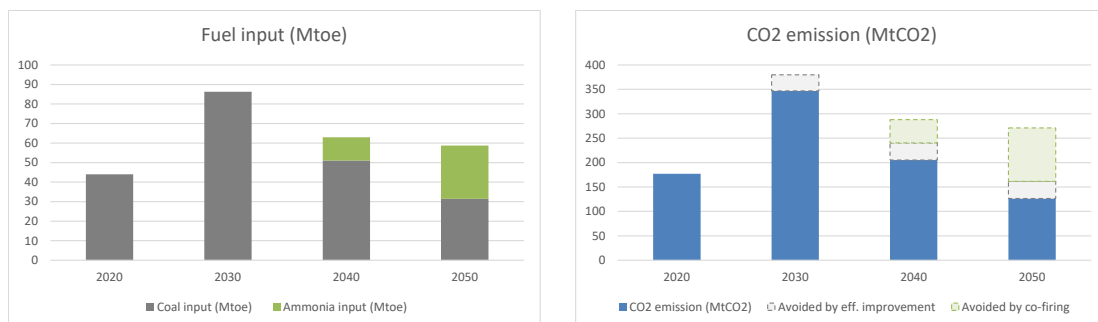
Source: Author (Capacity in the PDP is based on information from each country).

Figure 3.9. Fuel Input and CO₂ Emission by 2050 (Indonesia)

[Low scenario]



[High scenario]

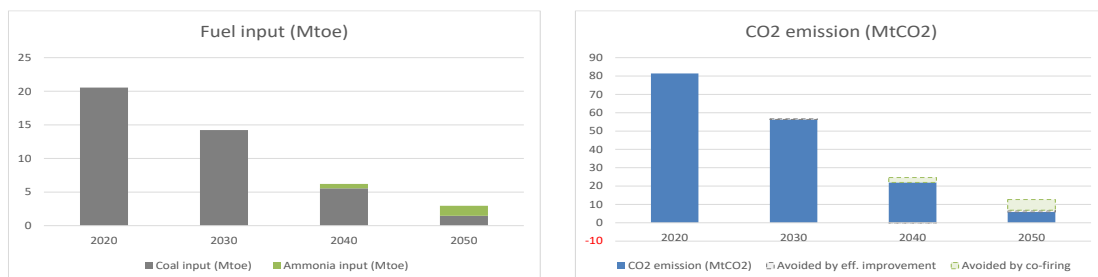


Note: Avoided by efficiency. Improvement shows the comparison with efficiency in 2020.

Source: Author.

Figure 3.10. Fuel Input and CO₂ Emission by 2050 (Malaysia)

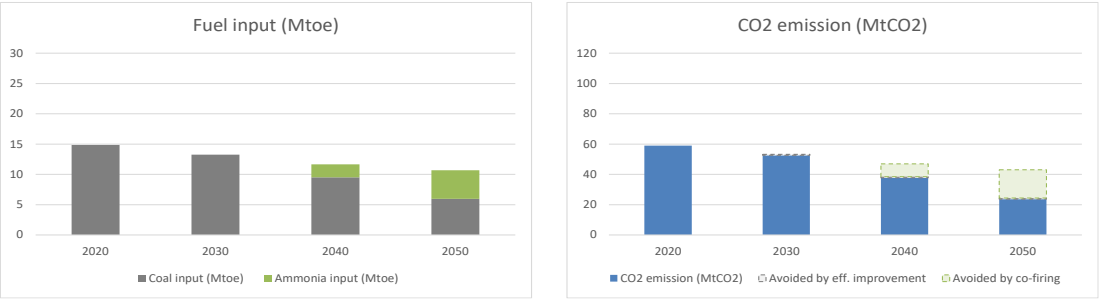
[Low / High scenario]



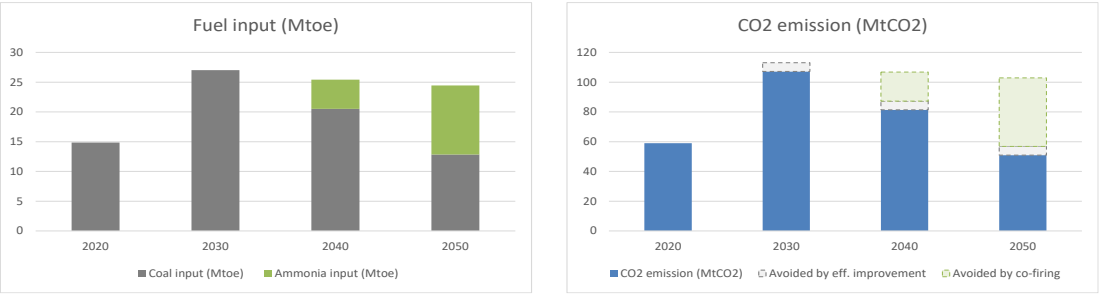
Source: Author.

Figure 3.11. Fuel Input and CO₂ Emission by 2050 (Philippines)

[Low scenario]



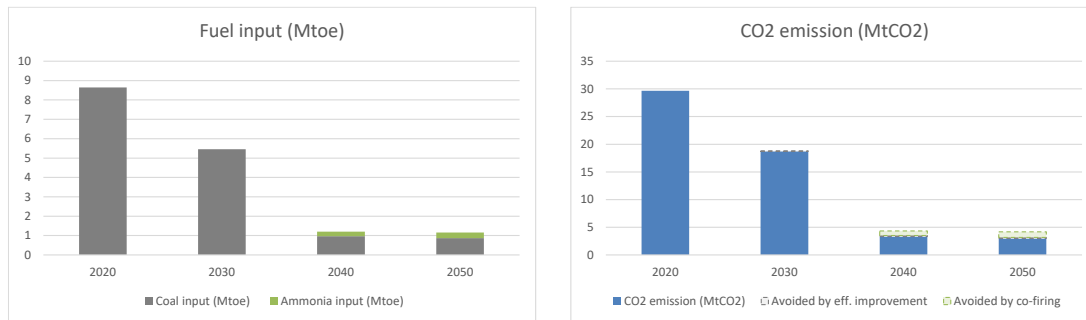
[High scenario]



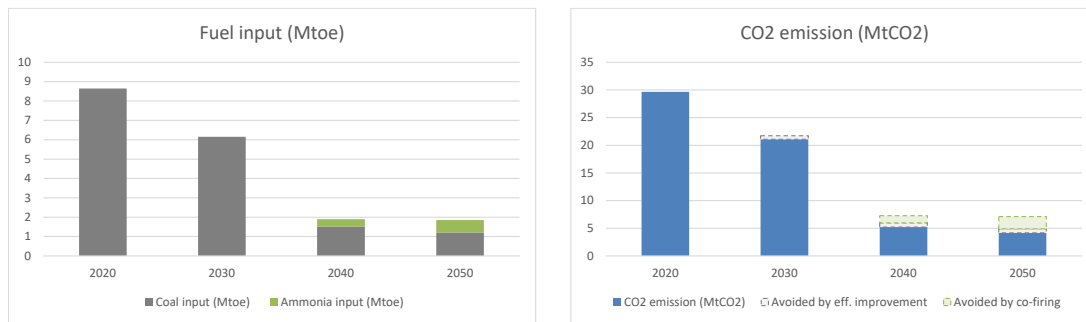
Source: Author.

Figure 3.12. Fuel Input and CO₂ Emission by 2050 (Thailand)

[Low scenario]



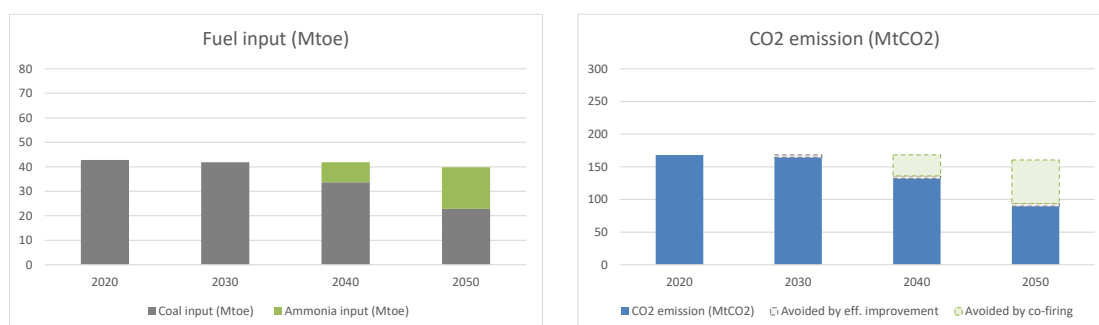
[High scenario]



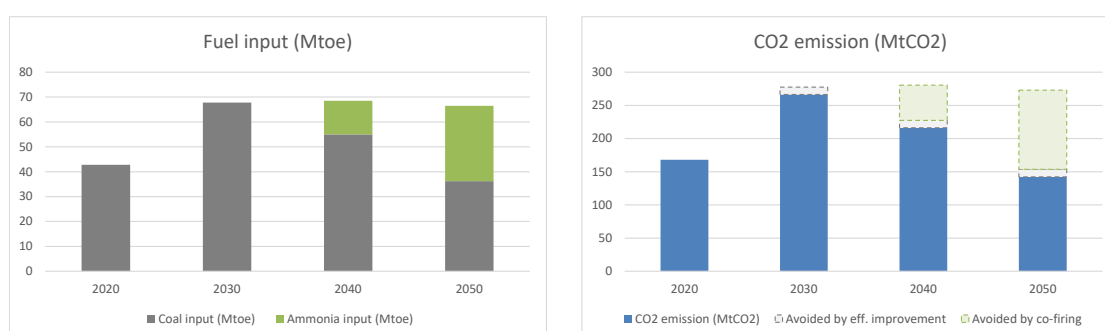
Source: Author.

Figure 3.13. Fuel Input and CO₂ Emission by 2050 (Viet Nam)

[Low scenario]



[High scenario]



Source: Author.

4. Issues for Ammonia Co-firing (Policy/Technology/Cost/Logistics)

Malaysia has a proven track record in ammonia production but does not have sufficient technology for ammonia co-firing. Therefore, it announced that the technical study of ammonia co-firing would be carried out with the cooperation of Japanese companies at the International Conference on Fuel Ammonia held in October 2021.

In the Philippines, since the electricity price is relatively high compared to other ASEAN countries, it is difficult to refurbish power generation facilities which lead to higher electricity prices. Therefore, like other decarbonisation technologies, raising funds for equipment refurbishment is challenging for ammonia co-firing. However, a Japanese private company has invested in a major electric power company in the Philippines and is considering the introduction of a power plant using green fuel, such as ammonia. Also, where energy resources are scarce, forming a supply chain that stably procures ammonia is also a challenge.

Viet Nam plans to promote renewable energy towards the realisation of carbon neutrality. On the other hand, since the number of coal-fired power generation units is large during the transition period, the cost of refurbishment for ammonia co-firing will be high. Moreover, stable and low-priced procurement is required to supply ammonia to many power plants. So far, ENV and Japan (METI, NEDO, JCOAL) have agreed to promote the sharing of technical information and cooperation.

Chapter 4

Conclusions

1. The Potential of Fuel Ammonia Will Keep Growing

In the energy sector, ammonia was originally intended to be used as a 'carrier' or a means of hydrogen transport. However, with a technology that allows direct combustion without cracking into hydrogen and nitrogen, the cost of co-firing in coal-fired power plants has become much lower, and ammonia's potential as a fuel has greatly expanded. As of June 2022, two coal-fired power plants in Japan are conducting demonstration tests of 20% co-firing. Furthermore, there is also a plan to increase the co-firing rate to 50% soon. If coal-fired power plants can raise their co-firing ratio to 50%, their carbon intensity will be on the same level as that of gas-fired power plants, and their value as a low-carbon power source will be significantly enhanced. This study mainly examined the potential of ammonia as a fuel for co-firing in power plants (coal-fired power generation). However, ammonia can also be used as a fuel for industrial heat and maritime transportation; thus, its demand potential will not be limited to power sector use.

Power demand in Asia is highly likely to keep growing in ASEAN countries. Several existing coal-fired power plants, on the other hand, have been built in recent years, and the average age of the coal power generation units is young in Asia. While coal-fired power plants should be closed as early as possible to achieve carbon neutrality and avoid catastrophic economic impacts caused by climate change, ASEAN countries could not afford to close such younger units without fully utilising and recovering their investment cost. However, it is challenging to substitute coal power generation units with zero-emission power sources, such as renewable and nuclear, and to develop incremental new generation capacities to meet the growing demand. Therefore, it is a realistic option to keep using existing coal-fired power plants with as few GHG emissions as possible. In this regard, co-firing ammonia with coal at existing units can perfectly meet this goal. Therefore, ammonia co-firing is an indispensable technology for ASEAN countries to achieve carbon neutrality in the future.

2. Addressing the Challenges to Fully Cultivate the Benefits of Fuel Ammonia

To fully enjoy the potential benefits of utilising fuel ammonia in ASEAN, several challenges need to be overcome.

First, the biggest challenge is the development of large-scale infrastructures for the use of ammonia as a fuel. Those infrastructures will include, but not be limited to, the ammonia production plant and storage facilities, berths and loading facilities for ammonia loading, large ammonia tankers for long-distance international transport, unloading and storage facilities at receiving sites, and replacement of existing burners for co-firing operations. In addition to these infrastructures, in the case of blue ammonia, made from fossil fuels, CCS facilities to capture the CO₂ generated during production and underground storage also need to be developed. During the introduction phase of ammonia, existing infrastructures for fertiliser production can be utilised. But once a full-scale introduction to the power sector begins, infrastructure for fuel ammonia must be developed from scratch to minimise the impact on the existing ammonia supply chain and market. Because such investments will take time, early investment decisions are necessary to utilise fuel ammonia quickly.

Second, supply cost must be reduced. This study shows that fuel ammonia is still expensive compared to existing fuels. Although the supply cost of ammonia is expected to decrease through economies of scale, learning curve effects, and logistics optimisation, a considerable cost reduction is still required to make it affordable for many ASEAN countries. In this regard, policy support will be necessary for consumer countries to promote the adoption of ammonia. For example, many countries currently adopt a feed-in tariff system to introduce renewable energy into their power generation mix. Similar policy support can be arranged for fuel ammonia because it is also a zero-emission fuel like renewable energy.

Third, HSE (health, safety, and environment) in ammonia supply must be ensured. Ammonia is a toxic substance and must be handled with great care by operators with specialised knowledge. Ammonia also has an odor, so sufficient leakage prevention measures must be taken. Ammonia is a commodity globally traded as a feedstock for fertiliser production and is utilised without serious HSE problems. When ammonia is used to generate power, a larger amount than when it is used as a feedstock for fertiliser must be transported and handled. However, the fertiliser manufacturing plants have already established appropriate standards and procedures to process ammonia safely, and such existing practices can be referred to and

adopted for power generation. In addition to toxicity and odor issues, ammonia is also known to increase NO_x emissions. But NO_x emissions can be controlled by devising an optimal combustion mode and installing an additional denitrification facility if needed. The knowledge and expertise on the proper combustion and control of the emissions will be accumulated as its operation continues.

Fourth, the impact of fuel ammonia used on other related product markets must be minimised. Since the Asian population is expected to continue to grow, demand for ammonia as a fertiliser feedstock is also expected to increase. In this context, if ammonia demand rises as fuel increases, competition over ammonia supply may occur between the fertiliser and power sectors. The adverse effects of this unwanted competition must be minimised. As for ammonia demand in the power sector, many countries will adopt policies to introduce ammonia for power generation with some numerical targets set. Its demand thus can be forecasted with a certain degree of certainty. In the future, the outlook for future ammonia demand must be regularly reviewed, and the results shared internationally so that the supply chain can be developed in a manner commensurate with future demand and avoid unwanted effects on the entire ammonia market.

3. Future Tasks

This study was not able to fully examine several important research items, which should be left for future research.

First, the ammonia supply potential in the ASEAN region needs to be elaborated more in detail. This study covered ammonia supply projects in the Americas, Australia, and the Middle East, but did not examine the production potential in the ASEAN region. In the future, fuel ammonia production may become more active in ASEAN because of domestic industrial development and energy security. Although the cost of production in ASEAN may be higher than in the Middle East or Australia, several governments in the region have expressed interest in strategically increasing ammonia production in the future as a domestically produced zero-emissions fuel. The production potential of hydrogen in each country must also be assessed to determine the production potential of ammonia in each country. Energy policymakers in the region will be highly interested in such a detailed assessment of hydrogen and ammonia potential in ASEAN.

Second, the economic evaluation of ammonia co-firing should be further expanded and detailed. In this study, only an economic evaluation of coal co-firing was conducted. But it is highly likely that co-firing with natural gas-fired power plants and mono-firing of ammonia will be introduced. Further detailed analysis is needed to determine the cost advantages (or disadvantages) of these various forms of ammonia use compared to, for example, renewable energy plus storage batteries or natural gas combined cycle power generation with CCUS.

Third and finally, a policy framework for promoting the introduction of ammonia should also be evaluated. Simply leaving it to market mechanism will not bring hydrogen and ammonia to the market. In the same way, governments adopted generous introduction policies when introducing renewable energy, government policy intervention is essential when introducing fuel ammonia. For example, a contract for difference policy, in which a specific price level or premium is set against the market transaction price, is being considered in Europe. The appropriate policy framework in the ASEAN context should also be explored in the future.

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