ERIA Research Project Report FY2023 No. 04

Study on the Applicability of CCT for a Comprehensive and Optimal Carbon-neutral Solution in ASEAN

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List of Abbreviations and Acronyms

AEDP	Alternative Energy Development Plan
AMS	ASEAN member state
ASEAN	Association of Southeast Asian Nations
A-USC	advanced ultra-supercritical
BESS	battery energy storage system
CCS	carbon capture and storage
CCT	clean coal technology
CCUS	carbon capture, usage, and storage
CFB	circulating fluidised-bed
CFPP	coal-fired power plant
CN	carbon neutrality
CO_2	carbon dioxide
COD	commercial operation date
COP	Conference of the Parties
COVID-19	Novel Coronavirus (2019-nCoV)
C&I	commercial and industrial
DEDE	Department of Alternative Energy Development and Efficiency, Ministry of Energy Thailand
DMF	Department of Mineral Fuels, Ministry of Energy Thailand
EPPO	Energy Policy and Planning office, Ministry of Energy Thailand
ERIA	Economic Research Institute for ASEAN and East Asia
ESS	energy storage system
EV	electric vehicle
EVN	Vietnam Electricity
FGD	flue gas desulphurisation system
GDP	gross domestic product
GHG	greenhouse gas
G20	Group of Twenty
IEA	International Energy Agency
IGCC	integrated coal gasification combined cycle
IGFC	IGCC + fuel cell

IPP	independent power producer
KEGA	key economic growth activity
LiB	lithium-ion battery
LNG	liquefied natural gas
MCH	methylcyclohexane
MEMR	Ministry of Energy and Mineral Resources of Indonesia
MOIT	Ministry of Industry and Trade (Viet Nam)
MoU	memorandum of understanding
mREC	Malaysia Renewable Energy Certificates (Malaysia)
MyRER	Malaysia Renewable Energy Roadmap
NEDO	New Energy and Industrial Technology Development Organization
NEP	National Energy Policy
NESTI	Nano Malaysia Energy Storage Technology Initiative
NRE	new and renewable energy
OWP	offshore wind power
PDP8	Latest power development plan of Viet Nam
PEFC	PEM electrode fuel cell
PETRONAS	Petroliam Nasional Berhad
PLN	PT Perusahaan Listrik Negara (Persero) (State Electricity Company)
PPA	power purchase agreement
PSA	pressure swing adsorption
PSP	pumped storage power
PV	photovoltaic
R&D	research and development
RE	renewable energy
RUEN	Rencana Umum Energi Nasional (National Energy General Plan)
RUPTL	Rencana Usaha Penyediaan Tenaga Listrik (National Power Development Plan of Indonesia)
SAF	sustainable aviation fuel
SOFC	solid oxide fuel cell
ST	Energy Commission of Malaysia
TNB	Tenaga Nasional Berhad
UNFCCC	United Nations Framework Convention on Climate Change

USC	ultra-super critical
VRE	variable renewable energy
WG	Working Group

Chapter 1

Background, Objectives, and Methodology of the Study

1. Background

Electricity demand in the ASEAN region is increasing as the region's economy grows steadily. Thus, power plant development should proceed towards a well-balanced optimal generation mix with coal, gas, and renewables to address the surging demand.

Coal and liquefied natural gas (LNG) are still the main energy sources for surging economic expansion in some ASEAN member states (AMSs) because of their affordability and reliability despite the worldwide decarbonisation trend. According to the Sixth ASEAN Energy Outlook published in 2020, renewables' capacity and share will remarkably increase with total energy demand. Fossil energy, such as coal and LNG, also increases even in the modal case of the ASEAN target scenario.

While the energy situation is quite different in the AMSs, most countries must facilitate a carbon-neutral policy, even if they mainly use fossil energy in this energy transition era. A stepwise transition by experienced clean coal technology (CCT) might be a practical way for these countries.

In October 2020, Japan's then-Prime Minister Yoshihide Suga unveiled a major shift in Japan's climate change position: the country now aims to become a carbon-neutral society by 2050. To materialise a carbon-neutral society, the Government of Japan aggressively facilitates energy improvement of the current CCT and research and development (R&D) of the next generation's CCT, carbon capture and storage (CCS), carbon capture, usage, and storage (CCUS), and carbon recycling.

This study proposes a set of tailor-made and optimal carbon-neutral solutions for each AMS, such as (i) combustion types (e.g. biomass cofiring, ammonia cofiring, hydrogen combustion, boiler types, such as ultra-super critical (USC), advance ultra-supercritical (A-USC), integrated coal gasification combined cycle (IGCC), IGCC + fuel cell (IGFC) equipped with environmental facilities; and (ii) operation techniques (e.g. flexibilisation measures). It also provides a comprehensive proposal by combining CCT. That is, combustion technologies and CO_2 storage/conversion technologies will be studied.

2. Objectives

The study aims to provide the following recommendations to support ASEAN in the energy transition.

1) By-country carbon-neutral solutions with CCT and relevant carbon-recycling technologies and measures
2) Carbon-neutral solutions with CCT and relevant carbon-recycling technologies and measures applicable to ASEAN
3) By-country and regional policy recommendations to be conducive to the energy transition efforts by ASEAN and respective AMSs.

3. Methodology

1) Formulation of by-country strategies for technology introduction, implementation, and sharing

The study focuses on identifying and formulating by-country strategies to facilitate the introduction, implementation, and sharing of technology:

- Electronic communication with Working Group (WG) members for information and advice to develop the optimal strategy for each target AMS
- Collective discussions at the two-time WG meetings as referred to 2) below
- Internet surveys to enhance the accuracy of the strategies to be formulated.

2) Working Group activities

- Establish a working group of members from the central governments and major public institutions in the respective target countries to identify issues and barriers to promoting the carbon-neutral policy. The members will present the current energy situation, CO_2 emission volume, and CCT roadmap. The study team (the Team) will give a basic idea of suitable and adaptable CCT for each country.
- Based on the data provided by members and the Team, all participants will discuss the direction for further study by the Team. Technology suppliers will join the technical discussions.

3) Technical study by the Team

- The study team will analyse the data provided through the WG and any data from the public domain to make a map using the energy policy, CO_2 volume, and transition potential of conventional to the latest CCT in each country.
- Combustion types, such as biomass cofiring; ammonia cofiring; hydrogen combustion, boiler types such as USC, A-USC, IGCC, and IGFC equipped with environmental facilities, and operation techniques, such as flexibilisation measures are considered in this study.

- Based on the discussion and technical study, the study team will work out a comprehensive and optimal CCT solution proposal for a carbon-neutral society.

First WG meeting: Discussion on topics such as potential technology introduction in each AMS, issues to be addressed, envisaged best practices, policy measures to be taken, benefits and advantages, etc.

Second WG meeting: Presentation by JCOAL of the draft report covering proposals for each AMS.

4. Expected Recommendations

The following recommendations will be provided to support ASEAN in the energy transition:

1) By-country carbon-neutral solutions with CCT and relevant carbon-recycling technologies and measures
2) Carbon-neutral solutions with CCT and relevant carbon-recycling technologies and measures applicable to ASEAN
3) By-country and regional policy recommendations to be conducive to the energy transition efforts by ASEAN and respective AMSs.

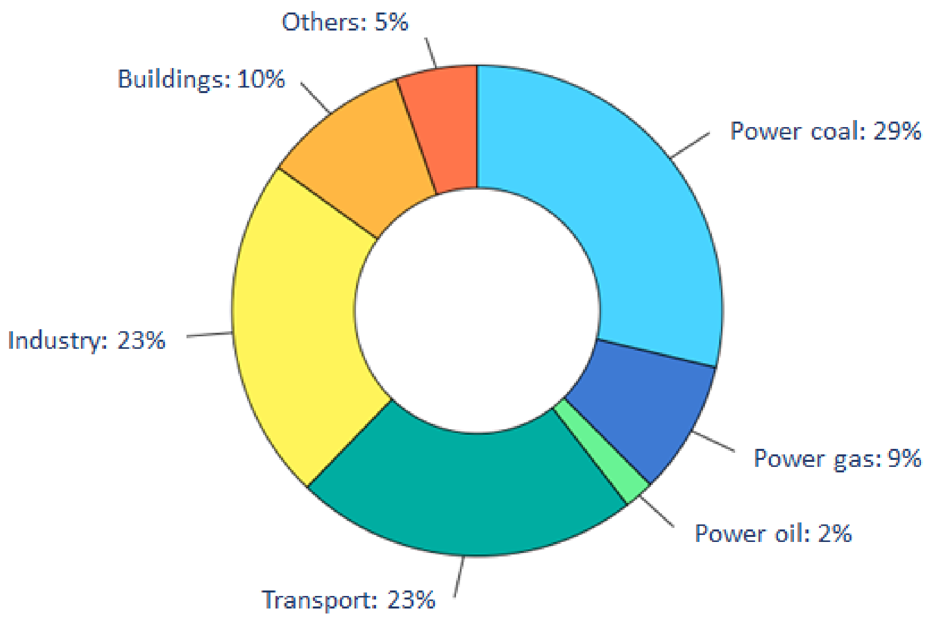
Chapter 2

Energy Transition Outlook and Best-Available Technologies

1. Background of Technologies Towards Carbon Neutrality

To address the global climate change issue, the CO_2 emission/absorption balance must be equivalent to zero by the effort of all sectors emitting CO_2 with everyday activities. As shown in Figure 2.1, the power and industry sectors are essential in mitigating their emission by introducing an innovative technology shift, often recognised as energy transition.

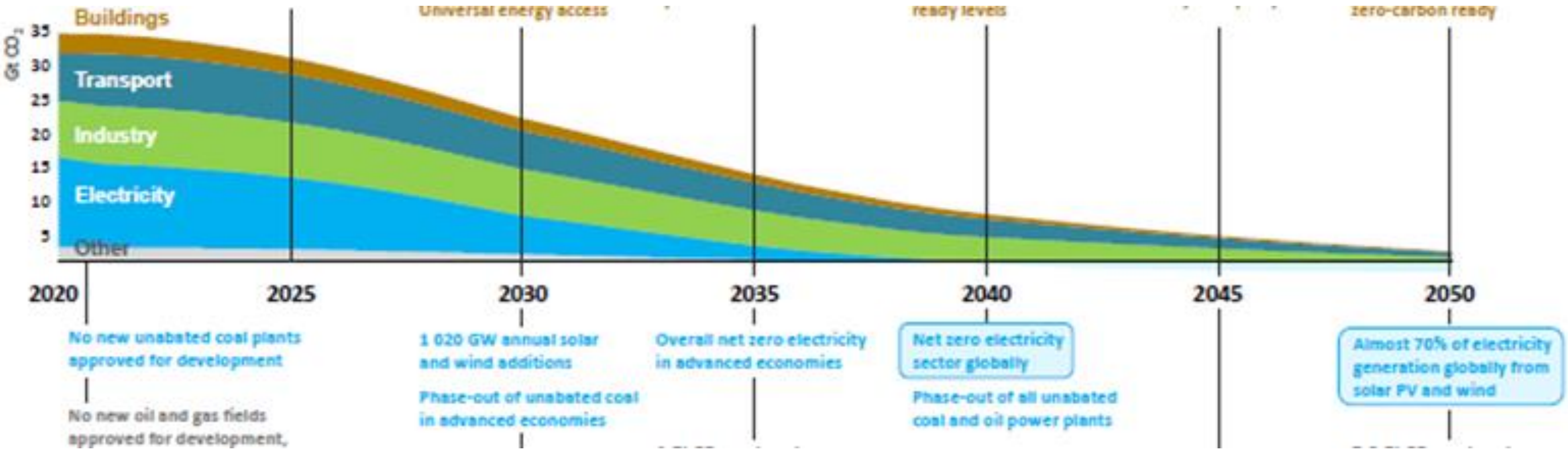
Figure 2.1. Global Energy–related CO_2 Emissions by Sector



Source: IEA (2021a).

Many countries are working towards carbon neutrality by 2050 and have set targets for each sector (Figure 2.2). The main focus in the transport sector is reducing CO_2 emissions through electric vehicles (EVs). The main countermeasures in the industry sector are the electrification of manufacturing processes and heat sources and the use of hydrogen.

Figure 2.2. CO_2 Reduction Milestones by 2050

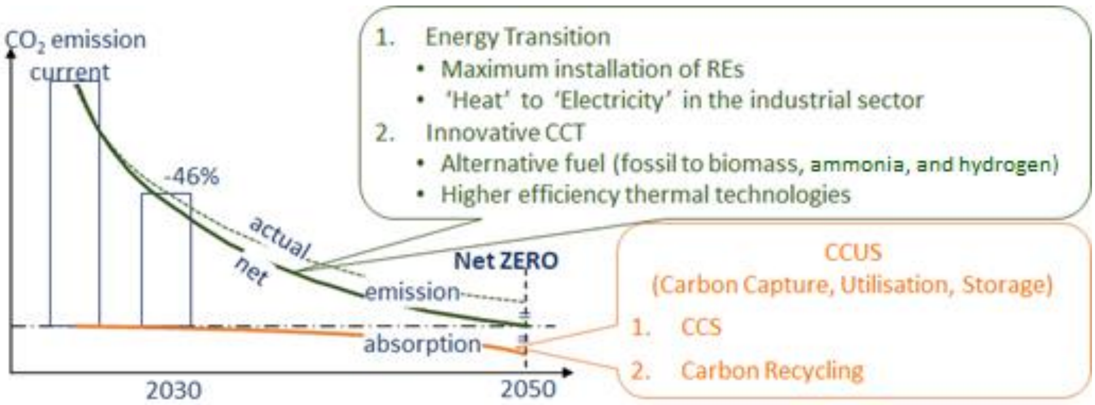


Source: IEA (2021b).

In this way, all industries are premised on using the so-called 'green power' that does not generate CO_2. Thus, how to achieve a transition to non-fossil energy in the power sector is most important.

CO_2 reduction measures towards net zero (as indicated by the dashed line in Figure 2.3) include the maximum introduction of renewable energy (RE), conversion from thermal energy to electrical energy, innovative CCT such as the introduction of carbon-neutral alternative fuels and power generation technology with higher efficiency,

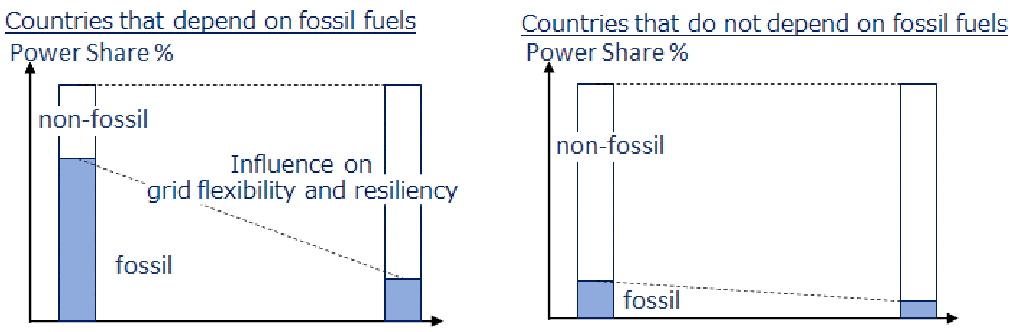
Figure 2.3. Conceptual Image towards Carbon Neutrality



Source: Edited by JCOAL Study Team based on data from METI (2021).

Since CO_2 reduction alone cannot achieve net zero, it is necessary to put the so-called 'negative emission" technology into practical use, which reuses or stores the emitted CO_2. The solid line of Figure 2.3 indicates that net zero will be achieved by integrating CO_2 reduction and CO_2 utilisation/storage.

Figure 2.4. Influence of Energy Transition on the Power Grid



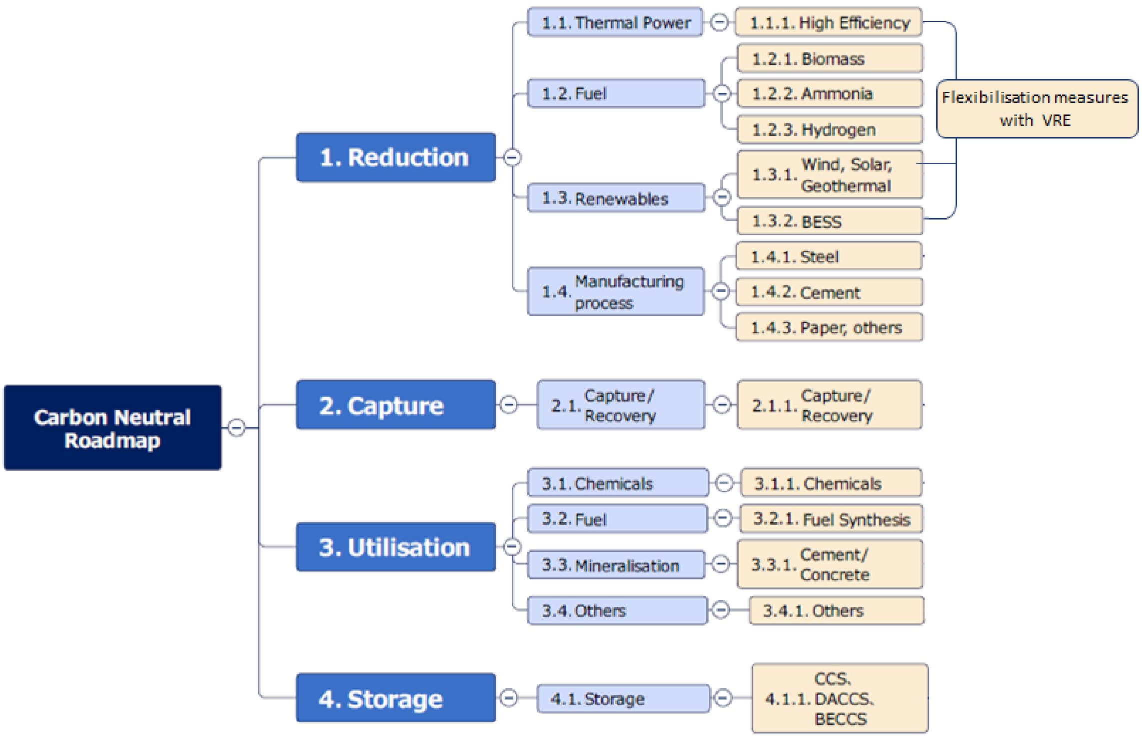
Source: JCOAL Study Team.

When introducing RE (Figure 2.4), we must consider that the fossil energy share directly affects the change in the RE share; then, the grid fluctuation and resilience will be affected.

1.1. Technology Roadmap Towards Carbon Neutrality and Its Categories

JCOAL is compiling a 'Technology Roadmap towards Carbon Neutrality'. Figure 2.5 indicates the four major technology categories – reduction, recovery, utilisation, and storage – and lists several specific technologies. Each technical example is described in the following sections.

Figure 2.5. Categories of Technology for Carbon Neutrality



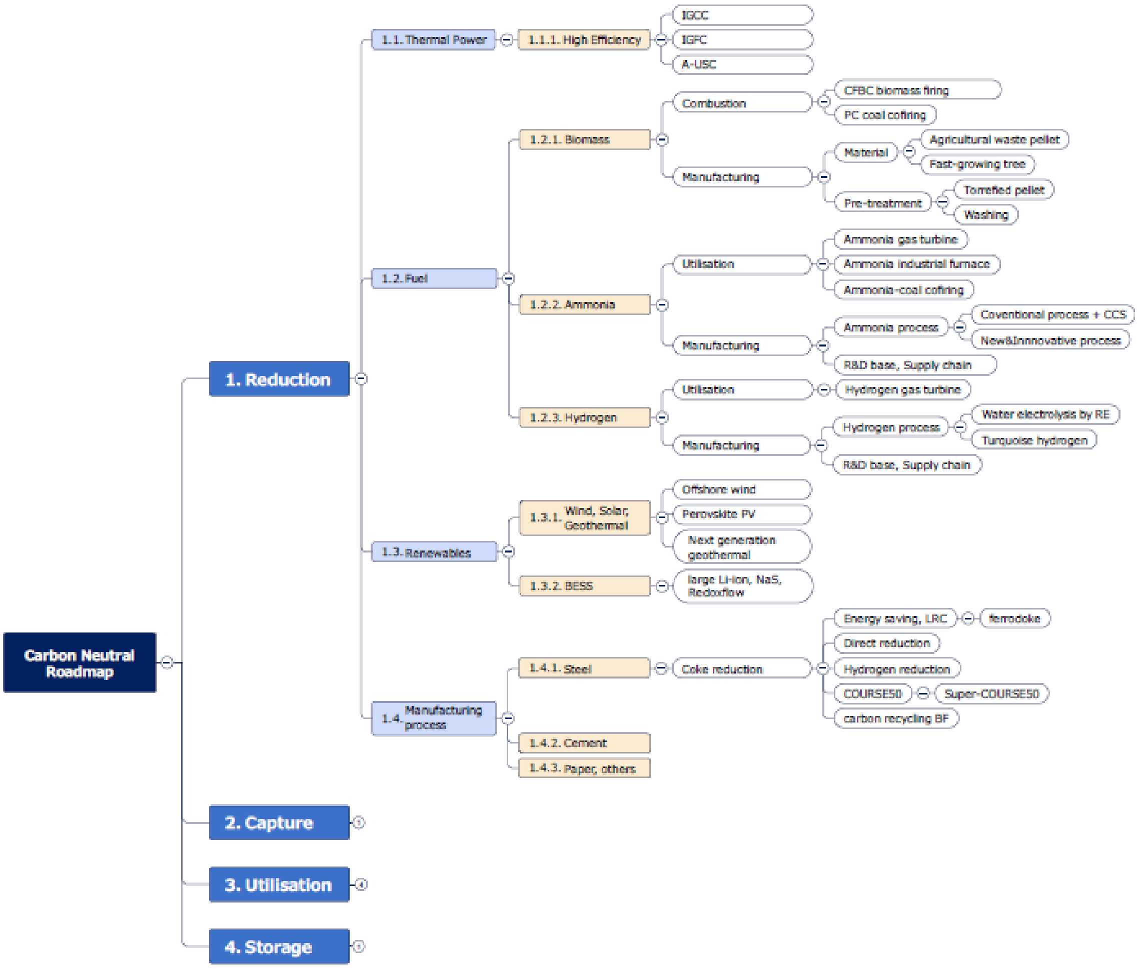
Source: JCOAL Study Team.

2. Key Technologies for CO_2 Reduction, Capture, Utilisation, and Storage

2.1. CO_2 Reduction

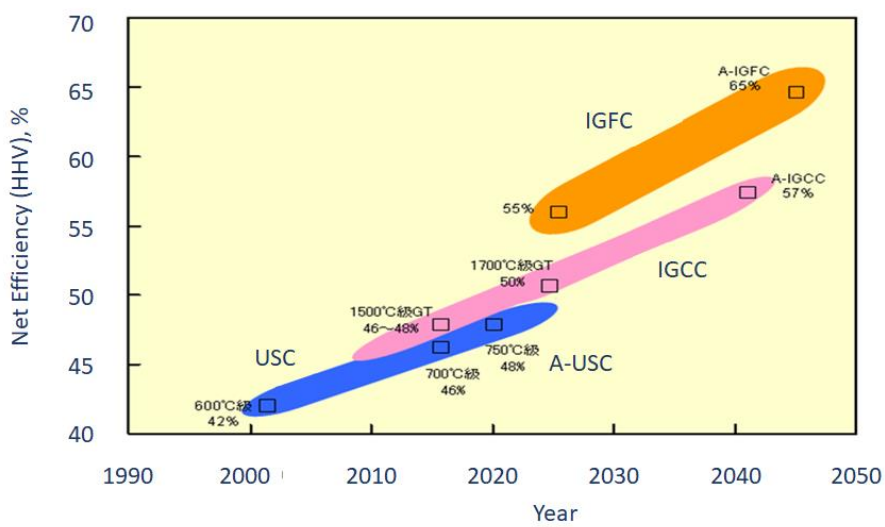
Figure 2.6 shows technologies in the 'reduction' category, including high-efficiency thermal power generation technologies, alternative fuels, RE, and industrial processes. For alternative fuels, utilisation of biomass, ammonia, and hydrogen are described. The example of a factory system integrating solar power, fuel cells, and power storage is shown later for RE. Finally, energy-intensive steel, cement, and paper industries are introduced for decarbonization in industrial processes.

Figure 2.6. CO_2 Reduction Technologies



Source: JCOAL Study Team.

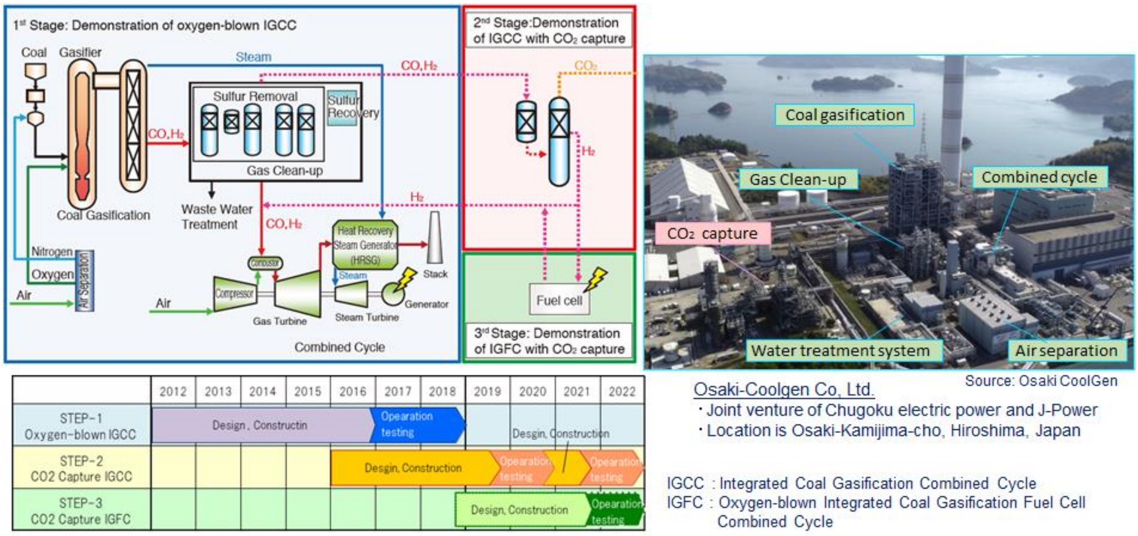
Figure 2.7. Efficiency Improvement of Low-emission Coal-fired Generation



Source: Edited by JCOAL Study Team based on data from METI (2010).

Since increasing power generation efficiency directly leads to reduced coal consumption per unit of power generated, it is one of the effective technologies for countries that have no choice but to use coal for energy security. Figure 2.7 shows the relationship between power generation efficiency and development year. Most coal-fired power plants (CFPPs) in Japan are USC, and several IGCC plants are in commercial operation. We believe that USC will be replaced with IGCC and IGFC as it reaches the end of its plant residual life.

Figure 2.8. IGFC Demonstration Project at Osaki



IGFC = integrated coal gasification combined cycle + fuel cell.
Source: Edited by JCOAL Study Team based on data from Third Regional HELE Seminar, 2021, presented by NEDO.

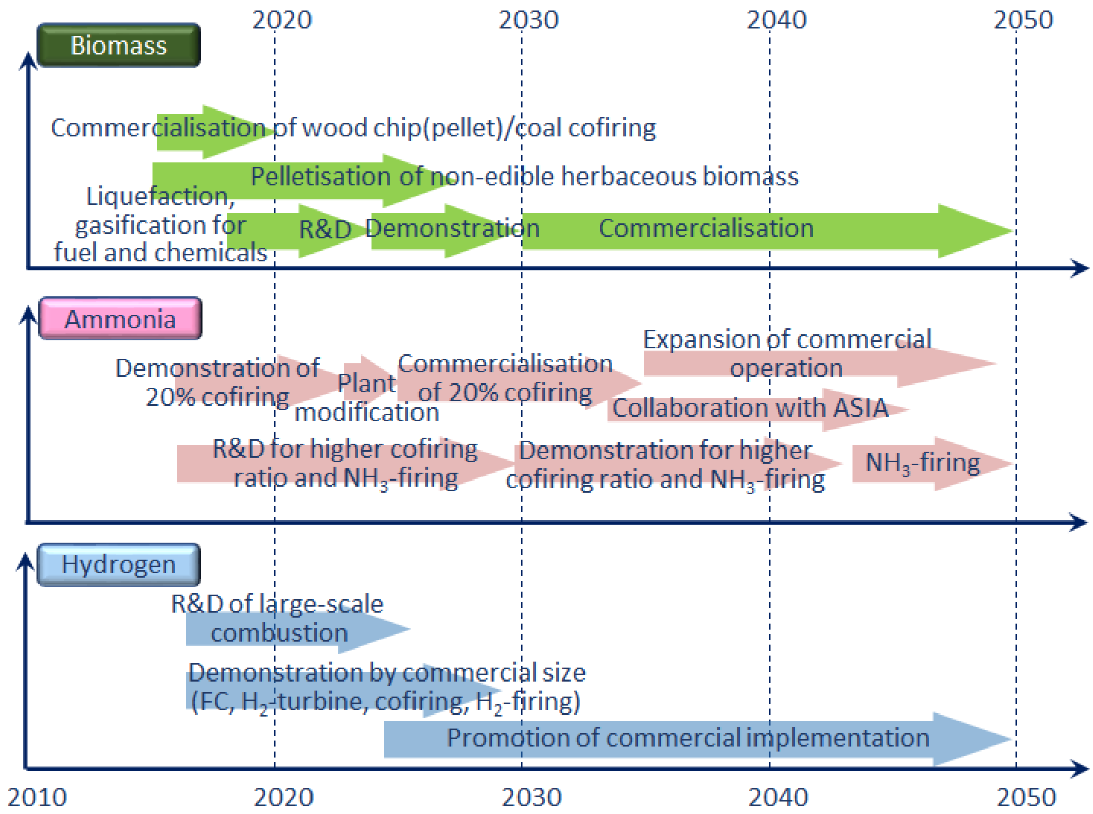
NEDO has been conducting the Osaki CoolGen Project with the technologies of oxygen-blown IGCC combined with solid oxide fuel cell (SOFC) at Osaki Kamijima, Hiroshima, to realise an innovative low-carbon emission CFPP. Its target is energy efficiency (HHV) of 47%, with 90% capturing CO_2, in the case of a 500 MW commercial plant.

Figure 2.9 shows the roadmap for the development of technologies for biomass fuel, which is carbon-neutral, and for ammonia and hydrogen, which are carbon-free. Biomass fuel is a proven and commercialised technology, although the combustion method differs depending on the type and scale. The focus of future R&D is shifting to the use of unused biomass resources, such as agricultural waste, and developing utilisation methods other than combustion, such as gasification.

Ammonia coal cofiring demonstration is undergoing a 20% cofiring ratio at the existing coal-fired USC plant, aiming for practical application by 2030. At the same time, the R&D of a high cofiring ratio and ammonia-dedicated firing technology is also underway. The Japanese government intends to spread 20% ammonia cofiring to the Asian region after 2030.

In addition to being used as a carbon-free fuel, hydrogen has many uses as an important reducing material for fuel cells and carbon recycling, which will be described later. Large-scale demonstrations of hydrogen combustion turbines are underway for fuel utilisation. But the highest development challenge for expanding use is cost reduction.

Figure 2.9. R&D Roadmap of Carbon-neutral Fuel for Power Generation



Source: Edited by JCOAL Study Team based on data from MAFF (2019) and METI (2020).

Examples of biomass-coal cofiring plants are shown in Figure 2.10 and 2.11. Both plants have been modified for operation with a higher cofiring ratio than the existing PC boiler.

Figure 2.10 is a biomass coal cofiring plant using the circulating fluidised-bed (CFB) combustion method. While the cofiring ratio of existing PC boilers is from 2% or 3% to less than 10%, this technology is widely applicable from a few percent cofiring to 100% biomass combustion. The range of combustible fuel types is also wide. But the maximum capacity size is not more than 500 MW class.

Figure 2.10. Biomass Cofiring Plant Designed for High Cofiring Ratio (1)

Panoramic view of the plant

Basic Configuration of CFB

CFB = circulating fluidised-bed.

Source: Chugoku Electric Power website, https://www.energia.co.jp/e/index.html.

Figure 2.11 is a method in which cofiring is performed inside the furnace by using a pulverising mill exclusively for coal and biomass in the existing PC boiler. The advantage of this method is that it can be used by modifying the existing PC boiler, but it is often used for wood chips and palm kernel shells due to its 'grindability' in mills.

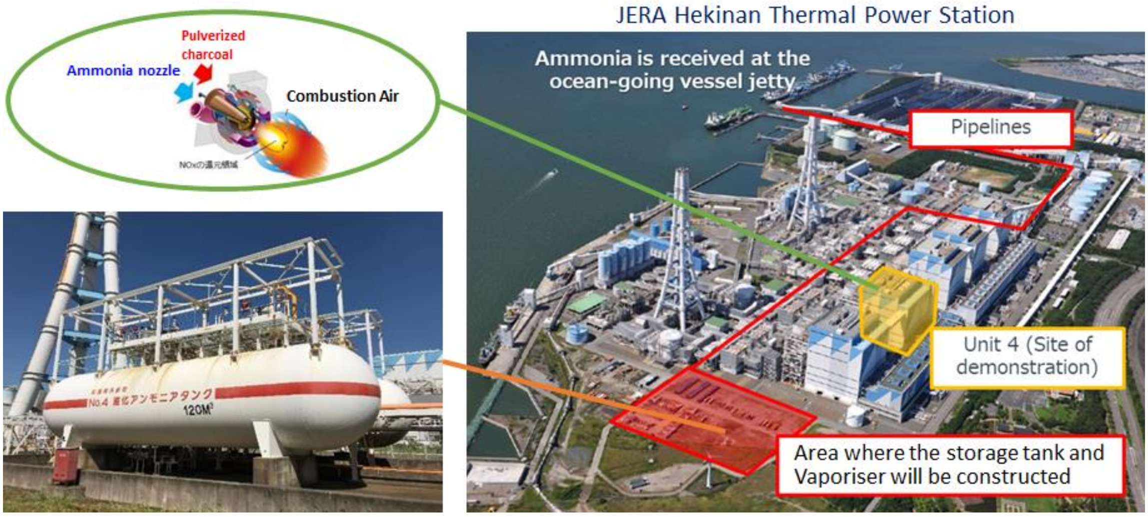
Figure 2.11. Biomass Cofiring Plant Designed for High Cofiring Ratio (2)

Panoramic view of the plant

Mixed combustion application using the dedicated mills

Source: MHI website, https://power.mhi.com/news/20180329.html.

Figure 2.12. Demonstration of Ammonia Cofiring in Existing USC Plant



Source: JERA (2022).

Figure 2.12 is an existing 1000 MW USC coal-fired plant that implements 20% ammonia cofiring. The test is performed in the unit in yellow. The ammonia is loaded in the area in red. The upper left is a burner modified for cofiring.

If 20% cofiring is done in this plant, 600,000 tons of ammonia will be required annually. Therefore, cofiring demonstration and establishment of a supply chain related to fuel ammonia are simultaneously being studied.

Figure Figure 2.13 shows an example of the energy transition to green electricity, called 'RE100' factory, Panasonic 'H_2 KIBOU FIELD Demonstration'. All electricity for the polymer electrolyte fuel cell (PEFC) assembly factory is supplied by hydrogen-PEFC and solar cells. Its energy supply share is PEFC 80%, solar photovoltaic (PV) 20%, peak electricity is 680 kW, and annual energy consumption is around 2.7 GWh.

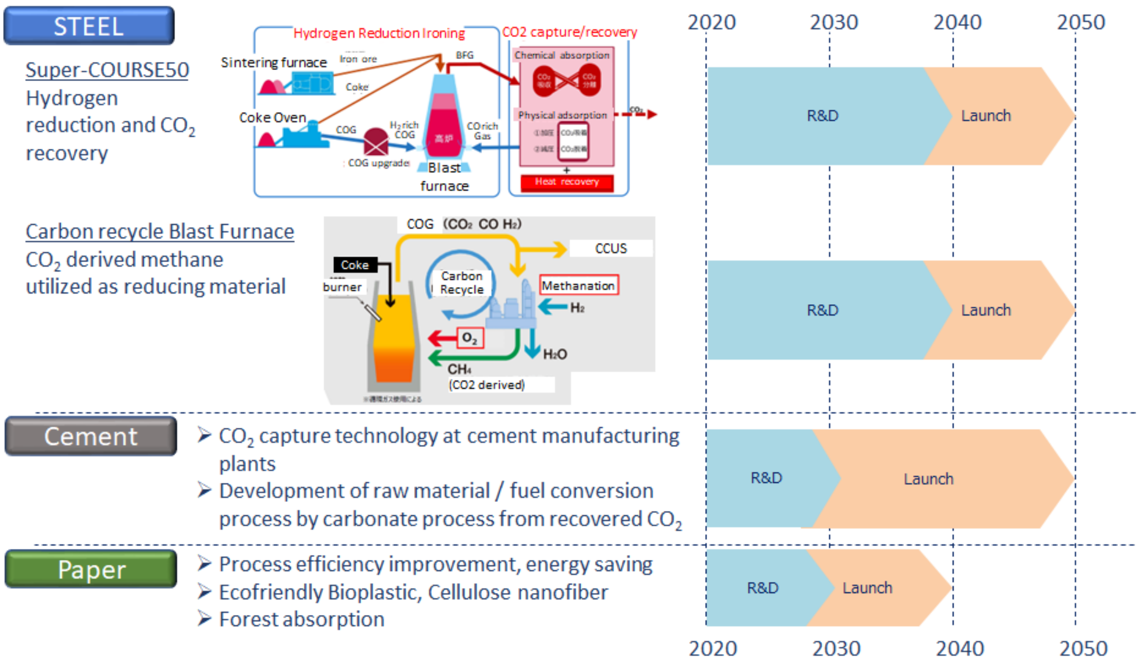
Figure 2.13. Demonstration of RE100 Factory, Panasonic 'H$_2$ Kibou Field Demonstration'

Source: Panasonic website, https://news.panasonic.com/jp/press/jn210524-1.

During sunny days, power from solar PV is consumed preferentially. During cloud days, power from a lithium-ion battery (LiB is consumed, and LiB is charged from the PEFC at night. Tentatively, conventional H_2 is supplied for PEFC generation, then will be shifted to green H_2 when its price becomes commercially competitive.

Figure 2.14 shows the carbon-neutral technology R&D roadmap in the industry sector – steel, cement, and paper. For example, coke used in pig iron production is the second-largest consumer of coal after power generation and emits a large amount of CO_2 in the process. Although it depends on the industrial structure, in the case of Japan, coke used in pig iron production accounts for about 40% of the CO_2 emissions of the entire industrial sector. Currently, two major development projects, Super-COURSE50 and carbon-neutral blast furnace, are underway for the carbon neutralisation of the steel industry. The former involves separating and recovering CO_2 from the coke oven gas, concentrating the hydrogen in the coke oven gas, returning it to the blast furnace, and using it for iron ore reduction. The latter uses hydrogen recovered from coke oven gas to synthesize methane, which is then used for iron ore reduction. The government supports both projects because of their large R&D investment.

Figure 2.14. Carbon-neutral Technology R&D Roadmap in the Industrial Sector



Source: Edited by JCOAL Study Team based on data from Nippon Steel website, JFE website (https://www.nipponsteel.com).

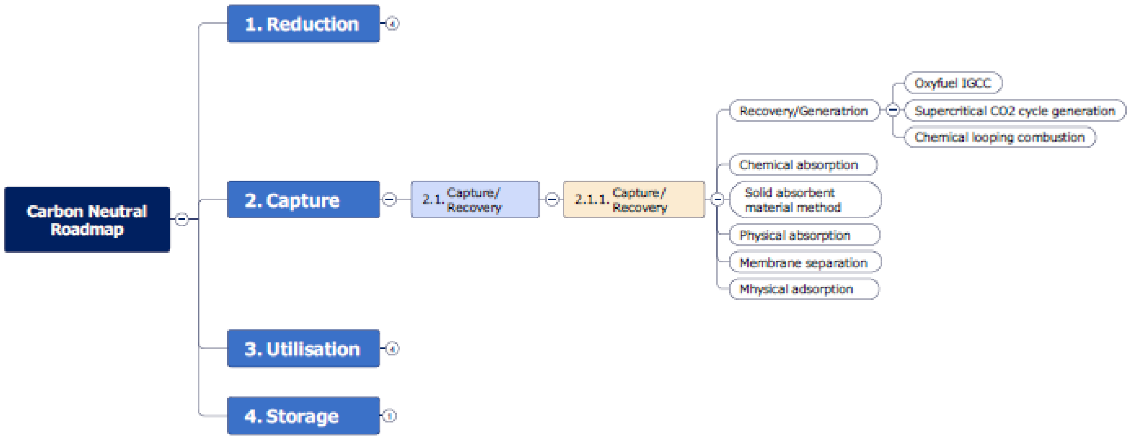
The main measures in the cement sector are to reduce CO_2 emissions by saving energy in processes, utilising hydrogen for heat sources, and recycling high-concentration CO_2 recovered from kilns.

The paper manufacturing sector, in addition to energy-saving processes and electrification of heat sources, is considering the development of bioplastic and cellulose nano-fibres, and the absorption of CO_2 by afforestation in their property.

2.2. CO_2 Capture

Figure 2.15 shows the classification of CO_2 capture technology. It can be broadly divided into two: a technology that separates CO_2 simultaneously as power generation (Table 2.1) and one that separates and recovers CO_2 from exhaust gas (Table 2.2).

Figure 2.15. CO_2 Capture Technologies



Source: JCOAL Study Team.

Table 2.1. Combined Power Generation and CO_2 Capture Technologies

Technology	Process	Status
Chemical looping cycle	Generation and CO_2 separation utilising the oxidation reaction by the fluidised bed combustion medium	R&D
Oxyfuel IGCC	CO_2 in the exhaust gas is circulated as an oxidant to gasifiers and turbines to generate combined power generation.	R&D

Source: Edited by JCOAL Study Team based on data from NEDO, Oki et al. (2011).

Chemical looping cycle and oxyfuel IGCC are innovative concepts that generate power and separate CO_2. However, they are still at the basic R&D stage; it will take time to put them to be proven.

On the other hand, the technologies for CO_2 recovery from flue gas shown in Table 2.2 and Figure 2.16 are getting closer to commercialisation. Several large-scale plants are being constructed around the world. However, efforts to reduce operating costs are still necessary, so several technologies are being developed in parallel.

Table 2.2. CO_2 Capture Technologies

Technology	Process	Application	Status
1. Chemical absorption	CO_2 separation/recovery through chemical reaction	Coal, cement, steel, refinery, chemical industry, LNG	Commercial
2. Physical absorption	CO_2 separation using dissolution equilibrium with solvent	Coal (high pressure), cement, refinery, chemical industry, LNG	Commercial
3. Solid absorbent material method	CO_2 separation using absorption equilibrium with porous material	Coal, cement, refinery, chemical industry	Demonstration
4. Physical adsorption	CO_2 separation using pressure swing of adsorption/desorption with porous material (PSA)	Coal, cement, steel, refinery, chemical industry	Commercial
5. Membrane separation	CO_2 separation using gas selectivity of ultra-membrane	Coal (high pressure), refinery, chemical industry, LNG	R&D

Source: Edited by JCOAL Study Team based on data from NEDO. (https://www.nedo.go.jp/english/).

Figure 2.16. CO_2 Capture Plant and Process Listed in Table 2.2

1. USA, Petra Nova, 4776t/d, EOR

1. Fukuoka, Sigma Power, 500t/d

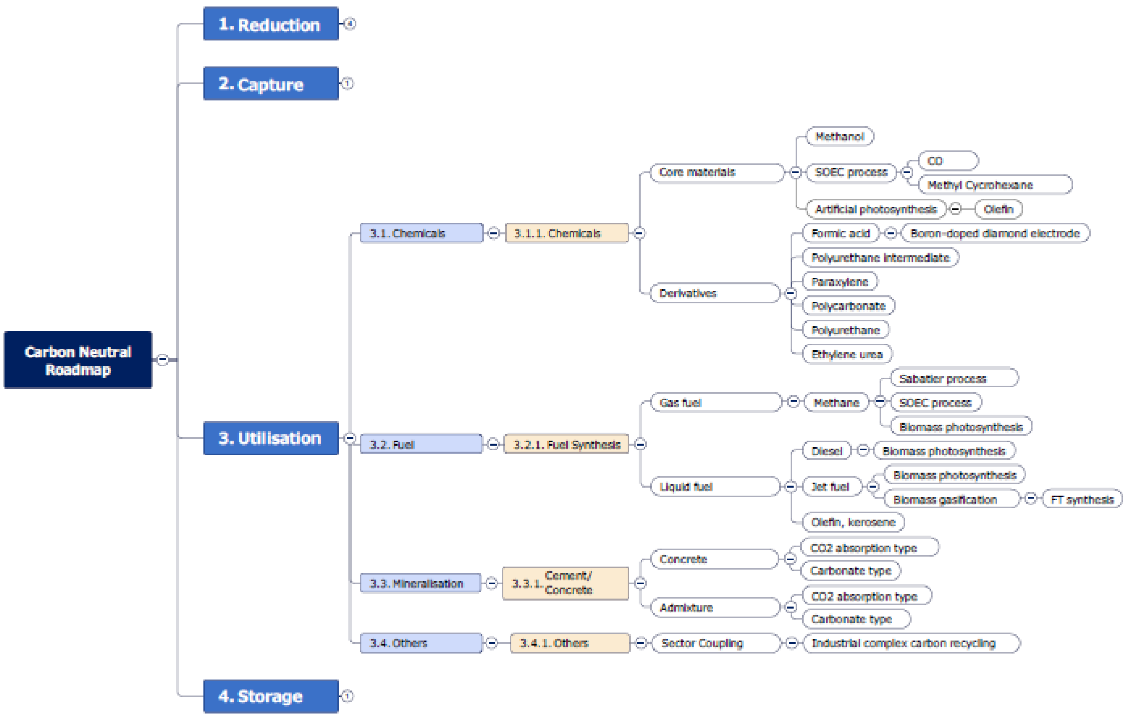
3. Kyoto, Maizuru, 40t/d

Source: Edited by JCOAL Study Team based on data from MHI, Toshiba, and KHI websites.

2.3. CO_2 Utilisation

Reusing CO_2 as a resource without releasing it into the atmosphere is an important negative emission and storage measure. Figure 2.17 shows the technology tree under 'Utilisation'. The main subcategories under 'Utilisation' are 'Chemicals', 'Fuels', 'Mineralisation', and 'Others'. CO and methanol, key substances obtained from CO_2 reduction reaction, are being studied in chemicals. Subsequent derivatives such as hydrocarbons, paraxylene, and polycarbonate are also being investigated. In terms of fuel, methane synthesis, sustainable aviation fuel (SAF), and other liquid fuels are also being studied. As for mineralisation, absorption into coal ash, cement, and concrete is being considered, and expected SAF commercialisation by the 2030s as a recycling method that does not use hydrogen.

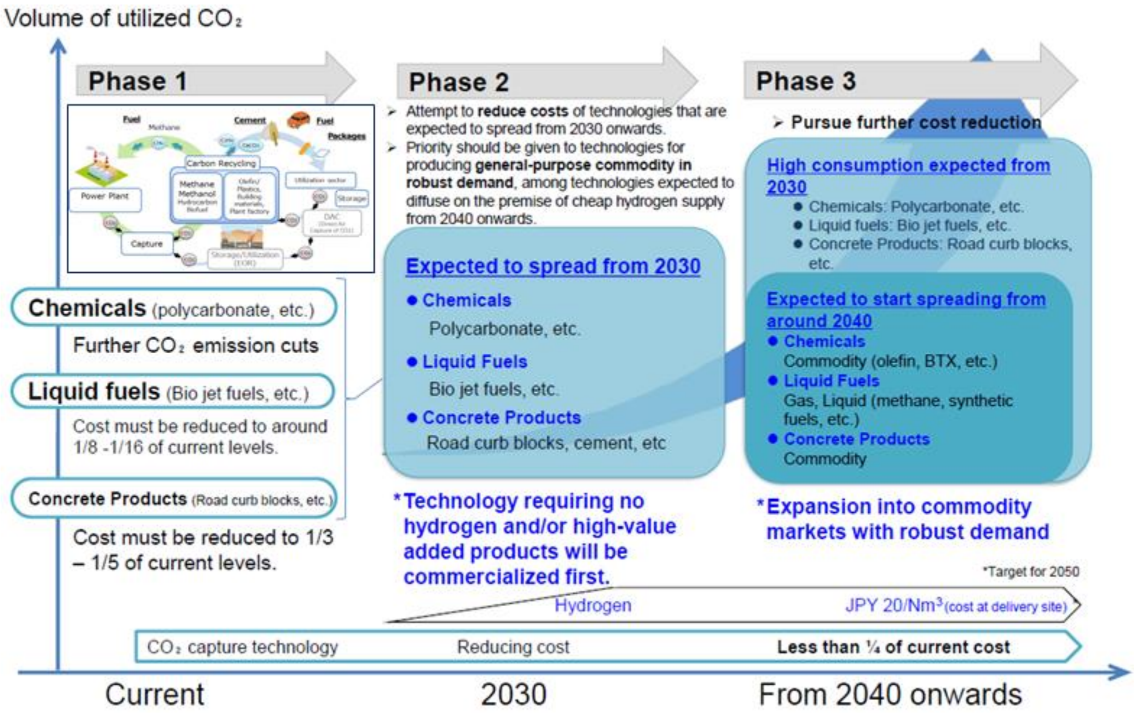
Figure 2.17. CO_2 Utilisation Technologies



Source: JCOAL Study Team.

Figure Figure 2.18 is the technology development roadmap for CO_2 recycling utilisation indicated by the Japanese government. Technologies that do not use hydrogen will be put into practical use in the 2030s, and technologies that use hydrogen will be developed along with reduced hydrogen costs.

Figure 2.18. Roadmap for Carbon-recycling Technologies



Source: METI (2019).

Figure 2.19 shows the SAF synthesis process and plant using photosynthetic reaction by algae, and biomass gasification with the Fischer-Tropsch process. SAF development is underway in the aviation sector to replace 10% of the total fuel capacity with SAF by 2030.

Figure 2.19. Biojet Fuel Process (Algae Photosynthesis, FT Synthesis)

FT = Fischer-Tropsch.
Source: Edited by JCOAL Study Team based on data from Nikkei (2021a).

In many cases, the conversion of CO_2 to chemicals is thermodynamically unfavourable, and hydrogen costs are directly affected. Therefore, price competitiveness must be considered severe compared to conventional products. However, it is possible to establish a policy considering the cost burden for carbon neutrality (CN), so we think technology development should be continued. Figure 2.20 shows the pilot plants for methane and methanol synthesis from CO_2, with multiple companies participating.

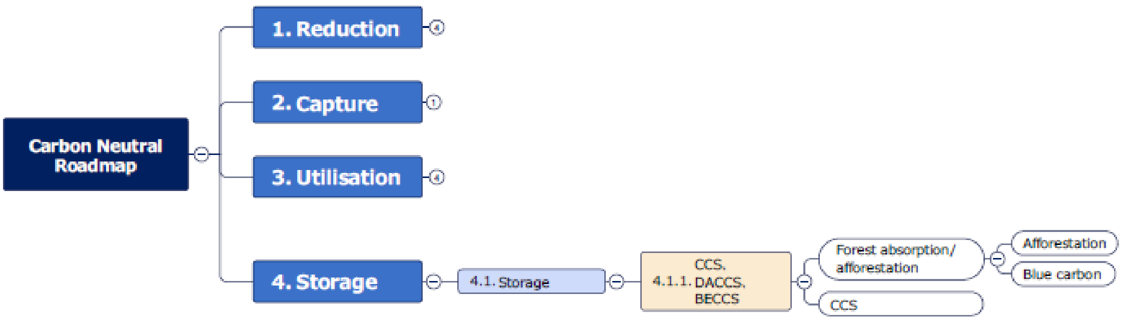
Figure 2.20. Pilot Plant of Methane and Methanol Syntheses from CO_2

Source: Edited by JCOAL Study Team based on data from the Hitachi Zosen website, Nikkei (2021b).

2.4. CO_2 Storage

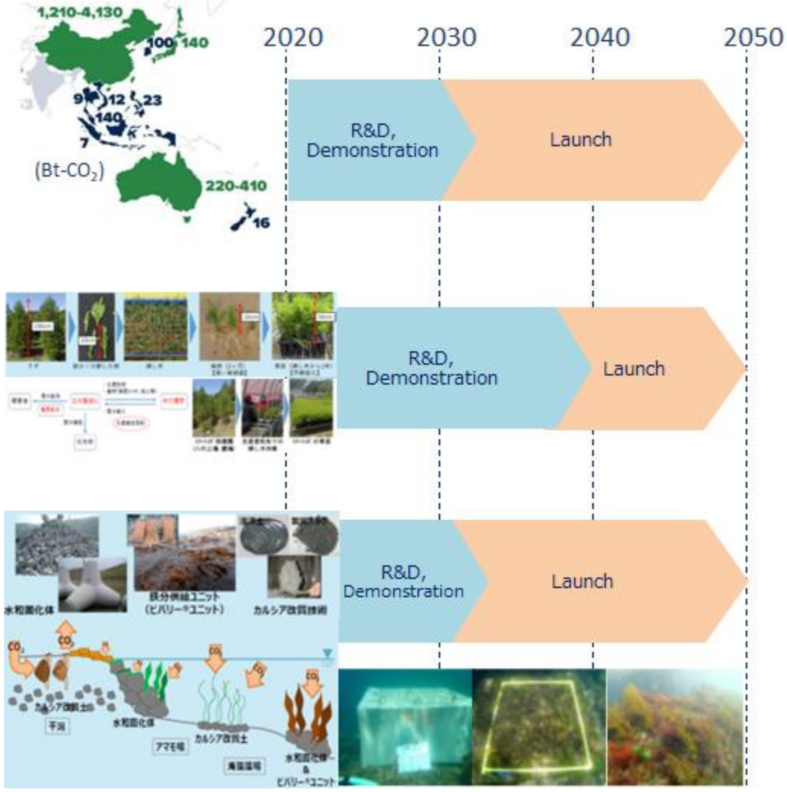
The final category is storage (Figure 2.21). The most common storage method is CCS. Many projects are underway worldwide as underground storage. There are also several absorption technologies by forests and absorption by seaweed. The development roadmap and examples of these technologies are shown in Figure 2.22. The ASEAN region is expected to have a large potential for this CO_2 storage.

Figure 2.21. CO_2 Storage Technologies



BECCS = bioenergy with CCS, CCS = carbon capture and storage, DACCS = direct air capture with CCS.
Source: JCOAL Study Team.

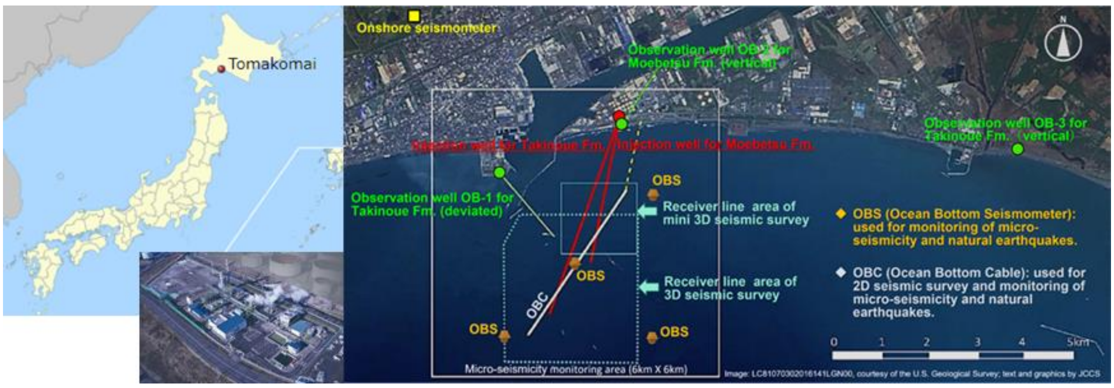
Figure 2.22. Roadmap of CCS, Afforestation, and Blue Carbon



Source: METI website, original data from Global CCS Institute, JCOAL Study Team, https://www.globalccsinstitute.com.

Figure 2.23 shows the Tomakomai CCS Project, conducted by the Ministry of Economy, Trade and Industry (METI), New Energy and Industrial Technology Development Organization (NEDO), and Japan CCS Co., Ltd (JCCS). It is the first large-scale CCS demonstration in Japan. The entire plant was constructed in FY2012–2015, followed by the injection starting from April 2016 at a scale of 100,000 tonnes per annum. The Tomakomai CCS Project achieved the initial target cumulative injection of 300,000 tonnes on 22 November 2019. Now the project is in the post-injection monitoring phase.

Figure 2.23. CCS Demonstration Project in Tomakomai



Source: Japan CCS website, https://www.japanccs.com/en/.

3. Recommendations

Below are the recommendations from the technological aspects.

1) The pathway to CN depends on the situation of the country. So, considering energy security and feasibility, selecting a tailored technology option for each country is necessary. For example, the use of the existing coal-fired plants is a practical solution for biomass and/or ammonia cofiring.

2) It is necessary to take comprehensive measures to achieve CN, including CCUS, which captures CO_2 and uses it for storage and carbon recycling, as well as technology to reduce CO_2 emissions.

3) In particular, CO_2 recovery has become a major issue in the power and industry sectors, so cross-sectoral cooperation is required. Policy initiatives for supporting such cooperative activities are effective. Also, financing schemes covering the entire carbon-neutral project would be essential to make this possible.

4) Proceeding with international cooperation when studying the adaptability of specific carbon-neutral technologies is also effective.

Chapter 3

By-country Situation and Perspectives

1. Indonesia

1.1. Energy and Power Sector Overview

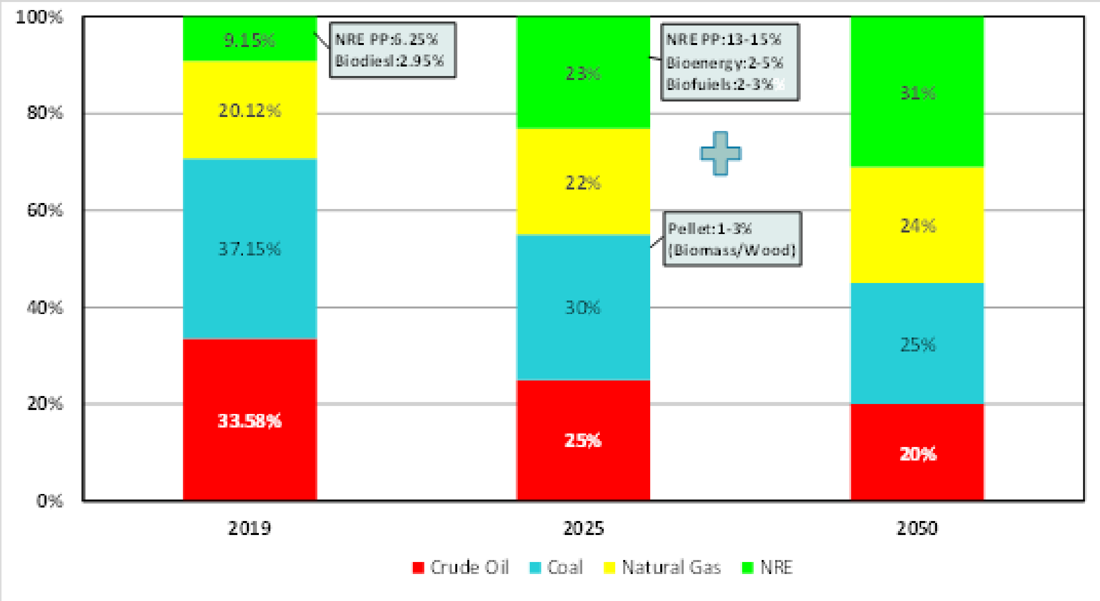
Endowed with fossil fuel resources such as crude oil, natural gas, and coal, Indonesia has been using these as its primary energy sources and a source of state revenue. However, as the reserves of fossil fuels are declining and depleting, and as a global call for emission reduction is intensifying, Indonesia has started to shift its energy policy towards a massive introduction of new and renewable energy (NRE) sources, in the hope of diversifying energy sources and curtailing the use of fossil energy.

1) Energy mix

Figure 3.1 shows the realisation and future target of the latest National Energy Plan (RUEN) formulated in 2017. NRE share in the total energy mix will increase from 9.15% in 2019 to 23% in 2025, and 31% in 2050, the largest in the energy mix in 2050.

In 2019, NRE contributed 9.15% of the total energy mix, comprising 6.2% of the NRE power plant and 2.95% of biodiesel. To achieve a 23% target of NRE share in 2025, the Indonesian government will increase the NRE power plant and boost bioenergy utilisation. Bioenergy power plants will contribute around 2%–5%, while biodiesel utilisation will contribute around 2%-3%. In addition to pursuing the target, the government will implement biomass cofiring with coal-fired power plants (CFPPs), which is expected to increase the NRE portion by 1%–3%. Currently, biomass used for cofiring in the CFPPs is not included in the NRE and is classified as coal by Indonesian government rules.

Figure 3.1. The Realisation and Target of National Energy Mix



Source: Working Group presentation for the Study on Biomass and Coal Co-combustion in the ASEAN Region (II).

2) National power development plan and key directions

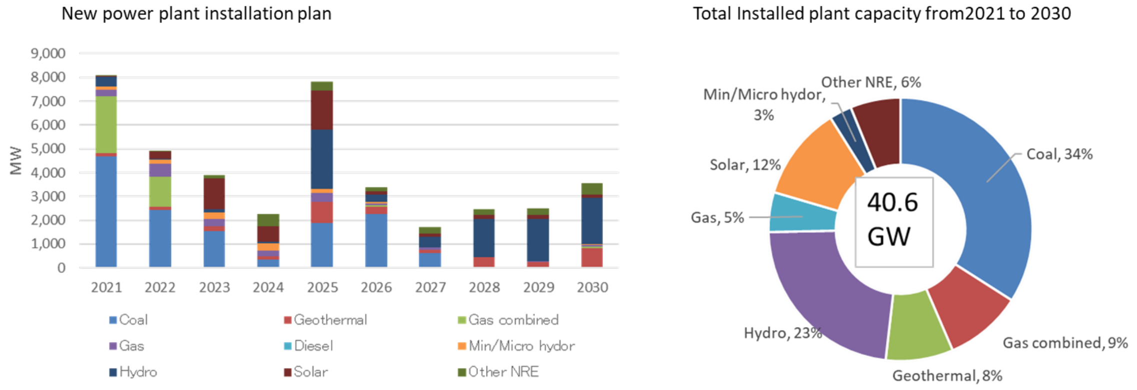
Indonesia's electricity supply business plan, known as RUPTL (*Rencana Usaha Penyediaan Tenaga Listrik*), is prepared by the Perusahaan Listrik Negara (PLN), the state-owned power company. The RUPTL is published annually to review the detailed electricity supply plan for 10 years.

It took more than a year from the issuance of the RUPTL in 2019 until the RUPTL in 2020 was released because the PLN had to observe the unusually slugging electricity demand growth due to the COVID-19 pandemic. The PLN also tried to identify how and to what extent it would have to reflect the impact of the pandemic and energy transition requirements to formulate the new RUPTL. The government also shifted to RE due to Indonesia's commitments under the Paris Agreement and its recently declared carbon neutrality objectives. The new RUPTL was released on 5 October 2021 after a review and revision of the power supply configuration as follows:

- Maintaining a demand–supply balance for each electricity grid to ensure the adequacy of the electricity supply
- No additional CFPP and sequential reduction of existing plants, and
- Increasing NRE to achieve the minimum target of 23% NRE mix starting in 2025.

Figure 3.2 shows the installed generation capacity of Indonesia in 2020 and 2030. The installed capacity in 2020 is 63.3 GW, and the expansion in RUPTL 2021–2030 is 40.6 GW. The total power plant capacity will be 99.2 GW in 2030. By substituting CFPPs with NRE power plants, the share of coal power in the projected installed capacity mix in 2030 will be less than half, and the NRE share will be 29%.

Figure 3.2. New Power Plant Installation Plan

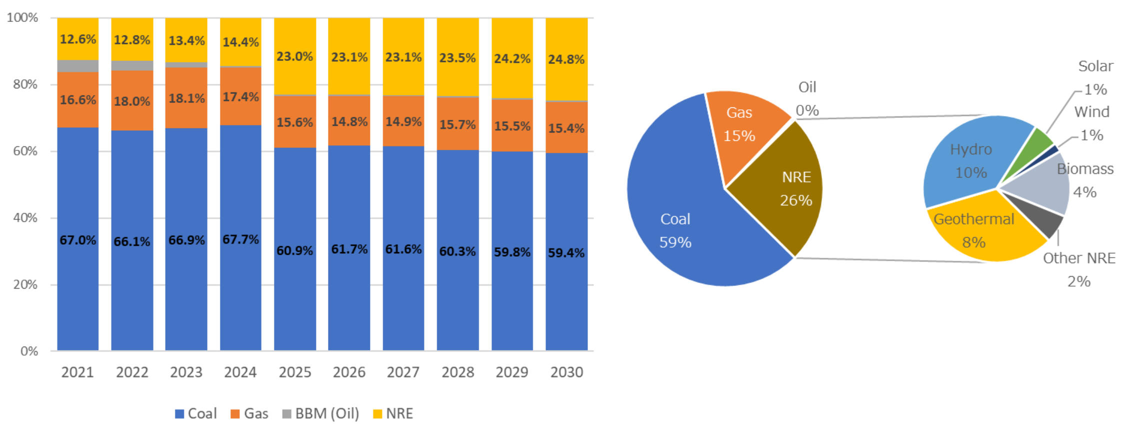


Source: PLN (2021).

3) Power generation energy mix

Figure 3.3 illustrates the electricity production and energy mix of power generation in 2030 based on RUPTL 2021. Total electricity production in 2030 will be 445 TWh. In 2025, NRE will significantly increase due to a policy response of 23% NRE generation. The main NRE are hydro, geothermal, and biomass, which are baseload power sources. But coal still accounts for 60% of electricity generation.

Figure 3.3. Electricity Production and Power Generation Energy Mix in 2030



Source: PLN (2021).

1.2. Policy Towards Carbon Neutrality and Other Related Policies

Figure 3.4 shows the statement and basic principles of the Indonesian President for CO_2 emission reductions. The basic principles are mainly the promotion of NRE use, the reduction of fossil fuels, especially coal, and the promotion of EVs.

Finally, President Joko Widodo declared at COP26 the promotion of RE and achievement of carbon neutrality (CN) by 2060 on the premise of accepting international support.

Figure 3.4. Main Pillars of Policy and President's Directions for Carbon Neutrality

New Zero Emission Principal

① Enhancement utilisation of New Renewable Energy (NRE)

② Reducing fossil energy
- Carbon Tax & Trading
- Co-firing of CFPP with NRE
- Retirement of CFPP

③ Electric vehicles

④ Enhancement of electricity consumption in household and industry

⑤ Utilisation of Carbon Capture and Storage

President's Direction

● UNFCCC – COP 21, December 2015
Reducing GHG emission by 29% (self-effort) **or 41%** (with international assistance) by 2030 according NDC

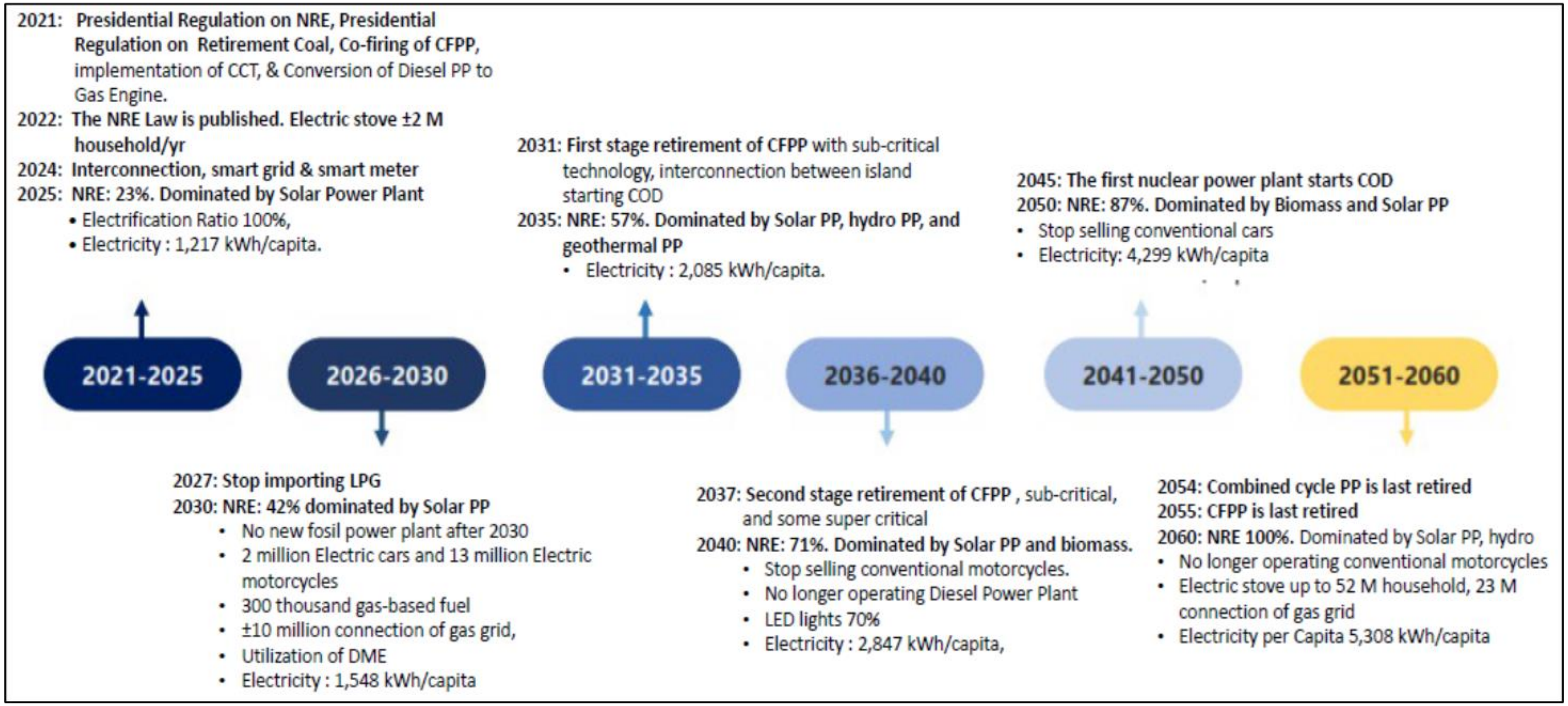
● Leaders Summit on Climate, April 2021
Attracting investment in the energy transition through the **development of biofuels, lithium battery industry and electric vehicles.**

● President RI State's Speech on 16 August 2021
Energy transition towards NRE and the acceleration of a green technology-based economy, will be an important change in our economy.

Source: Directorate General of Electricity, MEMR (2021).

Figure 3.5 shows the prepared roadmap based on this CN in 2060, and the items to be implemented are set annually.

Figure 3.5. Roadmap for Carbon Neutrality in 2060



Source: Directorate General of Electricity, MEMR (2021).

In addition, a new presidential regulation was enacted on September 2022 to achieve CN. The outline of this Presidential Regulation No. 112 of 2022 is as follows:

- Banning the development of new CFPPs with certain exceptions (including CFPPs already included in PLN's development plan [RUPTL])
- Reducing CFPPs by authorising the MEMR to accelerate the termination of CFPPs operated by the PLN and/or independent power producers (IPPs)
- Replacing the basis of the NRE tariff from the average electricity generation basic cost to a ceiling price based on the type of energy sources and locations
- Streamlining the procurement process of NRE projects through a direct appointment and selection and providing a time limit to conclude the entire process
- Providing incentives for geothermal power plants.

1.3. Ongoing and Planned Measures for Carbon Neutrality

The key CN measures by the Government of Indonesia are as follows:

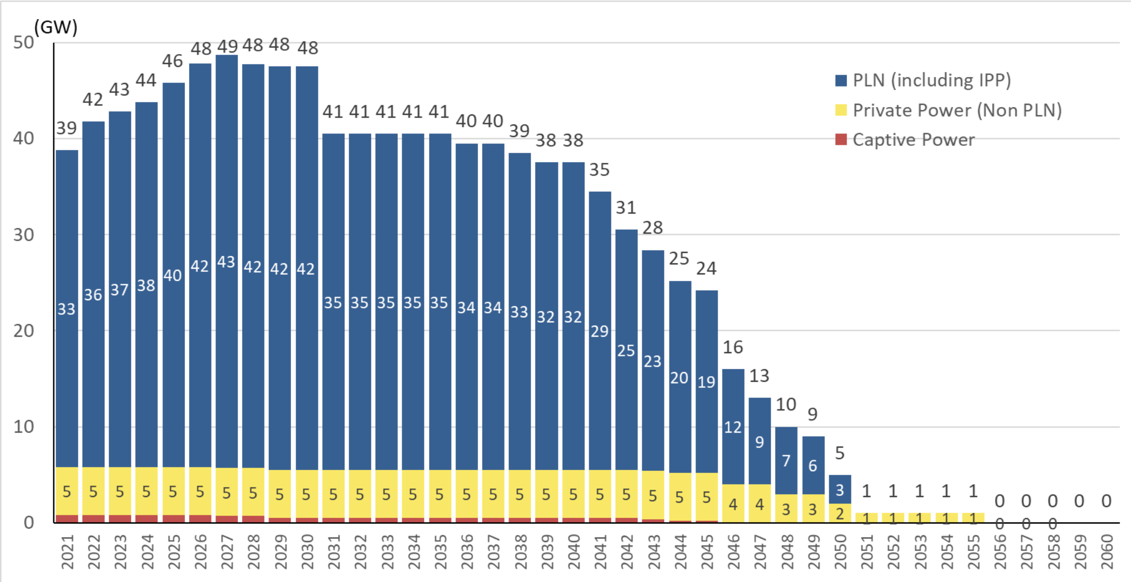
1) Decreasing CFPPs

Figure 3.6 shows the phaseout plan of the CFPPs, which will be gradually reduced from 2031 and abolished by 2056.

The basic principles are as follows:

- CFPP capacity will increase until 2027, coming from ongoing projects. There will be no new plants other than those contracted or being constructed.
- The CFPPs of IPPs will operate until the power purchase agreement (PPA) has ended; it cannot be extended.
- A retirement programme is applied to all CFPPs, including those for non-PLN and their own use.
  - 2031: First stage retirement of CFPPs with sub-critical technology
  - 2037: Second stage retirement of sub-critical and some super-critical CFPPs
  - 2054: The last group of combined cycle power plants is retired.
  - 2055: CFPPs are completely retired
- Action is needed to accelerate the retirement plan:
  - Study further the retirement of PLN's CFPPs before 2030 because of revaluation issues of PLN's assets
  - Prepare the CFPP regulation to support the implementation of retirement
  - Ban new CFPP permits

Figure 3.6. Phaseout Plan of Coal-fired Power Plants

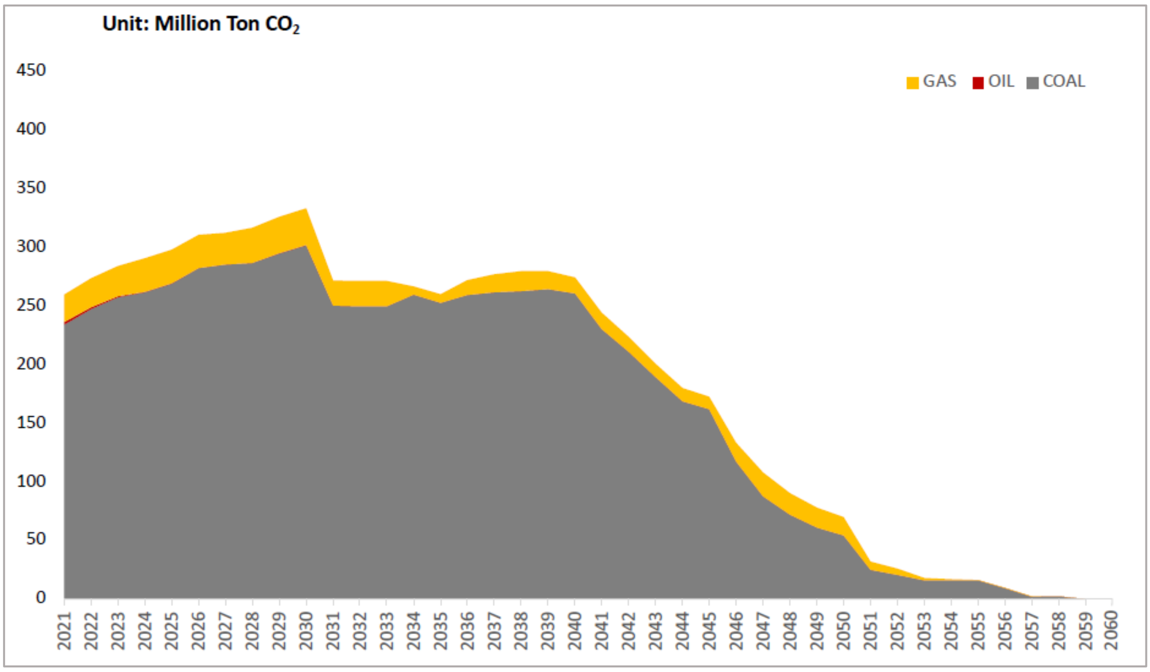


Source: The First Working Group Presentation for the Study on Net-zero Emission Scenario in Indonesia's Power Sector.

Figure Figure 3.7 shows the change in CO_2 emissions based on this reduction plan. The main changes are as follows.

- Total emissions from the power generation sector in 2021 were 60 million tonnes of CO_2-e.
- Towards 2030, power plant emissions will peak at 333 million tonnes CO_2-e.
- Emissions will sharply decrease by 2031 as coal and combined cycle power plants peak.
- Emissions will significantly go down after 2040, following the completion of fossil plant
- contracts.
- Emissions of power plants will be close to zero by 2057.

Figure 3.7. Projection of Power Generation Emission



Source: The First Working Group Presentation for the Study on Net-zero Emission Scenario in Indonesia's Power Sector.

Biomass cofiring at CFPPs is an effective and easy way to increase NRE share and manage municipal waste disposal. Table 3.1 shows PLN's biomass cofiring plan. The PLN conducted cofiring tests with a 5% biomass addition rate at 32 of 52 power plants. The PLN will increase RE to 23% by 2025; therefore, the biomass cofiring rate will increase to 20%–30%. Finally, biomass will be consumed at 8–14 million tonnes.

Table 3.1. Plan of Biomass Cofiring with Coal

	CFPP		**Biomass**	**Waste Pellet**
	No.	MW	(Million tonnes/year)	
Sumatra	13	2,315	2.82	0.122
Java	16	14,845	2.73	0.693
Kalimantan	10	979	1.16	0.053
Sulawesi	6	478	0.77	0.026
Papua & Maluku	3	41	0.17	0.002
Nusa Tenggara	4	237	0.40	0.0136
Total	52	18,895	8.05	0.9096

Source: PLN (2021).

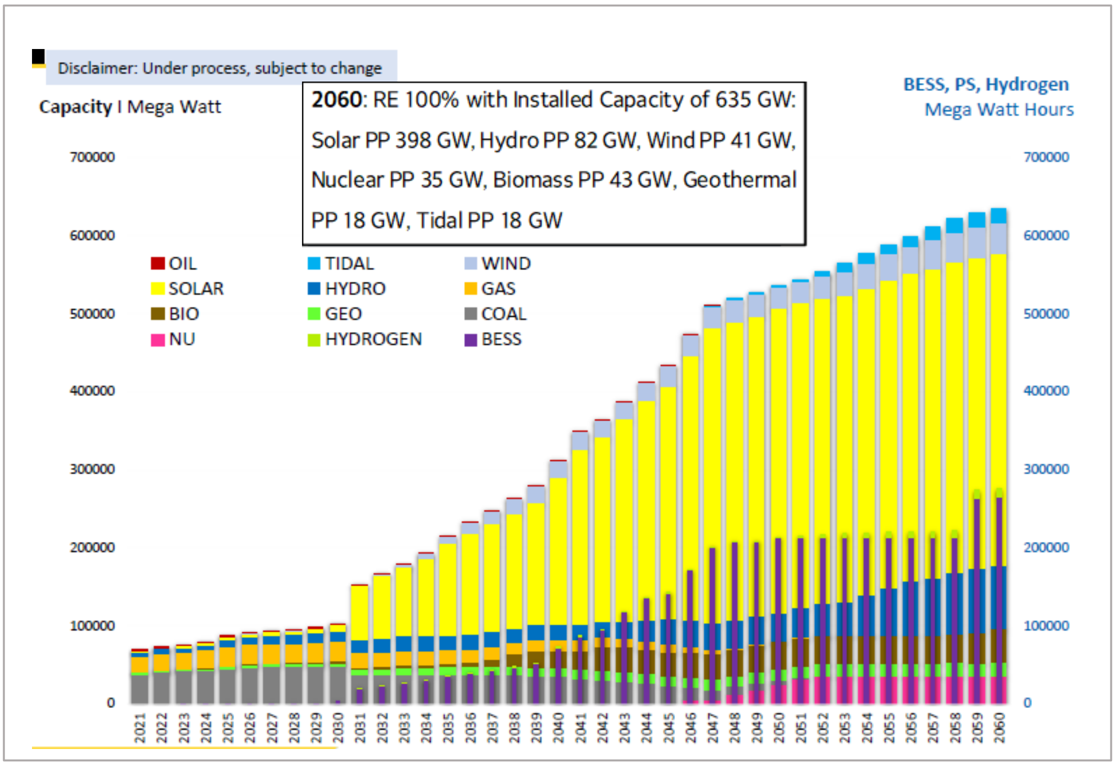
2) Promoting and increasing NRE

Error! Reference source not found. Figure 3.8 shows the power supply plan until 2060 that is under consideration based on the CFPP phaseout plan.

For 2021 to 2030 of this plan, the RUPTL is applied; for 2031 to 2060 of the plan, the following conditions are considered:

- CFPP/CCPP (combined cycle power plant): No new CFPP unless it has been contracted and constructed. The CFPP and CCPP will be retired according to age and/or contract (remaining < 1 GW: CFPP 2052, CCPP: 2050).
- NRE: Additional power plants after 2030 only from NRE. It will be dominated by VRE, such as solar power plants, starting in 2035 and, in the following year, by wind and tidal power plants.
- Geothermal: maximised up to 75% of total potency
- Hydropower: maximised, and the electricity is sent to load centres on other islands; hydropower also balances VRE plants.
- Storage: pump storage, battery energy storage system (BESS), and hydrogen fuel cells will be massively used after 2035. After that, hydrogen will be used gradually, starting in 2031 and massively in 2051.
- Nuclear power plant: to maintain system reliability, nuclear power plants will operate around 2045; in 2060, the total installed capacity of nuclear power will reach 35 GW.

Figure 3.8. Power Plant Capacity and Electricity Production by 2060



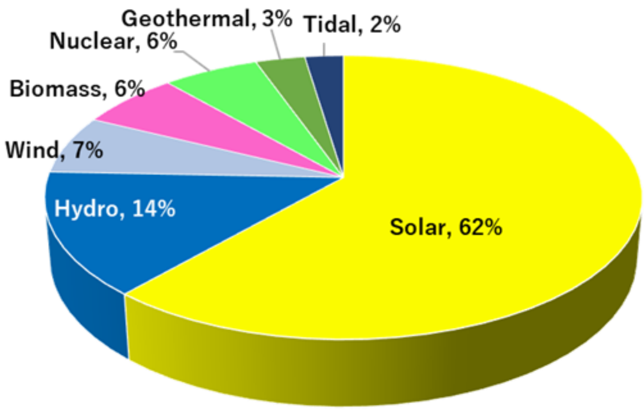
Source: The First Working Group Presentation for the Study on Net-zero Emission Scenario on Indonesia's Power Sector, MEMR (July 2022).

With the retirement of CFPPs starting in 2031, solar power will increase, followed by wind and tidal power. Since solar, wind, and tidal power are VRE, these VRE plants must be balanced with hydropower, which is the baseload power source.

NRE targets in 2060 are as follows.

- The goal is to build a fully decarbonised power sector with an installed capacity of 587 GW by 2060.
- As shown in Figure 3.9, the generation energy mix in 2060 is solar = 361 GW, hydropower = 83 GW, wind = 39 GW, bioenergy = 37 GW, nuclear = 35 GW, geothermal = 18 GW, and tidal power = 13.4 GW.
- Pumped-storage power generation: operation in 2025; 4,200 MW in 2060
- Storage batteries: Large-scale introduction starting in 2031, 140 GW in 2060
- Green hydrogen: Start in 2031, 520 MW in 2060

Figure 3.9. Power Energy Mix in 2060



Source: The First Working Group Presentation for the Study on Net-zero Emission Scenario in Indonesia's Power Sector, MEMR (July 2022).

Table 3.2 shows the NRE potential in Indonesia. Indonesia has abundant and various NRE resources. But currently, only 0.3% of the total potential has been utilised. The NRE potential is distributed as follows:

Table 3.2. NRE Potential

Energy Sources	Old (GW)	Updated (GW)
Solar	400.0	3,295
Hydro	90.0	99
Bioenergy	45.0	57
Wind	60.6	155
Geothermal	24,0	24
Ocean	18	60
Total	**637**	**3,686**

Source: The First Working Group Presentation for the Study on Net-zero Emission Scenario in Indonesia's Power Sector, MEMR (July 2022).

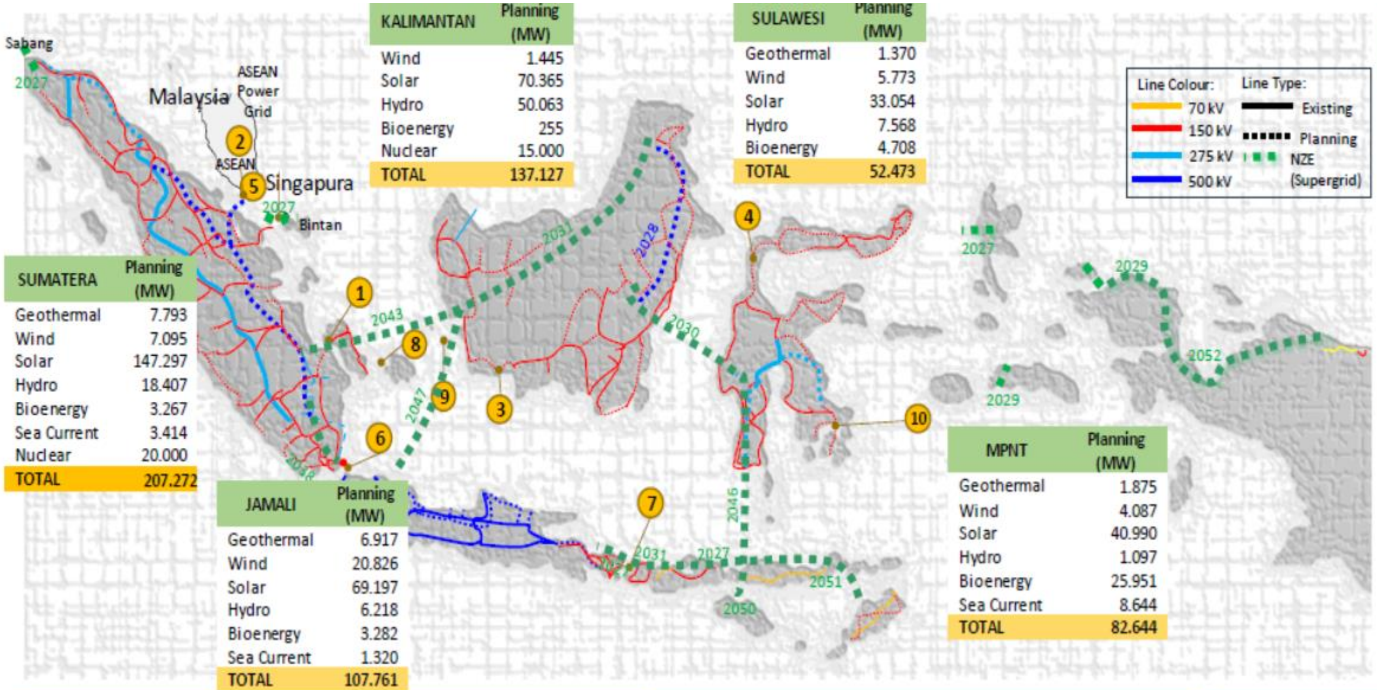
- Hydro potential spreads all over Indonesia
- Solar potential spreads all over Indonesia
- Wind potential (> 6 m/s) is particularly located in East Nusa Tenggara, South Kalimantan, West Java, Nanggroe Aceh Darussalam (NAD), and Papua
- Tidal energy potential, particularly in Maluku, East Nusa Tenggara, West Nusa Tenggara, and Bali
- Geothermal potential spreads in the ring of fire areas, including Sumatra, Java, Bali, Nusa Tenggara, Sulawesi, and Maluku.

Figure 3.10 shows a super grid plan for re-sharing resources.

NRE will increase as a substitute for coal. Since solar, wind, and tidal power are variable renewable energy (VRE), balancing these VRE plants with the base load power, such as hydropower, is necessary. However, the potential of each energy source is different in each region. Establishing the grid to achieve a balance across Indonesia is essential.

It is worth considering that microgrids may benefit some low electricity demand areas than getting connected to a larger network.

Figure 3.10. Super Grid Plan for Re-sharing Resources



SUMATERA	Planning (MW)
Geothermal	7.793
Wind	7.095
Solar	147.297
Hydro	18.407
Bioenergy	3.267
Sea Current	3.414
Nuclear	20.000
TOTAL	207.272

KALIMANTAN	Planning (MW)
Wind	1.445
Solar	70.365
Hydro	50.063
Bioenergy	255
Nuclear	15.000
TOTAL	137.127

SULAWESI	Planning (MW)
Geothermal	1.370
Wind	5.773
Solar	33.054
Hydro	7.568
Bioenergy	4.708
TOTAL	52.473

JAMALI	Planning (MW)
Geothermal	6.917
Wind	20.826
Solar	69.197
Hydro	6.218
Bioenergy	3.282
Sea Current	1.320
TOTAL	107.761

MPNT	Planning (MW)
Geothermal	1.875
Wind	4.087
Solar	40.990
Hydro	1.097
Bioenergy	25.951
Sea Current	8.644
TOTAL	82.644

National	Planning (MW)
Geothermal	17.955
Wind	39.226
Solar	360.902
Hydro	83.354
Bioenergy	37.463
Sea Current	13.378
Nuclear	35.000
TOTAL	587.278

A. Listed in *RUPTL*:

1. 150 kV Interconnection Sumatera-Bangka (2022);
2. 500 kV Interconnection Sumatera-Malaysia (2030), Supporting ASEAN Power Grid;
3. 150 kV Interconnection Kalimantan (2023);
4. 150 kV Interconnection Sulbagut-Sulbagsel (Tambu-Bangkir COD 2024).

B. Stated in RUPTL and need further study:

5. Interconnection Sumatera-Singapore (include Interconnection Sumatera-Bintan), supporting ASEAN Power Grid;
6. 500 kV Interconnection Sumatera-Jawa;
7. 150 kV Interconnection Bali-Lombok (require further study for Interconnection Jawa-Nusa Tenggara);
8. 150 kV Interconnection Bangka-Belitung (require further study for the Interconnection of Sumatera-Kalimantan);
9. Interconnection Belitung-Kalimantan (require further study for the Supergrid Nusantara program);
10. 150 kV Interconnection Baubau-Sulbagsel (require further study for the Bau-Bau Sulbagsel Interconnection System Reliability).

Source: The Second Working Group Presentation for the Study on Net-zero Emission Scenario in Indonesia's Power Sector (October 2022).

1.4. Applicable Technologies for Carbon Neutrality in Indonesia

Table 3.3 shows applicable technologies for CO_2 reduction and capture, utilisation, and storage of CO_2.

Based on Indonesia's CN plan, described in the previous section, applicable technologies for coal power generation, cofiring, storage, and NRE were reviewed. The results are reflected in the table.

1) CCT

Coal, Indonesia’s most abundant and major indigenous energy source, has been supporting the national revenue until today. However, coal is the biggest emitter of CO_2. As mentioned, no more CFPPs will be constructed; they will be phased out. This direction was confirmed at the G20 hosted by Indonesia in November 2022. The ‘no more new CFPP’ policy is conditional, except for financially closed ones and those under construction. Also, those under any specific national development plan can be exempted from the directive, according to the newly legislated Presidential Regulation No. 112 of 2022. With the little possibility for new CFPPs, the introduction of CCTs such as IGCC and A-USC cannot be envisaged as they are not technology for existing CFPPs.

However, as those existing CFPPs shall continuously contribute to the power supply and as balancing resources for grid stabilisation in parallel with progressing massive RE introduction and emerging new energy development, CCT and the accompanying appropriate environmental compliance and efficiency techniques remain crucial.

Table 3.3. Applicable Technologies for Carbon Neutrality in Indonesia (1)

Road Map towards Carbon Neutrality						Indonesia
Reduction	Thermal Power	High Efficiency	IGCC			Not applicable
			IGFC			Not applicable
			A-USC			Not applicable
	Fuel	Biomass	Combustion	CFBC biomass firing		Applicable
				PC coal cofiring		Highly applicable
			Manufacturing	Material	Agricultural waste pellet	
					fast-growing tree	
				Pre-treatment	Torrefied pellet	Not applicable
					Washing	Not applicable
		Ammonia	Utilization	Ammonia gas turbine		Applicable
				Ammonia industrial furnace		Not applicable
				Ammonia-coal cofiring		Applicable
			Manufacturing	Ammonia process	Coventional process + CCS	Not applicable
					New&Innnovative process	Not applicable
				R&D base, Supply chain		
		Hydrogen	Utilisation	Hydrogen gas turbine		Applicable
			Manufacturing	Hydrogen process	water electrolysis by RE	Applicable
					Turquoise hydrogen	Applicable
				R&D base, Supply chain		
	Renewables	Wind, Solar, Geothermal	Offshore wind			Highly applicable
			Perovskite PV			Highly applicable
			Next generation geothermal			Highly applicable
		BESS	large Li-ion, NaS, Redoxflow			Highly applicable
	Manufacturing process	Steel	Coke reduction	Energy saving, LRC	ferrodoke	
				Direct reduction		
				Hydrogen reduction COURSE50	Super-COURSE50	
				carbon recycling BF		
		Cement				

LRC = low-rank coal.

Source: JCOAL Study Team.

Table 3.4. Applicable Technologies for Carbon Neutrality in Indonesia (2)

Road Map towards Carbon Neutrality						Indonesia
Capture	Capture/ Recovery	Capture/ Recovery	Recovery/generation	Oxyfuel IGCC		Not applicable
				Supercritical CO2 cycle generation		Not applicable
				Chemical looping combustion		Not applicable
			chemical absorption			Optional
			solid absorbent material method			Optional
			physical absorption			Optional
			membrane separation			Optional
			physical adsorption			Optional
Utilization	Chemicals	Chemicals	Core materials	Methanol		
				SOEC process	CO	
					Methyl Cycrohexane	
				Artificial photosynthesis	Olefin	
			Derivatives	Formic acid	Boron-doped diamond electrode	
				Polyurethane intermediate		
				Para-xylene		
				Polycarbonate		
				Polyurethane		
				Ethylene urea		
	Fuel	Fuel Synthesis	Gas fuel	Methane	Sabatier process SOEC process	
					Biomass photosynthesis	
			Liquid fuel	Diesel	Biomass photosynthesis	
				Jet fuel	Biomass photosynthesis	
					Biomass gasification FT synthesis	
				Olefin, kerosene		
	Mineralization	Cement/concrete	Concrete	CO2 absorption type		
				Carbonate type		
			Admixture	CO2 absorption type		
				Carbonate type		
	Others	Others	Sector Coupling	Industrial complex carbon recycling		
Storage	Storage	CCS, DACCS, BECCS	Forest absorption/afforestation	afforestation		Applicable
				Blue carbon		Applicable
			CCS			Keenly pursued

Source: JCOAL Study Team.

2) Cofiring

CFPPs will increase until 2030 and will be phased out after 2031. However, coal is expected to remain a power generation source until 2057 as CO_2 emissions from CFPPs continue. Given the importance of enhanced environmental measures, especially in reducing CO_2 emissions, cofiring coal with biomass or ammonia, acknowledged as carbon-neutral, is effective. Currently, ammonia supply sufficiency and its value chain are yet to be secured. That the Government of Indonesia has been pursuing biomass cofiring implementation is the just and the most realistic measure to further reduce emissions from CFPPs towards 2030. During this period, Indonesia can explore possibilities for ammonia cofiring through studies and demonstrations, including cross-sectoral studies for the value chain formulation.

3) CCS/CCUS

CCS/CCUS is also effective in reducing CO_2 emissions from CFPPs. Many old oil wells in Indonesia are likely applicable for CO_2 storage. There is also potential for oil recovery as enhanced oil recovery.

4) NRE

NRE is expected to provide alternative power capacity as the capacity fulfilled by CFPPs decreases during its phasing down. Increased generation from RE is ongoing already. However, after 2031, the country will see the full-fledged development of various renewables. During its energy transition towards 2060, Indonesia has committed to developing 587 GW of clean energy–sourced power, of which 361 GW is solar, 83 GW is hydroelectric, and 39 GW is wind power. As CFPPs are phased down, VRE will take the overwhelming share of power generation. However, the issue of impacts on the grid will possibly emerge even in the early phase of the transition path. Then coal power can function as a balancing source while energy storage and other flexible sources like geothermal power are in place. Once-issued government initiative on rooftop solar power generation initially planned to be grid-connected is now pending following the concerns expressed by the PLN about the possible severe impact on the grid system.

In summary, NRE is no doubt anticipated to be the main force to support the power supply towards CN. And measures for grid stabilisation with flexible sources, including CFPPs, will be taken for sustainable power supply and energy transition.

5) Hydrogen

So far, Indonesia seems comparatively reserved about developing and utilising hydrogen. However, looking at the planned generation mix in 2060 in which solar dominance is outstanding and considering Indonesia is endowed with gas and coal, Indonesia will benefit from pursuing possibilities for both blue and green hydrogen.

1.5. Policy Recommendations with Key Considerations

President Joko Widodo declared at COP26 in 2021 to accelerate RE development and achieve CN with international support by 2060. Therefore, to ensure CN in 2060, RE will be gradually but steadily introduced and developed towards 2031, when the first planned retirement of CFPPs happens. NRE power plants will be massively added from thereon, while CFPPs will be phased down and then out.

1) Measures for grid system stabilisation

Grid system stability is probably the most crucial key to the energy transition.

In the case of Indonesia, like other AMSs, the situation could be more severe than in developed economies as VRE's introduction will proceed speedily to address the growing economy and power demand.

Indonesia has been trying hard to improve grid capacity and system management and will enhance its efforts in the coming years. Also, as part of ASEAN, Indonesia has an advantage from the ASEAN Power Grid; it will help the country with sustainable power supply and with requirements for grid flexibility. In addition to enhancing the grid system, flexibilisation can be ensured primarily through power plants that can perform flexible operations, such as pumped storage, gas, and coal. BESS and synchronous phase modifiers will also help.

Another idea that deserves attention is on-grid and off-grid power generation choices to ensure the resilience of the power supply and grid system. Accelerating grid stabilisation requires urgency. Capacity addition for fulfilling the last miles of hard-to-electrify remote areas is also urgent. However, a grid connection is not a must. Electrification plans with off-grid choices are worth considering, especially in island areas.

2) Coal-fired power plants can continue to contribute to the energy transition

Indonesia foresees a coal phase-down and phaseout in the power sector. However, as we have seen, VRE-solar and wind are clean but variable. Biomass is a big help in accelerating clean transition but is small to fulfil demand. Geothermal is anticipated to provide sufficient and invariable generation capacity but has yet to be smoothly developed. Ammonia and hydrogen are still midway through future application and deployment. The 'all-with-gas solution' is not realistic given the scale of energy, electricity demand, related infrastructure availability, and the fact that gas is also transitional.

In summary, coal will stay in the power generation mix of Indonesia for the foreseeable future and up to the latter part of the energy transition. Coal-fired power can be a flexible source if operated appropriately. So, Indonesia can continue using the existing CFPPs for power supply and supporting grid system stabilisation.

Even after retirement, CFPPs can be repurposed through conversion to synchronous phase modifiers, a proven and commercially available technology for grid stabilisation, or whatever purpose conducive to energy transformation.

We must note that environmental measures shall be continuously enhanced as long as CFPPs are utilised.

3) Shift of domestic coal use to the industrial sector

Coal is an important indigenous natural resource for Indonesia.

Forward-looking discussions by the government involving private sector players require urgency on shifting domestic coal use to the industrial sector for further clean and effective use suitable to the energy transition era. Its outcome will be conducive to the policy and policy instruments that will ensure appropriate and sustainable coal utilisation while the coal phase-down is progressing in the power sector.

4) Technology deployment to help with key knowledge and experience sharing with other AMSs

CCS, hydrogen, and ammonia utilisation is crucial technology requiring a grand design of cross-sectoral and internationally coordinated value chain based on sharing key knowledge and experiences between countries. In this context, collaboration with other AMSs will be beneficial.

5) The next national energy plan should be equipped with decarbonisation plans and perspectives

The last basic energy plan (RUEN) was enacted in 2017. An official supporting plan or policy is yet to be in place. The next RUEN is anticipated to be equipped with decarbonisation plans and perspectives that have been committed and mentioned on occasions, such as COP26 and 27 and G20 hosted by Indonesia.

2. Malaysia

2.1. Energy policy and power sector overview

1) National growth, energy, and climate change policy

Malaysia had been on a steady economic growth path until the COVID-19 global pandemic affected the country, like most economies worldwide. GDP growth in 2010-2019 was 4.3%–7.4%. The year 2020 saw a sharp decline to -5.6%; however, the country has seen a steady and early recovery from the pandemic. As of December 2022, the GDP growth rate was expected to reach 14.2%.

Malaysia has oil, gas, and RE, holding a large share of Southeast Asia’s fossil fuel resources. The country has always been conscious of the importance of energy security and has had clear energy policies addressing various energy supply and utilisation elements. Malaysia strategically incorporated coal as part of its energy mix. Such was in line with the country’s energy policy evolving to facilitate energy security, sustainability, and clean energy, which now constitute a major part of the globally shared concerns about energy.

At the same time, the country is environment-conscious; we see this in its introduction of USC power plants at an early stage. Currently, the standard specification of CFPPs in Malaysia is USC, with all required environmental equipment.

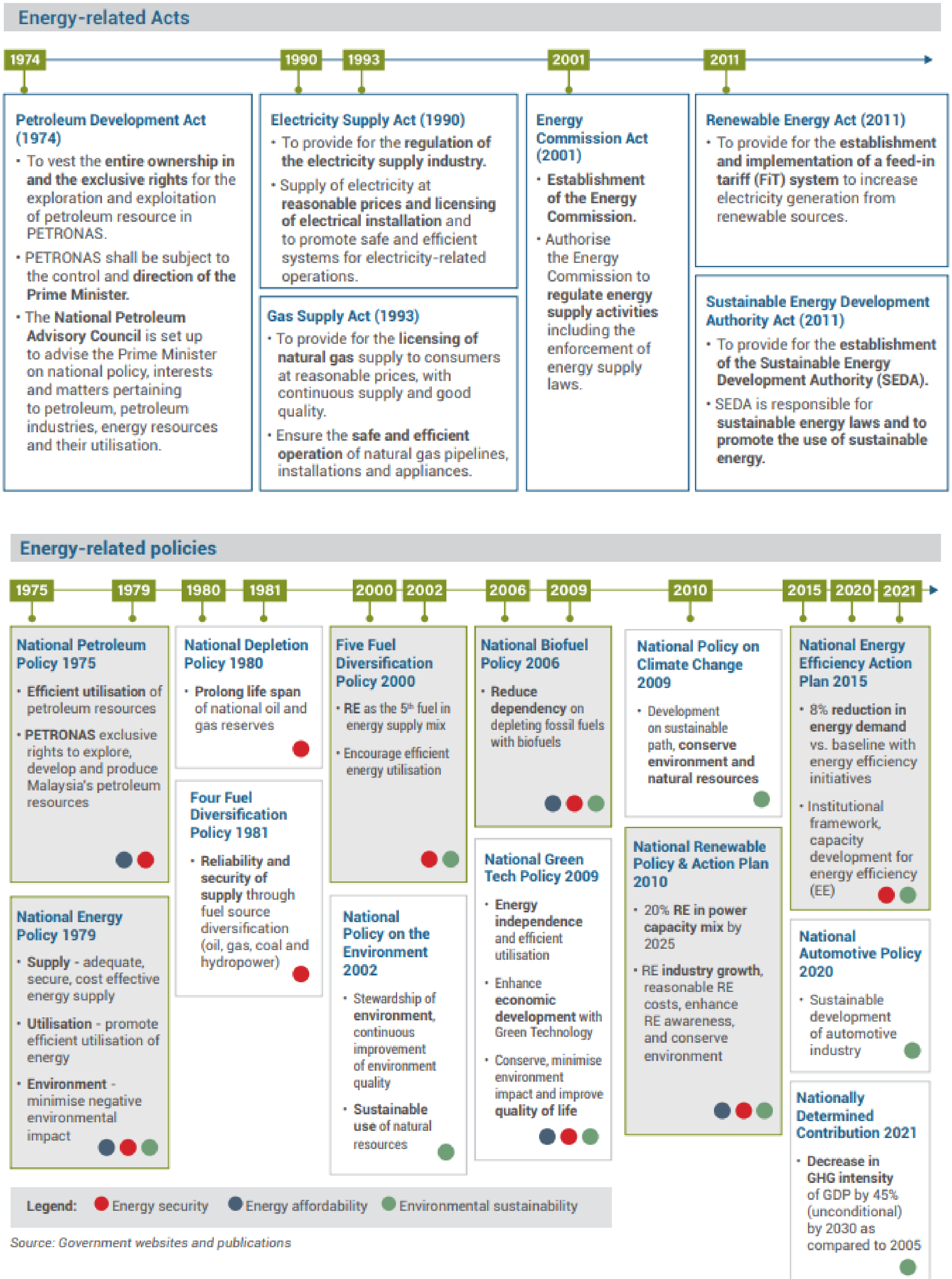
In the meantime, looking at the climate change policy, the country is committed to the unconditional CN target in 2050, the earliest announced in ASEAN, together with Brunei, Cambodia, the Lao PDR, and Viet Nam.

National targets to note are 31% RE share by 2025, reduction of coal capacity by 4.2 GW by 2029, coal phase-down expected to be completed by 2045, and energy intensity to be reduced by 45% by 2030.

Figure 3.11 reviews the major related energy laws and policies to date.

The following section outlines the organisation of Malaysia's power sector, which is unique in that it is integrated in parallel with independent operations across its regions.

Figure 3.11. Major National Energy-related Acts and Policies



Source: Economic Planning Unit, Prime Minister's Department (2022)

2) Organisation of Malaysia's power sector

The Ministry of Energy and Natural Resources (Ketsa), the line ministry that took over from the then Ministry of Energy, Science, Technology, Environment, and Climate Change in March 2020, has jurisdiction over the energy and electricity sector. The Economic Planning Unit (EPU) oversees the sector as the secretariat institution in charge of economic development policy. EPU has authorised the National Energy Policy 2022–2040 (NEP or DTN in the Malaysian language).

The Sustainable Energy Development Authority, a new wing for RE development established in 2011, is the implementing institution of the RE policy and has taken a central part in policy formulation as the author of Malaysia's Renewable Energy Roadmap (MyRER). The Energy Commission regulates and facilitates clean and sustainable energy utilisation nationally. In addition, the commission often undertakes a central role in the national delegation at international meetings.

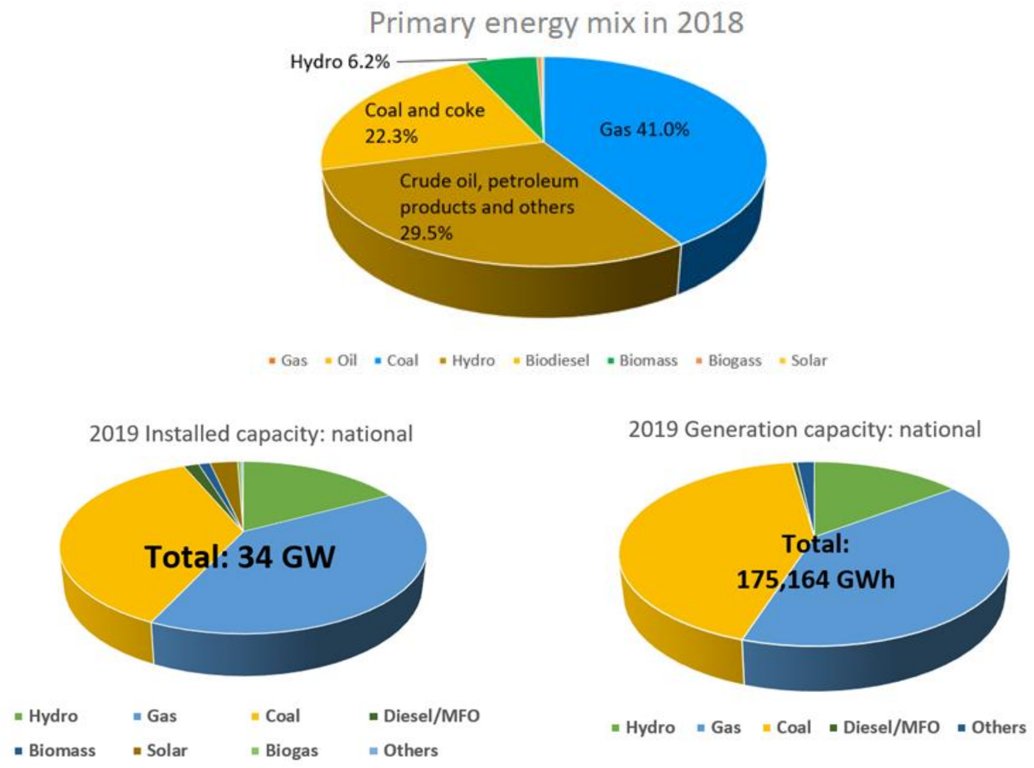
While the federal government formulates national policy and facilitates implementation, different institutions handle each region's day-to-day power sector management. For example, power generation, transmission, and distribution in Peninsular Malaysia are under the Tenaga Nasional Berhad (TNB) and the Grid System Operator; the same for Sabah is handled by the Sabah Electricity Corporation under the provincial government. The Electrical Inspectorate Unit under the Ministry of Utility Sarawak oversees the power sector in Sarawak. Sarawak Energy, the fully privatised and power sector leader in Sarawak, is active throughout the value chain generation, transmission, and distribution.

3) National electricity situation with diverse generation portfolio in the three regions

Figure 3.12 shows Malaysia's primary energy, installed capacity, and generation mix.

Fossil fuel and its products take the lion's share, 92.8% of the national primary energy mix. Coal and gas account for 36.7% and 39.8% of the national installed capacity and 42.8% and 40.2% of the national generation capacity in 2019. Overall, Malaysia is still fossil fuel dependent.

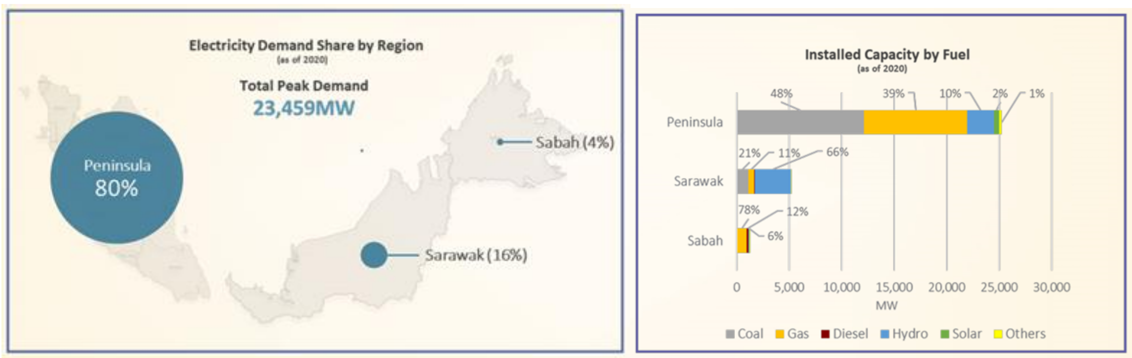
Figure 3.12. Malaysia's National Installed Capacity and Generation Capacity



Source: Energy Commission (2020).

Per by-region shares of electricity demand and by-fuel installed capacity in each region, the most populous peninsula, with 82% of the national population, holds 80% of the national power demand. It is the most dependent on fossil fuels, especially coal.

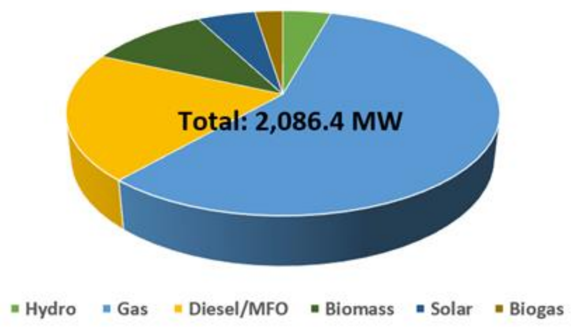
Figure 3.13. Electricity Demand Share by Region



Source: Malaysia country presentation at the First Working Group Meeting on 13 July 2022.

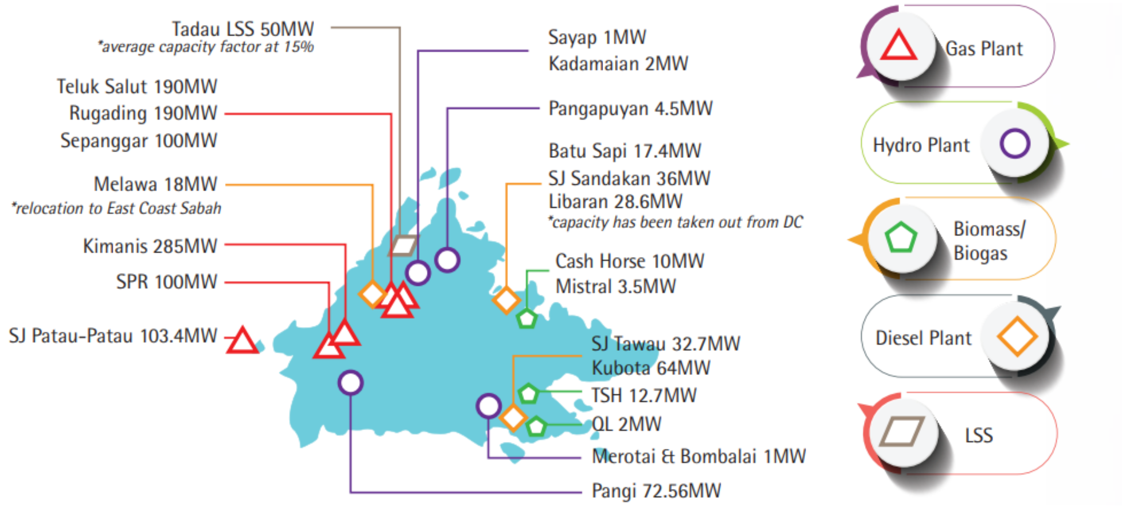
Sabah has several micro- to mid-scale power plants, mostly located on the region's west side. It also heavily depends on fossil fuels. However, it has no coal power and is primarily dependent on gas and diesel. The Sabah government desires to import electricity from Sarawak, with less population and surplus power to export, for which Syarikat Sesco Berhad (Sesco) and Sabah Electricity Sdn Bhd (SESB) signed a memorandum of understanding (MoU) on 6 August 2022. Their target is to trade 30 MW for 15 years by the end of 2023 through the Sarawak–Sabah interconnection via a 31 km 275 kV double circuit transmission line planned to be installed between Lawas substation in Sarawak to Mengalong substation in Sabah.[1]

Figure 3.14. Installed Capacity in Sabah, 2019



Source: Energy Commission (2020).

Figure 3.15. Power Plants in Sabah



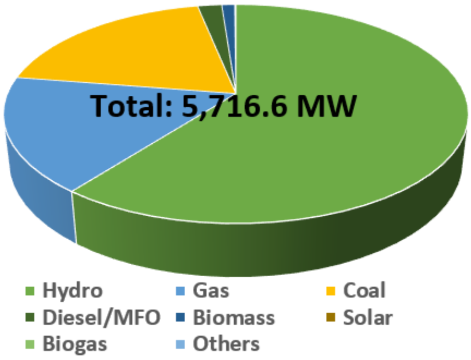
LSS = large-scale solar.
Source: Energy Commission (2020).

The Electrical Inspectorate Unit under the Ministry of Utility Sarawak government oversees the power sector. Sarawak Energy is the sole implementer from generation, transmission, and

[1] 'Sarawak to Export 30 MW Electricity for 15 Years to Sabah by the End of 2023', *Dayak Daily*, 6 August 2021, https://dayakdaily.com/sarawak-to-export-30mw-electricity-for-15-years-to-sabah-by-end-of-2023/

distribution to retail.

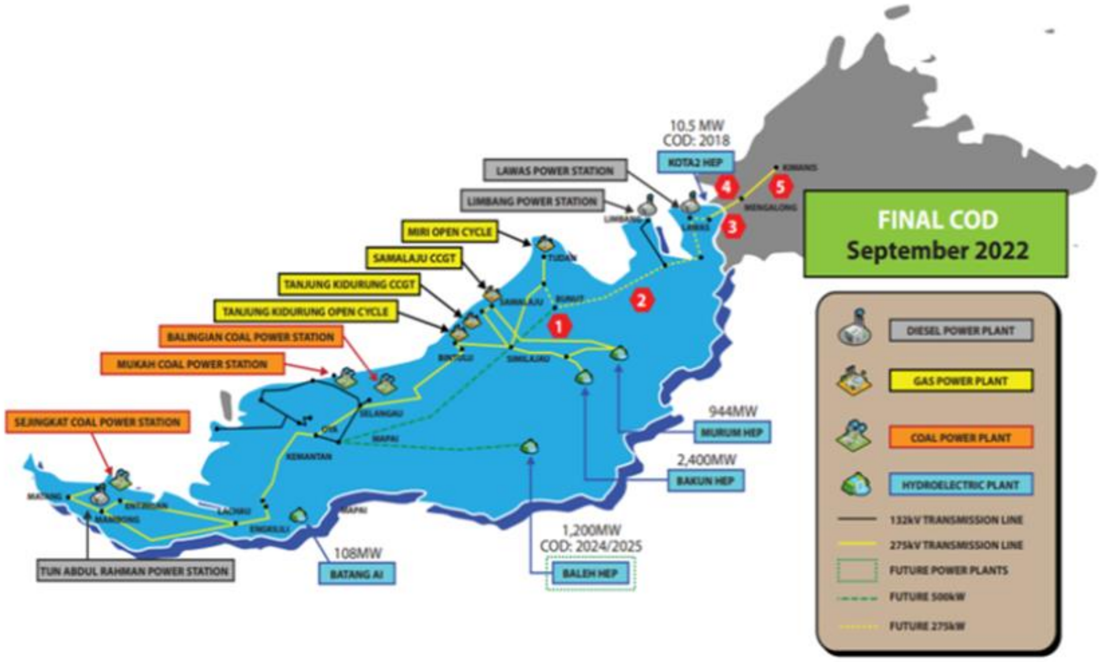
Figure 3.16. Installed Capacity in Sarawak, 2019



Source: Energy Commission (2020).

Endowed with abundant natural resources, Sarawak has a well-balanced electricity mix emphasising hydropower as the mainstay of its power generation (Figure 3.16). Thanks to its large- and mid-scale hydro projects (Figure 3.17), which boost the region's total supply capacity with the smallest population of all three regions in Malaysia.

Figure 3.17. Power Plants in Sarawak



Source: Energy Commission (2020).

Sarawak began to export electricity to West Kalimantan, Indonesia, in January 2016 through a 275 kV interconnection operated by Sarawak Energy. This project is Malaysia's first successful power trading project for Malaysia and has pushed up the position of Sarawak Energy as a green electricity exporter with its abundant hydropower resources.

During the 4 decades since the Four Fuel Policy in 1980, which diversified fuels for energy security, Malaysia switched to coal to generate power and has let CFPPs operate without having major opposition from its people. This was mainly because the environmental requirements for CFPPs have been well addressed. In the early stage, Malaysia shifted to super-critical and USC power plants during the last decade. After the latest introduction of the Jimah East Power Plant in 2019, USC accounted for 40% of all coal-fired power national installed capacity.

Table 3.5. List of Coal-fired Power Plants in Malaysia

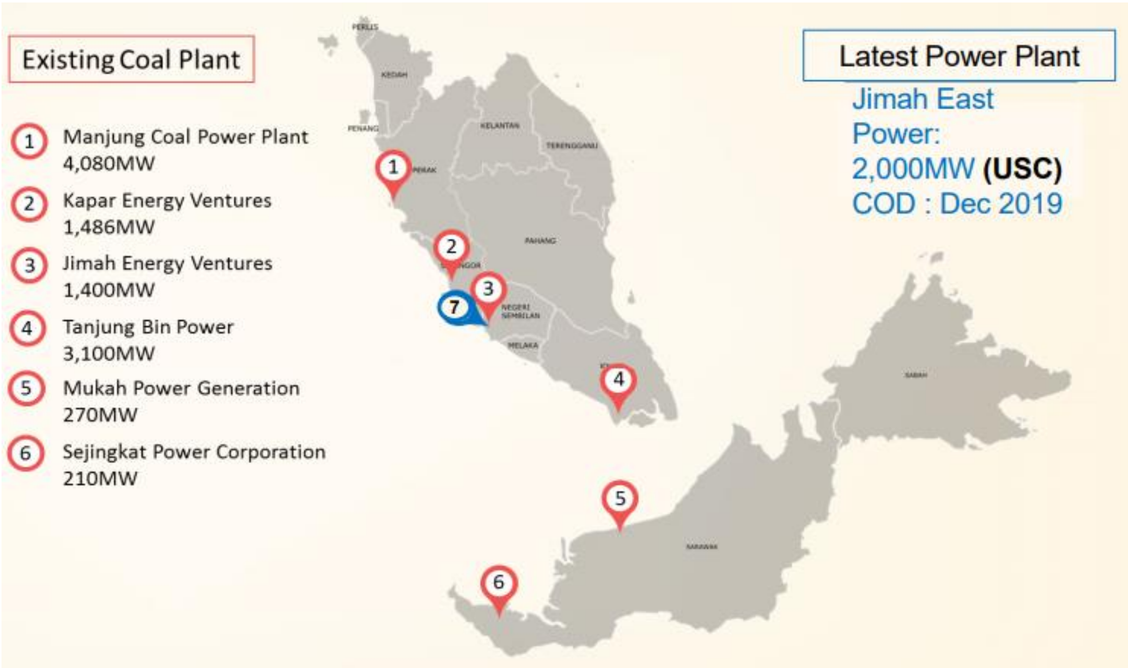
No.	Plant	Capacity	Tech	Coal Type
1	TNB Janamanjung	2,070 MW	SC	Sub-Bituminous
	TNB Janamanjung U4	1,010 MW	**USC**	Sub-Bituminous
	TNB Manjung Five	1,000 MW	**USC**	Sub-Bituminous
2	Kapar Energy Ventures	1,486 MW	SC	Bituminous
3	Jimah Energy Ventures :	1,400 MW	SC	70% Bituminous 30% Sub-bituminous
4	Tanjung Bin Power	2,100 MW	SC	70% Bituminous 30% Sub-bituminous
	Tanjung Bin Energy	1,000 MW	**USC**	Sub-Bituminous
5	Mukah Power Generation	270 MW	SC	Sub-Bituminous
6	Sejingkat Power Corporation	210 MW	SC	Sub-Bituminous
7	Jimah East Power	2,000 MW	USC	Sub-Bituminous

Source: Malaysia country presentation at the First Working Group Meeting on 8 July 2022.

However, from the other aspect, the smooth introduction of coal-fired power generation has made Malaysia build up its coal dependency. Today, the country ranks 18th among the top 40 countries with the highest share of coal in electricity generation.[2]

[2] 'Share of Coal in Electricity Generation and Coal Policies', Figure 2.4 on p. 58, "Coal in Net Zero Transition", IEA, November 2022, https://iea.blob.core.windows.net/assets/4192696b-6518-4cfc-bb34-acc9312bf4b2/CoalinNetZeroTransitions.pdf.

Figure 3.18. Map of Coal-fired Power Plants in Malaysia

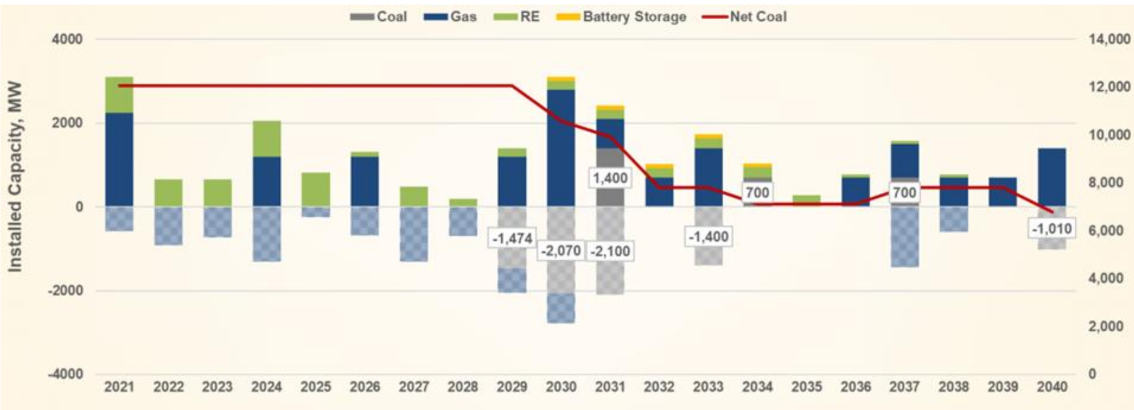


Source: Malaysia country presentation at the First Working Group Meeting on 8 July 2022.

So, it is natural for Malaysia to consider coal phase-down by retiring long-serving plants in the Peninsula in a phased manner in parallel with accelerated RE development and energy efficiency efforts. The total capacity of 8,054 MW of retired CFPPS is projected to be replaced by only 2,800 MW of coal capacity towards 2040, according to the currently available plan for Peninsular Malaysia (Figure 3.18).

Further, the government recently mentioned that over 7,000 MW CFPPs will expire by 2033. No new CFPPs will be constructed. In Malaysia's power sector, coal may be phased down gradually and then out even earlier than by 2040.

Figure 3.19. Capacity Additions and Retirements of Peninsular Malaysia



Source: Country presentation at the First Working Group (2022).

2.2. Long-term Policy Towards a Greener Future

1) Energy sector under the 12th Malaysia Plan

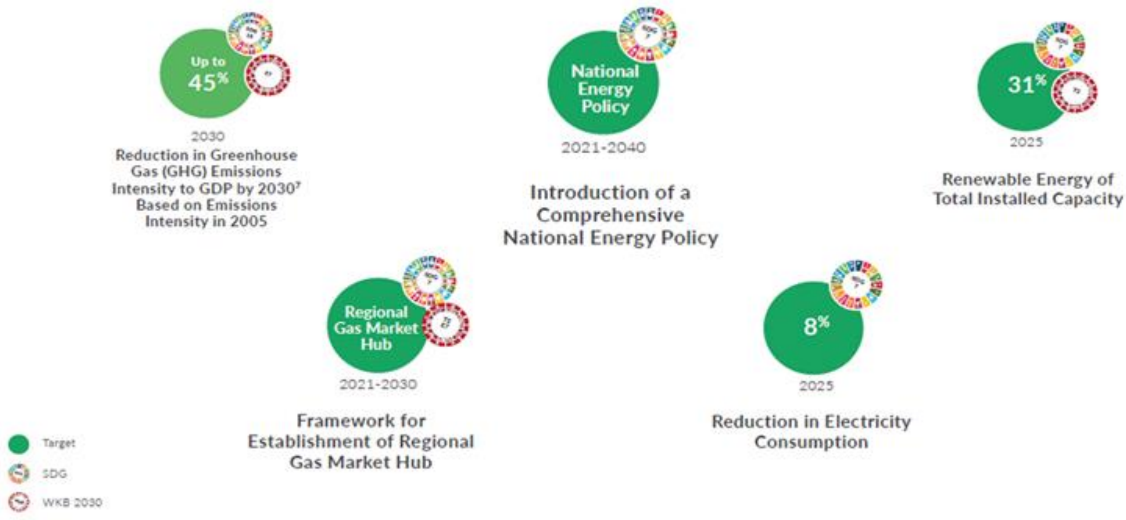
The 12th Malaysia Plan (the 12th Plan) is the 5-year national plan for 2021–2025, providing a major agenda for national recovery to restore economic stability and enhance national economic growth. It was announced in September 2021 and deemed the most ambitious and transformational-ever national plan.

The 12th Plan is anchored on Theme 1 – resetting the economy; Theme 2 – strengthening security, well-being, and inclusivity; and Theme 3 – advancing sustainability.

Developing future talent, accelerating technology adoption and innovation, enhancing connectivity and transport infrastructure, and strengthening the public service are catalytic enablers to support the achievement of the key themes.

The energy sector is well linked and interrelated to Theme 3, which focuses on advancing green growth, enhancing energy sustainability, and transforming the water sector. The energy sector is well linked and interrelated to Theme 2, and an immense contribution of energy transformation to the 12th Plan is anticipated while the country is transitioning.

Figure 3.20. Energy Sector Targets under the 12th Malaysia Plan



Source: EPU (2022).

The 12th Plan stipulates by-sector key economic growth activities called 'KEGA'. The energy sector has five KEGAs.

KEGA 5: ASEAN Hub – Establish ASEAN hubs in 12 activities, including the gas trading market

KEGA 7: Malaysian Commodities 2.0 – Move downstream products to generate higher returns and growth of new industries

KEGA 8: Logistics, Transportation, and Sustainable Mobility – Use green technology, low-carbon, and strategic traffic management

KEGA 11: Renewable Energy – Use new technologies, providing pilot localities, and offer to fund RE generation

KEGA12: Green Economy – Emphasise low-carbon activities, including green buildings, sustainable transportation, circular economy, etc.

2) National Energy Policy 2022–2040

The National Energy Policy 2022–2040 (NEP), a long-awaited national energy policy in line with national plans such as the 12th Malaysia Plan, has enlightened challenges and opportunities in the coming years of the energy transition. NEP tells us how Malaysia will overcome relevant challenges and use future opportunities while involving a broad range of stakeholders over multiple sectors and the people of Malaysia.

NEP shows the national ambition for a dynamic shift and a transition towards the competitive and future-proof energy, industrial, transportation, and relevant sectors, by which the country's future growth and development is anticipated to accelerate and enhance.

Figure 3.20 shows selected target areas and Low Carbon Nation Aspiration 2040 targets compared to the values in 2018. As shown in

Figure 3.21, by achieving the 2040 targets, many positive impacts on emission reduction and massive job creation are anticipated. This means all that work for energy transition is understood more as opportunities than challenges.

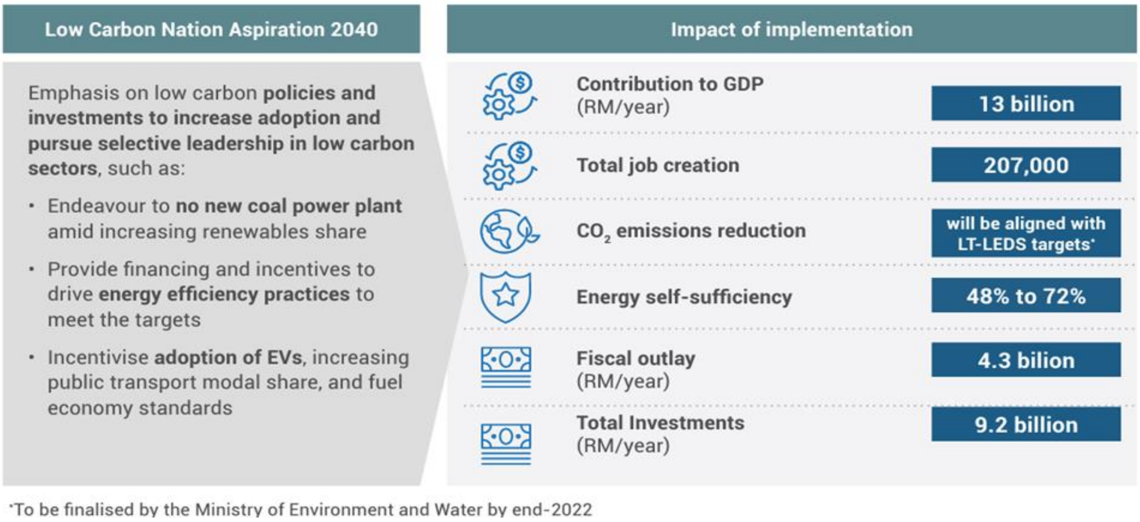
Figure 3.21. Selected Target Areas for Low-carbon National Aspiration

Selected Targets		2018	Low Carbon Nation Aspiration 2040
1. Percentage of urban public transport modal share	Energy affordability, Environmental sustainability	20%	50%
2. Percentage of electric vehicle (EV) share	Environmental sustainability	<1%	38%
3. Alternative fuel standard for heavy transport	Environmental sustainability	B5	B30
4. Percentage of Liquefied Natural Gas (LNG) as alternative fuel for marine transport	Environmental sustainability	0%	25%
5. Percentage of industrial and commercial energy efficiency savings	Energy affordability, Energy security, Environmental sustainability	<1%	11%
6. Percentage of residential energy efficiency savings	Energy affordability, Energy security, Environmental sustainability	<1%	10%
7. Total installed capacity of RE	Energy affordability, Energy security, Environmental sustainability	7,597 MW	18,431 MW
8. Percentage of coal in installed capacity	Energy affordability, Energy security, Environmental sustainability	31.4%	18.6%
9. Percentage of RE in TPES	Energy affordability, Energy security, Environmental sustainability	7.2%	17%

Legend: Energy security Energy affordability Environmental sustainability

Source: EPU (2022).

Figure 3.22. Low-carbon National Aspiration 2040 and Expected Impacts (Draft)



Source: EPU (2022).

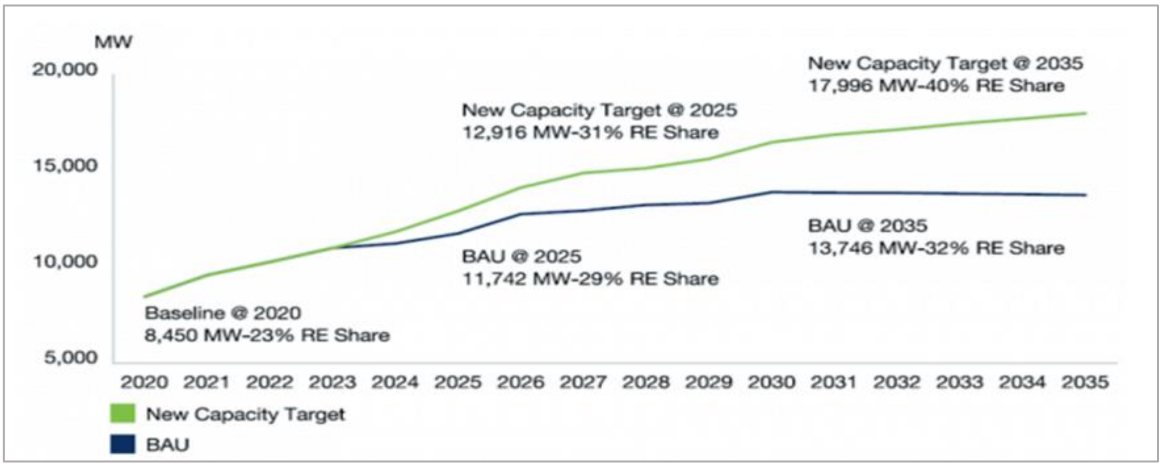
3) Malaysia Renewable Energy Roadmap (MyRER)

MyRER by SEDA is a 2022–2035 long-term RE roadmap and the first of its kind for Malaysia. MyRER constitutes national policy and policy rationale for CN by 2035, and its trajectory is to:

- achieve Malaysia's net-zero GHG emissions by 2050
- contribute to the national commitment to the Paris Agreement
- invest RM20 billion for 2025 and RM35 billion for 2035
- create, directly and indirectly in the RE sector, up to 46,636 jobs.

MyRER indicates RE, which currently accounts for 23% (8,450 MW) of the national electricity mix in 2020, will be increased to 31% (12,916 MW) in 2025 and 40% (17,996 MW) in 2035, through which energy intensity will decrease by 60% in 2035 (Figure 3.23).

Figure 3.23. Summary of RE Capacity Evolution and RE Share



Source: MyRER (2021).

2.3. By-technology Initiatives and Projects

1) Hydrogen Economy Position Paper

Hydrogen is deemed to be a key pillar of decarbonisation, and it is said to enable many more applications than those common today. However, most technologies that can contribute significantly are still nascent. The formulation of global and local value chains is also a major challenge.

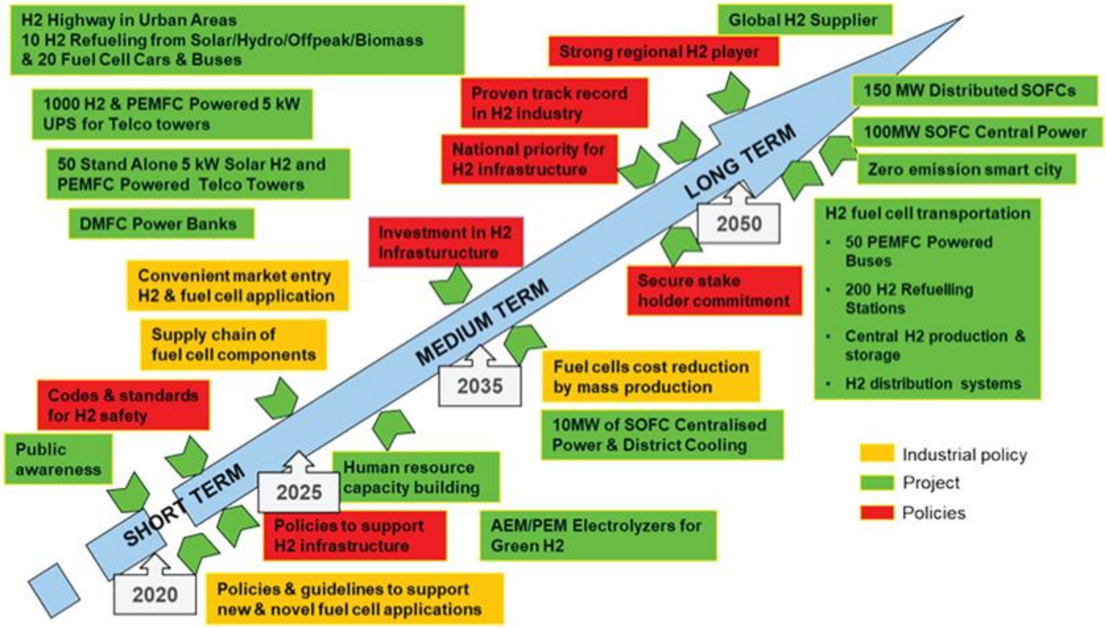
As of today, a fundamental policy on hydrogen is yet to be formulated in Malaysia.

However, in 2020, the Academy of Sciences Malaysia (Akademi Sains Malaysia) issued a Hydrogen Economy Position Paper to pursue possibilities to position hydrogen technology development and hydrogen utilisation as future key energy and industrial areas. The position paper clarifies that hydrogen must be defined as the sixth fuel for Malaysia and urges the government to accelerate policy and regulatory framework arrangements for technology development and near-future application. The position paper further implies that Malaysia can be a regional leader in hydrogen technology, focusing on hydrogen infrastructure, fuel cell applications, and emerging technology.

What the position paper and the document tell are yet to be authorised by the federal government. However, given the forward-looking observation of the possible challenges and opportunities under the 12th–18th Malaysia Plans (2021–2050). the paper deserves attention. The position paper also comprises all related sectors through recommendations for implementing by-group programmes and projects. The concerns described in the position paper may form the basis for further government consideration of hydrogen potential.

The Hydrogen Roadmap in 2020 in the position paper (Figure 3.24) foresees beyond 2050, when Malaysia will be a global hydrogen supplier. It indicates that policies and guidelines will be formulated, and safety codes and standards will be established by 2025.

Figure 3.24. Hydrogen Roadmap in 2020



Source: Akademi Sains Malaysia (2022).

The position paper mainly focuses on hydrogen for electricity in the energy and transportation sectors. Hydrogen also has a wide range of potential in industries, many of which would apply to Malaysia.

2) Nano Malaysia Energy Storage Technology Initiative (NESTI) Programme

The Nano Malaysia Energy Storage Technology Initiative (NESTI) Programme, launched in November 2021, is focused more on e-mobility and fuel cell development. Led by the Ministry of Science, Technology, and Innovation with Nano Malaysia Berhad as the implementing agency, it serves as a national-level platform to develop and commercialise energy storage systems.

The programme’s primary goal is for Malaysia to produce high-technology energy storage components and systems for energy storage technology applications for both domestic consumption and export markets. The country is envisaged to be a major exporter of EV components in the ASEAN region.

3) CCS-related Initiative

Petroliam Nasional Berhad (PETRONAS) has expressed at an early stage its intention to make decarbonisation its business opportunity and contribution to the global target for climate change.

During the last few years, PETRONAS has been enhancing its international collaboration with various domestic and international players in pursuit of decarbonisation contribution through CCS. In March 2022, PETRONAS inked an MoU with the New York–listed energy services giant Schlumberge. The Carbon Capture and Storage (CCS) Centre of Excellence is planned under the

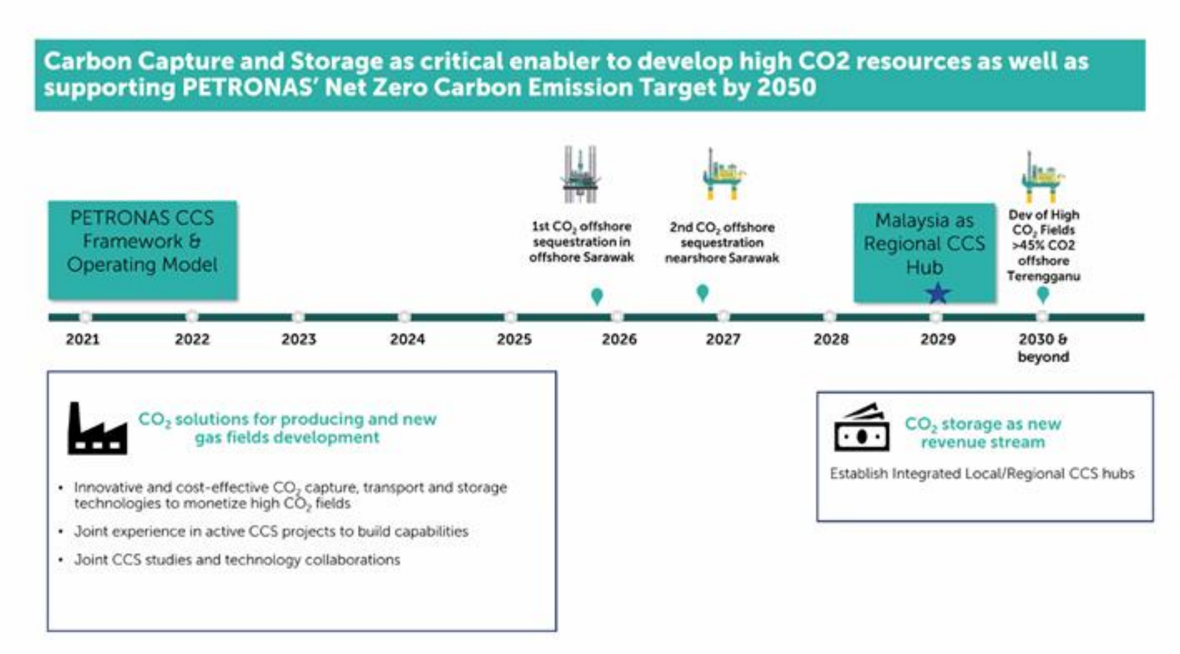
MoU, encompassing a cloud-based data repository for carbon storage, CO_2 separation technologies and capacity development, and emissions management.

PETRONAS signed a series of agreements on CCS studies and programmes with global technology and consulting companies such as DNV, Shell, JAPEX, JGC, etc., in 2022.

In September 2022, PETRONAS signed another MoU with the Japan Bank for International Cooperation (JBIC) for financing several decarbonisation technology areas, including CCS.

The year 2050 is the national target for net zero emissions and PETRONAS.

Figure 3.25. CCUS in NEZ Target of PETRONAS



Source: PETRONAS, https://www.petronas.com/flow/technology/getting-know-ccus-petronas.

2.4. Ongoing Projects and Projects in the Pipeline

1) TNB Genco-PETRONAS Gas and New Energy-IHI Project

A techno-economic evaluation study was conducted on the green and blue ammonia production supply chain through the partnership of the two Malaysian key players: Petronas and TNB GENCO, and Japanese Chugoku Electric, Mitsui, and IHI. The study, funded by METI, was completed in February 2022.

The techno-economic evaluation focused on the following:

- technology applicability of ammonia cofiring at USC power plant
- production supply chain, including the production of green ammonia from RE and blue ammonia from natural gas
- a CO_2 emissions reduction business model

- the possibility of the business model dissemination in the region with by-country tailored modification

2) Ammonia Cofiring Feasibility Study

TNB Research conducted a joint feasibility study of ammonia cofiring with sub-bituminous coal using its in-house combustion test rig. This study found that a significant CO_2 emissions reduction from flue gas was observed after ammonia had been injected.

Phase I of the study in 2021 is a desktop study on technical and economic aspects. It is being developed into the pilot phase and will be commercially implemented if the outcomes are good.

3) Biomass Cofiring Pilot Project

Kapar Energy Ventures has been collaborating with IHI Power System Malaysia. The project began in 2019, and pilot tests were conducted in July 2022.

4) Study for Commercial Conversion of Hydrogen to MCH (methylcyclohexane) in Trenganu

Malaysian PETRONAS Hydrogen and Japanese ENEOS partnered to conduct the study.

A joint feasibility study agreement, which constitutes a part of the MoU on clean hydrogen supply value chain development executed in August 2021, was signed in March 2022 (Phnom Penh Post, 2022).

The project aims to achieve the following by 2027:

- Max. 50,000 tonnes (50 KTPA) per year of hydrogen production and conversion to MCH, transportation of MCH to Japan, provision of clean hydrogen in Japan through ENEOS refineries
- If the project materialises, it will be the world's first commercial hydrogen-to-MCH project.

The investment decision is expected to be made by the end of 2023.

Figure 3.26. ENEOS Yokohama Tsunashima Hydrogen Station

Source: Phnom Penh Post (2022).

5) Kasawari 2 CCS Project

PETRONAS Carigali International Sdn, a subsidiary of PETRONAS, is engaging in the Kasawari 2 CCS Project. Oslo-listed Xodus is undertaking a feasibility study and conceptual design.

The CCS project is about capturing flared gas from the gas field in Kasawari, offshore Sarawak, and compressing it to inject it into the depleted reservoir. It is

expected to reduce CO_2 volume that is otherwise emitted via flaring by 76 million

tonnes over the expected field life, with an annual average saving of 3.7 million tonnes per year. Kasawari will be on stream in 2023, and CCS will follow as the second phase.

As for infrastructure, the following are additionally required:

- A new CO_2 sequestration platform, including facilities to recover hydrocarbons from the permeate stream before the CO_2 is compressed/pumped to the desired export pressure
- A new 135 km carbon steel pipeline to transport the CO_2 to the M1 field
- Three new injection wells.

Figure 3.27. Kasawari CCS Project Site

Source: The Energy Year (2021).

6) Sarawak H_2 Biscus Green Hydrogen and Ammonia Project and Power Supply Project

Sarawak Energy launched the first green hydrogen integrated production in ASEAN in 2019.

Figure 3.28. Sarawak Energy's Hydrogen Production Plant and Hydrogen Bus Terminal

Source: Presentation by Sarawak Energy for the ASEAN Energy Business Forum 2022

That initial project now has been developed into an international collaboration project involving Samsung Engineering, SEDC Energy, LOTTE Chemical, and POSOCO Holdings as project partners.

The production plant can produce 130 kg of hydrogen per day at a purity of 99.999% (five 9s) and is capable of supporting and fully refuelling up to 5 fuel cell buses and 10 fuel cell cars per day.[3]

Supported by the expanding hydropower potentials, the green hydrogen project is expected to see further development conducive to Malaysia's decarbonisation efforts.

2.5. Enabling Schemes in the Power Sector

The following are enabling schemes in Malaysia's energy and electricity sector, backed by government policies, for pushing the country forward to a green energy transition.

1) Green Electricity Tariff

Green Electricity Tariff (GET) is a government initiative to provide green electricity from RE supply to any electricity consumer to reduce their carbon footprint in electricity use. The GET programme is a part of the nation's initiatives to achieve net-zero GHG emissions by 2050.

[3] Sarawak Energy presentation at the ASEAN Energy Business Forum 2022 (virtual).

GET subscribers will be supplied with green electricity from solar power and hydropower. The envisaged major source is solar power through large-scale solar (LSS). In other words, it is available to the extent the capacity supplied by the LSS is available.

Under this programme, the Malaysia Renewable Energy Certificate (mREC) that complies with international REC standards can be obtained.

2) Malaysia Renewable Energy Certificates

The mREC represents the delivery of 1 MWh of RE to the grid and all associated environmental benefits of displacing 1 MWh of conventional power in Malaysia.

While mREC is not tradeable in Malaysia and is to be redeemed/retired to end customers directly, the owner of the redeemed/retired mREC can claim the rights to the generated RE.

The government expects mREC implementation to increase market demand for RE. Every purchase of mREC will increase funds for RE developers to build even more RE generators, making more RECs available in the market. Overall, it will reduce brown energy utilisation and increase clean energy utilisation.

For a company committed to a sustainability target despite inaccessible green energy for the time being, mREC is the easiest and most cost-effective way to achieve sustainability goals.

3) Carbon Trading Scheme

The carbon trading scheme constitutes a part of supporting schemes for energy transition since cost barriers bar shifting to clean energy. Currently, no carbon trading scheme, such as a domestic emission trading scheme (ETS), is in place in Malaysia. However, in September 2021, the Ministry of Environment and Water published the *National Guidance on International Voluntary Market Mechanisms* to guide any entity in Malaysia that intends to participate in international voluntary carbon markets.

While the national carbon trading scheme is being awaited, in September 2022, the state government of Sarawak announced that it would start a local carbon trading scheme in 2023. A national ETS or any other trading scheme will be considered and established based on the observed outcomes of the forthcoming implementation of Sarawak's carbon trading scheme, which is expected to help make such a scheme nationally available.

2.6. Policy Recommendations

Malaysia is endowed with oil, gas, and RE and has strategically incorporated coal into its energy mix. In addition, the country is recognised as one of the most proactively planning and responding AMSs to the requirements of energy transition through a series of long-term plans and policy initiatives. In summary, considering its energy transition pathway, it is steps ahead of other AMSs.

In 2021–2022, a major national plan, energy policy, and several energy transition initiatives towards 2050 and beyond were publicised. Many of those initiatives are plausibly formulated to align with the 12th Malaysia Plan and the expected future 5-year national plans so that they are organised in a way involving all relevant institutions and companies to play their roles in a concerted manner.

Tables 3.6 and 3.7 overview the decarbonisation technology from reduction, capture, utilisation, and storage, indicating high potential and/or applicable technology solutions for Malaysia.

Table 3.6. Applicable Technology Solutions for Malaysia: Reduction

Road Map towards Carbon Neutrality						Status	Policy/Programs/Projects
Reduction	Thermal Power	High Efficiency	IGCC			Not applicable	
			IGFC			Not applicable	
			A-USC			Not applicable	
	Fuel	Biomass	Combustion	CFBC biomass firing		Keenly pursued	
				PC coal cofiring		Keenly pursued	Pilot and demonstration progressing
			Manufacturing	Material	Agricultural waste pellet	Keenly pursued	
					Fast-growing tree	Not applicable	
				Pre-treatment	Torrefied pellet	Applicable	
					Washing	Not applicable	
		Ammonia	Utilisation	Ammonia gas turbine		Keenly pursued	Pilot and demonstration progressing
				Ammonia industrial furnace		Keenly pursued	
				Ammonia-coal cofiring		Keenly pursued	Study progressing
			Manufacturing	Ammonia process	Coventional process + CCS	Applicable	
					New & Innnovative process	Applicable	
				R&D base, Supply chain		Applicable	
		Hydrogen	Utilization	Hydrogen gas turbine		Not applicable	
			Manufacturing	Hydrogen process	Water electrolysis by RE	Keenly pursued	Hydrogen Economy Position Paper as a reference; Green hydrogen production from hydro power has been progressing and anticipated to scale up
					Turquoise	Keenly pursued	
				R&D base, Supply chain		Keenly pursued	Hydrogen Economy Position Paper as a reference; studies are progressing
	Renewables	Wind, Solar, Geothermal	Offshore wind			Not applicable	
			Perovskite PV			Keenly pursued	PV are being agressively developed with help of LSS, etc. In GET scheme for consumers, green electricity is mainly sourced from LSS projects
			Next generation geothermal			Not applicable	
		BESS	Large Li-ion, NaS, Redoxflow			Keenly pursued	12th Malaysia Plan & NEP
	Manufacturing process	Steel	Coke reduction	Energy saving, LRC	Ferrodoke	Not applicable	
				Direct reduction		Not applicable	
				Hydrogen reduction		Not applicable	
				COURSE50	Super-COURSE50	Not applicable	
				Carbon recycling BF		Not applicable	
		Cement					

Source: JCOAL Study Team.

Table 3.7. Applicable Technology Solutions for Malaysia: Reduction (2)

Road Map toward Carbon Neutrality						Status	Policy/Programs/Projects
Capture	Capture/ Recovery	Capture/ Recovery	Recovery/ generation	Oxyfuel IGCC		Not available	
				Supercritical CO_2 cycle generation			
				Chemical looping combustion			
			Chemical absorption				
			Solid absorbent material				
			Physical absorption				
			Membrane separation				
			Physical adsorption				
Utilisation	Chemicals	Chemicals	Core materials	Methanol		Currently not available	
				SOEC process	CO		
					Methyl Cycrohexane		
				Artificial photosynthesis	Olefin		
			Derivatives	Formic acid	Boron-doped diamond electrode		
				Polyurethane intermediate			
				Para-xylene			
				Polycarbonate			
				Polyurethane			
				Ethylene urea			
	Fuel	Fuel Synthesis	Gas fuel	Methane	Sabatier process		
					SOEC process		
					Biomass photosynthesis		
			Liquid fuel	Diesel	Biomass photosynthesis		
				Jet fuel	Biomass photosynthesis		
					Biomass gasification FT synthesis		
				Olefin, kerosene			
	Mineralisation	Cement/ concrete	Concrete	CO2 absorption			
				Carbonate type			
			Admixture	CO2 absorption			
				Carbonate type			
	Others	Others	Sector Coupling	Industrial complex carbon recycling		Highly applicable	
Storage	Storage	CCS, DACCS, BECCS	Forest absorption/ afforestation	Afforestation		Highly applicable	
				Blue carbon		Applicable	
			CCS			Keenly pursued	PETRONAS CCS roadmap; Kasawari CCS

Source: JCOAL Study Team.

1) Highly Potential Technology Areas

Highly potential technology areas in the context of policy directions and applicability are highlighted below.

Technology area 1: Hydrogen

Malaysia is outstanding in its determination to promote hydrogen development and utilisation. In 2019, a few years before the Hydrogen Economy Position Paper was published, Sarawak Energy started producing and refuelling hydrogen. It partnered with PETRONAS, Samsung Engineering, LOTTE Chemical, and POSCO Holdings.

The Hydrogen Economy Position Paper claims Malaysia could become on par with the United States and Australia in leading global hydrogen technology development and utilisation.

Both the position paper and Sarawak Energy coincidentally focus on green hydrogen, especially given the recent situation where hydrogen prices have skyrocketed with natural gas prices. Green hydrogen is gradually taking the primary position for massive production in the future.

Also, since it matters how much carbon footprint can be reduced throughout the hydrogen value chain to be formulated, Malaysia is on the right track in trying to focus on green hydrogen.

A few points for further consideration are:

- Currently, so much attention is paid to fuel cells and electricity when it comes to hydrogen. However, there are various areas, such as chemical and industrial processes, for which hydrogen can be utilised. So, it would be advisable that hydrogen development and utilisation policy be multisectoral and with a clear picture of value chains to be established.
- As the Hydrogen Position Paper clarifies, safety is a major concern in considering hydrogen use. Accordingly, safety considerations shall be a part of the basic policy that will be formulated.

Also, as with most industrial activities, hydrogen production entails carbon emissions, though the massive introduction of hydrogen is primarily for reducing emissions. Accordingly, the government is supposed to facilitate and oversee development and utilisation efforts by national and private companies while paying extra attention to how carbon footprint can be reduced during the process.

Technology area 2: Solar and hydro

Solar power and hydropower are undoubtedly important for clean and sustainable electricity supply and bolstering the anticipated green hydrogen development.

Technology area 3: CCS

CCS is crucial for the energy transition. However, only some projects have reached the commercial phase due to cost barriers and unforeseeable technology-related factors. Most commercial projects are at oil and gas development sites using CO_2 injections for enhanced recovery. For applying the technology to a power plant, incorporating CO_2 utilisation to make it CCUS for the increased economy of the project is required.

As the preceding part has clarified, PETRONAS is geared to engage in the Kasawari CCS project with domestic and international players, with a roadmap ready to back up the relevant activities. Thai government-owned PTT's subsidiary PTTEP is also considering going for a CCS project at its Lang Lebah field in Malaysia. The company has been developing a CCS project in Thailand already.

Kasawari CCS attracts such attention from ASEAN, the rest of Asia, and the world. Developing a sour gas field will be common throughout all incoming gas development projects in ASEAN. Since sour gas contains a high H2S and CO_2 content, its development entails technical difficulties and requires extra deliberation and measures in exploration, and so does the CCS project.

Considering that CCS-potential depleted fields in Malaysia will have the same conditions and requirements as others in Indonesia, Thailand will experience a similar situation. In collaboration with other AMSs, Malaysia would benefit from establishing a knowledge and data-sharing scheme among AMSs.

That way, the huge cost otherwise incurred at the initial stage can be avoided, and well-informed decisions on project implementation will be possible.

Other potential technology areas

In addition to the above areas, biofuel, energy storage, and biomass and ammonia cofiring at CFPPs are highly potential.

These existing and new energy areas and technologies are highly anticipated to open up opportunities for industry development, job creation, and social development as per the 12th Plan and beyond, for which cross-sectoral planning, coordination, and collaboration with more focus on industry areas are crucial.

Also, safety, economy, and energy security, in addition to energy transformation, shall be ensured.

2) Institutional Support

Institutional support and incentives will be required to facilitate the application of decarbonisation technology. And policymakers must note that such institutional support may also be transitional and must be followed up for modifications or further institutional changes. For instance, a feed-in tariff (FiT) is effective in supporting the introduction of renewables. However, preceding cases have shown that unbundling the power sector for a competitive market is crucial to accelerating RE introduction. RE will no longer depend on FiT since it must be incorporated into the competitive market. So, the power market in Malaysia on a single-buyer scheme will be changed during the power sector transformation. That way, Malaysia can materialise RE development and massive production of green hydrogen.

3) Coal phase-down Path

Malaysia has 12,546 MW of CFPPs, of which 2,000 MW commenced operations only in 2019. Given Malaysia's standard residual life and the economy of power plants, it is a little too early to retire the most recent ones before 2040.

However, it would work if those retired power plants were not just retired but appropriately reutilised through conversion to synchronous condensers, a proven and commercially available technology for grid stablisation,[4] or whatever purpose conducive to energy transformation.

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[4] Several retired thermal power plants were repurposed as synchronous condensers. The World Bank conducted a very useful study indicating that repurposing thermal power plants as synchronous condensers will be one of the options to address the issue of 'too young to retire' CFPPs in ASEAN (https://documents1.worldbank.org/curated/en/144181629878602689/pdf/Coal-Plant-Repurposing-for-Ageing-Coal-Fleets-in-Developing-Countries-Technical-Report.pdf).

The following and some websites show the technology and actual cases: http://pe.org.pl/articles/2015/10/12.pdf,

https://www.eaton.com/content/dam/eaton/services/eess/eess-documents/eaton-case-study-iou-synchronous-condenser-conversion-cs027014en.pdf;

https://energiforskmedia.blob.core.windows.net/media/22669/decommissioned-nuclear-power-plant-as-system-services-providers-energiforskrapport-2017-348.pdf

A coal-fired power phase-down and phaseout roadmap, as part of a national energy transition roadmap, shall be formulated. All necessary measures should be taken since coal-fired power, as a major part of the electricity mix, will continue to support energy security through sustainable electricity supply for at least the first half to the middle of the energy transition period. During that time, efforts to reduce emissions and environmental measures must continue, and operations shall be conducted in a way that contributes to preventing grid fluctuation.

4) Malaysia's position to support ASEAN's energy transition

Malaysia has an advantage since the country, as a member of the ASEAN community, has been involved in most areas of the energy sector – from fossil fuel production, power generation, clean utilisation of coal, renewable energy, and new energy development to regional grid integration. Moreover, as being ahead in terms of readiness for policy and standards formulation and legislation, Malaysia is highly anticipated to initiate government-to-government sharing of knowledge, experience, and information, as well as cooperation for regional value chain formulation and establishment. Such will benefit the country as the energy transition will be very costly, especially at its initial stage. Well-informed decisions are the key to the successful application of decarbonisation technology.

5) National Decarbonisation Roadmap

With NEP, the long-term energy policy, in place and MyRER, the national RE roadmap, the next anticipated is formulating a national decarbonisation roadmap that shows a cross-sectoral and inclusive energy transition pathway. Again, Malaysia can contribute to formulating an integrated roadmap of ASEAN decarbonisation and roadmaps of other AMSs by initiating the national roadmap formulation.

3. Thailand

3.1. Energy/Electricity Situation and Policies

Thailand's energy policy, 4D+E, is indicated by five keywords: digitalisation, deregulation, decarbonisation, decentralisation, and electrification.

Table outlines these five keywords, and Thailand is proceeding under this energy policy.

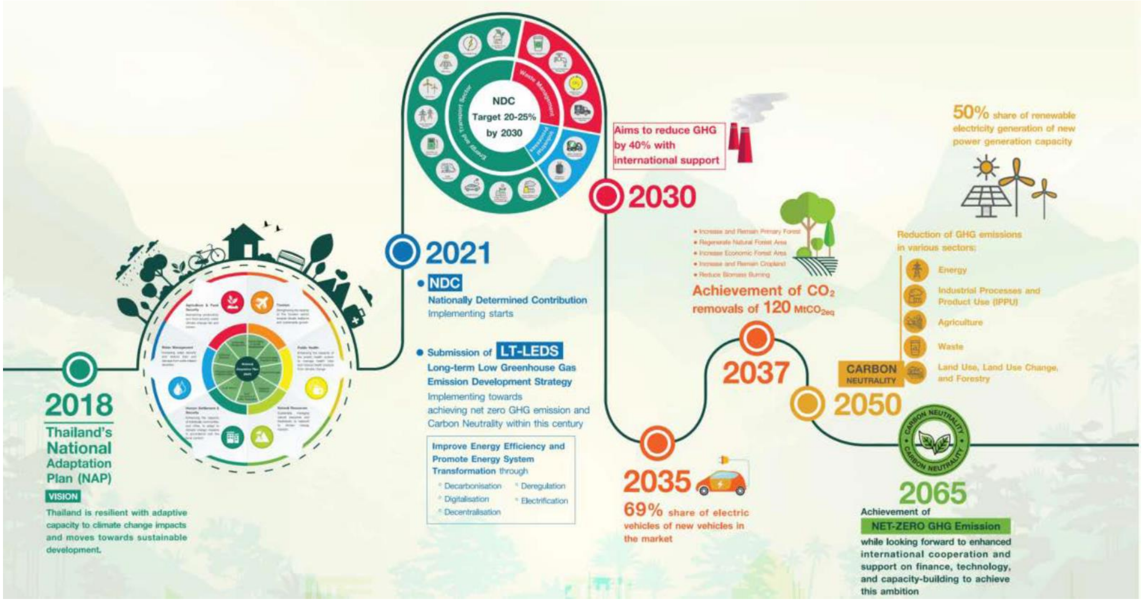
Table 3.8. Thailand's Energy Policy

Digitalisation	Enhance the transmission system to be 'Smart Grid'
	Support development of ESS for increasing stability to community and large power plant energy transformation energy direction
	Becoming ASEAN energy commercial centre
De-regulation	Originating of 'Sandbox' Project for energy innovation development
	Promote 'Energy Start-up' concept
	Conduct flexibility of ENCON fund utilisation for promoting community's energy business
	Increase opportunity for public for electricity purchasing ('Prosumer')
Decarbonisation	Promote production and utilisation of electricity from solar and bioenergy
	Absorb and increase value of agri. product (e.g. palm oil) by using as alternative fuels
Decentralisation	Promote P2P electricity trading by supporting of electricity conveying through on-grid and off-grid system
	Promote installation of community power plant
	Proceeding for community power plant network mapping
	Support electricity balance in southern area and Eastern Economic Corridor
Electrification	Extend the EV network
	Promote utilization of EV

Source: Working Group presentation for the Study on Biomass and Coal Co-combustion in the ASEAN Region (II), DEDE (June 2020).

Figure 3.29 shows Thailand's long-term GHG emission development strategy. In 2018, the country's National Adaptation Plan was announced. It aims towards resiliency with adaptive capacity to climate change impacts and moves towards sustainable development. In 2021, at COP26, Thailand pledged to enhance the nationally determined contribution or NDC to reduce GHG emissions by 30%–40% in 2030 from the previous target of 20%–25%, with international support. The country is committed to reaching CN by 2050 and net-zero GHG emissions by 2065. With these, the significant activities consist of an aspirational increase of EV share to the new vehicles in the market to be 69% by 2035. Likewise, a 50% share of renewable electricity generation of new power generation capacity is strategically planned by 2040.

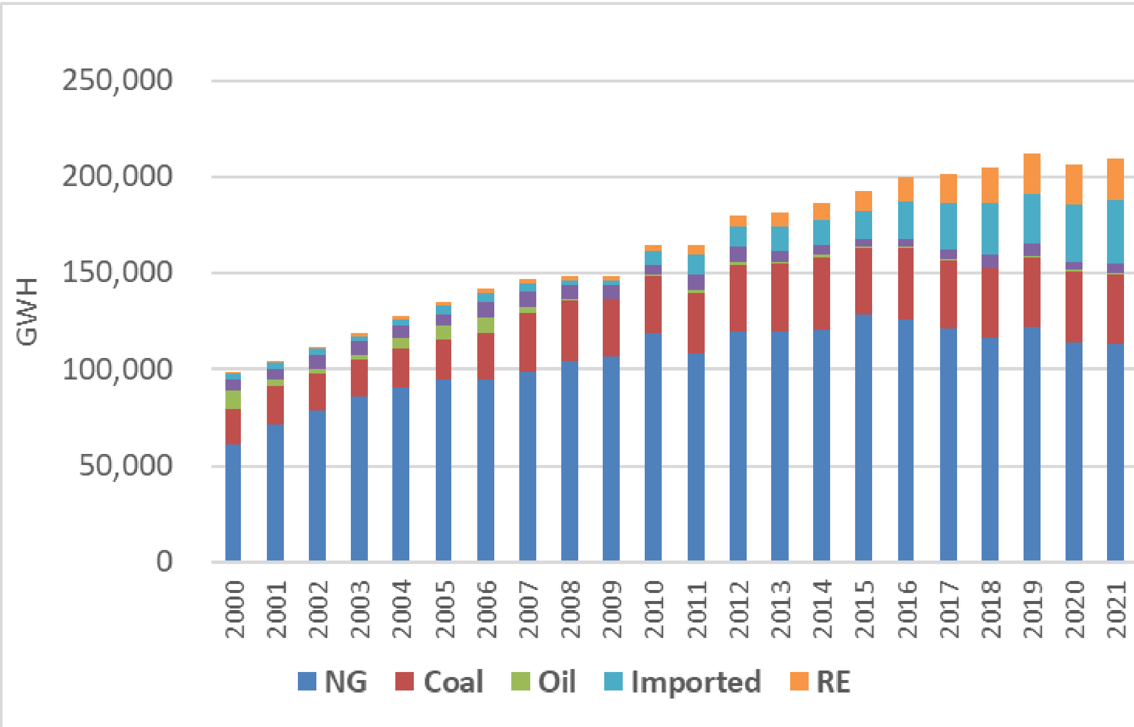
Figure 3.29. Thailand's Long-term GHG Emission Development Strategy



Source: The First Working Group Presentation for the Study on Thailand's Renewable Energy Promotion Policies, DEDE (July 2022).

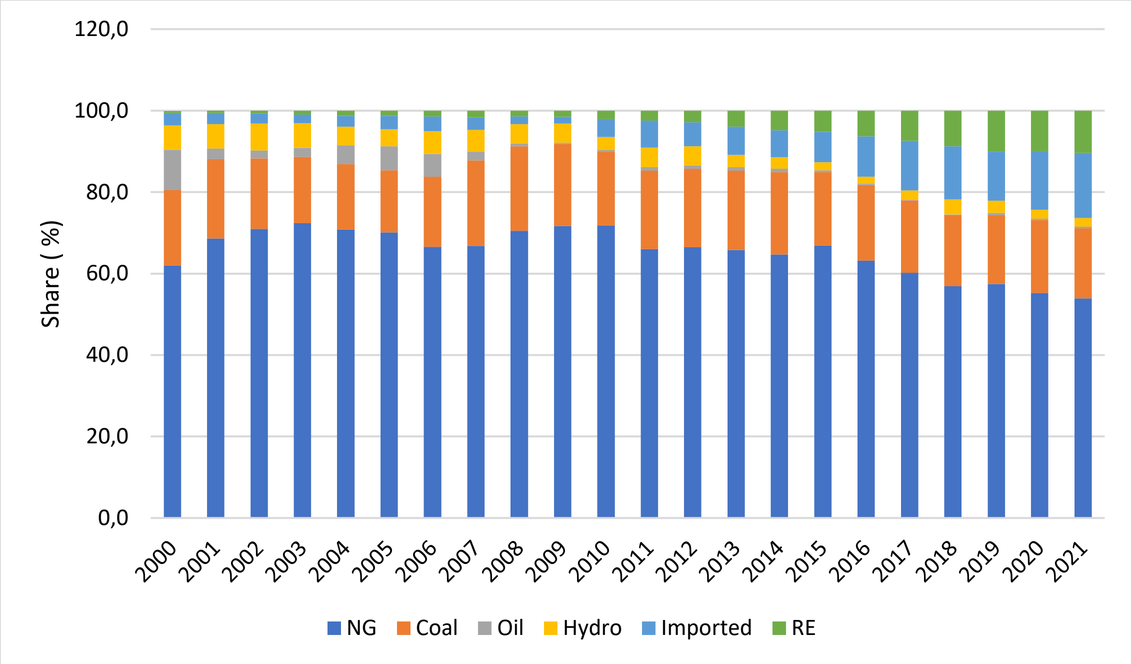
Figure 3.30 shows Thailand's recent power generation, and Figure 3.31 shows its recent power generation share of fuel. In the last 10 years, natural gas and coal had not grown, but imported fuels and RE did.

Figure 3.30. Power Generation by Fuel



Source: Edited by JCOAL Study Team based on data from EPPO, https://www.eppo.go.th/index.php/en/.

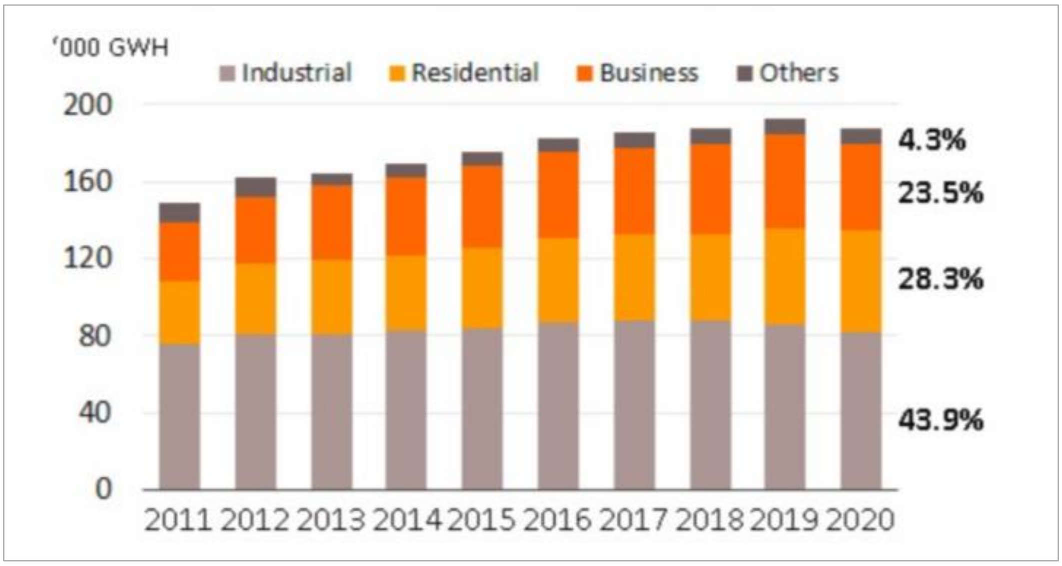
Figure 3.31. Power Generation Share by Fuel



Source: Edited by JCOAL Study Team based on data from EPPO (2022), https://www.eppo.go.th/index.php/en/.

In 2020, the major sources of demand were the industrial, household, and business sectors, which accounted for 43.9%, 28.3%, and 23.5% of national electricity consumption, and others at 4.3%.

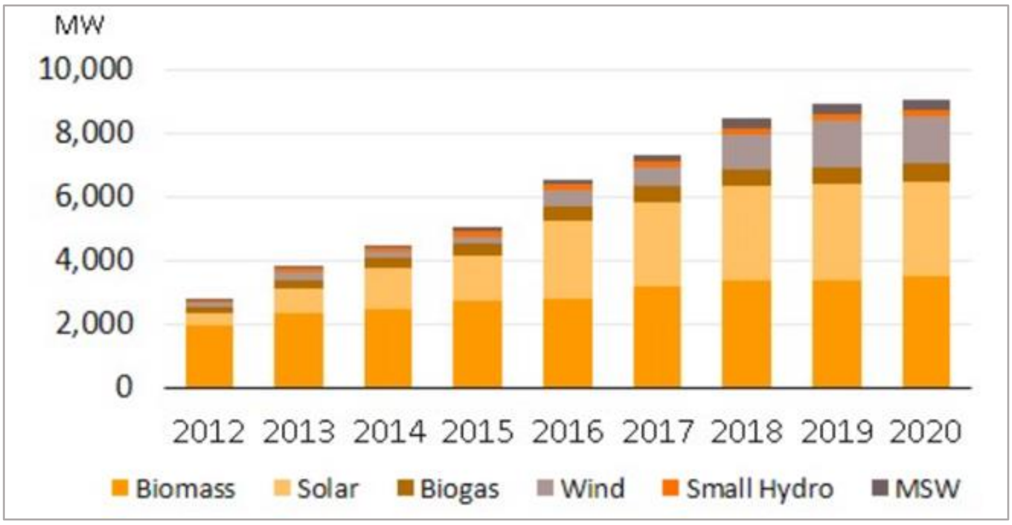
Figure 3.32. Electricity Consumption by Segment



Source: Energy Policy Planning Office, https://www.eppo.go.th/index.php/en/.

In 2020, natural gas fuelled 55.3% of the electricity produced in Thailand. Recently, the country's natural gas production has been declining, and imports are increasing, whereas RE sources contributed 10.0% of national electricity consumption in 2020 compared to only 2.1% in 2010.

Figure 3.33. Installed Capacity of Renewable Energy



Source: DEDE, https://www.dede.go.th/webmax.

The revision of the Power Development Plan (2018–2037) targets more than 56 GW of installed capacity by 2037. Actual electricity generation is only 53% towards meeting the target laid out in the Alternative Energy Development Plan (AEDP) 2015 of having 17 GW of renewable-powered supply by 2036. By segment, biomass generation has performed best, and supply is now 63% of the target, followed by waste-to-energy (59% of target supply), small hydro (51%), solar (50%), wind (50%), and biogas (43%).

Table 3.9. Total Capacity under PDP2018 Revision 1

Power capacity	PDP2015 (MW)	Power capacity	PDP2018 (MW)
Installed capacity as of 2014	37,612	Installed capacity as of 2018	46,090
Retired capacity (2015-2036)	-24,736	Retired capacity (2018-2037)	-25,310
New capacity (2015-2036)	57,459	New capacity (2018-2037)	56,431
Total capacity as of 2036	**70,335**	**Total capacity as of 2037**	**77,211**

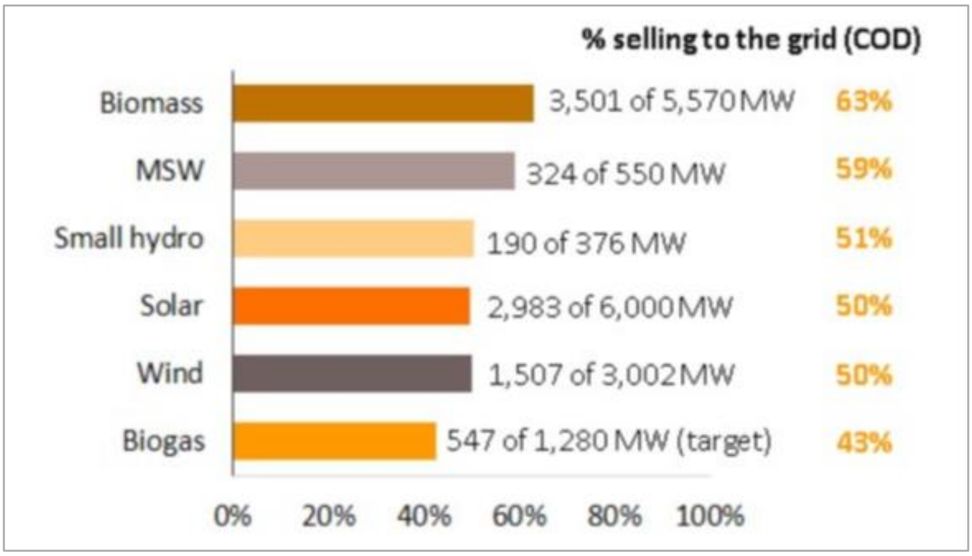
Source: EPPO (2020).

Table 3.10. Share of Fuel Used in Power Generation (%)

Fuel type	PDP2015	PDP2018	PDP2018 rev.1
Natural gas	37	53	53
Coal	23	12	11
Imported hydro	15	9	9
Renewable energy	20	20	21
Nuclear	5	0	0
Energy saving	0	6	6

Source: EPPO (2020).

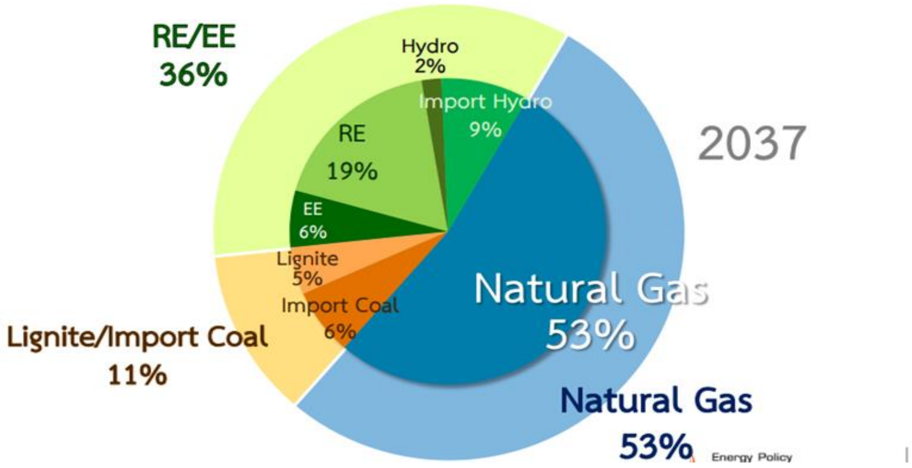
Figure 3.34. Renewable Energy Generation Capacity and AEDP Target (as of 2020)



Source: DEDE (2022).

A power plant, under the new AEDP 2018, consists of solar (54%), biomass (17%), hydro-floating solar hybrid (17%), and wind (9%). Of the 56 GW of new power generation from 2018 to 2037, RE accounted for 37% and combined cycle 27%, accounting for more than 60%. As a result, by 2037, natural gas will account for 53%, RE for 36%, and coal for 11%.

Figure 3.35. Power Plant under the New AEDP



Source: EPPO (2020).

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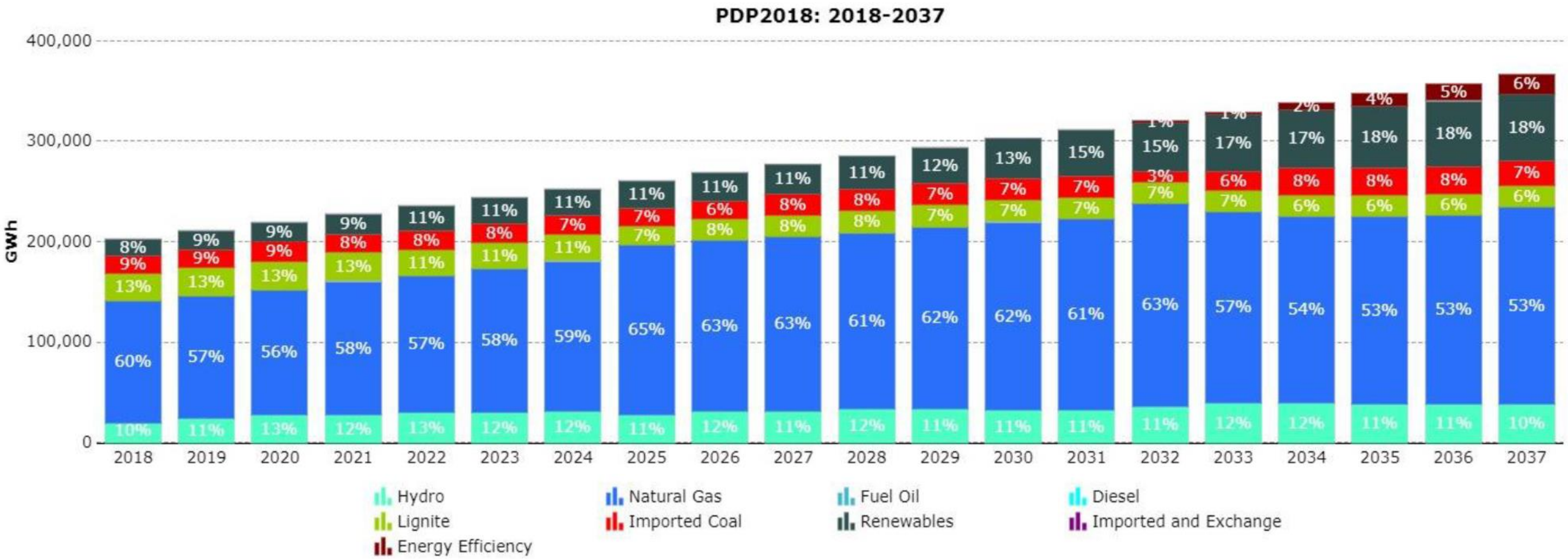
Figure 3.36 shows the power development plans for PDP 2018–2037 by type of power generation facilities.

Figure 3.36. Thailand's Power Development Plan 2018–2037 Revision 1



Source: Presentation of Thailand at the First Working Group Meeting, 8 July 2022.

3.2. Policy Towards Carbon Neutrality and Other Related Policies

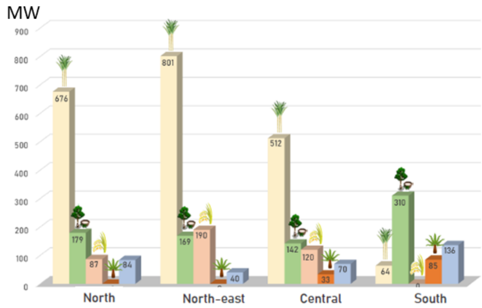
1) Biomass

This figure shows the biomass potential and current biomass power plant.

The Government of Thailand aims to utilise its domestic agricultural waste as a biomass energy source by adapting the 'community power plant project' concept, which needs smaller and distributed generation technologies. Bagasse and leaves are the largest biomass source in Thailand. The total capacity of the domestic biomass power plant is 3,700 MW. Out of this, 2,052 MW is of bagasse and leaves. Other major sources are rubberwood waste, rice husk, and palm cluster. In operation under a PPA are 256 biomass power plants.

Figure 3.37. Biomass Potential and Current Biomass Power Plant

	Potential (Mt/y)	Biomass power plant (MW)
Rice husk	1.38	400
Bagasse & Leaves	6.87	2052
Palm Cluster	0.99	118
Rubber wood waste	0.29	800
Others		330
total		3700

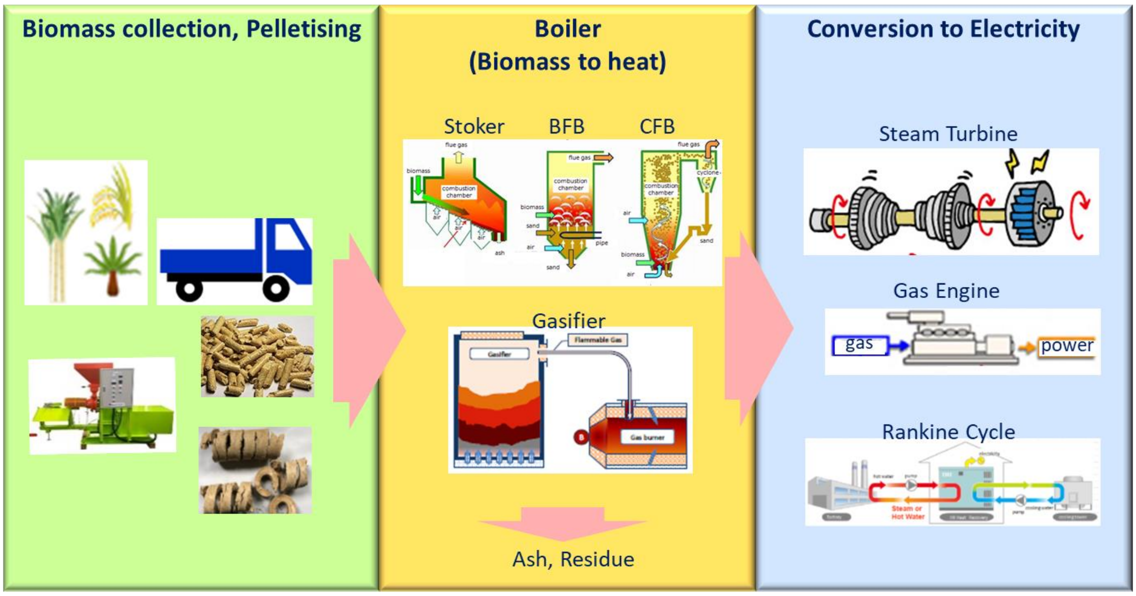


Biomass fuels in Thailand, categorized by type of biomass

Source: Working Group Presentation for the Study on Biomass and Coal Co-combustion in the ASEAN Region. EGAT (Feb. 2019).

Figure 3.38 shows adaptable technologies for biomass to energy in three portions: (i) biomass collection, (ii) biomass-to-heat conversion, and (iii) heat-to-power conversion. The technique must be properly selected for each portion. The technology chosen should be considered the electricity demand of nearby communities, suitable biomass type, volume, seasonal variation, and the economics of equipment costs.

Figure 3.38. Adaptable Technologies for Biomass to Energy



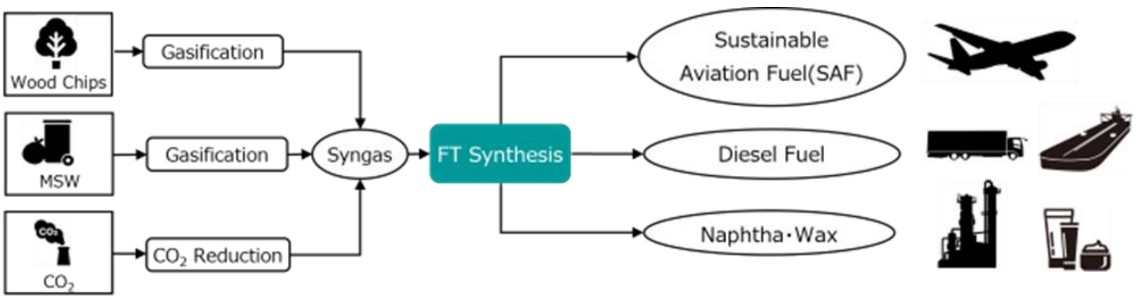
Source: ERIA & JCOAL (2020).

2) Synthetic Fuel

Synthetic fuels using carbon-neutral biomass as a carbon source consist of (i) gasification of biomass and (ii) synthesis of hydrocarbons by Fischer-Tropsch reaction of syngas. In Japan, several companies are in the pilot stage for commercialisation.

The reaction of synthesizing hydrocarbons from the cracked gas generated by pyrolyzing biomass in the first stage of the process has also been put to practical use in the world's industrial sector. In particular, the shift reaction that generates CO_2 and hydrogen through the reaction of carbon monoxide in the biomass decomposition gas with water is to be focused. Since the hydrogen required for the Fischer-Tropsch reaction is produced from CO and water by the shift reaction, the CO_2 produced as a by-product is of high purity. Therefore, if CO_2 can be stored, it can be used as a negative emission, contributing to CN.

Figure 3.39. Synthetic Fuel Process from Biomass (Ref. 1)



Sources: Toyo Engineering website, https://www.toyo-eng.com/jp/en/solution/e-fuel/;

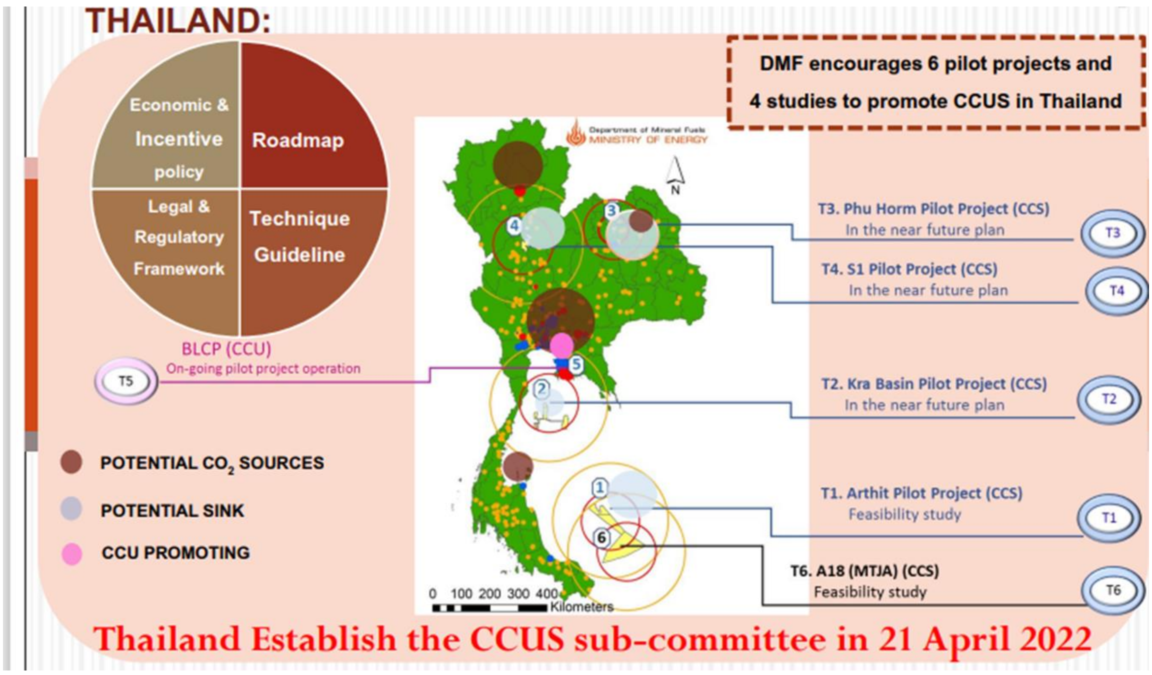
Figure 3.40. Synthetic Fuel Process from Biomass (Ref. 2)

Sources: News web, https://www.nikkei.com/article/DGXLRSP612791_Y1A610C2000000/.

3.3. Ongoing and Planned Measures for Carbon Neutrality

Figure 3.41 shows the current CCUS development in Thailand. The Thai Ministry of Energy established the CCUS sub-committee in April 2022. The ministry's Department of Mineral Fuels (DMF) has been facilitating six pilot projects and four studies on CCUS in the country.

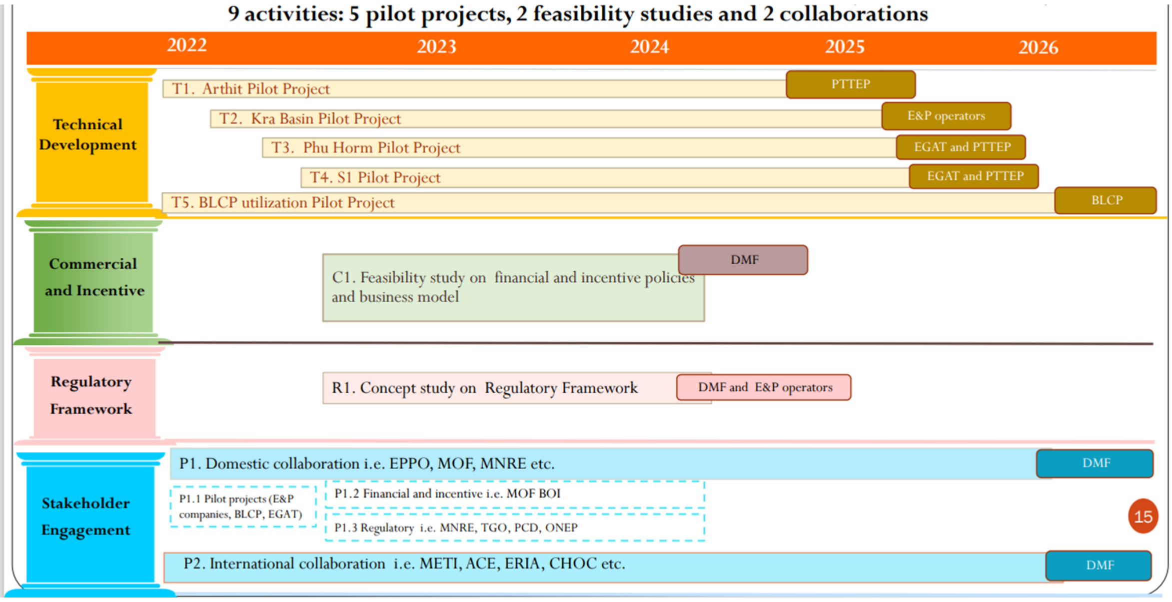
Figure 3.41. Current CCUS Development in Thailand



Source: Presentation of Thailand at the First Working Group Meeting on 8 July 2022.

Figure 3.42 shows Thailand's CCUS development work plan in 5 years from 2022 to 2026. There are five technical development projects, two feasibility studies, and two collaboration projects. They are also participating in the international collaboration projects shown at the end of the period.

Figure 3.42. CCUS Development Work Plan (2022–2026)



Source: Presentation of Thailand at the First Working Group Meeting on 8 July 2022.

Table 3.11 shows the applicable technologies for CO_2 reduction and for capture, utilisation, and storage of CO_2. It is important to describe each item to the extent that it can be technically applied according to the situation and needs of each country. In addition, it is important to review it according to economic feasibility and future changes in the situation.

Table 3.11. Applicable Technologies for Carbon Neutrality (1)

Road Map towards Carbon Neutrality						Thailand
Reduction	Thermal Power	High Efficiency	IGCC			Not applicable
			IGFC			
			A-USC			
	Fuel	Biomass	Combustion	CFBC biomass firing		Applicable
				PC coal cofiring		
			Manufacturing	Material	Agricultural waste pellet	Applicable
					Fast-growing tree	
				Pri-treatment	Torrefied pellet	Optional
					Washing	
		Ammonia	Utilisation	Ammonia gas turbine		Applicable
				Ammonia industrial furnace		
				Ammonia-coal cofiring		
			Manufacturing	Ammonia process	Coventional process + CCS	Optional
					New&Innnovative process	
				R&D base, Supply chain		
		Hydrogen	Utilisation	Hydrogen gas turbine		Applicable
			Manufacturing	Hydrogen process	Water electrolysis by RE	Applicable
					Turquoise hydrogen	
				R&D base, Supply chain		Optional
	Renewables	Wind, Solar, Geothermal	Offshore wind			Applicable
			Perovskite PV			
			Next generation geothermal			
		BESS	large Li-ion, NaS, Redoxflow			
	Manufactur-ing process	Steel	Coke reduction	Energy saving, LRC	Ferrodoke	Optional
				Direct reduction		
				Hydrogen reduction		
				COURSE50	Super-COURSE50	
				Carbon recycling BF		
		Cement				Applicable

Source: JCOAL.

Table 3.12 Applicable Technologies for Carbon Neutrality (2)

Road Map towards Carbon Neutrality						Thailand
Capture	Capture/ Recovery	Capture/ Recovery	Recovery/generatrion	Oxyfuel IGCC		Not applicable
				Supercritical CO_2 cycle generation		
				Chemical looping combustion		
			Chemical absorption			Applicable
			Solid absorbent material method			
			Physical absorption			
			Membrane separation			
			Physical adsorption			
Utilisation	Chemicals	Chemicals	Core materials	Methanol		Applicable
				SOEC process	CO	
					Methyl Cycrohexane	
				Artificial photosynthesis	Olefin	
			Derivatives	Formic acid	Boron-doped diamond electrode	
				Polyurethane intermediate		
				Para-xylene		
				Polycarbonate		
				Polyurethane		
				Ethylene urea		
	Fuel	Fuel Synthesis	Gas fuel	Methane	Sabatier process	Applicable
					SOEC process	
					Biomass photosynthesis	
			Liquid fuel	Diesel	Biomass photosynthesis	
				Jet fuel	Biomass photosynthesis	
					Biomass gasification FT synthesis	
				Olefin, kerosene		
	Mineralisation	Cement/ Concrete	Concrete	CO2 absorption type		Applicable
				Carbonate type		
			Admixture	CO2 absorption type		
				Carbonate type		
	Others	Others	Sector Coupling	Industrial complex carbon recycling		Applicable
Storage	Storage	CCS、DACCS、BECCS	Forest absorption/afforestation	Afforestation		Applicable
				Blue carbon		
			CCS			

Source: JCOAL Study Team.

3.4. Policy recommendations

The applicability of CCT for a carbon-neutral solution is as follows. According to the Thai government's energy policy 4D+E, the comprehensive utilisation of biomass is important, along with conventional RE, such as hydropower, and relatively new RE, such as solar and wind power.

1) On biomass utilisation in the power sector, the Thai government's policy to promote community power plant is the right choice as it accelerates the decentralisation of power sources and utilisation of domestic resources. Biomass combustion can be combined with many other technologies according to the type of biomass and plant scale to enhance the outcomes of the overall community power plant for further dissemination. In this context, individual optimisation is desirable.
2) Developing synthetic fuel from biomass gasification and fuel synthesis is desirable for biomass utilisation in the transport sector. Since the purity level of CO_2 produced as a by-product is quite high, substantial CO_2 reduction can be expected by replacing conventional fuels with synthetic fuels and storing them.
3) Hydrogen derived through a shift reaction of CO to CO_2 is expected to utilise combustion as carbon-free fuel, fuel cell, and key material for several carbon-recycling reaction pathways. In this connection, a study on the overall utilisation chain of biomass, hydrogen, and CO_2 will be recommended.

4) The Thai government is actively promoting CCS projects. There are various CO_2 sources and their concentration. Among them, the recovery of CO_2 from flue gas is particularly important. In this regard, government support will be very effective.

4. Viet Nam

Viet Nam is a dynamic, emerging economy with approximately 100 million people. Before the COVID-19 pandemic, the country recorded an annual GDP growth rate of 6%–7%, dramatically increasing energy demand and greenhouse gas (GHG) emissions. With high economic growth expected to continue, the country could face severe electricity shortages in 2030 if energy demand growth is unchecked.

According to the APEC Energy Working Group's Expert Group on Energy Data and Analysis, hydropower has been Viet Nam's clean, stable, and reliable energy source. But saturation has shrank hydropower's share in the country's electricity mix (from 37% in 2019 to 30% in 2020). Due to constraints in dam reservoir capacity, hydropower cannot meet the growing demand. Fossil fuels (coal, gas, and oil) account for about half of the electricity generation mix. Coal has been the cheapest and most readily available source, but Viet Nam increasingly depends on imports. Meanwhile, renewables such as small hydropower, solar, wind, and biomass account for only 16% of electricity generation.

In 2015, the government announced its first national development strategy on renewables, aiming to increase the share of renewables in total primary supply and electricity generation to about 32% by 2030.

4.1. Energy/Electricity Situation and Policies

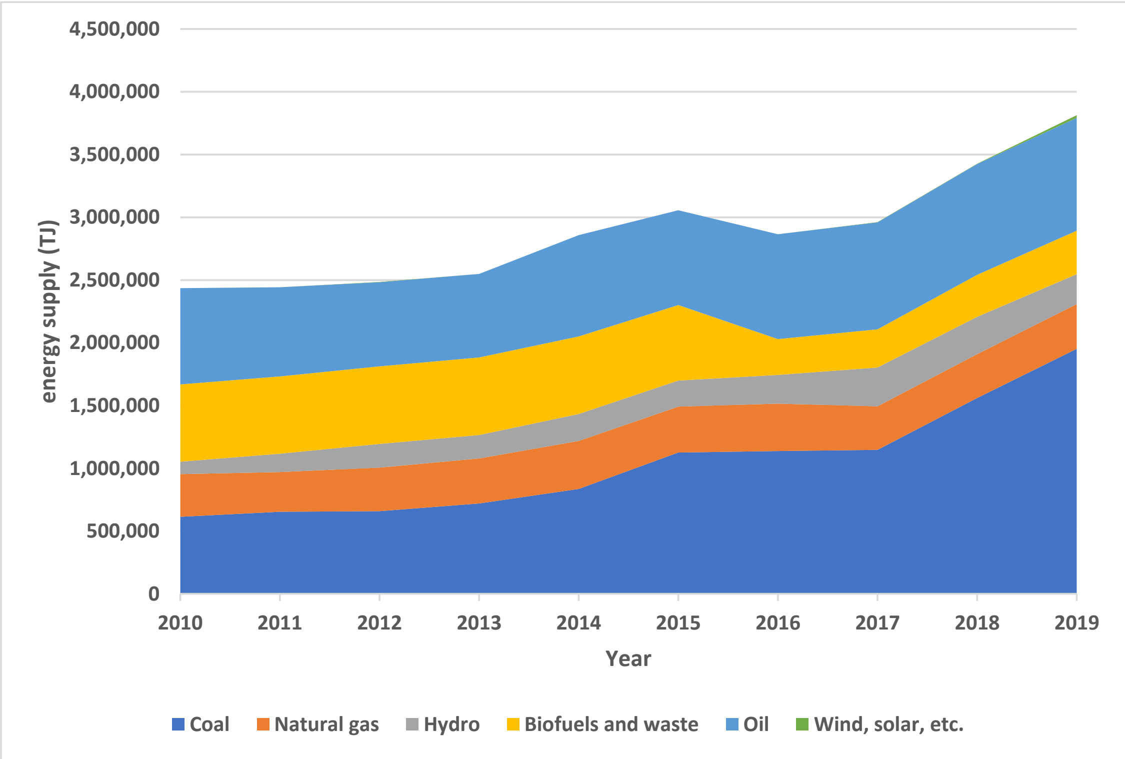
1) Current Energy Supply and Demand

Figure 3.43 shows the evolution of the energy supply from 2010 to 2019. Coal (blue) and oil (light blue) represent a large share of the energy supply sources.

In terms of the rate of increase, petroleum increased by 17% from 2010 to 2019, while coal increased by over 300%. So, it is no exaggeration to say that coal accounts for most of the increase in Viet Nam's energy supply.

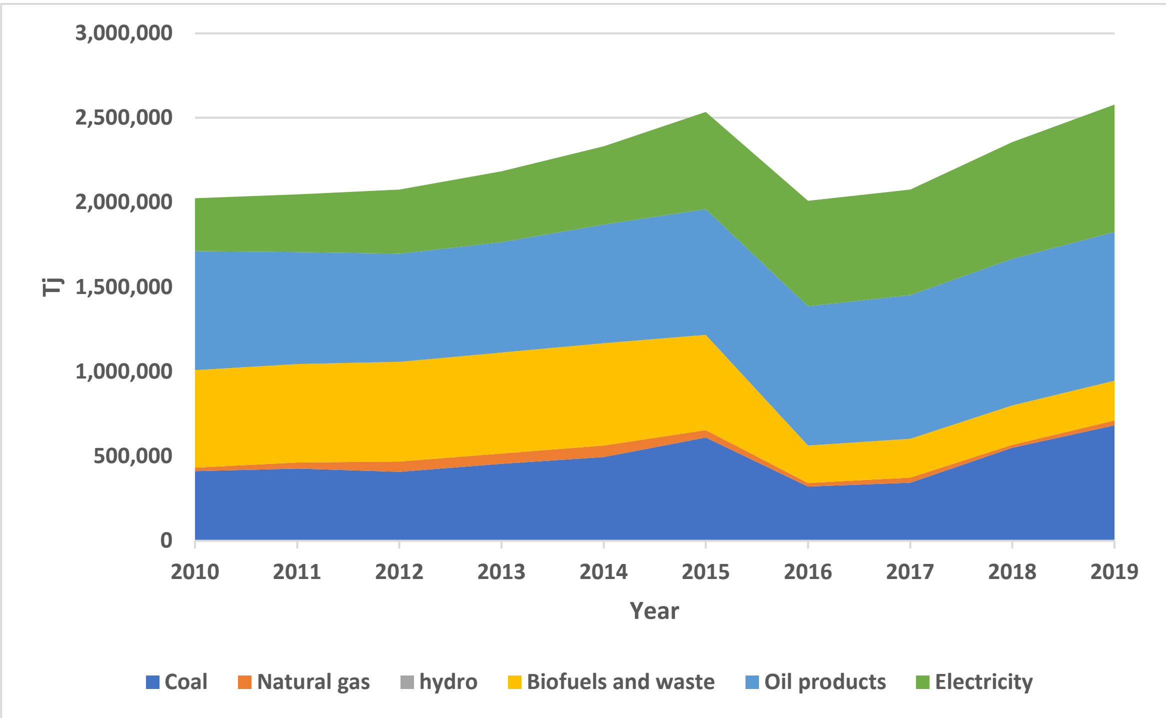
The evolution of energy consumption from 2010 to 2019 is also shown in Figure 3.44. The largest increases over this period have been in coal (66%) and electricity (240%). Regarding electricity consumption, Viet Nam ranks second in ASEAN, after Indonesia.

Figure 3.43. Total Energy Supply by Source in Viet Nam



Source: IEA (2021c).

Figure 3.44. Total Energy Consumption by Source in Viet Nam

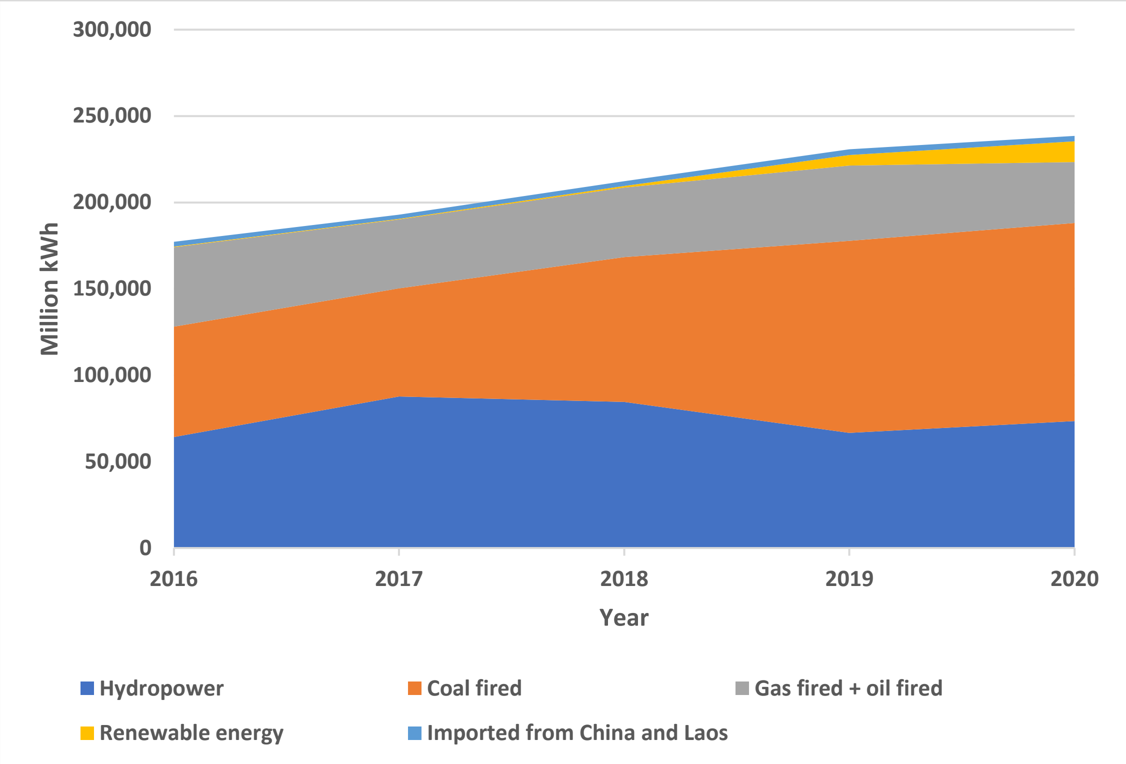


Source: IEA (2021c).

2) Power Production and Purchase by Sector

Figure 3.45 from the Vietnam Electricity (EVN) Annual Report (2021) shows the change in electricity generation between 2016 and 2020 by fuel type. The highest rate of increase in power generation is in coal-fired power, which increased by 1.8 times in 2020 compared to 2016.

Figure 3.45. Power Production and Purchase

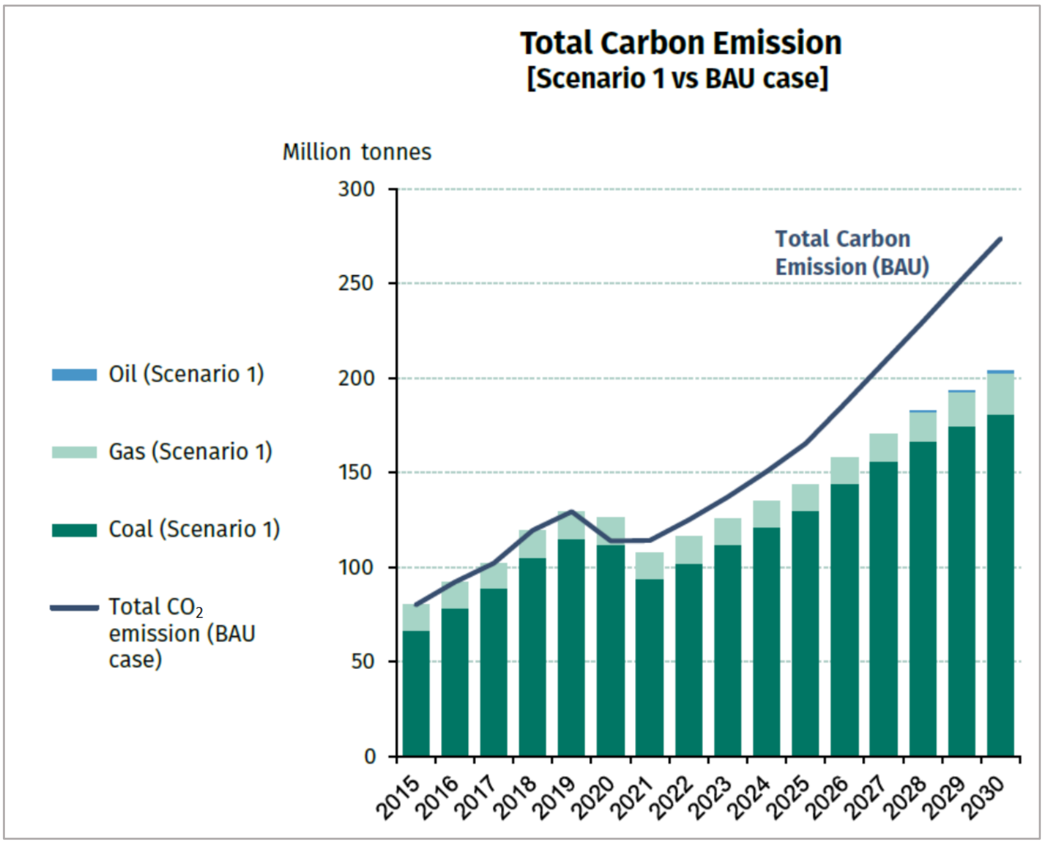


Source: EVN (2021).

3) Total Carbon Emission in Viet Nam

The projected CO_2 emissions up to 2030 are shown in Figure 3.46. CO_2 emissions will increase from 130 Mt in 2019 to 204 Mt in 2030, as existing and 9 GW of new committed coal facilities operate at a high capacity to meet strong demand growth over the next decade. Due to the increased share of non-fossil fuel generation, total carbon emissions in this scenario are 26% lower than in the business-as-usual scenario in 2030.

Figure 3.46. Total Carbon Emissions



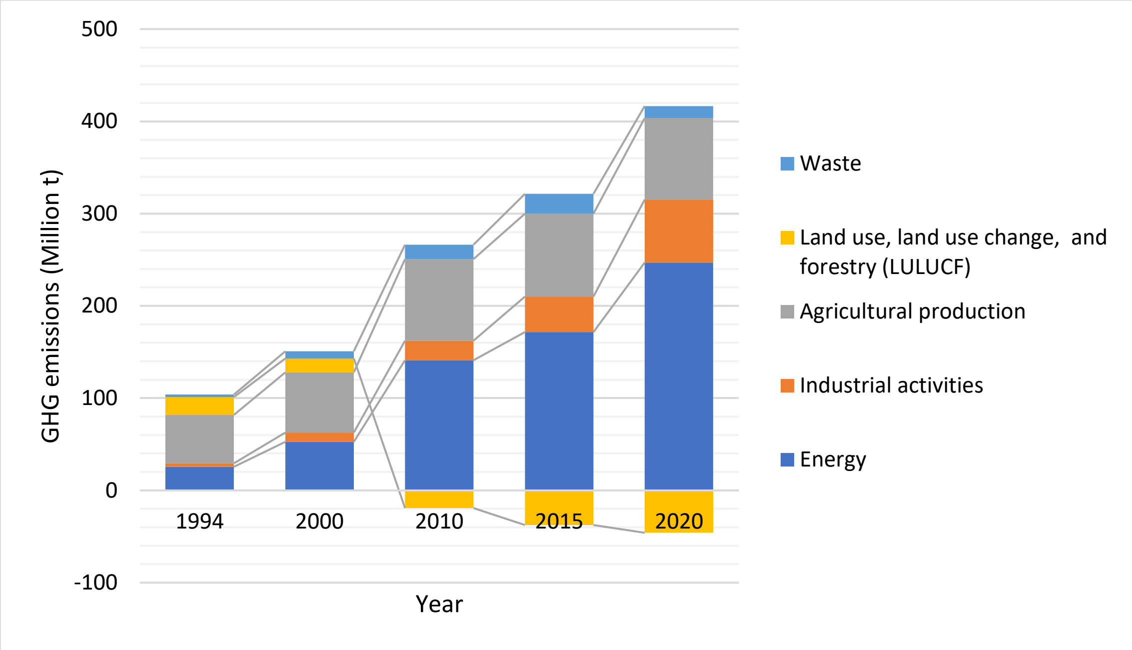
BAU = business-as-usual scenario.
Source: Liutong and Alvarez (2021).

Figure 3.47 shows the change in CO_2 emissions by industry in Viet Nam between 1994 and 2020, as reported at the 19th ASEAN Energy Security Forum on 16 June 2022.

CO_2 emissions have increased from 104 million tonnes in 1994 to 3.7 million tonnes in 2020, an increase of about 3.5 times. The largest share of the growth is in the energy sector, which accounted for 67% of CO_2 emissions in 2020.

GHG emissions from energy use and development increased from 141.2 million tonnes (CO_2) equivalent in 2010 to 247 million tonnes (CO_2) equivalent in 2020, 45% of which was related to electricity production in 2020.

Figure 3.47. Current Status of GHG Emissions in Viet Nam



Source: Edited by JCOAL Study Team based on data from MOIT (2022).

4.2. Review of PDP8 for 2030 and 2045 in Viet Nam

In 2021, Viet Nam's Ministry of Industry and Trade (MOIT) published the National Electricity Development Plan (PDP8) for 2021-2030. This included a vision to 2045, proposal number 1682/TTr-BCT.

The draft PDP8 was mainly concerned with RE introduction, and the results were presented in October 2021 and April 2022. It is currently awaiting approval by the Prime Minister.

The installed generation capacity by energy source for PDP8 is shown in Table 3.13. In the table, reference is made to EVN's annual report for actual data at the end of 2020. For the 2030 generation installed capacity plan, the March 2021 announcement and the October 2021 review are for the base scenario, while the April 2022 review is for the high scenario. A stacking graph based on these data is shown in Figure 3.48**.** MOIT proposes the following for the draft PDP8 (announced in March 2021) and the new PDP8 (reviewed in October 2021).

Coal-fired power generation capacity will reach approximately 29,429 MW in 2025 (base scenario) and grow to 40,649 MW in 2030 (base scenario), increasing from approximately 27.96% of total installed capacity in 2025 to about 28.3% of total installed capacity in 2030. No new CFPPs will be developed during this period (except those under construction between 2021 and 2025 and under investment promotion to start operation). Projects approved under the revised PDP7 but opposed by local communities or failed to meet development criteria (e.g. where the project is not feasible) are recommended to be suspended. However, 19,266 MW will be added until 2030, and PDP8 will take over coal-fired projects in PDP7. In the April 2022 review, CFPPs will no longer receive any increase in installed generating capacity.

Gas-fired power, including LNG, will increase to 27,471 MW by 2030 (base scenario). The share of gas-fired power, including LNG, is expected to grow from about 13.54% in 2025 to about 21.1% in 2030. However, of the approximately 17,900 MW of projects added in October 2021, only about 10,300 MW of gas-to-power projects will be developed by 2030 under the draft PDP8, while other projects will be deferred until after 2030. In the Northern Region, an additional 2,250 MW of gas-to-power projects were proposed for regional energy security reasons and to minimise inter-regional transmission, in addition to the recently approved approximately 1.5 GW. In the April 2022 review, the installed capacity of gas turbine–based thermal power generation approximately doubled.

Hydropower capacity (including large, medium, and small hydropower and pumped storage) would gradually increase from about 25,323 MW by 2025 (base scenario) to 26,684 MW by 2030 (base scenario). The share of hydropower is projected to decrease from about 24% in 2025 to about 19.39% in 2030. In the April 2022 review, it would increase to 30,946 MW (high scenario), but the share would increase slightly to about 20.14%.

Onshore and offshore wind capacity is expected to increase from about 11,320 MW in 2025 (base scenario) to 18,010 MW in 2030 (base scenario). However, given that more than 10 GW has been approved under the revised PDP7, the addition does not appear as large as expected from the private sector. In Letter No. 4219/EVN-TTD dated 22 July 2021, 144 wind power projects have signed PPAs for about 8,145 MW. The PPAs are for 8,145 MW. Only up to 2,000 MW can be generated for offshore wind power by 2030. The draft PDP8 has removed the list of large offshore power projects. The draft PDP8 states that they will represent about 11% of total installed capacity by 2025, decreasing to about 9% by 2030. The April 2022 review reinstated offshore power projects at 23,121 MW (high scenario).

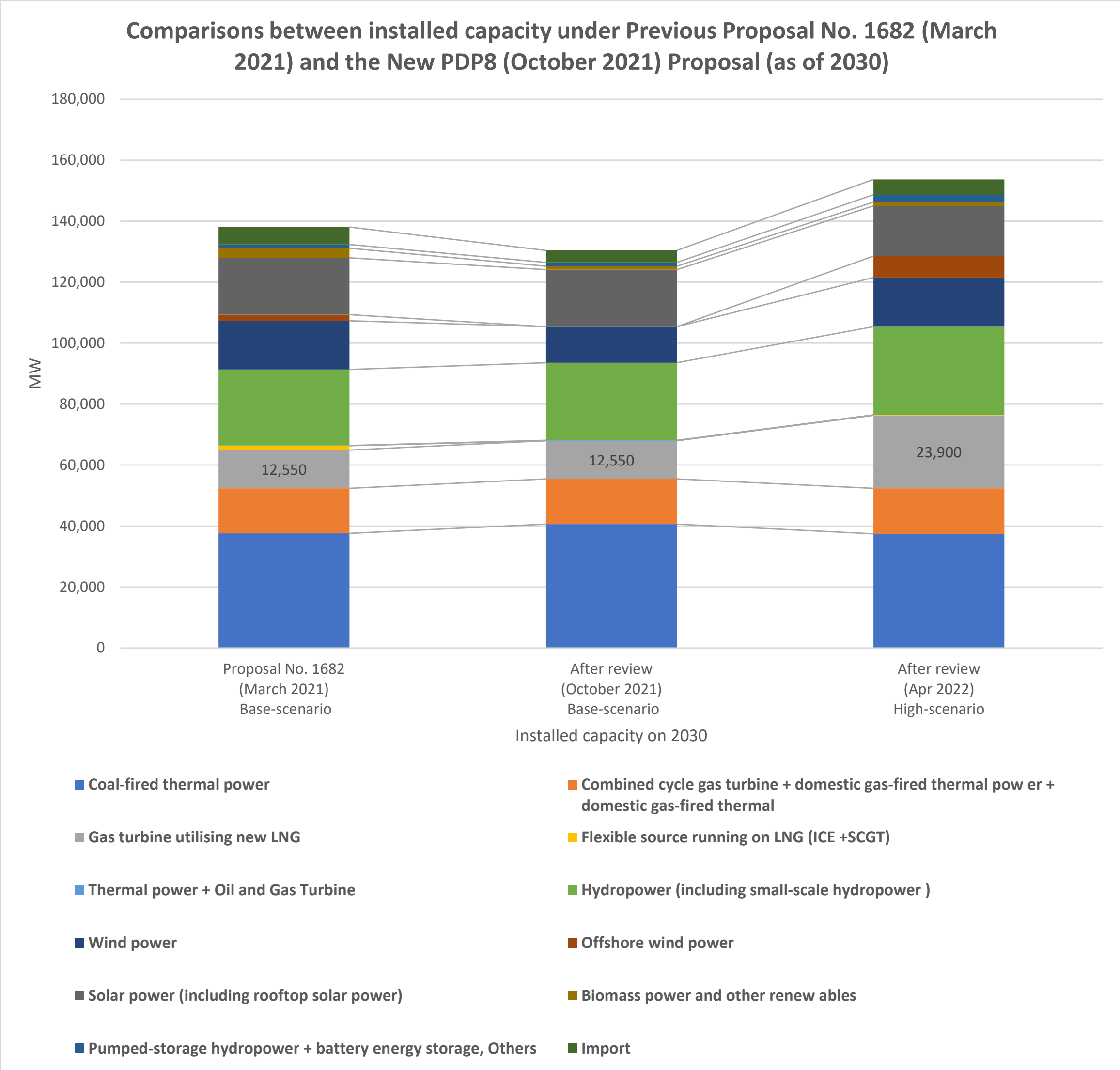
Table 3.13. Installed Generation Capacity by Energy Source for PDP8 (as of 2030)

Year / Item	2020	2030		
		Installed Capacity		
	End of 2020	Proposal no. 1682 (March 2021) Base scenario	After review (October 2021) Base scenario	After review (Apr 2022) High scenario
Coal-fired thermal power	21,838	37,573	40,649	37,467
Combined cycle gas turbine +domestic gas-fired thermal power + domestic gas-fired thermal		14,783	14,783	14,930
Gas turbine utilising new LNG	9,025	12,550	12,550	23,900
Flexible source running on LNG (ICE +SCGT)		1,400	0	150
Thermal power+oil and gas turbine		138	138	0
Hydropower (including small-scale hydropower)	20,993	24,872	25,484	28,946
Wind power	538	16,010	11,820	16,121
Offshore wind power		2,000	0	7,000
Solar power (including rooftop solar power)	16,506	18,640	18,640	16,491
Biomass power and other renew ables		3,150	1,170	1,230
Pumped-storage hydropower + battery energy storage, Others	325	1,200	1,200	2,450
Import	572	5,743	3,937	5,000
Total installed capacity (MW)	69,797	138,059	130,371	153,685

Source: Baker and McKenzie (2021).

For photovoltaics (PVs), the total capacity would reach about 17,240 MW in 2025 (base scenario) and 18,640 MW in 2030 (base scenario). Solar PV would account for approximately 16.79% of the total installed capacity in 2025 and about 14.3% in 2030. However, with 8,751 MW of solar PV plants in operation by the end of 2020 and a further 7,755 MW of rooftop PV systems in commercial operation, this does not appear to be as large an addition as the private sector might expect. The April 2022 review shows 16,491 MW (high scenario) and 2,149 MW less, likely due to the postponement of new solar PV projects.

Figure 3.48. Installed Generation Capacity by Energy Source for PDP8 (as of 2030)



Source: Edited by JCOAL Study Team based on data from Baker & McKenzie (2021, 2022).

The installed capacity of electricity generation by energy source in 2045 is shown in Table 3.14. A graph built up from this data is shown in Figure 3.49. By energy source, coal-fired power will reach a generation capacity of 50,699 MW (high scenario) in 2045. The share of coal-fired power will decrease to about 15.4% in 2045. Between 2030 and 2045, there is no change in the installed capacity of coal-fired power generation, but the share of coal-fired power in the total installed capacity decreases significantly. The decrease amounts to 13,232 MW.

Gas generation capacity gradually increases to 53,883 MW in 2045 (61,900 MW including base scenario and LNG flexible sources), or approximately 20.6% of total installed capacity (23.64% including LNG flexible sources). In the April 2022 review, it is reduced to 46,330 MW. But LNG flexible sources will increase by approximately 28,000 MW, bringing the combined total to 74,530 MW.

Table 3.14. Installed Generation Capacity by Energy Source for PDP8 (as of 2045)

Year / Item	2045 Installed Capacity		
	Proposal no. 1682 (March 2021) Base scenario	After review (October 2021) Base scenario	After review (Apr 2022) High scenario
Coal-fired thermal power	50,168	50,699	37,467
Combined cycle gas turbine + domestic gas-fired thermal power + domestic gas-fired thermal	12,754	14,783	14,930
Gas turbine utilising new LNG	38,150	39,050	31,400
Flexible source running on LNG (ICE +SCGT)	15,600	8,100	28,200
Thermal power + oil and gas turbine	0	0	0
Hydropower (including small-scale hydropower)	25,772	29,077	35,139
Wind power	39,610	27,110	55,950
Offshore wind power	21,000	21,000	66,500
Solar power (including rooftop solar power)	55,090	51,540	96,666
Biomass power and other renew ables	5,310	5,250	5,210
Pumped-storage hydropower +battery energy storage	7,800	6,600	29,250
Import	5,743	8,743	11,042
Total installed capacity (MW)	276,997	261,952	411,754

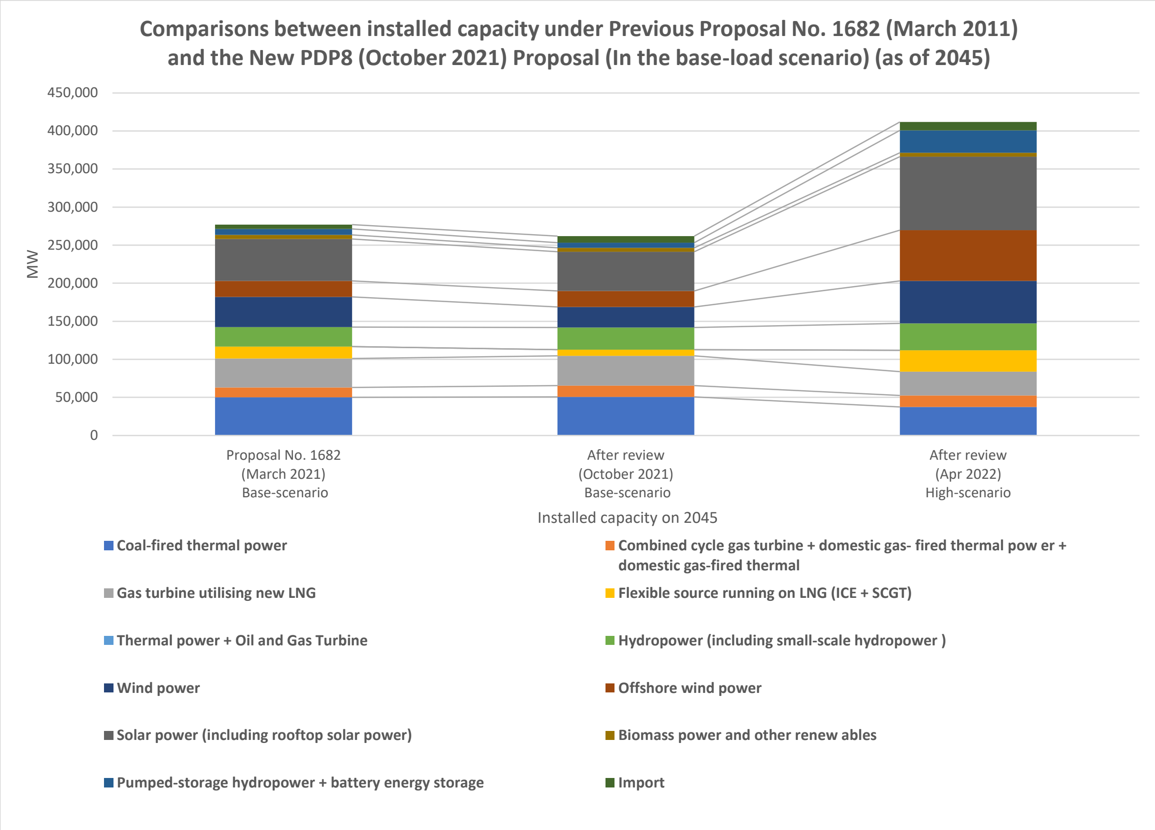
Source: Baker & McKenzie (2021, 2022).

Hydropower capacity (including large, medium, and small hydropower and pumped storage) will gradually increase, reaching approximately 29,077 MW in 2045 (base scenario). The share of hydropower will continue to decline (as hydropower potential is almost exhausted). In particular, the share of large, medium, and small hydropower and pumped storage will amount to about 12.58% of the total installed capacity in 2045. In the April 2022 review, hydropower installed capacity increased again to 35,139 MW (high scenario).

Wind power generation (onshore and near-shore wind capacity) will increase significantly to about 27,110 MW by 2045. For offshore wind power, the draft PDP8 proposes a significant increase in capacity to about 21,000 MW by 2045: in the April 2022 review, 28,840 MW more onshore wind and 45,500 MW more offshore wind under the high scenario, bringing the total to 122,450 MW.

Solar PV capacity will increase significantly to around 51,540 MW by 2045, accounting for about 19.3% of total installed capacity. The April 2022 review further increases installed capacity by 45,128 MW to 96,666 MW on a high scenario.

Figure 3.49. Installed Generation Capacity by Energy Source for PDP8 (as of 2045)



Source: Edited by JCOAL Study Team based on data from Baker & McKenzie (2021, 2022).

4.3. Policy Directions and Related Basic Policies for Decarbonisation

At COP26 in Glasgow in 2021, Prime Minister Pham Minh Chinh announced that the country would phase out coal power generation by the 2040s and achieve net-zero carbon emissions by 2050. In its National Strategy on Climate Change, Viet Nam has recently announced a 43.5% emission reduction target by 2030, sectoral emission targets for 2030 and 2050, and qualitative proposals for achieving the targets.

As in other countries, Viet Nam's emissions come from various energy and land-use systems. Approximately 30% of total GHG emissions come from the power sector, 30% from the industrial sector, and 10% from the transport sector.

Within the Vietnamese government, several agencies have announced specific CO_2 reduction policies. For example, the Electricity Development Programme 8 (PDP8) of the Ministry of Industry and Trade aims to switch approximately 75% of electricity generation capacity to renewables by 2045. Around 100 GW will come from solar power and 120 GW from wind power (a higher target for solar power is being considered). The ministry also announced using hydrogen and ammonia in thermal power generation schemes, paving the way for green hydrogen to replace fossil fuels partially.

In the transport sector, the Prime Minister encouraged the introduction of electric vehicles (EVs), EV charging infrastructure and the electrification of public transport. Public stakeholders acted accordingly. The Ministry of Finance reduced the registration fee for EVs.

Other government agencies have also made commitments. The Ministry of Agriculture and Rural Development has committed to halt deforestation by 2030, while the Ministry of Construction has set requirements to promote green building.

Outside of central government agencies, several ministries are also committed to decarbonisation.

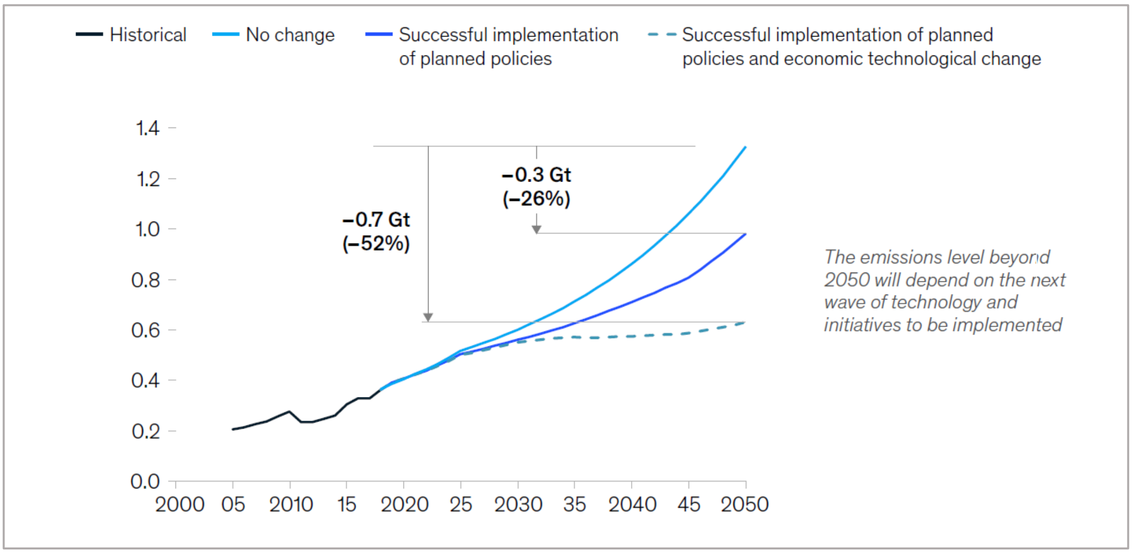
Quang Nam Province is working with the World Wide Fund for Nature (WWF) on forest conservation and is a pioneer in carbon sink projects in Viet Nam.

If the Government successfully implements these policies, emissions will likely be reduced, but not to the extent needed to achieve zero emissions by 2050.

Figure 3.50 illustrates this gap in three scenarios. The least desirable scenario is the one described earlier, where the industry continues to grow at the planned rate without technological change and the planned policies being successfully implemented. The scenario in the middle of the chart shows the case where the planned policy updates are successfully implemented. In the best scenario combining the latest plans with economically viable technological innovations, such as the conversion of passenger cars, motorcycles, and tricycles to EVs, more efficient agriculture, and a shift to advanced manufacturing, the emissions curve falls further. Under this scenario, emissions in Viet Nam could level off around 2035.

By 2050, they are almost at the same level as in 2025, at 0.6 gigatonnes.

Figure 3.50. Pathways of Viet Nam CO_2 Emissions, Gigatonnes of CO_2 Equivalent ($GtCO_2e$)



Source: Agarwal, et al. (2022).

4.4. Examples of Planned or Ongoing Initiatives, Related Measures, etc.

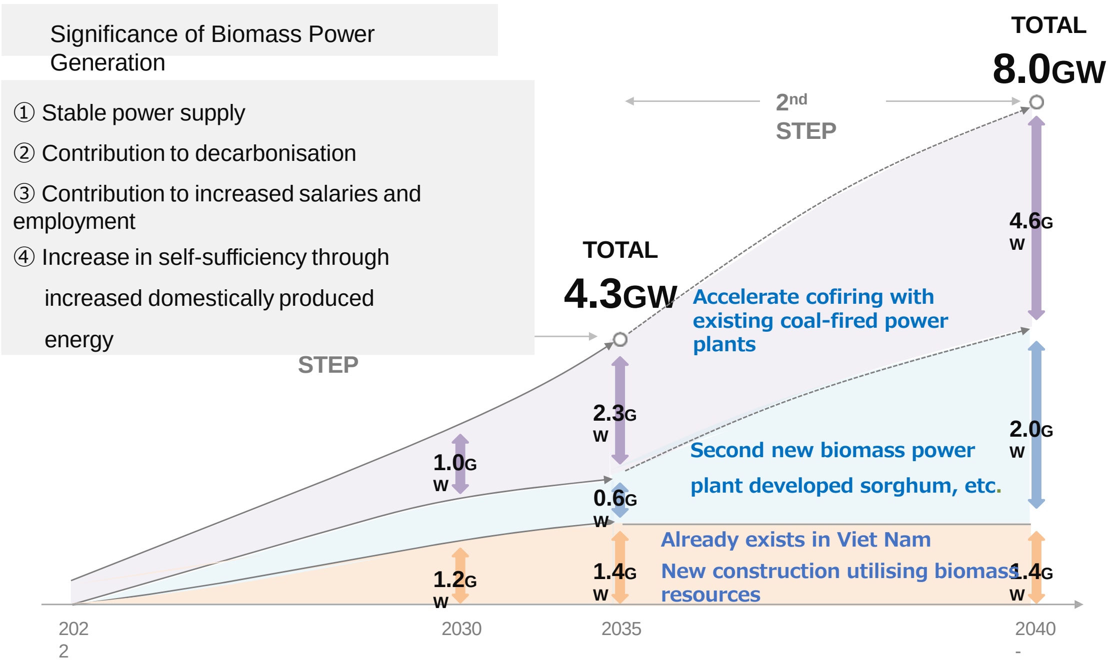
This section reports on the state of RE development in Viet Nam.

1) Power Generation using Biomass

A major concern for biomass power generation is the availability of fuel. But Viet Nam has a thriving agricultural and forestry industry, and a wide variety of biomass fuels are abundant. Although it is not widely known, Viet Nam is one of the world's leading agricultural countries, with many agricultural and forestry products boasting the top share of the international market. Viet Nam is also rich in forestry resources. It has a land area of approximately 33 million hectares (ha), of which forests cover about 14 million ha. Of this, about 70% is natural forests, and 30% is planted forests, although logging of natural forests was banned under a 2014 Prime Ministerial Decision. As of November 2018, the area of planted forests for commercial use, excluding security forests for protection and disaster prevention, was approximately 2.93 million ha.

As an example of biomass cofiring power generation in Viet Nam, the project being undertaken by the Japanese company erex is described. The company's power generation plan is shown in Figure 3.51: 1.4 GW of new biomass power plant using existing unused biomass; 0.6 GW of new biomass power plant using new biomass fuels including sorghum, by 2035; and 2.3 GW of bio-cofiring power generation at existing CFPPs, for a total of 4.3 GW. This plan could reduce CO_2 emissions by approximately 27 million tonnes per year, a reduction of roughly 10% compared to 2020. The company has already submitted a grand proposal to MOIT Viet Nam. The significance of working on biomass power generation includes stable electricity supply, contribution to decarbonisation, increased salaries and employment contribution for farmers, and increased self-sufficiency through increased domestic energy production.

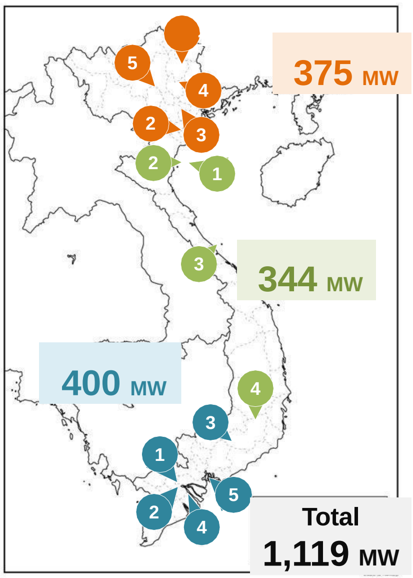
Figure 3.51. Erex's Power Generation Plan in Viet Nam



Source: Erex (2022a).

The locations of the power plants that erex is considering targetting for 2035 and their installed generation capacity are shown in Figure 3.52. In the diagram on the left, the potential in biomass power generation is shown in different colours – the darker the colour, the higher the potential. In addition, the power generation installed capacity is larger in the central and northern regions.

Figure 3.52. Biomass Power Plant Potential by Region in Viet Nam



Northern Region 375 MW

1	Bac Kan	50 MW
2	Hoa Binh	100 MW
3	Phu Tho	50 MW
4	Tuyen Quang	100 MW
5	Yen Bai	75 MW

Central Region 344 MW

1	Thanh Hoa 1	50 MW
2	Thanh Hoa 2	60 MW
3	Quang Binh	109 MW
4	Dak Lak	125 MW

Southern Region 400 MW

1	An Giang 1	75 MW
2	An Giang 2	100 MW
3	Binh Phuoc	50 MW
4	Can Tho	100 MW
5	Long An	75 MW

Source: Erex (2022a).

Erex was invited to participate in the conference on 27 August 2022 in Lao Cai Province, Viet Nam, under the theme 'Potential – Opportunity – Cooperation for Development' in the presence of Prime Minister Pham Minh Chinh. An MoU was signed between five Vietnamese provinces (Yang Bai, Tinh Quang, Bac Kan, Lai Chau, and Ha Giang) on the study of development projects using agriculture and forestry as raw materials and the construction of biomass power plants. Figure 3.53 shows the documents used at that time. For constructing new biomass power plants in PDP8, 14 new biomass power plants in 12 provinces with a total capacity of 1.2 MW are planned, and a shift of existing CFPPs to biomass cofiring and single combustion by 2030, with a total capacity of 100 MW. The drawing on the left shows potential sites for new biomass power plants.

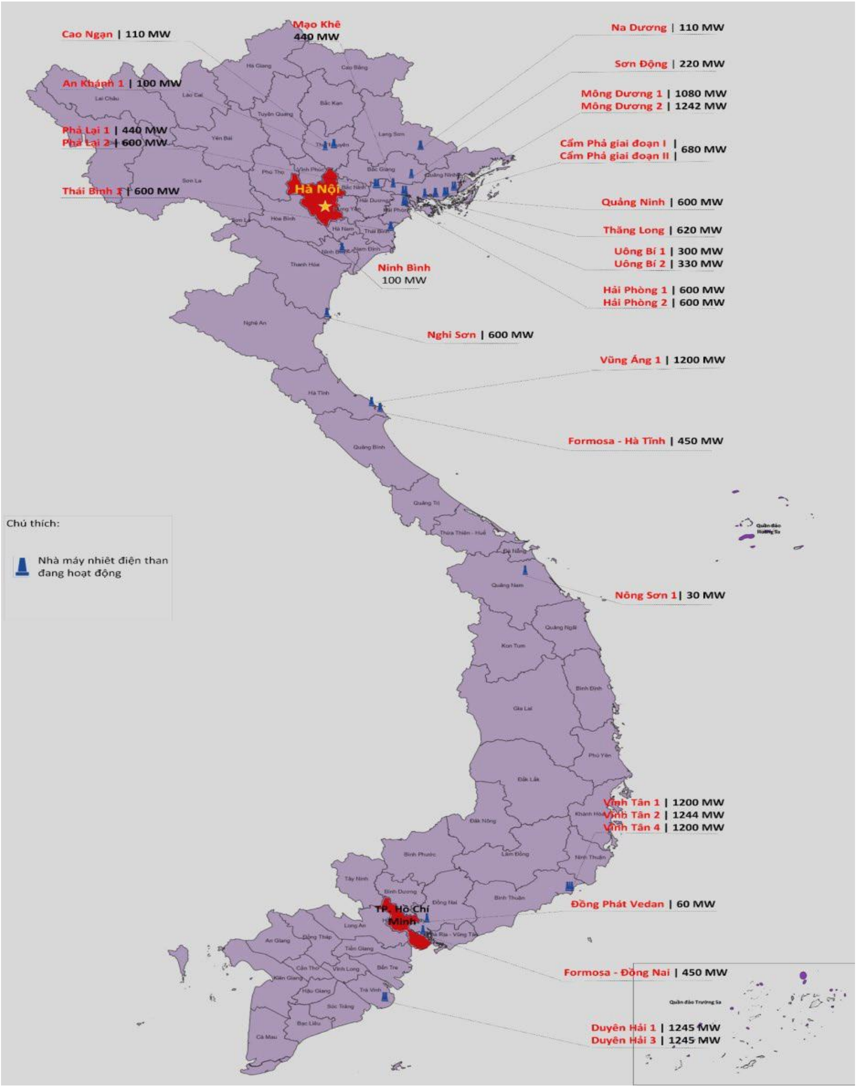
Figure 3.53. Candidate Sites for Newly Constructed Biomass Power Plants

		Project Name	Capacity
North	1	Yen Bai	75 MW
	2	Tuyen Quang	100 MW
	3	Hoa Binh	100 MW
	4	Phu Tho	50 MW
	5	Bac Kan	50 MW
Central	6	Thanh Hoa 2	60 MW
	7	Thanh Hoa 1	50 MW
	8	Quang Binh	109 MW
	9	Dak Lak	125 MW
South	10	Can Tho	100 MW
	11	An Giang 1	75 MW
	12	An Giang 2	100 MW
	13	Long An	75 MW
	14	Binh Phuoc	50 MW
		14 Projects in 12 Provinces	**1,119 MW**

Source: Erex (2022a).

The location of CFPPs and the specifications of each CFPP as of January 2022 are shown in Figure 3.54. Circulating fluidised bed-type boilers are suitable for biomass cofiring, with a total installed capacity of 4,600 MW or 22% of the total installed capacity as of January 2022.

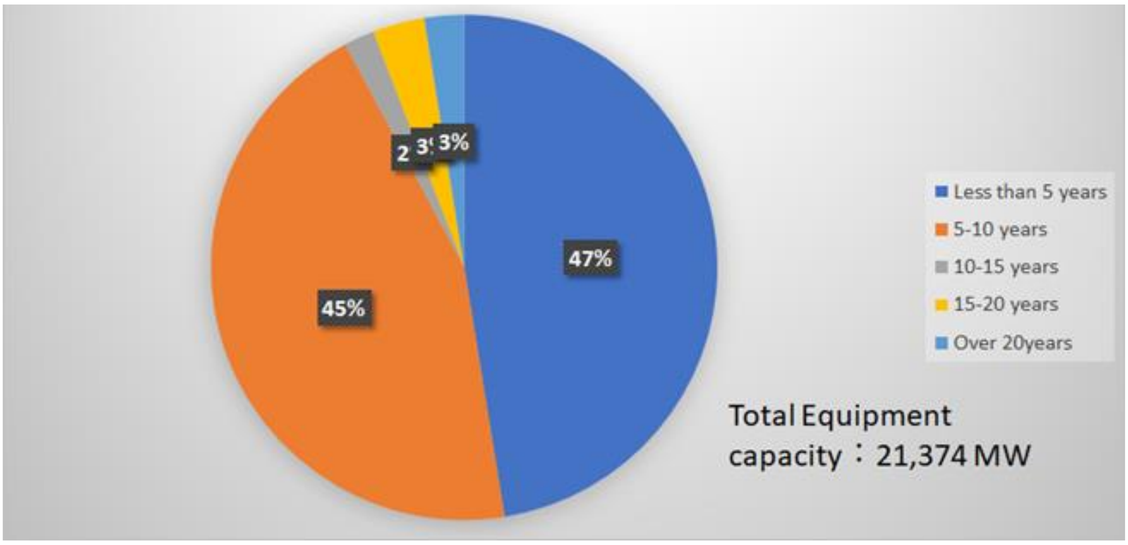
Figure 3.54. Current Status of Coal-fired Power in Viet Nam (as of January 2022)



Source: Erex (2022b).

A pie chart from the previous list of CFPPs by the number of years in operation is shown in Figure 3.55. Those operating for less than 5 years account for 47%. Those operating for 5–10 years account for 45%; those in operation for less than 10 years account for 92%.

Figure 3.55. Coal-fired Power Plants by Years Since the Start of Operation



Source: Edited by JCOAL Study Team based on data from erex (2022a).

2) Ammonia Cofiring with Coal

Ammonia supply is a challenge. However, Federal International has entered into an MoU with the Green Solutions Group to install a 200 MW electrolysis plant in Tra Vinh province, Viet Nam, which will produce 150,000–180,000 tonnes of ammonia and 30,000 tonnes of green hydrogen per year and is expected to be operational in 2024. The plant aims to reduce CO_2 emissions by cofiring ammonia and coal.

3) Solar Power Generation

Viet Nam's solar power generation has seen a significant increase in installed capacity since 2018, when the FiT policy was introduced, until the end of 2020, when the FiT price expires.

As of January 2021, approximately 19.4 MW of solar power generation had been installed. In a PDP8 review, MOIT and EVN have expressed continued support for commercial and industrial (C&I) rooftop solar power generation systems, despite the suspension of policy for utility-scale solar power generation projects. Developers provide electricity to customers at lower tariffs than the EVN, and these tariffs are guaranteed for up to 20 years.

Table 3.15 shows some C&I rooftop solar developers in Viet Nam.

Several well-known investors have entered this market. French utility EDF Renewables and its local partner, VinaCapital, have committed to invest US$100 million in a pipeline of 200 MW peak (MWp) C&I rooftop solar power generation systems over the next 3 years. Korean conglomerate SK Group and its local partner Nami Energy have committed US$200 million over the next few years, with an installation target of 250 MWp.

Table 3.15. Viet Nam's C&I Rooftop Solar Developers

Local Investor	Foreign Investor	Name of Company/ Joint Venture (if any)	Target C&I Rooftop Solar Capacity
Vina Capital	EDF Renewables	SkyX Solar	200 MWp by 2023-2024
REE	-	REE Solar Energy	500 MWp by 2025. Operating capacity 93 MWp (2021)
TTC Group	-	TTC Energy	EnergyUndisclosed. Operating capacity 50 MWp (2022).
Bamboo Capital Group	SP Group	BCG Energy	500 MWp by 2025.
Nami Energy	SK Group	-	250 MWp, no timeline specified.
-	Shire Oak International	Shire Oak International	250 MW in development. Operating capacity 52 MW (2021).
-	TotalEnergies	TotalEnergies	30-50 MWp per year.
-	Sojitz, Osaka Gas, LooopSOL	SOL Energy	10 MWp, no timeline specified.
-	GreenYellow	GreenYellow	Undisclosed. Operating capacity 70 MWp (2022)
	Norsk Solar	Norsk Solar	Undisclosed. Operating capacity 11 MWp (2021).
Copper Mountain Energy	Oman Investment Authority	CME	1000 MWp by 2024.

Source: Thu (2022).

4) Wind Power Generation

A recent study by the World Bank concluded that Viet Nam could increase its offshore wind power capacity by 11 GW to 25 GW by 2035. This is only if the government successfully develops and implements policies to grow this industry.

According to a World Bank study, 25 GW of wind power capacity by 2035 could meet 12% of Viet Nam's electricity demand and, in the process, stimulate the growth of a robust local supply chain, create thousands of skilled jobs, and potentially offshore wind-related exports to other global markets. So, it could add at least US$50 billion to the country's economy.

Currently, 18 offshore wind power projects operate in Viet Nam, all located offshore in relatively shallow waters.

Viet Nam has significant offshore wind power (OWP) potential, with an estimated technical potential of 475 GW within 200 km of the coast. This is the largest potential in Southeast Asia and corresponds to about six times Viet Nam's total installed capacity as of 2021. The windiest OWP areas, with average wind speeds exceeding 8 m/s, are located off the south-central coast near major demand centres, such as Ho Chi Minh.

This situation is shown in Figure 3.56. Large offshore wind resources also exist in the north.

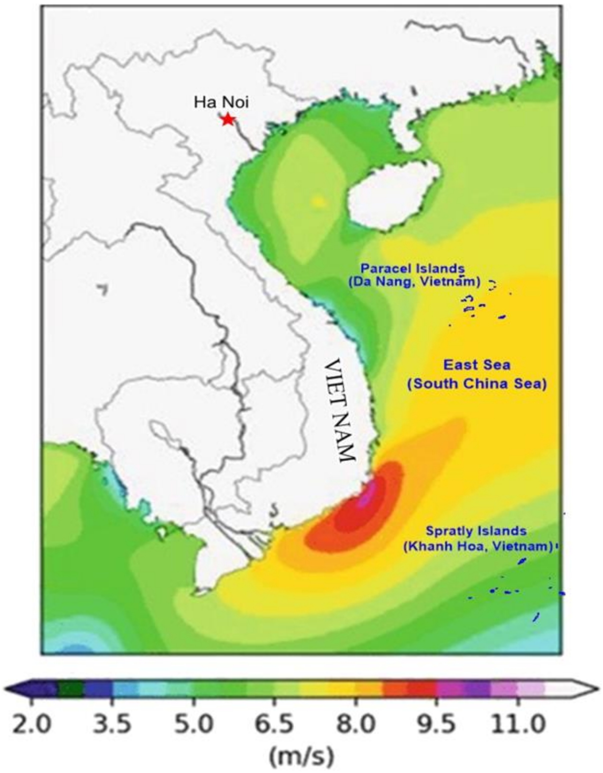
The rapid decline in technology costs has made offshore wind power an increasingly promising energy source.

OWP projects in Viet Nam first became eligible for FITs in 2011, and rates were revised in 2018. At the start of 2021, Viet Nam had one existing OWP plant of 99 MW in Bac Lieu province. In 2021, 20 new plants with a total capacity of 779 MW OWP projects will operate commercially, making Viet Nam the third-largest market for OWP capacity deployment after China and the

United Kingdom. Around 50 projects are in the preparation and construction phases, including the large Lagan (3.5 GW) and Thang Long (3.4 GW) projects.

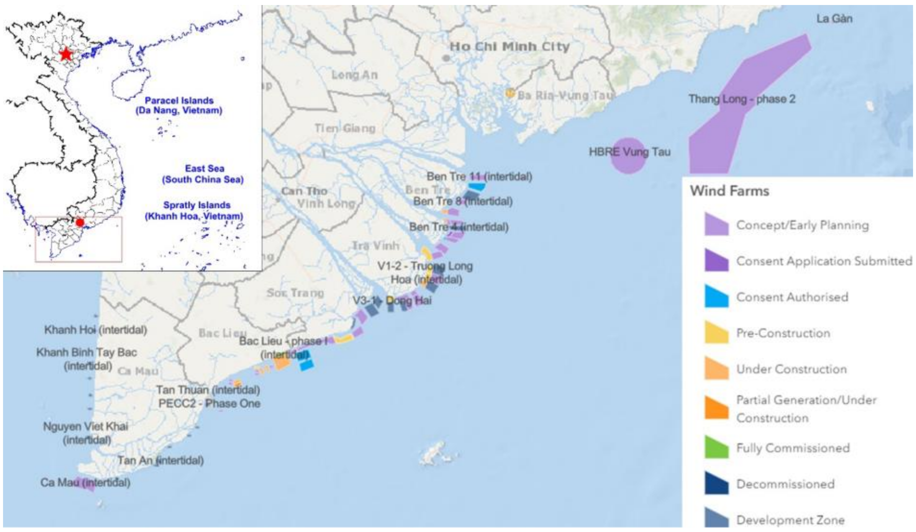
Figure 3.57 shows the status of these projects.

Figure 3.56. Offshore Wind Power Potential in Viet Nam and Nearby Areas



Source: Thang et al. (2022).

Figure 3.57. Viet Nam's OWP Projects, Southern Zone



Source: Thang et al. (2022).

Several challenges need to be overcome to ensure the success of large-scale offshore wind power projects.

One well-known challenge is the form of the PPA. The new public–private partnership (PPP) Law and the new Investment Law on Independent Power Producers (IPPs) removed the automatic qualification of government guarantees. The next challenge is transitioning to a tariff-bidding system. Now that FiT has ended, the Prime Minister stated that tariffs would be changed to an auction system, with competitive bidding for each wind power project to determine tariffs. However, critics predict that introducing a competitive tendering system could slow down the country's solar and wind power projects.

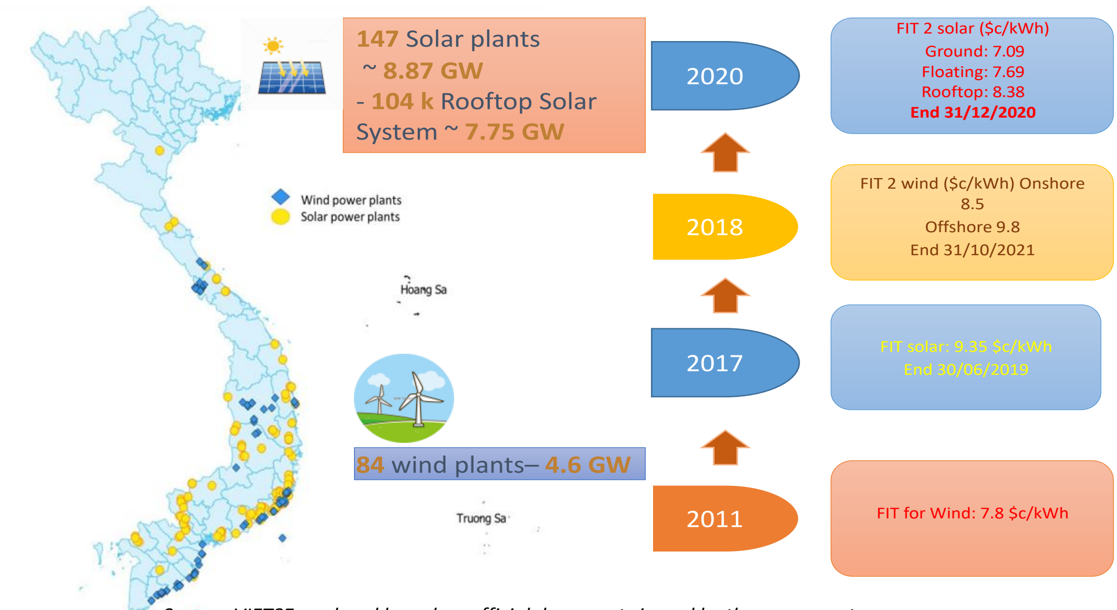
Grid network issues are also a major challenge. Most offshore wind power is located in southern Viet Nam, far from the main demand areas in the northern region, including Ha Noi where electricity demand is tight.

5) Position of solar power and wind power generation, FITs, the unit cost of electricity-generated power

The location of solar power generation and hydropower plants and FiT prices in Viet Nam are shown in Figure 3.58. The installed capacity of solar power generation is 8.87 GW for regular panels, 7.75 GW for roof-mounted types, and 4.6 GW for wind power.

Figure 3.59 shows the unit cost of electricity by type of generation. From left to right: coal-fired, hydropower, solar, onshore wind, offshore wind, waste, and biomass power generation. Coal-fired and hydroelectric power is sold at the price of electricity sold, while the rest is at the FiT price. The setting of the FiT price is an issue for the future.

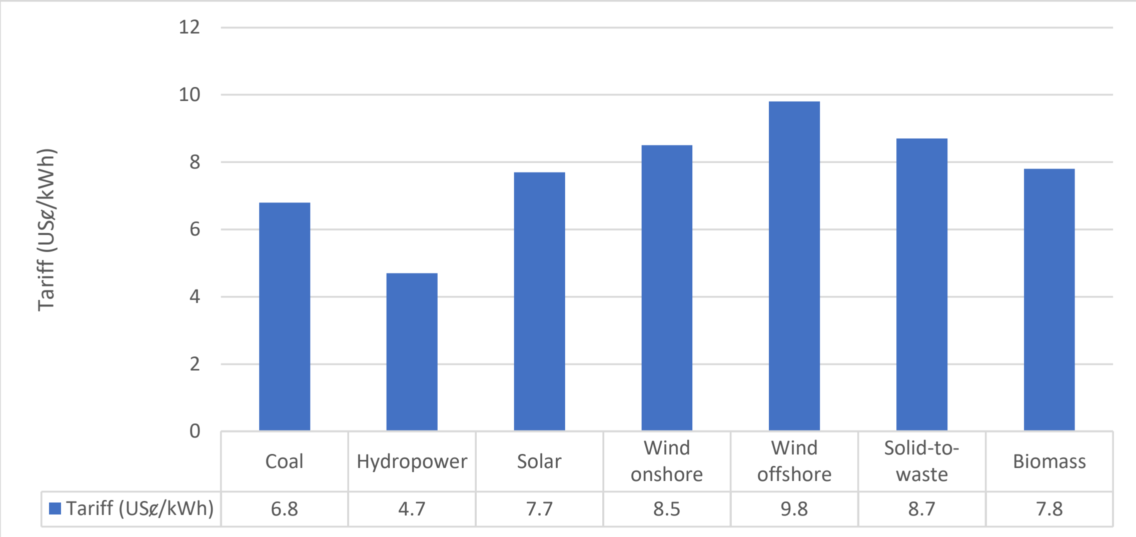
Figure 3.58. Location of Solar Power Generation and Hydropower Plants and FiT Prices in Viet Nam



Source: VIETSE analyzed based on official documents issued by the goverment

Source: Ngo To Nhien (2022).

Figure 3.59. The Unit Cost of Electricity by Type of Generation in Viet Nam



Source: Edited by JCOAL Study Team based on data from ADB (2021).

4.5. Policy Recommendations

In its keynote speech, Viet Nam, who chaired the 38th ASEAN Energy Ministers' Meeting (AMEM), stated that the country aims to achieve 50% RE by 2030/2050.[5] The draft PDP8 was mainly concerned with introducing RE, and the results were presented in October 2021 and April 2022. It is currently awaiting approval by the Prime Minister.

1) Summary of the Related Policies in Technological aspects

Technology area 1: Biomass-coal cofiring power generation

According to the EVN report, coal-fired power generation in Viet Nam in 2020 accounted for about half of the total power generation and about 30% of the capacity. Most CFPPs in Viet Nam have been operating for less than 10 years. So, using these facilities effectively to reduce CO_2 emissions would be more effective, and the feasibility of coal and biomass cofiring is high.

Technology area 2: Dedicated biomass-fired power generation

In Viet Nam, rice husks, rice straws, and sugarcane pomace from the vicinity of power stations can be compressed and transported to power stations and used directly as fuel, thus, eliminating the need to process them into solid fuel wood pellets. In addition, biomass called sorghum can be grown quickly and has a high potential for dedicated biomass firing.

[5] ASEAN Energy Business Form (AEBF) (virtual) 2020 held in November 2020.

Technical area 3: Ammonia cofiring with coal

Ammonia cofiring is a key measure to directly mitigate CO_2 emission from CFPPs in Viet Nam. In this regard, MOIT and the EVN are pursuing technical information and experience from the countries in its demonstration stage.

Technology area 4: PV power generation

There is no room for new PV projects under the draft PDP8, as the power source is unstable and affects grid stability. But the policy of no upper limit on the scale of development and capacity for rooftop PVs, provided they are not connected to the grid and are for private consumption, will enable development to proceed.

Technology area 5: Wind power

Viet Nam has areas with a high potential for offshore wind power, particularly in the south, and future development is expected.

Technology area 6: Carbon capture and storage

It will be necessary to introduce technology to capture and store CO_2 from coal-fired power flue gas to use coal-fired power effectively.

2) Technology areas with High Potential

Table 3.16 shows the technology areas for CN in Viet Nam. Technology areas with high potential regarding policy direction and applicability are circled with red lines. Many technologies that can be proposed are CO_2 reduction technologies.

Solar and wind power, introduced worldwide as variable RE, are promising power generation technologies that can take advantage of Viet Nam's geographical characteristics and should be actively introduced. Of course, it is necessary to introduce power storage technology, such as BESS, that can compensate for these fluctuations and load adjustment by other power sources, such as gas and coal-fired power. A development plan that considers the grid balance is necessary. In addition, we believe that the rooftop solar power described in the previous section is valuable as an off-grid power source and a power source that constitutes a virtual power plant in the future.

Since many CFPPs and the current power generation greatly depend on coal-fired power, biomass co-combustion, biomass dedicated firing, and ammonia cofiring, which can be used in existing infrastructure, are the main measures to reduce CO_2 in thermal power generation. In particular, Viet Nam is a promising country regarding fuel supply potential, so actively promoting domestic use is highly desirable.

Table 3.16. Carbon-neutral Technology with High Applicability in Viet Nam

Road Map towards Carbon Neutrality						Viet Nam
Reduction	Thermal Power	High Efficiency	IGCC			Optional
			IGFC			Optional
			A-USC			Optional
Reduction	Fuel	Biomass	Combustion	CFBC biomass firing		Keenly pursued
				PC coal cofiring		highly applicable
			Manufacturing	Material	Agricultural waste pellet	Keenly pursued
					Fast-growing tree	Keenly pursued
				Pre-treatment	Torrefied pellet	highly applicable
					Washing	Optional
		Ammonia	Utilisation	Ammonia gas turbine		Applicable
				Ammonia industrial furnace		Not applicable
				Ammonia-coal cofiring		highly applicable
			Manufacturing	Ammonia process	Conventional process + CCS	Optional
					New&Innnovative process	Optional
				R&D base, Supply chain		Applicable
		Hydrogen	Utilisation	Hydrogen gas turbine		Optional
			Manufacturing	Hydrogen process	Water electrolysis by RE	Applicable
					Turquoise hydrogen	Optional
				R&D base, Supply chain		Optional
	Renewables	Wind, Solar, Geothermal	Offshore wind			highly applicable
			Perovskite PV			Keenly pursued
			Next generation geothermal			Optional
		BESS	large Li-ion, NaS, Redoxflow			Applicable
Reduction	Manufacturing process	Steel	Coke reduction	Energy saving, LRC	Ferrocoke	Optional
				Direct reduction		Optional
				Hydrogen reduction		Optional
				COURSE50	Super-COURSE50	Optional
				Carbon recycling BF		Optional
		Cement				Optional
Capture	Capture/ Recovery	Capture/ Recovery	Recovery/generation	Oxyfuel IGCC		Optional
				Supercritical CO2 cycle generation		Optional
				Chemical looping combustion		Optional
			Chemical absorption			Optional
			Solid absorbent material method			Optional
			Physical absorption			Optional
			Membrane separation			Optional
			Physical adsorption			Optional

Source: JCOAL Study Team.

Similarly, cofiring with ammonia, which can be used by modifying existing power plants, has already begun in Japan at a 1,000 MW class USC plant. Therefore, we can expect to proceed with discussions with companies that have the technology.

Since CO_2 reduction alone cannot achieve CN, the negative emission CCS is also a technology that should be introduced. CO_2 recovery technology from thermal power generation exhaust gas is essential to introduce CCS or CCUS. We believe that early support from the government for its introduction is necessary.

3) Institutional Support

Financial support is needed to effectively utilise many CFPPs in Viet Nam, as the cost of capturing the flue gas from CFPPs is a bottleneck.

For solar and wind power generation, setting the FiT price at an appropriate level is necessary. But in the future, making the electricity market competitive and developing the electricity system for this purpose are necessary.

Chapter 4
Recommendations for the ASEAN Region

1. Available Technologies and Technical Solutions

Recommendations from the technological aspects are summarised as follows.

1) The pathway to CN depends on the country's situation. So, considering energy security and feasibility, selecting a tailored technology option for each country is necessary. For example, utilisation of existing CFPPs is a practical solution for biomass and/or ammonia cofiring.
2) To achieve CN, it is necessary to take comprehensive measures, including CCUS, which captures CO_2 and uses it for storage and carbon recycling, and adopt the appropriate technology to reduce CO_2 emissions.
3) In particular, CO_2 recovery has become a major issue in the power and industrial sectors, so cross-sectoral cooperation is required. Policy initiatives for supporting such cooperative activities are thought to be effective. Also, a financing scheme that covers the entire carbon-neutral project would be essential to make this possible.
4) It is also effective to proceed with international cooperation when studying the adaptability of specific carbon-neutral technologies.

2. Available Technologies and Technical Solutions: By-country Recommendations

2.1. Indonesia

The recommended technologies and technical solutions for Indonesia are as follows.

1) Clean Coal Technology (CCT)

Coal, Indonesia's most abundant and major indigenous energy source, has been supporting the national revenue. However, coal is also the biggest emitter of CO_2. As mentioned above, CFPPs will be phased out, and no new ones will be constructed. This direction was confirmed at the G20 hosted by Indonesia in November 2022. The above 'no more new CFPP' policy is conditional, with exceptions like financially closed ones and those under construction. Also, those under any specific national development plan can be exempted from the directive, according to the newly legislated Presidential Regulation No. 112 of 2022. With the little possibility for new CFPPs, the introduction of CCT, such as IGCC and A-USC, cannot be envisaged as they are not technology for existing CFPPs.

However, as those existing CFPPs shall continuously contribute to the power supply and as balancing resources for grid stabilisation, in parallel with progressing massive RE introduction and emerging new energy development, CCT and accompanying appropriate environmental compliance and efficiency techniques remain crucial.

2) Cofiring

CFPPs will increase until 2030 and will be phased out after 2031. However, coal is expected to remain a power generation source by 2057 until CO_2 emissions from CFPPs continue. Because of the importance of enhanced environmental measures, especially in reducing CO_2 emissions, cofiring coal with biomass or ammonia, acknowledged as carbon neutral, is effective. Currently, ammonia supply sufficiency and its value chain are yet to be secured. So, as the Government of Indonesia has been pursuing, biomass cofiring implementation is a just and most realistic measure to further reduce emissions from CFPPs towards 2030. During this period, Indonesia can explore possibilities for ammonia cofiring through studies and demonstrations, including cross-sectoral studies for value chain formulation.

3) Carbon Capture and Storage or Carbon Capture, Usage, and Storage (CCS or CCUS)

CCS or CCUS is also effective in reducing CO_2 emissions from the CFPPs. Many old oil wells in Indonesia are suitable for CCS. There is also potential for oil recovery as enhanced oil recovery.

4) New and Renewable Energy (NRE)

NRE is expected to provide alternative power capacity as the capacity fulfilled by CFPPs decreases during its phasing out. Increased generation from RE is already ongoing. However, after 2031, the country will see the full-fledged development of various renewables. During its energy transition towards 2060, Indonesia has committed to developing 587 GW of clean energy-sourced power, of which 361 GW is solar, 83 GW is hydroelectric, and 39 GW is wind power. As CFPPs are phased out, VRE will take the overwhelming share of power generation. On the way, impacts on the grid will emerge even in the early phase of the transition path. This is because coal power can function as a balancing source and VRE, a substantially intermittent source, cannot. However, Indonesia has advantages as it is endowed with invariable geothermal resources. The once-government-facilitated rooftop solar power generation envisaged to be grid-connected recently has been pending because of concerns raised about the possible severe impact on the grid system.

5) Hydrogen

So far, Indonesia seems comparatively reserved about developing and utilising hydrogen. However, looking at the planned generation mix in 2060 in which solar dominance is outstanding and considering Indonesia is endowed with gas and coal, the country would benefit in pursuing possibilities for both blue and green hydrogen.

Further, key considerations that would enhance the introduction and deployment of the above technologies are indicated below.

1) Measures for grid system stabilisation

Grid system stability is probably the most crucial key to the energy transition.

In the case of Indonesia, like other AMSs, the situation could be more severe than in developed economies as VRE's introduction will proceed speedily to address the growing economy and power demand.

Indonesia has been trying hard to enhance grid capacity and system management and will enhance its efforts in the coming years. Also, as part of ASEAN, Indonesia has an advantage from the ASEAN Power Grid that will help the country with sustainable power supply and the requirements for grid flexibility. In addition to enhancing the grid system, flexibilisation can be ensured primarily through power plants that can perform flexible operations, such as pumped storage, gas, and coal. BESS and synchronous phase modifiers will also help.

The other idea that deserves attention is about choices of on-grid and off-grid power generation to ensure the resilience of the power supply and grid system. Accelerating grid stabilisation requires urgency, and capacity addition for fulfilling the last miles of hard-to-electrify remote areas is also urgent. However, a grid connection is not a must. Electrification plans with off-grid choices are worth considering, especially in island areas.

2) Coal-fired power plants can remain contributing to energy transition

Coal will stay in the power generation mix of Indonesia for the foreseeable future and up to the latter part of the energy transition. Coal-fired power can be a flexible source if operated appropriately. So, Indonesia can continue using the existing CFPPs for power supply and supporting grid system stabilisation.

Even after retirement, CFPPs can be repurposed through conversion to synchronous phase modifiers, a proven and commercially available technology for grid stabilisation, or for whatever purpose conducive to energy transformation.

We must note that environmental measures shall be continuously enhanced as long as CFPPs are utilised.

3) Shift of domestic coal use to the industrial sector

Coal is an important indigenous natural resource for Indonesia.

The government and private sector players have been engaging in discussions on the green shift of domestic coal use to the industrial sector for further clean and effective use suitable to the energy transition era. The outcome of such discussions is expected to be conducive to the policy and policy instruments that will ensure appropriate and sustainable coal utilisation while the coal phase-down is progressing in the power sector.

4) Technology deployment helped with key knowledge and experience sharing with other AMSs

CCS, hydrogen, and ammonia utilisation is a crucial technology area requiring a grand design of a cross-sectoral and internationally coordinated value chain based on sharing key knowledge and experience between countries. In this context, collaboration with other AMSs will be beneficial.

5) The next national energy plan with decarbonisation plans and perspectives

The last basic energy plan (RUEN) was enacted in 2017. The official supporting plan or policy is yet to be in place. The next RUEN is anticipated to be equipped with decarbonisation plans and perspectives that have been committed and mentioned on occasions, such as COP26 and COP27 and G20 hosted by Indonesia.

2.2. Malaysia

1) Highly potential technology areas

Highly potential technology areas in the context of policy directions and applicability are highlighted below.

Technology area 1: Hydrogen

Malaysia is outstanding in promoting hydrogen development and utilisation. In 2019, a few years before the Hydrogen Economy Position Paper was released, Sarawak Energy had started hydrogen production and refuelling. It partnered with PETRONAS, Samsung Engineering, LOTTE Chemical, and POSCO Holdings.

The Hydrogen Economy Position Paper claims that Malaysia could be on par with the United States and Australia in leading global hydrogen technology development and utilisation in the future.

Both the position paper and Sarawak Energy coincidentally focus on green hydrogen. This is especially because of the recent situation where the prices of blue hydrogen have been surging, natural gas prices are skyrocketing, and green hydrogen is gradually taking the primary position for massive production in the future. Also, since it matters how much carbon footprint can be reduced throughout the hydrogen value chain to be formulated, Malaysia is on the right track in focusing on green hydrogen.

Below are a few points for further consideration:

- Currently, much attention is paid to fuel cells and electricity regarding hydrogen. However, there are various areas, such as chemical and industrial processes, for which hydrogen can be used. So, it would be advisable for the hydrogen development and utilisation policy to be multisectoral, with a clear picture of value chains to be established.
- As the Hydrogen Position Paper clarifies, safety is one of the major concerns in considering hydrogen use. Accordingly, safety considerations shall be a part of the basic policy that will be formulated soon.

Also, like most industrial activities, hydrogen production entails carbon emissions, though its massive introduction is primarily for reducing emissions. Accordingly, the government is supposed to facilitate and oversee development and utilisation efforts by national and private companies while paying extra attention to how carbon footprint can be reduced during the process.

Technology area 2: Solar and hydropower

Solar power and hydropower are undoubtedly important for clean and sustainable electricity supply and bolstering the anticipated green hydrogen development.

Technology area 3: CCS

CCS is deemed to be crucial for the energy transition. However, only some projects have reached the commercial phase due to the cost barriers and unforeseeable factors around the technology. Most commercial projects are in oil and gas development sites utilising CO_2 injections for enhanced recovery. Applying the technology to a power plant requires using CO_2 for CCUS to increase the project's economy.

As clarified in the preceding part, PETRONAS is ready to engage in the Kasawari CCS project with its domestic and international partners and a roadmap to back up the relevant activities. Thai government–owned PTT's subsidiary PTTEP is also considering going for a CCS project at its Lang Lebah field in Malaysia. The company has been developing a CCS project in Thailand already.

Kasawari CCS attracts such attention from ASEAN, the rest of Asia, and the world, as developing a sour gas field will be common throughout all incoming gas development projects in ASEAN. However, since sour gas contains a high content of H2S and CO_2, its development entails technical difficulties and requires extra deliberation and measures in exploration, as does the CCS project.

Considering that CCS-potential depleted fields in Malaysia will have the same conditions and requirements as the same for CCS projects in Indonesia, Thailand will experience a similar situation. In collaboration with other AMSs, Malaysia would benefit from establishing a knowledge and data-sharing scheme between AMSs.

That way, huge costs incurred at the initial stage can be avoided, and well-informed decisions on project implementation will be possible.

Other potential technology areas:

In addition to the above areas, biofuel, energy storage, biomass cofiring, and ammonia cofiring at CFPPs have a high potential.

These existing and new energy areas and technologies are anticipated to open up opportunities for industry development, job creation, and social development as per the 12th Plan and beyond, for which cross-sectoral planning, coordination, and collaboration with more focus on industry areas are crucial.

Also, safety, economy, and energy security and transformation shall be ensured.

2) Institutional support

Institutional support and incentives will be required to facilitate the application of decarbonisation technology. Policymakers must note that such institutional support may also be transitional and must be followed up for modifications or further institutional changes. For instance, FiT is quite effective in supporting the introduction of renewables. However, preceding cases have shown that unbundling the power sector for a competitive market is crucial to accelerating RE introduction. Therefore, RE will not depend on FiT anymore since it will have to be incorporated into the competitive market. So, Malaysia's power market on a single-buyer scheme will change during the power sector transformation. That way RE development and massive production of green hydrogen can be materialised.

3) Coal phase-down path

Malaysia has 12,546 MW of CFPPs, of which 2,000 MW commenced operations only in 2019. Because of the standard residual life and economy of power plants, it is a little too early to retire the most recent ones at some point before 2040.

However, it would work if those power plants were retired and appropriately reutilised through conversion into synchronous condensers, a proven and commercially available technology for grid stablisation,[6] or whatever purpose conducive to energy transformation.

A coal-fired power phase-down and phaseout roadmap as part of a national energy transition roadmap shall be formulated, and all necessary measures will be taken. This is because coal-fired power, as a major part of the electricity mix, will continue to support energy security through sustainable electricity supply for at least the first half to the middle of the energy transition period. During that time, efforts to reduce emissions and environmental measures must continue, and operations shall be conducted in a way that contributes to preventing grid fluctuation.

4) Malaysia's position to support ASEAN's energy transition

Malaysia has an advantage since the country, as a member of the ASEAN community, has been involved in most areas of the energy sector – from fossil fuel production, power generation, clean utilisation of coal, RE, and new energy development to regional grid integration. Being steps ahead in terms of readiness for policy and standards formulation and legislation, Malaysia is highly anticipated to initiate government-to-government sharing of knowledge, experience, information, and cooperation for regional value chain formulation and establishment. These will benefit the country as the energy transition will be very costly, especiallyat its initial stage. Well-informed decisions are the key to the successful application of decarbonisation technology.

5) National Decarbonisation Roadmap

Since NEP, the long-term energy policy is in place and so is MyRER, the national RE roadmap, Next anticipated is the formulation of a national decarbonisation roadmap showing a cross-sectoral and inclusive energy transition pathway. Again, Malaysia can contribute to formulating an integrated roadmap of ASEAN decarbonisation and roadmaps of other AMSs by initiating the national roadmap formulation.

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[6] There are several cases of reutilisation of retired thermal power plants repurposed as synchronous condensers. The World Bank conducted a very useful study to indicate repurposing of thermal power plants as synchronous condensers will be one of the most potential options to address the issue of so-called 'too young to retire' CFPPs in ASEAN. See the foregoing subchapter about Malaysia.

2.3. Thailand

The applicability of CCT for a carbon-neutral solution is as follows. According to the Thai government's energy policy 4D+E, the comprehensive utilisation of biomass is positioned as important, along with conventional RE, such as geothermal and hydropower, and relatively new RE, such as solar and wind power.

1) Regarding biomass utilisation in the power sector, the Thai government's policy to promote community power plants is the right choice, as it accelerates the decentralisation of power sources and utilisation of domestic resources. Biomass combustion can be combined with many other technologies according to the type of biomass and plant scale to enhance the overall community power plant outcomes for further dissemination. In this context, individual optimisation is desirable.

2) Regarding biomass utilisation in the transport sector, we think developing synthetic fuel from biomass gasification and fuel synthesis is desirable. Since the purity level of CO_2 produced as a by-product in the process is relatively high, substantial CO_2 reduction can be expected by replacing conventional fuels with synthetic fuels and storing them.

3) Hydrogen derived through a shift reaction of CO to CO_2 is expected to use combustion as carbon-free fuel, fuel cell, and key materials for several carbon-recycling reaction pathways. In this connection, a study on the overall utilisation chain of biomass, hydrogen, and CO_2 will be recommended.

4) The Thai government is actively promoting CCS projects. There are various CO_2 sources and their concentration. Among them, recovery of CO_2 from flue gas is particularly important. In this regard, government support would be very effective.

2.4. Viet Nam

In its keynote speech, Viet Nam, who chaired the AEBF in 2020, stated that it aims to achieve 50% RE by 2030/2050. The draft PDP8 was mainly concerned with introducing RE, and the results were presented in October 2021 and April 2022. The draft is currently awaiting approval by the Prime Minister.

Technology area 1: Biomass–coal cofiring power generation

According to the EVN report, coal-fired power generation in Viet Nam in 2020 accounted for about half of the total power generation and about 30% of the capacity. Most CFPPs in Viet Nam have operated for less than 10 years, so it would be best to use these facilities to reduce CO2 emissions efficiently. The feasibility of coal and biomass cofiring is high.

Technology area 2: Dedicated biomass-fired power generation

In Viet Nam, rice husks, rice straws, and sugarcane pomace from the vicinity of power stations can be compressed and transported to power stations and used directly as fuel, thus eliminating the need to process them into solid fuel wood pellets. In addition, a biomass called sorghum can be grown quickly and has a high potential for dedicated biomass firing.

Technical area 3: Ammonia cofiring with coal

Ammonia cofiring is one of the key measures to mitigate CO_2 emissions from CFPPs directly. In this regard, MOIT and EVN are pursuing technical information and experience from the countries in their demonstration stage.

Technology area 4: PV power generation

There is no room for new PV projects under the draft PDP8, as the power source is unstable and affects grid stability. But the policy of no upper limit on the scale of development and capacity for rooftop PVs, provided they are not connected to the grid and are for private consumption, will enable development to proceed.

Technology area 5: Wind power

In Viet Nam, there are areas with high potential for offshore wind power, particularly in the south, and future development is expected.

Technology area 6: CCS

To effectively use coal-fired power, it will be necessary to introduce technology to capture and store CO_2 from coal-fired power flue gas.

Many technologies that can be proposed are CO_2 reduction technologies. Solar and wind power, introduced worldwide as variable RE, is promising power generation technologies that can exploit Viet Nam's geographical characteristics and should be actively introduced. Of course, it is necessary to introduce power storage technology such as BESS to compensate for these fluctuations and load adjustment by other power sources, such as gas and coal-fired power. A development plan that considers the grid balance is necessary. In addition, we believe that the rooftop solar power described in the previous section is valuable as an off-grid power source and a power source that constitutes a virtual power plant in the future.

Since CFPPs are many and the current power generation is highly dependent on coal-fired power, biomass co-combustion, biomass dedicated firing, and ammonia cofiring, which can use existing infrastructure, are the main measures to reduce CO_2 in generating thermal power. In particular, Viet Nam is a promising country regarding fuel supply potential, so actively promoting domestic use is desirable.

Similarly, cofiring with ammonia, which can be used by modifying existing power plants, has already begun in Japan at a 1,000 MW class USC plant. Therefore, we can proceed with discussing with companies that have the technology.

Since CO_2 reduction alone cannot achieve CN, the so-called negative emission CCS is also a technology that should be introduced. CO_2 recovery technology from thermal power generation exhaust gas is an essential technology for CCS or CCUS in the future. We believe that early support from the government for its introduction is necessary.

Financial support is needed to effectively utilise many CFPPs in Viet Nam, as the cost of capturing the flue gas from CFPPs is a bottleneck. Setting the FiT price at an appropriate level for solar and wind power generation is important. But in the future, it is necessary to make the electricity market competitive, and the electricity system must be developed for this purpose.

3. Policy Recommendations for ASEAN

3.1. Highly Potential Technology Areas

Technology area 1: Biomass cofiring

Biomass cofiring and biomass dedicated firing will be one of the main measures to decarbonise the power and related sectors for the foreseeable future, especially towards 2030 when tangible emissions reduction outcomes shall be below 1.5°C. As a result of the study, we are pleased to learn that biomass cofiring and biomass-dedicated firing apply to all target countries. Both are supposed to apply to other AMSs, considering that technology prices are comparatively affordable and cofired biomass fuels are indigenously available. Using local biomass is expected to bring additional advantages to the local community through job creation and community participation during biomass collection and supply.

To ensure sustainability and supply security, having plural choices of biomass fuel is better to avoid dependence on a single biomass source.

Also, biomass cofiring is a transitional measure while CFPPs are being utilised.

Technology area 2: Ammonia cofiring

Indonesia, Malaysia, and Viet Nam have a high potential for ammonia cofiring deployment. Since ammonia cofiring is expected to follow the preceding biomass cofiring and then take the central role in decarbonised and non-variable electricity generation after 2030, R&D, demonstration, and regional value chain formulation shall go in parallel with the massive deployment of biomass cofiring.

Technology area 3: Hydrogen utilisation

Hydrogen is undoubtedly important in ASEAN. Some AMSs have a high potential for blue and green hydrogen production and utilisation. Others are expected to come up with green hydrogen deployment and utilisation in the future. Especially in the latter part of the energy transition, many renewables come on the grid, and massive curtailment to avoid fluctuation will be required if no measures are taken, enabling electricity use for green hydrogen. That is very good for AMSs embracing the hydrogen deployment plan with less carbon footprint. However, hydrogen has specific barriers, especially in terms of safety and difficulty in transportation. Hydrogen is said to be transported in a region but not between continents. Also, value chains shall be formulated throughout multiple sectors.

Therefore, planned value chain and development activities towards commercialisation, deployment, and application shall be better engaged through regional cooperation.

Technology area 4: Energy storage systems

BESSs and pumped storage hydropower are the currently available and applicable energy storage systems. Many BESSs have been commercialised. However, availability in terms of volume and prices is insufficient to address possible grid fluctuation. Even after availability and affordability are ensured, BESS may not fully address grid fluctuation issues due to capacity constraints.

In the meantime, pumped storage hydropower, a variation of hydropower technology, can store and release power as required at scale.

In summary, BESS is fast responsive with a limited capacity scale, while pumped storage hydropower is slow to respond, but large capacity is ensured. So, these technologies will be more effective if used in combination.

<u>Technology area 5: CCS and CCUS</u>

CCS is deemed crucial for the energy transition. However, some projects have reached the commercial phase due to cost barriers and unforeseeable factors around the technology. Most commercial projects are at oil and gas development sites utilising CO_2 injections for enhanced recovery. In applying the technology to a power plant, incorporating CO_2 utilisation is required to make it CCUS for the increased economy of the project.

In cooperation with international and domestic partners, Indonesian, Malaysian, and Thai national companies aggressively pursue CCS development in gas fields.

With many potential gas fields in ASEAN waiting for development, they are supposed to be sour gas fields. However, since sour gas contains a relatively high content of H2S and CO_2, its development entails technical difficulties and requires extra deliberation and measures in exploration. So does the CCS project.

Since fields and CCS candidate sites in ASEAN would have the same conditions and requirements, any country in the region would benefit from collaborating with other AMSs to establish a knowledge and data-sharing scheme among AMSs.

That way, huge costs incurred at the initial stage can be avoided, and well-informed decisions on project implementation will be possible.

Apart from CCS, R&D of CO_2 utilisation is underway worldwide to convert CO_2 into useful substances, such as methanol and other fuels. It is also important to monitor technology development trends so that ASEAN can respond when these technologies are adopted.

3.2. Key Considerations

1) Measures for grid system stabilisation are to be ensured

Readiness for the emerging issue of grid fluctuation with massive VRE introduction varies from one country to the other among AMSs. Preceding developed economies have experienced grid fluctuations and are still struggling to cope with such situation. In the case of ASEAN, the situation could be more severe as VRE's introduction will proceed speedily to address the growing economy and power demand.

That said, ASEAN has an advantage since the region has been facilitating system integration through the ASEAN Power Grid, which will help the countries address sustainable power supply and requirements for grid flexibility. All in all, grid system stability is crucial to the energy transition. So, every AMS should look into all kinds of measures to enhance flexibility at the grid, power plant, and any other facility.

In addition to enhancing the grid system, flexibilisation can be ensured primarily through power plants that can perform flexible operations, such as pumped storage, gas, and coal. BESS and synchronous phase modifiers will also help.

The other idea that deserves attention is on-grid and off-grid power generation choices to ensure power supply and grid system resilience. Accelerating grid stabilisation requires urgency, and capacity addition for fulfilling the last miles of hard-to-electrify remote areas is also urgent. However, a grid connection is not a must. Electrification plans with off-grid choices are worth considering, especially in island areas.

2) Coal-fired power plants can remain contributing to the energy transition

Many AMSs, including the four target countries in this study, foresee a coal phase-down and phaseout in the power sector. However, as we have seen, VRE-solar and wind are clean but variable; biomass is a big help in accelerating clean transition but is small to fulfil demand; and ammonia and hydrogen are still in the midway for future application and deployment. 'All-with-gas solution' is unrealistic because of the scale of energy and electricity demand related to infrastructure availability and the fact that gas is also transitional.

In summary, coal will stay in most AMSs' and ASEAN power generation mix for the foreseeable future and up to the latter part of the energy transition. Coal-fired power can be a flexible source if operated appropriately. So, the four target countries – Indonesia, Malaysia, Thailand, and Viet Nam – can continue using the existing CFPPs for power supply and supporting grid system stabilisation.

Even after retirement, CFPPs can be repurposed through conversion to synchronous phase modifiers, a proven and commercially available technology for grid stabilisation, or whatever purpose conducive to energy transformation.

We must note that environmental measures shall be continuously enhanced as long as CFPPs are utilised.

3) Enhanced collaboration and cooperation are required

As mentioned, CCS, hydrogen, and ammonia utilisation is a crucial technology area that requires a grand design of a cross-sectoral and internationally coordinated value chain based on sharing key knowledge and experiences among countries. In this context, collaboration and cooperation between AMSs and, some cases, all-ASEAN will be beneficial.

4) Not to waste anything

Waste management is now another emerging global issue, especially in emerging and growing economies. ASEAN is no exception. Addressing relevant issues while going through energy transition pathways means the ASEAN community will get closer to a circular economy. The issue provides challenges and opportunities as with the energy transition. Among others, utilisation of coal ash from CFPPs for roadbed materials, FGD (flue gas desulphurisation system) gypsum for construction materials, municipal waste for waste-to-energy power generation, and RE power plant waste such as retired solar panels for recycling can be considered.

5) A new, cross-sectoral platform for ASEAN decarbonisation

Given the need for well-concerted cross-sectoral coordination and the importance of early planning and actions, establishing a cross-sectoral and overarching platform for coordinating ASEAN decarbonisation would be worth considering. Such a coordinating platform is envisaged to be part of the ASEAN Centre for Energy (ACE), as ACE coordinates the ASEAN energy sector decarbonisation policy facilitation and activities.

The decarbonisation platform is to overview decarbonisation-related activities and projects in the pipeline in ASEAN and interact with non-energy and energy sector ASEAN organisations, if such actions are considered beneficial for efficiency and further coordination.

References

Technologies

Chugoku Electric Power website, https://www.energia.co.jp/e/business/int_business/skills/thermal-pg.html (accessed 11 October 2022).

Hitachi Zosen website, https://www.hitachizosen.co.jp/english/business/field/electrolytic-hydrogen/methanation.html (accessed 11 October 2022).

IEA (2021a), Global Energy-related CO_2 Emissions by Sector, May, https://www.iea.org/data-and-statistics/charts/global-energy-related-CO2-emissions-by-sector (accessed 11 October 2022).

IEA (2021b), Net Zero by 2050: A Roadmap for the Global Energy Sector, May. https://www.iea.org/reports/net-zero-by-2050 (accessed 11 October 2022).

Japan CCS Co website, https://www.japanccs.com/en/business/ (accessed 11 October 2022).

JERA (2022), JERA and IHI Move Up the Start of Large-Volume Co-firing of Fuel Ammonia in the Demonstration Project at Hekinan Thermal Power Station', press release, 31 May, https://www.jera.co.jp/english/information/20220531_917 (accessed 11 October 2022).

JFE website, https://www.jfe-steel.co.jp/en/company/carbon.html (accessed 11 October 2022).

KHI website, https://www.khi.co.jp/pressrelease/detail/20200924_1.html (accessed 11 October 2022).

MAFF (2019), Biomass Utilisation Promotion Meeting, https://www.maff.go.jp/j/shokusan/biomass/attach/pdf/index-17.pdf (accessed 11 October 2022) (in Japanese).

METI (2020), Green Growth Strategy Through Achieving Carbon Neutrality in 2050, Tokyo, https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/index.html (accessed 11 October 2022).

METI (2021), Outline of Strategic Energy Plan, October, https://www.enecho.meti.go.jp/en/category/others/basic_plan/ (accessed 11 October 2022).

METI (2010), New Developments in Clean Coal Policies, https://www.meti.go.jp/policy/tech_evaluation/c00/C0000000H21/100308_clean-coal/clean-coal_6-1.pdf (accessed 11 October 2022).

MHI website, https://power.mhi.com/news/20180329.html (accessed 11 October 2022).

MHI website, https://www.mhi.com/products/engineering/CO2plants_projectrecords.html (accessed 11 October 2022).

METI website, original data from Global CCS Institute (2021), https://www.enecho.meti.go.jp/about/special/johoteikyo/asiaccusnetwork.html (accessed 11 October 2022).

METI (2019), Roadmap for Carbon Recycling Technologies, https://www.meti.go.jp/english/press/2021/pdf/0726_003a.pdf (accessed 11 October 2022).

Nikkei (2021a), press release, 18 June, https://www.nikkei.com/article/DGXLRSP612791_Y1A610C2000000/ (accessed 11 October 2022).

Nikkei (2021b), MGC Co., Ltd. Methanol from CO2, press release, 21 September, https://www.nikkei.com/article/DGKKZO75456250T00C21A9TB0000/ (accessed 11 October 2022).

Nippon Steel website, https://www.nipponsteel.com/ir/library/pdf/20210330_ZC.pdf (accessed 11 October 2022) (in Japanese).

NEDO Chemical looping cycle, https://www.nedo.go.jp/news/press/AA5_100464.html (accessed 11 October 2022).

NEDO website, https://www.nedo.go.jp/content/100932834.pdf (accessed 11 October 2022).

Oki, Y., J. Inumaru, S. Hara, M. Kobayashi, H. Watanabe, S. Umemoto, and H. Makino (2011), Development of Oxy-fuel IGCC System with CO_2 Recirculation for CO_2 Capture', *Energy Procedia* Vol. 4, 2011,pp. 1066-1073, Elsevier, Amsterdam https://www.sciencedirect.com/science/article/pii/S1876610211001585 (accessed 11 October 2022).

Panasonic Group (2021), Demonstration of RE100 Solution Using Pure Hydrogen Fuel Cells, https://news.panasonic.com/jp/press/jn210524-1 (accessed 11 October 2022).

Toshiba (2020), Toshiba Starts Operation of Large-Scale Carbon Capture Facility, news release, https://www.global.toshiba/ww/news/energy/2020/10/news-20201031-01.html (accessed 11 October 2022).

Indonesia

Directorate General of Electricity, MEMR (2021), Energy Policy towards Carbon Neutrality in Indonesia, presented at the 30th Clean Coal Day International Symposium, 21 September 2021, https://jcoal-ccd2021.com/en/program/S1_speech-3_Energy.html (accessed on 30 September 2021).

PLN (2021), RUPTL 2021, https://web.pln.co.id/statics/uploads/2021/10/ruptl-2021-2030.pdf (accessed on 10 June 2022).

Malaysia

Akademi Sains Malaysia (2022), Position Paper on Hydrogen Economy, 28 July, https://www.akademisains.gov.my/asm-publication/position-paper-on-hydrogen-economy/ (accessed 15 November 2022).

Battersby, A. (2002), Petronas Advances Carbon Capture and Storage Ambitions: Memorandum of Understanding with Schlumberger Will Establish CCS Centre of Excellence, 22 March, https://www.upstreamonline.com/energy-transition/petronas-advances-carbon-capture-and-storage-ambitions/2-1-1190011 (accessed 3 October 2022).

Battersby, A. (2022), Petronas Advances Massive Carbon Capture and Storage Project, Studies Continue Ahead of Expected FID before the End of the Year, 6 July, https://www.upstreamonline.com/field-development/petronas-advances-massive-carbon-capture-and-storage-project/2-1-1253191 (accessed 3 October 2022).

Bernama (2021), 'Govt to Enhance EV Technology through NESTI', *New Straits Times*, 21 October, https://www.nst.com.my/news/nation/2021/10/738582/govt-enhance-ev-technology-through-nesti (accessed 3 October 2022).

BusinessToday (2021), NanoMalaysia Energy Storage Technology Initiative Programme Launched, 23 November, https://www.businesstoday.com.my/2021/11/23/nanomalaysia-energy-storage-technology-initiative-programme-launched/ (accessed 15 November 2022).

Capital Markets Malaysia (2020), Climate Bonds Initiative, Green Infrastructure Investment Opportunities (GIIO) Malaysia, https://www.climatebonds.net/resources/reports/green-infrastructure-investment-opportunities-malaysia (accessed 15 November 2022).

Economic Planning Unit (EPU), Prime Minister's Department (2022), National Energy Policy 2022–2040, https://www.epu.gov.my/sites/default/files/2022-09/National_Energy_Policy_2022-2040.pdf (accessed 15 November 2022).

Energy Commission (2020), *Malaysia Energy Statistics Handbook.* Putrajaya, Malaysia. https://www.st.gov.my/ms/contents/files/download/116/Malaysia_Energy_Statistics_Handbook_2020.pdf (15 November 2022).

Evans, D. (2021), Petronas Advances Giant Kasawari CCS Project as FEED Competition Heats Up, *Energy Voice*, 6 December, https://www.energyvoice.com/oilandgas/asia/369987/petronas-advances-giant-kasawari-ccs-project-as-feed-competition-heats-up/ (accessed 3 October 2022).

Hydrogen Central (2022), Samsung Engineering Signs MoU with SEDC Energy and Sarawak Energy Berhad for Sarawak H2biscus Green Hydrogen & Ammonia Project Supply of Electricity, 9 September, https://hydrogen-central.com/samsung-engineering-signs-MoU-sedc-energy-sarawak-energy-berhad-sarawak-h2biscus-green-hydrogen-ammonia-project-supply-electricity/ (accessed 5 October 2022).

IEA (2022), Coal in Net Zero Transition, November, https://iea.blob.core.windows.net/assets/4192696b-6518-4cfc-bb34-acc9312bf4b2/CoalinNetZeroTransitions.pdf (accessed 15 November 2022).

JBIC (2022), JBIC Signs MOU with Petroliam Nasional Berhad (PETRONAS) of Malaysia, 27 September, https://www.jbic.go.jp/en/information/press/press-2022/0927-016824.html (accessed 23 November 2021).

Lexology (2022), Malaysia's Road to Sustainable Energy: New Initiatives Announced, 8 September.. https://www.lexology.com/library/detail.aspx?g=ddb53d50-a97a-4161-b5d3-7e8ecf0861a4#:~:text=As%20a%20pilot%20initiative%2C%20three,%2Dcost%20and%20low%2Dcarbon (accessed 23 November 2021).

MalayMail (2021), NanoMalaysia Energy Storage Technology Initiative to Develop, Commercialise Energy Storage Systems, says Dr Adham, Malaymail, 23 November, https://www.malaymail.com/news/malaysia/2021/11/23/nanomalaysia-energy-storage-technology-initiative-to-develop-commercialise/2023022 (accessed 23 November 2021).

Malaysia Green Attribute Tracking System (mGATS), Understanding Green Electricity Tariff, https://www.mgats.com.my/green-electricity-tariff (accessed 15 November 2022).

SEDA (2021), Malaysia Renewable Energy Roadmap (MyRER), https://www.seda.gov.my/reportal/myrer/

MIDA (2021), Gov't to Enhance EV Technology through NESTI – Adham, 20 October, https://www.mida.gov.my/mida-news/govt-to-enhance-ev-technology-through-nesti-adham/ (accessed on 5 October 2022).

OEUK (2021), Xodus Awarded Contract for PETRONAS CCS Project in Malaysia, 10 August, https://oeuk.org.uk/xodus-awarded-contract-for-petronas-ccs-project-in-malaysia/ (accessed 3 October 2022).

Phnom Penh Post (2022), Petronas, Eneos Looking at Commercial Hydrogen, 15 March, https://www.phnompenhpost.com/business/petronas-eneos-looking-commercial-hydrogen (accessed 3 October 2022).

Sarawak Energy presentation at the ASEAN Energy Business Forum 2022 (virtual). (accessed 15 September 2022*) (*The conference record was for the paid participants only and is not available in the public domain.)

The 12th Malaysia Plan, https://rmke12.epu.gov.my/en (accessed 15 November 2022).

The Energy Year (2021), Petronas Awards Engineering Contract for Kasawari CCS, News, 10 August, https://theenergyyear.com/news/petronas-awards-engineering-contract-for-kasawari-ccs/ (accessed 3 October 2022).

Zimmer, M., A. Kuhanathan, and A. Badre (2021), Abolishing Fuel Subsidies in a Green and Just Transition, https://www.allianz.com/content/dam/onemarketing/azcom/Allianz_com/economic-research/publications/specials/en/2021/may/2021_05_19_Fossil_Subsidies.pdf (accessed 15 November 2022).

Thailand

EGAT, Working Group Presentation for the Study on Biomass and Coal Co-combustion in the ASEAN Region in February 2019 (accessed 18 August 2022).

EPPO, *Energy Statistic Annual Report*, http://www.eppo.go.th/index.php/en/en-energystatistics/electricity-statistic (accessed 18 August 2022).

EPPO (2020), Thailand's Power Development Plan 2018–2037 Revision 1, March (accessed 18 August 2022).

ERIA & JCOAL (2020), Biomass and Coal Co-combustion in the ASEAN Region (Phase 2), Final Report (October 2020). Jakarta: ERIA.

Kiatfuengfoo, V. (2020), The Direction of Electricity Policy in Thailand, 19 March, https://www.nedo.go.jp/content/100933863.pdf (accessed 18 August 2022).

Toyo Engineering website, https://www.toyo-eng.com/jp/en/solution/e-fuel/ (accessed 18 August 2022).

Viet Nam

Agarwal, V., J. Deffarges, B. Delteil, M. Francois, and K. Tara (2022), Charting a Path for Viet Nam to Achieve its Net-zero Goals, October, Melbourne, Australia: McKinsey & Company, https://www.mckinsey.com/capabilities/sustainability/our-insights/charting-a-path-for-vietnam-to-achieve-its-net-zero-goals (accessed 8 November 2022).

Asian Development Bank (ADB) (2021), Regional: Opportunities to Accelerate Coal to Clean Power Transition in Selected Southeast Asian Developing Member Countries, Technical Assistance Consultant's Report, October, https://www.adb.org/sites/default/files/project-documents/55024/55024-001-tacr-en.pdf (accessed 17 June 2022).

Baker & McKenzie (2021), Vietnam: October 2021 updates to the Draft PDP8, https://insightplus.bakermckenzie.com/bm/attachment_dw.action?attkey=FRbANEucS95NMLRN47z%2BeeOgEFCt8EGQJsWJiCH2WAUTleh6%2BAJHruNkrWNztLuO&nav=FRbANEucS95NMLRN47z%2BeeOgEFCt8EGQbuwypnpZjc4%3D&attdocparam=pB7HEsg%2FZ312Bk8OIuOIH1c%2BY4beLEAeK13zYkvUKc8%3D&fromContentView=1 (accessed 4 March 2022).

Baker & McKenzie (2022), Update on Draft National Power Development Plan #8 (PDP8) under MOIT Report 3787, dated 4 July 2022, https://singchamvn.org/wp-content/uploads/2022/07/Baker_Presentation-on-Updates-on-July-2022-Draft-PDP8-11-July-2022415931922.4.pdf(accessed 23 March 2023)

erex (2022a), Development of Biomass Business, June, https://www.erex.co.jp/en/wp-content/uploads/sites/2/2022/07/20220701_01.pdf (accessed 29 June 2022).

erex (2022b), Progress Toward Development of Biomass Business in Vietnam, press release 16 September, https://www.erex.co.jp/en/wp-content/uploads/sites/2/2022/09/20220920_Biomass.pdf (accessed 11 October 2022).

EVN (2021), *Annual Report 2021*, https://www.evn.com.vn/userfile/User/tcdl/files/EVNAnnualReport2021%20final%2022_10_2021.pdf (accessed 14 March 2022).

IEA (2022), World Energy Statistics and Balances, August, https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances (accessed 12 April 2022).

Liutong, Z and O. Alvarez (2021), Power in ASEAN: Accelerating Clean Energy in Vietnam and Indonesia', Water Rock Energy Modelling, https://www.aigcc.net/wp-content/uploads/2021/10/AIGCC_ASEAN-Report_2021_FINAL.pdf (accessed 12 April 2022).

MOIT Viet Nam (2022), The 19th Asean+3 Energy Security Forum (2022), Session 5: ASEAN Member States Report on Energy Security on 16 June 2022, Overview of the Vietnamese Energy Sector （accessed 16 June 2021）.

Morris, D. (2022), Vietnam - Power Development Plan 8 Published - Latest Content of the Draft National Power Plan 8, https://www.lexology.com/library/detail.aspx?g=f4e4437c-687f-4070-a529-aee0998bf4b3 (accessed 23 May 2022).

National Energy Policy 2022-2040 (2022)_Only hard copy available.

Ngo To Nhien (2022), CO_2 Abatement Scenarios for Vietnam's Power Sector to 2030, June, *Vietnam Initiative for Energy Transition'*, https://ember-climate.org/app/uploads/2022/06/ACEF2022_CO2-Abatement-Scenarios-for-Vietnams-Power-Sector-to-2030.pdf (accessed 16 June 2022).

Thang Nam Do, P.J. Burke, L. Hughes, and Ta Dinh Thi (2022), Policy Options for Offshore Wind Power in Viet Nam, https://www.anu.edu.au/files/document-collection/ZCEAP%20WP%20Do%20et%20al.%202022%20Vietnam%20offshore%20wind%20power%20policy%20%28002%29.pdf (accessed 17 November 2022).

Thu, Vu (2022), Vietnam's Renewable Energy Strategy Can Make or Break Economy's Manufacturing Future Leading Exporters Need Clean Energy to Compete Globally, May, https://ieefa.org/sites/default/files/2022-05/Vietnams%20Renewable%20Energy%20Strategy%20Can%20Make%20or%20Break%20Economys%20Manufacturing%20Future_May%202022.pdf (accessed 8 November 2022).

Appendixes

Appendix I: Working Group Members

Country	Institution	Name and Designation
Indonesia	Ministry of Energy and Mineral Resources (MEMR)	Mr Junifer Saut Pangidoan Simanjuntak, S.T., M.T. Senior Electricity Inspector, Directorate General of Electricity
		Mr Tri Suhartanto, S.T., M.Eng Mid-Level Electricity Inspector, Directorate General of Electricity
		Mr Andi Hanif, ST, M.Eng Mid-Level Electricity Inspector, Directorate of Electricity Engineering and Environment, Directorate General of Electricity
Malaysia	Energy Commission (ST)	Mr Mohd Amirulazry Mohd Amin, Assistant Director
Thailand	Ministry of Energy	Mr Tananchai Mahattanachai, Senior Professional Geologist, Department of Mineral Fuels (DMF)
		Dr Yaowateera Achawangkul, Mechanical Engineer, Senior Professional Level of the Energy Research Division, Department of Alternative Energy Development and Efficiency (DEDE)
Vietnam	Ministry of Industry and Trade	Mr Doan Ngoc Duong, Deputy Director General, IE(Institute of Energy)
	Ministry of Industry and Trade	Dr Nguyen Manh Cuong, Deputy Head of Power System Development Department IE(Institute of Energy)

Appendix II: Report of the First Working Group Meeting

ERIA Research Project 2021/2022

First Working Group Meeting for the Study on the Applicability of CCT for Comprehensive and Optimal Carbon-neutral Solution in ASEAN

Virtual meeting held on 8 July 2022

At the outset, Ms Yamada, a study team member, as MC called on JCOAL's Director of International Collaboration Department to deliver his brief remarks to welcome the working group members and the guests on behalf of Dr Phoumin, Senior Energy Economist, ERIA.

Dr Murakami: Firstly, on behalf of Dr Han Phoumin, Senior Energy Economist of ERIA, I would like to welcome and express our appreciation to the working group members from Indonesia, Malaysia, and Thailand, as well as the special guests from ACE, for their participation in this important working group for the ERIA study on the applicability of CCT for comprehensive and optimal carbon-neutral solution in ASEAN. As you know, in the era of the energy transition, action for carbon neutrality is essential. But the pathway would be different from one country to the other because of differences in the respective situations and potentials of the countries. However, some measures and solutions are better to be worked on regionally in close collaboration with other countries. There this study will be of some help. In the study, the essential components are (i) inputs from the working group members, (ii) literature surveys by the JCOAL Study Team, and (iii) discussions in the working group. These three components are essential to complete these studies. I hope we will have a fruitful discussion and everybody will get good takeaways.

The briefing on the schedule was provided while viewing the on-screen meeting agenda, followed by a self-introduction of participants.

Dr Ambiyah: My name is Ambiyah Abdullah. I am working with my colleague, Amira Bilqis, for the joint study group for a joint report on the CCT, together with JCOAL. We aim to publish a policy brief in August 2022 and a strategic report by next year, August 2023.

Ms Amira: My name is Amira Bilqis, and I am the associate for modelling and policy planning. I look forward to gathering more insights, as ACE is now working on a strategic report and policy brief on CCT and CCU.

Mr Tri: My name is Tri Suhartanto from the Directorate General of Electricity. My friend is Mr Andi Hanif from the same directorate general. Unfortunately, the other member, Mr Junifer, cannot join us due to another appointment falling at the same time. So, Mr Andi and I will engage in a discussion with you.

Mr Andi: My name is Andy Hanif, and my specialisation is reliability and electricity safety. I look forward to inputs we can consider while elaborating our future policy and its direction. We will also try to share the latest information on the energy transition in Indonesia. Mr Tri has experience working with ERIA, so we expect fruitful exchanges with you.

Mr Amirulazry: My name is Mohammad Amirulazry. I am the only representative from Malaysia. I serve as Assistant Director for Electricity Market Operation and Economic Regulator Department in Malaysia's Energy Commission. I expect this study to have an optimal carbon-neutral solution, especially in Malaysia and ASEAN. As you might know, Malaysia aims to be a carbon-neutral country by 2050 at the earliest.

Mr Yaowateera: My name is Yaowateera Achawangkul. I work at the Department of Alternative Energy Development and Efficiency, abbreviated as DEDE, under the Ministry of Energy of Thailand. I am very happy to see everybody and am glad to work on this study again. I expect this study to correspond with Thailand's emission reduction targets. Thailand aspires to be carbon neutral by 2050 and to have net-zero carbon emissions by 2065, respectively. Therefore, this study will be conducted to contribute to Thailand's relevant policy towards the committed targets.

Mr Tananchai: My name is Tananchai Mahattanachai. My profession is geophysicist, but I work for the Department of Mineral Fuels, Ministry of Energy Thailand. I have been serving the department for over 20 years.

The study team members also introduced themselves.

Dr Murakami: Hello, I am Kazuyuki Murakami, Director of International Collaboration Department, JCOAL. Under this study, I do energy sector analysis. Also, having worked for JCOAL's roadmap of technology for carbon neutrality, I handle the technology chapter of this study to identify the technology options and their availability for ASEAN and the four target AMSs in cooperation with my colleagues working for country subchapters.

Mr Ozawa: My name is Ozawa. I am the chief engineer of JCOAL. Being a professional boiler engineer, I have worked for decades in basic plant design and engineering parts of a thermal power plant. Since I came to JCOAL, I have been working on new areas like applicable CCT for ASEAN and biomass and ammonia cofiring.

Mr Otaka: Good afternoon. I am Otaka, programme manager of resources, a department of JCOAL. I am a professional in coal characteristics analysis and other chemical analyses of resources. I was a leading member of the two-phase ERIA study on coal-biomass cofiring potential in ASEAN, for which I also conducted the techno-economic analysis. Under this study, I undertake the Indonesia subchapter.

Mr Teuchi: My name is Teuchi, a geologist. I belong to the Technology Strategy Center of JCOAL, where I work on the research and development of carbon-recycling technologies. I undertake the Thailand subchapter.

Mr Yamashita: My name is Yamashita. I serve in the Resources Development Department. I am a mining engineer. Decades back, I worked at a coal mine in Japan under the seabed. And just 4 years ago, I worked on developing an underground coal mine in East Kalimantan, Indonesia. I undertake the Viet Nam subchapter.

Mr Nakano: My name is Tatsuhito Nakano. I serve as Deputy Manager of the International Collaboration Department and Accounting Group in the General Affairs Department. My major is resources science. After joining JCOAL, I experienced international cooperation and business development for CCT and budget control and accounting. I oversee the processes and progress of this study and offer help when required. I look forward to the discussion.

Mr Tri made the first presentation on behalf of all Indonesian members.

Following the presentation, Mr Andi Hanif made supplementary clarification.

Andi Hanif: Since the presentation has provided the required overview, I would like to refer to the information from Mr Tri on Indonesia's energy transition and provide additional clarification.

The grand design of Indonesia's energy transition is net-zero emissions in 2060. This vision consists of three main activities: (i) we will retire the existing coal power plants; (ii) we will also try to stop the construction and contract of new coal power plants; (iii) we will try to increase the installed capacity of new and renewable energy. Any technology that can support our vision of net-zero emission will be welcome. For example, clean coal technology, super grid technology, and all those technologies would possibly support that vision.

【Q&A with Indonesia】

Dr Murakami: I have one question on the availability factor of solar. In your presentation, solar capacity and share of capacity are growing. I talk about dependence in relation to the grid fluctuation issues. I would like to know what you think about solar's availability factor. As the availability factor of solar is around 10% to 15%, its generation dependence is not so high.

Mr Andi: I agree that a solar power plant has a relatively lower availability factor. We understand that. That is why we are trying to support and enhance the battery industry, which we hope will substitute for the insufficient availability factor of solar. If battery production can be done in Indonesia, it will also be cost-competitive. And then the other technologies supporting the situation are super grid and microgrid. In our activity. We prefer that solar power focuses on the decentralized systems of small, remote islands and is to be managed by PLN rather than IPPs. We are trying to articulate the overall power system on many different grids, divided into more than 17,000 islands, for sustainable power supply and optimal grid management.

So, the number we put in the presentation is for the entire Indonesian archipelago, including East Indonesia. As I said, we are open to other technology that can support our people. For now, battery for energy storage is one of the envisaged major solutions. Through local production, prices can be lower, and deploying batteries, with super-grid and small/micro-grid, can support our efforts to address the intermittency of renewable energy.

Ms Yamada: I have a minor comment on the graph on slide 10. Towards 2060, combined cycled power plants will go off before coal-fired power plants go off. That means in your country, both gas and coal are transitional, which is one of the features of Indonesia's energy transition. We understand that one of your key majors will be retiring inefficient coal-fired power plants first, followed by other coal-fired power plants in a phased manner. All these tell us that coal can be transitional and will have roles even in the energy transition.

Malaysia was the second presenter.

【Q&A with Malaysia】

Ms Yamada: I have a few questions. Malaysia will replace the existing 8,054-megawatt (MW) coal-fired plant with only 2,800 MW. So, overall, the coal-fired power plant installed capacity will be less. However, 2,800 megawatts are coming in. In that context, I would like to know for what year Malaysia has set its national target for coal-fired power plant phaseout or phase-down to zero.

Mr Amirulazry: Starting in 2029, we will embark on the phase-down by retiring the first coal power plant. Others will follow as time goes by. We will substitute the reduced installed capacity with gas and RE. That is what I can tell you now. We must see what it will be like because the government's comprehensive national energy policy is currently being discussed. That is why we can say that in 2040, we will have around 2,800 MW of coal in the electricity-installed capacity mix.

Ms Yamada: Thank you for the clear explanation, which I fully understand. I have a personal concern. If you construct a coal-fired power plant now, it will cause concern about its economy since the life of a power plant in Malaysia is generally much longer, thanks to high-level O&M techniques of utilities and engineers.

Mr Amirulazry: I understand, but the government has decided that there will be no more new coal power plants. However, I understand what you said; our power plants are well maintained and operate well. I do not know; maybe they will focus on cofiring after this.

Ms Yamada: Exactly, that can happen in any country. You are right; it depends on the energy security situation and supply requirements.

Mr Amirulazry: For example, Germany has been initiating green energy utilisation. But recently, we have seen Russia stop the gas supply, and Germany had no choice but to resume the operation of their coal power plants.

Thailand had two presentations: Mr Yaowateera, from DEDE, Ministry of Energy, and Mr Tananchai, from the DMF, Ministry of Energy.

Mr Yaowateera made the presentation, followed by Mr Tananchai.

Mr Yaowateera's presentation can be summarised as follows:

- Thailand's renewable energy (RE) status: the share of RE in 2021 was 14.62%, which decreased compared to 2020 due to the COVID-19 pandemic.
- Thailand's long-term GHG emission development strategy: Thailand aims to reduce 40% of GHG in 2030 with international support. In addition, Thailand aims to achieve carbon neutrality and net-zero carbon emissions by 2050 and 2065, respectively.
- The Ministry of Energy of Thailand is preparing the 'National Energy Plan (NEP) 2022', which aims to (i) increase the share of RE in new power installed capacity by 2040, (ii) promote the use of electric vehicles to be more than 30% of total vehicles by 2030, (iii) increase energy efficiency to be more than 30% by applying new technology and innovation, and (iv) energy transition coping with the 4D 1E policy.
- The 4D 1E policy consists of digitalisation, decarbonisation, decentralisation, deregulation, and electrification. The decarbonisation policy aims to reduce carbon emissions by replacing fossil fuels with clean energy, such as solar and bioenergy.
- Thailand also introduces the bio-circular-green (BCG) economic model, which aims to consolidate the concept of bio-material use, recycling, zero waste, and natural problem-solving. The expected outcomes from the BCG economic model are to increase domestic GDP to THB4.3 trillion within 5 years, support the local economy (e.g. agriculture sector), and contribute to the United Nations Sustainable Developments Goals.

【Q&A with Thailand】

Ms Amira: Thank you so much for the two presentations. I was impressed, especially by the presentation on the development of CCUS in Thailand. Considering the carbon market will constitute a crucial part of CCUS development in Thailand, I wonder if the government has implemented domestic policies or something to kickstart the carbon market. Also, have you already brought the matter to REPSSN or maybe to the ASEAN Forum on Coal (AFOC)?

Mr Tananchai: Yes, it is quite new, and we are trying to initiate this topic into AFOC and Asian cooperation. Now we are at the stage of setting up. We formulated a cooperation programme for CCUS, which was already submitted to ACE for the concept note for circulation to the AMSs. Hopefully, we will get good feedback from them. Another important domain of CCUS is the carbon market because it is one of the important mechanisms to drive and incentivise the CCUS project in ASEAN.

Finally, the study team presented on the identified potentials and findings of the study.

【Q&A with the Study Team】

Mr Amirulazry: I have just one question to be addressed. For the recommendations to ASEAN, will it be like a 'one-fit-for-all' recommendation or will recommendations be provided for the four AMSs?

Ms Yamada: We have chosen four countries with high potential: Indonesia, Malaysia, Thailand, and Viet Nam. Dr Ambiyah mentioned the other study that is now ongoing and the framework of the ACE-JCOAL cooperation in close collaboration with AFOC. The study is more in pursuit of ASEAN's readiness to introduce and apply CCT and CCU technology during their energy transition. So, the subjects are the same: energy transition and technology for carbon neutrality, but the approaches are different. In this study, the main focus is on the four AMSs. So, individual recommendations for those AMSs will be furnished in addition to the recommendations to ASEAN. The method is to prepare by-country recommendations from which we make extracts and formulate those for ASEAN. So, the focus is more on by-country recommendations, though we also regard our recommendations to all ASEAN as important.

Mr Tananchai: I have a little observation that the topic of our working group is applicability of CCT for comprehensive and optimal carbon neutrality. But we agreed that CCUS plays an important role in carbon neutrality, so I would like to suggest that CCUS be considered part of the target technology.

Ms Yamada: Thank you, Tananchai-san and Teuchi-san, who are engaged in the Thai study and have been conducting literature surveys for months. However, he could not obtain a full range of information due to language barriers and/or limited availability of information in the public domain. So far, his analytical work has focused more on biomass-dedicated firing and the introduction of relevant technology. However, the study team's report today is to provide initial ideas. And we are expecting your and Mr Yao's cooperation to help Ozawa-san by giving him advice and relevant information, including the advice you have just provided about the inclusion of CCUS as part of the target technology. We appreciate your advice and your forthcoming cooperation with us.

Ms Yamada: Amirul-san, I heard that Malaysia is very positive about deregulation or improving the tariff systems so that the electricity sector will be more competitive. I think the energy commission must be in the central position. If we may know, how much is the progress as of today because that is related to renewable energy development? It is a general observation that the more competitive the electricity sector, the smoother renewable energy development proceeds. And that Malaysia is now trying to go further in that direction is being mentioned in some internet sources.

Mr Amirulazry: It is a very good question, and I would like to check updates on the matter and communicate further by email.

Ms Yamada: Thank you very much, Amirul-san. Let us communicate further by email. We will draft the minutes, which will be shared with you for comments. Before we close this meeting, the team would like to express its wholehearted thankfulness to all working group members and the guests from ACE.

The meeting was closed with the announcement that the Second Working Group Meeting is scheduled in the middle of October 2022. The meeting will be held physically at the ERIA headquarters in Jakarta, Indonesia, if the situation allows.

Attendance: Working Group Members and Observers

Country	Institution		Attendance
Indonesia		Mr Tri Suhartanto, S.T., M.Eng Mid-Level Electricity Inspector, Directorate General of Electricity	@ MS Teams
		Mr Andi Hanif, ST, M.Eng Mid-Level Electricity Inspector, Directorate of Electricity Engineering and Environment, Directorate General of Electricity	@ MS Teams
Malaysia	Energy Commission (ST)	Ir Mohd Helmi bin Mohd Zaihan, Assistant Director	@ MS Teams
		Mr Mohd Amirulazry Mohd Amin, Assistant Director	@ MS Teams
Thailand	Ministry of Energy	Mr Tananchai Mahattanachai, Senior Professional Geologist, Department of Mineral Fuels (DMF)	@ MS Teams
		Dr Yaowateera Achawangkul, Mechanical Engineer, Senior Professional Level of the Energy Research Division, Department of Alternative Energy Development and Efficiency (DEDE)	@ MS Teams
Vietnam	Ministry of Industry and Trade	Mr Doan Ngoc Duong, Deputy Director General, IE(Institute of Energy)	@ MS Teams
	Ministry of Industry and Trade	Dr Nguyen Manh Cuong, Deputy Head of Power System Development Department IE(Institute of Energy)	@ MS Teams
ASEAN Centre for Energy (ACE)		Dr Ambiyah Abdullah - Senior Officer, Energy Modelling and Policy Planning (MPP)	@ MS Teams
		Ms Amira Bilqis - Associate Officer, Energy Modelling and Policy Planning (MPP)	@ MS Teams

Attendance: ERIA and JCOAL

Organization	Participants
Economic Research Institute for ASEAN and East Asia (ERIA)	Dr Han Phoumin, Energy Economist
Japan Coal Frontier Organization (JCOAL)	Dr MURAKAMI Kazuyuki, Director, International Collaboration Department
Japan Coal Frontier Organization (JCOAL)	Mr OTAKA Yasuo, Senior Program Manager, Resources Development
Japan Coal Frontier Organization (JCOAL)	Mr YAMASHITA Eiji, Senior Program Manager, Resources Development
Japan Coal Frontier Organization (JCOAL)	Mr OZAWA Masahiro, Chief Engineer, International Collaboration Department
Japan Coal Frontier Organization (JCOAL)	Ms YAMADA Fumiko, Assistant Director, International Collaboration Department
Japan Coal Frontier Organization (JCOAL)	Mr TEUCHI Shinjiro, Deputy Manager, R&D Development Department

Appendix III: Report of the Second Working Group Meeting

ERIA Research Project 2021/2022

Second Working Group Meeting for the Study on the Applicability of CCT for Comprehensive and Optimal Carbon-neutral Solution in ASEAN

Hybrid Meeting held in Jakarta, Indonesia, and on MS Teams on 18 October 2022

At the outset, Ms Yamada of JCOAL, serving as MC, expressed the team's gratitude to working group members who came all the way and made themselves available at the busiest period of the year. Appreciation was expressed also to the directors of ERIA attending the meeting.

Then Mr Toru Furuichi, Director General of Research and Policy Design Department, ERIA, welcomed the delegates.

Mr Furuichi: Today, I am very pleased to welcome you all to the second working group meeting on the 'Applicability of the CCT for Comprehensive and Optimal Carbon-neutral Solution in ASEAN'. This study is one of the important studies in line with ERIA's recent published document on the technology list and the perspectives for the transition of finance in ASEAN TLPTFA, which aims to support the smooth energy transition in developing Asia with realistic approaches that can facilitate many countries in Asia to embark on pathways to carbon neutrality with consideration of energy security, affordability, accessibility, and environmental protection simultaneously. It is very important to note that among the transition technologies, cofiring at coal-fired power generation with ammonia and hydrogen fuel is highly recommended in the ASEAN Energy Transition Study.

ASEAN countries have announced their respective carbon neutrality targets before or at the COP-26, which impressed us that ASEAN made one big leap forward in the initial part of their energy pathways. However, we are aware that pathways to carbon neutrality will be diverse among countries. There will be numerous opportunities to reduce emissions in the ASEAN region, and such opportunities will be fully utilised only if optimal solutions with applicable technologies were in place. Some countries would have limited abilities to straightaway jump to massive renewable energy and new energy development and introduction due to economic constraints.

In the meantime, CCT, combined with CCUS, will remain important for ASEAN.

Many ASEAN countries adopt CCTs, which are vital for energy security as coal contributes sustainable power supply at affordable cost. In addition, coal supply is steadily available within the region. Now the question is what are the CCTs that are for decarbonisation and energy transition? Given that high dependence on fossil fuels could continue in the region, improving emission reductions is necessary through the introduction of a highly efficient coal power plant with CCT technologies, such as coal and ammonia cofiring, and coal and biomass cofiring in power generation. At the same time, the possibility of CCUS is vital and relevant for the energy transition towards carbon neutrality. Gradually, all transition technologies will need to be identified and financed across multiple sectors.

Ladies and gentlemen, I wish to take this opportunity to thank all the working group members for their contribution to this study, which is very important for ASEAN energy security and support to the AMSs' energy transition.

Then Dr Kazuyuki Murakami, Director of International Collaboration Department, JCOAL, made remarks on behalf of JCOAL and its study team.

Dr Murakami: Firstly, I would like to express my sincere appreciation to all of you for participating in this working group meeting for the study on the applicability of CCT for comprehensive and optimal carbon-neutral solution in ASEAN. We are very happy to present our draft report for technology introduction and the reports of these four countries regarding the trend for carbon neutrality with the energy shift from fossil to non-fossil fuels. It is an irreversible trend, and many countries have announced their carbon-neutral target and related policies. Since most measures for carbon neutrality are basically at the R&D or demonstration stage, it is still difficult to clearly show the practical solution option. In this regard, this study has an important meaning, and all of you can be requested to join the discussion today actively.

After the discussion of today's meetings, the JCOAL Study Team will try its best to identify suitable and applicable technology options for furnishing recommendations to all four target AMSs and to overall ASEAN at the end of November 2022.

ERIA officers, working group members, guest working group members, and JCOAL Study Team members introduced themselves.

The JCOAL Study Team presented on decarbonisation technology solutions.

Q & A session on decarbonisation technology solutions

Mr Doan: Can you change to slide 12, question about Japan's policy on carbon neutrality by 2050? I have questions about the carbon neutrality goal of Japan. Here, I see a huge number of carbon dioxide emissions in electricity, but it decreased very much – about half in 10 years. I was wondering how CO_2 emissions from electricity generation decreased.

Dr Murakami: Thank you very much; you make a good point. So far, our government has declared about 46% reduction towards 2030, with 2013 being the base year. That is 9 years back from today. That was when the most emissions were observed in our country. So, the main measure for decreasing is phasing out all coal-fired plants and cofiring. So, by combining these measures in addition to energy mix optimisation, mainly introducing RE, we can achieve 46% reduction by 2030.

Mr Doan: To my understanding, will the power demand decrease in Japan in the next decade?

Dr Murakami: No, the demand is mostly the same so far.

Mr Doan: That is stable. Maybe it is not changing much in the next 10 years. Actually, we have about a 10% increase per year.

Dr Murakami: I understand that the required measure depends on the country's situation. Yes, I understand that Viet Nam's situation is very challenging.

Mr Amirulazry: Okay, just one more question from me: slide number 19, concerning the NOx emission. So, you are saying that stable combustion and reduced NOx emissions with 20% of ammonia cofiring have been achieved. I understand that when you try a higher cofiring of ammonia, you create more or additional NOx emissions. So, how do you reduce NOx emissions? Maybe you need more equipment or something to reduce NOx?

Dr Murakami: Okay. So far, in our previous study, according to IHI on the technology supplier, by 20%, NOx generation does not increase because the main factor or origin of NOx is air. I mean, nitrogen is the main factor. If we increase ammonia by 20%, chemical NOx may increase, but we expect it to decrease by controlling combustion temperature. Also, NOx can be reduced after the boiler. They think they do not need to modify more but in the case of a higher-mixing ratio, they must consider the SCR units' performance improvement.

Mr Amirulazry: Okay. Yes, thank you. I understand.

Mr Doan: So, may we relate to the question? I think the emission reduction comes from ammonia cofiring because ammonia is a clean fuel.

Murakami: Yes.

Ir. Mohd Helmi bin Mohd Zaihan, Malaysia: I am unfamiliar with the map of Japan. Are these in separate locations? Or are these plants located near each other?

Murakami: No, the top one is located in West Japan, and the Soma energy plant is in the northern part of Japan.

Mr Helmi: So, you're planning to fire the biomass. Where do you get the biomass resources?

Dr Murakami: Good question. So, most biomass resources are imported by the trading agent and the utilities. In these cases, they own a coal yard, a storing site of biomass close to the thermal power plant.

Dr Yao: In Thailand, biomass is collected and sent to Japan. Some companies must modify their plant for cofiring.

Murakami: In Japan, most USC plants conduct 1%–4% biomass cofiring without modification.

Mr Andi: Dr Murakami-san, in my understanding, carbon cannot be recycled. So, how does carbon-recycling work?

Dr Murakami: Please move to number 24. Yes, this is the roadmap by the government. Now, we are in phase 1, looking for any possibility of carbon recycling and recycling other materials. Also, in parallel, we are conducting reality check about CO_2 recovery. If CO_2 is recovered, it costs more. So, the commercialisation of CO_2 recycling becomes difficult. Interaction with any person over R&D, which we are also conducting through the supplier, universities, and all centres concerned. Government supports and funds R&D for carbon recycling. Now, our government has decided to support 14 sectors of the future industry, one of which is carbon recycling. That is the current situation in Japan.

Dr Phoumin: Normally, the carbon is related to CCUS. If you can recycle, as Dr Murakami said, it is a mini product. If hydrogen is combined with CO_2, you produce a specific fuel. If you have industrial waste available, you can produce many kinds of construction materials using carbon. You see many other materials. So, carbon can be recycled. But Dr Murakami said that the net hydrogen, this becomes commercialised, then the cost becomes available. Carbon must be recycled as much as possible.and The rest of the carbon is to be permanently stored underground.

Dr Cuong: May I have one more question. It is about CCUS. Some people say CCUS is the licence for emissions; so it could violate the environment. What is the reason the Japanese chose CCUS as one of the solutions for a net-zero goal?

Dr Murakami: It is difficult, but we do not have many options. I mean, we do not have enough resources. You have to consider all the technology to achieve carbon neutrality. So that is why CCUS is rather important to other countries.

Dr Phoumin: ERIA is working on CCUS. You can become a member of the Asia CCUS Network Forum. I think some of my colleagues can take the attendance and reach out to you. Actually, CCUS is quite important because the region still yields fossil fuels. In the East Asia Region, the share of fossil fuel is almost 80% in the primary energy supply mix. . So, if we continue using fossil fuels because of energy security or because of coal stability or supply security, the clean use of fossil fuel is very critical in which the carbon recycling technology is vital in the whole process. Generally, we cannot recycle 100% of the emission. The NOx can be reduced with the environmental facility to a much lower acceptable standard. But CO_2 cannot be captured basically, so you need to recycle the CO2 emission. Then the remaining CO2 must be injected to be stored underground.

In that case, if you still use fossil fuel, you need to use CCUS. Otherwise, you must offset with reforestation, afforestation that is still okay. But as long as you continue using fossil fuel, you must combine with CCUS. ERIA conducted the study, and we found that the capture cost of CO2 is very high representing about 70% of the whole value chain of CCUS. Basically, the capturing cost varies depending on types of industries ranging from petrochemical to power generation.. Power generation represents almost $60 per tonne CO_2 currently, transport represents around 5%, and injection around 25%. So, we want to bring down the capture cost in the future. So, I think this working group is relevant to our members. I hope to pass your name on to my team. Thank you.

The Indonesian member made an updated presentation, followed by JCOAL Study Team's by-country observation and perspectives presentation on Indonesia.

Q & A session on the presentation on Malaysia:

Mr Helmi: I have questions for Indonesia. In one of your earlier slides, you mentioned that Indonesia will have its first nuclear power plant by 2049, if I'm not mistaken. This means the construction for the same will start soon. So, how do you convince your public that nuclear is the way forward? Because, for example, in Malaysia, nuclear is taboo. We do not want nuclear, so we would like to learn from Indonesia.

Mr Andi: That is a very good question. So it is okay that our discussion has reached another point. We already have three reactors in Indonesia, but only a kind of research reactor. We tried to install a nuclear power plant in the 1960s during the term of our first president. Then the decision maker in our ministry already found a keyword that will convince people, commitment from the top management, I mean, the president or the prime minister. If the president says to do it, it will be a little bit easier. So, if the president or the prime minister is still not sure, the people will not be sure. So, that is why we propose to the president this net-zero emissions scenario to assure him. We are happy that our current president is not objecting to a nuclear power plant. That is why the president and the national energy council agreed to put the nuclear power plant in the scenario. Yes, that is our answer. Thank you.

Dr Phoumin: We were very impressed with your presentation. Looking at your national installed power capacity, for coal, it goes to zero, in 2059, 2057, and nuclear, new energy and renewable energy will be generation sources from there onwards. Do you have hydrogen or ammonia, a 100% coal power plant? I just want to check because you have hydrogen. Will you import ammonia and hydrogen for power generation, or do you not have any power generation from ammonia or hydrogen?

Mr Andi: We do not have any for now, but this is the programme. This is the direction from the Energy Council and the president as head of the Energy Council. We will build nuclear; we will build hydro, gas, etc. And how we do it, you find the way. That is how we work. So, for now, we do not have hydrogen. Maybe our member from Indonesia, the Indonesian from ACE, and ERIA already know that our president said, "You must build the highway from Jakarta to Surabaya. That is my direction. How you build it is your duty; find a way. Say, now we have a long highway on the island of Jafa, and then after this long highway into Sumatra, the same thing will happen. We will do the same in the energy sector. Yes, and all sectors, because the focus of our president – and maybe the next president – is infrastructure and how to build it. So, my answer is no. We still do not have, but we will find a way to do that – whether we will build ourselves or we will import nuclear energy. We still have no idea who will support us – Russia, the United States, China, or all. We still do not have an idea, but we will find ways.

Dr Phoumin: I am very excited about that roadmap. ERIA is interested in being involved in Indonesia as you want to develop further. We support the ministry in that net-zero emission roadmap. I am unsure how because I see solar and wind coming, so they are intermittent. Then the capacity of green hydrogen production is quite small compared to the scale of renewables, right? So, I want to know whether you will completely use curtailed electricity or wind or solar farms. I also think importing ammonia and hydrogen will be critical for Indonesia to meet that objective.

Mr Andi: Maybe this is the key information like nuclear, where will we buy the uranium. We do not have uranium; just the same problem. But we will put it as a concern. Thank you.

Dr Ambiyah: I would like to ask you to elaborate on the projection of power generation emissions. I am concerned about the kind of scenario you envisage and whether factors, such as energy efficiency reduction in power generation, are considered. Or are you only focusing on the expansion of renewables in Indonesia's power sector?

Mr Andi: There is no doubt we will create the efficiency of the coal power plant. We already do cofiring in several coal-fired power plants. Then we have a kind of safety competition for the power plant. We call it the safety competition of power plants, the cofiring biomass, and how the power plant reduces emissions and increases efficiency. It is one of the points of that competition. So, we will not stop because we are the more significant coal exporter.

Yes, we are the larger exporter, so when we will not stop. We still focus on the condition of our economy. Coal is one of the high-income sources in our country. So, we are not going to like stop producing and utilising coal. We will do other things like increase efficiency and use cofiring; we already do that now. Okay, so in the year 2057, yes, we hope to stop the coal power plants. But we also hope that the coal power plants in that year can be 100% very efficient or very clean. We do not know what technology will arise. But this is the direction, and as I explained before; we will find a way to find the technology, and we must be optimistic. Thank you.

By-country observation and perspectives presentation: Malaysia

Q & A session on Malaysia's presentation

Mr Helmi: As one recommendation we found for Malaysia, our minister was at one of the programmes on green energy tariffs last year. You can buy an electricity tariff for customer needs in the peninsula region, which we call the great electricity tariff. By that, you enjoy the electricity supply from renewable energy only. But we have a premium charge of around 3.7% per kWh, so this is new and underway in ASEAN countries. This is one of the programmes that may encourage the reduction of the carbon footprint in electricity consumption. Then maybe the way forward is to increase the quota for this year, and because it is enrolled to receive the internationally recognized renewable energy safety kit (IREK) after the end of the 20-day year to prove that the energy we are using is from renewable energy. So, voluntarily, it is similar, unlike in Europe where renewable portfolio standards are mandatory. Also, the renewable certificates will be traded in Malaysia only and are recognised by the government.

Dr Phoumin: But what does the one who produces green renewable electricity get in return? Does he get any carbon credit or not?

Dr Yao: The company can buy this renewable certificate.

Mr Helmi: In Malaysia, we have one organization called mGATS (Malaysia Green Attribute Tracking System) that is a national marketplace for renewable certificates called mREC. Renewable certificates will be pooled and sold to companies that need the certificates.

Mr Amirulazry: The other good thing is that buyers are given opportunities several times. We will announce in November and December 2022; we opened the following quarter later – supposedly around March 2023.

Dr Phoumin: Thank you so much. Thank you for your plan. We go back to Yamada-san. I think your report on Malaysia is very detailed, but I just want to see the hydrogen economy that Malaysia committed. Sometime back in 2005, they had a hydrogen roadmap that was stopped. It has started again and seems to be good. Now is the right time because hydrogen is a potential game changer. So, I think Malaysia should be engaging in the supply chain. If we are promoting the hydrogen economy in ASEAN and East Asia, then the supply chain should be established. It has been proven recently that the segment of hydrogen carrier, SIP carrier, from Australia is successful. Brunei asked for Tokyo's support for the Olympic Games recently.

Dr Murakami: I think this will be very, very good for Malaysia. ASEAN countries have already taken a dip in exploring hydrogen technology.

Dr Phoumin: Yes, but the fuel stock can come from anywhere. But green hydrogen comes from renewables.. But more hydrogen is produced from natural gas, currently 95%. So, Malaysia has the potential for clean hydrogen, which can be tapped from the hydro potential in Sarawak. Hydrogen is a very big game changer for Malaysia. That is why maybe you can highlight in the master plan, the roadmap of hydrogen. Perhaps this will encourage ASEAN to follow the Malaysian model. But now I am happy to see Thailand also taking the hydrogen issue seriously. I want to follow that closely.

Dr Yao: Yes, you can. We have the report.

Mr Amirulazry: We now have the hydrogen roadmap; it is not a policy but a proposal.

Mr Helmi: Akademi Sains's roadmap has yet to become a policy. It is just one of the government's research projects and is still being reviewed. So, it is not yet a final government policy.

Ms Yamada: Can it be a part of the national team for considering the policy. Is Akademi Sains a government institution?

Mr Amirulazry: Yes, to both. It is a government agency.

Ms Yamada: While it is yet to be finalised as a policy, it is something, especially considering that multiple sectors and organisations are involved. Group studies and projects are proposed and are sorted chronologically by 5-year plans towards 2050. It would benefit your government to incorporate its vision and proposals when Malaysia's national hydrogen policy is ready for implementation.

Mr Helmi: Let us see and hope a confirmed hydrogen policy is in place soon.

The member from Thailand made an updated presentation, followed by JCOAL Study Team by-country observation and perspectives presentation: Thailand

Q & A session on presentation on Thailand

Ms Yamada: I have a question about slide no. 4. What is the difference between carbon neutrality and necessary emissions? We usually use those with the same meaning, but they may have different meanings on this slide.

Dr Yao: For carbon neutrality, we can use carbon sinks, such as afforestation, etc., while net-zero emissions mean we have no emissions.

Mr Tananchai: The carbon neutrality measures comprise natural carbon sinks like afforestation. While net-zero emissions mean what we are producing, we take it back, including the CCUS, to ensure technology can abide by the mission to net zero.

Ms Yamada: In slide no. 5, you say at the bottom 'to minimise overall costs'. Thailand has developed a portfolio of complementary renewable energy sources and intelligent control systems to manage variable sources. I am particularly interested in intelligent control systems. To what extent are these intelligent? Are they a kind of artificial intelligence or AI? Do you already have particular systems in mind that are already commercially established?

Dr Yao: Yes, Yamada-san. To better forecast power generation while balancing between VRE and other power, we use the Internet of Things or IoT and the application and platform to forecast by using meteorological data, such as wind direction, solar deviation, etc., to evaluate it with the domestic energy demand. It is the tough headstart that ECA demonstrated because ECA now has launched a forecasting centre. We recognise that, in the future, we will have an effect on power generation, which may be higher. Therefore, we must decide and utilise the same innovations to decide what can be used. What can we do to use as flexible sources – the natural gas or hydropower plant.

Yamada: So, that is an additional problem.

Dr Yao: Yes, for a different study.

Ms Yamada: My last question concerns the second to the last slide. Here you mention biojet and hydrogen. Do you say that this is sustainable aviation fuel? What kind of fuel is biojet?

Dr Yao: J-set is a sustainable aviation fuel that we will try to adopt in the future. So, demand will be high for J-set in the future. Naturally, there will be a considerable decrease in the use of the bioenergy and bio off field.

Ms Yamada: Thank you very much. May I ask Mr Tananchai to make some supplementary updates or comment on Ozawa-san's presentation?

Mr Tananchai: Thank you, Ms Yamada, I do not have any presentation right now. I would like to update you a bit about the CCUS plan in Thailand. Tomorrow we will have our first meeting of the national CCUS subcommittees. We will have our prime minister. After tomorrow, we will eventually have a more solid plan for the pilot project and the study. It is now updated, and it is more than what we currently have to do in June. The pilot project now becomes 10 pilot projects, and the study on device use in the United States and Thailand is has increased to 11 studies.

Anyway, we will update you after tomorrow's meeting with the department of internal affairs. We are going to press ahead and get approval from the subcommittee tomorrow. We will update you soon. Thank you very much.

Ms Yamada: Thank you very much, Mr Tananchai. We are expecting updates maybe by email; we can communicate later.

Dr Phoumin: I have a quick question for Mr Tananchai. You said that Thailand would hold an important meeting tomorrow about its CCUS plan. After that meeting, Thailand will have a roadmap for the CCUS. Is my understanding correct?

Mr Tananchai: It is just a plan. The roadmap is coming. We plan to finish our CCUS roadmap next year.

Dr Cuong: Thank you so much. I still have questions regarding your second to the last slide. What is the point of conducting capacity building and information dissemination? That is the first question. Is there any problem regarding the public about renewable energy? Is there any problem? Do you still have problems making the public understand renewable energy and digital technology like biomass and biogas? I do not think the public believes that burning biomass will generate power and release heat into the atmosphere. My second question concerns the consequences. Capacity rating is an important issue in the new renewable energy policy. The next question is about adequate environmental policy. We are considering a scheme under which we can charge fees according to the degree of carbon intensity released into the atmosphere.

Dr Yao: Is that large-scale or small hydropower? The cost of small-scale hydropower cannot compete with conventional ones. The cost would be slightly higher than the large-scale hydropower. Is it possible to revise this summary again? One thing on the third recommendation on biomass, the classification of biomass is not popular for transport. We can discuss classification later.

By-country observation and perspectives presentation: Viet Nam

Q & A session on the presentation on Viet Nam

Mr Duong: About the carbon capture in storage as a solution, we would have a problem with CCS. For example, under the ATP policies, we cannot get knowledge to maintain the existing coal fired power plants. They just provide the loan to retire a coal-fired power plant, not for CCS or carbon capture to maintain the operation of the coal-fired power plant. That is the problem for us.

Mr Yamashita: It is all very valuable. I know that for countries, it is difficult to reduce finance, so CCS or CCUS is right. Money is very important. Many coal-fired power plants are currently in operation. Those power plants have been in operation for less than 10 years. As coal-fired power plants usually have an operating life of 30 to 40 years, CCUS must be installed to reduce the CO_2 emissions from coal-fired power plants to keep them operating longer in the future. CCUS is quite an effective choice of technology, however, as of today finance scheme availability is rather slim, though many institutions are considering to establish or enhance finance schemes for CCUS. The issue is how to get finance to implement CCUS.

Dr Murakami: I put that ad, so your point is very good. It is one of the recommendations for this report in preparing CCS. So, strong government support is recommended. That might be one of the recommendations of this study. Thank you.

Mr Helmi: I have a question. In one of your recommendations regarding solar power, you mentioned that solar power is encouraged only for self-consumption. And if self-consumption for rooftops, there is no limit; it is not connected to the grid. What if the customers want to connect their facilities to the grid? Is there any special charge or limit on the installed capacity?

Mr Duong: I cannot answer that question. You may know that as the presentation of the report clearly indicated. In the last few years, we have installed a huge solar power capacity, about 20 GW, both land-based and on rooftops. Those have a very big capacity. So, the government decided that was enough for rooftops, at least for the next 10 years because of the issues with the power system operation. So, the government will not encourage rooftop solar installation, try to sell the power to the grid, and encourage self-consumption for rooftop solar. So, generating that scale of solar capacity will not affect the overall power grid operation. That is the direction of the government.

Mr Helmi: Just another quick question. Is the electricity tariff in Viet Nam cost-effective? Or is it heavily subsidized?

Mr Duong: That is a very tough question. In Viet Nam, there are state-owned corporations not responsible for the operation of the power system. Even with EVN as a single buyer of all generated power, the tariff of all and any power producers with any power resources reflects all required costs for generation. We will determine the tariff of the power system based on the summary of all power generation sources, including feed-in tariffs. But because the feed-in tariff is quite high, that may be creating solar wood rust. So, in short, we are experiencing some loss in this operation since we cannot compensate for such a high feeding tariff of solar or wind power. But in the mid to long term, it is necessary as we proceed with the energy transition pathway. Currently, the government wants to stabilise the economy by not pressuring the enterprises and increasing the power tariff. Increasing the power tariff later will enable the economy to gain.

Mr Duong: I agree with the presentation on Viet Nam. However, looking at nos. 87 and 88 on the eastern power system in PDP8, some would ask why, after reviewing, the capacity will tremendously increase.

I see some differences between what you present as the tentative power plan of Viet Nam and the latest draft PDP 8 that is under discussion in the government. I just guessed because I do not remember all the details. But you may need to mention that the two columns on the left are not based on the base scenario for power demand. Up to April this year, the data on the right is based on a high scenario. The process is a little complicated. In any case, it should be the most technical consideration–based scenario.

Mr Yamashita: We will look into it and later confirm how we shall express the situation in this part of the report.

Dr Phoumin: It is good that you say hydrogen or ammonia cofiring may be suitable for Viet Nam or other countries. However, more information may be required regarding the commercialisation, the maturity of the technology, and the cost because green hydrogen and green ammonia will still be expensive. As for Viet Nam, as long as we understand the PDP8 and other resources, hydrogen remains costly for a country like Viet Nam.

Mr Yamashita: In my view, solar and wind are clean, but they can make intermittent power supply of VRE. Then coal power can complement those shortcomings and support the grid through flexible operations. That way, we can also sustain the economy of the overall power supply. That is what we do in Japan, and it may also apply to Viet Nam.

Dr Phoumin: Just one more minute. As for hydrogen utilisation, we all know that Japan is the leading country in studying and researching ammonia in existing coal-fired power plants. We expect a continuously updated information about your technological advances so that we can eventually keep our plant as close to reality as possible.

Finally, at the wrap-up session, the study schedule towards the end of November 2022 was confirmed. The closing remarks by ERIA and the JCOAL Study Team followed.

Dr Phoumin: I thank and congratulate all working group members of these important studies. In particular, I thank Furuichi-san for his time. He is very busy with many projects. I greatly appreciate his giving high importance to this study. I am also very thankful to the JCOAL Study Team, headed by Dr Murakami, for putting their best efforts into this study, which is important for the ASEAN region. I think there is no single pathway towards the carbon neutrality solution.

We are seeking multiple pathways suitable for the respective countries. That is why we see a kind of variation among target countries – how countries seek different ways to work on carbon neutrality and CO_2 emissions. This is great because we cannot meet all these countries' needs. Each country has different requirements and economic and social circumstances, which must be tailored to find an appropriate way to meet carbon neutrality with affordability, balancing with security and environmental concerns.

I would like to express my appreciation for the great contributions of the countries. The report could not meet the very high standard without your contribution through this very, informative discussion and contribution. I am confident that countries can use the report. It could give food for policy formulation, support direction and thinking towards the roadmap to carbon neutrality, or whatever use this report is for.

Mr Otaka: The discussion was long and very fruitful, so my remarks would be very short. Thank you very much for all your cooperation – your insights and comments during the discussion. We will prepare a study report based on the members' inputs, comments, and discussions. The final draft report will be compiled and sent to the Working Group members next month for their consideration.

We look forward to your comments on the draft to improve the final report.

Attendance of Working Group Members (Regular and Guest members)

Country	Institution		Attendance
Indonesia	Ministry of Energy and Mineral Resources (MEMR)	Mr Junifer Saut Pangidoan Simanjuntak, S.T., M.T. Senior Electricity Inspector, Directorate General of Electricity	@ MS Teams
		Mr Tri Suhartanto, S.T., M.Eng Mid-Level Electricity Inspector, Directorate General of Electricity	@ MS Teams
		Mr Andi Hanif, ST, M.Eng Mid-Level Electricity Inspector, Directorate of Electricity Engineering and Environment, Directorate General of Electricity	@ ERIA Headquarters
Malaysia	Energy Commission (ST)	Ir Mohd Helmi bin Mohd Zaihan, Assistant Director	@ ERIA Headquarters
		Mr Mohd Amirulazry Mohd Amin, Assistant Director	@ ERIA Headquarters
Thailand	Ministry of Energy	Mr Tananchai Mahattanachai, Senior Professional Geologist, Department of Mineral Fuels (DMF)	@ MS Teams
		Dr Yaowateera Achawangkul, Mechanical Engineer, Senior Professional Level of the Energy Research Division, Department of Alternative Energy Development and Efficiency (DEDE)	@ ERIA Headquarters
Vietnam	Ministry of Industry and Trade	Mr Doan Ngoc Duong, Deputy Director General, IE(Institute of Energy)	@ ERIA Headquarters
	Ministry of Industry and Trade	Dr Nguyen Manh Cuong, Deputy Head of Power System Development Department IE(Institute of Energy)	@ ERIA Headquarters
ASEAN Centre for Energy (ACE)		Dr Andy Tirta - Manager, Energy Modelling and Policy Planning (MPP)	@ ERIA Headquarters
		Dr Ambiyah Abdullah - Senior Officer, Energy Modelling and Policy Planning (MPP)	@ ERIA Headquarters
		Ms Amira Bilqis - Associate Officer, Energy Modelling and Policy Planning (MPP)	@ ERIA Headquarters

Attendance of ERIA and JCOAL

Organization	Participants
Economic Research Institute for ASEAN and East Asia (ERIA)	Dr Han Phoumin, Energy Economist
Japan Coal Frontier Organization (JCOAL)	Dr MURAKAMI Kazuyuki, Director, International Collaboration Department
Japan Coal Frontier Organization (JCOAL)	Mr OTAKA Yasuo, Senior Program Manager, Resources Development
Japan Coal Frontier Organization (JCOAL)	Mr YAMASHITA Eiji, Senior Program Manager, Resources Development
Japan Coal Frontier Organization (JCOAL)	Mr OZAWA Masahiro, Chief Engineer, International Collaboration Department
Japan Coal Frontier Organization (JCOAL)	Ms YAMADA Fumiko, Assistant Director, International Collaboration Department
Japan Coal Frontier Organization (JCOAL)	Mr TEUCHI Shinjiro, Deputy Manager, R&D Development Department