ERIA Research Project Report FY2025, No. 5

Decarbonisation of ASEAN Energy Systems: Optimum Technology Selection Model Analysis up to 2060

Updated 2024

Edited by

Seiya Endo

Soichi Morimoto

Hideaki Obane

Kei Shimogori

Ichiro Kutani

Toshiyuki Sakamoto

Kentaro Noma

Economic Research Institute
for ASEAN and East Asia

Decarbonisation of ASEAN Energy Systems: Optimum Technology Selection Model Analysis up to 2060

Updated 2024

Economic Research Institute for ASEAN and East Asia (ERIA)
Sentral Senayan II 6th Floor
Jalan Asia Afrika No. 8, Gelora Bung Karno
Senayan, Jakarta Pusat 10270
Indonesia

ERIA Research Project FY2025, No. 5
Published in June 2025

Preface

The Economic Research Institute for ASEAN and East Asia (ERIA), in collaboration with the Institute of Energy Economics, Japan (IEEJ), has been conducting research on decarbonisation pathways for Association of Southeast Asian Nations (ASEAN) energy systems using quantitative modelling. This report builds on previous findings, refining the analytical framework to better support ASEAN Member States in achieving their carbon neutrality goals.

Since 2021, ERIA and IEEJ have continuously enhanced the carbon neutrality scenario analysis, evaluating decarbonisation technologies based on socio-economic conditions, resource availability, and feasibility. The model has been applied across ASEAN, integrating energy efficiency, electrification, renewable energy expansion, and emerging technologies such as hydrogen, ammonia, and carbon capture, utilisation, and storage (CCUS). This year's study further expands on regional considerations, refines energy demand modelling, and explores ASEAN interconnectivity to optimise resource sharing and technology deployment.

The 2024 update highlights energy savings and electrification, alongside a low-carbon power supply, as central strategies for ASEAN's decarbonisation. The report also underscores the role of transitional technologies, including fuel switching from coal to natural gas, co-firing with hydrogen, ammonia, and biomass, and implementing CCUS for fossil fuel-based power generation.

Furthermore, the report emphasises the importance of resource sharing within ASEAN. By modelling regional divisions in Indonesia and Malaysia, it explores intra-ASEAN energy trade and cross-border hydrogen transport, demonstrating how regions with renewable energy surpluses can supply energy to others. Natural gas is expected to remain a key component of ASEAN's energy mix, primarily in industrial and power sectors. Additionally, CCUS technologies will play a crucial role in mitigating emissions from coal and gas-fired power plants, as well as industrial processes such as steel and cement production.

Beyond ASEAN, this study extends its scope to a preparatory study on Bangladesh, assessing the feasibility of adapting the decarbonisation framework to other regions.

We hope this report serves as a valuable reference for policymakers, researchers, and industry stakeholders in shaping energy transition strategies. ERIA remains committed to delivering research-driven solutions that promote economic prosperity, environmental sustainability, and energy security.

Naoto Okura
Director General for Research and Policy Design
Economic Research Institute for ASEAN and East Asia

Acknowledgements

The Economic Research Institute for ASEAN and East Asia (ERIA) expresses its sincere appreciation to the Institute of Energy Economics, Japan (IEEJ) and Prof Takashi Otsuki of Yokohama National University for their valuable collaboration on this relevant and important project, 'Preparation of Carbon-Neutral Road Map for ASEAN Countries'. This collaboration was made possible through the sophisticated optimisation model – the IEEJ-New Earth_ASEAN model – formulated based on the New Earth Global model. Special thanks are extended to the Natural Resources and Fuel Department, Agency of Natural Resources and Energy, Ministry of Economy, Trade and Industry, Japan for facilitating discussions between ERIA, IEEJ, and Association of Southeast Asian Nations (ASEAN) countries, enabling the presentation of model results and the exchange of information on future energy plans.

Naoto Okura
Director General for Research and Policy Design
Economic Research Institute for ASEAN and East Asia

List of Project Members

Economic Research Institute for ASEAN and East Asia

Kentaro Noma, Programme Manager on Energy, The Asia Zero Emission Center

Institute of Energy Economics, Japan

Seiya Endo, Economist, Energy Data and Modelling Center

Soichi Morimoto, Senior Researcher, Climate Change and Energy Efficiency Unit

Hideaki Obane, Senior Economist, Energy Data and Modelling Center

Kei Shimogori, Senior Researcher, Energy Security Unit

Ichiro Kutani, Director, Energy Security Unit

Toshiyuki Sakamoto, Director, Climate Change and Energy Efficiency Unit

Takashi Otsuki, Principal Research Fellow; Associate Professor, Faculty of Engineering, Yokohama National University

Yuji Matsuo, Principal Research Fellow; Associate Professor, College of Asia Pacific Studies, Ritsumeikan Asia Pacific University

Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

ASEAN	Association of Southeast Asian Nations
BECCS	bioenergy with carbon capture and storage
CO_2	carbon dioxide
COVID-19	coronavirus disease
CCS	carbon dioxide capture and storage
DAC	direct air capture
DACCS	direct air capture with carbon storage
ERIA	Economic Research Institute for ASEAN and East Asia
GDP	gross domestic product
GW	gigawatt
H_2	hydrogen
IEA	International Energy Agency
IEEJ	Institute of Energy Economics, Japan
IEEJ-NE	IEEJ-New Earth
Mtoe	million tonnes of oil equivalent
NH_3	ammonia
Nm^3	normal cubic metre
PV	photovoltaic
t	tonne
UN	United Nations

Chapter 1

Background

As of April 2024, 146 countries have announced their ambitions to achieve carbon neutrality, with specific target years identified. The Association of Southeast Asian Nations (ASEAN) Member States have also set ambitious medium- to long-term greenhouse gas emission reduction targets. To identify pathways for achieving these goals, ASEAN countries have been collaborating with developed countries over the past few years to develop road maps towards decarbonisation. When formulating these road maps, it is important to consider the unique characteristics of Asian countries, such as significant economic growth, high dependence on fossil fuels, and limited wind resources. Additionally, Russia's invasion of Ukraine continues to have a negative impact on fuel switching from coal to natural gas in the region due to high natural gas prices.

As in the previous year, this study

(i) aims to quantitatively describe the energy transition pathway necessary to realise carbon neutrality in ASEAN countries through model analysis;

(ii) provides information to formulate energy policies in each country and seek support from developed countries; and

(iii) suggests strategies to minimise the additional costs of transforming the energy supply–demand structure by using a cost-optimal technology selection model, which evaluates combinations of energy technologies.

This study employs a single model covering 10 ASEAN countries. During the analysis of the model, discussions were held with ASEAN governments regarding energy policies and actual situations. The discussions considered the assumptions used in the analysis and guided the prioritisation of technologies for introduction. The study serves as a second opinion to support ASEAN countries in developing their road maps for the energy transition towards carbon neutrality.

This is the third year of the study. In the first year, the focus was on developing the energy technology model and assessing the technology pathway for the ASEAN region. In the second year, the study centred on country-specific analyses for selected countries. This year, the analysis is updated.

Chapter 2

Analytical Framework

2.1. Institute of Energy Economics, Japan–New Earth Model

The analysis was conducted using the Institute of Energy Economics, Japan (IEEJ)–New Earth (NE) model, an optimal technology model developed by Otsuki et al. (2022, 2019), which encompasses the entire energy system. The analysis covers all 10 ASEAN countries from 2017 to 2060,[1] with representative years set as 2019,[2] 2030, 2040, 2050, and 2060. The focus of the study is on energy-related carbon dioxide (CO_2).

The IEEJ-NE model was formulated as a linear programming model. Like the market allocation model developed by the Energy Technology Systems Analysis Program of the International Energy Agency (IEA), the IEEJ-NE model considers the cost and performance of each energy technology as input values. The model then determines a single combination of the scale and operational patterns of individual energy technologies that minimises the total cost of the energy system, subject to constraints, such as CO_2 emissions and power supply–demand balance. The model covers both the energy conversion and end-use sectors (industry, transport, residential, and commercial), and incorporates more than 350 technologies within these sectors. It evaluates technology combinations based on factors such as capital costs, fuel costs, and CO_2 emissions for each technology. Included technologies range from low-carbon options, such as solar photovoltaic (PV) power generation, onshore and offshore wind power generation, hydrogen (H_2)-fired power generation, ammonia (NH_3)-fired power generation, negative-emission technologies such as direct air capture with carbon storage (DACCS), and bioenergy with carbon capture and storage (BECCS) (Table 2.1). The IEEJ-NE model provides a comprehensive representation of the energy system, from primary energy production and imports to secondary energy conversion, intraregional energy trade, CO_2 capture and storage (CCS), and final energy consumption. The model also assumes the consumption of various energy types across sectors (Figure 2.1).

The modelling of end-use sectors is based on data from the Economic Research Institute for ASEAN and East Asia (ERIA) outlook, the IEA energy balance table, and the IEEJ

[1] In the updated model, power plants that commenced operation between 2017 and 2020 were newly considered as existing capacity, with the base year set to 2019.

[2] Brunei Darussalam, Cambodia, Indonesia, the Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam.

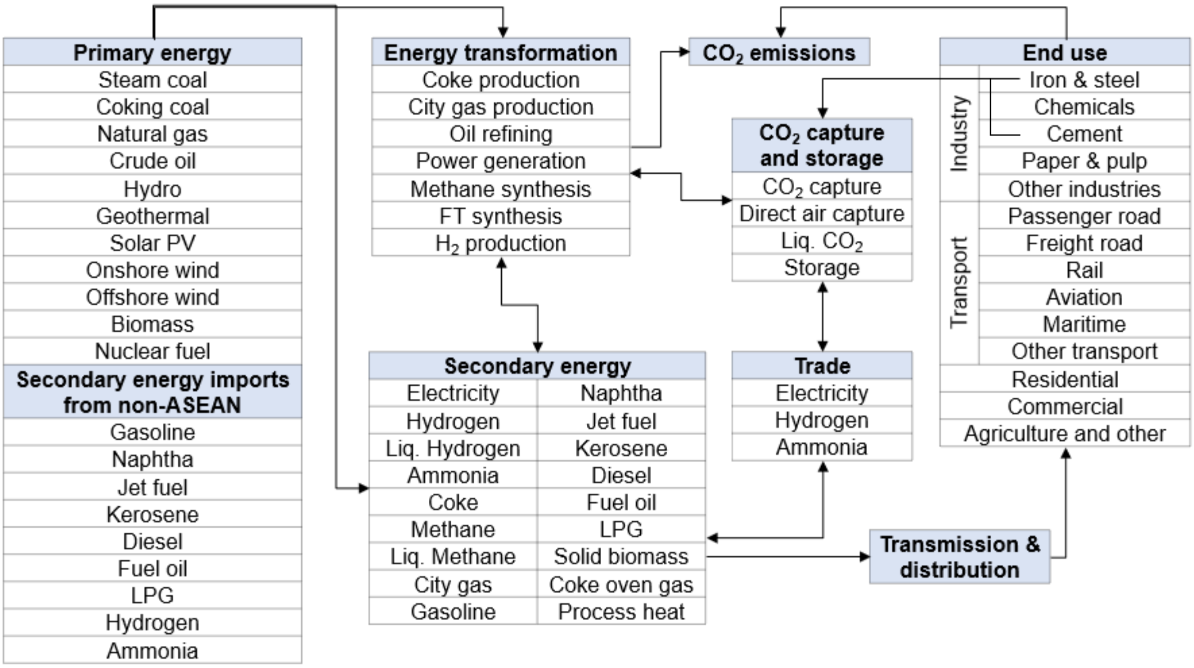
outlook. However, some sectors could not be fully simulated due to data limitations in the public domain (Figure 2.2).

Table 2.1. Selected Clean Technologies in the Model

Renewables	Solar photovoltaic, onshore wind, offshore wind, hydropower, geothermal, biomass
Nuclear	Light water reactor
CO_2 capture, utilisation, and storage	CO_2 capture: Chemical absorption, physical absorption, direct air capture CO_2 utilisation: Methane synthesis, FT liquid fuel synthesis CO_2 storage: Geological storage
H_2	Supply: Electrolysis, coal gasification, methane reforming, H_2 separation from NH_3, H_2 trade amongst ASEAN countries, H_2 imports from non-ASEAN countries Consumption: H_2 turbine, natural gas–H_2 co-firing, fuel cell electric vehicle, H_2-based direct reduced iron–electric arc furnace, fuel cell ship, H_2 aviation, H_2 heat for industries, fuel synthesis (methane, FT liquid fuel, NH_3)
NH_3	Supply: NH_3 synthesis, NH_3 trade amongst ASEAN countries, NH_3 imports from non-ASEAN countries Consumption: NH_3 turbine, coal–NH_3 co-firing, H_2 separation
Negative-emission technologies	Direct air capture with CCS (direct air CCS), biomass-fired power generation with CCS (bioenergy with carbon capture and storage)

ASEAN = Association of Southeast Asian Nations, CCS = carbon capture and storage, CO_2 = carbon dioxide, FT = Fischer-Tropsch, H_2 = hydrogen, NH_3 = ammonia.
Source: Author.

Figure 2.1. Modelled Energy System



CO_2 = carbon dioxide, H_2 = hydrogen, FT = Fischer-Tropsch, liq. = liquid, LPG = liquefied petroleum gas, PV = photovoltaic.
Source: Author.

Figure 2.2. Data Availability for Modelled End-use Sectors

		BRN	KHM	IDN	LAO	MYS	MMR	PHL	SGP	THA	VNM
Industry	Iron & Steel			✓		✓	✓	✓		✓	✓
	Cement			✓				✓		✓	✓
	Chemicals	✓		✓		✓	✓	✓	✓	✓	✓
	Paper & Pulp			✓			✓	✓		✓	✓
	Other Industries	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Transport	Passenger LDV	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Bus & Truck	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Rail			✓		✓	✓	✓	✓	✓	✓
	Aviation			✓		✓	✓	✓		✓	✓
	Navigation			✓		✓	✓	✓	✓	✓	✓
	Other Transport	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Residential & Commercial		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Agriculture and Other		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

BRN = Brunei Darussalam, KHM = Cambodia, IDN = Indonesia, LAO = Lao People's Democratic Republic, LDV = light-duty vehicle, MYS = Malaysia, MMR = Myanmar, PHL = Philippines, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Note: The assumptions regarding the manufacturing processes for iron and steel production in each country are based on data from the World Steel Association (2019). Cement sector assumptions, such as efficiency factors per country, are based on data from the Global Cement and Concrete Association (2019).
Source: Author.

In the model, the total cost—expressed as the sum of fixed costs, fuel costs, and variable costs, such as the operation and maintenance (O&M) expenses—is minimised using the objective function indicated in equation (1):

$$\boldsymbol{min\,TotalCost} = \sum_{y}\sum_{r}\sum_{i}\left(\boldsymbol{Fix_{y,r,i}} + \boldsymbol{Fuel_{y,r,i}} + \boldsymbol{Variable_{y,r,i}}\right)\cdot \boldsymbol{R_y} \qquad \mathbf{(1)}$$

Fix: fixed cost (the sum of the annualised capital cost and fixed O&M cost); *Fuel*: fuel cost; *Variable*: O&M cost; *R*: discount coefficient (discount rate is 8%); subscript *y* for year, *r* for region, and *i* for technology.

The model operates under typical constraints, including CO_2 emission limits for representative years, power supply–demand balance at each time slice, the maximum introducible capacity of each power source, and the load curve requirements (see Otsuki et al. [2022, 2019]). To ensure supply reliability when solar PV and wind power plants are not generating electricity, the model requires energy storage discharge (e.g. lithium-ion batteries), H_2-/NH_3-fired power generation, or other thermal power generation operated with CCS.

Power supply and demand are divided into 4-hour time resolutions to express the fluctuation of renewable energy output and the necessary amount of absorption means. One year for power supply–demand was split into 2,190 time slices (4-hour resolutions).

The model explicitly simulates co-firing technologies in both existing and new thermal power plants, such as coal co-fired with NH_3 and gas co-fired with H_2. The technologies included in the model are coal-fired power generation, co-firing coal and biomass (20%), co-firing coal and NH_3 (20%), integrated coal gasification combined cycle (IGCC), gas-fired power generation, gas combined (cycle power generation), co-firing gas and H_2 (H_2 rations: 20%, 40%, 60%, 80%), oil-fired power generation, hydropower, geothermal power, solar PV, onshore and offshore wind power, biomass-fired power generation, nuclear power, H_2-fired power generation (available after 2050), NH_3-fired power generation (available after 2050), pumped hydropower storage, lithium-ion battery storage, and H_2 storage tanks.

For H_2 and NH_3 supply and demand, the model simulates both domestic production within ASEAN countries and imports from outside the region. The model assumes that H_2 can be used for power generation, fuel synthesis, industry, and transport, whilst NH_3 is used only for power generation.

The model considers negative-emission technologies, specifically direct air capture with DACCS and BECCS. Direct air capture (DAC) extracts CO_2 directly from the atmosphere. The captured CO_2 can either be permanently stored in deep geological formations, achieving negative emissions, or combined with H_2 to produce synthetic fuels through carbon recycling. Currently, 17 DAC plants operate worldwide, collectively capturing less than 10,000 tonnes of CO_2 per year (IEA, 2023a). However, DAC requires a large amount of energy and remains costly at US$600 per tonne of carbon dioxide (tCO_2) annually. Nevertheless, with rising carbon prices aimed at achieving carbon neutrality, DAC could become cost-competitive.

2.2. Preconditions

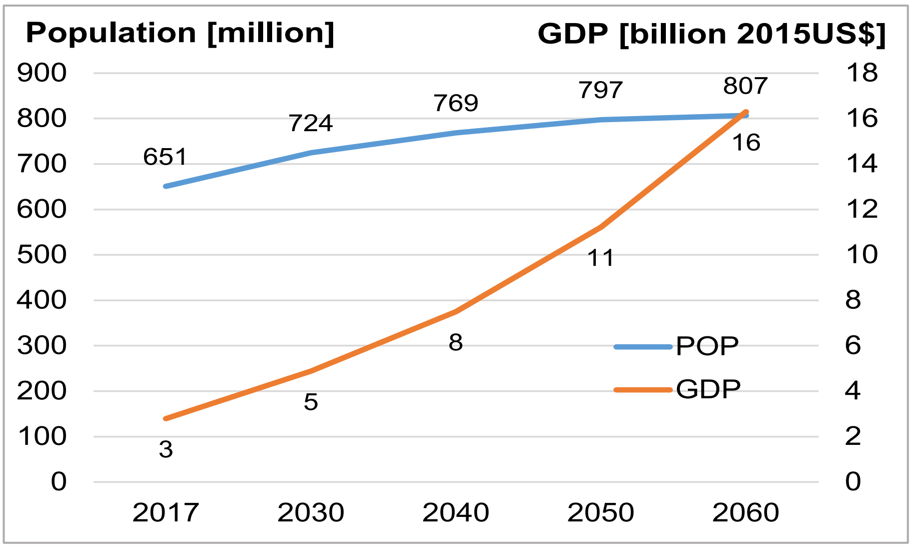
2.2.1. Key assumptions

(a) Economic indicators

Estimating future energy demand requires certain assumptions about gross domestic product (GDP) and population. GDP projections are based on data from ERIA (Figure 2.3–Figure 2.6) whilst population estimates are drawn from the United Nations (UN) (2023).

GDP projections for Southeast Asian countries are subject to significant uncertainty due to the variability in future economic growth rates. For this analysis, the GDP growth rates from the ERIA outlook (ERIA, 2023a) were adopted, as few institutions offer a unified long-term economic outlook for all 10 Southeast Asian countries through 2050. The ERIA projections are developed by a team of experts with country-specific knowledge, enhancing the situation. In contrast, population projections are generally less uncertain than GDP forecasts. This study adopts the medium variant scenario, considered a moderate projection within the UN's set of population scenarios. This variant is also widely used in other energy supply–demand analyses, including those by IEA (2023b), allowing for more effective comparisons between studies.

Figure 2.3. Population (million) and GDP (2015 US$ billion) for ASEAN Countries

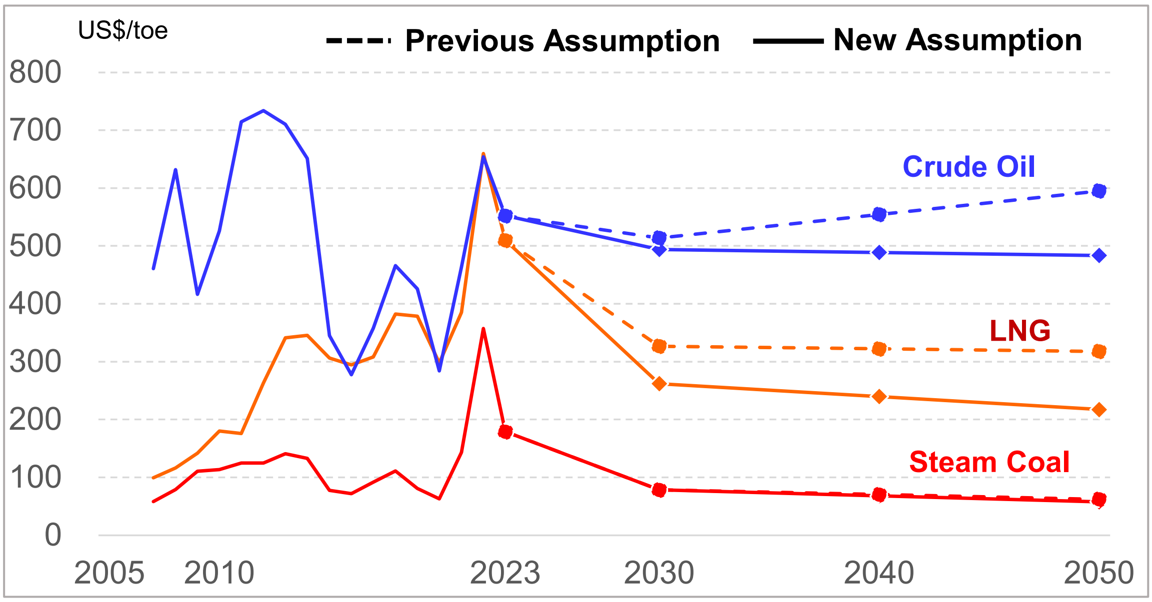


ASEAN = Association of Southeast Asian Nations, GDP = gross domestic product, POP = population.
Source: Based on Economic Research Institute for ASEAN and East Asia (2023a).

(b) Fossil fuel prices

This study projects future fossil fuel prices in ASEAN based on the stated policies scenario of IEA (2023b), which reflects the current energy circumstances (Figure 2.4). Fossil fuel prices surged to extremely high levels in 2022, driven by the Ukraine crisis and sanctions imposed on Russia, which tightened the global fossil fuel supply. In this revision, projected prices have been adjusted downward to reflect the recent decline in global energy prices.

Figure 2.4. Future Fossil Fuel Prices in ASEAN



ASEAN = Association of Southeast Asian Nations, LNG = liquified natural gas, toe = tonne of oil equivalent.

Source: Estimated by the Institute of Energy Economics, Japan, based on the stated policies scenario of IEA (2022 and 2023b).

(c) Grid connections amongst ASEAN countries

ASEAN countries initiated the ASEAN Power Grid concept in 2007, which has since facilitated the construction and operation of multiple cross-border interconnectors. By 2021, the total transmission capacity had reached 5.7 gigawatts (GW). Further expansion of regional power grids remains a priority for ASEAN Member States. This study applies a total transmission capacity constraint of 126 GW,[3] total including regional transmission lines within Indonesia and Malaysia, based on planned infrastructure developments and feedback received from individual countries.

[3] 54 GW for international transmission only.

(d) Hydrogen and ammonia imports from non-ASEAN countries

The maximum permissible imports of H_2 and NH_3 from outside ASEAN are assumed to be up to 15% of the total baseline primary energy supply in 2040, rising to 30% after 2050. However, specific adjustments were made for Indonesia and Brunei Darussalam following consultations with national representatives: Indonesia's import limits are set at 5% in 2040 and 8% after 2050, whilst Brunei Darussalam is assumed to import no H_2 and NH_3. The assumed import prices of H_2 and NH_3, inclusive of transport costs, are presented in Table 2.2. These prices are based on Japan's long-term targets (Ministerial Council on Renewable Energy, Hydrogen and Related Issues, 2023). Although highly ambitious, they remain feasible compared with IEA's (2020) estimate of a global average hydrogen production cost (excluding transport) of US$0.11–US$0.30 per normal cubic metre of hydrogen (Nm^3-H_2) or US$1.2–US$3.3 per kilogramme of H_2 by 2050.

The study does not specify the production method for imported H_2, whether green H_2 produced via electrolysis powered by renewable electricity or blue H_2 derived from fossil fuels combined with CCS. No specific H_2-exporting countries are identified. However, due to geographic proximity and clean hydrogen production potential, Australia, India, and Middle Eastern countries are considered likely candidates.

Table 2.2. Price of Imported Hydrogen and Ammonia (US cent/Nm^3-H_2)

Fuel	2030	2040	2050	2060
Hydrogen	30.0	25.0	20.0	17.5
Ammonia	17.5	16.9	16.3	15.6

H_2 = hydrogen, Nm^3 = normal cubic metre.
Source: Author, based on Japan's long-term targets (Ministerial Council on Renewable Energy, Hydrogen and Related Issues, 2023).

(e) Annual CO_2 storage capacity

Cumulative CO_2 storage potential and assumed annual CO_2 storage capacities are shown in Table 2.3 and Table 2.4, respectively. The annual storage capacity is estimated at 0.3% of each country's cumulative CO_2 storage potential in 2040, increasing to 0.6% in 2050 and 0.9% in 2060, representing the medium scenario.[4] All three scenarios ensure sustainable CO_2 storage capacity beyond 2060. Accurately estimating CO_2 storage potential remains difficult. However, IEA (2021) has reported that ASEAN countries possess abundant CO_2 storage potential, with a combined cumulative capacity of 133.4 gigatonnes of CO_2 ($GtCO_2$) across six countries: Brunei Darussalam, Indonesia, Malaysia,

[4] In the previous model, 0.5% for 2040, 0.8% for 2050, and 1.1% for 2060 were assumed, close to the current high case.

the Philippines, Thailand, and Viet Nam. This study considers the possibility of cross-border CO_2 imports and exports amongst ASEAN countries.

Table 2.3. Cumulative CO_2 Storage Potential

($GtCO_2$)	Depleted Oil/Gas Fields, Enhanced Oil Recovery	Aquifers	Total
Brunei Darussalam	0.6	-	0.6
Indonesia	-	8.4	8.4
Malaysia	-	80	80
Philippines	0.3	22	22.3
Thailand	1.4	8.9	10.3
Viet Nam	1.4	10.4	11.8

CO_2 = carbon dioxide, $GtCO_2$ = gigatonnes of carbon dioxide.
Source: IEA (2021).

Table 2.4. Annual CO_2 Storage Capacity
(share of cumulative potential)

	2040	2050	2060
Low	0.2%	0.4%	0.6%
Medium (Adopted)	0.3%	0.6%	0.9%
High	0.4%	0.8%	1.2%

CO_2 = carbon dioxide.
Source: Author.

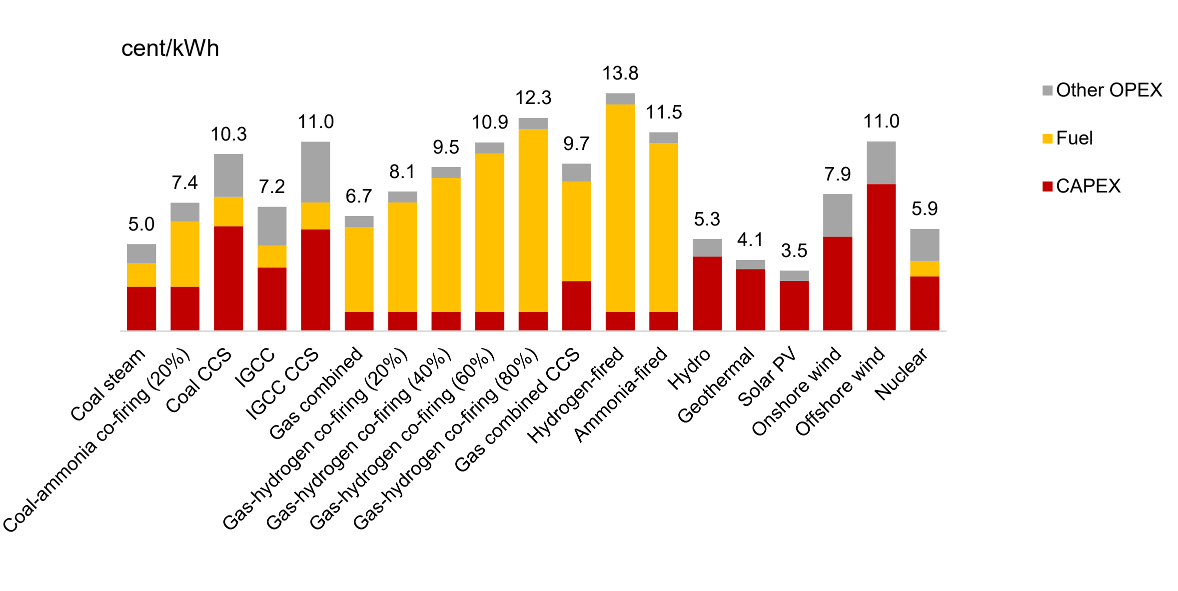
(f) Supply potential of biofuels for vehicles

In transport, the model considers the expanded use of biofuels as well as the electrification of vehicles. The biofuel supply potential is assumed to increase in proportion to the demand for road transport throughout the study period.

(g) Power generation technologies

Parameters for power generation technologies were sourced from publicly available reports, such as those by the Danish Energy Agency (2021), and supplemented with data provided by ASEAN countries. The capacity factors of various power generation technologies and the required storage battery capacity are determined endogenously within the model.

Figure 2.5. Levelised Cost of Electricity in 2050 for Indonesia



CAPEX = capital expenditure, CCS = carbon dioxide capture and storage, H_2 = hydrogen, IGCC = integrated coal gasification combined cycle, kWh = kilowatt-hour, Nm^3 = normal cubic metre, OPEX = operating expenditure, PV = photovoltaic.

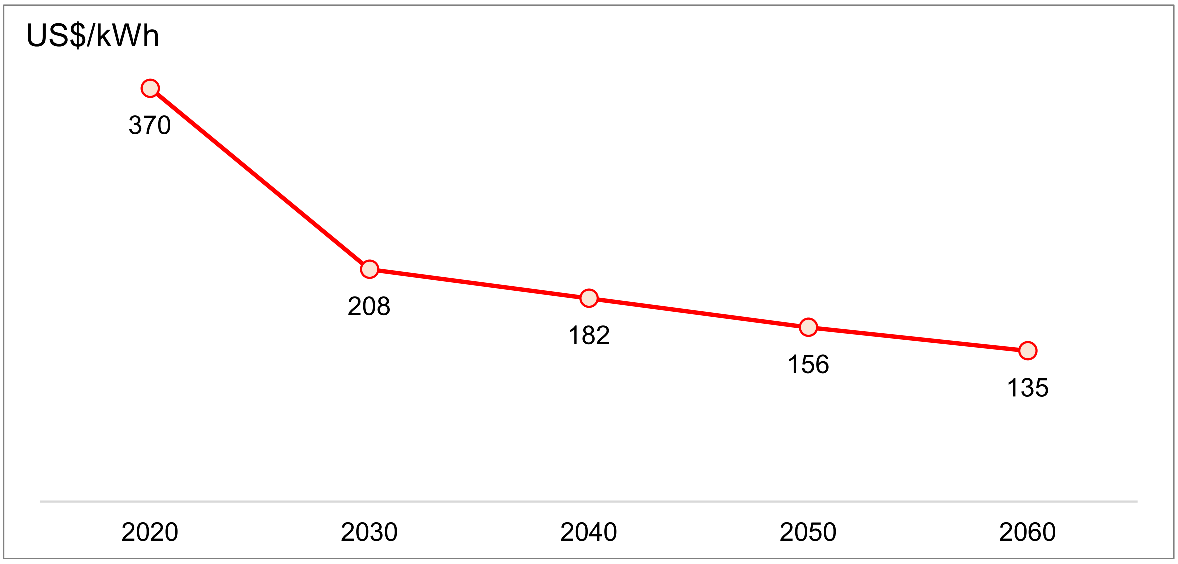
Note: H_2 price: US$0.20/$Nm^3$-$H_2$; ammonia price: US$0.16/Nm^3-H_2; capacity factors: 40% for hydropower, 80% for geothermal, 15% for solar PV, 20% for onshore wind, 30% for offshore wind, 80% for nuclear, 60% for the rest of the technologies.

Source: Estimated by the Institute of Energy Economics, Japan, based on Danish Energy Agency (2021).

(h) Energy storage technologies

The model includes pumped hydro storage, lithium-ion batteries, and compressed H_2 tanks as energy storage technologies. The required capacities for lithium-ion batteries and compressed H_2 tanks are determined endogenously within the model simulations. Lithium-ion battery manufacturing costs are expected to decline substantially over time, with future cost reductions based on forecasts from the National Renewable Energy Laboratory of the United States (Figure 2.6).

Figure 2.6. Assumed Lithium-ion Battery Cost

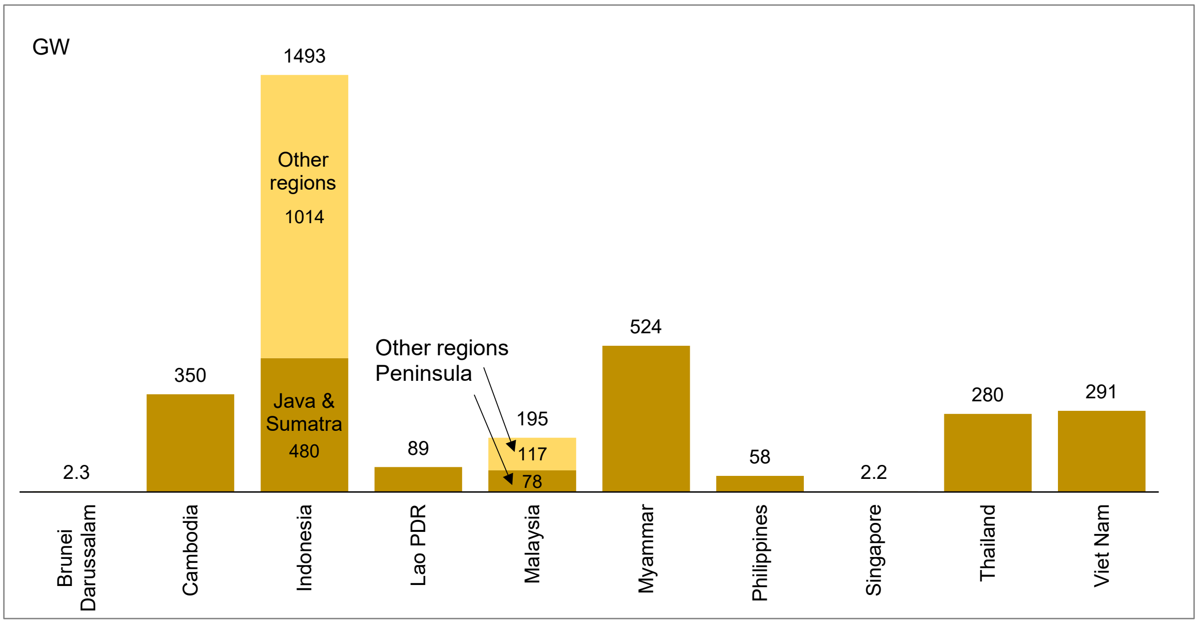


kWh = kilowatt-hour.
Source: Cole and Frazier (2020).

(i) Upper limits of solar photovoltaic capacity

The estimated upper limit for solar PV capacity across ASEAN is 3,284 GW, derived from geographic information system data and country-specific information (Figure 2.7).

Figure 2.7. Upper Limits of Solar Photovoltaic Capacity

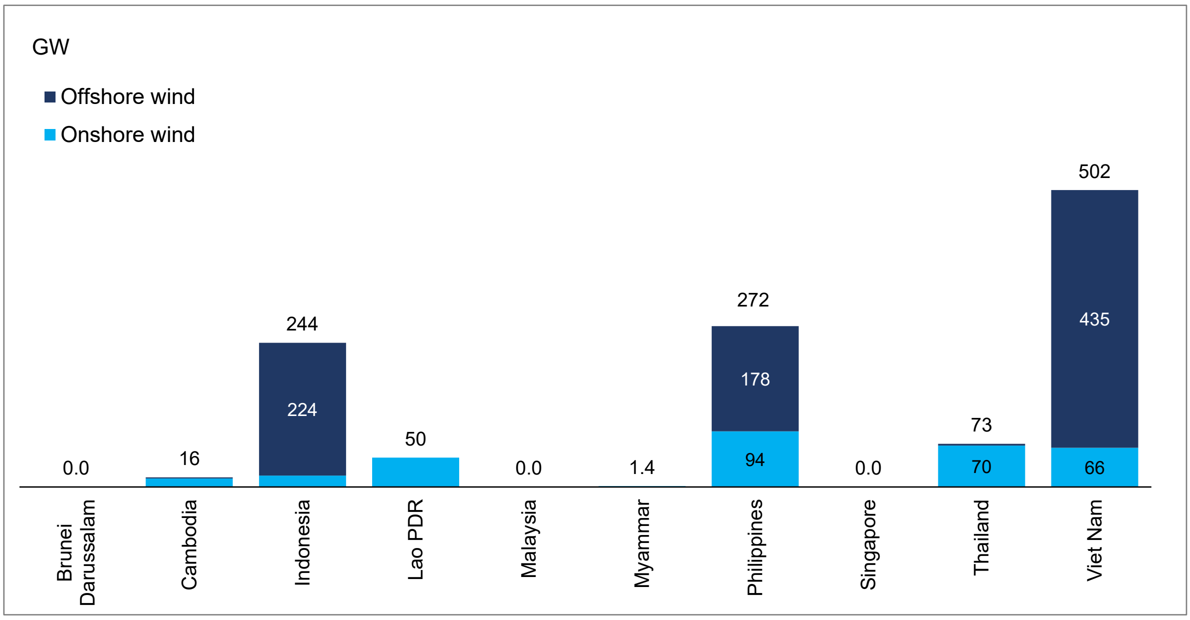


GW = gigawatts, Lao PDR = Lao People's Democratic Republic.
Source: Author.

(j) Upper limits of wind power capacity

The model estimates the maximum wind power generation capacity separately for onshore and offshore installations. These limits, based on geographic information system data and national information, are set at 315 GW for onshore wind and 843 GW for offshore wind (Figure 2.8).

Figure 2.8. Upper Limits of Wind Power Capacity

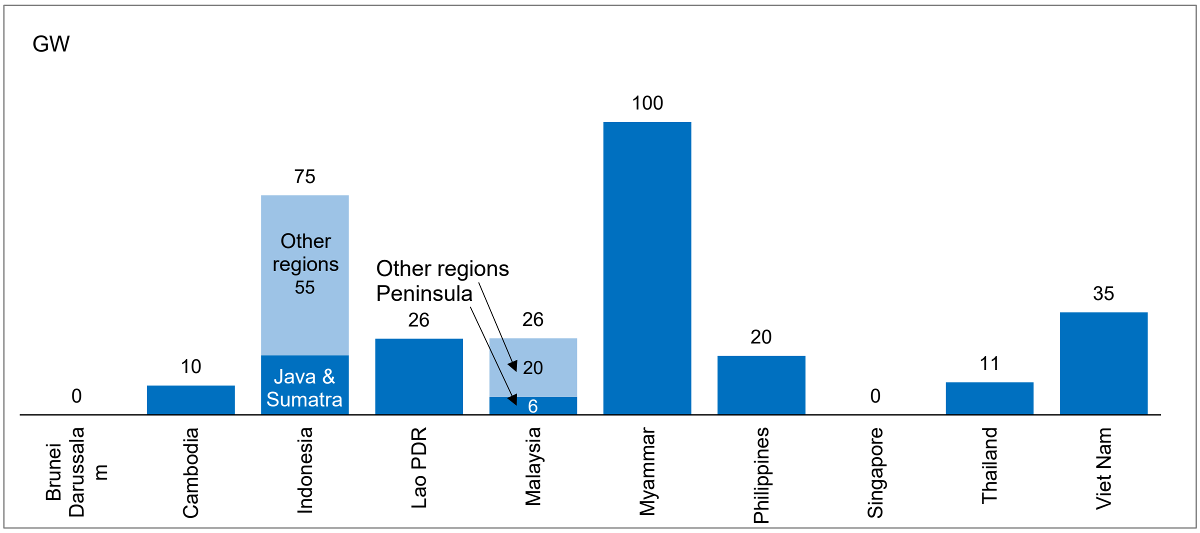


GW = gigawatt, Lao PDR = Lao People's Democratic Republic.
Source: Author.

(k) Upper limit of hydropower capacity

The upper limit for hydropower capacity across ASEAN is estimated at 304 GW based on data from PwC (2018) and country-specific contributions provided by ASEAN Member States (Figure 2.9).

Figure 2.9. Upper Limit of Hydropower Capacity

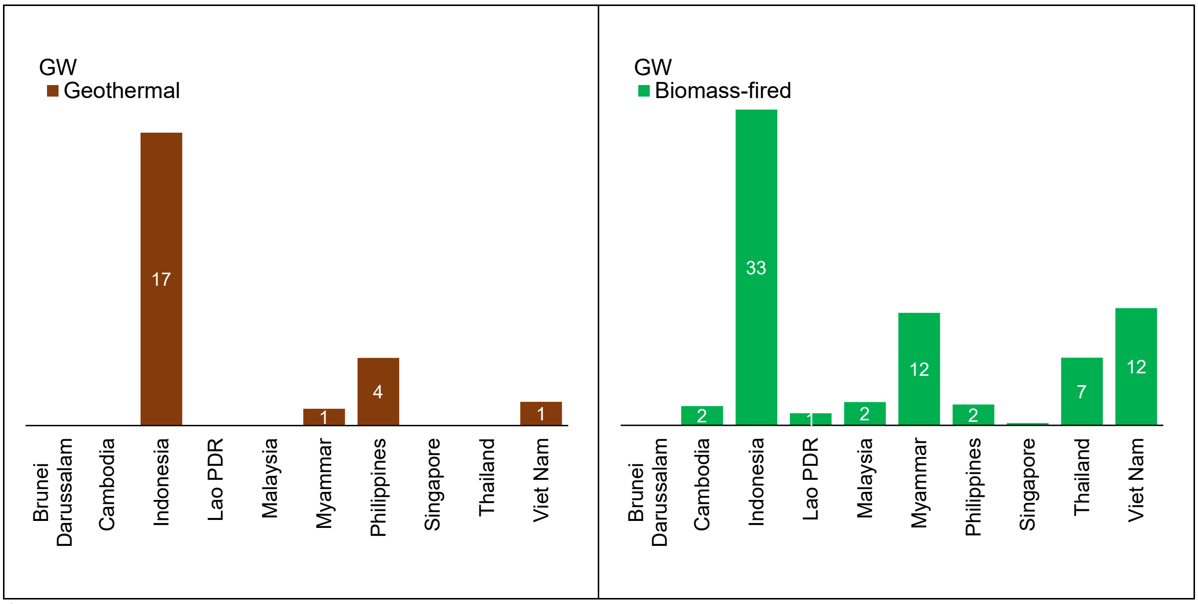


GW = gigawatt., Lao PDR = Lao People's Democratic Republic.
Source: Author.

(l) Upper limits of geothermal and biomass power capacity

The upper limits for geothermal and biomass-fired power generation capacities in ASEAN are estimated to be 24 GW and 71 GW, respectively. Indonesia, in particular, demonstrates relatively high potential for both types of power generation (Figure 2.10).

Figure 2.10. Upper Limits of Geothermal and Biomass Power Capacity



GW = gigawatt, Lao PDR = Lao People's Democratic Republic.
Source: Author.

2.2.2. Case settings

Like the previous report,[5] this study analyses the CN2050/2060 case, which reflects the nationally declared carbon neutrality targets and considers carbon sinks in Brunei Darussalam, Cambodia, Indonesia, Malaysia, Myanmar, Thailand, and Viet Nam. These assumptions were developed through discussions with each country (Table 2.5).

Table 2.5. Assumed Carbon Neutrality Target Years and Carbon Sinks in CN2050/2060

Country	CN Target Year	Energy-related CO_2 Emission Reduction Target from 2017	Assumed Natural Carbon Sink (LULUCF) in the Target Year
Brunei Darussalam	2050	-50% (3.5 Mt)	Information from Brunei (-4.4 Mt)
Cambodia	2050	+37% (26.0 Mt)	2050 target of the LTS4CN scenario in the LTS (-50.2 Mt)
Indonesia	2060	-50% (245.5 Mt)	2050 target of the LCCP scenario in the LTS (-300 Mt)
Lao PDR	2050	-100%	-
Malaysia	2050	-22% (164.0 Mt)	2016 value of the inventory (-241Mt)
Myanmar	2060	-60% (12.0 Mt)	2040 target of the unconditional NDC (-13 Mt)
Philippines	2060	-100%	-
Singapore	2050	-100%	-
Thailand	2050	-61% (95.5 Mt)	2050 target of the Carbon Neutrality Pathway in the LTS (-120 Mt)
Viet Nam	2050	-70% (57.3 Mt)	2030 target of the unconditional NDC (-59 Mt)

CN = carbon neutrality; CO_2 = carbon dioxide; Lao PDR = Lao People's Democratic Republic; LULUCF = land use, land-use change, and forestry; LTS = long-term strategy; LTS4CN = long-term strategy for carbon neutrality; LCCP = low-carbon scenario compatible with Paris Agreement target; Mt = metric tonne; NDC = nationally determined contribution.
Source: Author.

[5] ERIA Research Project 2022 No. 05 (ERIA, 2022) and ERIA Research Project 2023 No. 30 (ERIA, 2023b).

Chapter 3

Major Updates to the Model

3.1. Re-estimation of Energy Demand

3.1.1. General method of demand estimation

The energy model used in this project requires energy demand assumptions as exogenous variables. For this year's study, the research team has refined the methodology for estimating energy demand and incorporated the most recent data on energy supply, demand, and socio-economic factors. This section outlines the methodology employed for estimating energy demand. The process is outlined as follows:

(i) Assumptions regarding GDP and population are set exogenously.

(ii) Subsequently, several socio-economic parameters closely related to energy demand are estimated using econometric methods and classified by sector. In the case of the industrial sector, the parameters include the production volume of energy-intensive materials such as steel, cement, pulp and paper, and chemical products. In the case of transport, the number of vehicles is estimated as a key indicator of energy demand. In the residential and commercial sector, GDP or GDP per capita serves as a direct determinant of energy demand. These parameters are estimated through econometric regression based on population and GDP data.

(iii) Energy consumption is subsequently deriving energy intensity from sectoral activity indicators and actual energy consumption data. The results of this estimation serve as input data for the IEEJ-NE model and as key assumptions for optimisation calculations.

Throughout this year's research project, the methodology has been continually refined through the integration of up-to-date data collection and advanced econometric estimation works.

3.1.2. Macroeconomic assumption

(a) Gross domestic product

The GDP assumption mainly relies on the ERIA outlook (ERIA, 2023a), which projects an annual growth rate of 4.1%. For short-term growth rates, the International Monetary Fund (2024) projections are referenced. In general, these projections are lower than those presented in the previous outlook (ERIA, 2020), which anticipated a growth rate of 4.2%. The revision reflects the prolonged impact of the coronavirus disease (COVID-19) pandemic, the ongoing Ukrainian crisis, and the resulting global inflation, all of which have a negative impact on the GDP assumption.

Table 3.1. Gross Domestic Product Assumption

(US$ million)

	2019	2030	2040	2050	2060
Brunei	13	18	22	27	28
Cambodia	21	41	75	134	209
Indonesia	950	1,898	3,033	4,711	7,123
Lao PDR	16	27	48	83	129
Malaysia	333	483	642	817	1,001
Myanmar	69	118	201	327	511
Philippines	351	667	1,134	1,847	2,899
Singapore	334	451	560	683	830
Thailand	432	582	797	1,093	1,500
Viet Nam	273	594	991	1,503	2,073

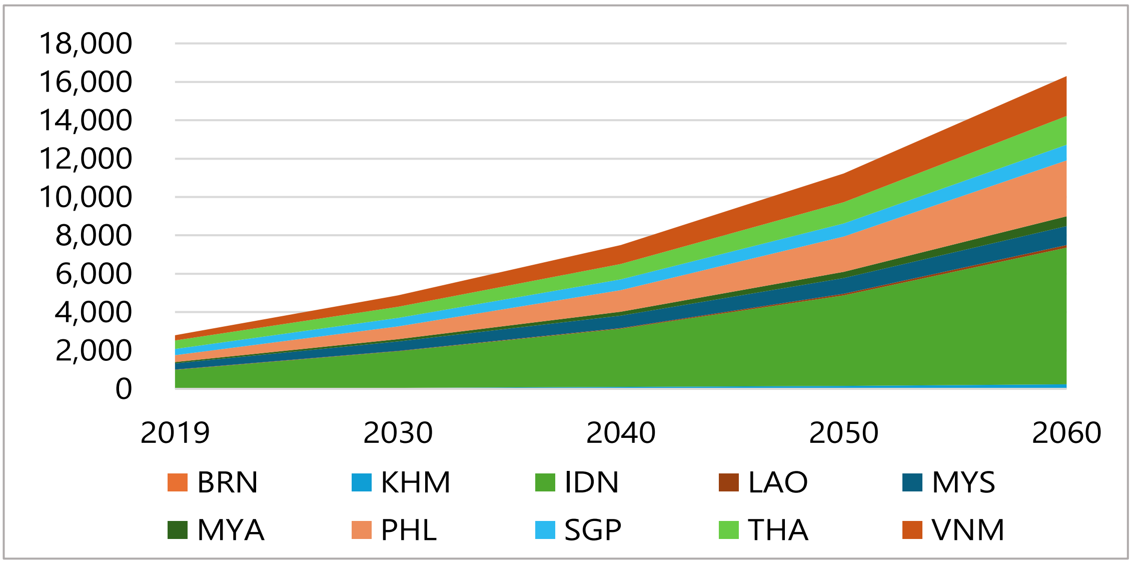
Lao PDR = Lao People's Democratic Republic.

Note: Constant price 2015.

Source: Estimated from Economic Research Institute for ASEAN and East Asia (2023a) and International Monetary Fund (2024).

Figure 3.1. Gross Domestic Product Assumption

(US$ thousand)



BRN = Brunei Darussalam, IDN = Indonesia, KHM = Cambodia, LAO = Lao People's Democratic Republic, MYA = Myanmar, MYS = Malaysia, PHL = Philippines, SGP = Singapore, THA = Thailand, VNM = Viet Nam.

Source: Estimated from Economic Research Institute for ASEAN and East Asia (2023a) and International Monetary Fund (2024).

(b) Population

The population assumption is based on UN (2022), which provides population projections up to the year 2100 for all countries. In consideration of varying perspectives, this analysis adopts the medium variant scenario to represent moderate demographic trends.

Table 3.2. Population Assumption

(thousand)

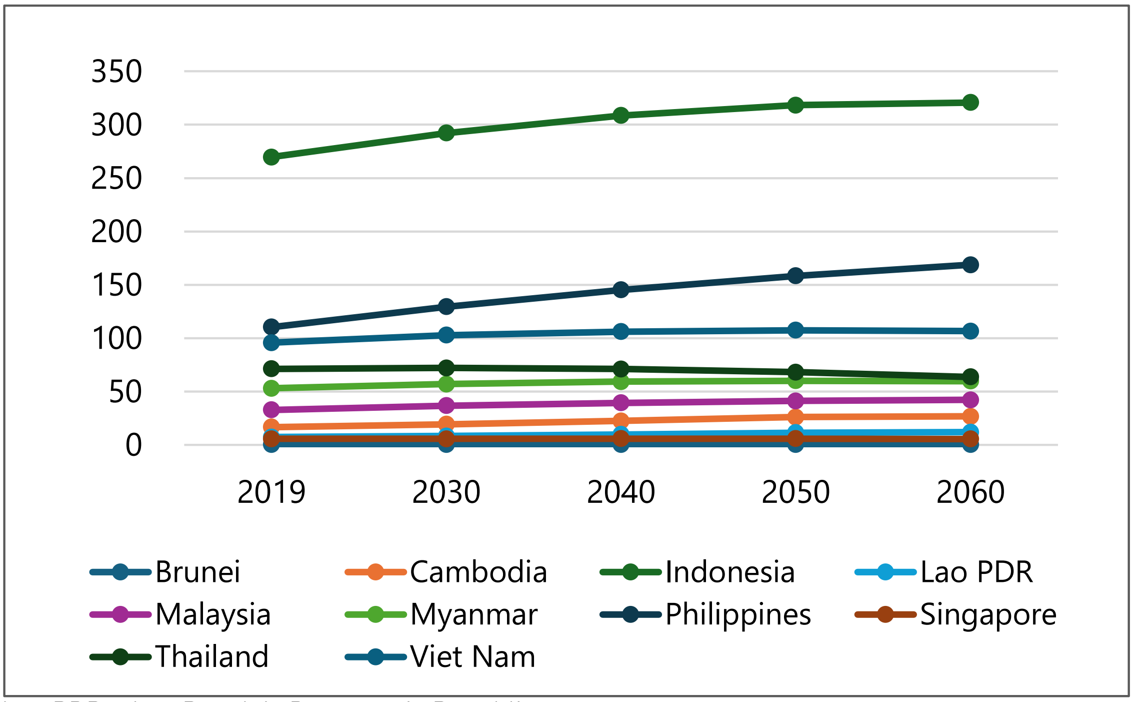
	2019	2030	2040	2050	2060
Brunei	438	474	494	501	492
Cambodia	16,730	19,420	22,540	26,160	26,746
Indonesia	269,583	292,212	308,678	318,249	320,809
Lao PDR	7,300	8,400	9,800	11,400	11,877
Malaysia	32,804	36,727	39,382	41,180	42,237
Myanmar	53,040	57,033	59,261	60,120	59,845
Philippines	110,381	129,508	145,313	158,406	168,748
Singapore	5,704	5,740	5,895	5,839	5,669
Thailand	71,308	72,109	71,062	68,113	63,648
Viet Nam	95,777	102,870	106,193	107,415	106,622

Lao PDR = Lao People's Democratic Republic.

Source: United Nations (2022).

Figure 3.2. Population Assumption

(million)



Lao PDR = Lao People's Democratic Republic.
Source: United Nations (2022).

3.1.3. Key parameters for demand sectors

The World Steel Association (2023) provides data on crude steel production in Southeast Asian countries, which served as the basis for estimation. A correlation was identified between steel production and GDP over the past 20 years, including data from non-ASEAN regions. This correlation was used to estimate the elasticity of steel production growth with respect to future GDP growth, as few outlooks for steel production in Southeast Asia countries are available. These estimates were then applied to the outlook for each country.

A similar methodology was used to estimate the production of other materials. Cement production estimates were based on the figures provided by the United States Geological Survey (2023). In addition, vehicle ownership figures, a key parameter for transport, were available from ASEANStat (2022) and the Japan Automobile Manufacturers Association (2023). Based on the observed correlation between vehicle ownership and GDP per capita, the same econometric methodology was employed to project the future number of vehicles per capita.

Table 3.3. Crude Steel Production

(thousand tonnes)

	2019	2030	2040	2050	2060
Brunei	0	0	0	0	0
Cambodia	0	0	0	0	0
Indonesia	8,600	22,313	30,884	38,275	46,415
Lao PDR	0	0	0	0	0
Malaysia	6,900	8,074	9,265	9,366	9,154
Myanmar	350	641	846	954	1,005
Philippines	1,400	2,426	3,631	4,862	6,393
Singapore	766	695	899	1,056	1,248
Thailand	4,246	6,762	8,647	10,206	12,158
Viet Nam	17,500	35,135	49,979	60,139	66,842

Lao PDR = Lao People's Democratic Republic.
Source: Estimated from World Steel Association (2023).

Table 3.4. Cement Production

(thousand tonnes)

	2019	2030	2040	2050	2060
Brunei	163	185	233	263	251
Cambodia	2,014	4,047	7,397	12,273	18,066
Indonesia	70,000	111,038	171,050	234,572	312,954
Lao PDR	2,497	4,257	7,529	12,180	17,664
Malaysia	21,920	29,242	33,684	33,910	32,738
Myanmar	2,807	5,826	7,576	8,371	8,614
Philippines	29,782	53,732	73,928	89,587	104,920
Singapore	0	0	0	0	0
Thailand	43,284	61,379	72,671	78,750	85,401
Viet Nam	97,000	162,737	223,070	256,365	269,732

Lao PDR = Lao People's Democratic Republic.
Source: Estimated from United States Geological Survey (2023).

Table 3.5. Vehicle Ownership

(thousand)

	2019	2030	2040	2050	2060
Brunei	285	326	382	396	313
Cambodia	60	115	202	302	369
Indonesia	20,846	37,867	61,583	87,640	118,548
Lao PDR	215	403	683	994	1,214
Malaysia	16,054	22,449	27,483	29,630	24,361
Myanmar	1,007	1,793	3,405	5,205	9,255
Philippines	5,029	9,007	15,724	21,957	34,279
Singapore	812	1,005	1,180	1,224	1,290
Thailand	18,513	24,994	32,166	37,136	35,759
Viet Nam	3,538	10,125	15,456	19,190	20,877

Lao PDR = Lao People's Democratic Republic.

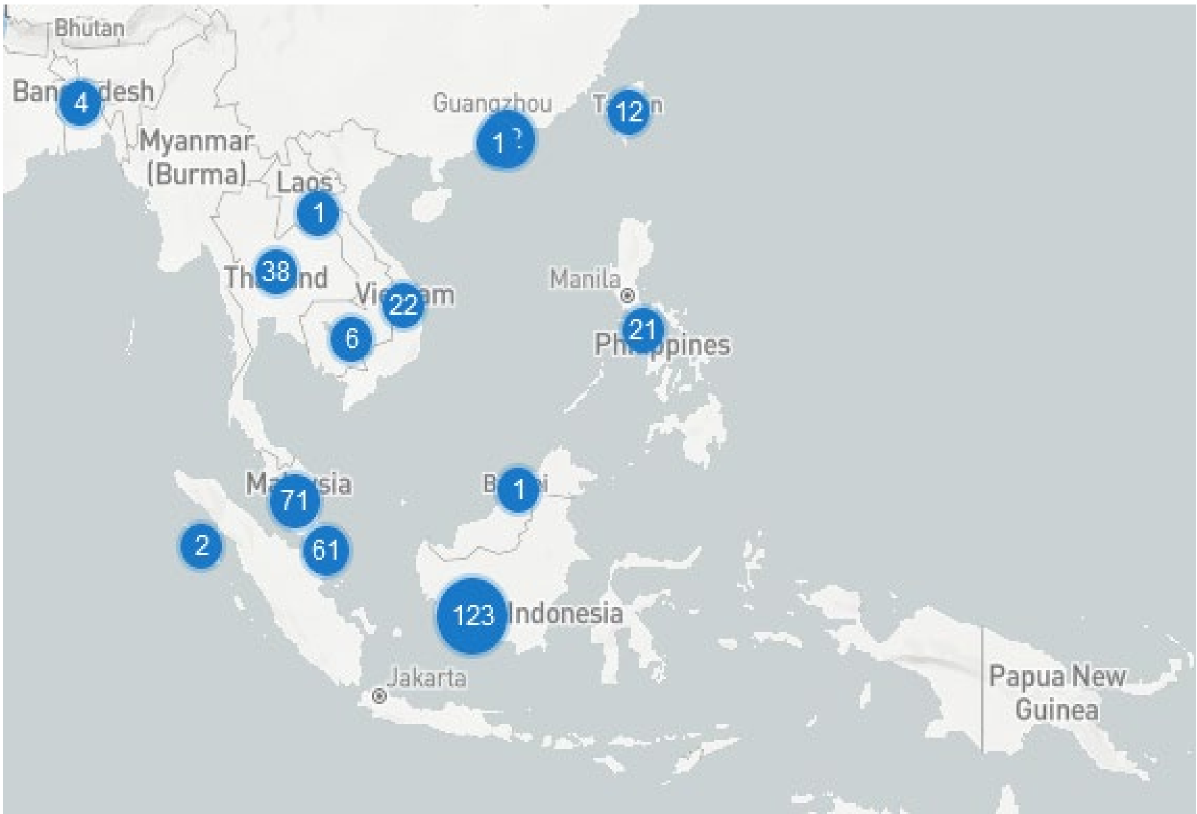
Source: Estimated from ASEANStats (2022) and the Japan Automobile Manufacturers Association (2023).

3.1.4. Additional demand on data centres

Global data centre power consumption has reached unprecedented levels, driven by the explosive growth of cloud computing, emerging artificial intelligence technologies, and digital transformation initiatives. Current projections by IEA (2024) suggest that data centre power demand could reach 1,050 terawatt hours (TWh), or about 4% of global power generation, by 2026. However, significant uncertainties remain regarding technological advances in energy efficiency and the impact of emerging computing paradigms. Taking these dynamics into account is crucial when analysing future energy decarbonisation road maps.

As of July 2024, the ASEAN region hosts 340 data centres, with one-third concentrated in Indonesia. Singapore, however, remains home to the most advanced companies. The demand outlook was estimated by dividing the global demand forecast (Japan Science and Technology Agency, 2022) by the current number of data centres. It should be noted, however, that this estimate is based on underdeveloped statistics, and future demand remains highly uncertain due to uncertainties in both future information technology demand and power consumption efficiency.

Figure 3.3. Data Centres in Southeast Asia (July 2024)



Source: Data Center Map (2024).

Table 3.6. Data Centre Demand Projection

(terawatt hour)

	2030	2040	2050
Brunei	0.1	0.2	0.9
Cambodia	0.0	0.0	0.0
Indonesia	8.0	25.8	110.3
Lao PDR	0.1	0.2	0.9
Malaysia	4.6	14.9	63.6
Myanmar	0.1	0.4	1.8
Philippines	1.4	4.4	18.8
Singapore	4.0	6.4	16.4
Thailand	2.5	8.0	34.1
Viet Nam	1.4	4.6	19.7

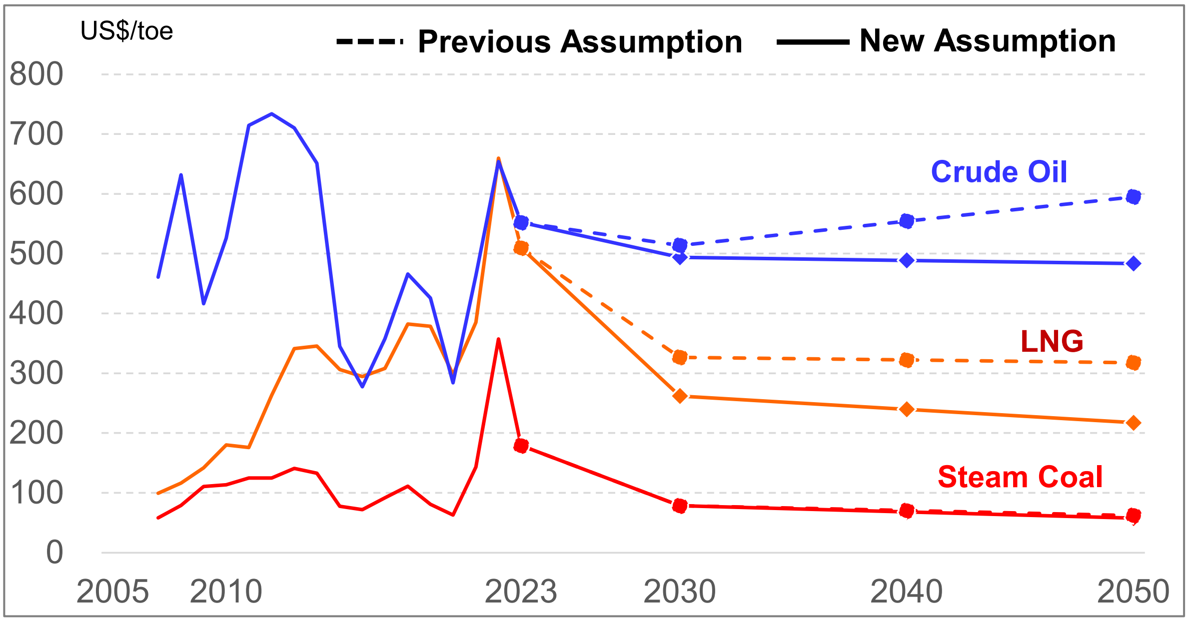
Lao PDR = Lao People's Democratic Republic.

Source: Estimated From Data Center Map (2024) and Japan Science and Technology Agency (2022).

3.2. Fossil Fuel Price

The latest outlook from IEA (2023b) has been incorporated into the fossil fuel price updates. According to this assumption, oil and natural gas prices, which had previously been assumed to be significantly elevated, have returned to levels observed prior to the onset of the crisis in Ukraine.

Figure 3.4. Fossil Fuel Price Assumption

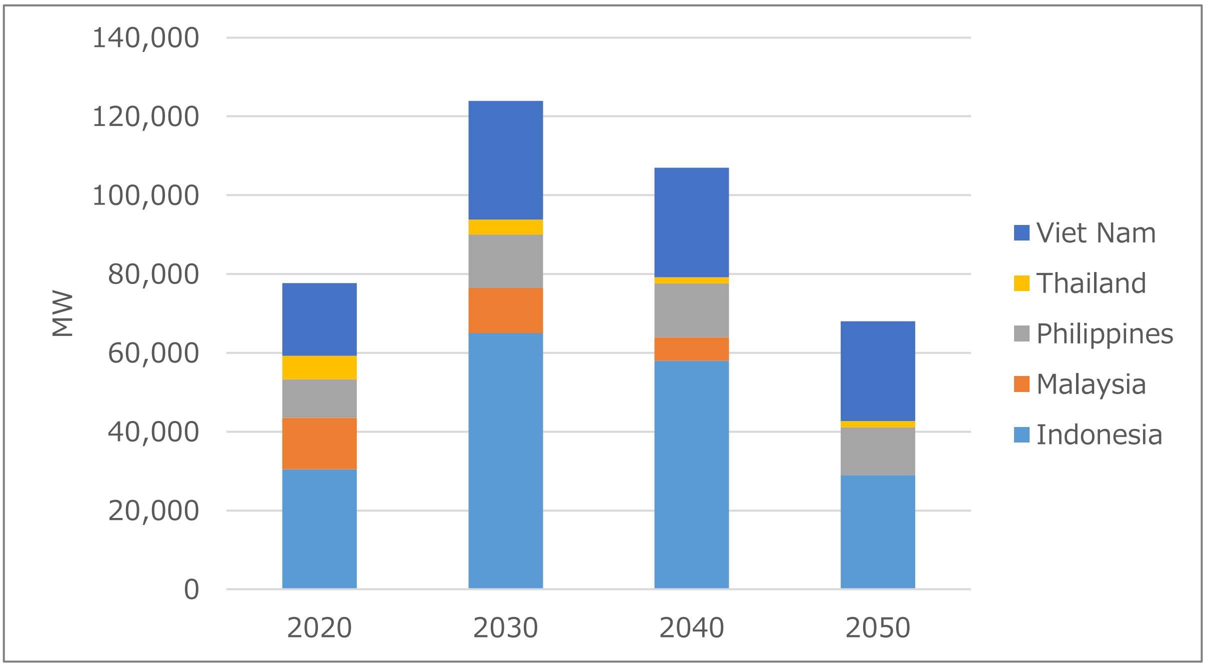


LNG = liquified natural gas, toe = tonne of oil equivalent.
Source: Estimated by the Institute of Energy Economics, Japan, based on the Stated Policies Scenario of the International Energy Agency (2022, 2023b).

3.3. Power Plant Capacity and Base Year

The base year of the previous model, set in 2017, is outdated. In the updated model, power plants that commenced operation in 2017–2020 are incorporated as part of existing capacity, with the base year adjusted to 2019. The capacity of coal-fired power plants is exogenously given in the model until 2060, based on Figure 3.5. For Indonesia, Malaysia, the Philippines, Thailand, and Viet Nam, the assumed capacity includes existing power plants and new installations, reflecting each country's national outlook as presented in ERIA (2024).

Figure 3.5. Outlook for Coal-fired Power Plant Capacity in Five Countries



MW = megawatts.
Source: Author, based on Economic Research Institute for ASEAN and East Asia (2024).

3.4. Regional Division of Indonesia and Malaysia

The previous model treated each country as a single node and assumed that renewable energy resources in remote regions, such as Kalimantan, could be used exclusively for hydrogen production through water electrolysis. In this study, Indonesia has been divided into five regions and Malaysia into three regions. Hydrogen transport amongst countries and regions, using ships and pipelines, has been explicitly considered. Regional service demand was estimated by prorating population, GDP, vehicle stock, and other factors (Table 3.7 and Table 3.8). The upper limit for regional renewable energy resources was either derived from literature values or prorated based on land area.

Table 3.7. Examples of Regional Statistics for Indonesia (2022)

	Population (2022)	Real GDP (2022)	Stock of Passenger Cars (2022)	Area
Java–Bali	58%	60%	71%	7%
Sumatra	22%	21%	16%	25%
Kalimantan	6%	8%	5%	28%
Sulawesi	7%	7%	6%	10%
Maluku–Nusa Tenggara–Papua	7%	4%	2%	29%

GDP = gross domestic product.
Source: BPS-Statistics Indonesia (2023).

Table 38. Examples of Regional Statistics for Malaysia (2022)

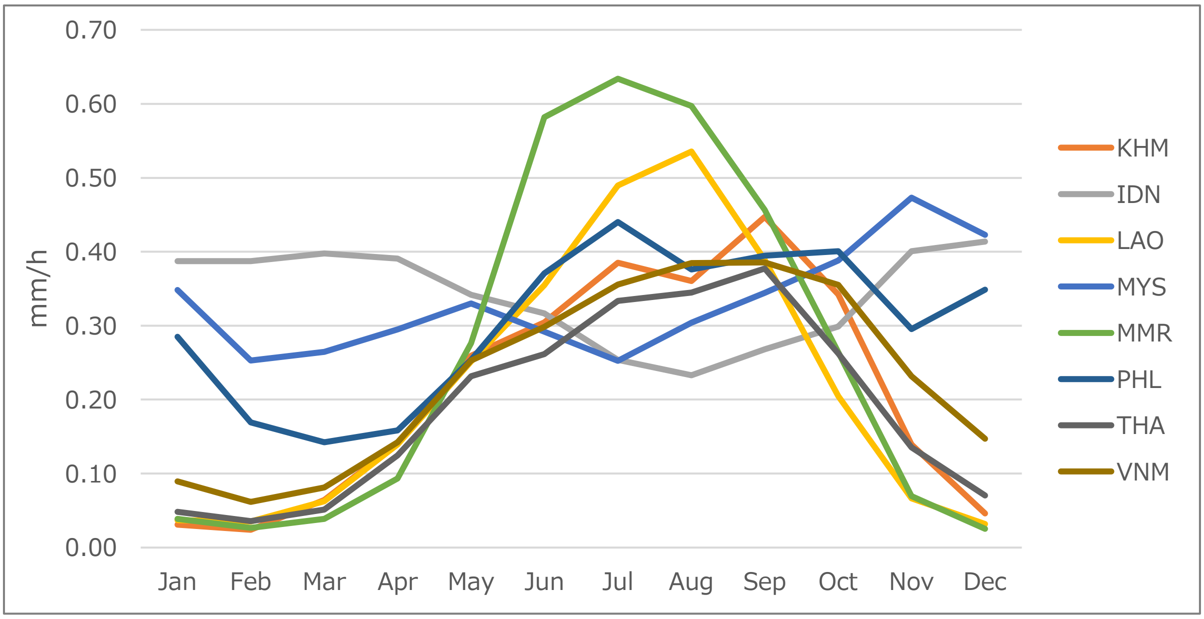
	Population (2022)	Real GDP (2022)	Stock of Passenger Cars (2020)	Area
Peninsular Malaysia	82%	85%	87%	40%
Sabah	11%	5%	6%	22%
Sarawak	8%	9%	7%	38%

GDP = gross domestic product.
Source: Department of Statistics, Malaysia (2023).

3.5. Seasonal Variations in Hydropower Generation

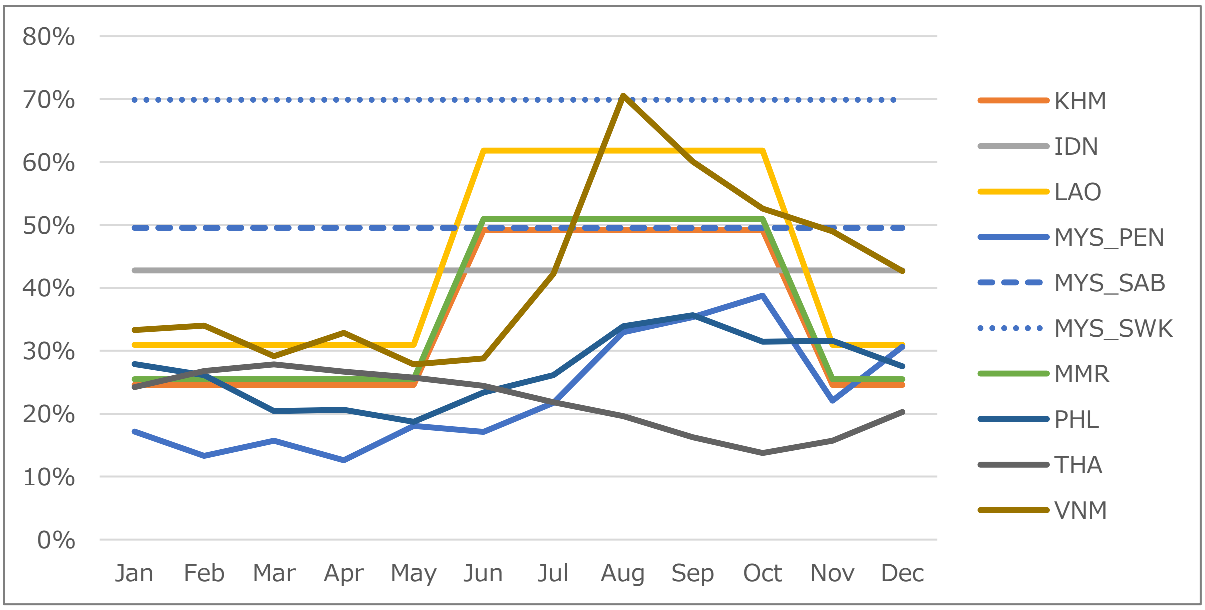
The previous model assumed a constant capacity factor for hydropower generation throughout the year. However, actual hydropower generation exhibits seasonal variations. The updated model incorporates a monthly capacity factor based on observed data, with actual values available for Peninsular Malaysia, the Philippines, Thailand, and Viet Nam. For other countries and regions, simplified assumptions were made based on precipitation patterns (Figure 3.6 and Figure 3.7).

Figure 3.6. Monthly Precipitation (10-year Average for 2014–2023)



IDN = Indonesia, KHM = Cambodia, LAO = Lao People's Democratic Republic, mm/h = millimetres per hour, MYA = Myanmar, MYS = Malaysia, PHL = Philippines, THA = Thailand, VNM = Viet Nam.
Source: Author, based on International Energy Agency (2024b).

Figure 3.7. Assumed Capacity Factor of Hydropower Generation



IDN = Indonesia, KHM = Cambodia, LAO = Lao People's Democratic Republic, MMR = Myanmar, MYS_PEN = Peninsular Malaysia, MYS_SAB = Sabah Malaysia, MYS_SWK = Sarawak Malaysia, PHL = Philippines, THA = Thailand, VNM = Viet Nam.
Source: Author.

3.6. Industrial Technology

In the previous model, CCUS was applied exclusively to blast furnaces, and some subsectors lacked options for hydrogen and ammonia utilisation. The updated model now incorporates cement kilns with CCUS, where the technology specifications are based on coal-fired power generation with CCUS. Hydrogen and ammonia boilers and furnaces have been incorporated across all subsectors, with technology specifications modelled on natural gas boilers and furnaces. It should be noted that hydrogen and ammonia distribution costs are included in the model, albeit simplified for clarity.

Chapter 4

Results and Conclusions for ASEAN

4.1. Results

This chapter presents the results for ASEAN, compared with those from the previous year's report (ERIA, 2023b). Country-specific results can be found in the appendix.

CO_2 emissions from the power sector decrease significantly from 2040 onwards (Figure 4.1). By 2050, the power sector will become a source of negative emissions, offsetting some residual emissions from sectors with higher abatement costs, such as high-temperature industrial heat and heavy-duty vehicles. However, emissions from the final consumption sector also decrease significantly compared with scenarios without emission constraints. The persistence of energy-related CO_2 emissions by 2060 is due to emission reduction targets being set on a country-by-country basis, taking into account carbon sinks, including emissions from the land use, land-use change, and forestry sector.

Compared with previous results, the deployment of negative emission technologies, such as BECCS and DACCS, after 2050 has decreased. Moreover, power sector emissions, previously projected to approach zero by 2040, now declined at a slower pace. This adjustment is mainly due to a downward revision in transport demand for heavy-duty vehicles, which has led to reduced residual emissions.

Final energy consumption in 2060 is projected to be 2.4 times higher than in 2019 (Figure 4.3). The energy mix shows an increase in electricity and natural gas use and a decrease in oil consumption. Electricity's share reaches 31% by 2060. The demand for natural gas increases, mainly in the industrial sector, whilst electricity demand increases across the industrial, residential and commercial, and transport sectors. The decline in oil consumption is primarily due to the electrification of passenger vehicles (Figure 4.7). Hydrogen consumption as a final energy source mainly occurs in industrial boilers and furnaces (Figure 4.8).

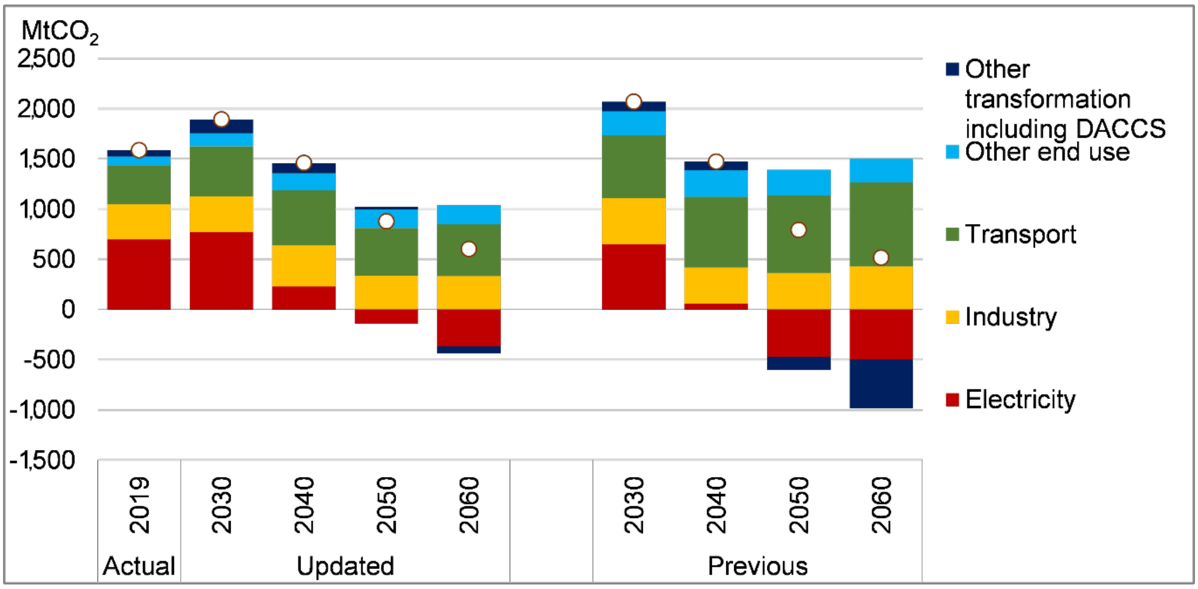
In comparison to previous results, total final energy consumption in 2060 has decreased by 10%. This decline reflects downward revisions in energy service demand, accounting for trends after the COVID-19 pandemic and the Ukraine crisis. Oil consumption has dropped sharply as a result of a reassessment of vehicle transport demand.

Electricity generation is projected to increase significantly more than final energy consumption, reaching 5.1 times the 2019 level by 2060 (Figure 4.4). Renewable energy, mainly solar PV, is expected to expand rapidly after 2030, reaching a 63% share by 2060. Following the installation of more than 1 TW of variable renewable energy capacity by 2050, representing a 44% share, significant battery storage will be deployed in combination with low-carbon thermal-fired power plants to address the intermittency of variable renewable energy (Figure 4.6). The share of electricity from thermal power generation increases towards 2060, with low-carbon thermal generation achieved mainly through CO_2 capture in coal- and gas-fired plants, as well as biomass and ammonia co-firing in coal-fired plants (Figure 4.4 and Figure 4.5). Ammonia single-firing and BECCS capacity expand after 2050.

Compared with previous results, total electricity generation in 2060 has decreased by 29%. This reduction is attributed to lower final energy consumption and reduced electricity requirements for CO_2 capture facilities, including DACCS, outweighing newly considered additional electricity demand from data centres. The share of gas-fired power with CO_2 capture has expanded, replacing ammonia and hydrogen-fired generation. The shift is primarily driven by two factors: reduced reliance on DACCS, which has lowered the need for CO_2 storage capacity, and a downward revision in natural gas prices.

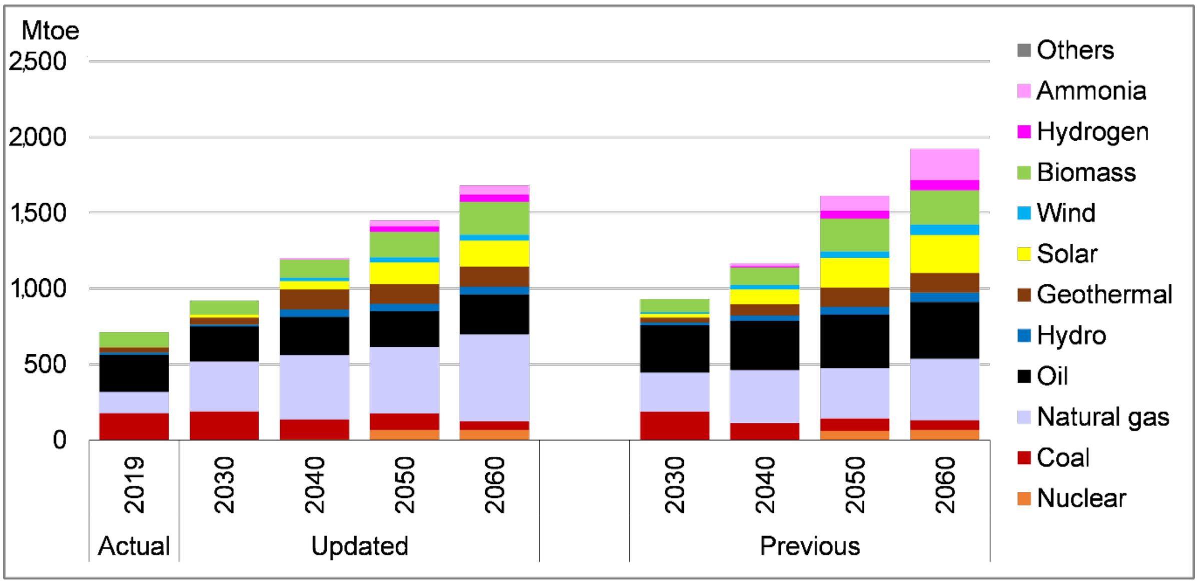
Primary energy supply (Figure 4.2) reflects these changes in final energy consumption and power generation. Imports of hydrogen and ammonia from outside ASEAN have decreased compared with levels in the previous report, largely due to reduced service demand and lower natural gas prices. However, hydrogen remains a key energy carrier across the power, industry, and transport sectors. Domestic hydrogen production occurs in regions with high renewable energy potential relative to energy demand, such as Sumatra and Sarawak, with distribution throughout the ASEAN. CO_2 emissions from fossil fuels are reduced through CCS technologies (Figure 4.9). Initially, CO_2 capture facilities are installed in coal-fired power plants, later expanding to gas- and biomass-fired plants. These facilities play a role in blast furnaces and cement kilns. Finally, energy system costs increase because of decarbonisation efforts. By 2060, the marginal abatement cost of CO_2 will reach US$200 per tonne of CO_2 (Figure 4.10), whilst the marginal cost of electricity rises to US$0.8.5 per kWh, which is 1.6 times the base year model estimate (Figure 4.11).

Figure 4.1. CO_2 Emissions by Sector



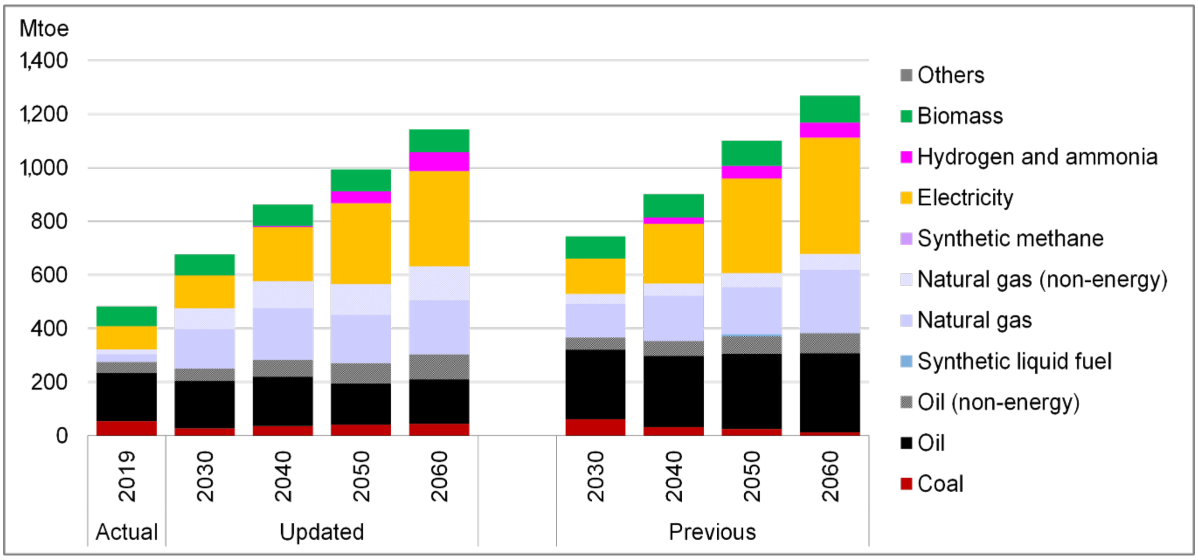
DACCS = direct air carbon capture and storage, MtCO2 = metric tonne of carbon dioxide.
Source: Author.

Figure 4.2. Primary Energy Supply by Source



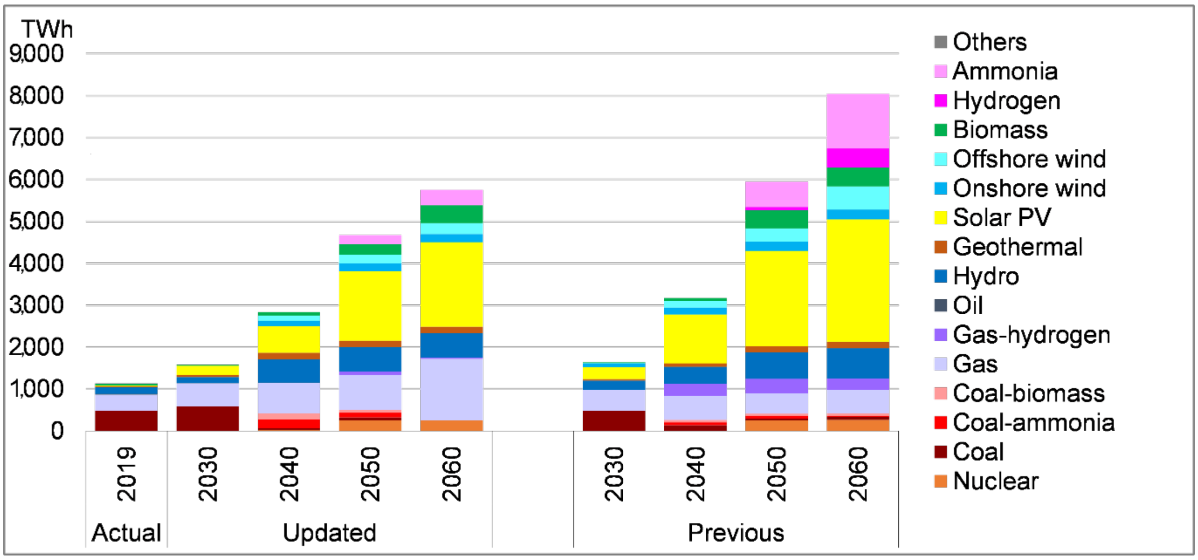
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure 4.3. Final Energy Consumption by Source



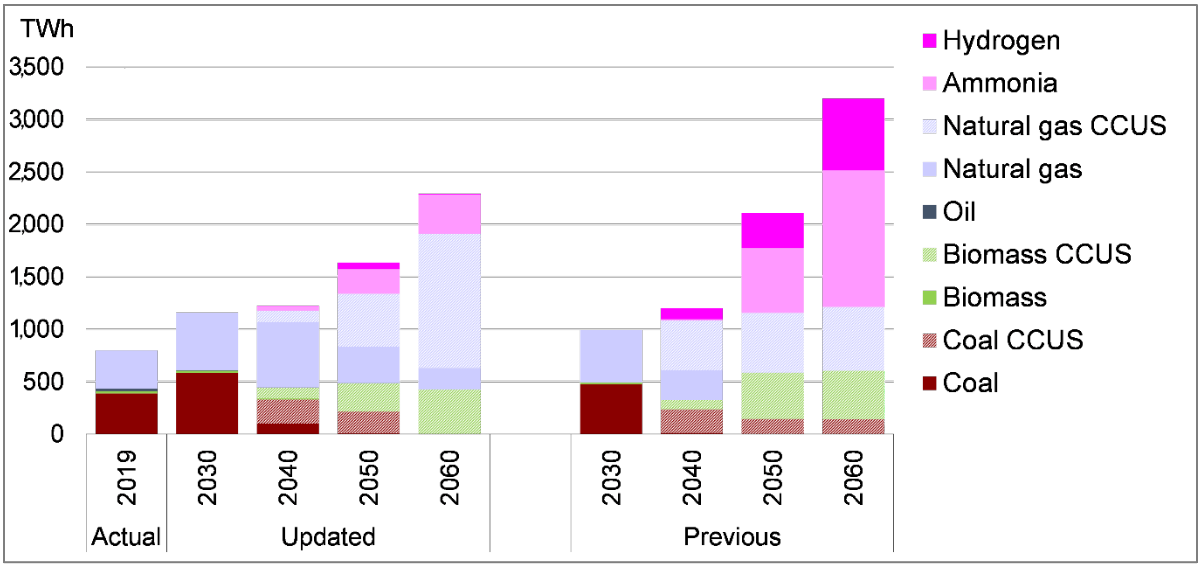
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure 4.4 Power Generation by Technology



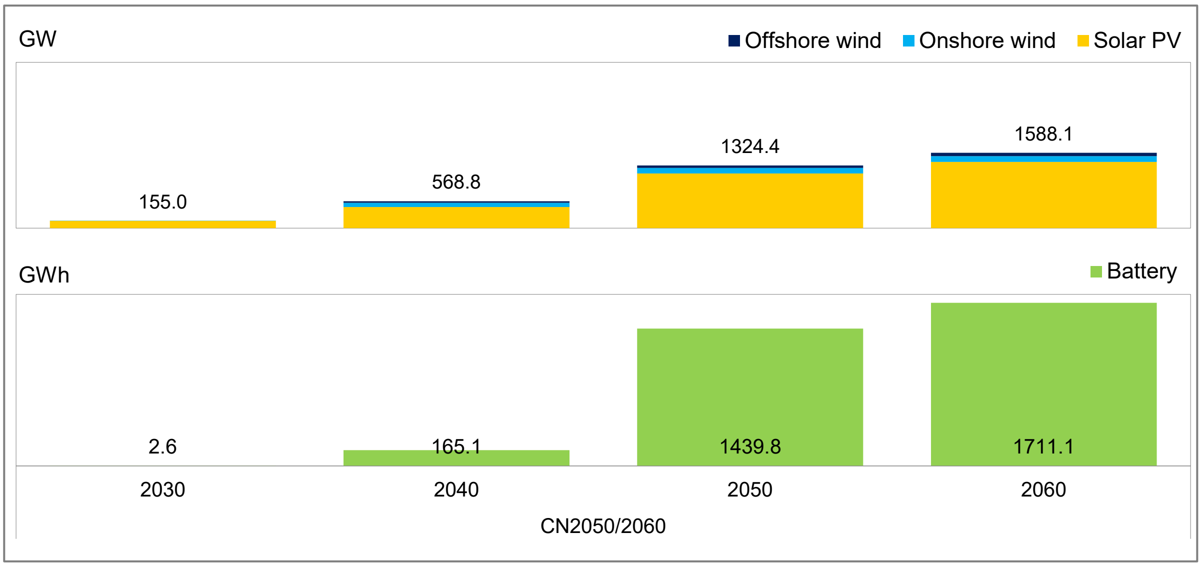
PV = photovoltaic, TWh = terawatt hour.
Source: Author.

Figure 4.5. Thermal Power Generation by Source



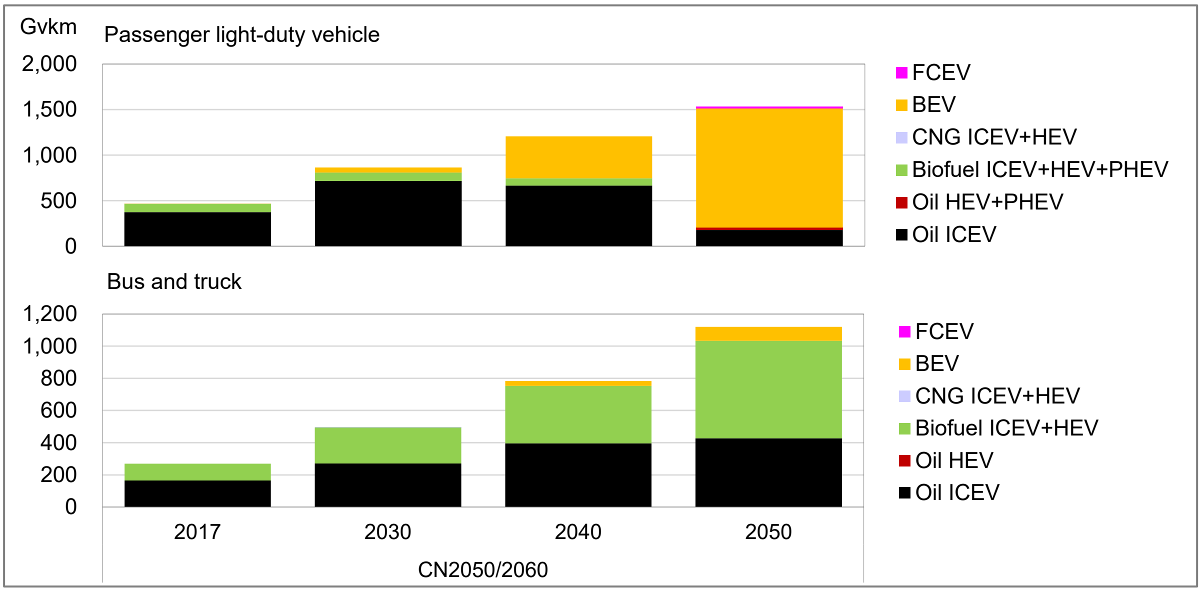
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure 4.6. Installed Capacity of Variable Renewable Energy and Battery



GW = gigawatt, GWh = gigawatt hour, PV = photovoltaic.
Source: Author.

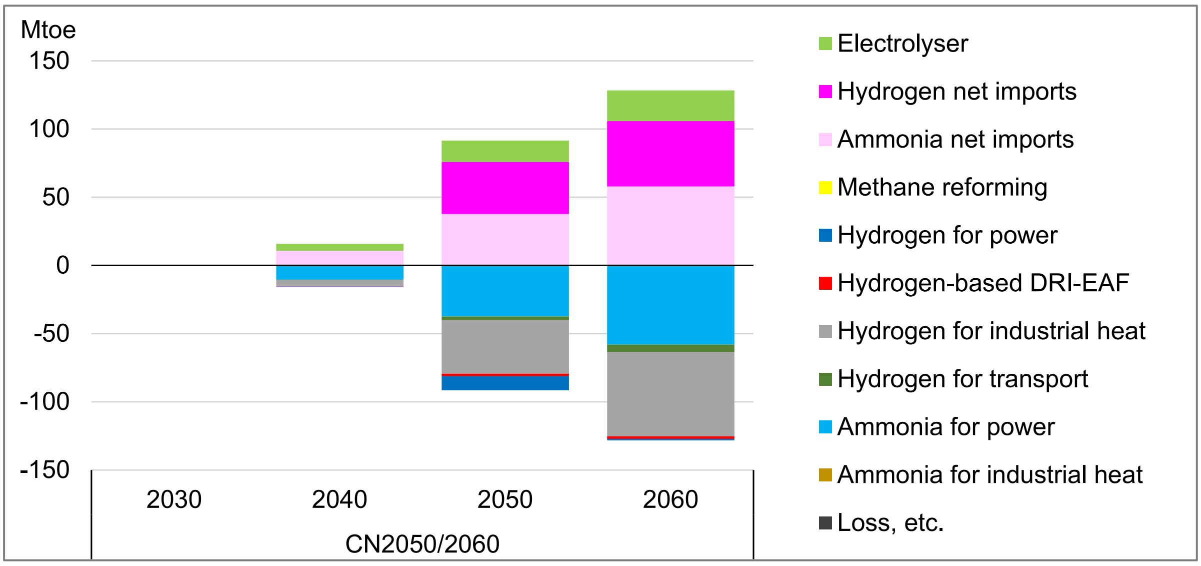
Figure 4.7. Road Transport Demand



BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, Gvkm = billion vehicle-kilometres, PHEV = plug-in hybrid electric vehicle.

Source: Author.

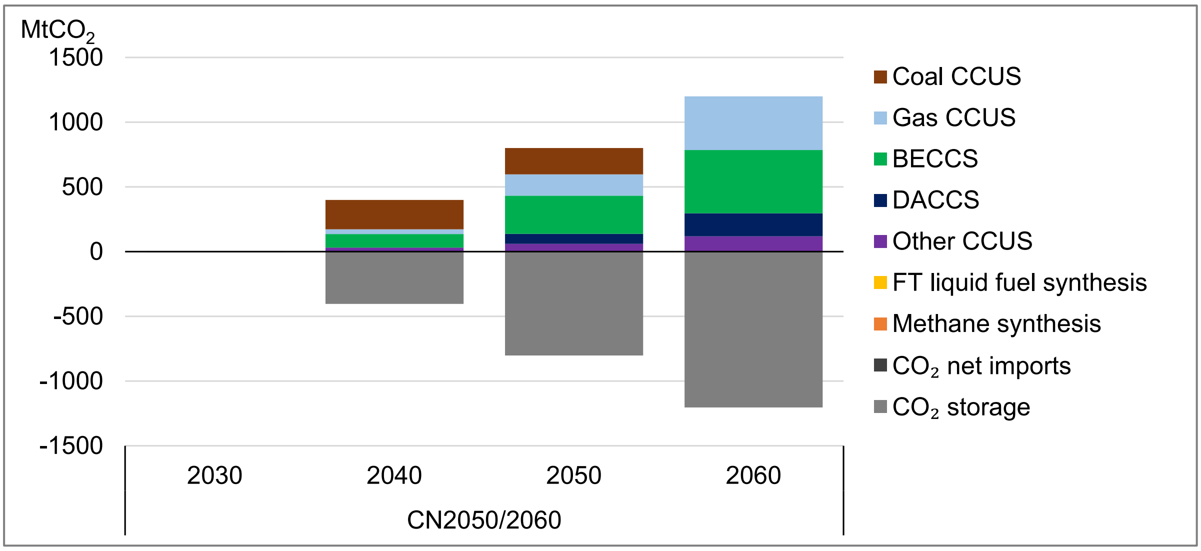
Figure 4.8. Supply and Demand of Hydrogen and Ammonia



DRI-EAF = direct reduced iron–electric arc furnace, Mtoe = million tonnes of oil equivalent.

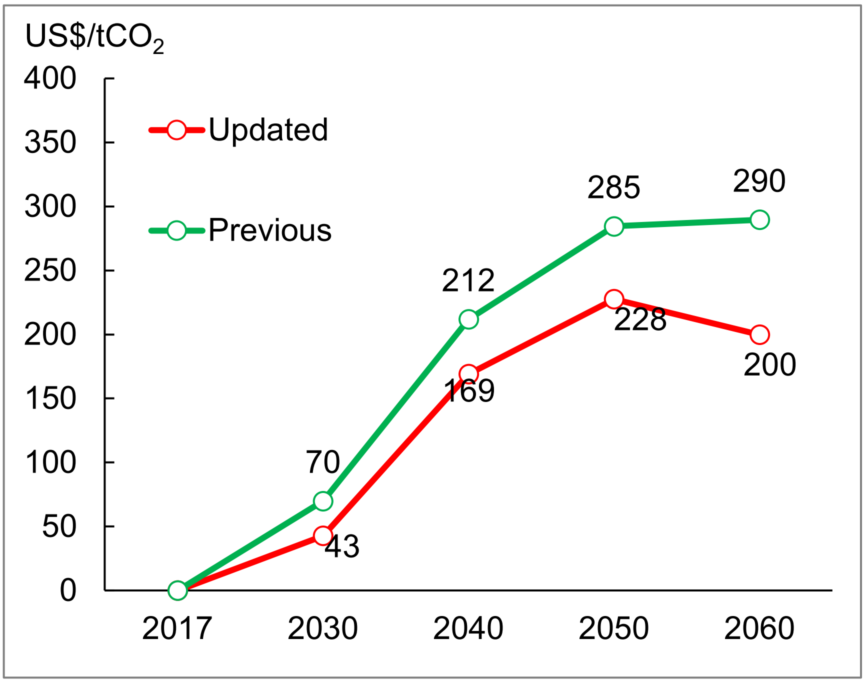
Source: Author.

Figure 4.9. Carbon Capture, Utilisation, and Storage



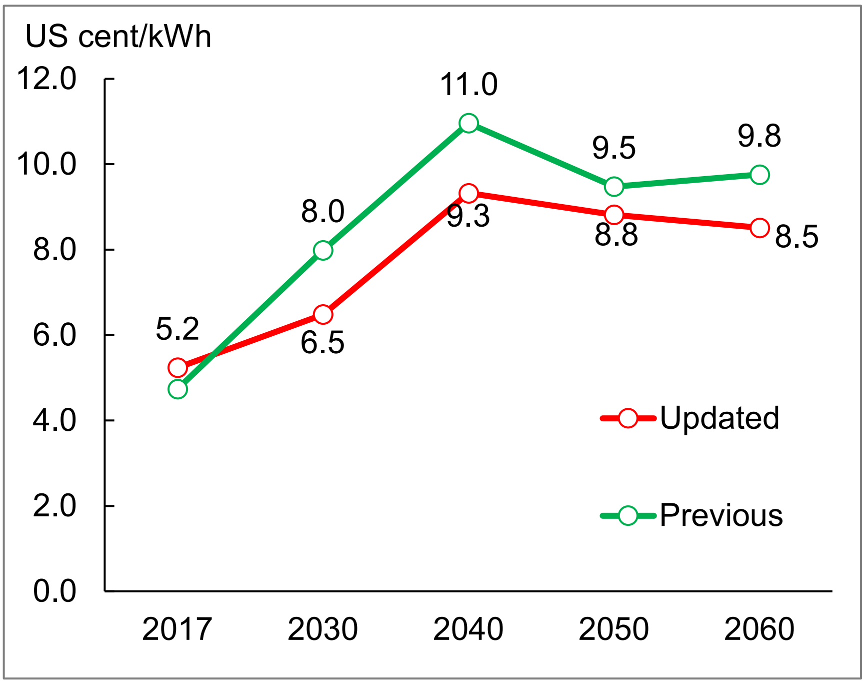
BECCS = bioenergy with carbon capture and storage; CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; FT = Fischer–Tropsch; $MtCO_2$ = metric tonnes of carbon dioxide.
Source: Author.

Figure 4.10. Marginal Abatement Cost of CO_2



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.
Source: Author.

Figure 4.11. Marginal Cost of Electricity



kWh = kilowatt-hour.
Source: Author.

4.2. Conclusions

This study incorporates major updates to the IEEJ-NE_ASEAN model, developed since 2021. These updates include a reassessment of energy service demand. Whilst certain differences from previous results, such as reduced total energy consumption and the prioritisation of gas expansion over hydrogen and ammonia, are evident, the main implications for ASEAN remain consistent throughout this study.

- Energy savings and electrification in end-use sectors, combined with a low-carbon power supply, are core strategies for decarbonising ASEAN energy systems.
- During transition periods, various low-carbon technologies can effectively reduce CO_2 emissions. In the power sector, strategies such as fuel switching from coal to natural gas, deploying more efficient turbines, co-firing with biomass, hydrogen, and ammonia, as well as fossil-fuel-fired power generation with CCS, can support progress towards deep decarbonisation.
- The simulation results imply significant economic challenges associated with decarbonisation.

In addition, the analysis highlights four further implications. First, the expansion of variable renewable energy in power generation must be supported by maintaining a certain level of thermal power generation and installing substantial battery capacity and hydrogen storage tanks to ensure supply flexibility.

Second, resource sharing within ASEAN matters. The updated model divides Indonesia and Malaysia into five and three regions, respectively, enabling the explicit modelling of international interconnection and intra-ASEAN hydrogen transport. The results indicate that regions with renewable energy surpluses can export electricity and hydrogen to others. Hydrogen finds widespread application in the industrial, transport, and power sectors (e.g. co-firing with gas-fired power).

Third, natural gas emerges as a key energy source, with its consumption continuing to grow during the transition period and over the long term. Its share in the primary energy supply is projected to increase from 21% in 2019 to 34% in 2060, becoming the largest component of the energy mix. The use of natural gas is expected to expand in the industrial and power sectors.

Fourth, CCS technologies are essential. As shown in the assumptions, the installed capacity of coal-fired power plants in ASEAN is expected to increase by 2030. Expanding coal-fired power plants with CCS offers a viable strategy for reducing CO_2 emissions whilst effectively utilising existing facilities. Furthermore, CCS is considered a cost-effective option for gas-fired power plants, blast furnaces, and cement kilns. Over the long term, CCS will be a prerequisite for negative emission technologies, such as BECCS and DACCS.

Chapter 5

Preparation for Analysis of Bangladesh

This year, data collection commenced with the objective of developing a model for Bangladesh. This chapter presents a selection of the data collected.

5.1. Basic Indicators (Data and Projection)

5.1.1. Gross domestic product

Bangladesh's economy experienced steady growth of 6%–8% per year until 2019. Although the growth rate declined in 2020 due to the COVID-19 pandemic, it began recovering from 2021 onwards.

The International Monetary Fund projects an annual growth rate of about 7% in 2024–2029, aligning with historical trends. The government has set more ambitious targets, aiming for an annual growth rate of 9.0% by 2030 and 9.9% by 2040. It should be noted that these government projections were released in March 2020, before the full impact of the COVID-19 pandemic and the Ukraine crisis had emerged.

Caution should be exercised when interpreting energy demand estimates based on GDP projections, given the inherent uncertainties surrounding the country's economic growth.

Table 5.1. Gross Domestic Product Growth Rate (Historical and Projected)

Year	Historical	IMF Projection	Government of Bangladesh Projection
2019	7.9%		
2020	3.4%		
2021	6.9%		
2022	7.1%		
2023	6.0%		
2024		5.7%	8.3%
2025		6.6%	8.5%
2026		7.1%	
2027		7.2%	

Year	Historical	IMF Projection	Government of Bangladesh Projection
2028		7.0%	
2029		7.0%	
2030			9.0%
2035			9.4%
2040			9.9%

IMF = International Monetary Fund.
Sources: IMF (2021) and Government of Bangladesh (2020).

5.2. Population

In 2020, Bangladesh's population was reported as 166.4 million by the UN. According to the Ministry of Planning, Bangladesh, the population was 169.8 million, indicating a minor discrepancy between the two datasets.

Looking forward, the UN projects an annual population growth rate of about 0.8%, whilst the government estimates a slightly higher growth rate of about 1.0%. As with GDP assumptions, differences in population growth forecasts introduce variability in long-term energy demand estimations, making population growth an important parameter in the analysis of Bangladesh's energy road map.

Table 5.2. Population in Bangladesh (Historical and Projected)
(million)

	2010	2015	2020	2025	2030	2035	2041	Growth rate (2020–41)
UN (2022)	147.5	156.9	166.4	175.6	183.7	190.6	197.0	0.81%
MOP (2020)			169.8	180.5	190.6	200.1	210.3	1.02%

MOP = Ministry of Planning, UN = United Nations.
Sources: UN (2022) and Government of Bangladesh (2020).

5.3. Socio-economic Data

Socio-economic data, such as vehicle ownership and metal production, are essential for energy model analysis to evaluate future energy demand accurately. To facilitate more reliable projections, relevant data for Bangladesh have been collected.

5.3.1. Industry

In the industrial sector, material production represents a significant source of energy consumption, making it a crucial variable in energy model analysis. Table 5.3 presents a summary of recent large-scale material production in Bangladesh.

Table 5.3. Large Industry Production in Bangladesh

Year	Pulp, paper, and paperboard	Basic chemicals	Refined petroleum products	Cement, lime, and plaster; concrete products	Basic iron, steel, and other non-ferrous metals
Unit	M.T.	C. No	M.T.	M.T.	M.T.
2016–17	3,745	1,359	99,238	233,264	39,321
2017–18	4,150	1,512	101,232	322,534	49,403
2018–19	4,450	1,627	108,957	412,521	61,383
2019–20	4,825	1,209	92,569	548,652	77,343
2020–21	5,150	1,105	110,698	683,982	96,988
2021–22	6,250	1,210	114,781	831,551	117,598

C. No = cubic number, M.T. = metric tonne.
Source: Bangladesh Bureau of Statistics (2023).

The production of cement and basic metals has expanded significantly in recent years. Such economic activities typically involve high energy consumption, especially from fossil fuels. If this trend continues over the coming decades, both material production and energy consumption are expected to increase significantly. Therefore, energy conservation and the decarbonisation of these sectors will be major challenges in Bangladesh's pathway towards achieving carbon neutrality.

5.3.2. Transport

Within the transport sector, energy consumption from automobiles represents a significant proportion of total energy use. One key indicator of this consumption is vehicle ownership.

Table 5.4. Vehicle Ownership in Bangladesh

Year	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22
Auto Rickshaw	236,100	252,011	276,881	297,184	308,191	315,402
Bus	147,972	155,466	162,492	168,531	174,305	182,556
Truck/Van	65,829	75,978	82,515	86,139	90,189	95,374
Private Passenger Car	335,374	358,075	378,739	396,157	415,161	438,819
Motorcycle	1,728,269	2,059,453	2,421,594	2,736,026	3,050,628	3,461,678
Truck/Cargo	205,647	228,549	249,190	265,023	279,754	294,236
Other Vehicles	99,561	109,170	118,589	126,351	133,443	139,536
Total	2,818,752	3,238,702	3,690,000	4,075,411	4,451,671	4,927,601

Source: Bangladesh Bureau of Statistics (2023).

Most vehicles in Bangladesh are motorcycles, with auto-rickshaws about equal in number to private passenger cars. As the economy continues to develop, the number of private passenger cars is expected to increase. However, motorcycles will remain an essential mode of transport, and motorcycle trends must be considered when assessing future energy consumption.

Data on transport volume are available for shipping, rail, and air transport, but some figures presented here may not be fully up to date.

Table 5.5. Railway, Water, and Air Transport in Bangladesh

	Railway Transport				Water Transport		Air Transport	
	Freight		Passeng		Pass	Carg	Pass	Freig Ma
	1 000 tonnes	Million t-km	Mill	P km	Millio	Million tonnes	Millio	Thousand tonnes
2012–13	2,524	677	65	8,135	250	19	6.87	223
2013–14	2,555	694	67	8,711	156	22	7.01	246
2014–15	2,555	694	67	8,711	169	23	7.10	239
2016–17	3,870	1,053	78	10,040	212	19	7.94	279
2017–18	4,550	1,237	99	12,994	306	23	8.48	292
2018–19					315	56	10.24	328
2019–20					251	60	12.40	383
2020–21							13.67	366
2021–22							5.53	276

p-km = passenger-kilometre, t-km = tonnes-kilometre.
Source: Bangladesh Bureau of Statistics (2023).

5.4. Energy Data

Energy demand in Bangladesh has increased significantly due to rapid economic growth. Primary energy supply reached 49,306 million tonnes of oil equivalent in 2021, reflecting an annual growth rate of 4.8% since 2000. Electricity generation has expanded even more rapidly, reaching 95,000 GWh in 2021, with an annual average increase of 9% since 2000.

Table 5.6. Energy Demand and Power Generation in Bangladesh

		2000	2005	2010	2015	2020	2021	Growth Rate 2000–21
Primary Energy Supply	Ktoe	18,291	23,129	29,765	37,883	45,376	49,306	4.8%
Final Consumption	Ktoe	14,935	18,282	22,526	26,606	30,132	32,637	3.8%
Power Generation	GWh	15,771	26,447	40,797	59,297	85,500	95,481	9.0%

GWh = gigawatt hour, Ktoe = kilotonne of oil equivalent.
Source: IEA (2023c)

Natural gas is the most consumed energy source in Bangladesh, with about 80% sourced domestically. The remaining energy supply includes imported coal and natural gas, as well as domestic biofuels (primarily solid biofuel). In final demand, electricity accounts for over 20%, biomass for over 20%, and the remainder consists of fossil fuels.

As with primary supply, gas-fired power generation dominates electricity production, accounting for more than 70% of the total. The remaining generation is mostly from oil and coal. Bangladesh imports less than 10% of its electricity from neighbouring countries.

Table 5.7. Energy Demand and Supply in Bangladesh (2021)

Energy Type (ktoe)	Coal	Oil	Gas	Nuclear	Hydro	Biofuels and Waste	Other Renewables	Heat	Electricity	Total
Primary Supply	3,409	10,611	26,717	0	60	7,771	42	0	697	49,306
Domestic Production	377	315	21,515	0	60	7,775	42	0	0	30,083
Final Consumption	2,203	4,906	10,127	0	0	7,629	0	0	7,772	32,637

Ktoe = kilotonne of oil equivalent.
Source: International Energy Agency (2023).

Table 5.8. Power Generation in Bangladesh

Energy Source (GWh)	Coal	Oil	Gas	Hydro	Biomass	Solar/wind	Geothermal	Total
Power Generation	5,297	19,193	69,814	694	0	483	0	95,481
Share (%)	6%	20%	73%	1%	0%	1%	0%	100%

GWh = gigawatt hour.
Source: International Energy Agency (2023c).

References

Association of Southeast Asian Nations (2022), *ASEAN Statistical Yearbook 2022*. Jakarta: ASEAN Secretariat.

Badan Pusat Statistik-Statistics Indonesia (2023), *Statistical Yearbook of Indonesia 2023*. Jakarta: Badan Pusat Statistik.

Bangladesh Bureau of Statistics (2023), *Statistical Yearbook Bangladesh 2022, 42nd Edition*. Dhaka: BBS.

Cole, W. and A.W. Frazier (2020), *Cost Projections for Utility-scale Battery Storage: 2020 Update*. Golden, CO: National Renewable Energy Laboratory.

Danish Energy Agency (2021), *Technology Data for the Indonesian Power Sector Catalogue for Generation and Storage of Electricity*. https://wipogreen.wipo.int/wipogreen-database/articles/138826 (accessed 28 June 2024).

Data Center Map (2024), Data Centers. https://www.datacentermap.com/datacenters/ (accessed 28 June 2024).

Department of Statistics, Malaysia (2023), *Statistics Yearbook Malaysia 2022.* Putrajaya: Department of Statistics, Malaysia.

Economic Research Institute for ASEAN and East Asia (2021), *Energy Outlook and Energy Saving Potential in East Asia 2020*. Jakarta: ERIA.

Economic Research Institute for ASEAN and East Asia (2022), *Decarbonisation of ASEAN Energy Systems: Optimum Technology Selection Model Analysis up to 2060*. Jakarta: ERIA.

Economic Research Institute for ASEAN and East Asia (2023a), *Energy Outlook and Energy Saving Potential in East Asia 2023*. Jakarta: ERIA.

Economic Research Institute for ASEAN and East Asia (2023b), *Decarbonisation of ASEAN Energy Systems: Optimum Technology Selection Model Analysis up to 2060, Updated 2023*. Jakarta: ERIA.

Economic Research Institute for ASEAN and East Asia (2024), *Potential Utilisation of Fuel Ammonia in ASEAN Countries*. Jakarta: ERIA.

Global Cement and Concrete Association (2019), *GCCA Getting the Numbers Right Project Report*. https://gccassociation.org/sustainability-innovation/gnr-gcca-in-numbers/ (accessed 28 June 2024).

International Energy Agency (2020), *Energy Technology Perspectives 2020 Special Report on Carbon Capture, Utilisation and Storage*. Paris: IEA.

International Energy Agency (2021), *Carbon capture, utilisation and storage: the opportunity in Southeast Asia*. Paris: IEA.

International Energy Agency (2022), *World Energy Outlook 2022*. Paris: IEA.

International Energy Agency (2023a), *Energy Technology Perspectives*. Paris: IEA.

International *Energy* Agency (2023b), *World Energy Outlook 2023*. Paris: IEA.

International Energy Agency (2023c), *World Energy Balances*. https://www.iea.org/data-and-statistics/data-product/world-energy-balances (accessed 28 June 2024).

International Energy Agency (2024a), *Electricity 2024. Paris: IEA.*

International Energy Agency (2024b), *Weather, Climate and Energy Tracker*. https://www.iea.org/data-and-statistics/data-tools/weather-for-energy-tracker?tab=Weather+for+energy+tracker (accessed 28 June 2024).

The Japan Science and Technology Agency (2022), *Impact of Progress of Information Society on Energy Consumption (Vol. 4): Feasibility Study of Technologies for Decreasing Energy Consumption of Data Centers*. https://www.jst.go.jp/lcs/en/proposals/fy2021-pp-01.html (accessed 28 June 2024).

International Monetary Fund (2024), *World Economic Outlook*. Washington, DC: IMF.

Ministerial Council on Renewable Energy, Hydrogen and Related Issues (2023), *Basic Hydrogen Strategy*. https://www.meti.go.jp/shingikai/enecho/shoene_shinene/suiso_seisaku/pdf/20230606_5.pdf (accessed 28 June 2024).

Ministry of Planning, Government of the People's Republic of Bangladesh (2020), *Perspective Plan of Bangladesh 2021–2041.* https://oldweb.lged.gov.bd/uploadeddocument/unitpublication/1/1049/vision%202021-2041.pdf (accessed 28 June 2024).

Otsuki, T., R. Komiyama, and Y. Fujii (2019), 'Techno-economic Assessment of Hydrogen Energy in the Electricity and Transport Sectors Using a Spatially-disaggregated Global Energy System Model', *Journal of the Japan Institute of Energy*, 98(4), pp.62–72.

Otsuki, T., H. Obane, Y. Kawakami, K. Shimogori, Y. Mizuno, S. Morimoto, and Y. Matsuo (2022), 'Energy Mix for Net Zero CO2 Emissions by 2050 in Japan, An Analysis Considering Siting Constraints on Variable Renewable Energy', *Electrical Engineering Japan*, 215(4).

PwC (2018), *Power In Indonesia: Investment and Taxation Guide,* November 2018, 6th Edition. https://www.pwc.com/id/en/pwc-publications/industries-publications/energy--utilities---mining-publications/power-guide-2018.html (accessed 28 June 2024).

United Nations (2022), *World Population Prospects 2022*. New York: UN.

U.S. Geological Survey (2023), *Mineral Commodity Summaries.* https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries (accessed 28 June 2024).

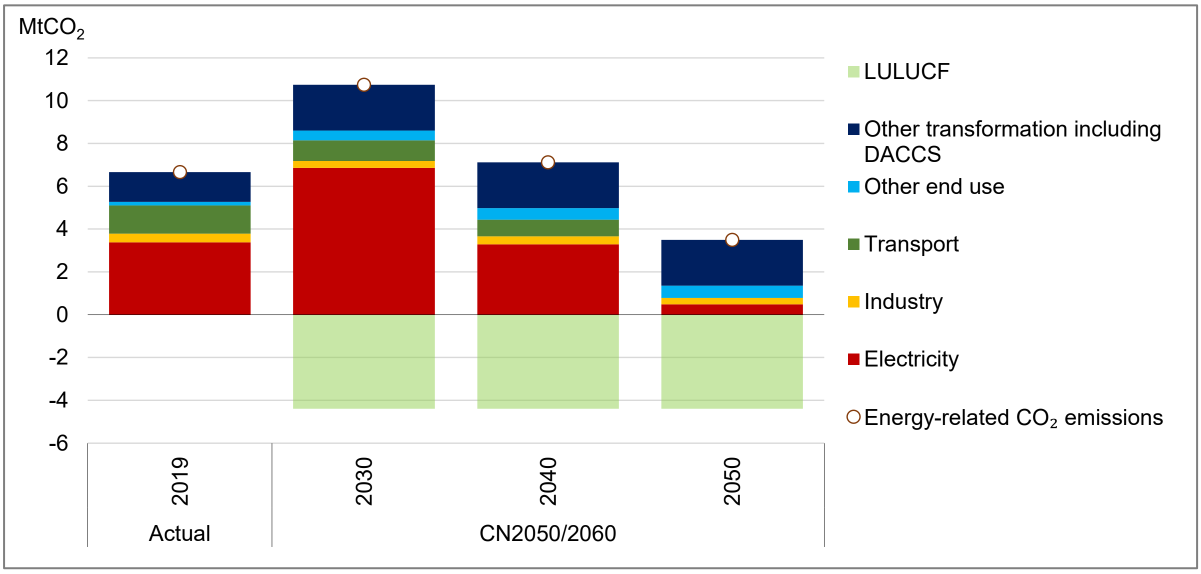
World Steel Association (2019), *Steel Statistical Yearbook 2019*, Concise Version. Brussels.

Appendix

A-1. Brunei Darussalam

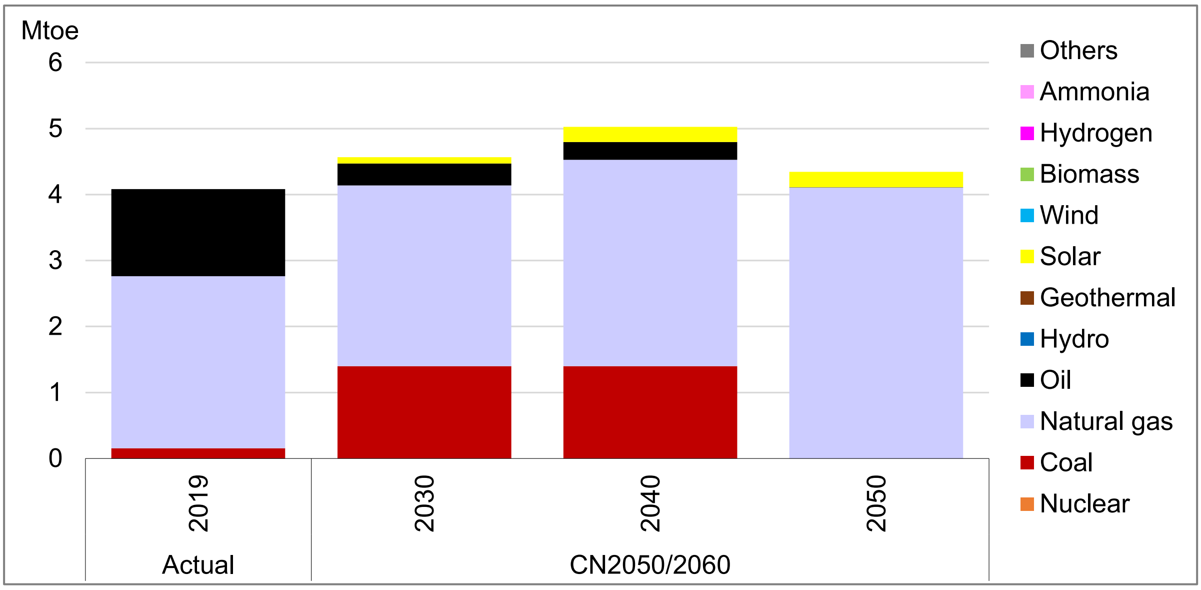
Carbon capture and storage (CCS) has been introduced to reduce emissions from coal-fired power plants, which could increase alongside the expansion of chemical plants, and from gas-fired power plants, the main source of electricity generation. Due to the limited land area, both ground-mounted and floating solar PV systems are utilised. Importing electricity from Sarawak, Malaysia, is considered an important option to diversify supply sources. In the transport sector, transitioning to electric vehicles remains a key strategy.

Figure A.1. CO_2 Emissions by Sector (Brunei Darussalam)



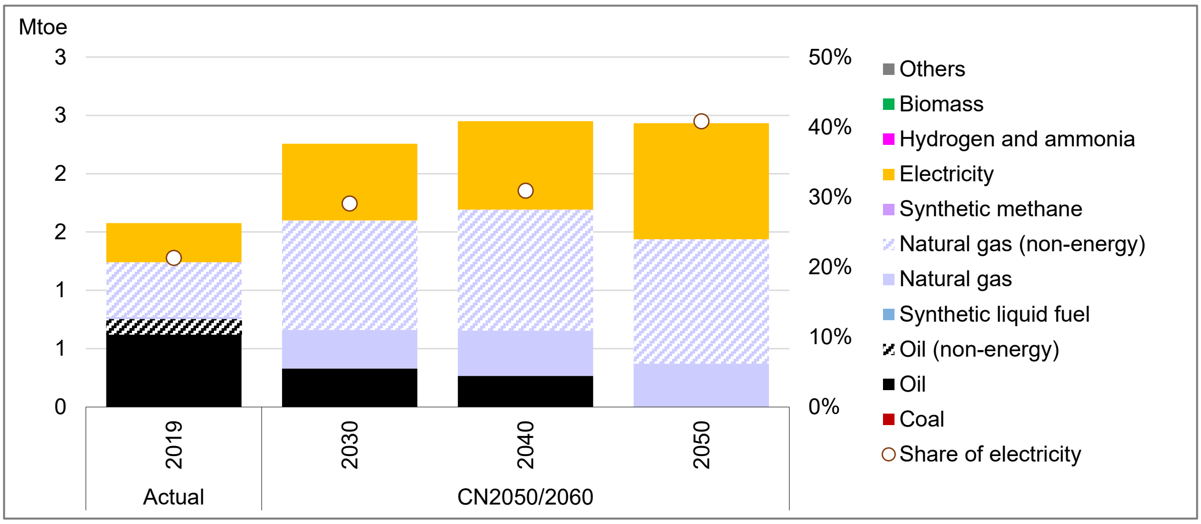
CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.2. Primary Energy Supply by Source (Brunei Darussalam)



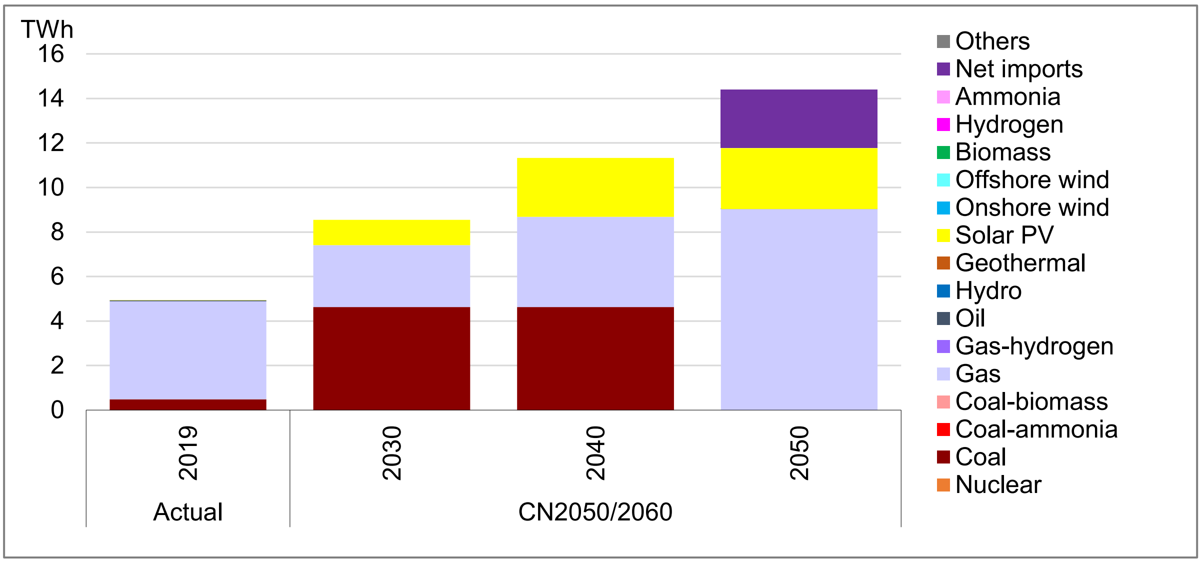
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.3. Final Energy Consumption by Source (Brunei Darussalam)



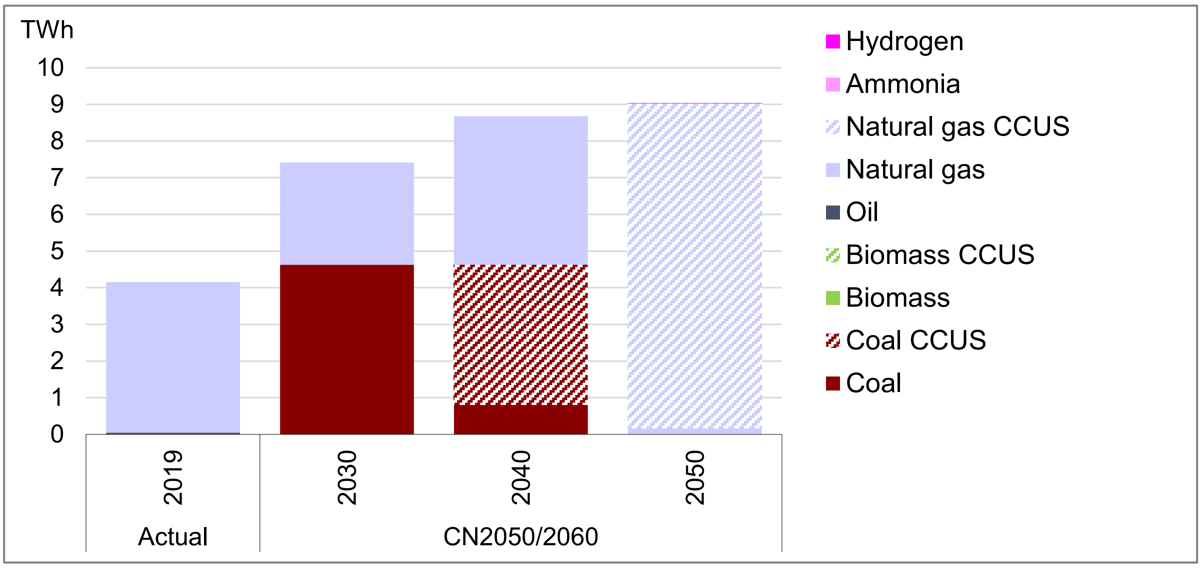
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.4. Power Generation by Technology (Brunei Darussalam)



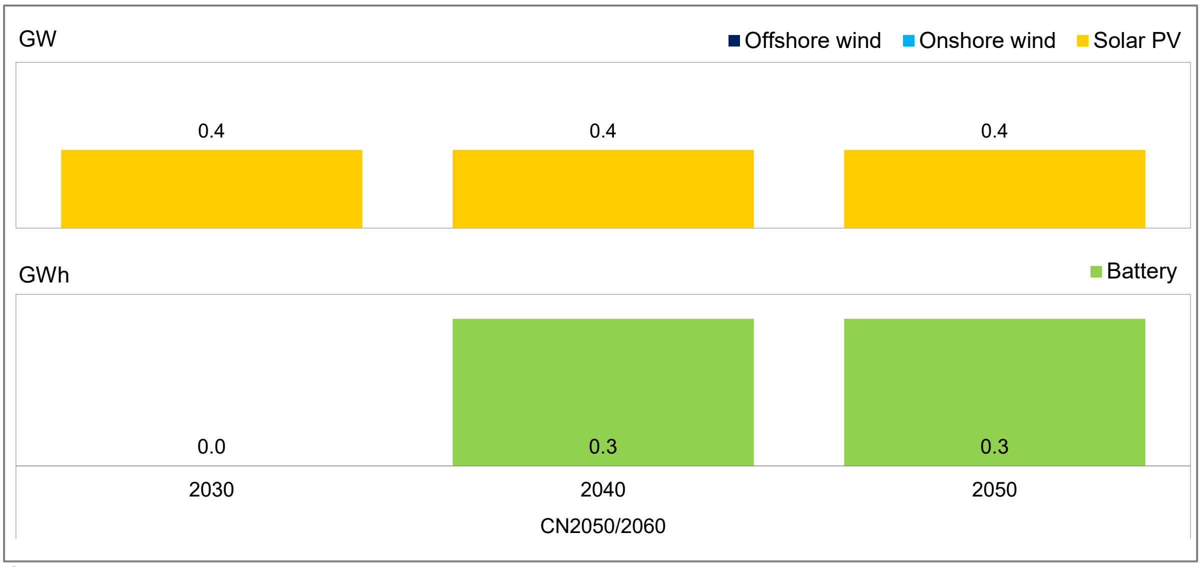
TWh = terawatt hour, PV = photovoltaic.
Source: Author.

Figure A.5. Thermal Power Generation by Source (Brunei Darussalam)



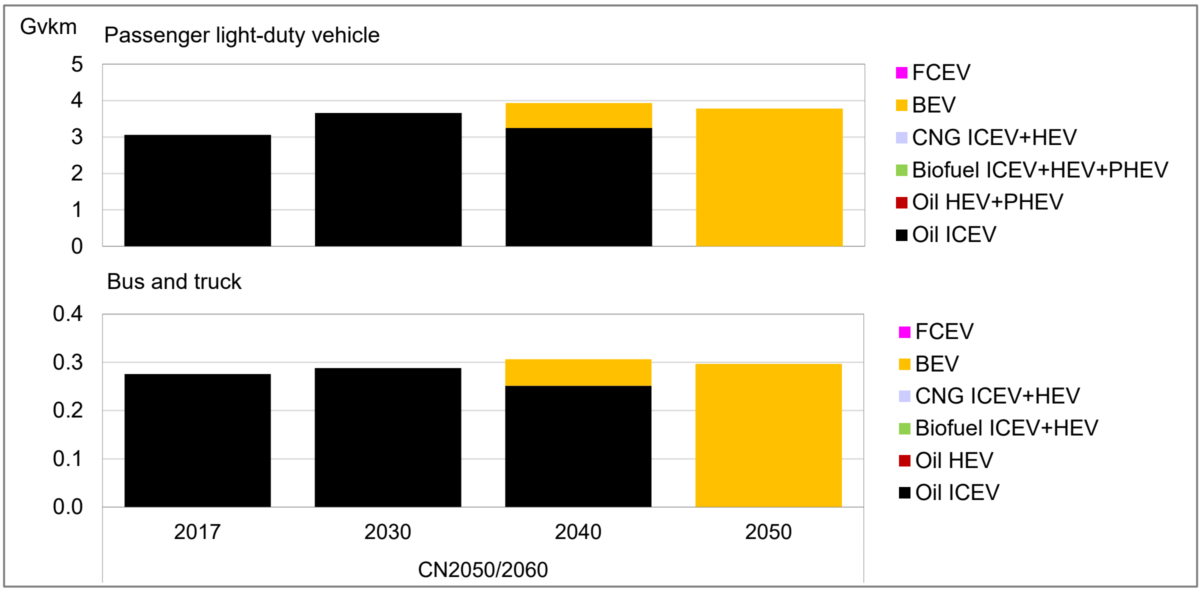
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure A.6. Installed Capacity of Variable Renewable Energy and Battery (Brunei Darussalam)



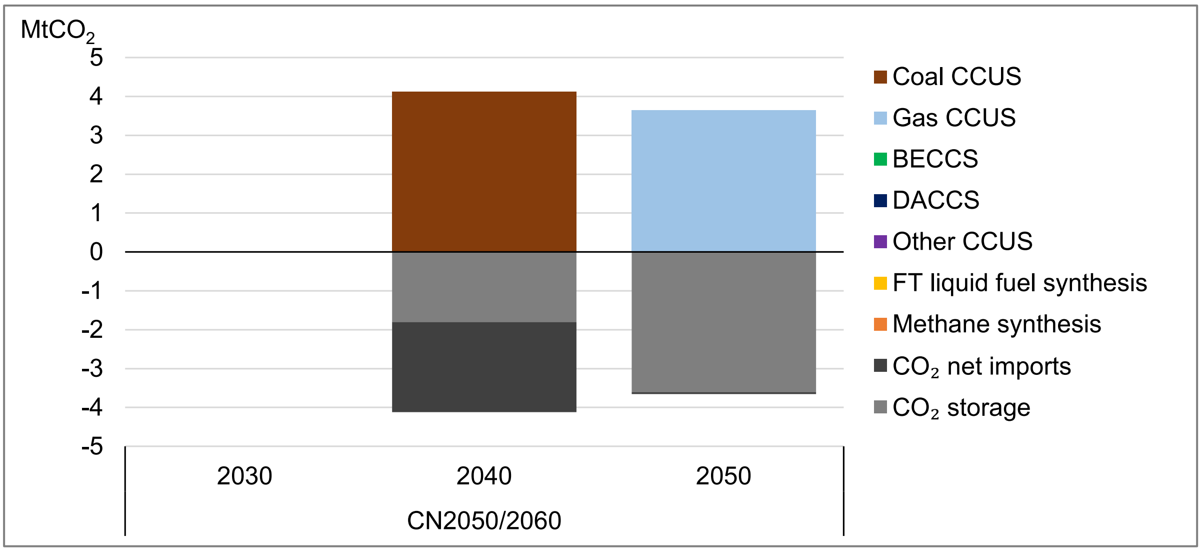
GW = gigawatt, PV = photovoltaic.
Source: Author.

Figure A.7. Road Transport Demand (Brunei Darussalam)



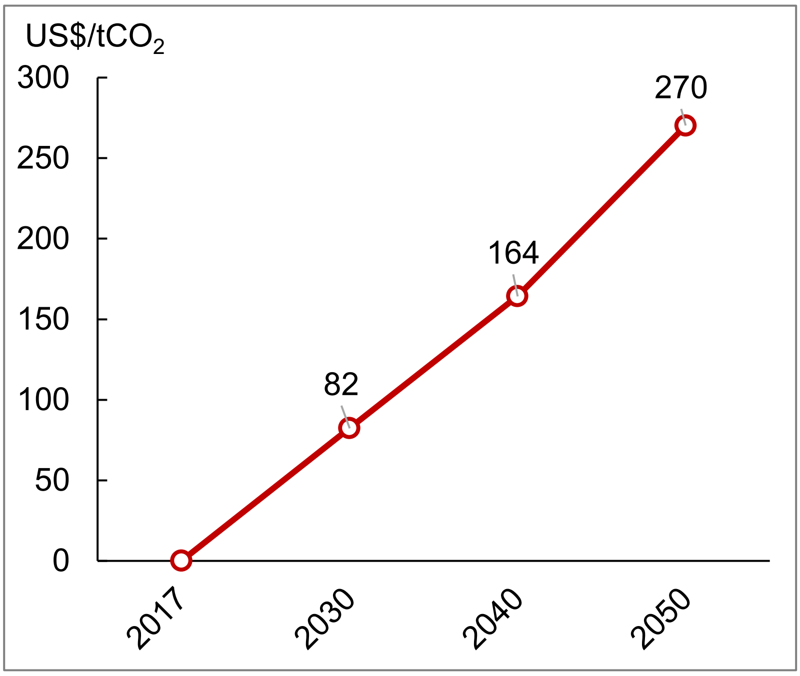
BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, Gvkm = billion vehicle-kilometres, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Author.

Figure A.8. Carbon Capture, Utilisation, and Storage (Brunei Darussalam)



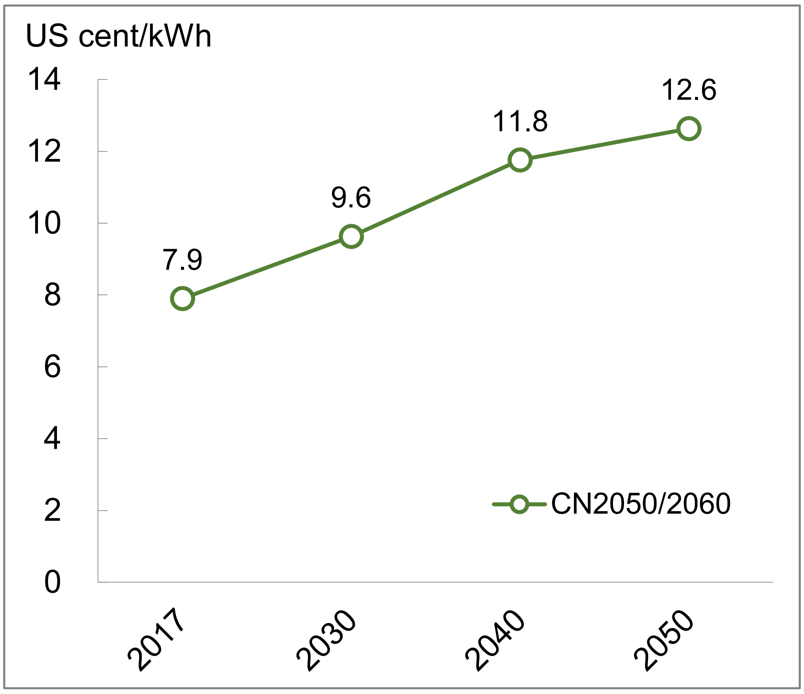
BECCS = bioenergy with carbon capture and storage; CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; FT = Fischer–Tropsch; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.9. Marginal Abatement Cost of CO_2 (Brunei Darussalam)



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.
Source: Author.

Figure A.10. Marginal Cost of Electricity (Brunei Darussalam)

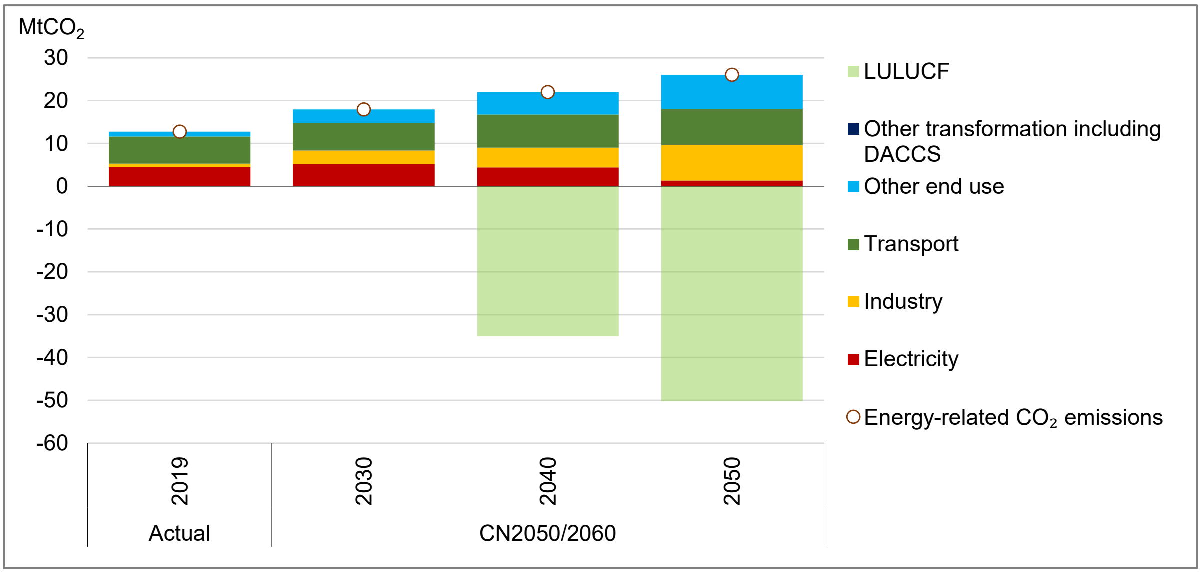


kWh = kilowatt-hour.
Source: Author.

A-2. Cambodia

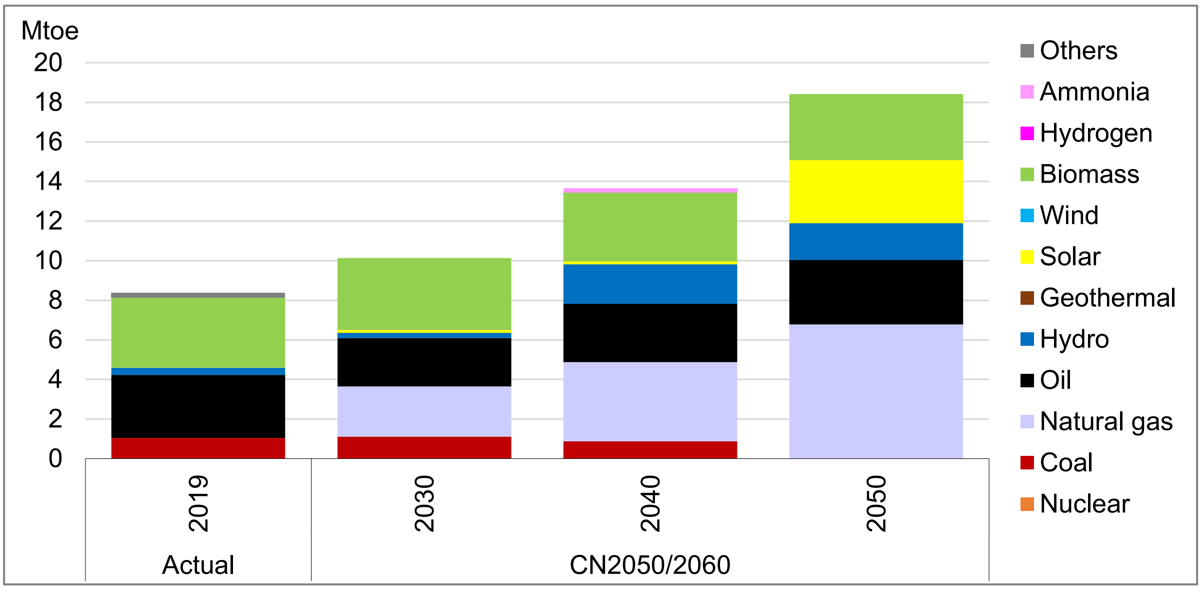
Whilst natural gas is used to a limited extent, it is poised for significant growth in line with Cambodia's decarbonisation efforts, particularly in the industrial and power sectors. By 2050, hydropower and solar PV are projected to experience substantial growth, becoming the country's main sources of electricity generation. Cambodia has abundant renewable energy sources, including hydropower, solar PV, and onshore wind. However, except for hydropower, these resources do not reach their full potential in the optimal pathway, given the assumed emission constraints.

Figure A.11. CO_2 Emissions by Sector (Cambodia)



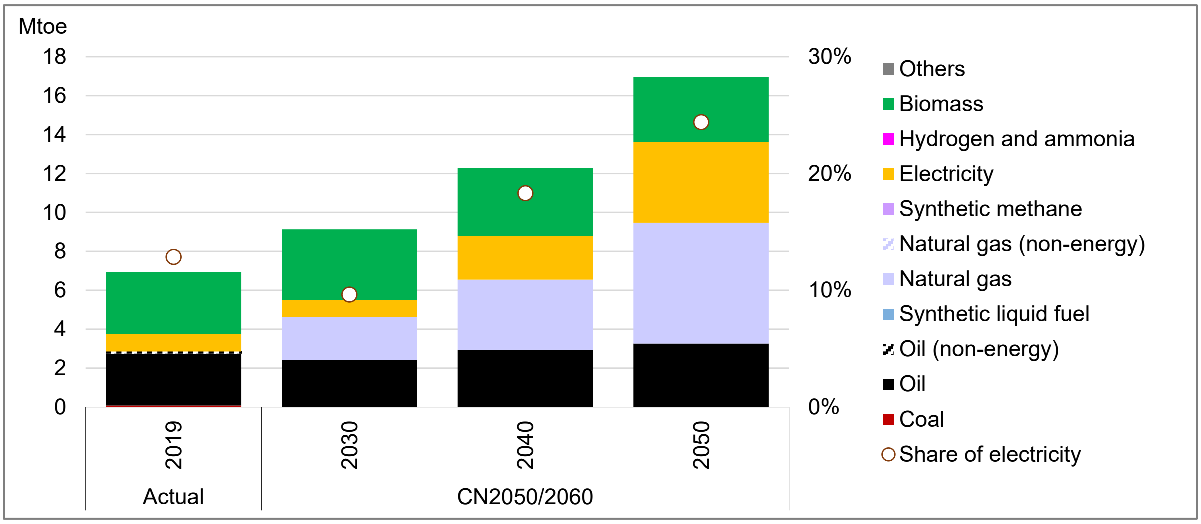
CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.12. Primary Energy Supply by Source (Cambodia)



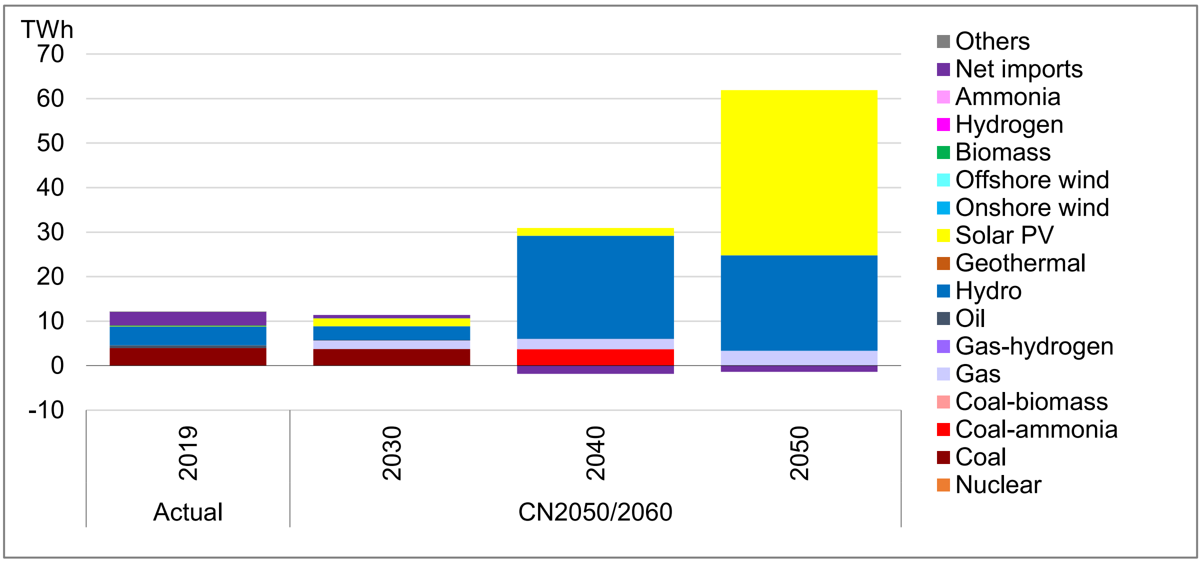
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.13. Final Energy Consumption by Source (Cambodia)



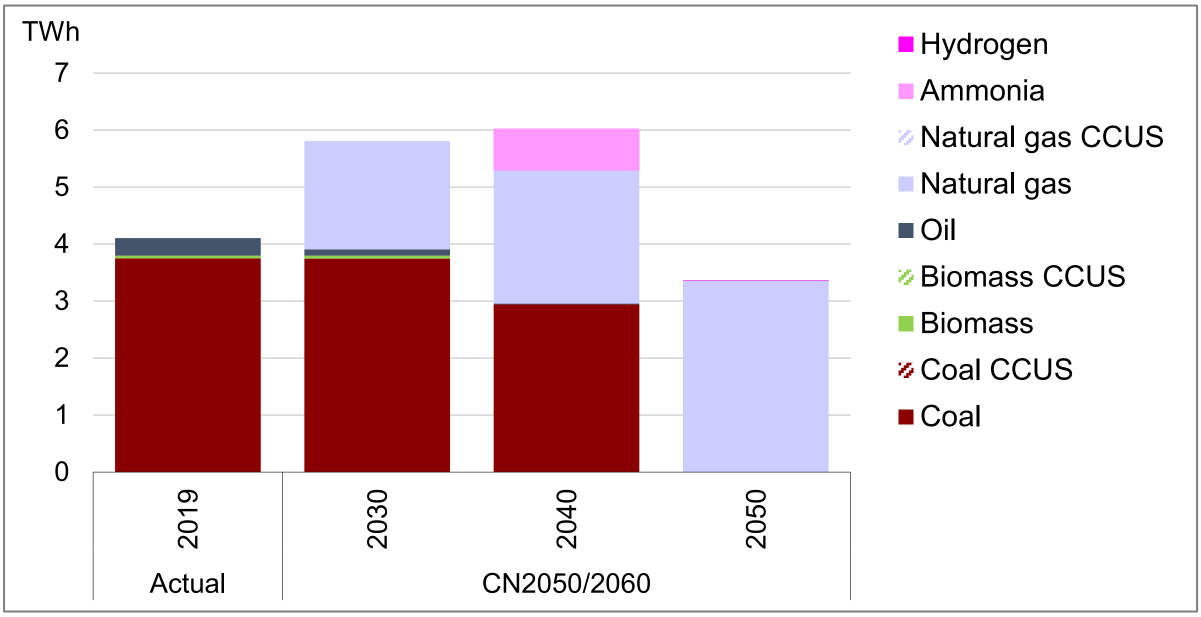
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.14. Power Generation by Technology (Cambodia)



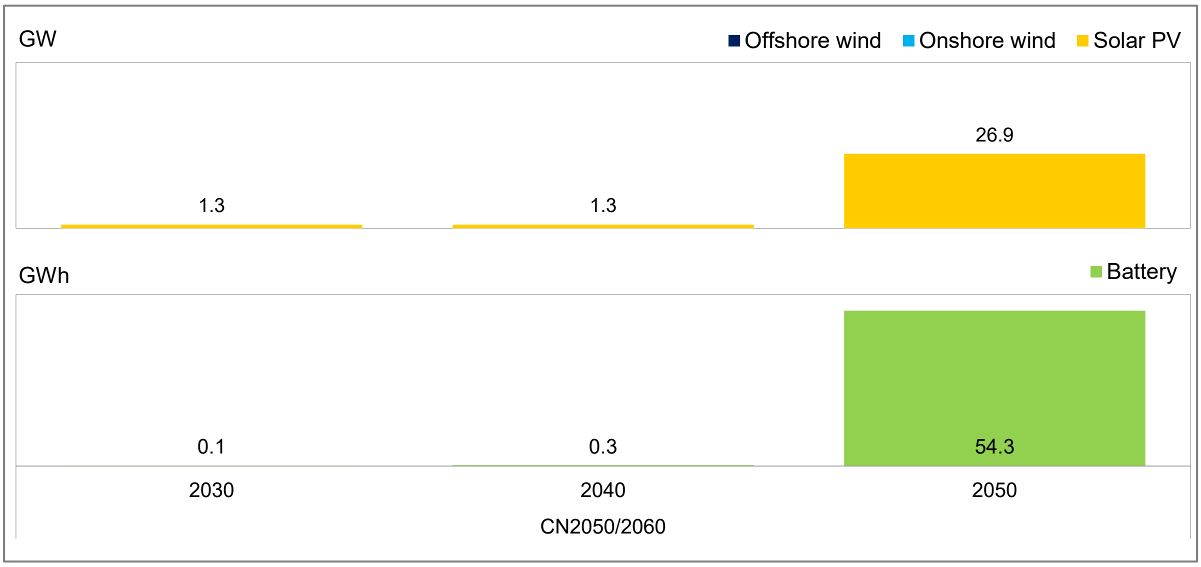
TWh = terawatt hour, PV = photovoltaic.
Source: Author.

Figure A.15. Thermal Power Generation by Source (Cambodia)



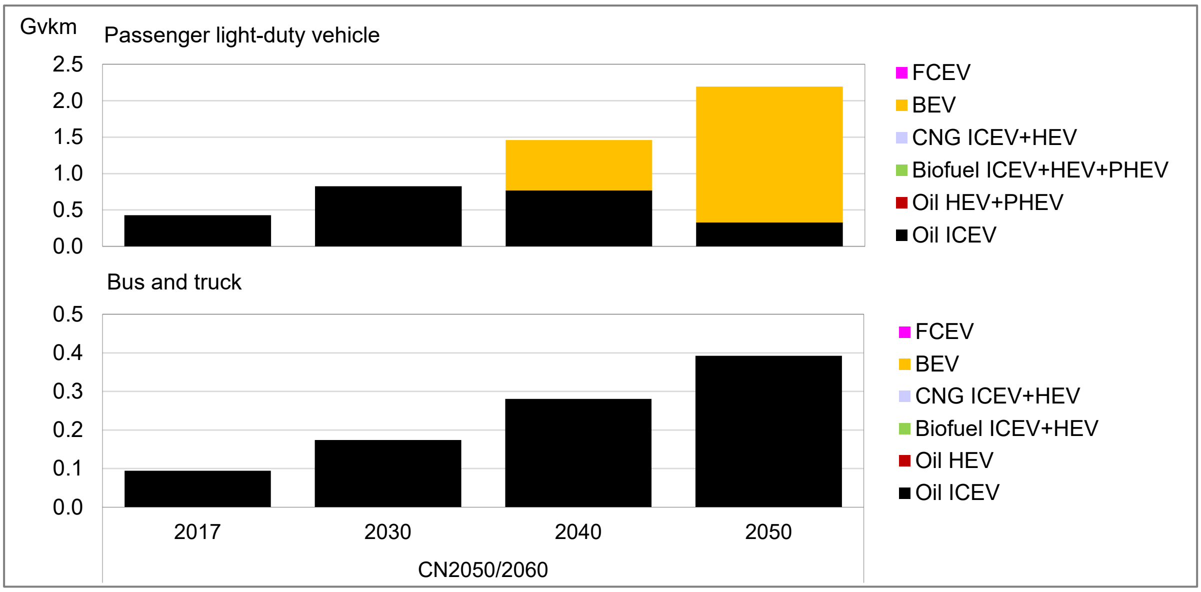
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure A.16. Installed Capacity of Variable Renewable Energy and Battery (Cambodia)



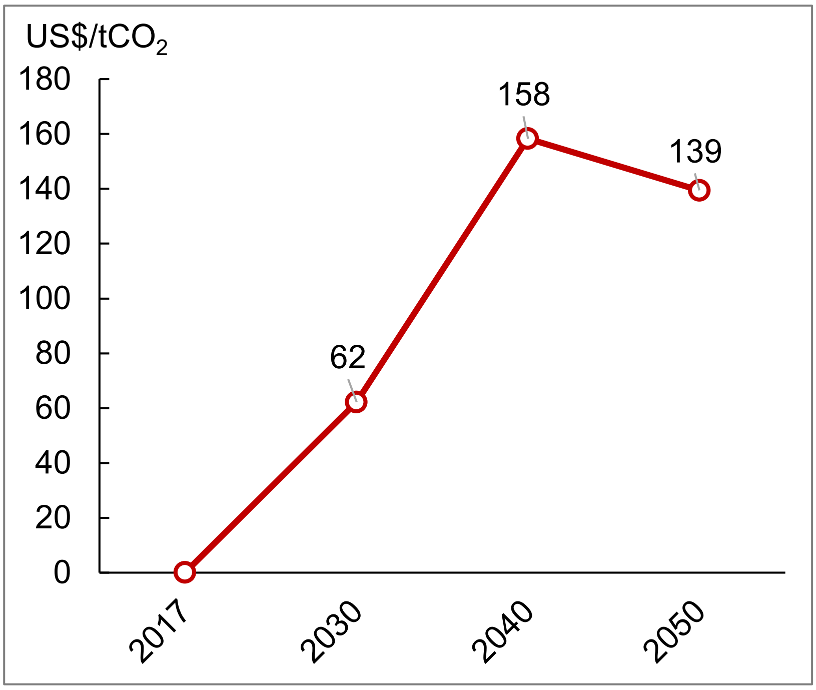
GW = gigawatt, PV = photovoltaic.
Source: Author.

Figure A.17. Road Transport Demand (Cambodia)



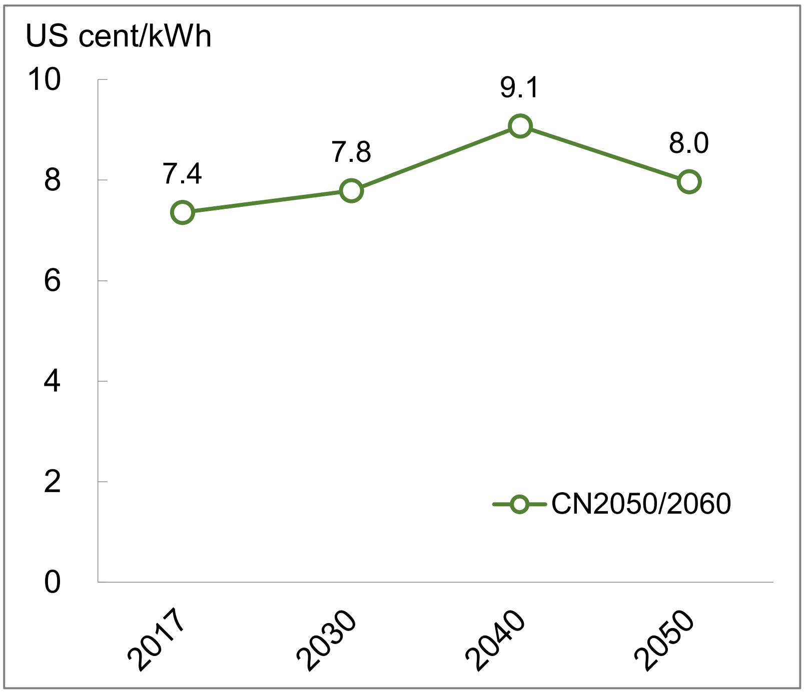
BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, Gvkm = billion vehicle-kilometres, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Author.

Figure A.18. Marginal Abatement Cost of CO_2 (Cambodia)



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.
Source: Author.

Figure A.19. Marginal Cost of Electricity (Cambodia)

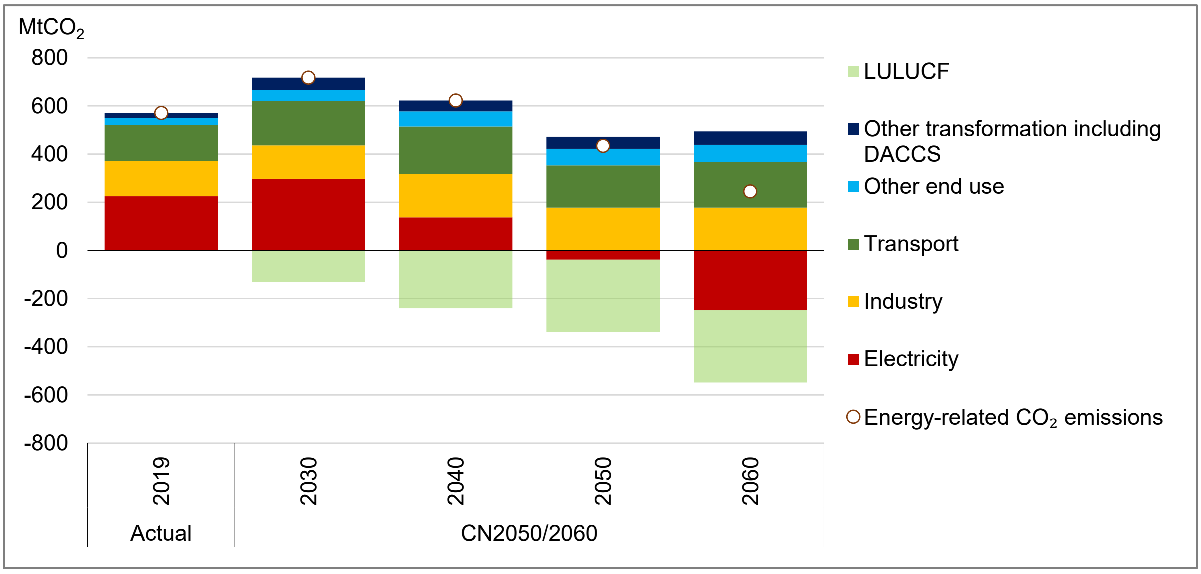


kWh = kilowatt-hour.
Source: Author.

A-3. Indonesia

Significant expansion in power generation, projected to be 7.1 times larger in 2060 than in 2019, is expected. In the medium term, coal-fired, geothermal, hydropower, and solar PV generation are expected to expand. Over the long term, solar PV, nuclear, and biomass-fired power generation will see substantial increases. The share of renewable energy is projected to reach 71% by 2060. In terms of final energy consumption, both natural gas and electricity consumption are expected to increase steadily from the medium to the long term. Hydrogen produced in Sumatra will be transported to Java-Bali, the main demand centre, as well as to the neighbouring countries, contributing to the broader decarbonisation of the region.

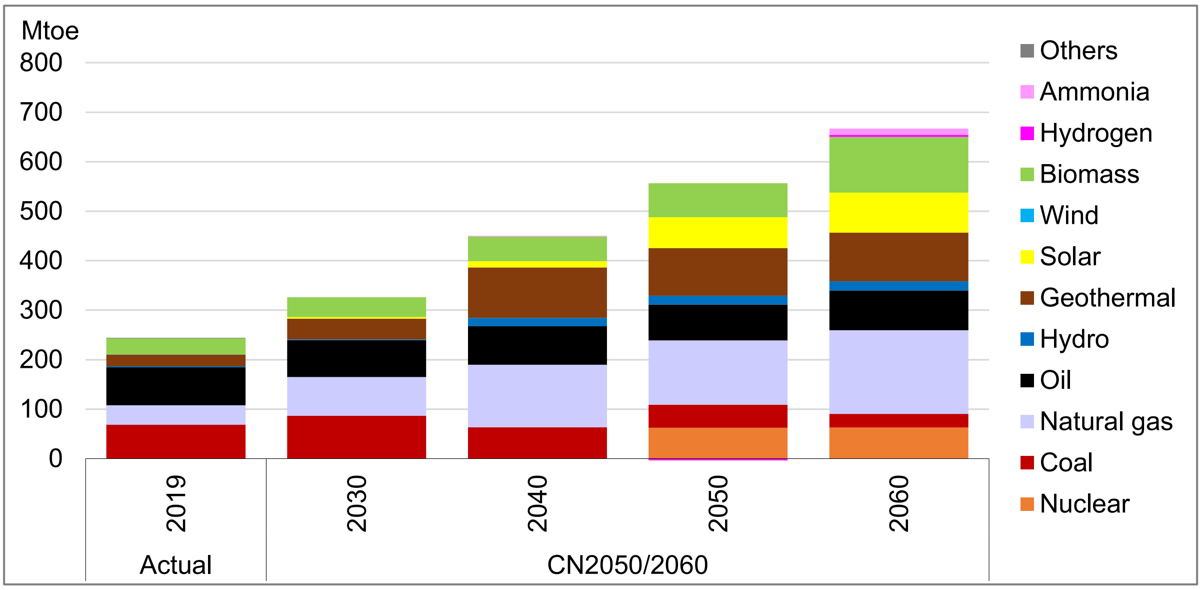
Figure A.20. CO_2 Emissions by Sector (Indonesia)



CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = metric tonne of carbon dioxide.

Source: Author.

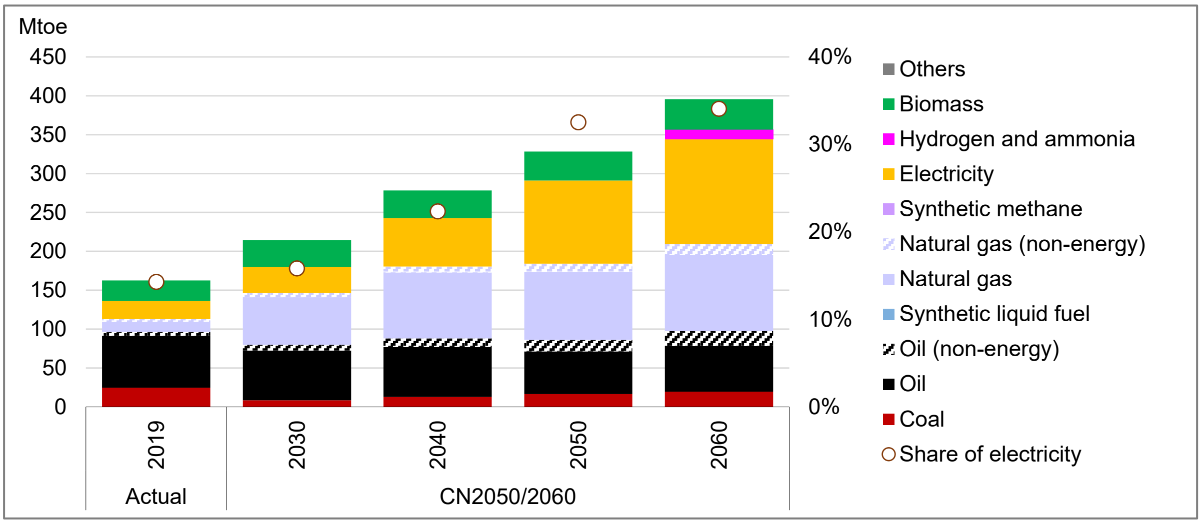
Figure A.21. Primary Energy Supply by Source (Indonesia)



Mtoe = million tonnes of oil equivalent.

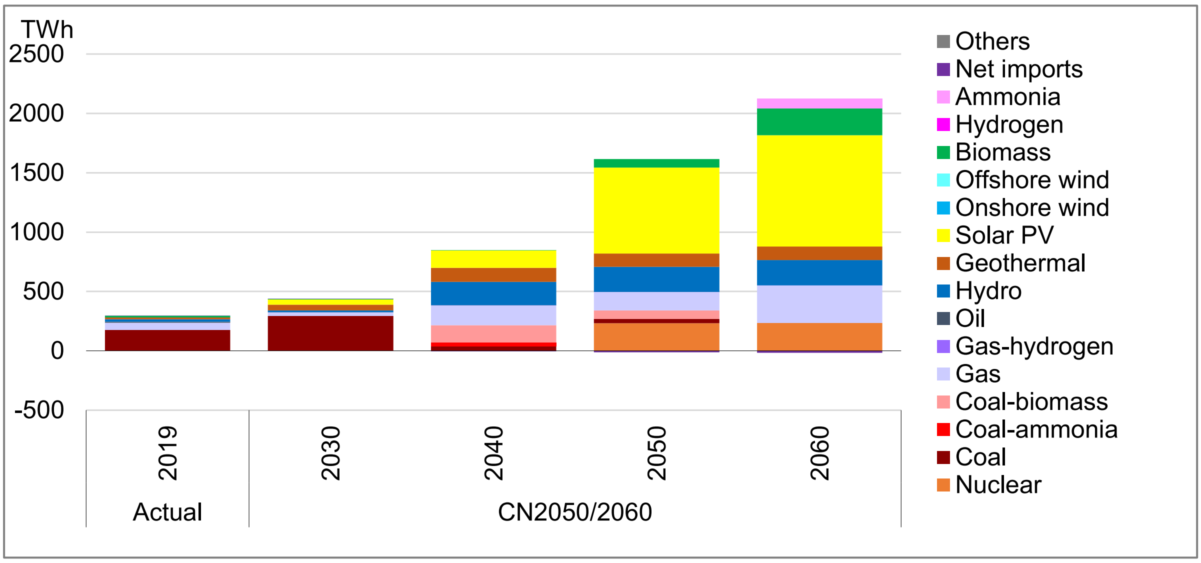
Source: Author.

Figure A.22. Final Energy Consumption by Source (Indonesia)



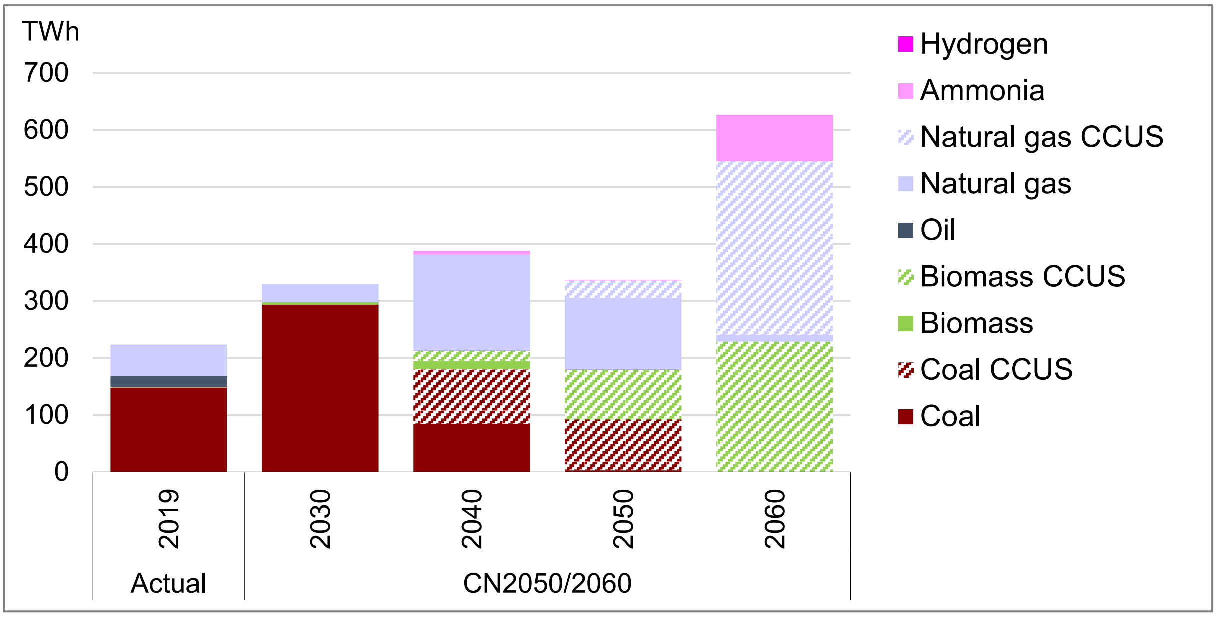
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.23. Power Generation by Technology (Indonesia)



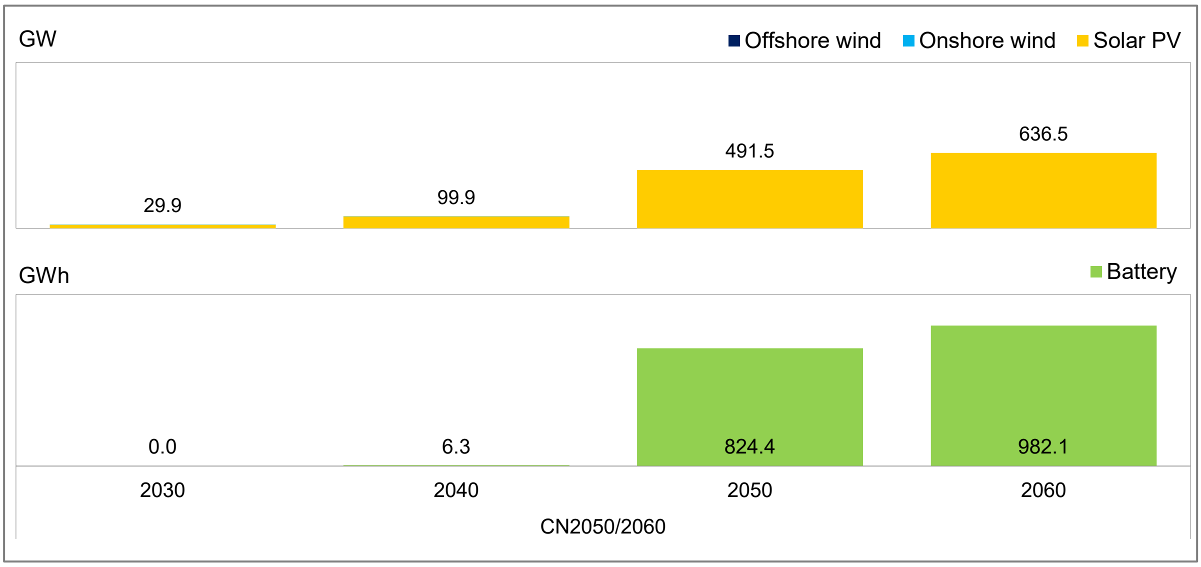
TWh = terawatt hour, PV = photovoltaic.
Source: Author.

Figure A.24. Thermal Power Generation by Source (Indonesia)



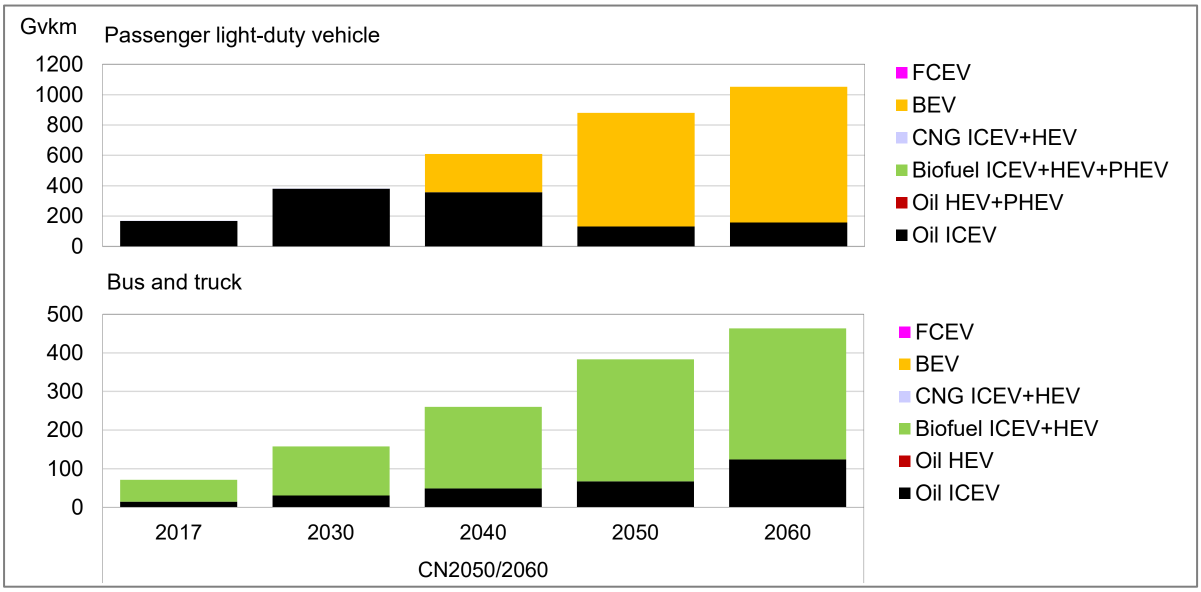
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure A.25. Installed Capacity of Variable Renewable Energy and Battery (Indonesia)



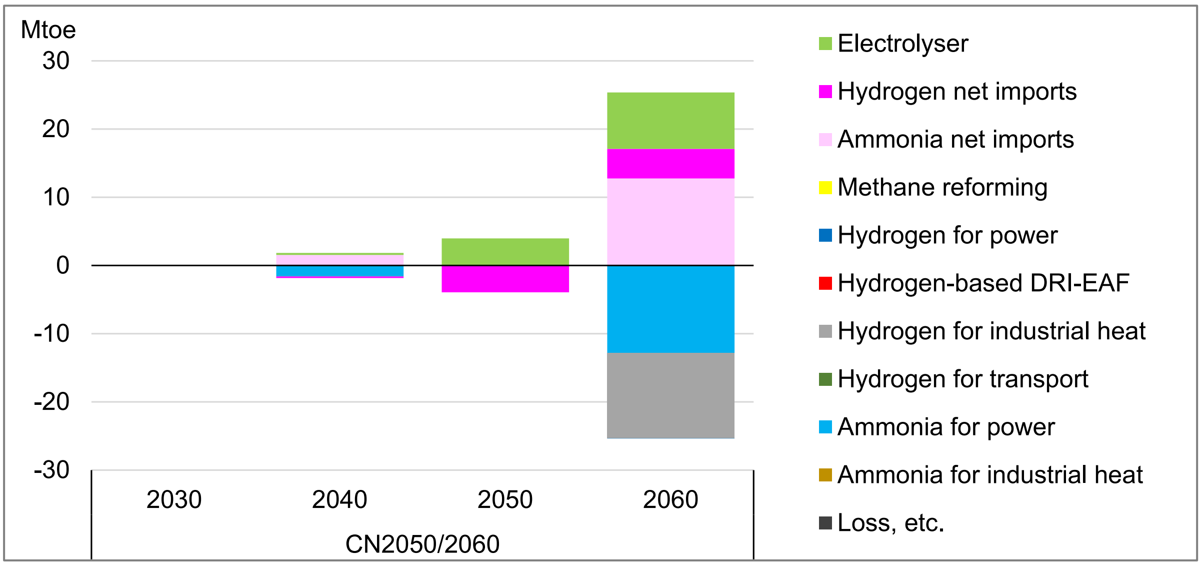
GW = gigawatt, PV = photovoltaic.
Source: Author.

Figure A.26. Road Transport Demand (Indonesia)



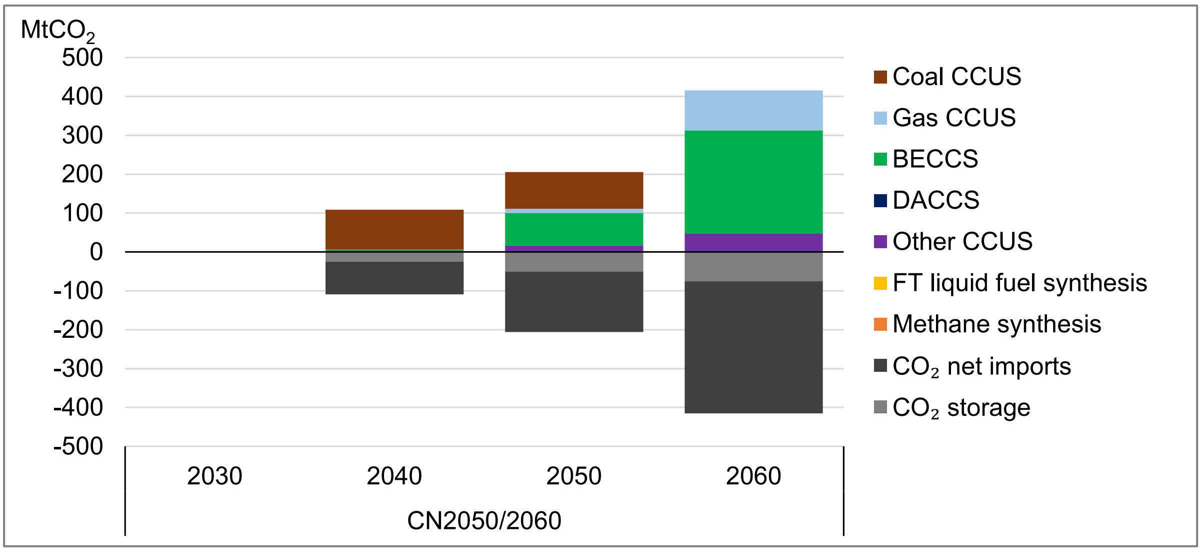
BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, Gvkm = billion vehicle-kilometres, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Author.

Figure A.27. Supply and Demand of Hydrogen and Ammonia (Indonesia)



DRI-EAF = direct reduced iron–electric arc furnace, Mtoe = million tonnes of oil equivalent.
Source: Author.

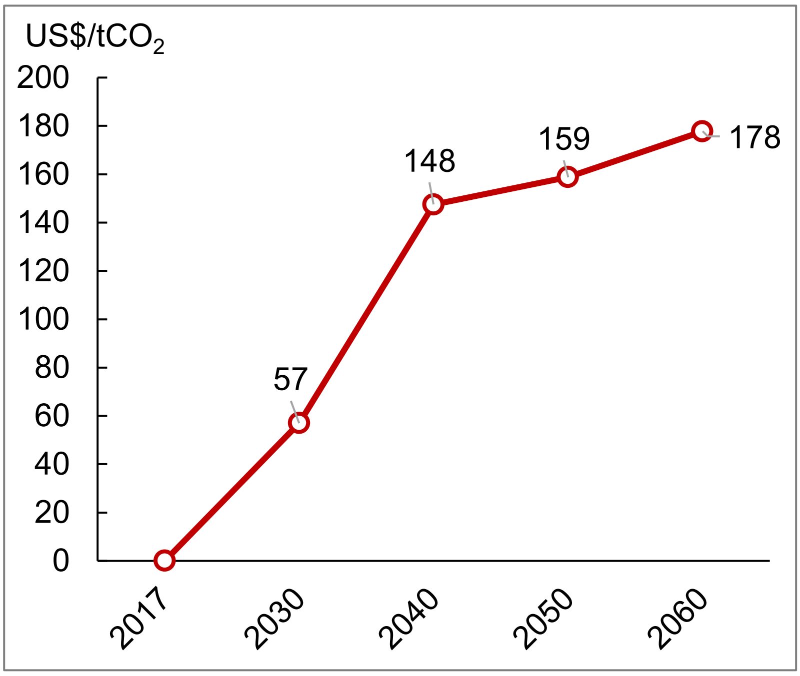
Figure A.28. Carbon Capture, Utilisation, and Storage (Indonesia)



BECCS = bioenergy with carbon capture and storage; CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; FT = Fischer–Tropsch; $MtCO_2$ = metric tonne of carbon dioxide.

Source: Author.

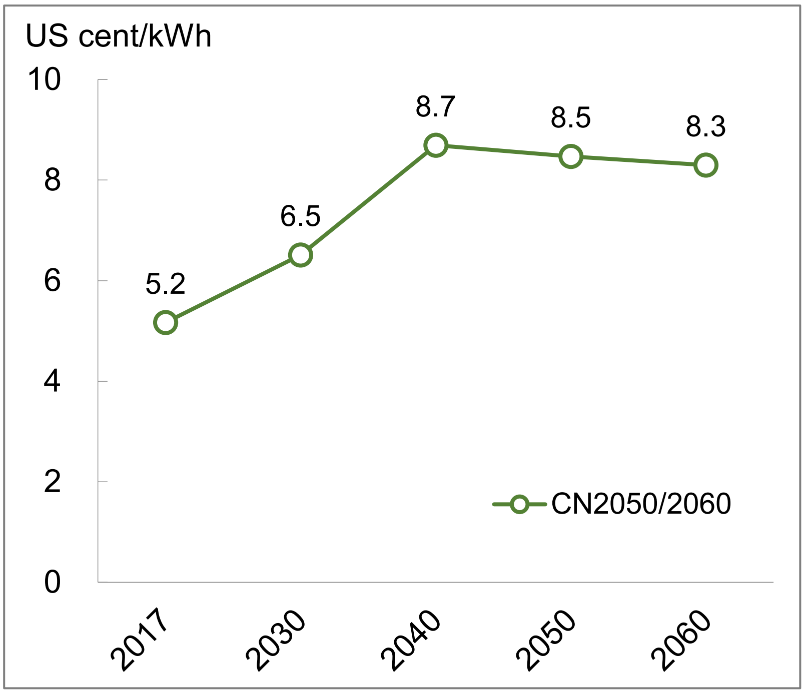
Figure A.29. Marginal Abatement Cost of CO_2 (Indonesia)



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.

Source: Author.

Figure A.30. Marginal Cost of Electricity (Indonesia)

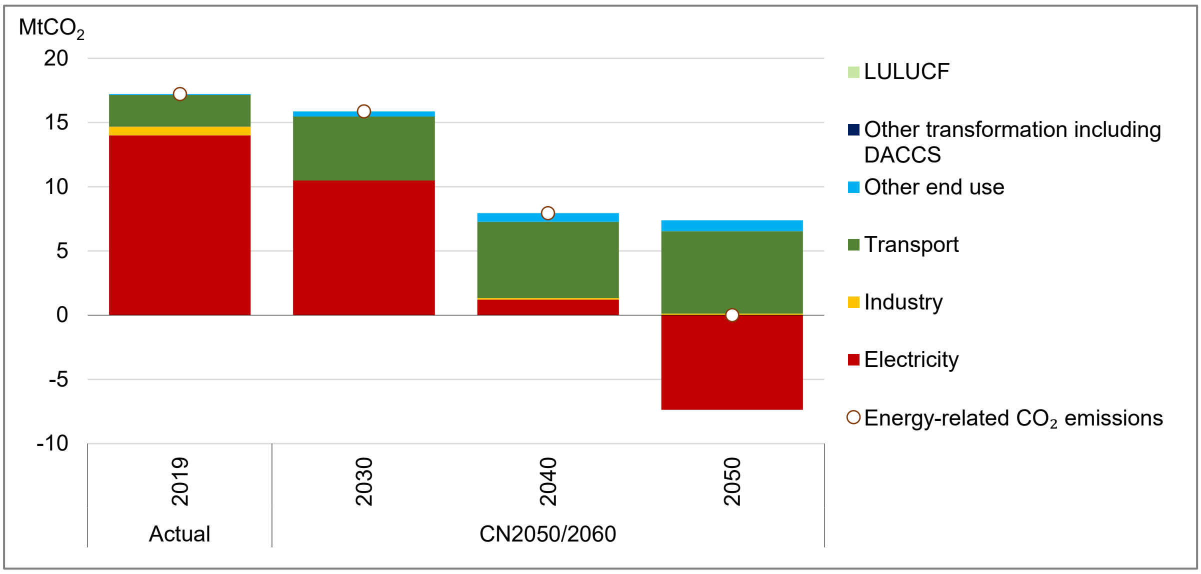


kWh = kilowatt-hour.
Source: Author.

A-4. Lao People's Democratic Republic

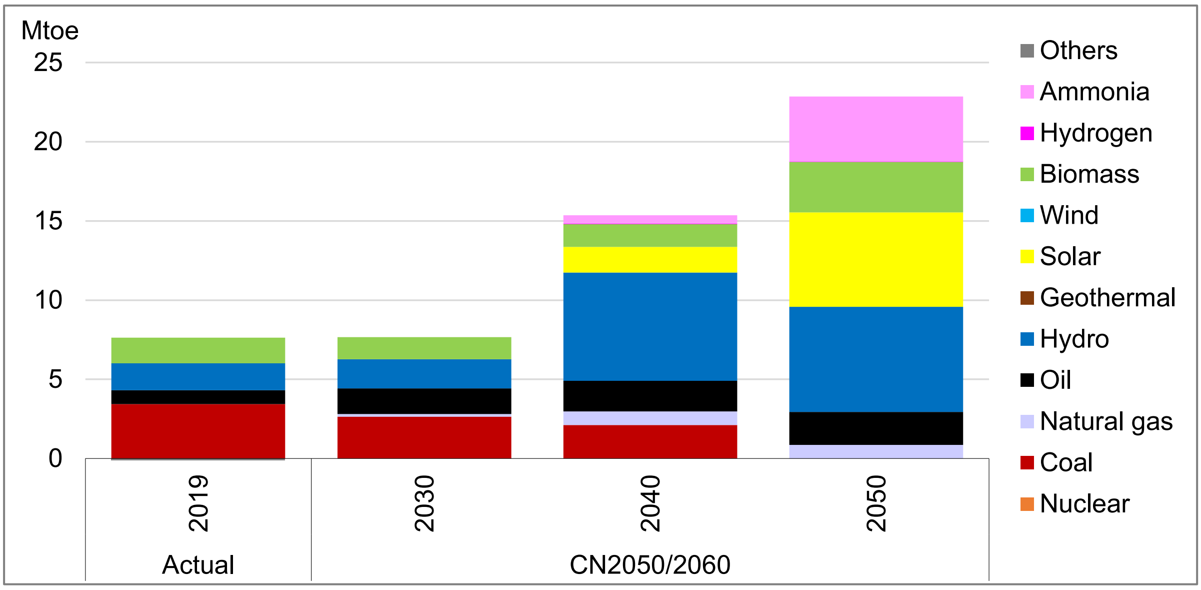
Hydropower remains the dominant source of electricity generation, whilst solar PV is projected to become a significant contributor by 2050. Most of the rapidly growing electricity production is exported, contributing to the decarbonisation efforts of the region.

Figure A.31. CO_2 Emissions by Sector (Lao People's Democratic Republic)



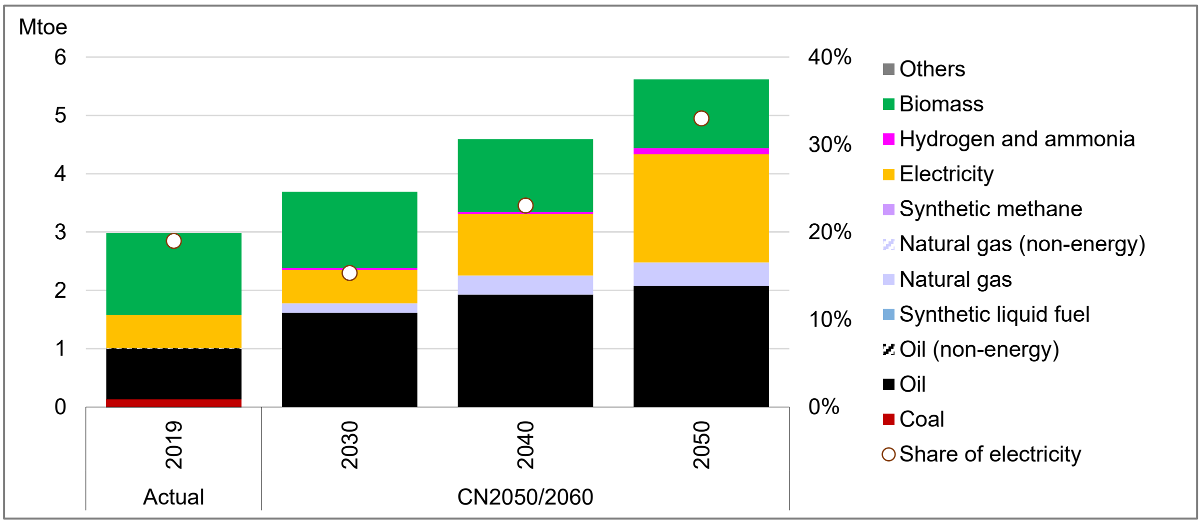
CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.32. Primary Energy Supply by Source (Lao People's Democratic Republic)



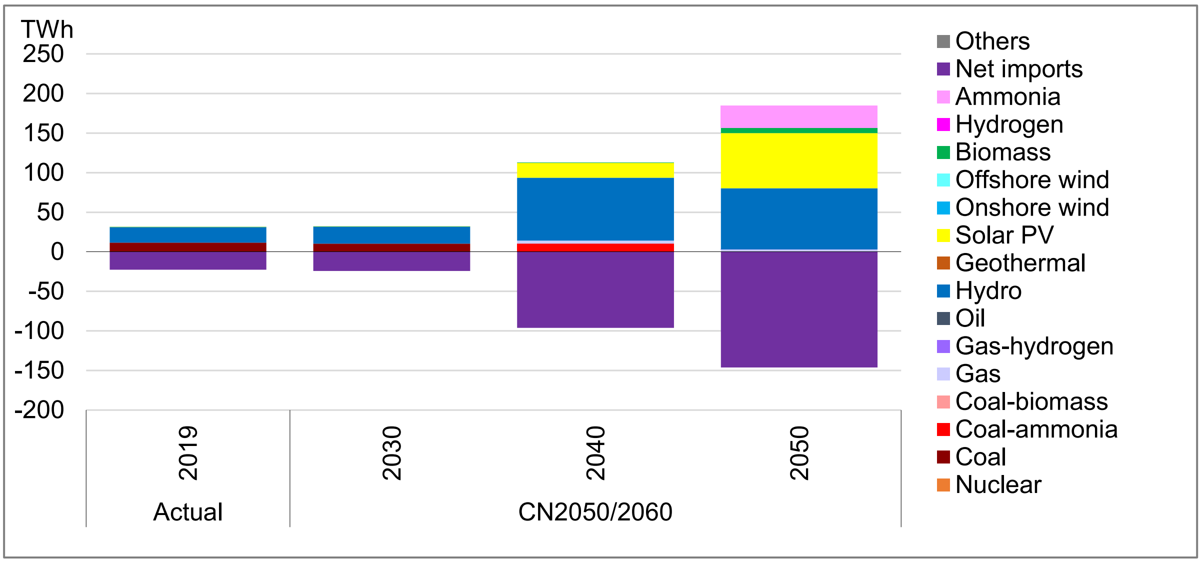
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.33. Final Energy Consumption by Source (Lao People's Democratic Republic)



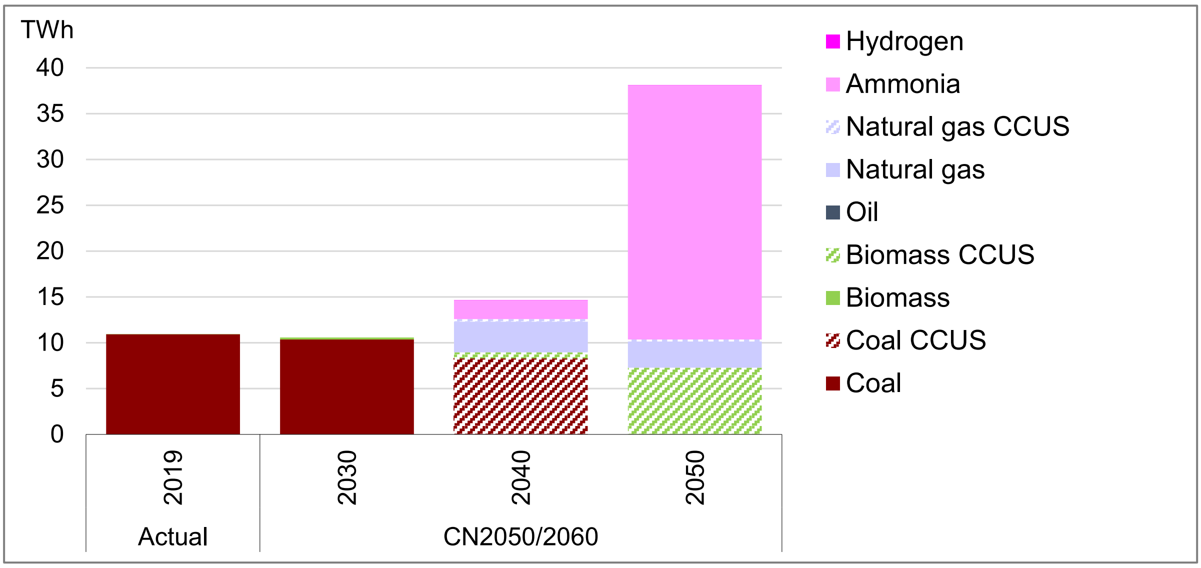
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.34. Power Generation by Technology (Lao People's Democratic Republic)



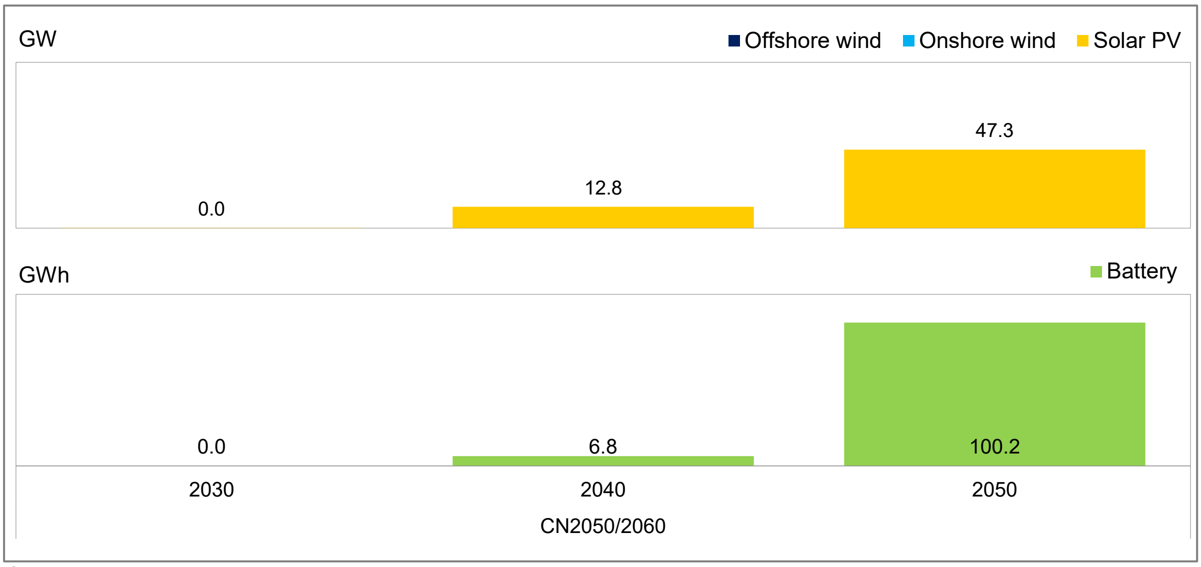
TWh = terawatt hour, PV = photovoltaic.
Source: Author.

Figure A.35. Thermal Power Generation by Source (Lao People's Democratic Republic)



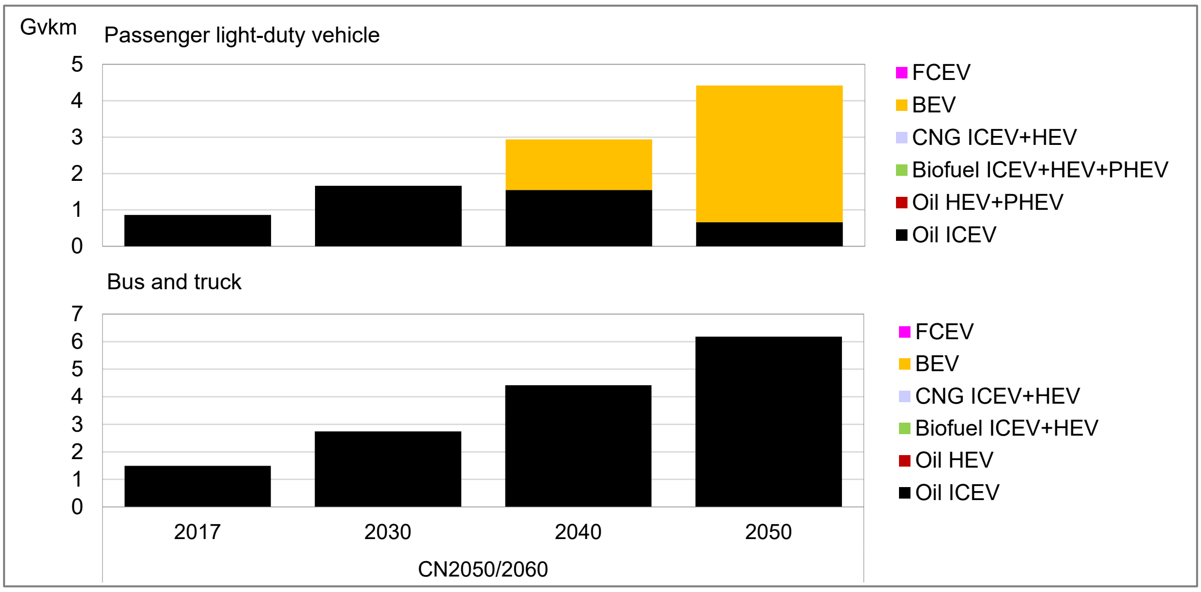
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure A.36. Installed Capacity of Variable Renewable Energy and Battery (Lao People's Democratic Republic)



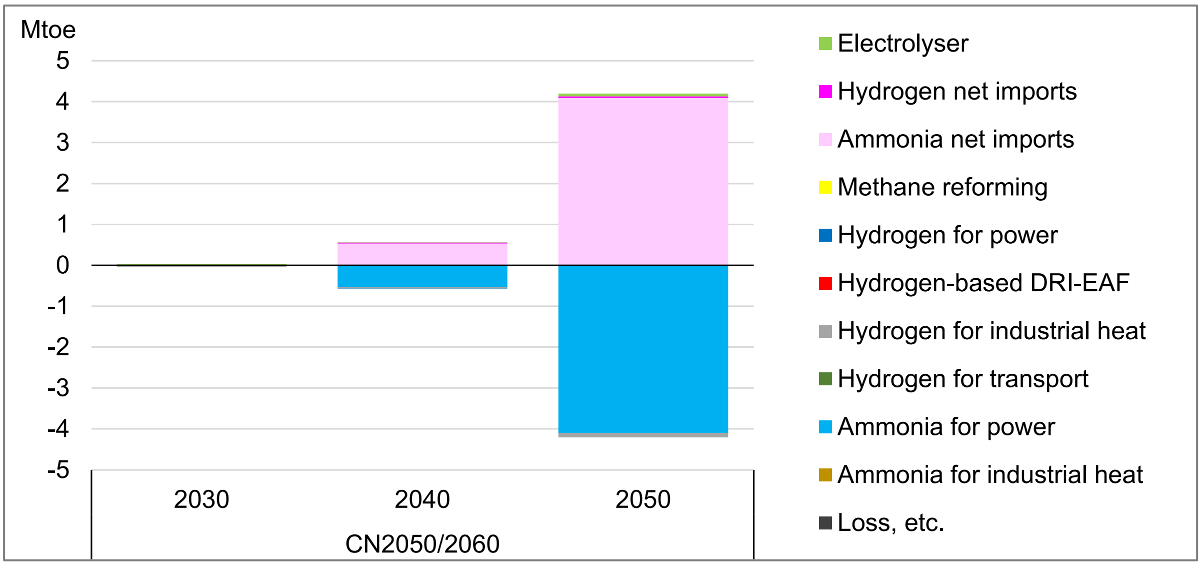
GW = gigawatt, PV = photovoltaic.
Source: Author.

Figure A.37. Road Transport Demand (Lao People's Democratic Republic)



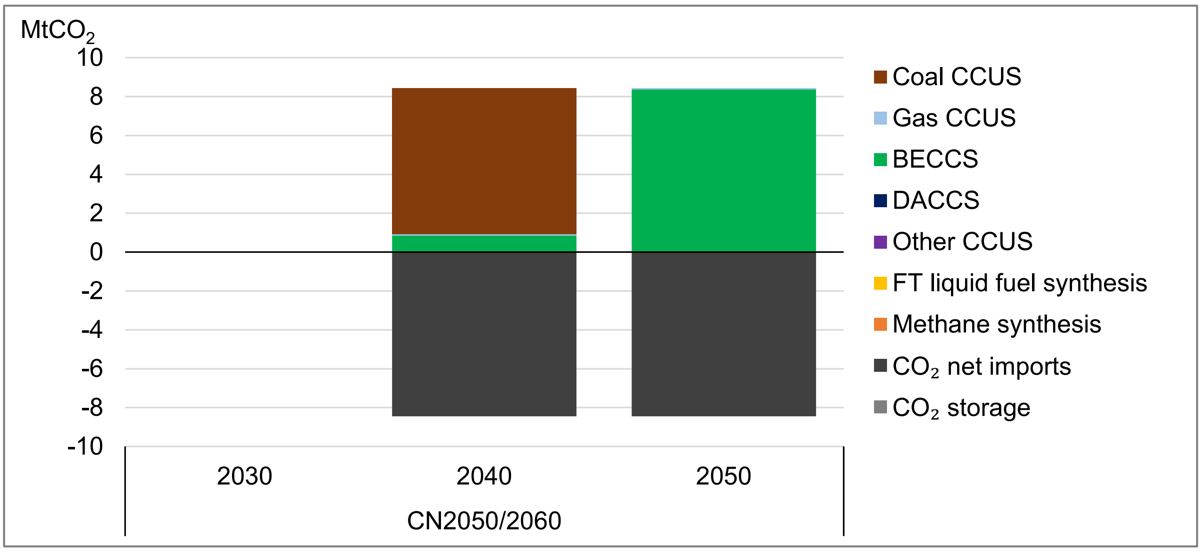
BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, Gvkm = billion vehicle-kilometres, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Author.

Figure A.38. Supply and Demand of Hydrogen and Ammonia (Lao People's Democratic Republic)



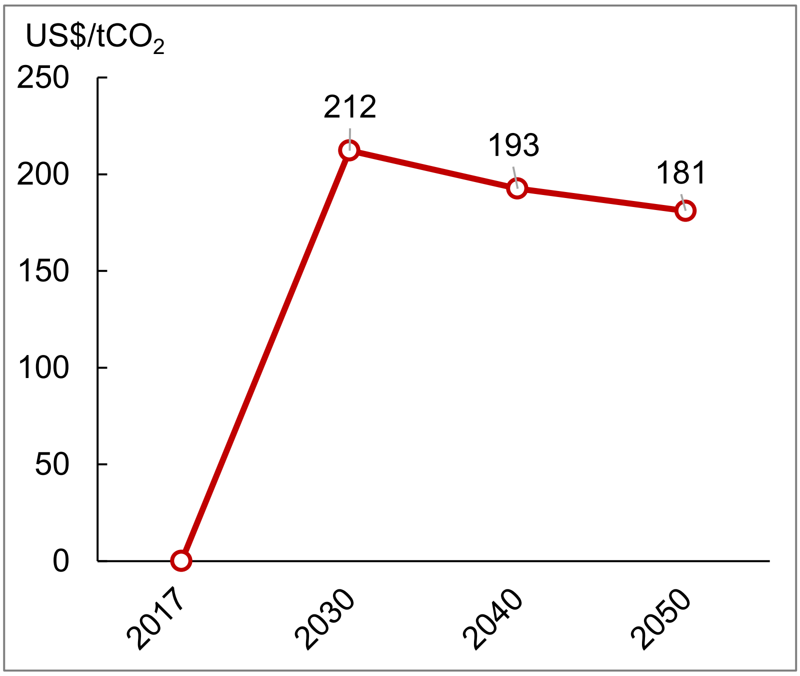
DRI-EAF = direct reduced iron–electric arc furnace, Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.39. Carbon Capture, Utilisation, and Storage (Lao People's Democratic Republic)



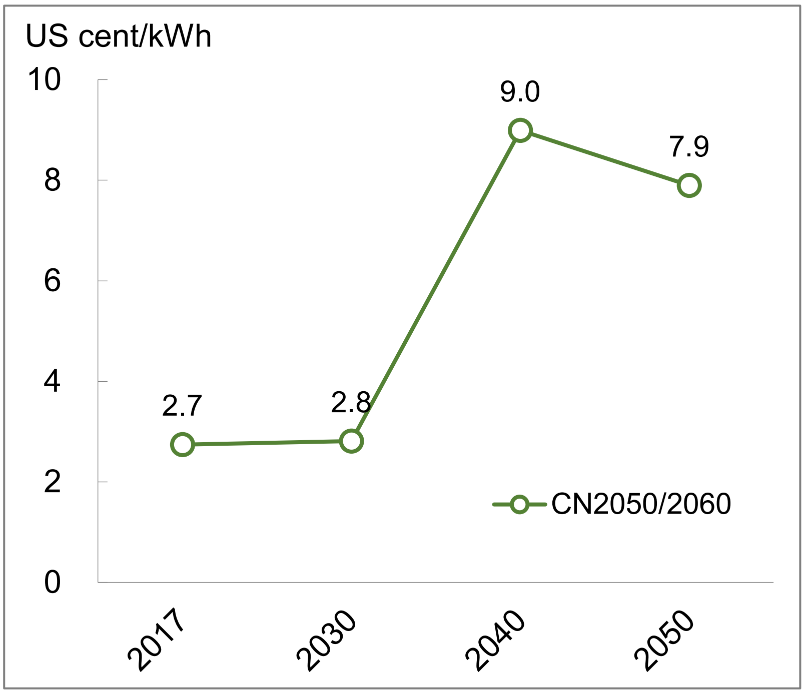
BECCS = bioenergy with carbon capture and storage; CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; FT = Fischer–Tropsch; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.40. Marginal Abatement Cost of CO_2 (Lao People's Democratic Republic)



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.
Source: Author.

Figure A.41. Marginal Cost of Electricity (Lao People's Democratic Republic)

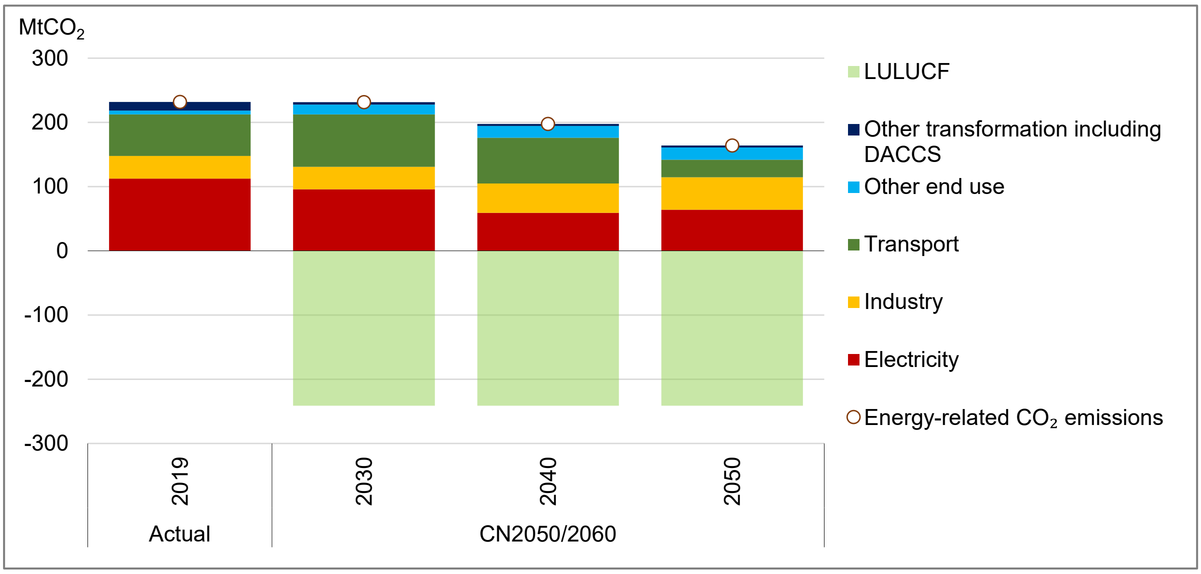


kWh = kilowatt-hour.
Source: Author.

A-5. Malaysia

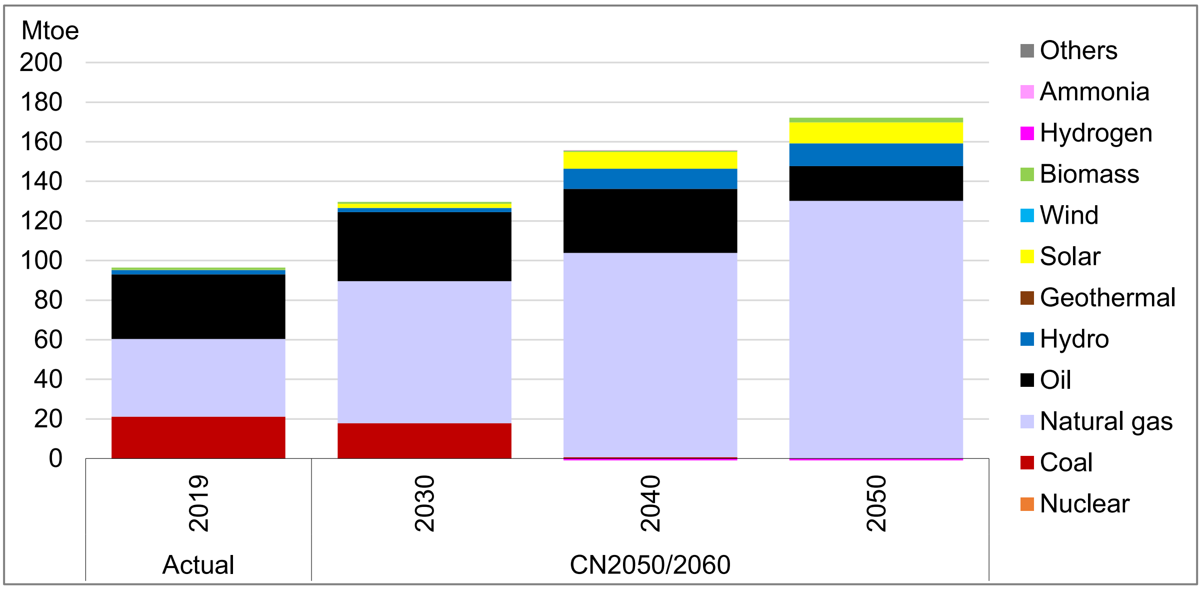
Natural gas is projected to expand as Malaysia's most important energy source, including for non-energy use. Coal-fired power generation is expected to decline after 2030, whilst gas-fired power, hydropower, and solar PV capacity will continue to increase. Hydropower in Sarawak is utilised not only for electricity exports to Brunei Darussalam but also for hydrogen production, with most of the hydrogen produced being exported. Malaysia imports CO_2 from neighbouring countries, taking advantage of its abundant CO_2 storage capacity.

Figure A.42. CO_2 Emissions by Sector (Malaysia)



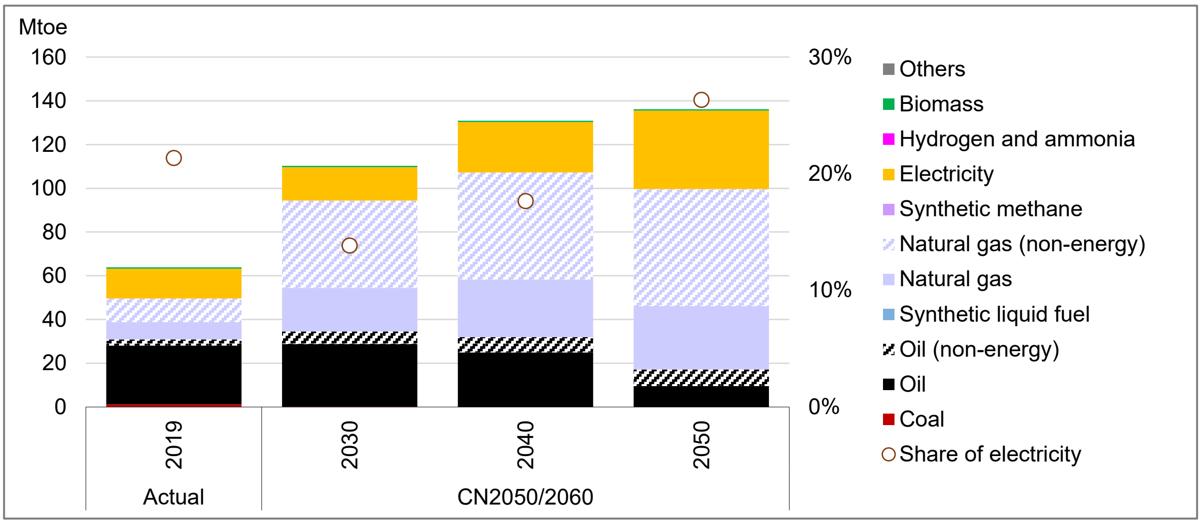
CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.43. Primary Energy Supply by Source (Malaysia)



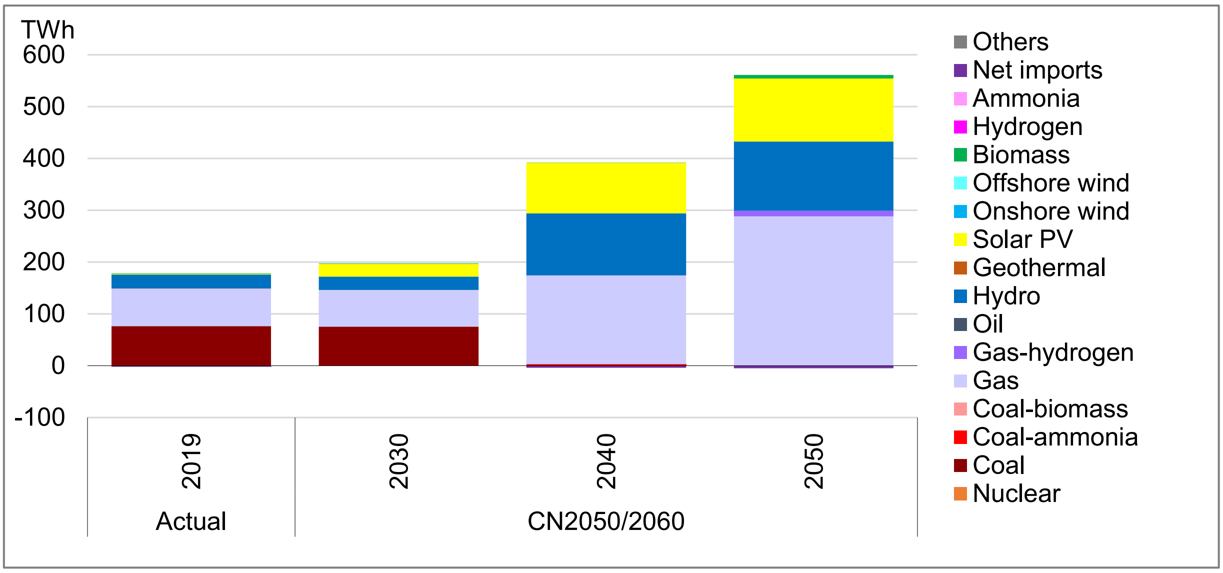
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.44. Final Energy Consumption by Source (Malaysia)



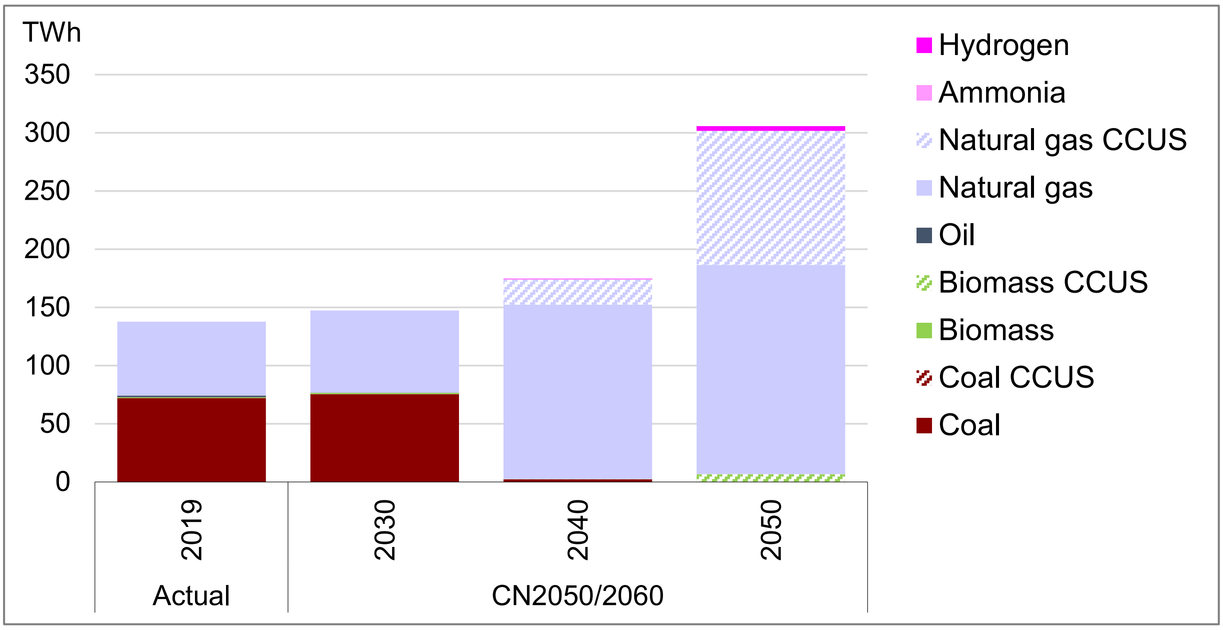
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.45. Power Generation by Technology (Malaysia)



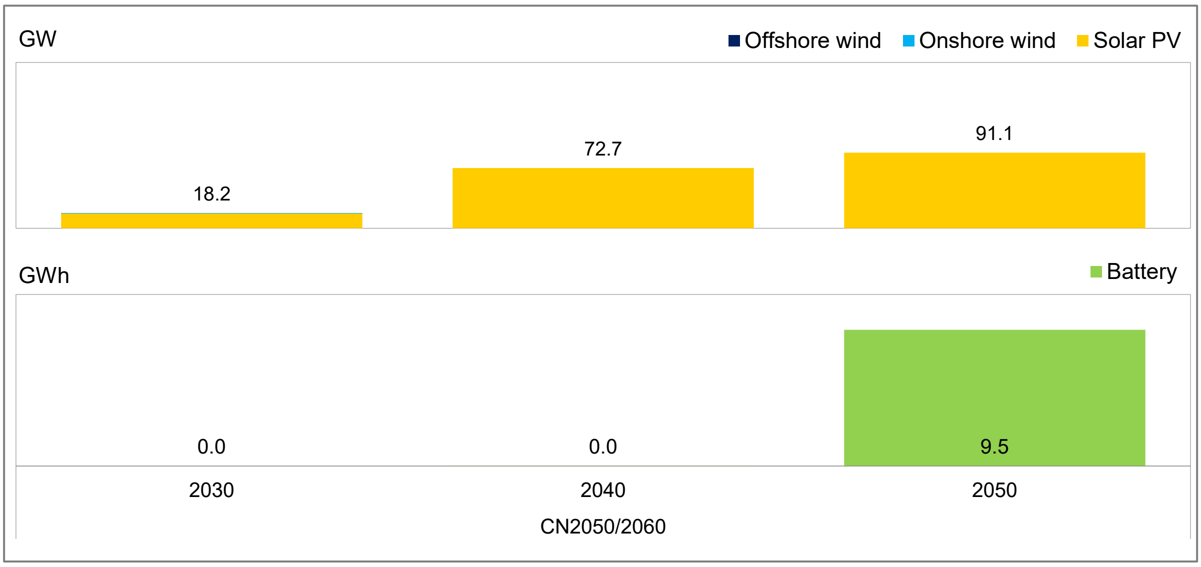
TWh = terawatt hour, PV = photovoltaic.
Source: Author.

Figure A.46. Thermal Power Generation by Source (Malaysia)



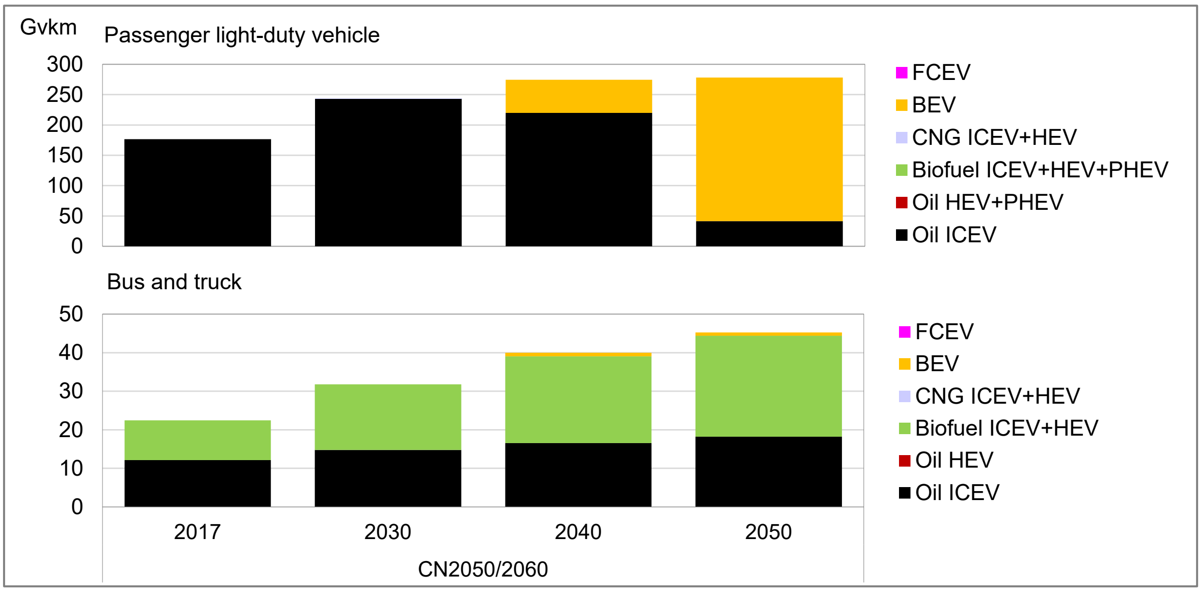
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure A.47. Installed Capacity of Variable Renewable Energy and Battery (Malaysia)



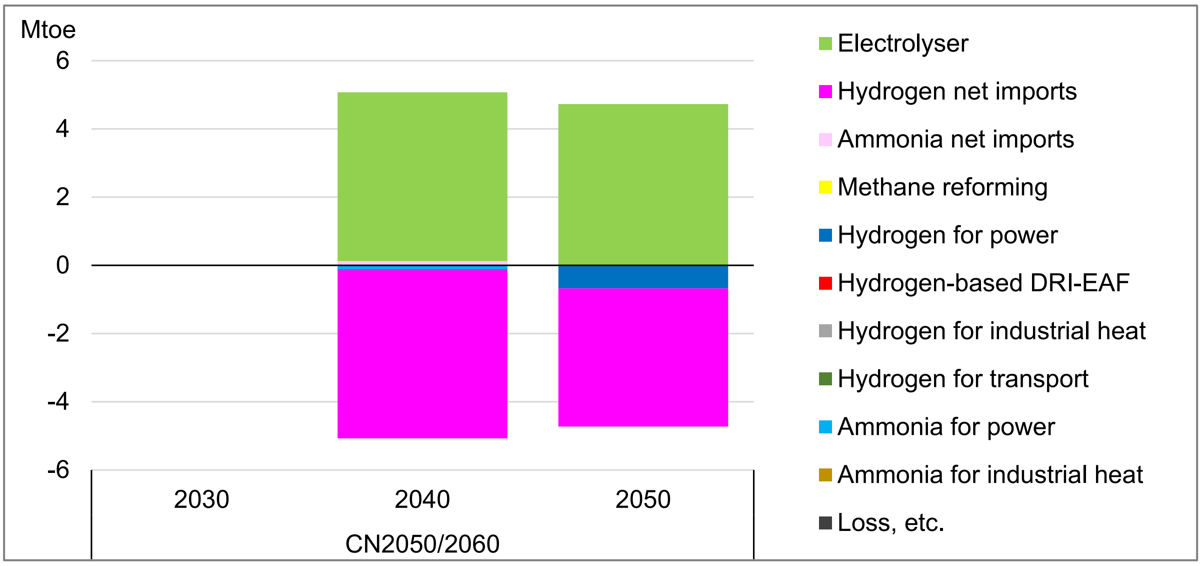
GW = gigawatt, PV = photovoltaic.
Source: Author.

Figure A.48. Road Transport Demand (Malaysia)



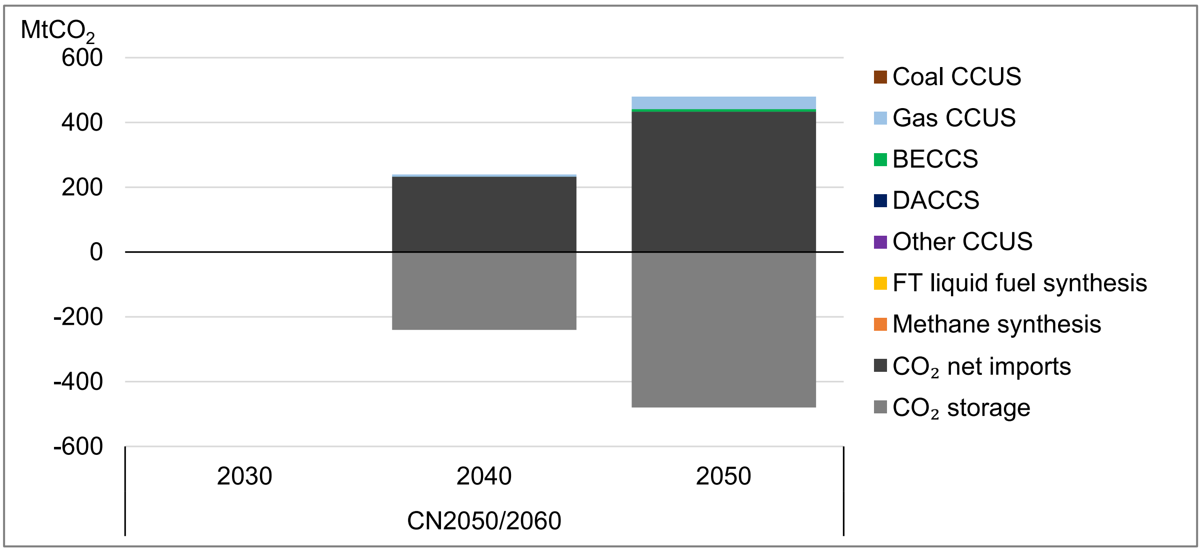
BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, Gvkm = billion vehicle-kilometres, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Author.

Figure A.49. Supply and Demand of Hydrogen and Ammonia (Malaysia)



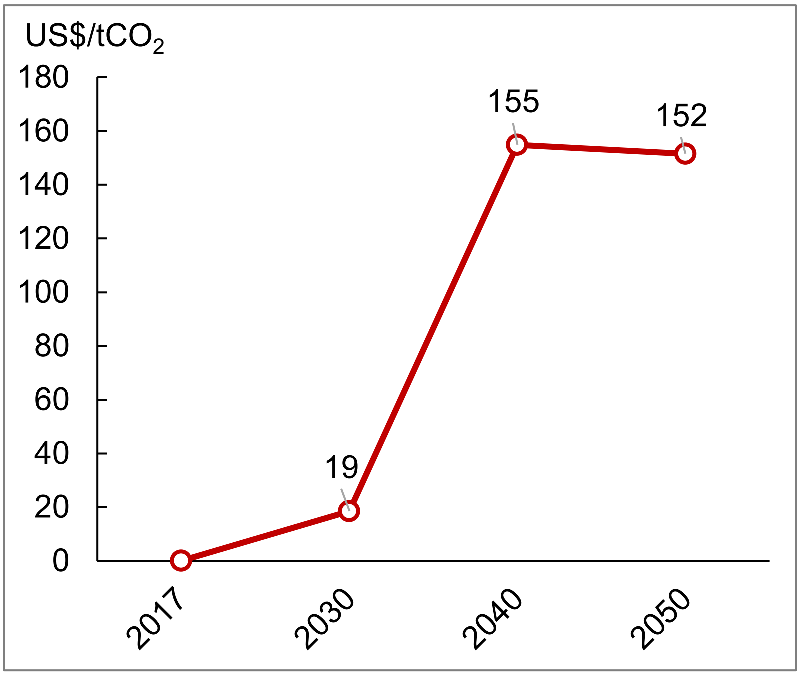
DRI-EAF = direct reduced iron–electric arc furnace, Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.50. Carbon Capture, Utilisation, and Storage (Malaysia)



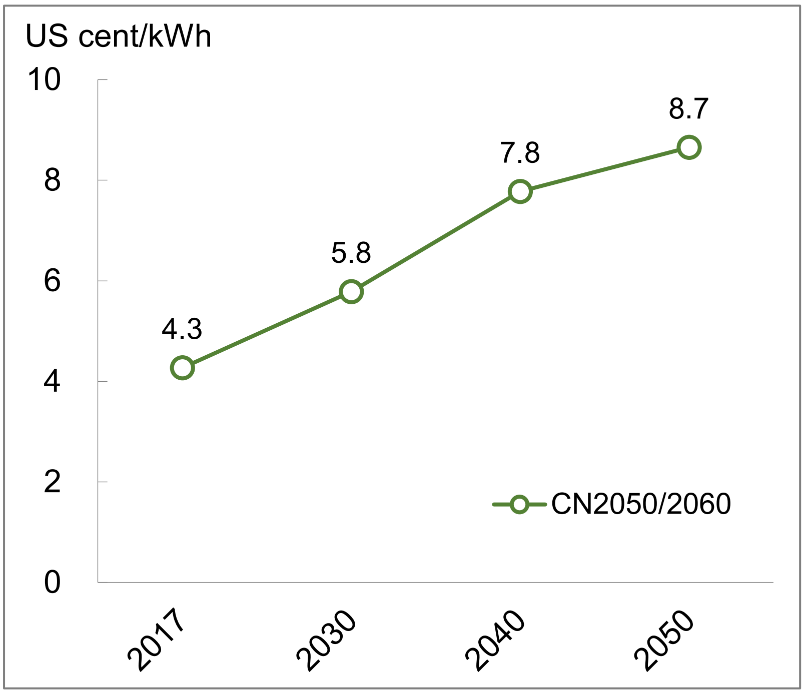
BECCS = bioenergy with carbon capture and storage; CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; FT = Fischer–Tropsch; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.51. Marginal Abatement Cost of CO_2 (Malaysia)



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.
Source: Author.

Figure A.52. Marginal Cost of Electricity (Malaysia)

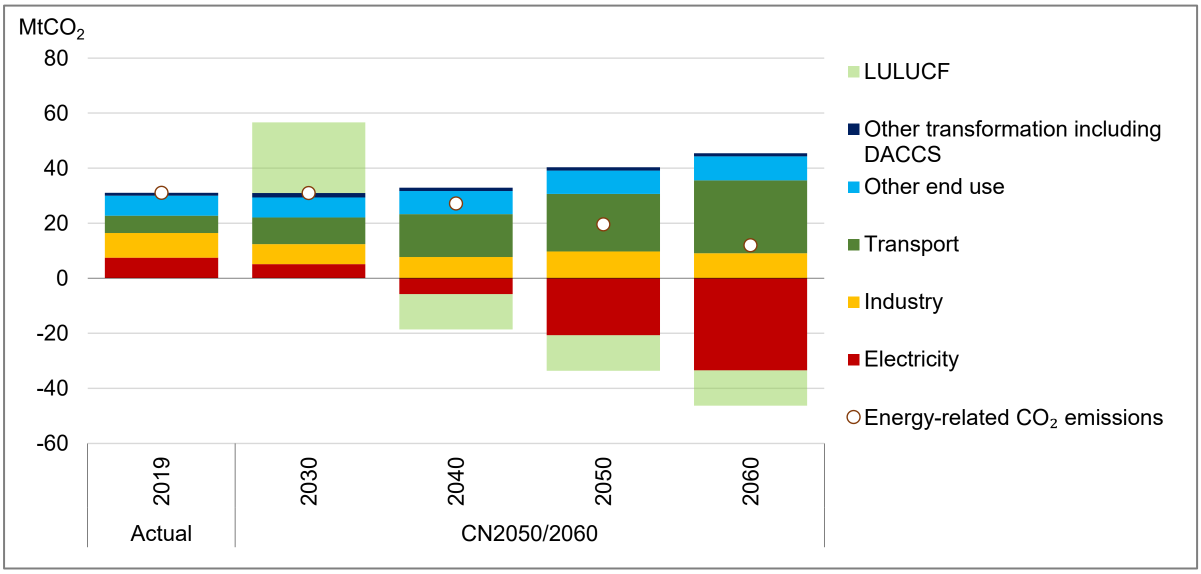


kWh = kilowatt-hour.
Source: Author.

A-6. Myanmar

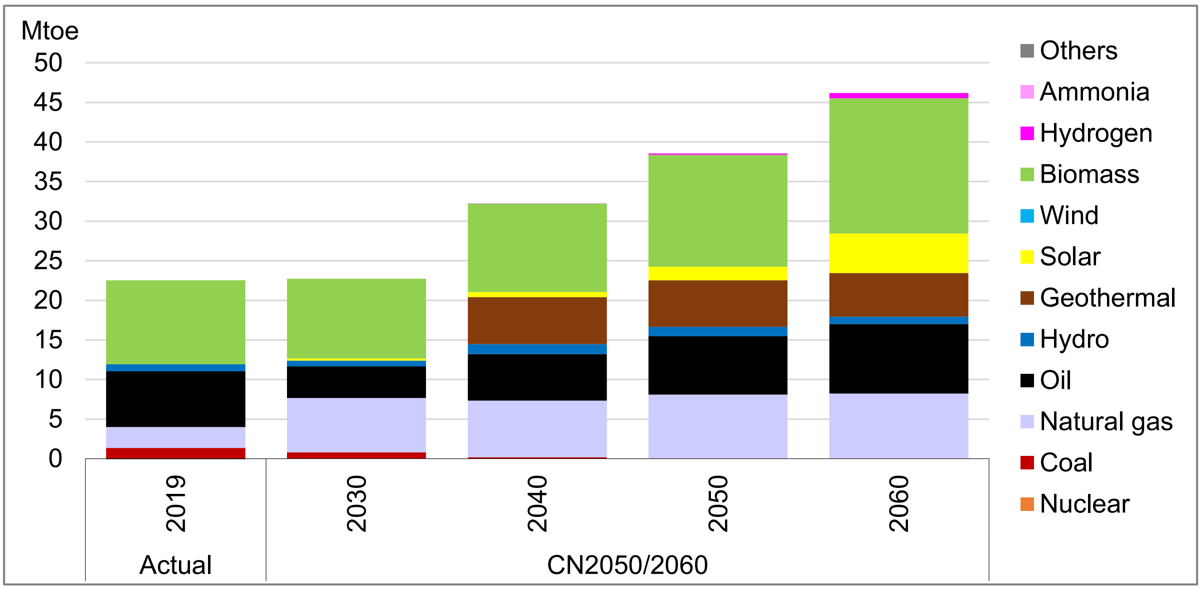
Large, long-term increase in electricity demand is expected to be met by a diverse mix of renewable energy sources, including hydropower, geothermal, solar PV, and biomass. Biomass-fired power, combined with CCS, will act as a negative emission source, helping to offset residual emissions.

Figure A.53. CO_2 Emissions by Sector (Myanmar)



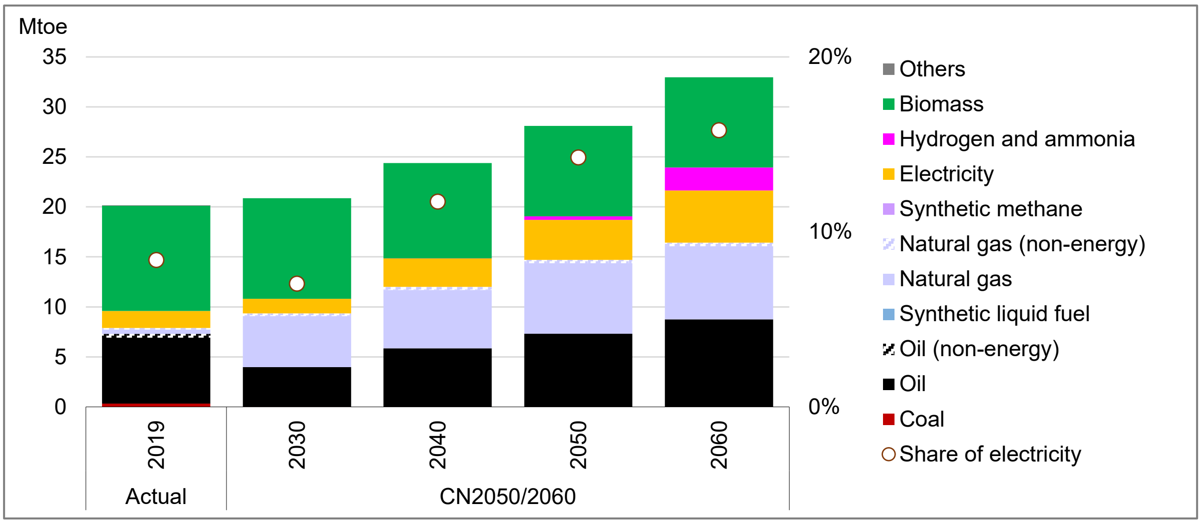
CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.54. Primary Energy Supply by Source (Myanmar)



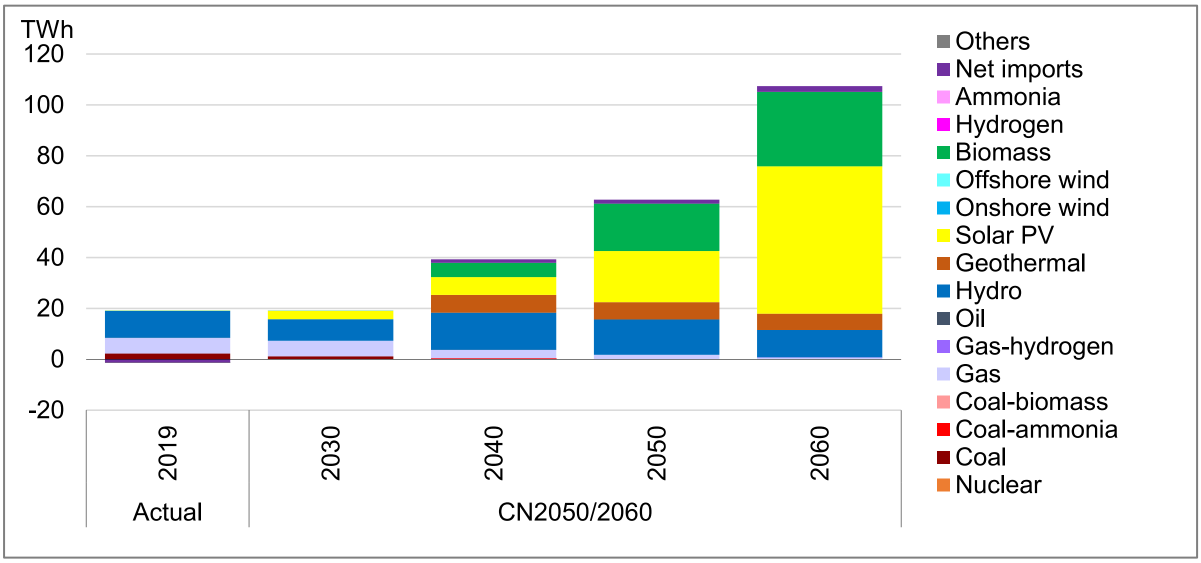
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.55. Final Energy Consumption by Source (Myanmar)



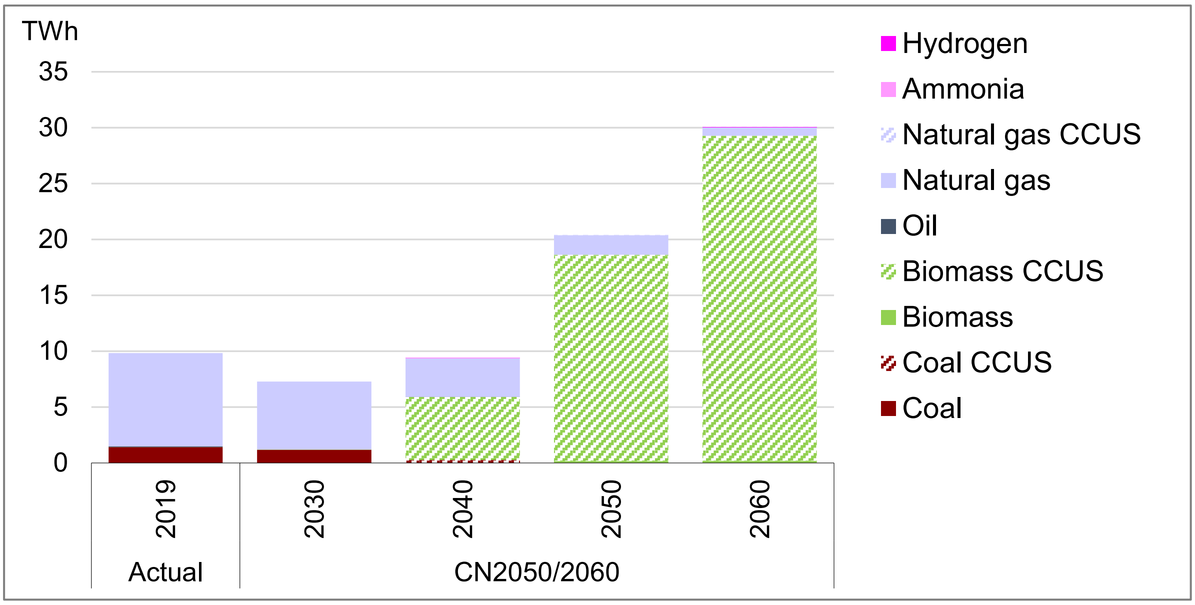
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.56. Power Generation by Technology (Myanmar)



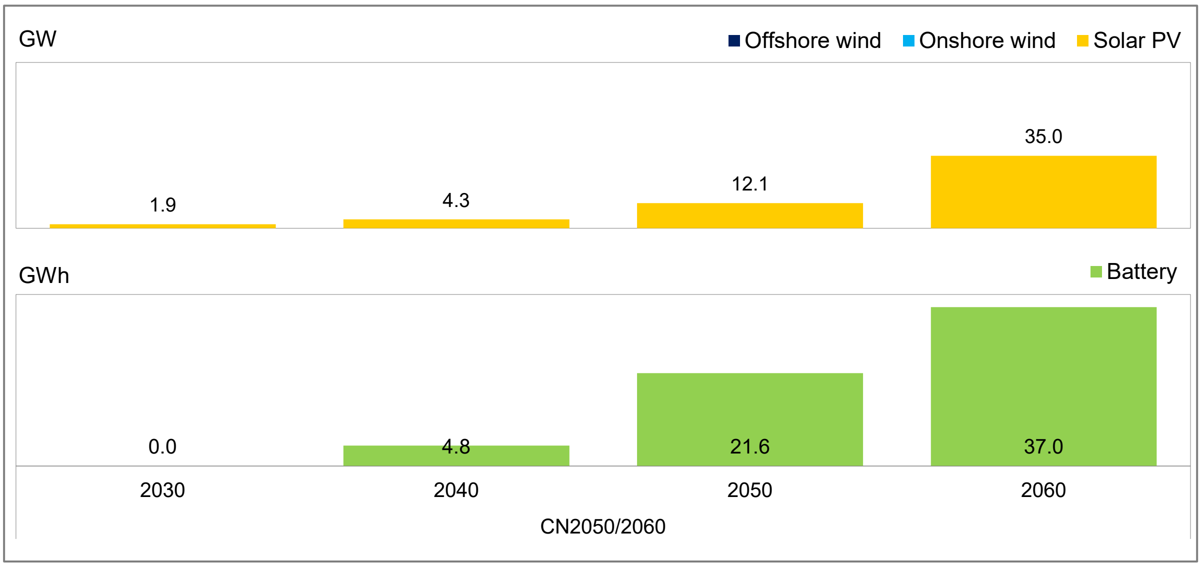
TWh = terawatt hour, PV = photovoltaic.
Source: Author.

Figure A.57. Thermal Power Generation by Source (Myanmar)



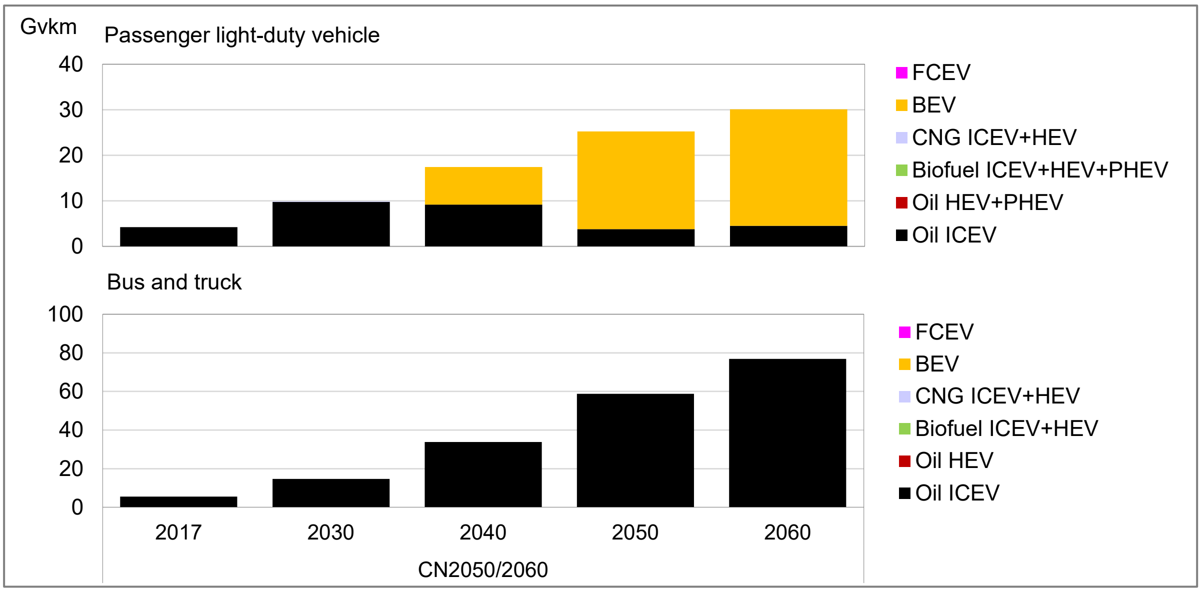
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure A.58. Installed Capacity of Variable Renewable Energy and Battery (Myanmar)



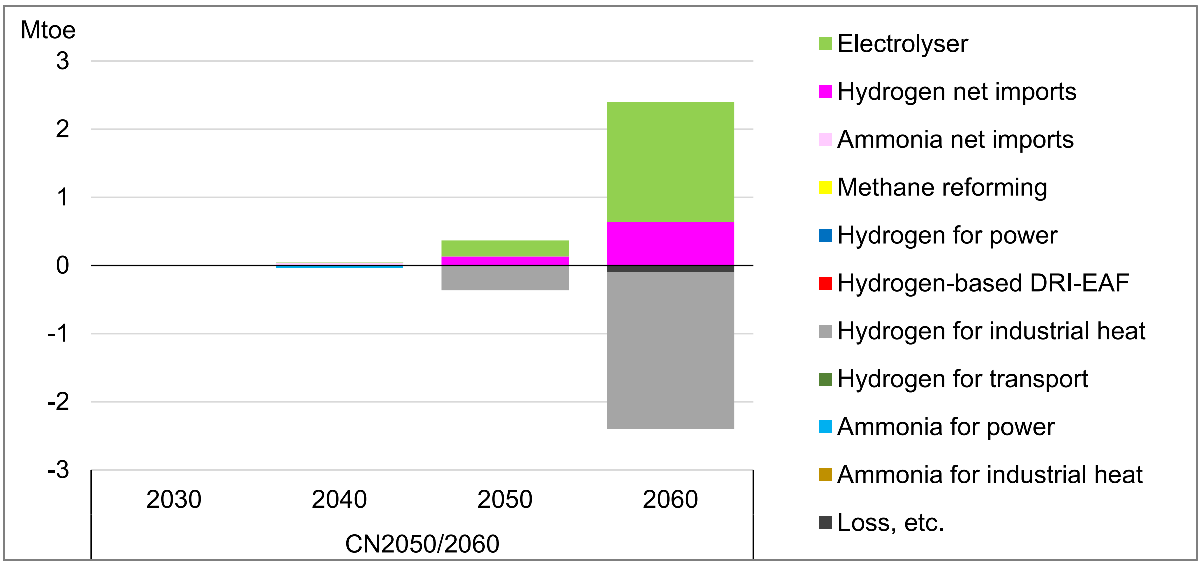
GW = gigawatt, PV = photovoltaic.
Source: Author.

Figure A.59. Road Transport Demand (Myanmar)



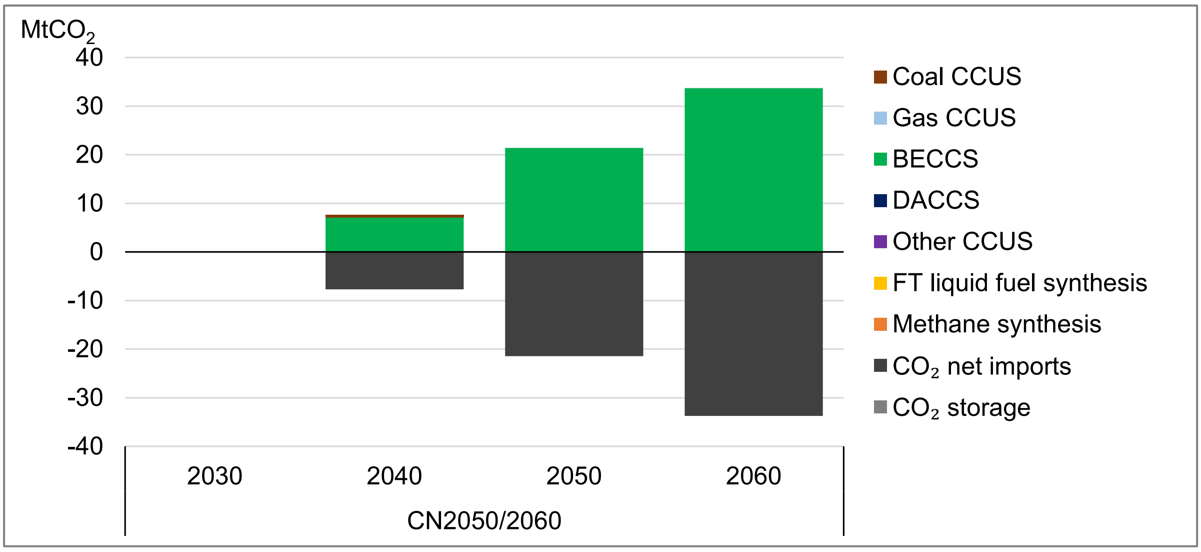
BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, Gvkm = billion vehicle-kilometres, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Author.

Figure A.60. Supply and Demand of Hydrogen and Ammonia (Myanmar)



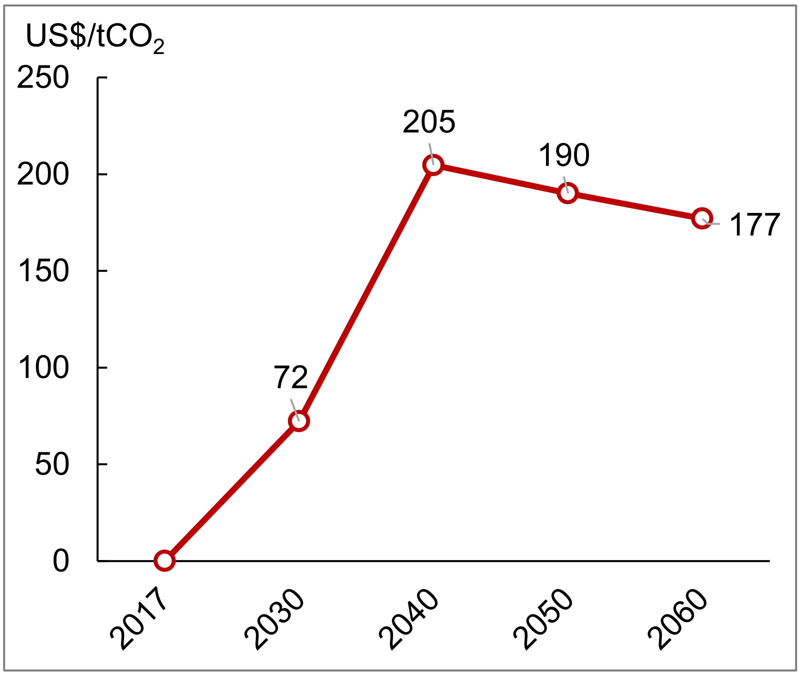
DRI-EAF = direct reduced iron–electric arc furnace, Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.61. Carbon Capture, Utilisation, and Storage (Myanmar)



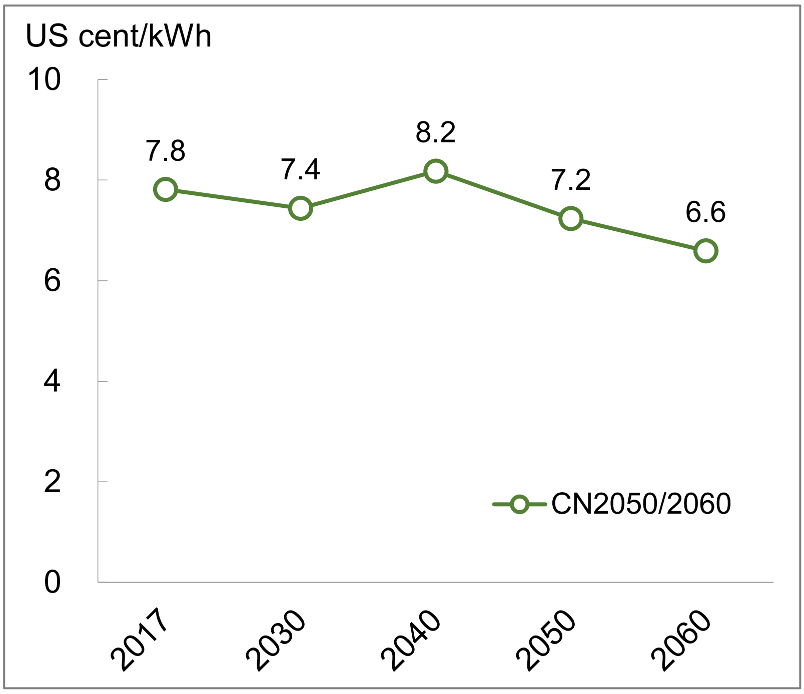
BECCS = bioenergy with carbon capture and storage; CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; FT = Fischer–Tropsch; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.62. Marginal Abatement Cost of CO_2 (Myanmar)



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.
Source: Author.

Figure A.63. Marginal Cost of Electricity (Myanmar)

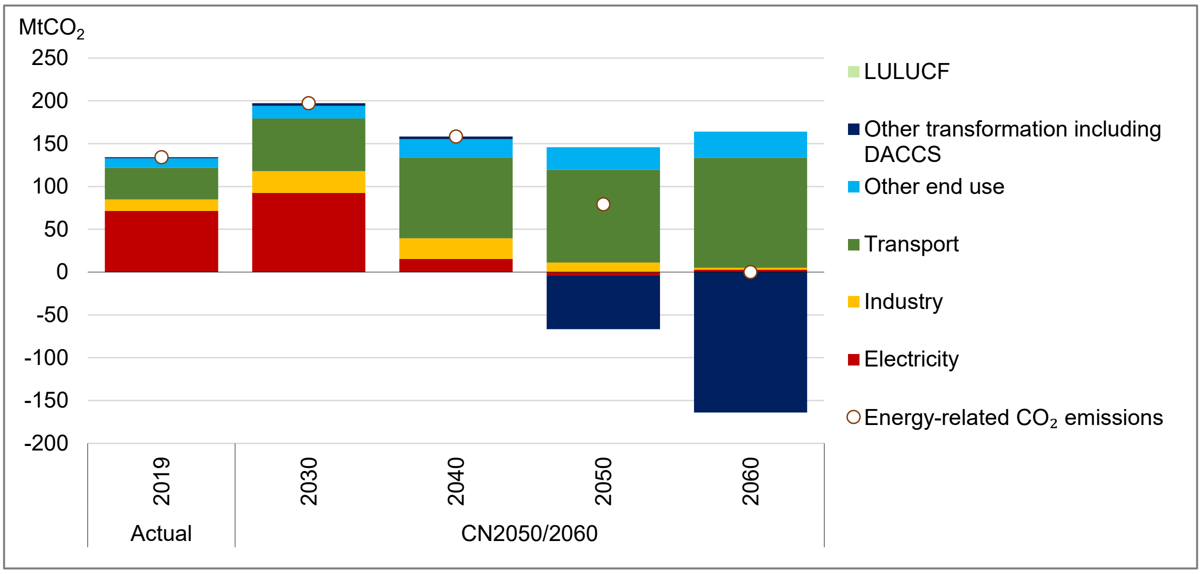


kWh = kilowatt-hour.
Source: Author.

A-7. Philippines

Energy service demands are projected to grow significantly, with final energy consumption in 2060 reaching 3.7 times the 2019 level. Transport demand is expected to grow significantly, with residual emissions from heavy-duty vehicles being offset by DACCS. In power generation, thermal power will remain a major component in the medium to long term, with coal- and gas-fired power generation continuing to expand. Consequently, CCS and ammonia and hydrogen co-firing will be important options for reducing emissions from thermal generation. Although the Philippines has significant potential for both onshore and offshore wind power, these options are not selected at scale in the current model due to their lower cost competitiveness.

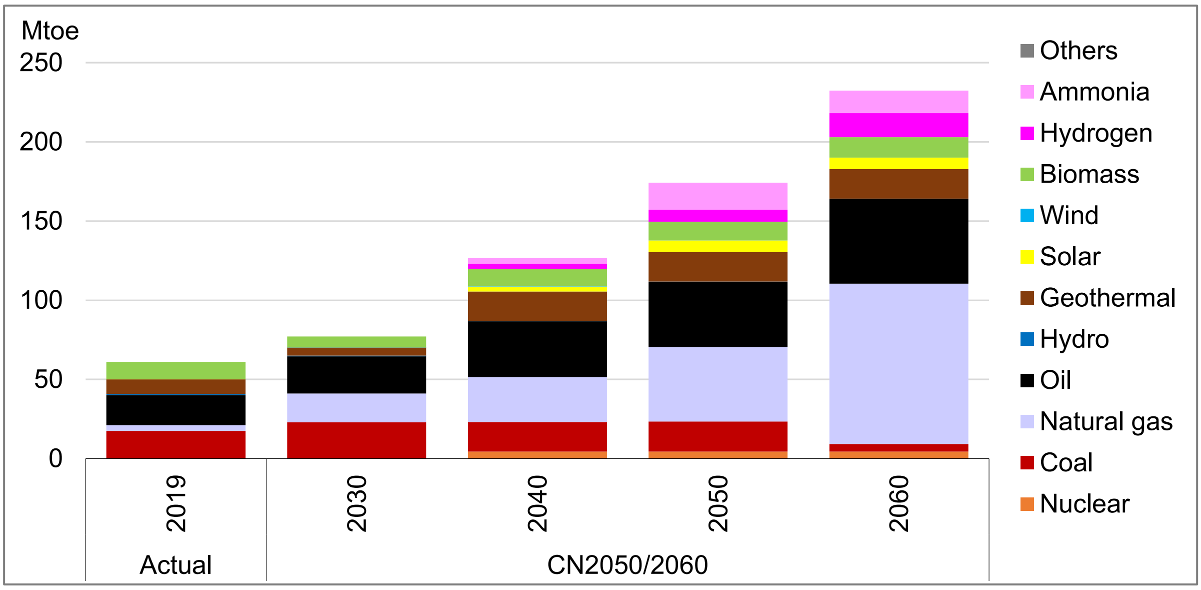
Figure A.64. CO_2 Emissions by Sector (Philippines)



CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = metric tonne of carbon dioxide.

Source: Author.

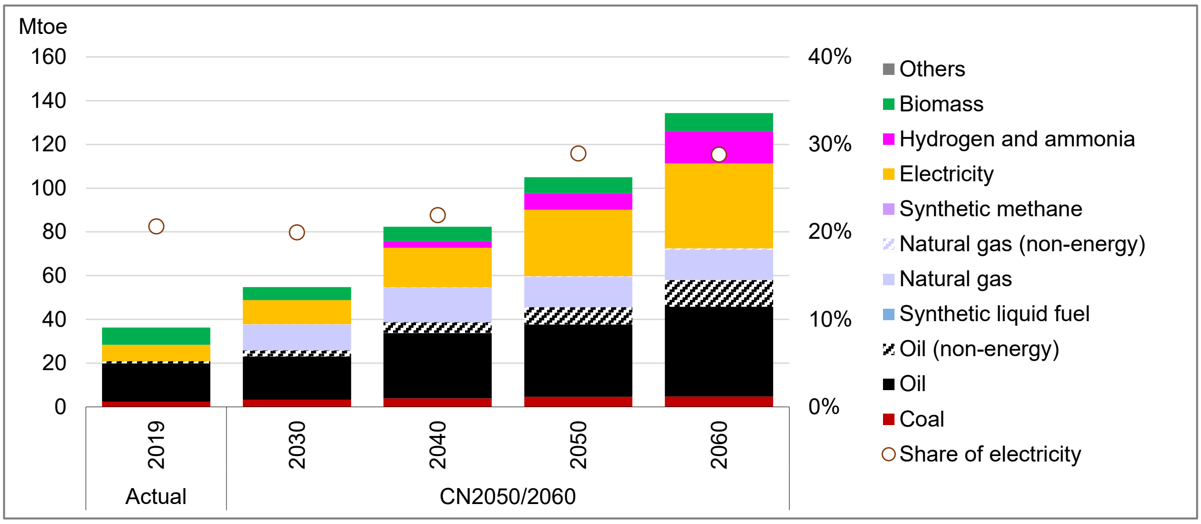
Figure A.65. Primary Energy Supply by Source (Philippines)



Mtoe = million tonnes of oil equivalent.

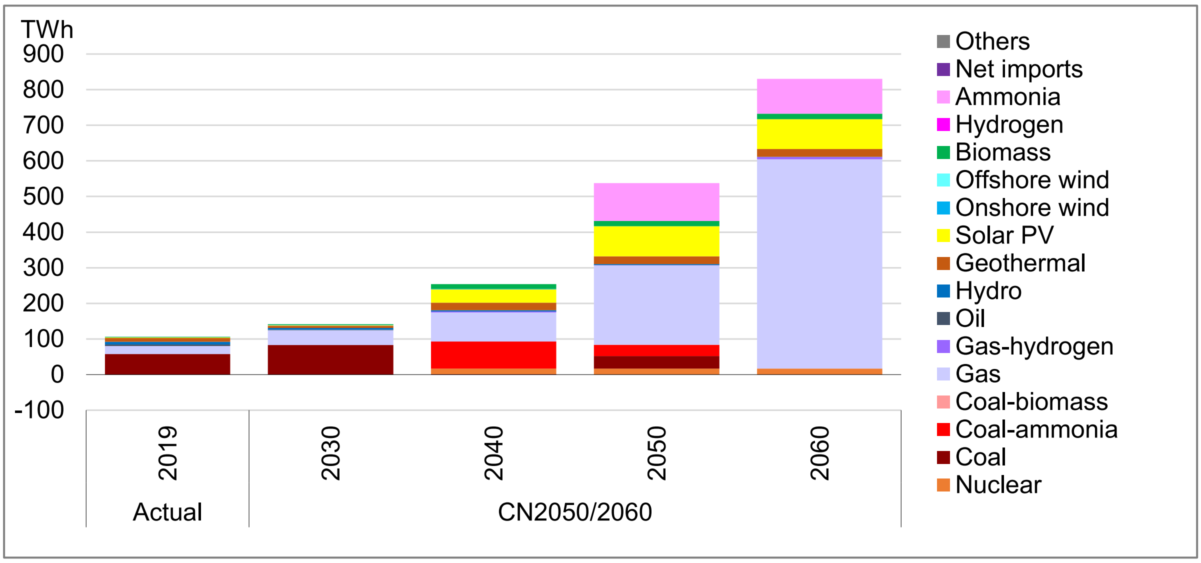
Source: Author.

Figure A.66. Final Energy Consumption by Source (Philippines)



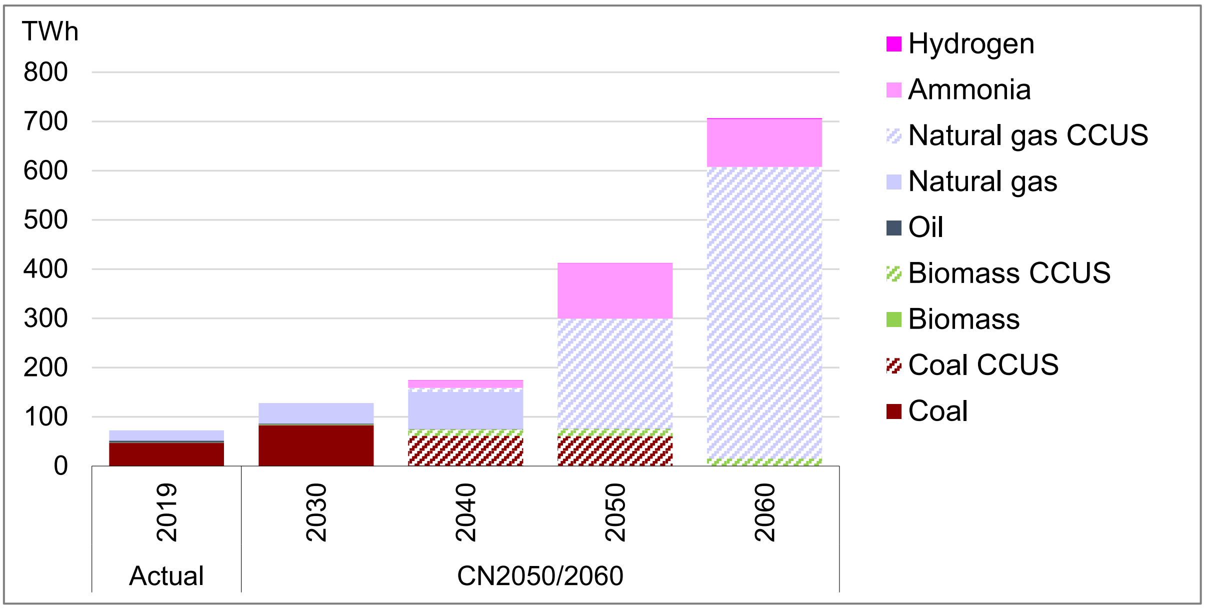
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.67. Power Generation by Technology (Philippines)



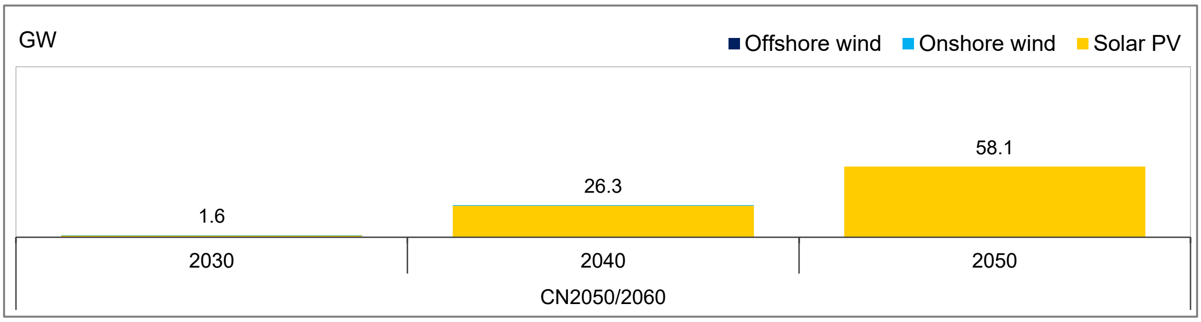
TWh = terawatt hour, PV = photovoltaic.
Source: Author.

Figure A.68. Thermal Power Generation by Source (Philippines)



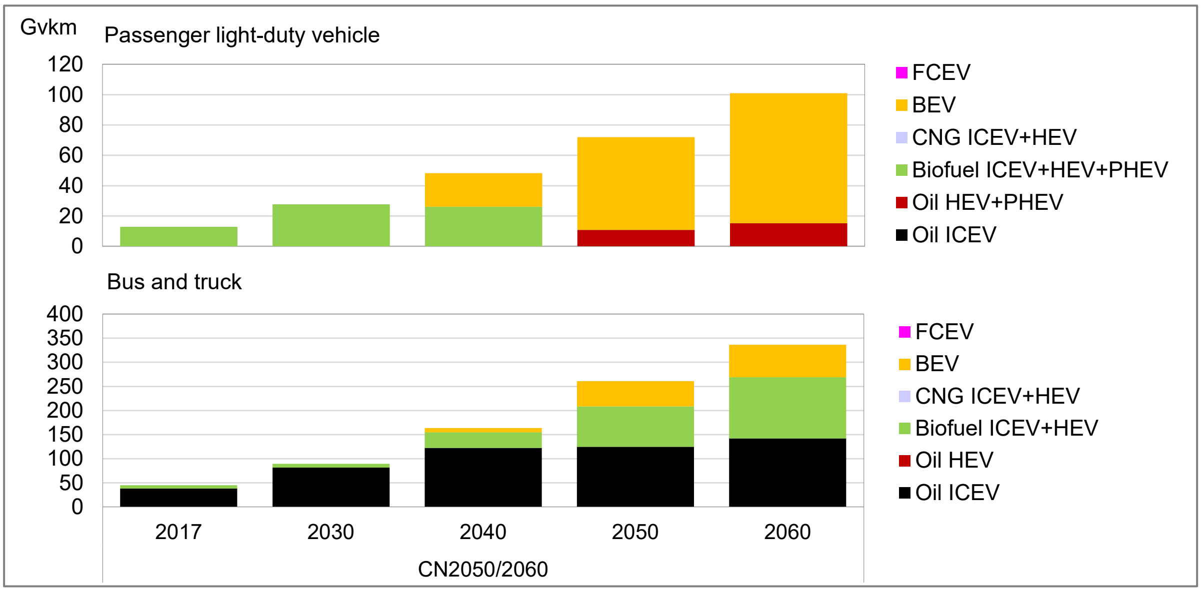
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure A.69. Installed Capacity of Variable Renewable Energy (Philippines)



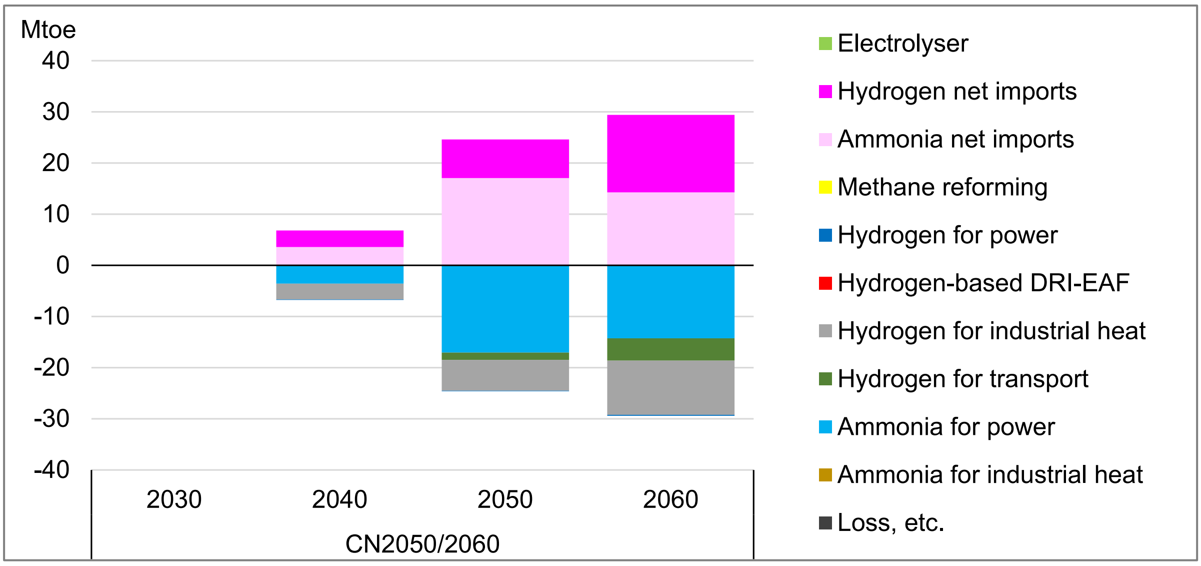
GW = gigawatt, PV = photovoltaic.
Source: Author.

Figure A.70. Road Transport Demand (Philippines)



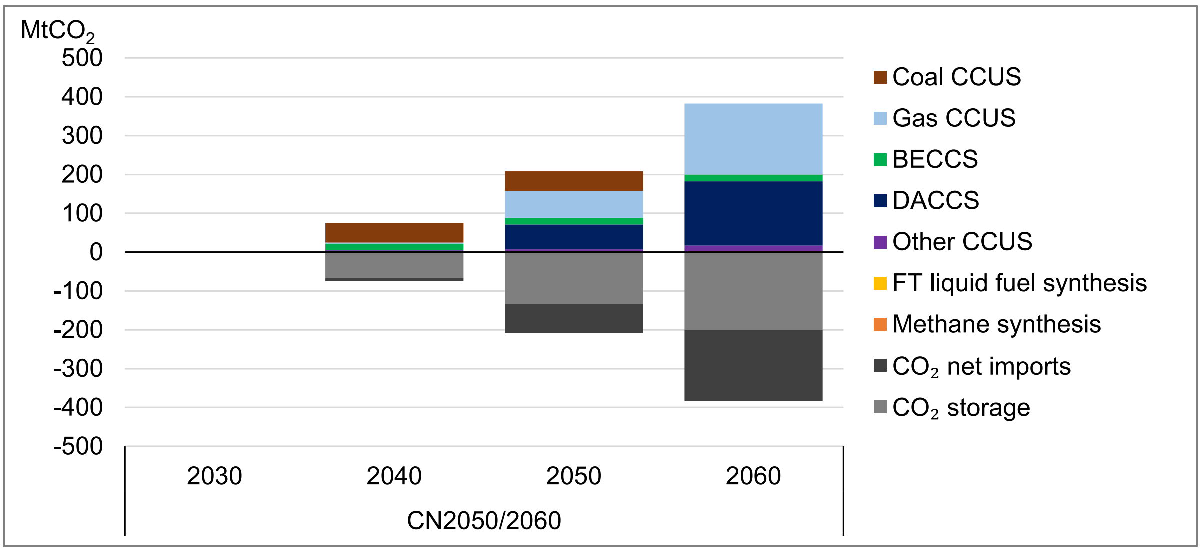
BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, Gvkm = billion vehicle-kilometres, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Author.

Figure A.71. Supply and Demand of Hydrogen and Ammonia (Philippines)



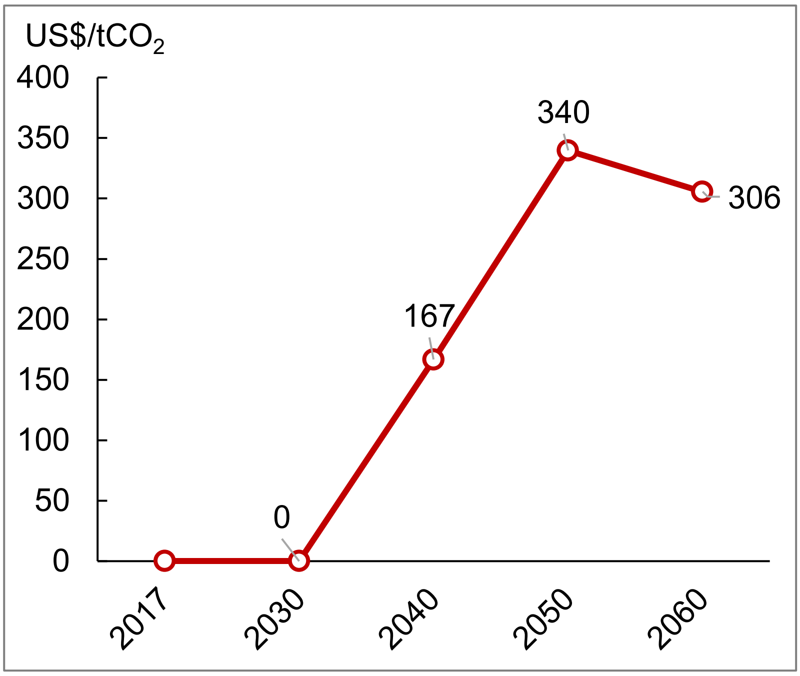
DRI-EAF = direct reduced iron–electric arc furnace, Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.72. Carbon Capture, Utilisation, and Storage (Philippines)



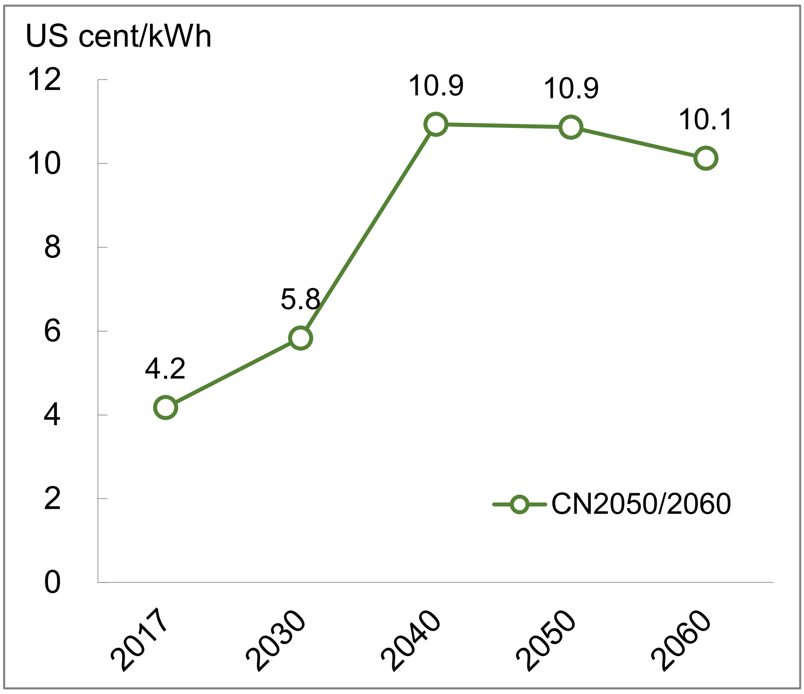
BECCS = bioenergy with carbon capture and storage; CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; FT = Fischer–Tropsch; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.73. Marginal Abatement Cost of CO_2 (Philippines)



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.
Source: Author.

Figure A.74. Marginal Cost of Electricity (Philippines)

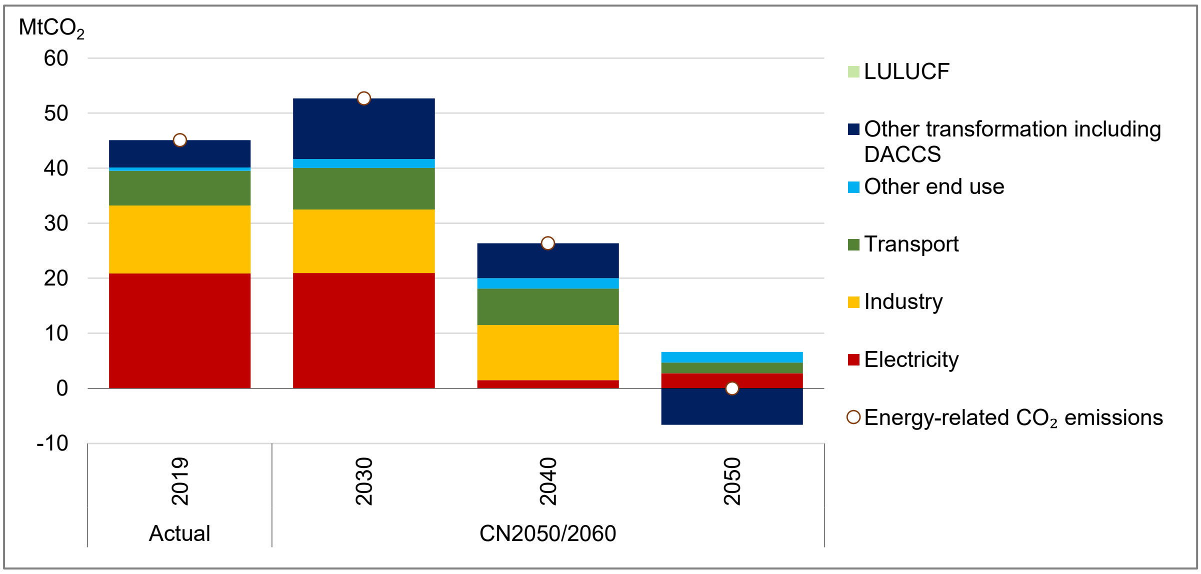


kWh = kilowatt-hour.
Source: Author.

A-8. Singapore

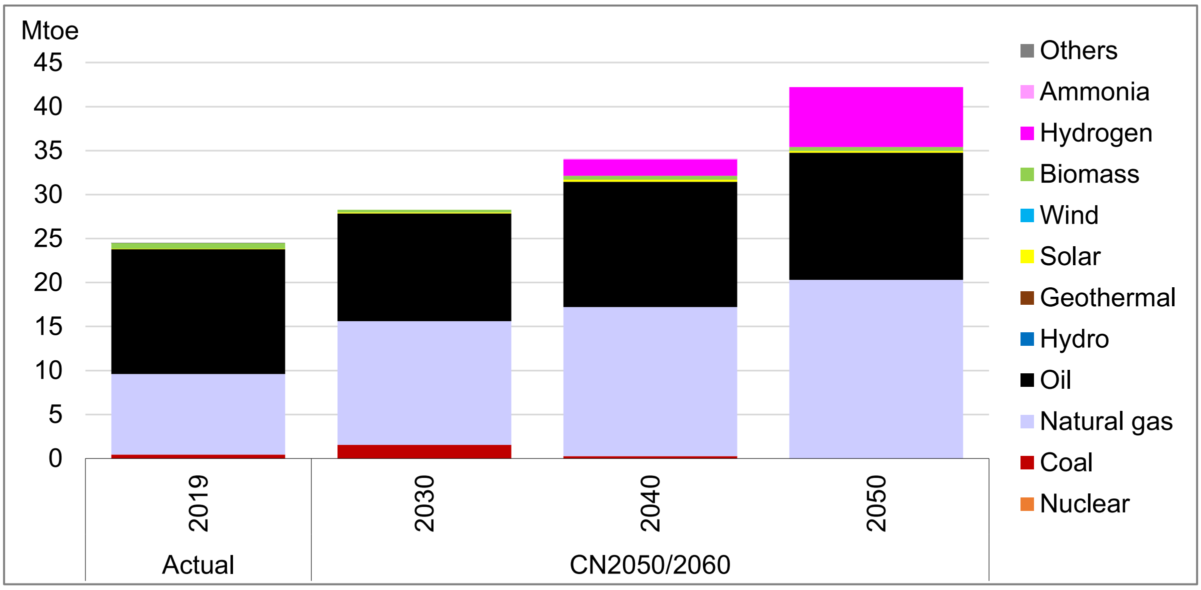
Natural gas is projected to remain Singapore's most important energy source in the medium to long term. Whilst oil consumption will persist for non-energy uses, its use as an energy source is expected to decrease significantly due to vehicle electrification. After 2040, imported hydrogen from the region will also play a role in the industrial sector. Given Singapore's limited domestic renewable energy resources, gas-fired power plants with CCS will be extremely important in the power sector.

Figure A.75. CO_2 Emissions by Sector (Singapore)



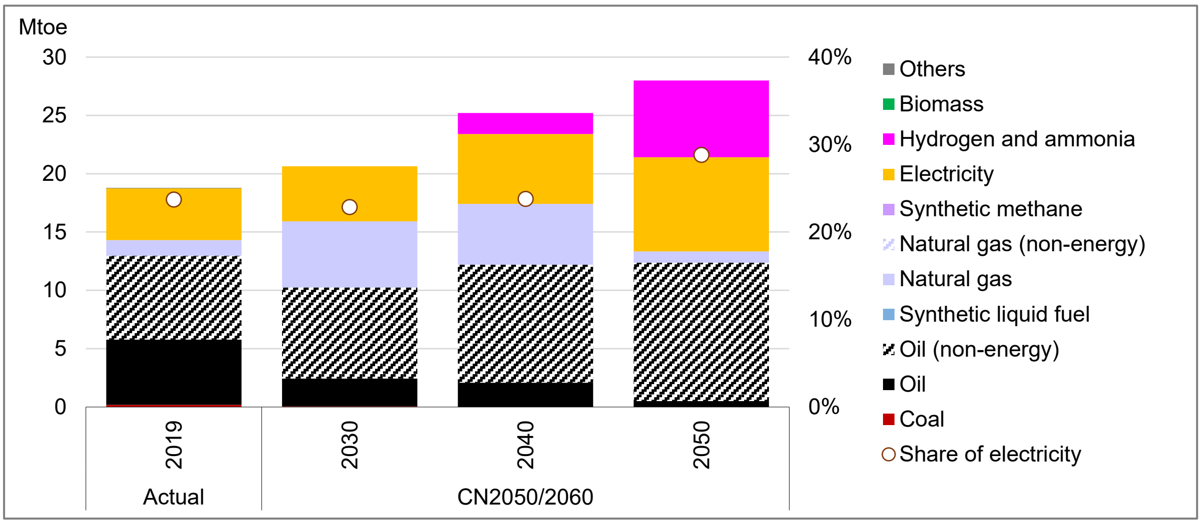
CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.76. Primary Energy Supply by Source (Singapore)



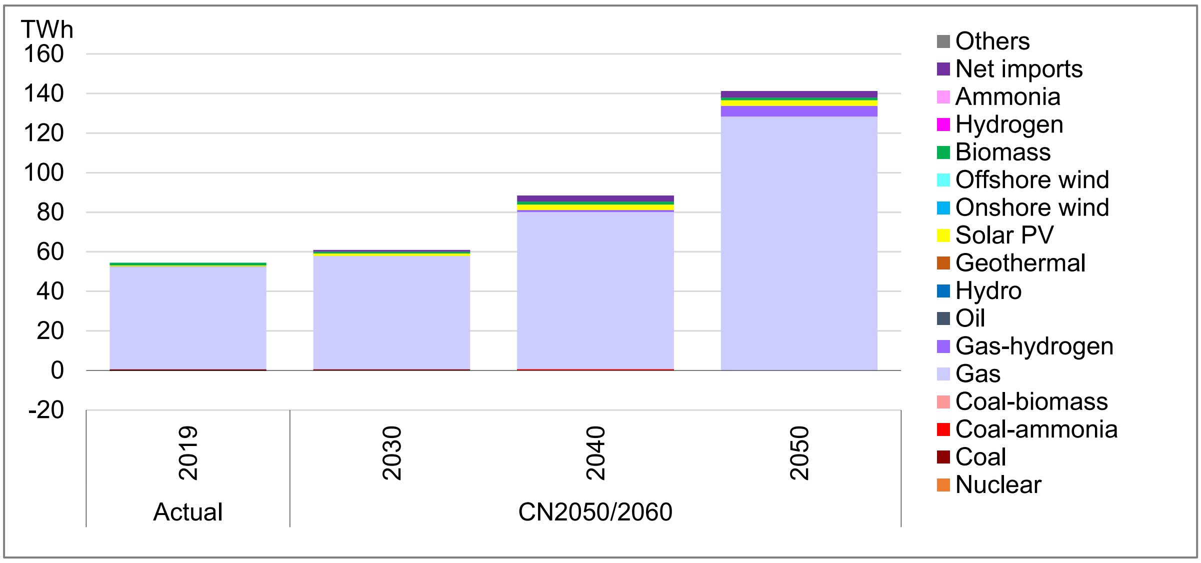
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.77. Final Energy Consumption by Source (Singapore)



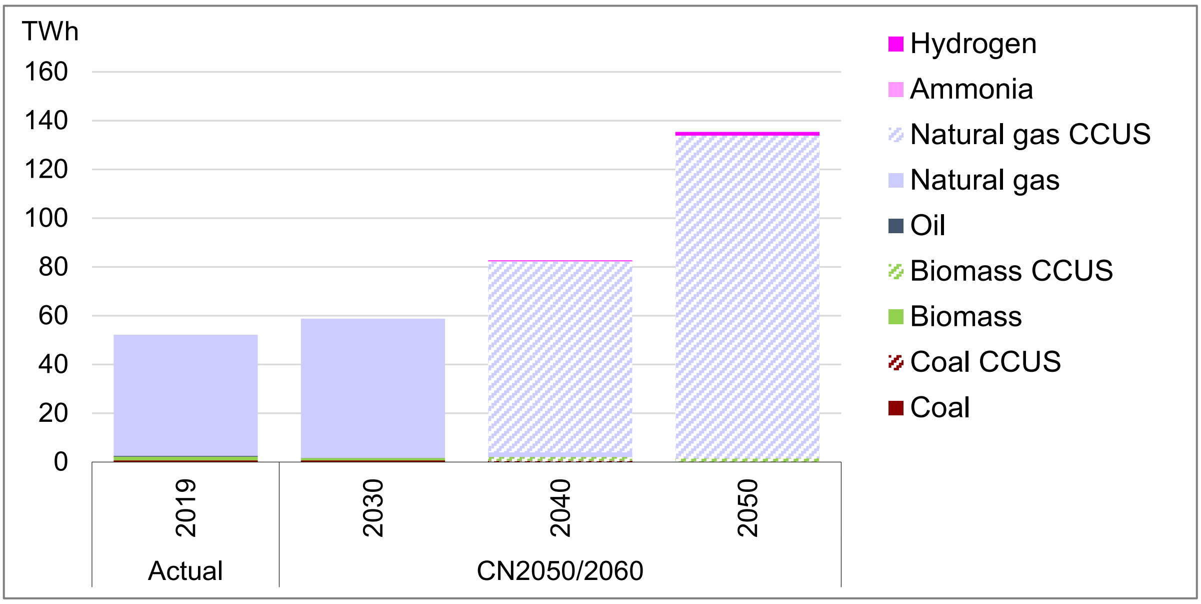
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.78. Power Generation by Technology (Singapore)



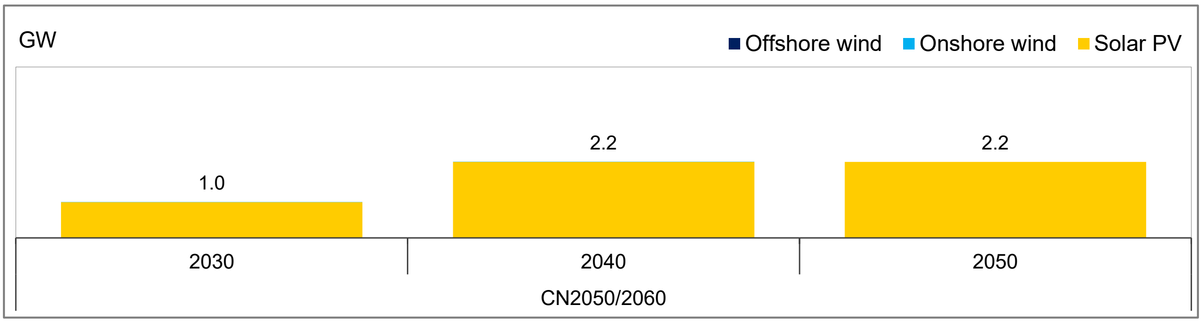
TWh = terawatt hour, PV = photovoltaic.
Source: Author.

Figure A.79. Thermal Power Generation by Source (Singapore)



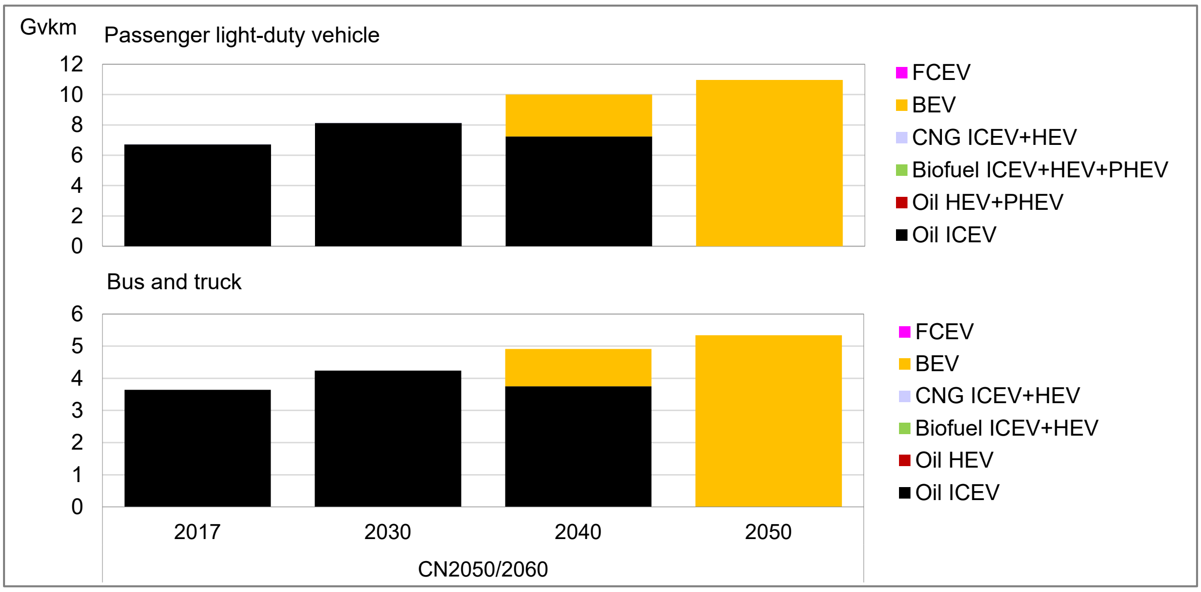
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure A.80. Installed Capacity of Variable Renewable Energy (Singapore)



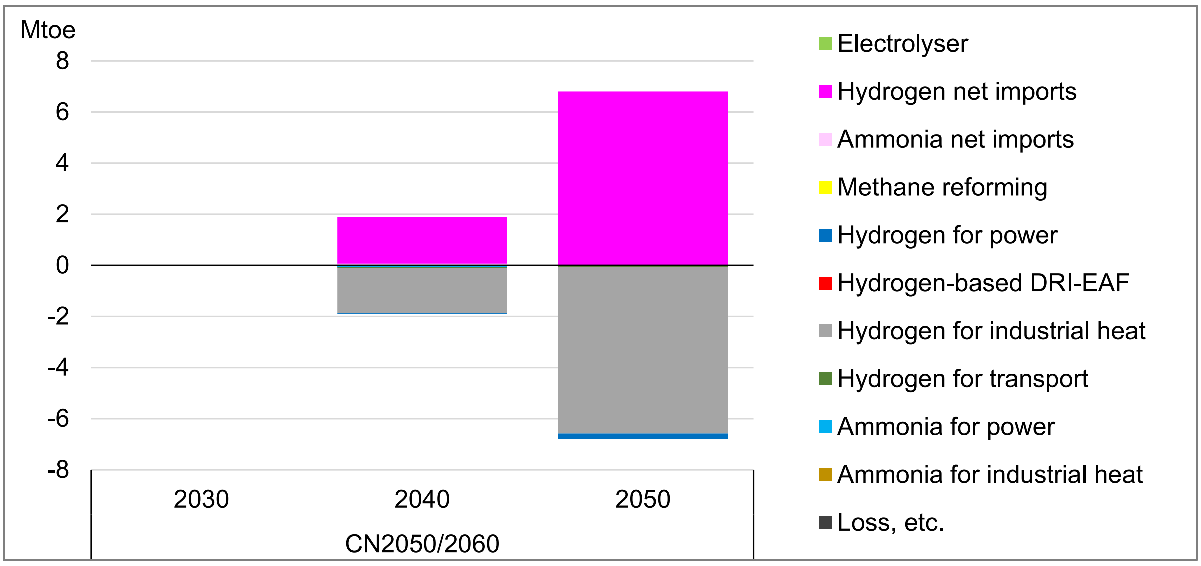
GW = gigawatt, PV = photovoltaic.
Source: Author.

Figure A.81. Road Transport Demand (Singapore)



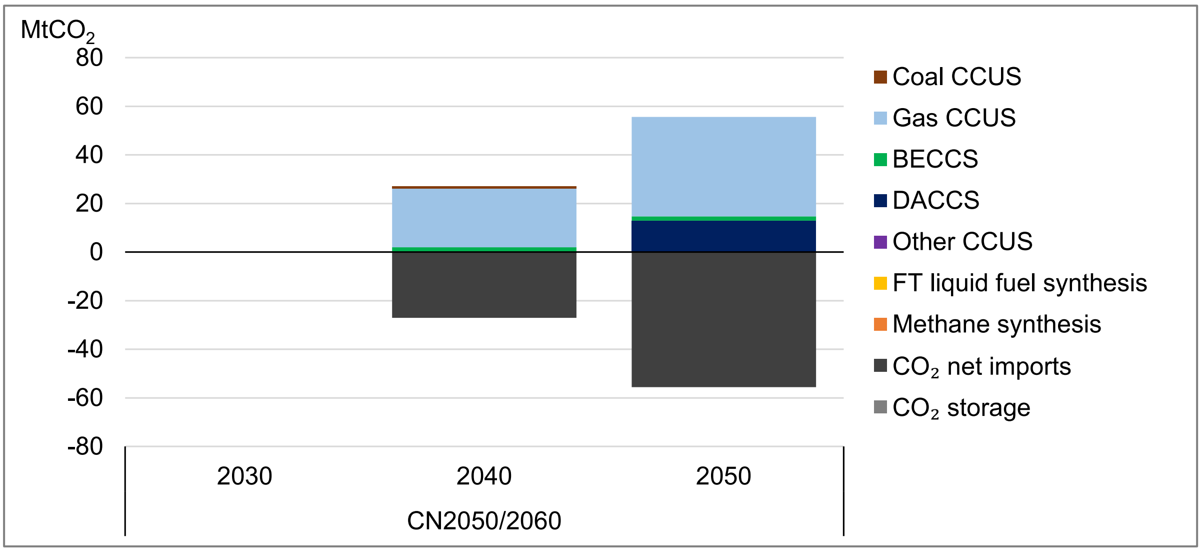
BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, Gvkm = billion vehicle-kilometres, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Author.

Figure A.82. Supply and Demand of Hydrogen and Ammonia (Singapore)



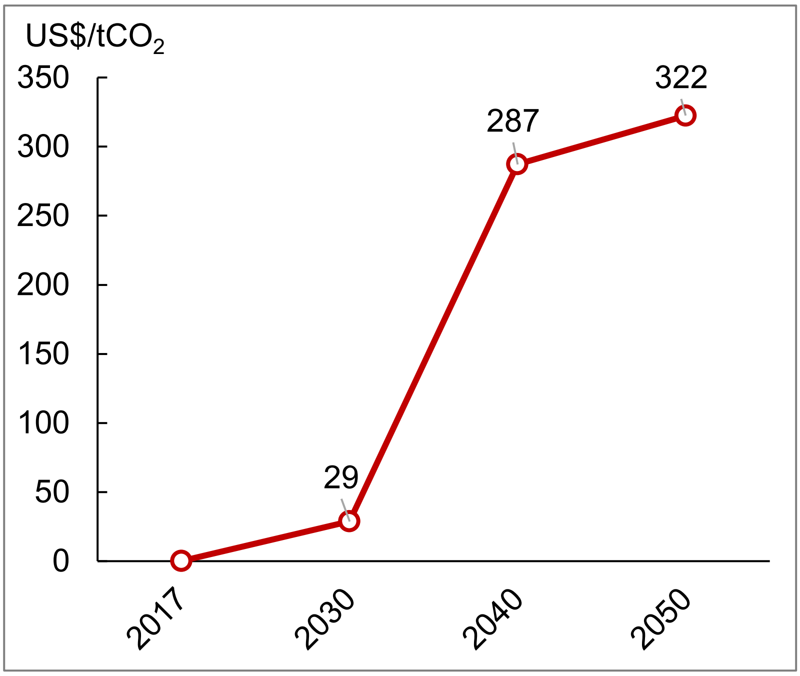
DRI-EAF = direct reduced iron–electric arc furnace, Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.83. Carbon Capture, Utilisation, and Storage (Singapore)



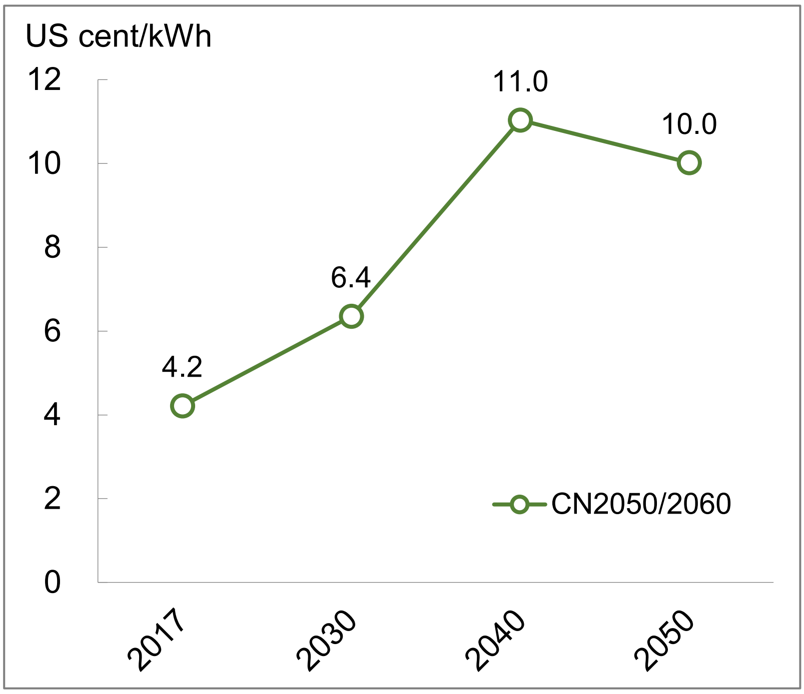
BECCS = bioenergy with carbon capture and storage; CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; FT = Fischer–Tropsch; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.84. Marginal Abatement Cost of CO_2 (Singapore)



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.
Source: Author.

Figure A.85. Marginal Cost of Electricity (Singapore)



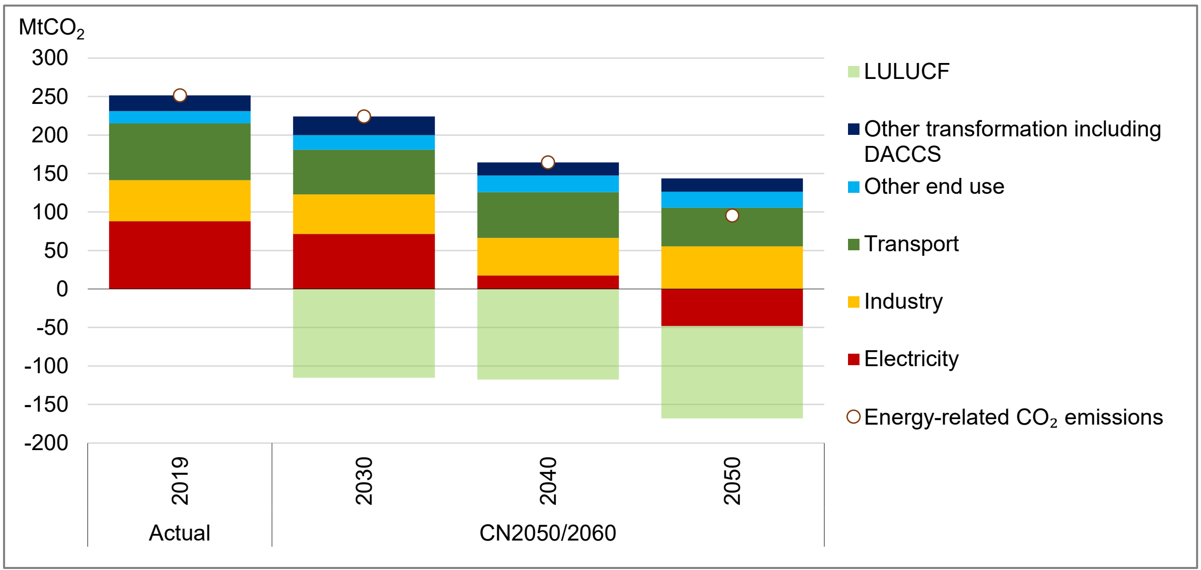
kWh = kilowatt-hour.
Source: Author.

A-9. Thailand

Shifting to zero-emission vehicles (ZEVs) reduces oil consumption. In line with Thailand's targets, 50% of all new passenger cars will be ZEVs by 2030, with a complete shift to

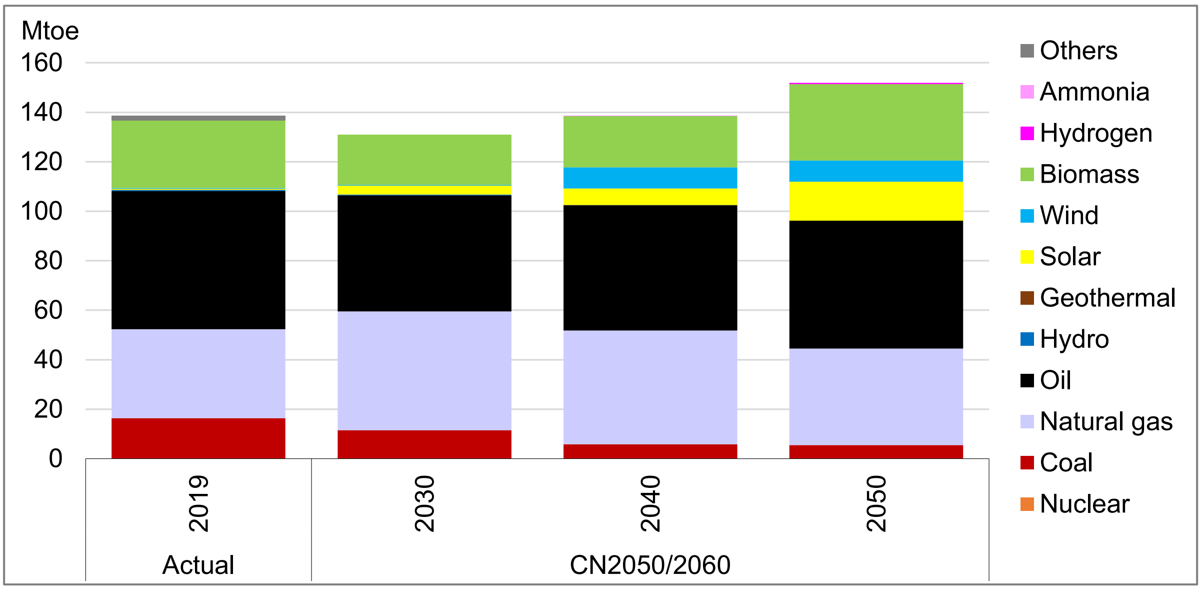
100% ZEVs by 2040. In the power sector, onshore wind and solar PV capacity will expand rapidly after 2030. Gas-fired and biomass-fired power generation, incorporating BECCS technology, will be employed for dispatchable energy needs. Additionally, importing electricity from Lao People's Democratic Republic remains a viable option.

Figure A.86. CO_2 Emissions by Sector (Thailand)



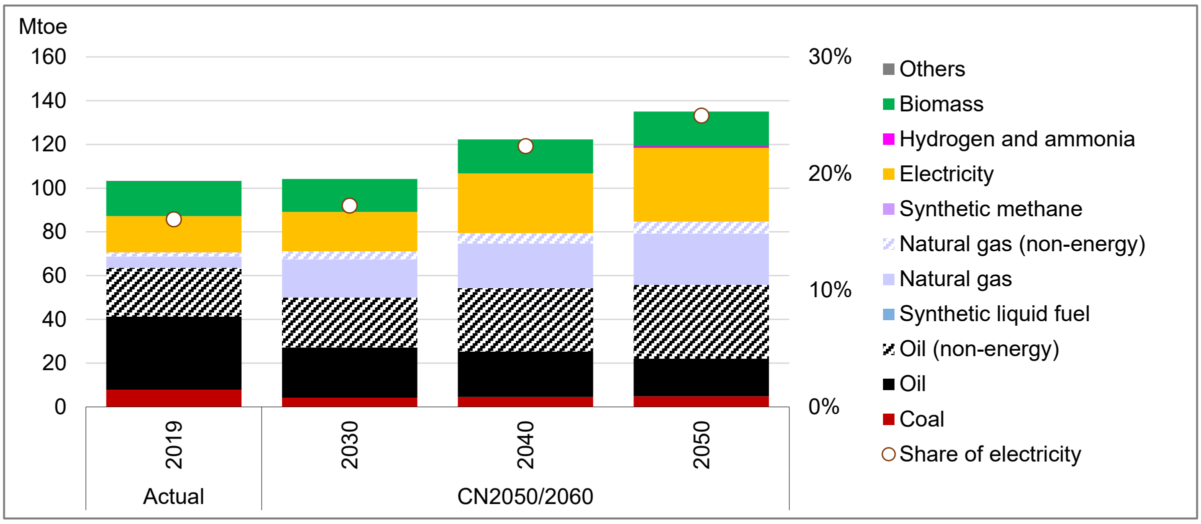
CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.87. Primary Energy Supply by Source (Thailand)



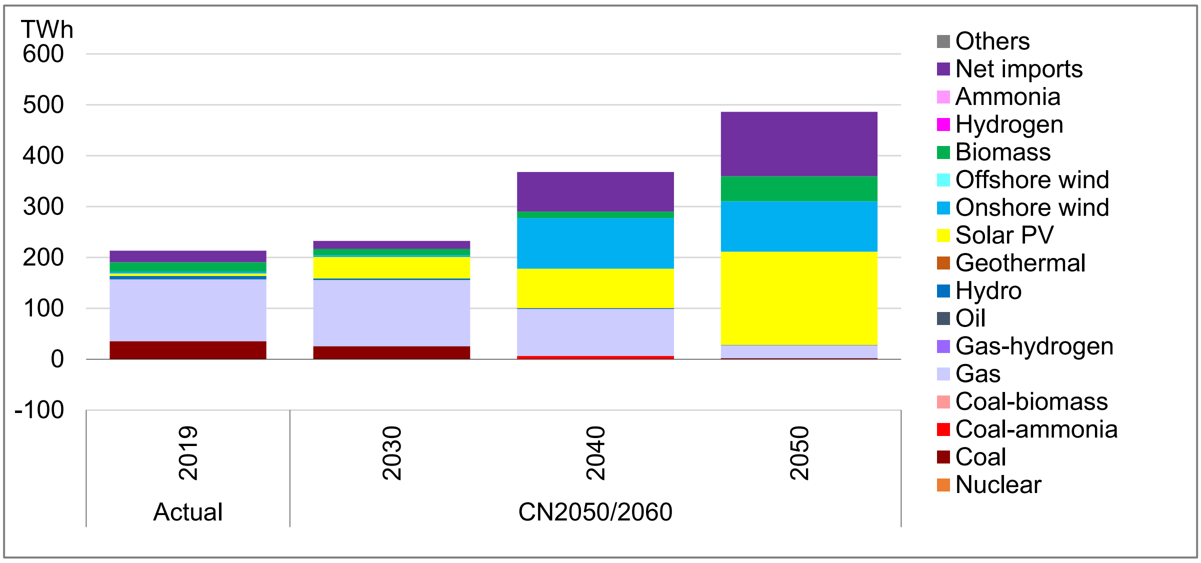
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.88. Final Energy Consumption by Source (Thailand)



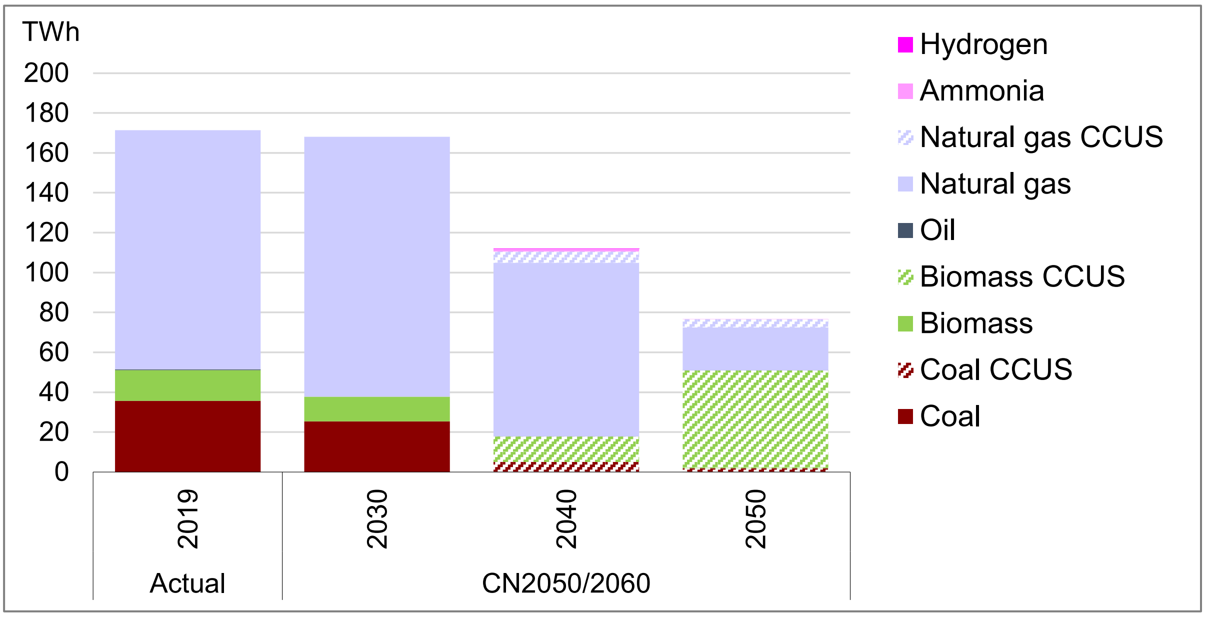
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.89. Power Generation by Technology (Thailand)



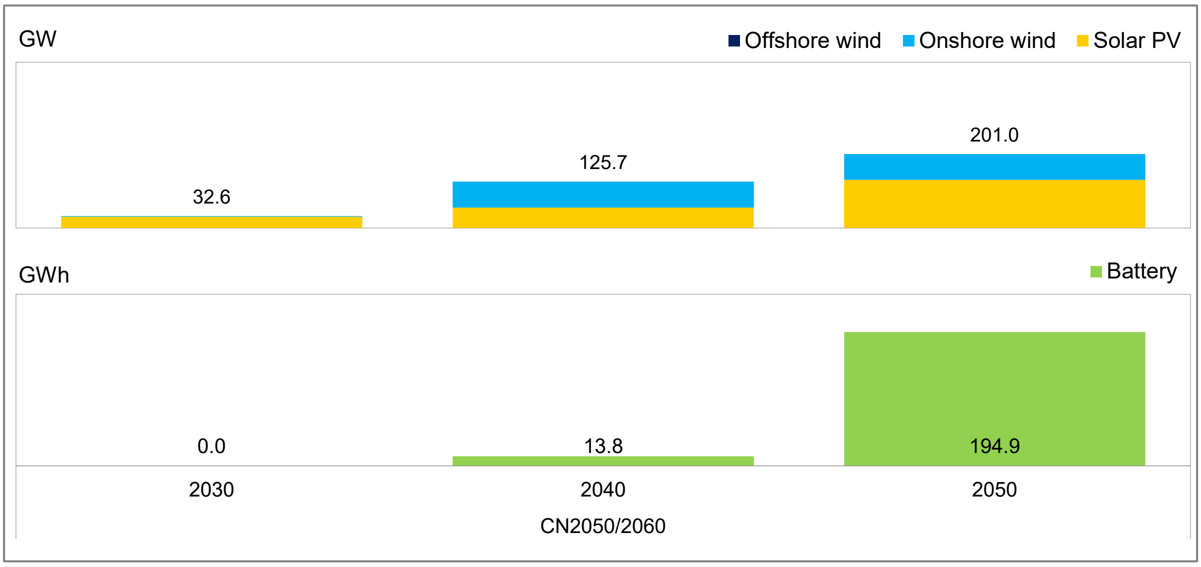
TWh = terawatt hour, PV = photovoltaic.
Source: Author.

Figure A.90. Thermal Power Generation by Source (Thailand)



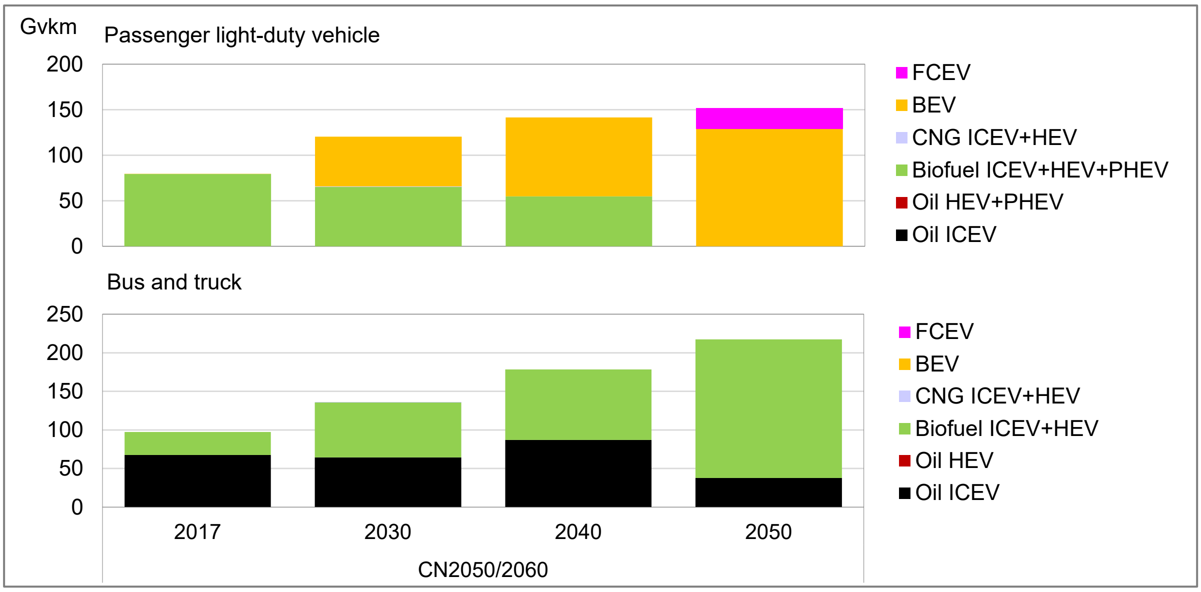
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure A.91. Installed Capacity of Variable Renewable Energy and Battery (Thailand)



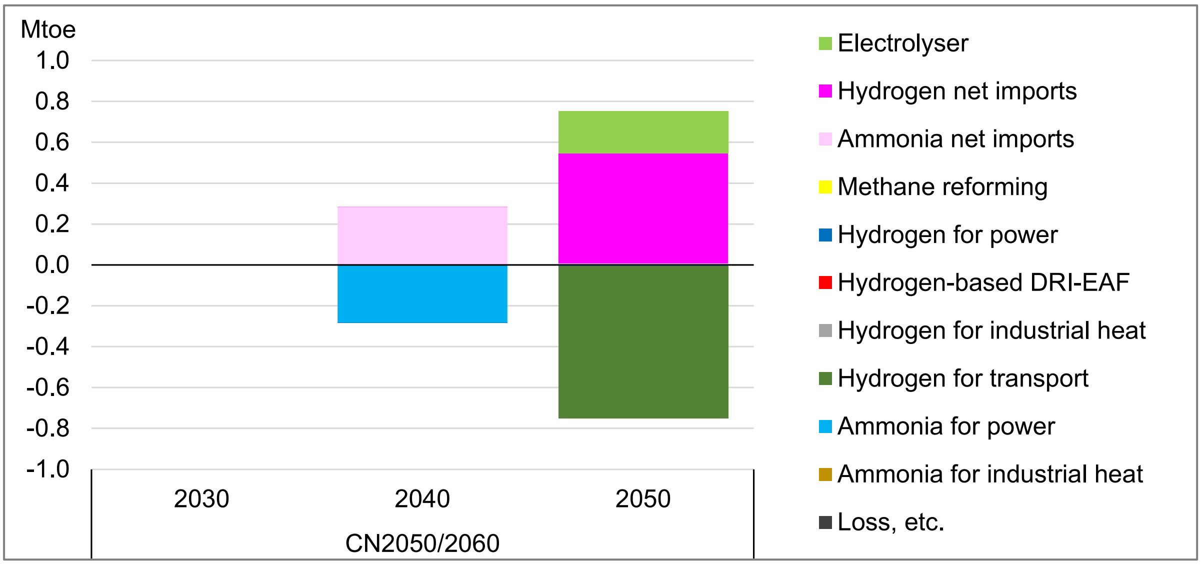
GW = gigawatt, PV = photovoltaic.
Source: Author.

Figure A.92. Road Transport Demand (Thailand)



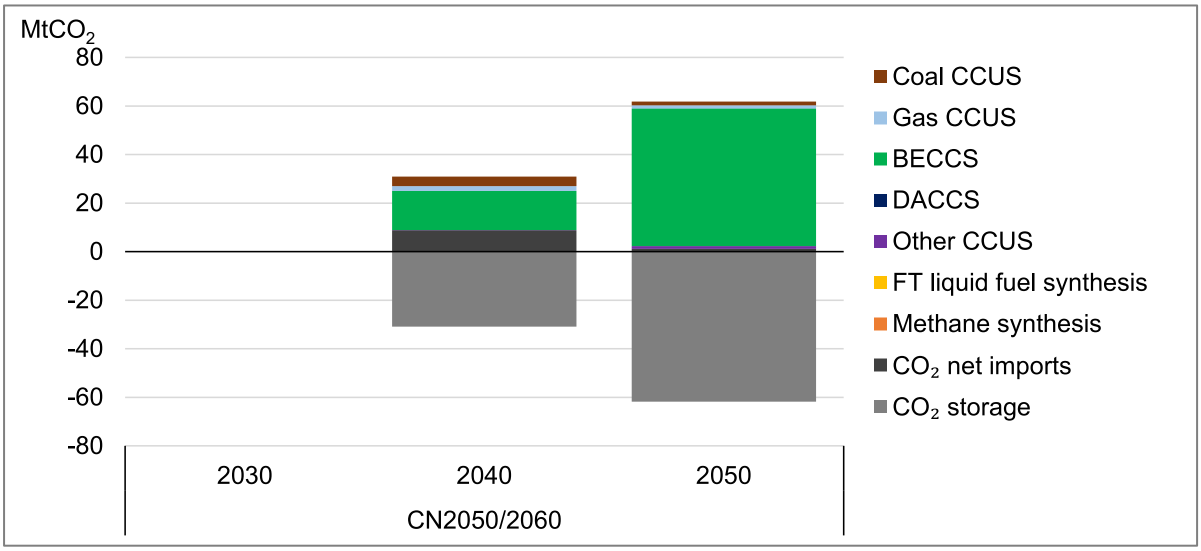
BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, Gvkm = billion vehicle-kilometres, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Author.

Figure A.93. Supply and Demand of Hydrogen and Ammonia (Thailand)



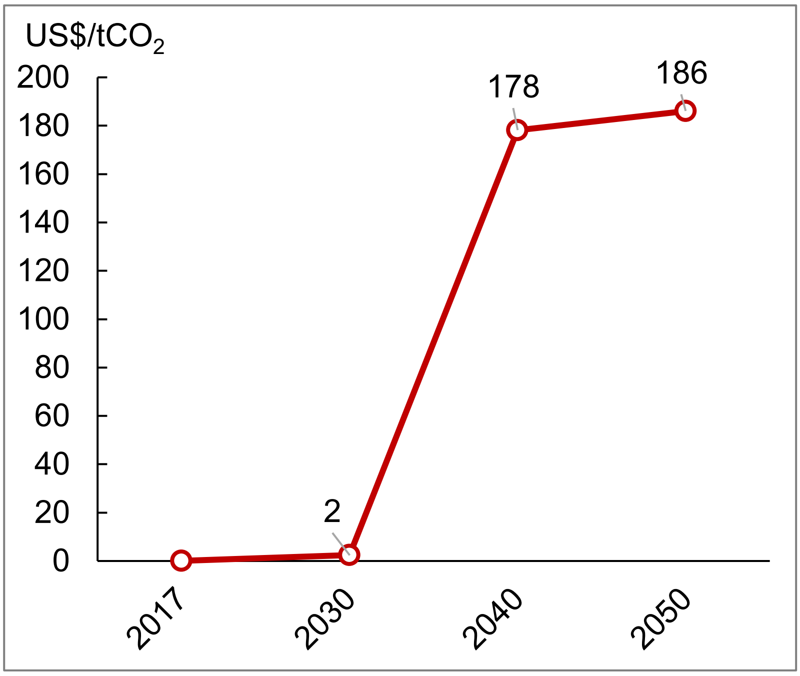
DRI-EAF = direct reduced iron–electric arc furnace, Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.94. Carbon Capture, Utilisation, and Storage (Thailand)



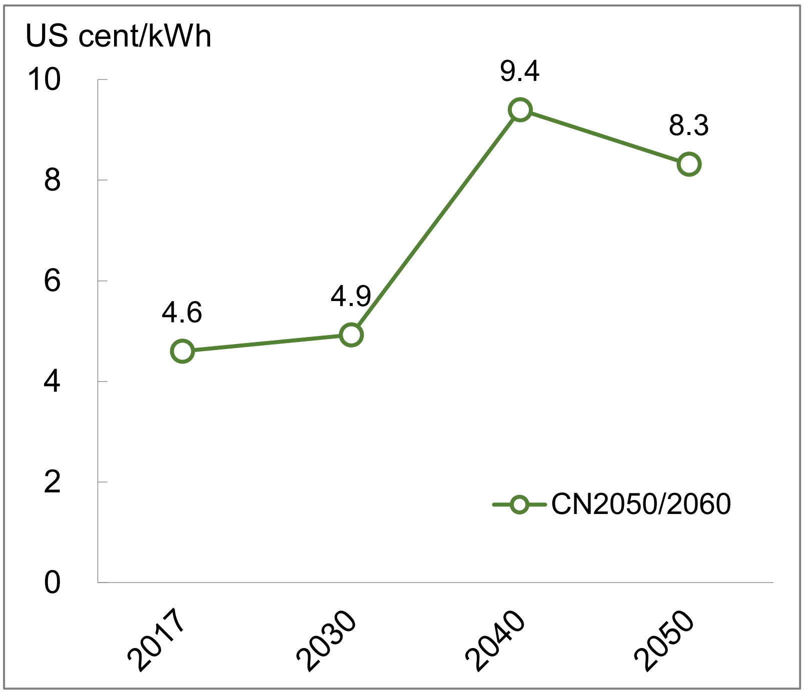
BECCS = bioenergy with carbon capture and storage; CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; FT = Fischer–Tropsch; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.95. Marginal Abatement Cost of CO_2 (Thailand)



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.
Source: Author.

Figure A.196. Marginal Cost of Electricity (Thailand)

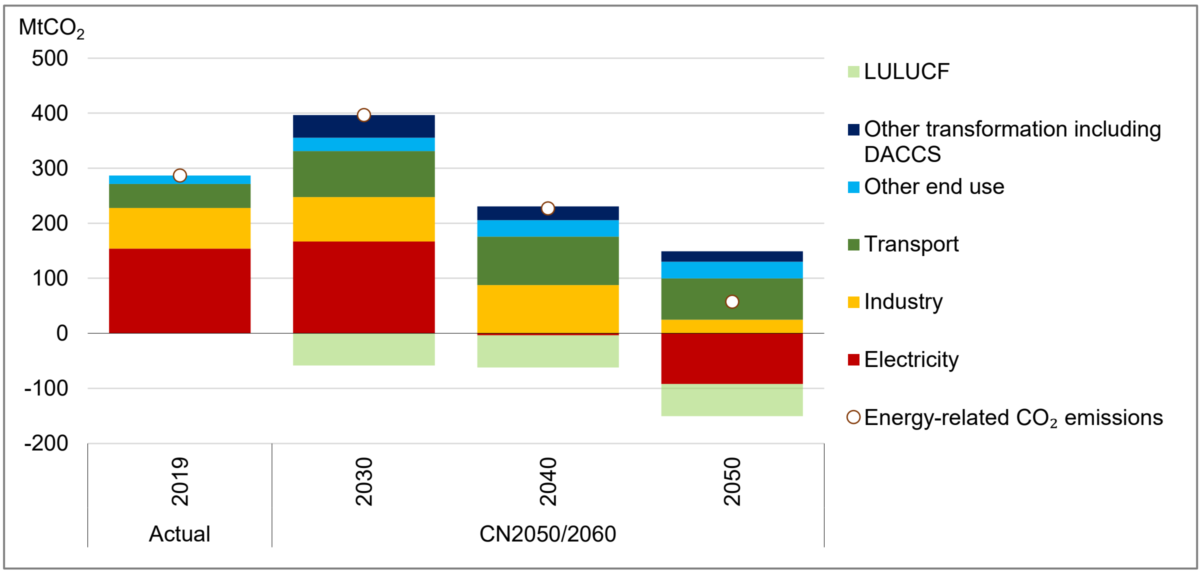


kWh = kilowatt-hour.
Source: Author.

A-10. Viet Nam

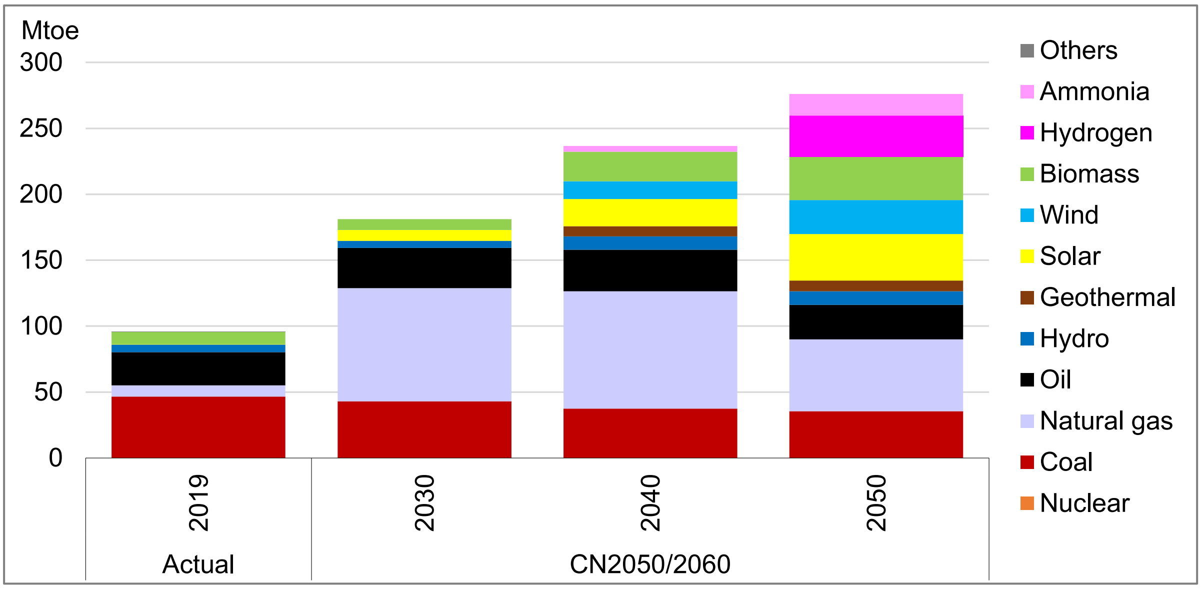
In Viet Nam, where strong economic growth is expected, final energy consumption increases rapidly even under the carbon neutrality scenario, which incorporates electrification and energy efficiency measures. By 2050, it is expected to be 3.2 times higher than in 2019. The growth in total power generation is even more significant, reaching 4.8 times the 2019 level by 2050. Viet Nam is endowed with abundant renewable energy resources such as hydropower, solar PV, onshore wind, offshore wind, and biomass. The power generation mix shows a significant growth in all these renewable energy sources. Fossil fuel–based power generation continues to play an important role, especially during the transition period, with coal-fired power becoming a low-carbon energy source through CCS and ammonia co-firing after 2040. In addition, domestically produced hydrogen, generated using surplus electricity from renewable sources, is utilised in both the industrial and power sectors.

Figure A.97. CO_2 Emissions by Sector (Viet Nam)



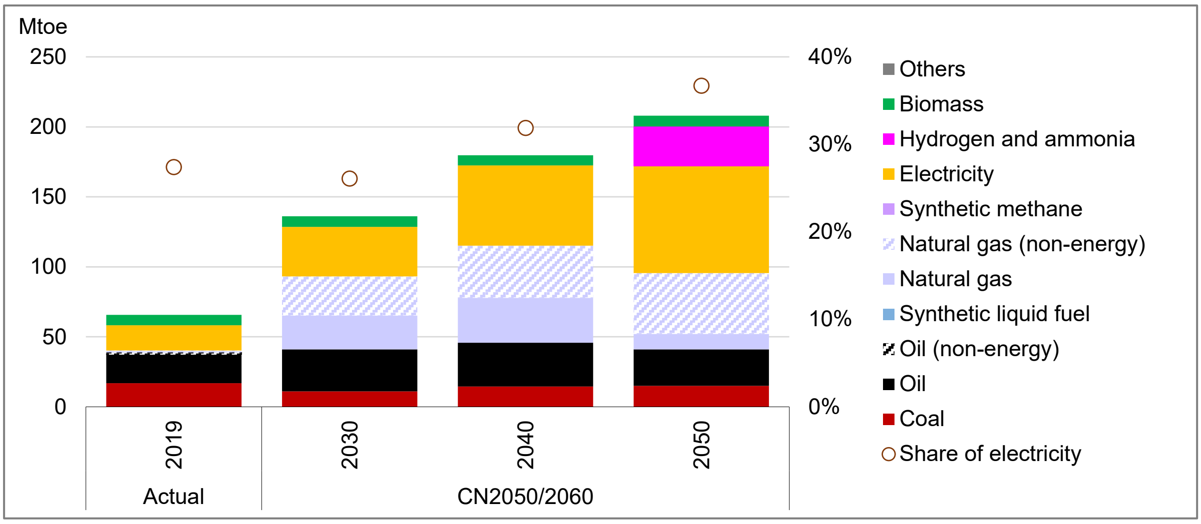
CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = metric tonne of carbon dioxide.
Source: Author.

Figure A.98. Primary Energy Supply by Source (Viet Nam)



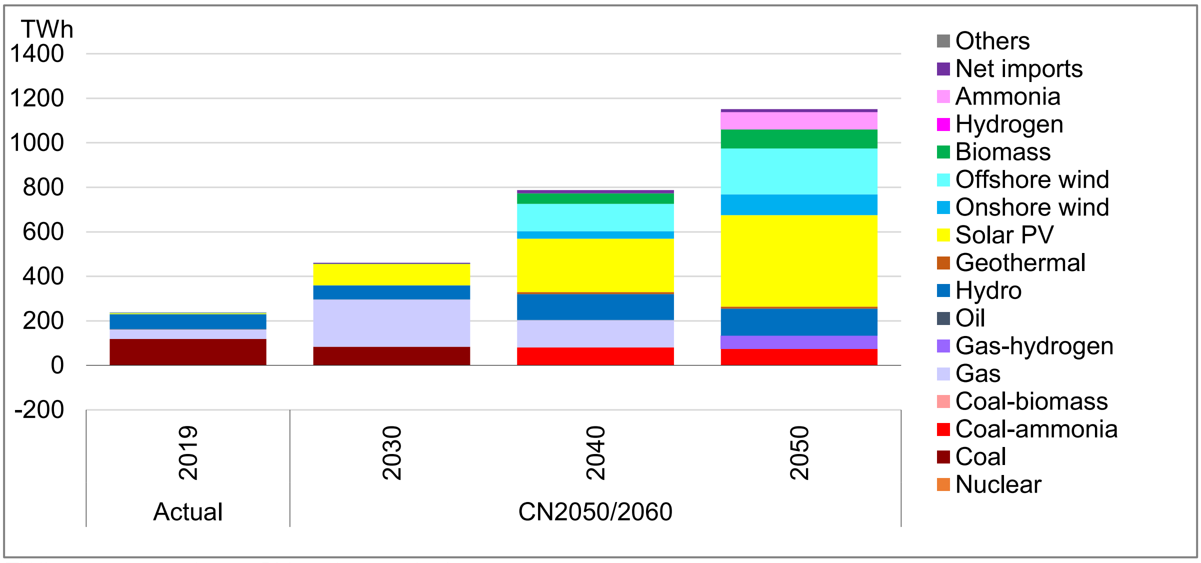
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.99. Final Energy Consumption by Source (Viet Nam)



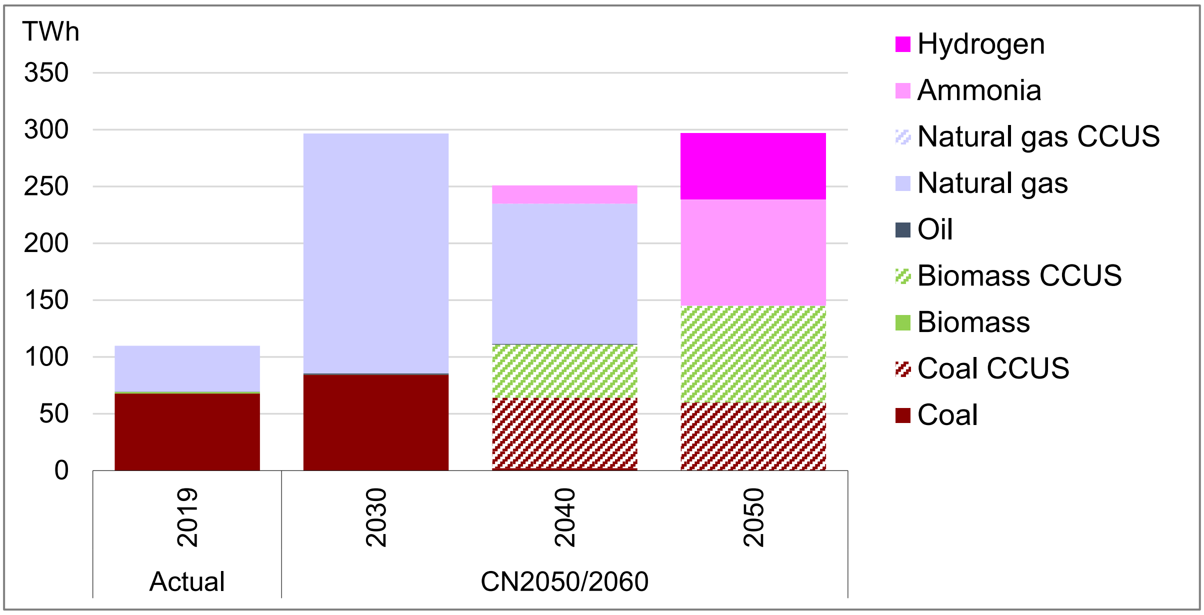
Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure A.100. Power Generation by Technology (Viet Nam)



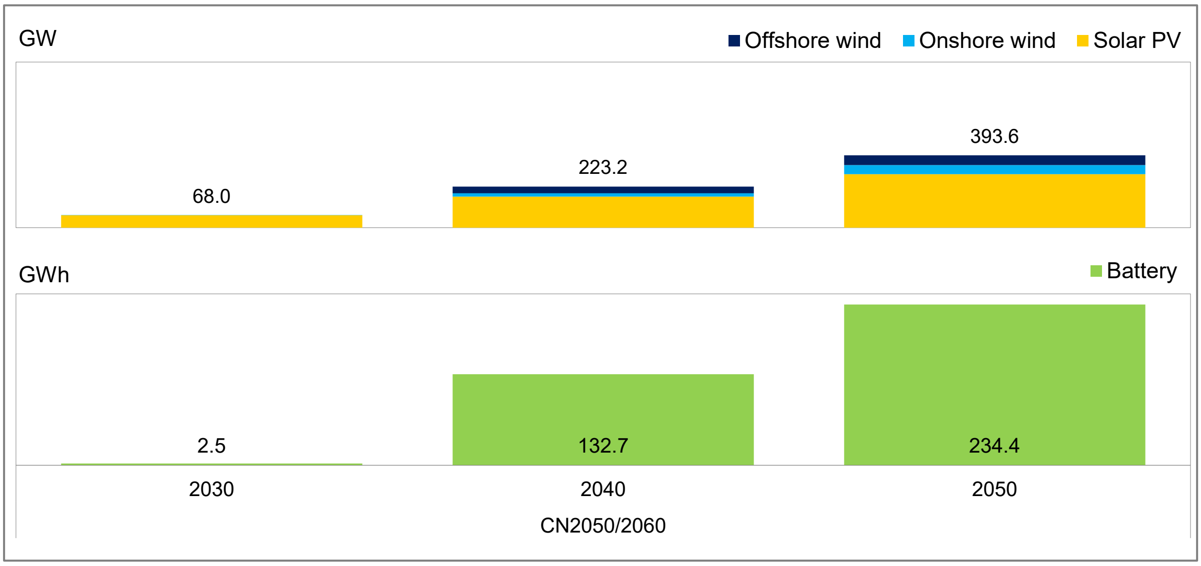
TWh = terawatt hour, PV = photovoltaic.
Source: Author.

Figure A.101. Thermal Power Generation by Source (Viet Nam)



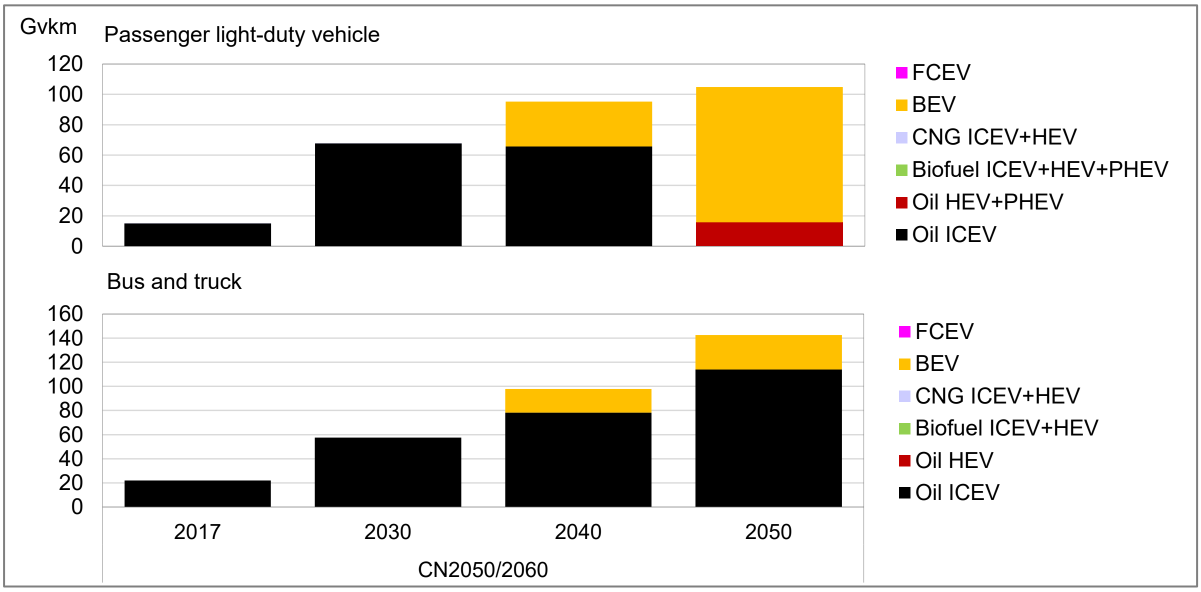
CCUS = carbon capture, utilisation, and storage; TWh = terawatt hour.
Source: Author.

Figure A.102. Installed Capacity of Variable Renewable Energy and Battery (Viet Nam)



GW = gigawatt, PV = photovoltaic.
Source: Author.

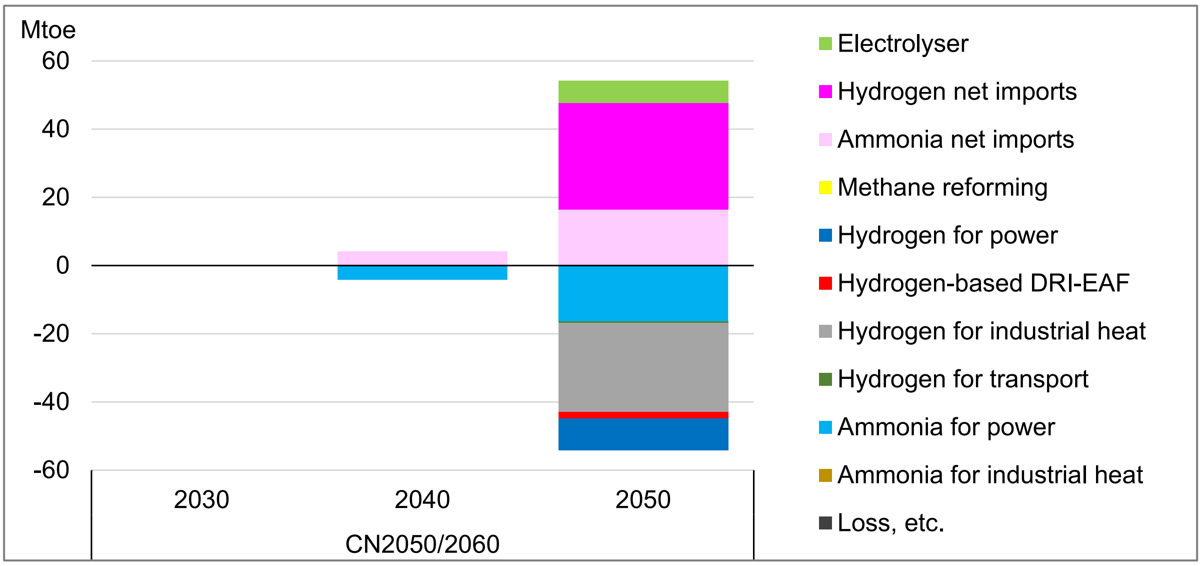
Figure A.103. Road Transport Demand (Viet Nam)



BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, Gvkm = billion vehicle-kilometres, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.

Source: Author.

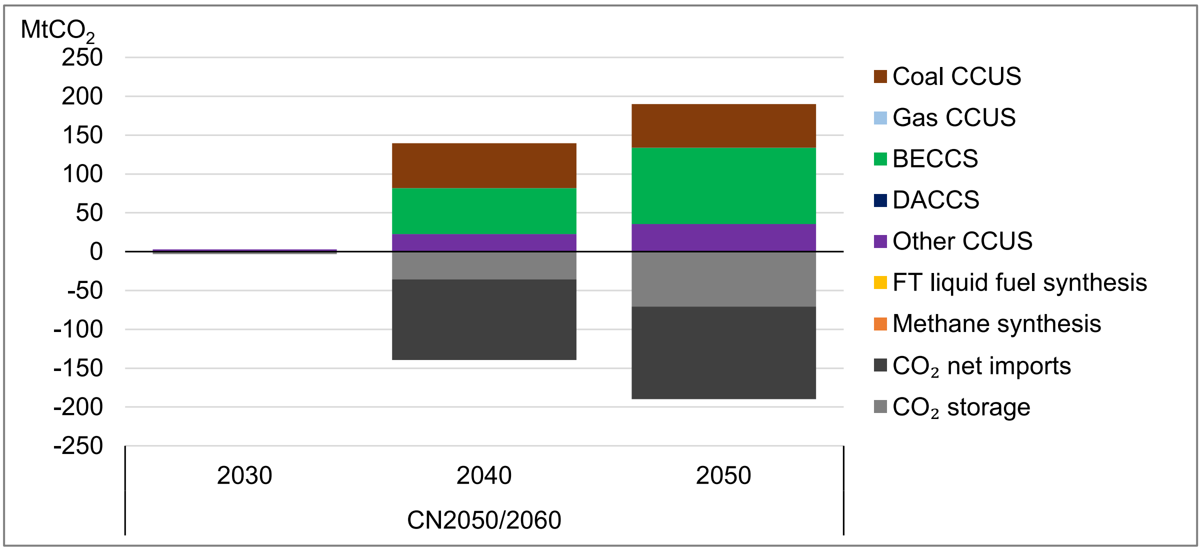
Figure A.104. Supply and Demand of Hydrogen and Ammonia (Viet Nam)



DRI-EAF = direct reduced iron–electric arc furnace, Mtoe = million tonnes of oil equivalent.

Source: Author.

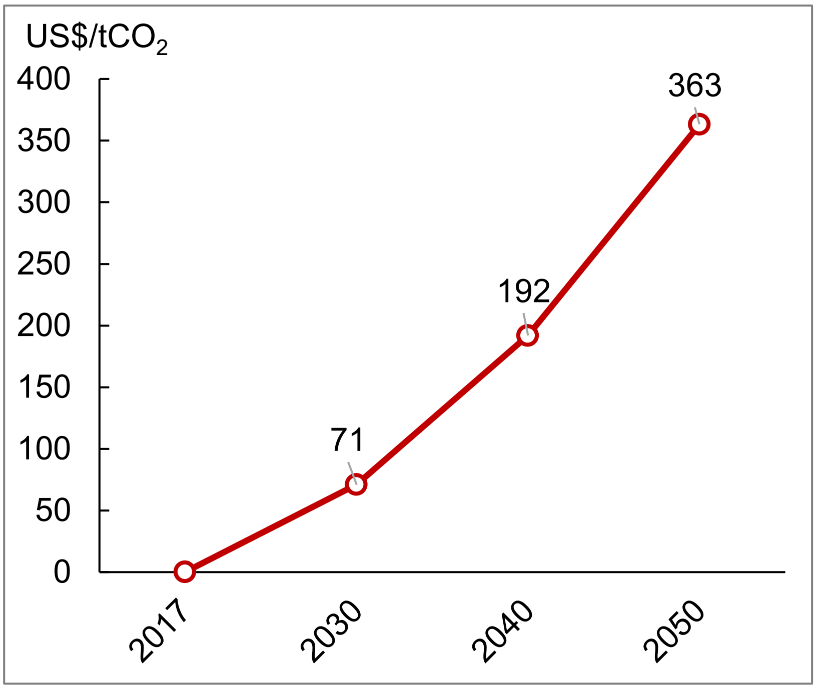
Figure A.105. Carbon Capture, Utilisation, and Storage (Viet Nam)



BECCS = bioenergy with carbon capture and storage; CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; DACCS = direct air carbon capture and storage; FT = Fischer–Tropsch; $MtCO_2$ = metric tonne of carbon dioxide.

Source: Author.

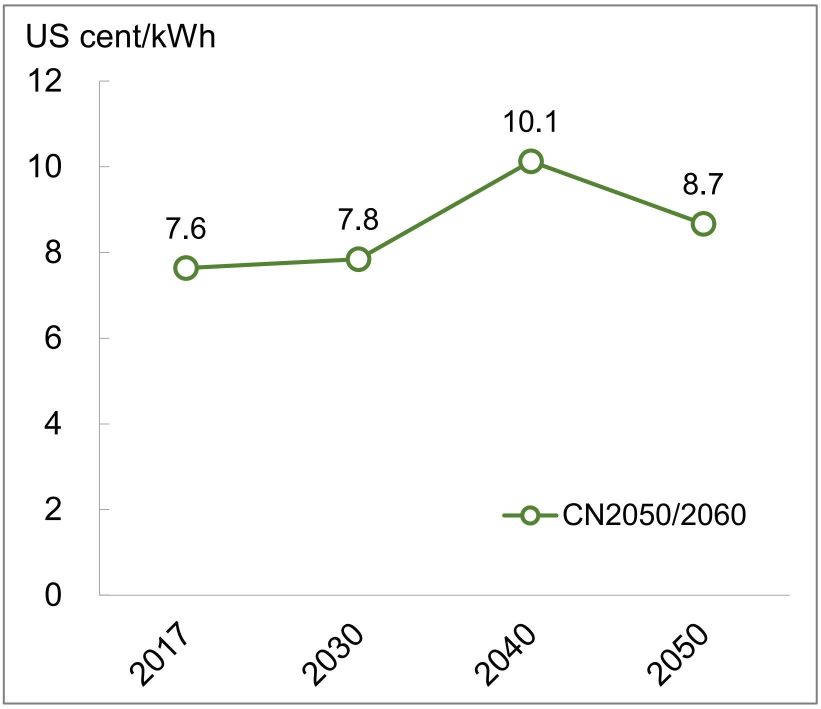
Figure A.106. Marginal Abatement Cost of CO_2 (Viet Nam)



CO_2 = carbon dioxide, tCO_2 = total carbon dioxide.

Source: Author.

Figure A.107. Marginal Cost of Electricity (Viet Nam)



kWh = kilowatt-hour.
Source: Author.