ERIA Research Project Report FY2024, No. 12

Analysis on Energy Cost of LCET-CN based on ERIA Energy Outlook Models 2024

Edited by

Shigeru Kimura

Citra Endah Nur Setyawati

Economic Research Institute for ASEAN and East Asia

Analysis on Energy Cost of LCET-CN based on ERIA Energy Outlook Models 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 Report FY2024 No. 12

Published in August 2024

Foreword

Currently, the national pathway to achieve carbon neutrality by 2050 or later is a key focus. Optimisation approaches such as the Linear Programming method are commonly applied to select zero-emission fuels and technologies under cost-minimisation conditions. ERIA began exploring national pathways to achieve carbon neutrality by 2050 or later in 2019–20 under the EAS Energy Outlook framework. However, it used an econometric approach to select traditional renewable energy sources (hydro, geothermal, and biomass), variable renewable energy sources (solar and wind), nuclear power, CCS for thermal power plants, and hydrogen use for industry, transport (road), and thermal power plants (known as cofiring) manually.

ERIA has newly produced LCET-CN (Low Carbon Energy Transition – Carbon Neutral) scenarios for the 17 EAS countries in addition to the BAU (Business as Usual) and APS (Alternative Policy Scenario), which reflects aggressive EEC and RE targets. This LCET-CN scenario does not guarantee a cost-minimum pathway due to the application of the econometric approach. However, using the energy outlook results until 2050, we can conduct a cost comparison analysis between BAU and LCET-CN. In other words, we compare the future energy costs of a fossil fuel society and a clean energy society.

Energy costs consist of the following items:

a. Fossil fuels, which include coal, oil, and gas,

b. Power investment costs,

c. Hydrogen costs,

d. CCS costs.

The BAU scenario requires significant fuel costs for coal, oil, and gas, and thermal power investment. In contrast, the LCET-CN scenario requires renewable energy, nuclear power, hydrogen, and CCS. Energy consumption and power generation by all power sources come from the EAS Energy Outlook for both BAU and LCET-CN, but fuel prices (including hydrogen), unit investment costs of all power sources, and CCS costs are assumptions. Thus, if we change the assumptions, the cost comparison results will also change.

This report includes:

a. Revised LCET-CN results, and

b. The cost comparison results for the 17 EAS countries.

However, both the LCET-CN and the cost comparison analysis do not cover all low or zero-carbon fuels and technologies. These include thermal power generation with cofiring hydrogen, ammonia, and biomass; the necessary capacity of battery electric storage systems (BESS) for solar PV; demand and supply of e-fuels and e-methane; and DACCS (Direct Air Carbon Capture and Storage) and BECCS (Bioenergy with Carbon Capture and Storage).

ERIA primarily uses an econometric model, which has limitations in reflecting all low and zero-carbon fuels and technologies. Nonetheless, ERIA, in collaboration with ERIA Working Group members for the EAS Energy Outlook and Energy Saving Potential in the East Asia Region, is dedicated to incorporating these fuels and technologies as much as possible.

We hope this report will provide valuable discussion points regarding the achievement of carbon neutrality to energy policymakers, academia, and private/public companies in the EAS region.

Tetsuya Watanabe

President of ERIA (Economic Research Institute for ASEAN and East Asia)

Acknowledgements

This report was prepared in collaboration with the ERIA Working Group for EAS Energy Outlook and Energy Saving Potential, which consists of energy outlook modelers from the 17 EAS countries. Additionally, I would like to express my appreciation to the Institute of Energy Economics, Japan (IEEJ) for updating the energy outlook and energy-saving potential, as well as the LCET-CN scenario for the EAS +7 countries.

I also extend my gratitude to ERIA research associates, namely Citra Endah Nur Setyawati and Ryan Wiratama Bhaskara, for their engagement in publishing this report. Finally, I would like to give special thanks to the ERIA editing team, led by Stefan Wesiak, for their remarkable work in editing this report.

Shigeru Kimura

Senior Policy Fellow on Energy Affairs

Economic Research Institute for ASEAN and East Asia

List of Project Members

Shigeru Kimura, ERIA

Citra Endah Nur Setyawati, ERIA

Han Phoumin, ERIA

Alloysius Joko Purwanto, ERIA

Ryan Wiratama Bhaskara, ERIA

Laksmita Dwi Hersaputri, ERIA

Maekawa Kiminori, Senior Research Director & Group Manager, International Cooperation Group, IEEJ

Cecilya L. Malik, Energy Consultant, Indonesia

Shamim Ahmad, Assistant Director, Resources and Energy Insights Branch, Office of the Chief Economist, Department of Climate Change, Energy, the Environment and Water (DCCEEW), Australia

Adarsh Kumar Singh, *Energy Studies Programme, School of International Studies, Jawaharlal Nehru University, Delhi, India*

Heang Theangseng, Chief of Energy Statistics, Department of Energy Development, General Department of Energy, Ministry of Mines and Energy (MME), Cambodia

Hui Li, Assistant Professor, Center for Energy and Environmental Policy Research (CEEP), Beijing Institute of Technology (BIT), China

Ruining Zhang, Center for Energy and Environmental Policy Research (CEEP), Beijing Institute of Technology (BIT), China

Atul Kumar, Professor, Energy Study Programme, School of International Studies, Jawaharlal Nehru University (JNU), India

Suharyati Nugroho, Coordinator/Head, Energy Planning Division, Energy Policy Bureau, Secretary General, National Energy Council (NEC), Indonesia

Eto Ryo, Senior Economist, Energy and Economic Analysis Group (EEA), EDMC, IEEJ, Japan

Seiya Endo, Senior Economist, ESA, EDMC, IEEJ, Japan

Ryohei Ikarii, Senior Economist, ESA, EDMC, IEEJ, Japan

Davanhny Xaneth, Chief, Energy Policy Division, Department of Energy Policy and Planning, Ministry of Energy and Mines (MEM), Lao PDR

Zaharin Zulkifli, Deputy Director, Strategic Planning and Communication Department, Energy Commission (ST), Malaysia

Swe Swe Than, Deputy Director, Oil and Gas Planning Department (OGPD), Ministry of Energy (MOE), Myanmar

Lilibeth T. Morales, Senior Science Research Specialist, Policy Formulation and Research Division, Energy Policy and Planning Bureau (EPPB), Department of Energy (DOE), Philippines

Kyung-Jin Boo, Research Professor, Institute of Engineering Research, Seoul National University (SNU), Republic of Korea

Zhong Sheng, Senior Research Fellow, Energy Studies Institute (ESI), National University of Singapore (NUS), Singapore

Supit Padrem, Energy Policy and Planning Office (EPPO), Ministry of Energy (MOEN), Thailand

Vichien Tantiwisarn, Energy Policy and Planning Office, Thailand

Surasit Tanthadiloke, Energy Policy and Planning Office, Thailand

Clara Gillispie, Senior Advisor, Board of Advisors, The National Bureau of Asian Research (NBR), United States

Nguyen Minh Bao, Energy Consultant, Viet Nam

Hien Dang, Energy Consultant, New Zealand

Table of Contents

List of Figures

List of Tables

Introduction

EAS Energy Outlook Update and Analysis

The EAS Energy Outlook, which includes 17 EAS countries excluding Russia, has been updated every 2 years. The last update occurred in 2021–22, with the next update planned for 2023-24. Based on the updated models from 2021–22, ERIA conducted two studies in 2022–23:

1. Review of the Existing LCET-CN Scenario: This involved improving the Low Carbon Energy Transition – Carbon Neutral (LCET-CN) scenario where possible.
2. Cost Comparison Analysis: This compared the Business as Usual (BAU) scenario with the revised LCET-CN scenario.

To support these efforts, ERIA, with assistance from IEEJ, held two working group meetings for the EAS Energy Outlook and Energy Saving Potential in January and May 2023.

Review of the Existing LCET-CN Scenario

ERIA requested working group members to review several aspects:

- Energy-saving policies in the LCET-CN compared to BAU and the Alternative Policy Scenario (APS).
- Policies for electric vehicle (EV) penetration.
- Increased use of renewable energy, particularly solar PV and wind power.
- Hydrogen demand and supply perspectives.
- Availability of Carbon Capture and Storage (CCS).

As a result, some members successfully improved their LCET-CN scenarios.

Cost Comparison Analysis

ERIA asked working group members to estimate the energy costs for both the BAU and LCET-CN scenarios to determine which would incur higher costs. Energy costs included:

- Fuel costs (fossil fuels and hydrogen).
- Power investment costs per power source.
- CCS costs.
- Energy-saving costs (though this was omitted due to insufficient data).

Fuel Costs Estimation Process

1. Calculate the increased amount of each fuel between 2019 and 2050.
2. Multiply the assumed unit cost of each fuel by the increased amount in 2050.
3. Compare the estimated fuel costs between BAU and APS.

Assumed unit costs for 2050 (2019 constant price) were:

	2019/2020		2050 (2019 Constant Price)	
Coal	80.03	US$/ton	98	US$/ton
Oil	41	US$/bbl	100	US$/bbl
Gas	7.77	US$/MMBTU	7.5	US$/MMBTU
Hydrogen	0.8	US$/Nm^3	0.1	US$/Nm^3
CCS	-	US$/$CO_2$ ton	70	US$/$CO_2$ ton

Power Capital Cost Estimation Process

1. Calculate the increase in power generation per source from 2019 to 2050.
2. Calculate additional power capacity needed, considering the capacity factor of each power source.
3. Multiply the assumed unit capital cost by the necessary increase in power capacity.
4. Compare the estimated power capital costs between BAU and LCET-CN.

Assumed capacity factors and unit capital costs for 2050 were:

	2019		by 2050	
Coal	75	%	75	%
Oil	75	%	75	%
Gas	75	%	75	%
Hydrogen	-	%	75	%
Nuclear	80	%	80	%
Hydro	60	%	60	%
Geothermal	75	%	75	%
Solar	15	%	17	%
Wind	25	%	30	%
2Biomass	75	%	75	%

And the assumed unit capital cost of each power source were:

	2019		by 2050	
Coal	1,500	US$/KW	1,525	US$/KW
Oil	-	US$/KW	-	US$/KW
Gas	700	US$/KW	700	US$/KW
Hydrogen		US$/MW	700	US$/KW
Nuclear	4,500	US$/KW	3,575	US$/KW
Hydro	2,000	US$/KW	2,223	US$/KW
Geothermal	4,000	US$/KW	4,256	US$/KW
Solar	1,600	US$/KW	307	US$/KW
Wind	1,600	US$/KW	1,235	US$/KW
Biomass	2,000	US$/KW	3,019	US$/KW

BAU will basically increase thermal power plants; on the other hand, LCET-CN will increase renewable, nuclear, and hydrogen power plants.

For CCS cost, ERIA requested the members to estimate CCS treatment costs. Theoretically CCS consists of following three activities: capture CO2, transport CO2 and Store CO2. But this analysis assumes CCS running cost of CO2 defined as US$/CO2 ton. The estimation process is shown below:

CCS Cost Estimation Process

1. Obtain CO_2 emissions for coal and gas in 2050 from the EAS Energy Outlook.

2. Calculate the share of coal and gas consumption in power generation.

3. Calculate CO_2 emissions by the power sector.

4. Multiply the CCS share of coal and gas power generation by the CO_2 emissions.

5. Multiply the unit cost of CCS by the CO_2 emissions treated by CCS.

Cost Comparison Results

The comparison considered:

- Fuel Costs: Higher for BAU due to reliance on fossil fuels.
- Power Capital Costs: Higher for LCET-CN due to increased renewable and hydrogen power plants, which have lower capacity factors than thermal plants.
- CCS Costs: Applicable only to the LCET-CN scenario.

Generally, the fuel costs for LCET-CN are much lower than for BAU. However, power capital costs are higher for LCET-CN due to the need for substantial renewable energy capacities. This analysis provides valuable insights for policymakers, academia, and private/public companies in the EAS region regarding the pathway to carbon neutrality.

Chapter 1
Australia Country Report

Shamim Ahmad
Department of Climate Change, Energy, the Environment and Water, Australia

Seiya Endo
The Institute of Energy Economics, Japan

1. Basic Concept of Low-carbon Energy Transition–Carbon Neutrality

The energy sector is a major source of greenhouse gas (GHG) emissions in Australia. In 2020, approximately 79% of Australia's GHG emissions were energy-related, followed by agriculture (13%), industrial processes (6%), and waste (2%) (IEA, 2023). Electricity generation is the biggest contributor to energy-related GHG emissions, and it is undergoing a rapid transition in the country.[1]

In June 2022, the Australian government lodged an updated National Determined Contribution (NDC) with the United Nations Framework Convention on Climate Change secretariat. The updated NDC commits Australia to a more ambitious emissions reduction target of 43% below 2005 levels, and reaffirms Australia's commitment to net-zero emissions by 2050. In October 2022, the country also signed up to the Global Methane Pledge alongside 130 signatories who are collectively targeting a reduction in methane emissions of at least 30% from the 2020 level by 2030 (IEA, 2023).

Australia is implementing a suite of new policies for accelerating the development of technologies to achieve net-zero emissions. Australia's new technology partnership approach is creating international cooperation on innovation and deployment of low emissions technologies for the production and trade of hydrogen and critical minerals. Australia has the potential to play a key role in clean energy transition globally by supplying critical minerals used in many clean energy technologies. The country aims to decarbonise its power sector, and the government has put forward a plan to increase the share of renewable electricity generation to 82% of the national electricity market by 2030 (IEA, 2023).

This study attempts to develop a low-carbon energy transition–carbon neutral (LCET–CN) scenario for Australia, and to estimate the investment costs and emissions reduction benefits under the scenario compared to the business as usual (BAU) scenario. Low-carbon energy transition of an economy consists of a pathway towards the transformation

[1] Unless otherwise cited, all data in the report are attributed to the Institute of Energy Economics, Japan's economic modelling results for Australia, which are included in full as an appendix to the publication.

of energy-related activities that produces low levels of GHG emissions. Carbon neutrality of energy systems refers to a condition when carbon emissions and carbon removal from the atmosphere are balanced for the energy-related activities.

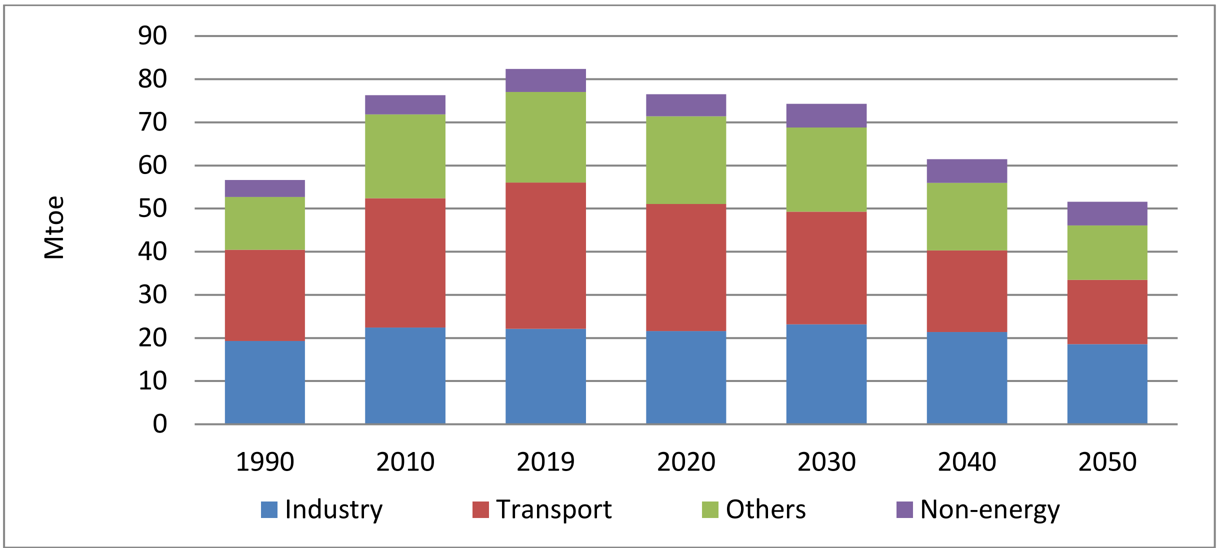
Achieving the LCET–CN scenario requires major structural changes of energy systems. However, mapping a single pathway for net-zero targets involves a high level of uncertainty.

2. Low-carbon Energy Transition–Carbon Neutral Scenario Results

2.1. Final Energy Consumption

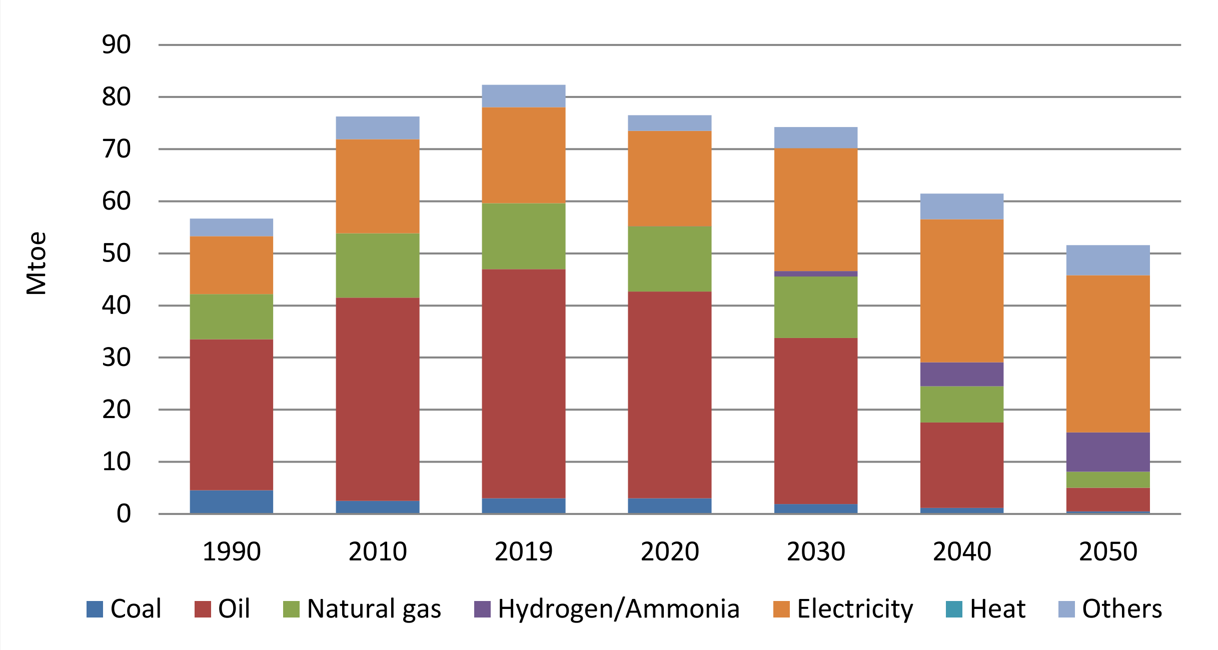
In the LCET–CN scenario, total final energy consumption will decrease from 82.3 million tonnes of oil equivalent (Mtoe) in 2019 to 51.6 Mtoe in 2050, or by about 37.4% or an average of 1.5% per year. Energy consumption in the transport sector will decline strongly (55.9%) because of efficiency improvements and other structural changes despite continued growth in vehicle ownership. Energy use in the 'others', sector, i.e. residential and services, will decrease at an average annual rate of 1.7%, from 21.0 Mtoe in 2019 to 12.6 Mtoe in 2050. The industry sector's energy use will decline by 0.6% per year during the same period but non-energy's use will grow by 0.1% per year. Consumption of coal, oil, and natural gas will decline sharply, but demand for electricity and other renewables will grow. The share of hydrogen and ammonia in the final energy mix is expected to be the second highest (14.7%), behind electricity. Electricity's share will increase from 22.4% in 2019 to 58.5% in 2050 (Figure 1.1, Figure 1.2).

Figure 1.1. Final Energy Consumption by Sector, LCET–CN Scenario (1990–2050)



LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Authors.

Figure 1.2. Final Energy Consumption by Fuel Type, LCET–CN Scenario (1990–2050)



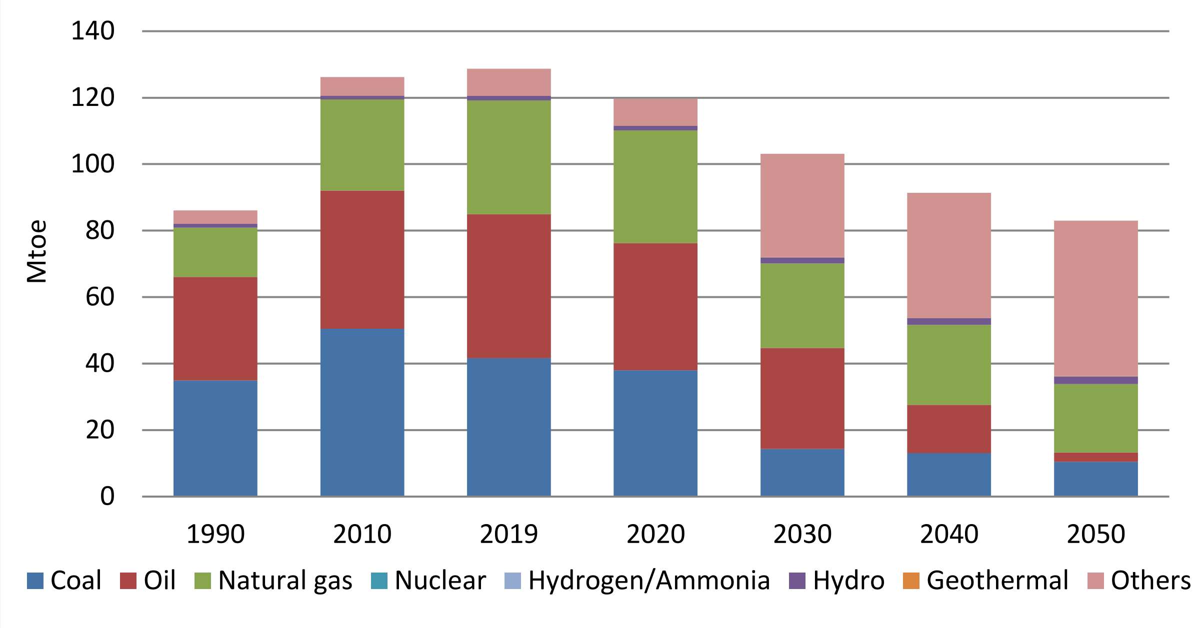
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Authors.

2.2. Primary Energy Supply

Total primary energy consumption is projected to decrease from 128.7 Mtoe in 2019 to 83.0 Mtoe in 2050, with an equivalent average rate of 1.4% per year. During the period, coal consumption will decline sharply by 4.3% per year and oil consumption by 8.5% per year. The use of natural gas will decline from 34.3 Mtoe in 2019 to 20.5 Mtoe in 2050, with an equivalent average rate of 1.6% per year.

The share of fossil fuels in the primary energy mix will drop from 92.6% in 2019 to 40.8% in 2050. Hydropower's share will increase modestly from 1.0% in 2019 to 2.8% in 2050. In contrast, the share of non-hydro renewable energy (others) will grow rapidly from 6.3% in 2019 to 56.4% in 2050. The demand for non-hydro renewable energy is projected to grow at 5.8% per year during the outlook period, supported by the growth of solar and wind energy (7.1%) and biomass (4.5%) (Figure 3).

Figure 1.3. Primary Energy Supply by Fuel Type, LCET–CN Scenario (1990–2050)

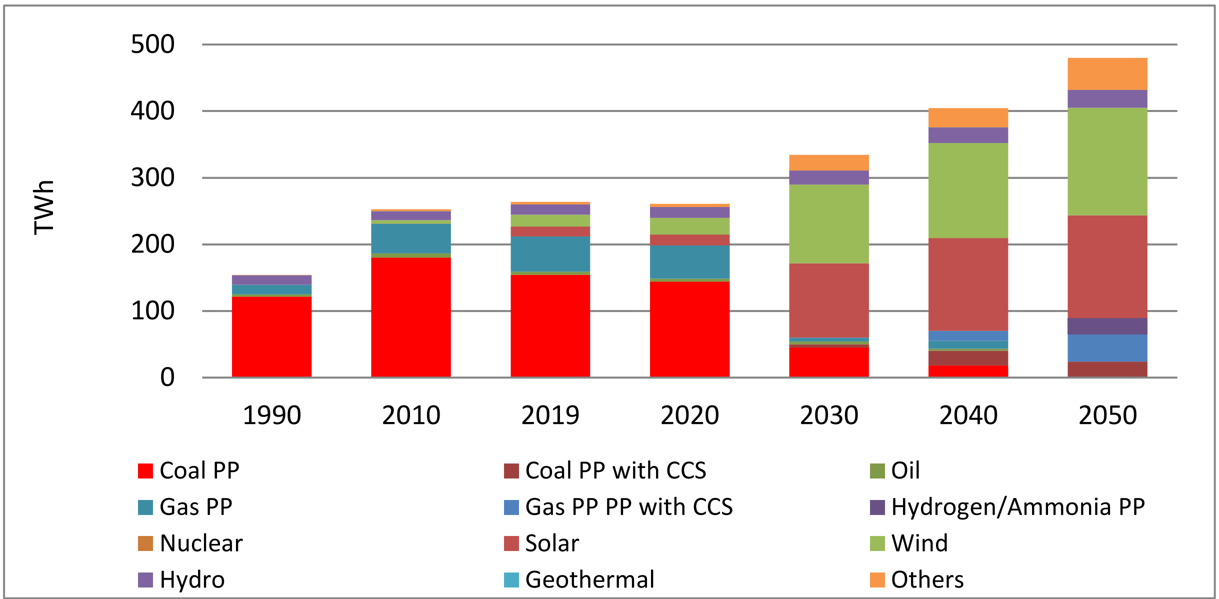


LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Authors.

2.3. Power Generation

In the LCET–CN scenario, electricity generation will grow from 263.7 terawatt-hours (TWh) in 2019 to 480.2 TWh in 2050 at an equivalent average rate of 2.0% per year. The share of fossil fuels in the power generation mix will fall sharply from 80.4% in 2019 to 13.6% in 2050, of which 8.6% will be gas power plants with carbon capture and storage (CCS) and 5.0% coal-fired power plants with CCS. All inefficient coal, gas, and oil-fired power plants will be closed by 2040. In 2050, about 86.4% of power generation will come from net-zero carbon sources. Green hydrogen and ammonia will take up 5.0% in 2050, solar energy 32.1%, wind energy 33.6%, hydropower 5.6%, and other renewables, 10.0% (Figure 4).

Figure 1.4. Electricity Generation by Fuel Type, LCET–CN Scenario (1990–2050)



LCET–CN = low-carbon energy transition–carbon neutral, CCS = carbon capture and storage, PP = power plant, TWh = terawatt-hour.
Source: Authors.

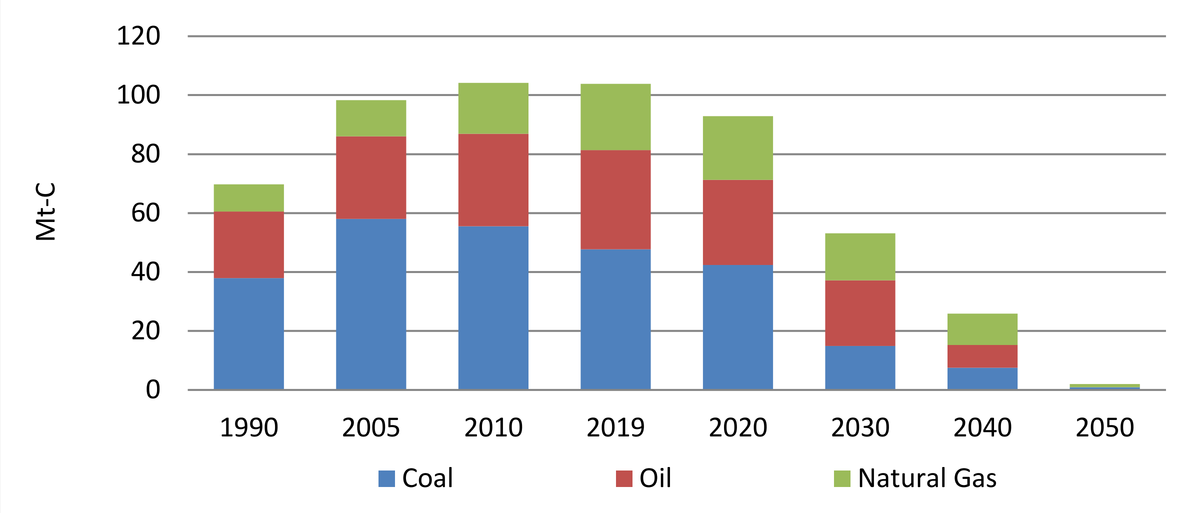
2.4. Carbon Dioxide Emissions

Carbon dioxide (CO_2) emissions from energy consumption will decline from 103.8 million tonnes of carbon (Mt-C) in 2019 to 1.2 Mt-C in 2050 or an equivalent decrease by an average rate of 13.5% per year. In 2030, emissions saving is projected to be 42.3 Mt-C or 44.3% compared with the BAU scenario. However, emissions saving is projected to reach 88.9 Mt-C or 98.7% compared with the BAU scenario in 2050.

The rate of emissions reduction over the outlook period is faster than the declining rate of primary energy consumption in the LCET-CN scenario, reflecting the increased use of less carbon-intensive and renewable energy sources in the primary energy supply. The lower emissions growth rate indicates that energy-saving options are effective in reducing CO_2 emissions. The reduced use of coal in power generation and reduced oil consumption in the transport sector are main contributors for the reduction of CO_2 emissions in the LCET–CN scenario.

Less fossil fuel use has a direct impact on CO_2 emissions reduction. The LCET–CN scenario was developed to analyse the decarbonisation pathway of energy-related activities. Under this scenario, CO_2 emissions appear to be 46.0% (or 45.2 Mt-C) less than the 2005 level in 2030, and 98.8% (or 97.2 Mt-C) less than the 2005 level in 2050 (Figure 5).

Figure 1.5. Total CO_2 Emissions by Fuel Type, LCET–CN Scenario (1990–2050)



CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: Authors.

2.5. Hydrogen Demand Across the Sectors

The widespread use of hydrogen as a fuel in the economy was envisioned by some researchers in early 1970s (Bockris, 1972). However, until recently hydrogen was not seen as a viable fuel in Australia. Hydrogen is now emerging as one of the important fuels in transitioning to an energy system with net-zero emissions. It is a clean fuel that has the potential to power vehicles, generate electricity, and produce heat. Hydrogen can also be used as energy storage for generating electricity to keep the grid stable during potential fluctuation of wind and solar energy in the power systems. Australia has an abundance of renewable resources to produce clean hydrogen for domestic use and to supply the world.

Under the LCET–CN scenario, consumption of hydrogen will increase sharply after 2030. The share of hydrogen and ammonia in the final energy mix is expected to increase from 1.4% (1.0 Mtoe) in 2030 to 14.7% (7.6 Mtoe) in 2050. Hydrogen demand as a final energy will be the second highest behind electricity in 2050. Affordable hydrogen fuel cell vehicles and the development of adequate infrastructure for hydrogen refuelling stations will contribute to increased hydrogen use in the transport sector. Iron and steel, chemicals, and mining will also contribute to the increased demand of hydrogen in 2050.

In the LCET–CN scenario, green hydrogen and ammonia will take up 5.0% (24 TWh) of electricity generation requiring an input of 4.6 Mtoe of hydrogen fuel in 2050.

3. Cost Comparison between BAU and LCET–CN Scenarios

3.1 Introduction

This section provides a high-level analysis of cost comparison between the BAU and LCET–CN scenarios. The analysis attempts to quantify the total investment costs that would be needed to implement all assumptions of the LCET–CN scenario, and then compare them with the BAU costs. The cost estimation of both scenarios requires detail cost data of fuels and technologies in relation to outlook results.

This study, in estimating investment costs, uses the outlook results of energy consumption by sectors by fuel types, input fuels of power plants, construction cost, capacity factor of power plants, and electricity output of power plants in 2019 and 2050. The additional capacity requirements of different generation technologies for both the BAU and LCET–CN scenarios are estimated by using the increased amount of electricity demands in 2050 (compared to 2019) and the capacity factors of corresponding generation technologies.

The difference between energy demand in the LCET–CN and BAU scenarios in 2050 is due to the energy efficiency improvement and actions taken on energy transition over the period to 2050.

3.2. Fuel Cost

The results in this study show the decline of fossil fuel demand over the outlook period under both the BAU and LCET–CN scenarios. A sharp decline in fossil fuel use and a large uptake of renewable energy use are projected in the LCET–CN scenario. Fuel cost is estimated by applying the fuel prices assumptions of Table 1 and the changes of fossil fuel use over the outlook period to 2050 (Tables 1.2 and 1.3).

Table 1.1. Fuel Cost Assumptions

Fuel Type	Unit	2019/2020	2050 (2019 constant price)
Coal	US$/ tonne	80.03	98
Oil	US$/bbl	41	100
Gas	US$/MMBtu	7.77	7.5
Hydrogen	US$/$Nm^3$	0.8	0.3
CCS	US$/$tCO_2$	NA	30

bbl = barrel, CCS = carbon capture and storage, tCO_2 = tonnes of carbon dioxide, MMBtu = metric million British thermal unit, NA = not applicable, Nm^3= normal cubic metre.
Source: ERIA (2023).

In the BAU scenario, coal consumption is projected to decrease from 41.7 Mtoe in 2019 to 29.8 Mtoe in 2050 resulting in a saving of US$1,869 million. Similarly, oil will contribute a saving of US$4,782 million in 2050. However, gas demand is projected to increase from 34.3 Mtoe in 2019 to 46.0 Mtoe in 2050 at an increased cost of US$3,377 million. The net savings of fuel costs is projected to be US$3,274 million under the BAU scenario (Table 1.2).

Table 1.2. Fuel Costs in BAU Scenario

Fuel Type	Primary Energy Consumption (Mtoe)			Fuel Cost (US$ million)
	2019	2050	2050-2019	2050-2019
Coal	41.7	29.8	–11.9	–1,869
Oil	43.3	36.3	–7.0	–4,782
Gas	34.3	46.0	11.7	3,377
Hydrogen	0	0	0	0
Total	**119.3**	**112.1**	**–7.2**	**–3,274**

BAU = business as usual, Mtoe = million tonnes of oil equivalent.
Source: Authors.

In the LCET–CN scenario, the consumption of all fossil fuels (coal, oil, and gas) is projected to decrease. The highest decline is projected to be for oil demand from 43.3 Mtoe in 2019 to 2.8 Mtoe in 2050, which will result in a cost reduction of US$27,856 million for oil in 2050. Electrification in the transport sector will significantly contribute to this reduced demand of oil. The cost of coal is projected to decrease by US$4,924 million in 2050. A significant increase of renewable electricity in generation mix will contribute to this reduced coal demand. Meanwhile, gas demand is projected to decrease from 34.3 Mtoe in 2019 to 20.5 Mtoe in 2050, which will contribute to a cost reduction of US$3,972 million. The LCET–CN scenario provides a net reduction of fuel costs at around US$36,752 million in 2050 (Table 1.3).

Table 1.3. Fuel Costs in LCET–CN Scenario

Fuel Type	Primary Energy Consumption (Mtoe)			Fuel Cost (US$ million)
	2019	2050	2050–2019	2050–2019
Coal	41.7	10.5	–31.2	–4,924
Oil	43.3	2.8	–40.5	–27,856
Gas	34.3	20.5	–13.8	–3,972
Hydrogen	0	0	0	0
Total	**119.3**	**33.8**	**–85.5**	**–36,752**

LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Authors.

3.3. Power Generation Investment

This section provides a high-level analysis of the investment costs for the additional generation capacity that would be required to meet the electricity demand in 2050 under both the BAU and LCET–CN scenarios. Table 1.4 provides assumptions on investment costs and capacity factors of electricity generation technologies by fuel types.

Table 1.4. Investment Cost and Capacity Factors

Fuel Type	Investment Cost (US$/KW)		Capacity Factors (%)	
	2019	2050	2019	2050
Coal	1,500	1,525	75	80
Oil	700	700	75	80
Gas	700	700	75	80
Hydrogen	-	700	-	80
Hydro	2,000	2,223	50	40
Geothermal	4,000	4,256	50	50
Solar	1,600	307	17	17
Wind	1,600	1,235	40	40
Biomass	2,000	3,019	50	70

KW = kilowatt.
Source: ERIA (2023).

As mentioned in the previous section, the additional capacity required to meet the electricity demand in 2050 is estimated by using capacity factors of generation technologies and the increased amount of electricity demand in 2050. The estimated cost of generation technology is the multiplication of additional capacity and investment cost per unit (Tables 5 and 6).

The additional capacity for the LCET–CN scenario in 2050 is much higher than the BAU scenario. In BAU, additional capacity for coal and oil fired power generation will not be required. However, 3,711 megawatts (MW) of additional gas-fired generation capacity will be required in 2050 at a cost of US$2,598 million. In contrast, electricity generation from renewable energy sources (solar, wind, biomass, hydro, and geothermal) will require total additional capacity of 50,317 MW in 2050 at an aggregated cost of US$33,482 million. The highest capacity addition is expected to occur for solar power (33,863 MW at a cost of US$10,396 million) followed by wind power plants (14,736 MW at a cost of US$18,199 million) in 2050 (Table 5).

Table 1.5. Power Generation Investment Costs: BAU Scenario

Fuel Type	Generation Outputs (TWh)			Additional Capacity (MW)	Costs (US$ million)
	2019	2050	2050–2019	2019–2050	2019–2050
Coal	154.3	143.2	–11.2	0	0
Oil	4.9	2.8	–2.2	0	0
Gas	52.8	78.8	26.0	3,711	2,598
Hydrogen	-	0.0	0.0	0	0
Hydro	15.6	17.0	1.4	397	883
Geothermal	0	0.1	0.1	13	56
Solar	14.8	65.3	50.4	33,863	10,396
Wind	17.7	69.3	51.6	14,736	18,199
Biomass	3.5	11.5	8.0	1,308	3,948
Total*	**263.7**	**387.9**	**124.2**	**54,028**	**36,079**

BAU = business as usual, MW = megawatt, TWh = terawatt-hour.
Note: *Numbers may not add due to rounding.
Source: Authors.

The additional capacity needed for the LCET–CN scenario in 2050 is 148,536 MW, which is much higher than the BAU scenario. This is due to more aggressive assumptions on power generation from renewable energy sources in 2050. In the LCET-CN scenario, around 82% electricity will be generated from renewable energy starting from 2030. As a result, total investment cost for capacity addition is estimated to be US$111,063 million (Table 6).

Few remaining coal-fired and gas-fired power plants will operate with CCS in 2050 with no additional capacity. The highest capacity addition will take place for solar power (93,531 MW for US$28,714 million) followed by wind power plants (41,055 MW for US$50,703 million) in 2050 (Table 1.6).

Table 1.6. Power Generation Investment Costs: LCET–CN Scenario

Fuel	Generation outputs (TWh)			Additional Capacity (MW)	Cost (US$ million)
	2019	2050	2050–2019	2019–2050	2019–2050
Coal	154.3	24.0	–130.3	0	0
Oil	4.9	0.0	–4.9	0	0
Gas	52.8	41.3	–11.5	0	0
Hydrogen	-	24.3	24.0	3,426	2,398
Hydro	15.6	26.8	11.2	3,203	7,121
Geothermal	0	0.1	0.1	21	91
Solar	14.8	154.1	139.3	93,531	28,714
Wind	17.7	161.6	143.9	41,055	50,703
Biomass	3.5	48.3	44.8	7,299	22,036
Total	**263.7**	**480.2**	**216.5**	**148,536**	**111,063**

LCET–CN = low-carbon energy transition–carbon neutral, MW = megawatt, TWh = terawatt-hour.
Source: Authors.

3.4. Carbon Capture and Storage Cost

In the LCET–CN scenario, the introduction of CCS will be implemented starting from 2030. The CCS projects will be implemented for coal-fired and natural gas-fired power plants.

As shown in Table 7, the CCS cost is assumed to be around US$70 per tonne of carbon dioxide in 2050. The total investment cost for CCS is estimated to be US$2,416 million in 2050, of which the CCS cost of coal-fired power plants is US$1,178 million, and the CCS cost of gas-fired power plants is around US$1,238 million (Table 1.7).

Table 1.7. Investment Cost of Carbon Capture and Storage for LCET–CN Scenario in 2050

	Fuel Consumption (Mtoe)	CO_2 Emissions (Mt-C)	CO_2 Emissions (Mt-CO_2e)	Cost of CCS (US$ million)
Coal-fired Power Plants with CCS	5.0	5.1	18.7	1,178
Natural Gas-fired Plants with CCS	9.2	5.4	19.7	1,238
Total	**14.2**	**10.5**	**38.4**	**2,416**

CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, Mtoe= million tonnes of oil equivalent, Mt-C = million tonnes of carbon, Mt-CO_2e= million tonnes of carbon dioxide equivalent.
Source: Authors.

3.5. Overall Cost

The cost components of the LCET–CN and BAU scenarios are summarised in Table 8. It is expected that power plants will require US$36,079 million capital investment by 2050 under the BAU scenario. In contrast, investment cost in power plants including CCS is expected to be US$113,479 million in the LCET–CN scenario over the projection period. The LCET–CN scenario also requires US$5,187 million investment in energy saving equipment by 2050. However, reduction of fuel costs would be more under the LCET–CN scenario when compared with the BAU scenario.

In the LCET–CN scenario, renewable energy and hydrogen would significantly replace fossil fuels for power generation, and oil products for transportation. As a result, investment cost in the LCET–CN scenario is much higher when compared with the BAU scenario. However, LCET–CN offers significant environmental benefits in terms of CO_2 emissions reduction. Introduction of carbon prices would reduce the overall costs under the LCET–CN scenario.

Table 1.8. Cost Comparison between LCET–CN and BAU Scenarios (2019–2050)

	Unit	BAU (2019–2050)	LCET–CN (2019–2050)
Fuel Cost	US$ million	–3,274	–36,752
Power Plant Capital Cost	US$ million	36,079	111,063
CCS Cost	US$ million	0	2,416
Energy Saving Equipment Cost	US$ million	0	5,187

BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Authors.

4. Conclusions and Recommendations

4.1. Conclusions

Australia's emissions reduction target is economy-wide which aims to reduce GHG emissions by 43% by 2030, compared to 2005 levels, and net-zero emissions by 2050. The LCET–CN scenario in this study focuses on analysing Australia's abatement of energy-related GHG emissions, and the costs of emissions reduction to reach net-zero emissions by 2050.

In the LCET–CN scenario, Australia will achieve its NDC target of emissions reduction from energy related activities. The scenario results show that the country's energy related CO_2 emissions are 46% lower than the 2005 level in 2030 and almost 99% lower in 2050.

The LCET–CN scenario needs more investments compared to the BAU scenario due to the needs in renewable energy, hydrogen, and CCS technologies for the transition of mainly the power sector. It also requires investment in energy saving equipment over the projection period.

The overall cost under the LCET–CN scenario reduces if carbon prices are introduced in the analysis. The electricity generation sector will drive and enable other sectors (i.e. industry and transport) to achieve their emissions reduction goals.

4.2. Recommendations

Decarbonisation of the power generation system requires earlier and faster closure of inefficient fossil fuel power plants. Faster deployment of technologies is critical for reaching net-zero targets by 2050. It is also important to implement CCS technology in existing efficient coal-fired and gas-fired power plants.

Major investment in solar, wind, batteries, pumped hydro, and transmission infrastructure is required for the power system. Earlier and faster deployment of existing renewable energy technologies in the power system will reduce GHG emissions faster than the current 2030 target. Using green hydrogen and ammonia fuel in power plants will also be required to decarbonise the power generation system.

Deployment of adequate energy storage technologies is essential to support faster growth of non-hydro renewable electricity technologies. Greater attention is also required to replacing ageing electricity grid infrastructure.

Affordable hydrogen fuel cell vehicles and development of adequate infrastructure for hydrogen refuelling stations and electric vehicle charging stations will be required for increased use of hydrogen and electric vehicles in the transport sector.

Low-carbon technologies must be adopted earlier and faster to decarbonise the transport, industry, residential, and service sectors. Faster electrification is critical for transport and heavy industry.

Energy efficiency improvement is faster in the LCET–CN scenario than in BAU scenario. Improved and efficient end-use technologies must be adopted faster to reduce final energy consumption in end-use sectors. Transport has more opportunities for energy saving. Energy saving in industry comes from improved efficiency in large energy-intensive industries. Improved energy efficiency and energy savings plays an important role to decarbonise the end-use sector.

References

Bockris, J. (1972), 'A Hydrogen Economy', *Science,* 176(4041), 1323. https://www.science.org/doi/10.1126/science.176.4041.1323. (accessed 27 November 2023).

Economic Research Institute of for ASEAN and East Asia (ERIA) (2023), *Generation Investment Costs*. Jakarta: ERIA.

Institute of Energy Economics, Japan (IEEJ) (2023), *Energy Outlook Modelling for Australia*. Tokyo: IEEJ.

International Energy Agency (IEA) (2023), *Australia 2023: Energy Policy Review*. Paris : IEA. (accessed 15 November 2023).

Chapter 2

Brunei Darussalam Report

Updated by Cecilya Malik, ASEAN Expert

Energy Consultant, Indonesia

1. Background

A low-carbon energy transition refers to the shift from high-carbon or fossil fuel-based energy sources to low-carbon or renewable energy sources. The transition involves adopting technologies and practices that produce fewer emissions per unit of energy generated. This can include renewable energy sources such as solar, wind, hydroelectric, geothermal, and biomass, as well as nuclear power, which produces minimal emissions during electricity generation. Additionally, energy efficiency measures and improvements in energy storage technologies play a crucial role in this transition.

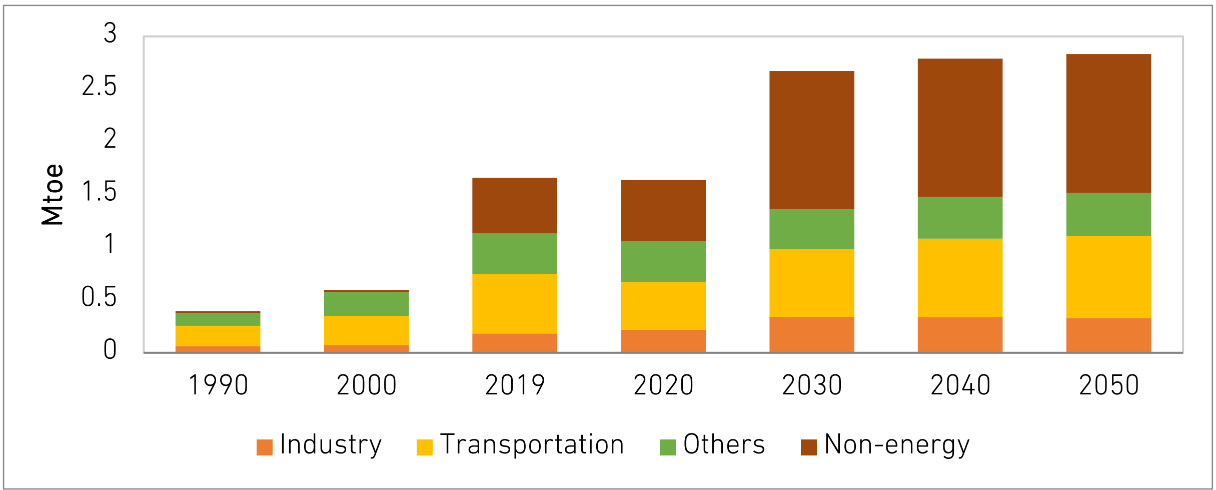
Carbon neutrality or achieving a net-zero carbon footprint means balancing emissions with carbon removal or offsetting measures. It involves reducing emissions as much as possible and then offsetting any remaining emissions through activities that remove carbon dioxide from the atmosphere or prevent additional emissions. In the *Energy Outlook and Energy-Saving Potential in East Asia 2023,* Brunei Darussalam includes carbon capture and storage (CCS) technologies under its low-carbon energy transition–carbon neutral (LCET-CN) scenario in addition to an increased share of solar in the power mix by 2050. This transition requires coordinated efforts from the government, businesses, and individuals to invest in renewable energy infrastructure, adopt energy-efficient technologies, and implement policies that incentivise low-carbon practices. This study analyses the cost requirements for an energy transition towards carbon neutrality for Brunei Darussalam.

2. Final Energy Consumption (historical trend: 2019, 2030, 2040, 2050)

Under the LCET-CN scenario, the total final energy consumption (TFEC) for Brunei Darussalam is expected to reach 3 million tonnes of oil equivalent (Mtoe) in 2050, increasing at an average rate of 1.7% per year over 2019–2050 (Figure 2.1). This rate is lower than that of the business-as-usual (BAU) scenario at 2.1% per year. The lower growth rate under the LCET-CN scenario is expected to occur primarily in the transport sector (22%) as a result of stricter fuel efficiency regulations and the introduction of electric vehicles (EVs). Further reductions of 20% would occur as stringent energy efficiency and conservation measures for buildings are implemented in the 'others' sector.

Figure 2.1. Final Energy Consumption by Sector, LCET-CN Scenario, 1990–2050

(Mtoe)

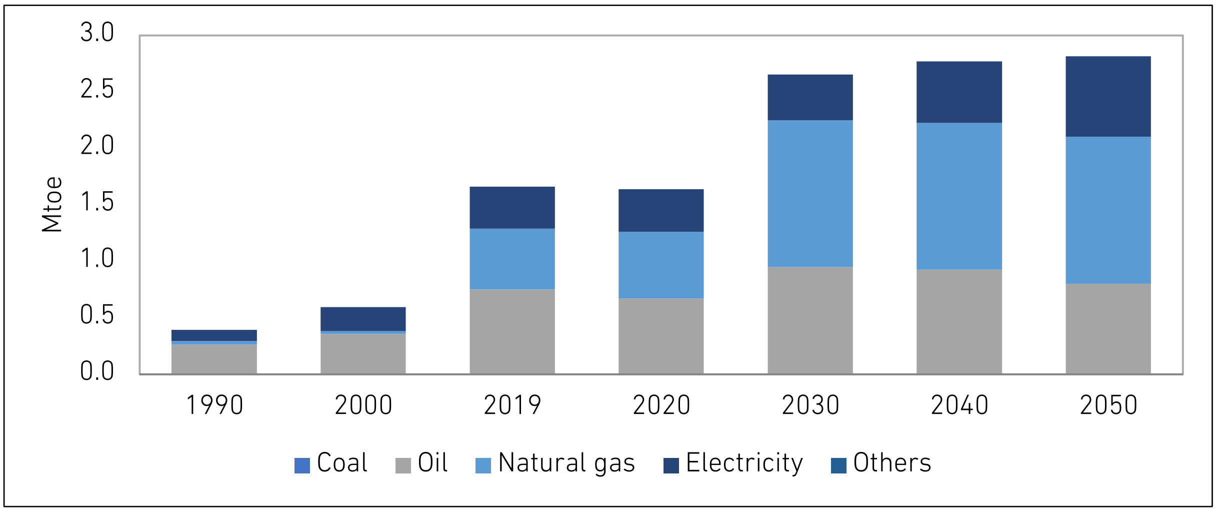


LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

In 2050 under the LCET-CN scenario, the share of electricity at 25.3% would be higher in the TFEC than the 14.4% share under the BAU scenario, in line with the anticipated electricity demand for EVs. Whilst the share of oil will decline to 28.5%, the share of natural gas in the TFEC is expected to increase to 46.2% under the LCET-CN scenario as demand for natural gas continues to surge with the expansion of the downstream industry. Figure 2.2 shows the final energy consumption by fuel under the LCET-CN scenario.

Figure 2.2. Final Energy Consumption by Fuel, LCET-CN Scenario, 1990–2050

(Mtoe)



LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

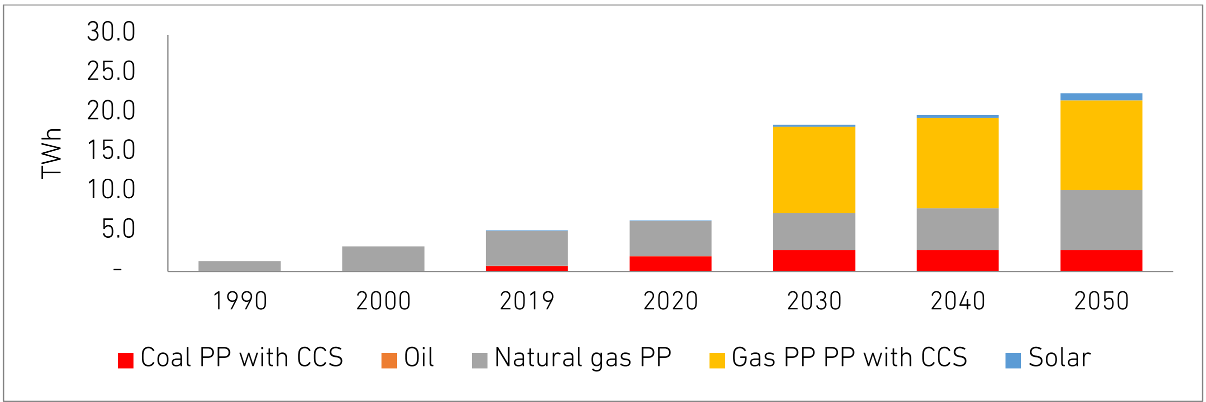
3. Power Generation (historical trend: 2019, 2030, 2040, 2050)

Total electricity generation under the LCET-CN scenario is projected to increase at 4.9% per year from 2019 until 2050, reaching 22.6 terawatt-hours (TWh). Total power generation includes the own-use generation of coal to operate the Hengyi Phase I and Hengyi Phase II petrochemical complex projects. Under the LCET-CN scenario, coal would still be used in generating electricity for Hengyi Phase 1. Yet during Hengyi Phase II, there would be a transition from coal to gas-fired power generation, including carbon capture, use, and storage (CCUS). The transition would result in a moderate reduction in electricity generation to 22.6 TWh in 2050 from 25.0 TWh under the BAU scenario.

Overall, the share of generation under the LCET-CN scenario is expected to remain unchanged from fossil fuels, with an increased natural gas share (including with CCUS) to 84% in 2050 compared with 25% under the BAU scenario, whilst the share of coal would drop to 12% from 75% in the BAU scenario. Renewable energy in Brunei Darussalam is only solar; this share would be 4% in the total electricity generation mix in 2050 under the LCET-CN scenario.

Figure 2.3. Electricity Generation by Fuel, LCET-CN Scenario, 1990–2050

(TWh)



CCS = carbon capture and storage, LCET-CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: Author's calculations.

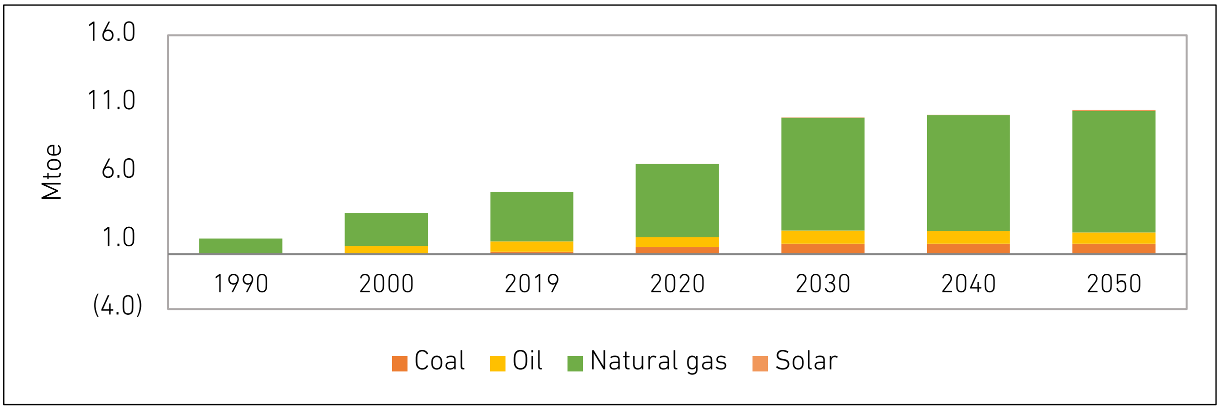
Total electricity generation under the LCET-CN scenario is projected to increase 4.9% per year from 2019 until 2050 (Figure 2.3).

4. Primary Energy Supply (historical trend: 2019, 2030, 2040, and 2050)

The total primary energy supply (TPES) under the LCET-CN scenario is expected to reach 10.4 Mtoe in 2050, increasing at an average rate of 2.8% per year from 2019 (Figure 2.4). The TPES under the LCET-CN scenario would decline by 24.3% compared to the BAU scenario. The share of natural gas in the TPES is projected to increase to 84.3% in 2050, and the shares of coal and oil would decline to 7.4% and 7.6%, respectively. The trend would be due to the switch from natural gas to coal during Hengyi Phase II.

Figure 2.4. Total Primary Energy Supply by Fuel Type, LCET-CN Scenario, 1990–2050

(Mtoe)



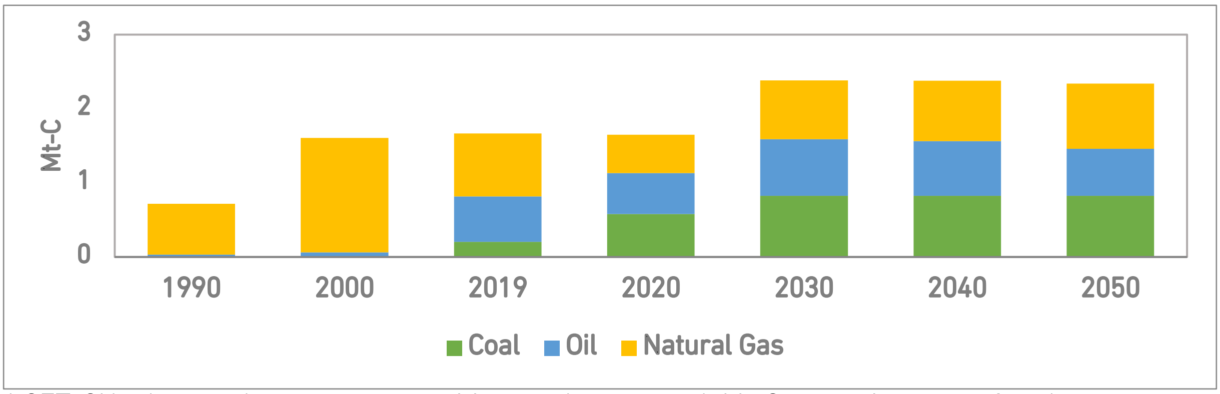
LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

5. Emissions

Total emissions will peak in 2030 and show a declining trend of about 0.17% per year to reach 2.3 million tonnes of carbon (MtC) in 2050, as less demand for oil is expected. Natural gas will become the major source of emissions, with a 37.6% share in 2050, followed by coal with 35.2%. Oil is projected to emit the least, at 27.2%. Using a CCUS unit in natural gas power plants would reduce emissions by 67.6% under the LCET-CN scenario compared with the alternative policy scenario (APS).

Figure 2.5. Total Emissions by Fuel Type, LCET-CN Scenario, 1990–2050

(MtC)



LCET-CN = low-carbon energy transition–carbon neutral, Mt-C = metric tonne of carbon.
Source: Author's calculations.

6. Hydrogen Demand across the Sector

Hydrogen demand was not assumed under the Brunei Darussalam LCET-CN scenario.

7. Energy Cost Comparison

7.1. Assumptions

An analysis of energy costs was carried out to compare the BAU and LCET-CN scenarios. The objective of this analysis to see the total energy costs needed to implement all assumptions under the LCET-CN scenario. The basic assumptions for this analysis are stated in Tables 2.1–2.3.

Table 2.1. Assumed Fuel Costs

Fuel	2019/2020	2050 (2019 constant price)	Unit
Coal	80.03	98.00	US$/tonne
Oil	41.00	100.00	US$/bbl
Gas	7.77	7.50	US$/mmbtu
Hydrogen	0.80	0.30	US$/$Nm^3$
CCS	0	30.00	US$/$tCO_2$

bbl = barrel, CCS = carbon capture and storage, CO_2 = carbon dioxide, mmbtu = million British thermal units, Nm^3 = normal cubic metre, tCO_2 = tonne of carbon dioxide.
Source: Author's calculations.

Table 2.2. Assumed Construction Costs of Power Plants
(US$/kilowatt)

Fuel	2019	by 2050
Coal	1,500	1,525
Oil	0	0
Gas	700	700
Hydrogen	0	700
Nuclear	4,500	3,575
Hydro	2,000	2,223
Geothermal	4,000	4,256
Solar	1,600	307
Wind	1,600	1,235
Biomass	2,000	3,019

Source: Author's calculations.

Table 2.3. Assumed Capacity Factors of Power Plants
(%)

Fuel	2019	by 2050
Coal	75	80
Oil	75	80
Gas	75	80
Hydrogen	0	80
Nuclear	100	80
Hydro	50	40
Geothermal	50	50
Solar	17	17
Wind	40	40
Biomass	50	70

Source: Author's calculations.

7.2. Fuel Costs

Based on fuel cost assumptions in Table 2.1, fuel costs are shown in Table 2.4.

Table 2.4. Fuel Cost Comparison, BAU and LCET-CN Scenarios, 2050

Fuel	Primary Energy Consumption, BAU, 2019 (Mtoe)	Primary Energy Consumption, BAU, 2050 (Mtoe)	Primary Energy Consumption, LCET-CN, 2050 (Mtoe)	Total Investment Cost, BAU, 2050 (US$ million)	Total Investment Cost, LCET-CN, 2050 (US$ million)
Coal	0.19	5.38	0.78	820	93
Oil	0.74	1.38	0.80	440	41
Gas	3.60	7.16	8.89	1,028	1,527
Hydrogen	0	0	0	0	0
Total	**4.53**	**13.92**	**10.47**	**2,288**	**1,662**

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

From the results above, the total investment fuel cost in 2050 for the BAU scenario is expected to be US$2,288 million, higher than that of the LCET-CN scenario at US$1,662 million.

7.3. Power Generation Investment

Based on power generation investment assumptions in Tables 2–3, the total investment costs for power plants in 2050 under the BAU and LCET-CN scenarios are in Table 2.5.

From Table 2.5, the total additional capacity needed for the BAU scenario would be 2,850 megawatts (MW) from the 2019 level. The additional capacity under the LCET-CN scenario would be slightly higher at 2,955 MW. As explained previously, own-use of coal for operating the Hengyi Phase I is assumed to not be affected under the LCET-CN scenario; only in the Hengyi Phase II would coal be replaced with gas-fired power generation, including CCUS. This transition would result in a in a moderate reduction in electricity generation in 2050. Thus, the total additional capacity from coal and gas under the LCET-CN scenario (2,368 MW) would be lower than that under the BAU scenario (2,829 MW). In addition, Brunei Darussalam would increase its solar capacity under the LCET-CN scenario (an additional 586 MW compared to 21 MW under the BAU scenario) to reduce emissions. The total investment for power plants in 2050 under the BAU scenario would therefore be around US$4,115 million, while under the LCET-CN scenario, it would be US$2,079 million.

Table 2.5. Power Plant Cost Comparisons, BAU and LCET-CN Scenarios, 2050

	Electricity Generation, BAU, 2019 (TWh)	Electricity Generation, BAU, 2050 (TWh)	Electricity Generation, LCET-CN, 2050 (TWh)	Additional Capacity, BAU, (MW)	Additional Capacity, LCET-CN (MW)	Total Investment Cost, BAU, 2050 (US$ million)	Total Investment Cost, LCET-CN, 2050 (US$ million)
Coal	0.67	18.75	2.72	2,580	292	3,934	446
Oil	0.05	0.00	0.00	0			
Gas	4.45	6.20	19.74	249	2,076	174	1,453
Hydrogen	0.00	0.00	0.00	0	0	0	0
Hydro	0.00	0.00	0.00	0	0	0	0
Solar	0.00	0.03	0.87	21	586	7	180
Wind	0.00	0.00	0.00	0	0	0	0
Biomass	0.00	0.00	0.87	0	0	0	0
Total	**5.17**	**24.98**	**23.34**	**2,850**	**2,955**	**4,115**	**2,079**

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent, MW = megawatt, TWh = terawatt-hour.

Source: Author's calculations.

7.4. Carbon Capture and Storage Costs

The introduction of CCS for natural gas power plants would be implemented under the LCET-CN scenario starting in 2041. Based on Table 2.1, the CCS costs are around US$30 per tonne of carbon dioxide (Table 2.6).

Table 2.6. Total Investment Cost of CCS for LCET-CN Scenario in 2050

	Consumption for LCET-CN in 2050 (Mtoe)	Emissions for LCET-CN ($MtCO_2$)	Emissions for LCET-CN (MtC)	Total Investment Cost of CCS for LCET-CN (US$ million)
Coal Power Plant with CCS	0.00	0.000	0.000	0
Natural Gas Plant with CCS	0.07	0.142	0.039	4
Total	**0.07**	**0.142**	**0.039**	**4**

CCS = carbon capture and storage, LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent, MtC = million tonnes of carbon, $MtCO_2$ = million tonnes of carbon dioxide.
Source: Author's calculations.

Table 2.6 indicates that the total investment costs of CCS under the LCET-CN scenario would be around US$4 million.

7.5. Overall Costs

The breakdown of the total investment costs is shown in Table 2.7.

Table 2.7. Overall Total Investment Costs for BAU and LCET-CN Scenarios in 2050

	BAU	LCET–CN	LCET–CN vs. BAU
Total Fuel Cost Investment (US$ million)	2,288	1,662	–626
Total Power Capital Cost Investment (US$ million)	133	67	–66
Total CCS Cost Investment (US$ million)	0	4	4
Total (US$ million)	**2,421**	**1,733**	**–688**

BAU = business as usual, CCS = carbon capture and storage, LCET-CN = low-carbon energy transition–carbon neutral.
Source: Author's calculations.

Overall investment costs under the BAU scenario in 2050 are projected to be US$2,421 million, while under the LCET-CN scenario, they are US$1,733 million.

8. Conclusions and Recommendations

Brunei Darussalam will remain reliant on fossil fuels to meet growing energy demand, even under the LCET-CN scenario. The non-energy sector will drive energy demand, as a significant volume of natural gas is needed to expand downstream industries as the economy diversifies. Transport would offer the greatest savings in the LCET-CN scenario, with improved vehicle efficiency and greater use of EVs. The power sector under the LCET-CN scenario would be decarbonised through CCS and increasing shares of renewable energy (mainly solar) as well.

Overall, the energy-related emissions of Brunei Darussalam would decrease significantly in the LCET-CN scenario by 2050 (i.e., 70%) compared to the BAU scenario. Projected carbon removal of about 3.8 MtC and emissions of 2.3 MtC in 2050 would result in a net sink of –1.5 MtC. Hence, the NDC and net-zero emissions target are assumed to be achieved under the LCET scenario, which means that ambitious measures are required to put the economy on a sustainable energy pathway to achieve net-zero emissions by 2050.

The total investment cost of the LCET–CN scenario is estimated to be US$1,733 million, which is lower than that in the BAU scenario, US$2,421 million. This result indicates that implementing all measures assumed under the LCET–CN scenario would enable Brunei Darussalam to attain net-zero emissions by 2050. This is in line with the government energy strategies being developed to achieve net-zero emissions by 2050. The total investment reduction of the energy sector by implementing the LCET–CN scenario would be US$688 million compared to implementation of the BAU scenario.

The main reduction in total investment would be due to lower fuel costs (US$626 million), as fuel costs are the largest portion of the total investment (95% in the BAU and 96% in the LCET–CN scenarios). Introduction of CCS is assumed to be from 2030 in the LCET-CN scenario, and the investment in CCS would reach US$4 million in 2050, around 1% of the total investment. If the cost of CCS technology is reduced by 2050, the investment cost of CCS is expected to be reduced significantly.

Chapter 3
Cambodia Country Report

Heang Theangseng

Department of Energy Development, Ministry of Mines and Energy, Cambodia

1. Background

Cambodia's nationally determined contribution (NDC) targets the country's emissions rising by up to 90 million tonnes of carbon dioxide equivalent (tCO_2e) per year by 2030, whilst emissions are expected to increase to 155 million tCO_2e per year (MtCO2e) in a business-as-usual (BAU) scenario (Table 3.1).

Table 3.1. Emissions, BAU Scenario, 2030

Sector	Sectoral Share (%)	Emissions ($MtCO_2e$)
FOLU	49.2	76.3
Energy	22.2	34.4
Agriculture	17.5	27.1
IPPU	9.0	13.9
Waste	2.1	3.3

BAU = business as usual, FOLU = forestry and other land use, IPPU = industrial processes and product use, $MtCO_2e$ = million tonne of carbon dioxide equivalent.
Source: Government of Cambodia, National Council for Sustainable Development and Ministry of Environment (2020).

Forestry and other land use (FOLU) would mark the highest emissions under the BAU scenario in 2030, at 49.2% of total emissions, followed by energy at 22.2%, agriculture at 17.5%, and industrial processes and product use at 9.0%. The estimated emissions reduction under the NDC in 2030 would be about 64.5 $MtCO_2e$ per year, or a 41.7% reduction, of which 59.1% would be from FOLU (Table 3.2). About 38 $MtCO_2e$ are assumed as carbon sink by forests to 2050.

Table 3.2. BAU Scenario Emissions and NDC Emissions Reductions

Sector	BAU 2016 Emissions ($MtCO_2e$)	BAU 2030 Emissions ($MtCO_2e$)	NDC 2030 Scenario ($MtCO_2e$)	NDC 2030 Reduction ($MtCO_2e$)	NDC 2030 Reduction (%)
FOLU	76.3	76.3	38.2	–38.1	–50
Energy	15.1	34.4	20.7	–13.7	–40
Agriculture	21.2	27.1	20.9	–6.2	–23
IPPU	9.9	13.9	8.0	–5.9	–42
Waste	2.7	3.3	2.7	–0.6	–18
Total	**125.2**	**155.0**	**90.5**	**–64.5**	**–42**

BAU = business as usual, FOLU = forestry and other land use, IPPU = industrial processes and product use, $MtCO_2e$ = million tonnes of carbon dioxide equivalent, NDC = nationally determined contribution.
Source: Government of Cambodia, National Council for Sustainable Development and Ministry of Environment (2020).

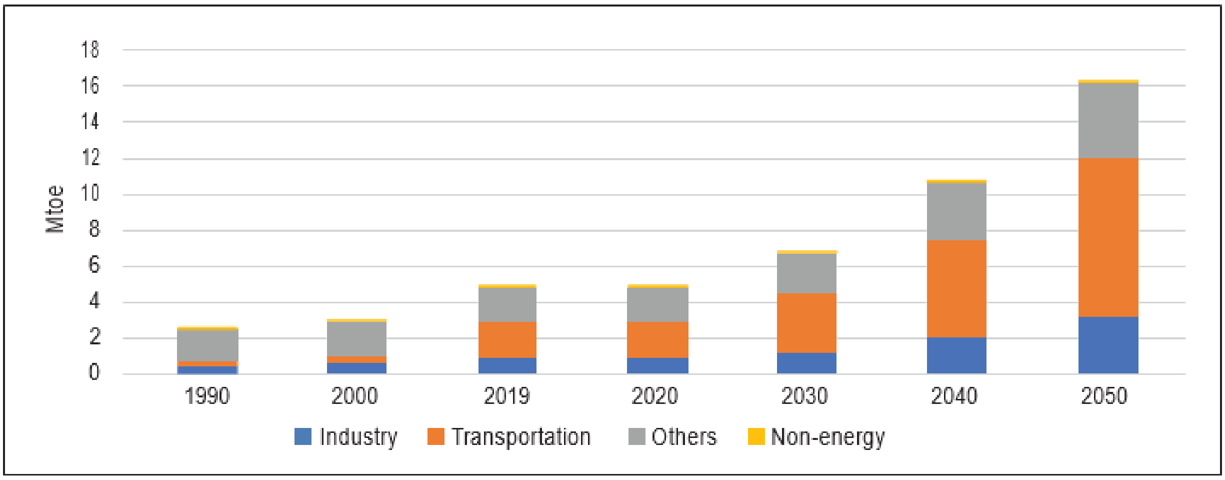
To ensure that the low-carbon energy transition–carbon neutral (LCET-CN) scenario is in line with Cambodia's NDC emissions reduction target, in addition to assuming carbon sink by forests to 2050, decreased oil demand is projected at 9.4% per year in the industrial sector and at 18.6% per year in the transport sector during 2040–2050 due to electrification. New technologies would also be applied, such as coal power plants using clean coal technologies with carbon capture and storage (CCS) and natural gas power plants using CCS in 2040–2050.

2. Final Energy Consumption

Figure 3.1 illustrates final energy consumption by sector during 1990–2050 under the LCET-CN scenario. The average annual growth rate (AAGR) would be 3.9% per year, which is the same as the AAGR of final energy consumption in alternative policy scenario (APS) 5.

Demand is projected to be strongest in the transport sector with an AAGR of 4.73% during 2019–2050, from 2.09 million tonnes of oil equivalent (Mtoe) to 8.74 Mtoe. The industrial sector is projected to follow, with an AAGR of 4.20% from 0.95 Mtoe in 2019 to 3.35 Mtoe in 2050. The 'others' sector would be next, at 2.60%, from 1.91 Mtoe in 2019 to 4.19 Mtoe in 2050.

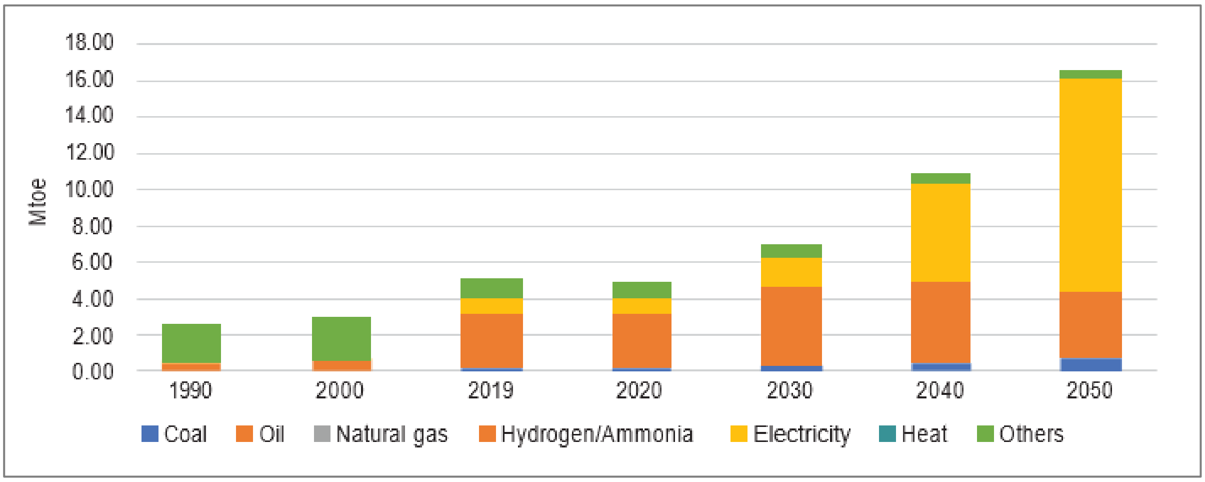
Figure 3.1. Total Final Energy Consumption by Sector, LCET-CN Scenario



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

Figure 3.2 reveals that the highest shares of electricity demand would be during 2040–2050 under the LCET-CN scenario, the result of reducing oil demand in the transport sector. The AAGR of total final energy consumption (TFEC) under the LCET-CN scenario is projected to increase by 3.9% during 2019–2050. Electricity would dominate at 50.4% of TFEC in 2040 and 71.2% in 2050, followed by oil at 41.5% in 2040, before dropping to 22.8% in 2050.

Figure 3.2. Total Final Energy Consumption by Fuel, LCET-CN Scenario

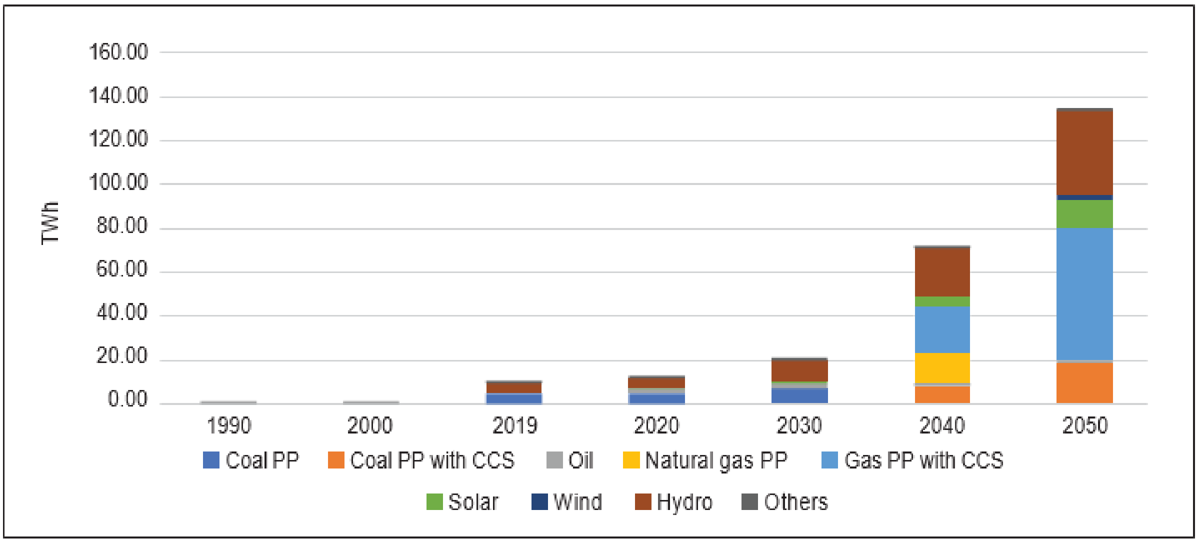


Mtoe = million tonnes of oil equivalent.
Source: Author.

3. Power Generation

Figure 3.3 shows that Cambodia's total electricity generation in 2050 would be 134.02 terawatt-hours (TWh) under the LCET-CN scenario, much higher than in the APS5 at 65.82 TWh due to the projected huge decrease in oil demand during 2040–2050. Emissions would be reduced as natural gas power plants become the main contributor to electricity generation during 2032–2040; natural gas with CCS and coal with CCS would then be the highest contributors during 2040–2050. Electricity generation is projected to have an AAGR of 9.1%, with solar energy having the highest share at 16.9% during 2019–2050.

Figure 3.3. Total Electricity Generation, LCET-CN Scenario

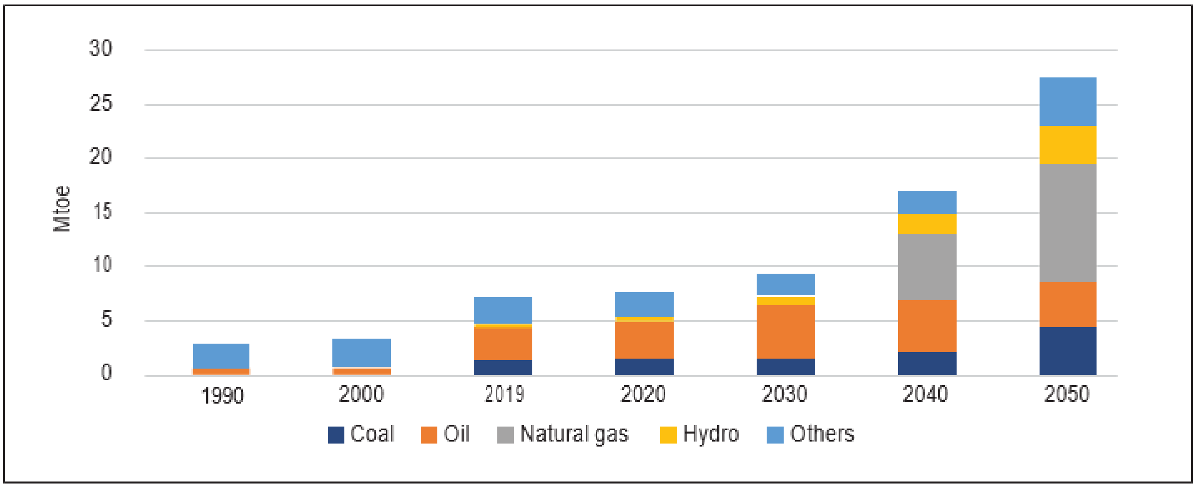


CCS = carbon capture and storage, PP = power plant, TWh =terawatt-hour.
Source: Author.

4. Primary Energy Supply

In 2050, the total primary energy supply (TPES) under the LCET-CN scenario would be 27.35 Mtoe, much higher than in the APS5 at 21.76 Mtoe (Figure 3.4). The TPES would record an AAGR of 4.4% during 2019–2050 under the LCET-CN scenario and 3.6% under the APS5. Biomass would be the only fuel to register a negative AAGR at –1.05%, due to people replacing firewood with liquefied petroleum gas (LPG) as cooking fuel in both urban and rural areas.

Figure 3.4. Total Primary Energy Supply by Fuel, LCET-CN Scenario

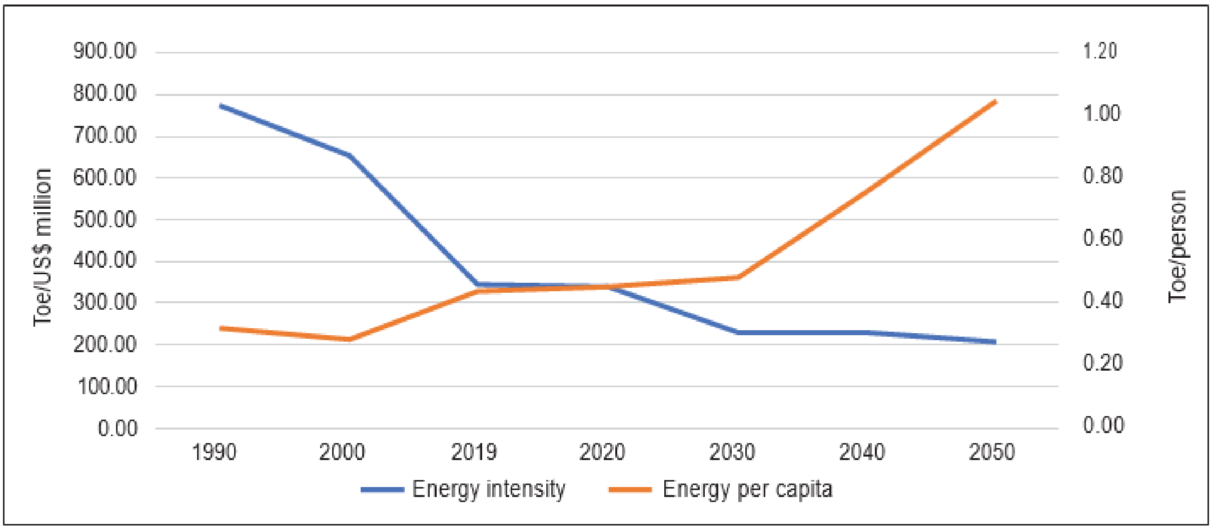


Mtoe = million tonnes of oil equivalent.
Source: Author.

Figure 3.5 shows that primary energy intensity decreased from 775 tonnes of oil equivalent (toe)/US$1 million in 1990 to 343 toe/US$1 million in 2019 and would further decrease to 204 toe/US$1 million in 2050 under the LCET-CN scenario. The trend indicates that energy would be used more efficiently due to implementation of an energy efficiency and conservation programme and use of new technologies.

Primary energy per capita increased from 0.32 toe/person in 1990 to 0.43 toe/person in 2019 and would further increase to 1.05 toe/person in 2050 under the LCET-CN scenario, indicating that living standards are improving, resulting in increasing energy demand per capita.

Figure 3.5. Energy Indicators, LCET-CN Scenario

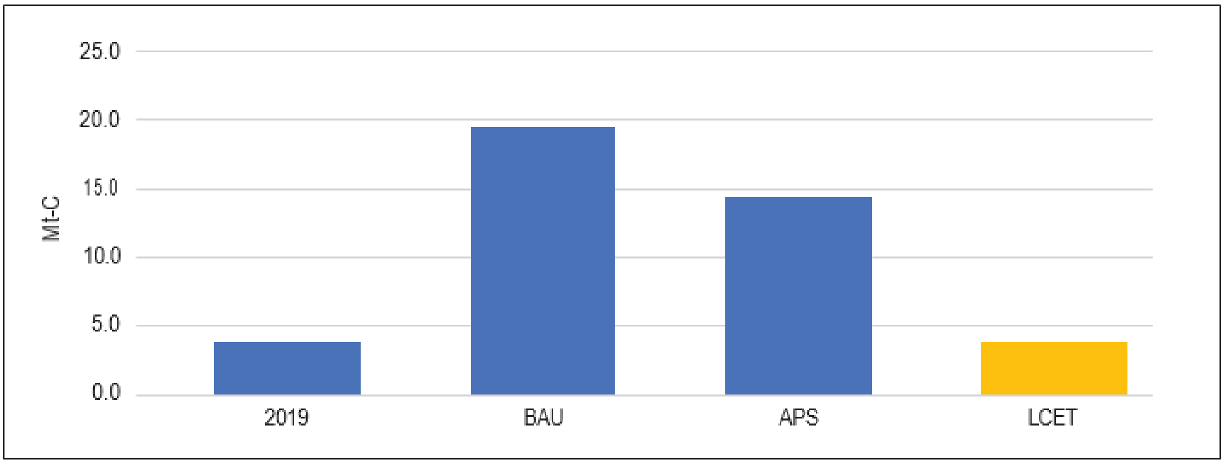


Source: Author.

5. Emissions

Emissions from energy consumption are projected to decrease by 3.7% per year during 2040–2050, from 5.64 million tonnes of carbon (MtC) to 3.85 MtC under the LCET-CN scenario. Under the APS5, the AAGR of emissions are projected to increase by 4.3% during 2019–2050. Emissions under the LCET-CN scenario would decrease by 10.5 MtC or about 73.2% by 2050 compared to the APS5 (Figure 5). Carbon sink by forests is assumed to be about 38 $MtCO_2e$ or about 10 MtC. Through applying CCS technologies, Cambodia could achieve carbon neutrality by 2050.

Figure 3.6. Emissions Reduction under the BAU, APS5, and LCET-CN Scenarios



APS = alternative policy scenario, BAU = business as usual, LCET = low carbon energy transition, Mt-C = million tonnes of carbon.
Source: Author.

6. Cost Comparison

6.1. Assumptions

Implementing the LCET-CN scenario implies investing in low-carbon technologies covering energy-saving technologies, renewable energy, hydrogen, and CCS. An analysis on energy cost was carried out to estimate the total investment costs in implementing such policies and programmes under the LCET-CN scenario. The basic assumptions for this analysis cover fuel costs (Table 3.3), construction costs of power plants (Table 3.4), and capacity factors of power plants (Table 3.5).

Table 3.3. Assumed Fuel Costs

Scenario	Coal	Oil	Gas	Total Cost (US$ million)
BAU	4.27	12.69	7.12	9,126.70
LCET-CN	4.49	4.03	11.02	4,332.31

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral.
Source: Author's calculations.

Table 3.4. Assumed Construction Costs of Power Plants

Scenario	Coal	Oil	Gas	Hydro	Solar	Wind	Biomass	Total (TWh)	Total Cost (US$ million)
BAU	12.49	1.16	43.03	15.66	5.92	0.00	0.10	78.36	14,672.31
LCET-CN	17.95	1.16	61.54	38.46	11.86	2.96	0.10	134.02	34,459.20

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, TWh = terawatt-hour.
Source: Author's calculations.

Table 3.5. Assumed Capacity Factors of Power Plants

(%)

Fuel	2019	by 2050
Coal	75	80
Oil	75	80
Gas	75	80
Hydro	50	40
Solar	17	17
Wind	40	40
Biomass	50	70

Source: Author's calculations.

6.2. Fuel Costs

Under the LCET-CN scenario, the primary energy consumption in 2050 would be 19.54 Mtoe, while under the BAU scenario, it would be 24.08 Mtoe. Consequently, the total investment fuel costs in 2050 under the LCET-CN scenario would be lower than those under the BAU scenario, US$4,332 million compared to US$9,127 million (Table 3.6).

Table 3.6. Fuel Cost Comparison, BAU and LCET-CN Scenarios

Fuel	Primary Energy Consumption, BAU, 2019 (Mtoe)	Primary Energy Consumption, BAU, 2050 (Mtoe)	Primary Energy Consumption, LCET-CN, 2050 (Mtoe)	Total Investment Cost, BAU, 2050 (US$ million)	Total Investment Cost, LCET-CN, 2050 (US$ million)
Coal	1.23	4.27	4.49	480	514
Oil	3.11	12.69	4.03	6,592	635
Gas	0	7.12	11.02	2,055	3,183
Hydrogen					
Total	**4.33**	**24.08**	**19.54**	**9,127**	**4,332**

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

6.3. Power Generation Investment

The construction cost and capacity factor assumptions in Tables 3.3 and 3.4 are the basis of calculating the total investment cost for power plants in 2050 under the BAU and LCET-CN scenarios. The capacity factor for each power plant in both scenarios determines the additional capacity of the power plants to produce electricity in 2050. The total investment cost to construct these new plants in each scenario is shown in Table 3.7.

Table 3.7. Power Plant Cost Comparison, BAU and LCET-CN Scenarios, 2050

Fuel	Electricity Generation, BAU, 2019 (TWh)	Electricity Generation, BAU, 2050 (TWh)	Electricity Generation, LCET-CN, 2050 (TWh)	Additional Capacity, BAU (MW)	Additional Capacity, LCET-CN (MW)	Total Investment Cost, BAU, 2050 (US$ million)	Total Investment Cost, LCET-CN, 2050 (US$ million)
Coal	3.92	12.49	17.9	1,223	2,002	1,865	3,053
Oil	0.75	1.16	1.2	57			
Gas	0.00	43.03	61.5	6,140	8,781	4,298	6,147
Hydrogen	0.00	0.00	0.0	0	0		0
Nuclear	0.00	0.00	0.0	0	0		0
Hydro	4.15	15.66	38.5	3,286	9,793	7,305	21,770
Geothermal	0.00	0.00	0.0	0	0	0	0
Solar	0.09	5.92	11.9	3,911	7,963	1,201	2,445
Wind	0.00	0.00	3.0	0	844	0	1,042
Biomass	0.09	0.10	0.1	1	1	3	3
Total	9.01	78.00	134.0	14,677	29,384	14,672	34,459

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, MW = megawatt, TWh = terawatt-hour.
Source: Author’s calculations.

The amount of electricity generated in 2050 under the LCET-CN scenario would be greater than that under the BAU scenario, 134 TWh versus 78 TWh. The types of plants would be gas and renewable energy under the BAU scenario. Under the LCET-CN scenario, electricity generation from renewable energy power plants would increase significantly since the target of this scenario is to achieve net-zero emissions. Based on the capacity factor assumption of each plant, the total additional capacity requirement under the BAU scenario would be 14,677 MW, with gas plants comprising the majority constructed (6,140 MW). Under the LCET-CN scenario, the total additional capacity requirement would be 29,384 MW, where 9,793 MW would be from hydropower plants, 8,781 MW from liquefied natural gas (LNG) power plants, and 7,963 MW from solar power plants. Based on the construction cost assumptions, the renewable energy power plant construction costs would be higher than those of the fossil fuel plants (except solar power plants). As a result, the total investment cost for power plants in 2050 under the BAU scenario would be US$14,672 million, lower than that under the LCET-CN scenario at US$34,459 million.

6.4. Carbon Capture and Storage Costs

The introduction of CCS would be implemented under the LCET-CN scenario starting from 2040 for coal and natural gas power plants. Based on assumptions in Table 3.4, the CCS cost is around US$30/t$CO_2$ (Table 3.8).

Table 3.8. Total Investment Cost of Carbon Capture and Storage for the LCET-CN Scenario, 2050

	Fuel Consumption for LCET-CN, 2050 (Mtoe)	Emissions for LCET-CN ($MtCO_2$)	Emissions for LCET-CN (MtC)	Total Investment Cost of CCS for LCET-CN (US$ million)
Coal Power Plant with CCS	3.86	14.40	3.92	388.80
Natural Gas Plant with CCS	11.02	23.47	6.39	633.91
Total	**14.88**	**37.87**	**10.32**	**1,022.72**

CCS = carbon capture and storage, LCET-CN = low-carbon energy transition–carbon neutral, MtC = million tonnes of carbon, $MtCO_2$ = million tonnes of carbon dioxide equivalent, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

Table 3.8 indicates that the total investment cost of CCS under the LCET-CN scenario would be US$1,022.72 million. The total consists of CCS projects for coal power plants at US$388.80 million and US$633.91 million for natural gas power plants with CCS.

6.5. Overall Cost

Based on analysis, the breakdown of the total investment costs for both scenarios is in Table 3.9.

Table 3.9. Total Investment Cost
(US$ million)

No.	Cost	BAU	LCET-CN
A	Fuel Cost in 2050	9,126.70	4,332.31
	CCS in 2050	0.00	1,022.72
	Total	9,126.70	5,355.03
B	Power capital cost	14,672.31	34,459.20
	Total	**23,799.01**	**39,814.23**

BAU = business as usual, CCS = carbon capture and storage, LCET-CN = low-carbon energy transition–carbon neutral,
Source: Author's calculations.

The overall investment cost under the BAU scenario in 2050 is projected to be US$23,799.01 million, while under the LCET-CN scenario, it is US$39,814.23 million.

7. Conclusions

From the calculation of total investment costs, the LCET-CN scenario would cost more compared to the BAU scenario due to applying CCS technologies for gas and coal power plants.

However, efforts need to be in place to achieve net-zero emissions in Cambodia by 2050. It cannot only depend on the availability of new technologies and investment; the government must also create a legal framework, encourage the development of an expert workforce, and raise public awareness. Moreover, regional cooperation and understanding between economies in the region need to be strengthened through dialogues, seminars, and workshops so that net-zero emissions can be achieved by the whole region.

Key findings are as follows:

(i) Energy demand is expected to continue to grow significantly, driven by robust economic growth, industrialisation, urbanisation, and population growth. Energy efficiency and conservation are reflected in the APS and LCET-CN scenarios.

(ii) Energy intensity will further decrease until 2050 due to more efficient use of energy.

(iii) The AAGR of energy demand in the transport sector is projected to be the highest at 5.3% from 2.09 Mtoe in 2019 to 10.46 Mtoe in 2050 under the BAU scenario. Under the LCET-CN scenario, this AAGR is projected to be lower at 4.7%, reaching only 8.74 Mtoe in 2050.

(iv) Coal demand is increasing and would witness the highest AAGR of 5.8% under the BAU scenario. It is projected to be slightly lower at 5.0% under the APS5 and LCET-CN scenarios.

(v) LNG power plants will become the major power generation source. The LNG share in total power generation output is increasing continually, from 6.4% in 2032 to 55.0% in 2050 under the BAU scenario. Under the LCET-CN scenario, natural gas power plants would be the main power-generating source during 2032–2040. Natural gas with CCS and coal with CCS would then contribute the highest generation during 2040–2050, thereby reducing emissions. The projected AAGR in power generation under the LCET-CN scenario is 9.1%. Solar energy would have the highest AAGR at 16.9% during 2019–2050. Hydropower plants would be the second major source of power generation, with their share in total power generation output increasing to 46% by 2019 but dropping to 20% in 2050 due to LNG's huge contribution.

To implement energy efficiency and conservation measures, the following actions are recommended:

(i) Establish appropriate policies, including targets and road maps, to promote these measures. Targets should be for the short, medium, and long term, and focussed on the construction and industrial sectors. The long-term plan should be based on an assessment of energy-saving potential of all energy sectors, including residential and commercial sectors, which have large energy-saving potential up to 2050. Some activities can promote these measures, such as (a) support for the development of professionals in the energy conservation field, who can be responsible for energy management and operation; verification and monitoring; consultancy and engineering services provision; and the planning, supervision, and promotion of the implementation of energy conservation measures; (b) support for the development of the institutional capability of agencies and organisations in the public and private sectors to be responsible for planning, supervision, and promotion of the implementation of energy conservation measures; (c) support for the operation of energy service companies to alleviate technical and financial risks of entrepreneurs who wish to implement energy conservation measures; and (d) energy conservation public relations and knowledge provision through educational institutions and fostering of awareness amongst youth.

(ii) Establish a compulsory energy standard and labelling system for electrical appliances, as the annual growth of electricity demand in the residential and commercial sectors is projected to be substantial.

(iii) Prioritise the development of advanced hydro and thermal power technologies, including coal and natural gas. Hydropower and thermal power plants will be the major source of power generation up to 2050. Therefore, advanced technologies for both types of resources should be prioritised for development from project design onwards.

(iv) Prioritise renewable energy development policies. Renewable energy is an important resource for energy independence, energy security, and emissions abatement. The strategy and mechanisms to support renewable energy development must be built up.

(v) Keep in touch with international and regional CCUS frameworks, such as the Asia CCUS Network, and monitor the development and deployment of CCUS under appropriate carbon-pricing mechanisms in Asia as conducted by Organisation for Economic Co-operation and Development countries and the network. CCS and CCUS will be important innovations in decarbonisation technologies.

References

Electricity Authority of Cambodia (2019), *Annual Report 2019,* Phnom Penh.

Government of Cambodia, Ministry of Economic and Finance (2021), *Economic Growth Evaluation 2021,* Phnom Penh.

Government of Cambodia, Ministry of Mines and Energy (2020), *Power Development Master Plan 2020–2040,* Phnom Penh.

Government of Cambodia, National Council for Sustainable Development and Ministry of Environment (2020), *Cambodia's Updated Nationally Determined Contribution,* Phnom Penh.

National Statistics Institute (2020), *General Population Census of the Kingdom of Cambodia 2019,* Phnom Penh: Government of Cambodia, Ministry of Planning.

World Bank, World Bank Open Data, https://data.worldbank.org/ [accessed 17 December 2019].

Chapter 4
China Country Report

Hui Li and Ruining Zhang

Center for Energy and Environmental Policy Research, Beijing Institute of Technology, China

1. Introduction

In an effort to promote low-carbon development and further China's 'dual-carbon' objective, which was formally declared in 2020, the central and local administrations of China have enacted a variety of measures. As a consequence, China has made significant progress in its transition towards low-carbon energy sources. According to the National Development and Reform Commission (NDRC, 2023), the entire annual energy consumption in 2022 was 5.41 billion tonnes of standard coal, representing a 2.9% rise compared to the previous year. The consumption of crude oil declined by 3.1%, whilst natural gas consumption decreased by 1.2%. Conversely, there was a 3.6% increase in electricity use. Coal utilisation represents 56.2% of the overall energy consumption. Renewable energy sources, such as natural gas, hydropower, nuclear power, wind power, and solar power, constituted 25.9% of the overall energy consumption, marking a 0.4% increase. The average coal use per kilowatt-hour (kWh) of thermal power generation in major energy-consuming industrial businesses decreased by 0.2%. China's carbon dioxide emissions (CO_2) intensity, measured as the amount of carbon dioxide emitted per unit of gross domestic product (GDP), decreased by 0.8%.

Advancements have been made in the process of transitioning towards environmentally sustainable practices and promoting growth. According to the National Bureau of Statistics (NBS, 2023a), the energy intensity of GDP in 2022 declined by 0.1% compared to the previous year, for every CNY10,000 of GDP. The total capacity for clean energy generation, including hydropower, nuclear power, wind power, solar power, and other sources, reached 2,959.9 billion kilowatt-hours (kWh), representing an 8.5% increase compared to the previous year. Out of the 339 cities that were observed at the prefecture level and higher, 62.8% complied with the yearly air quality regulations. The mean annual concentration of particulate matter ($PM_{2.5}$) was 29 μg/m^3, representing a decrease of 3.3% compared to the preceding year.

This report provides projections for future energy demand, energy production, and carbon emissions based on low-carbon energy transition LCET scenarios, and offers policy suggestions.

2. Macro Assumptions

China's GDP in 2023 reached CNY12,6058.2 billion, an increase of 5.2% over the previous year at constant prices. Table 4.1 shows the assumptions of the average annual growth rate (AAGR) of GDP and population. Based on the estimation of the Economic Research Institute for ASEAN and East Asia (ERIA), the average AAGR of GDP is projected to be 5.7% in 2020–2030, 4.5% in 2030–2040, and 3.4% in 2040–2050.

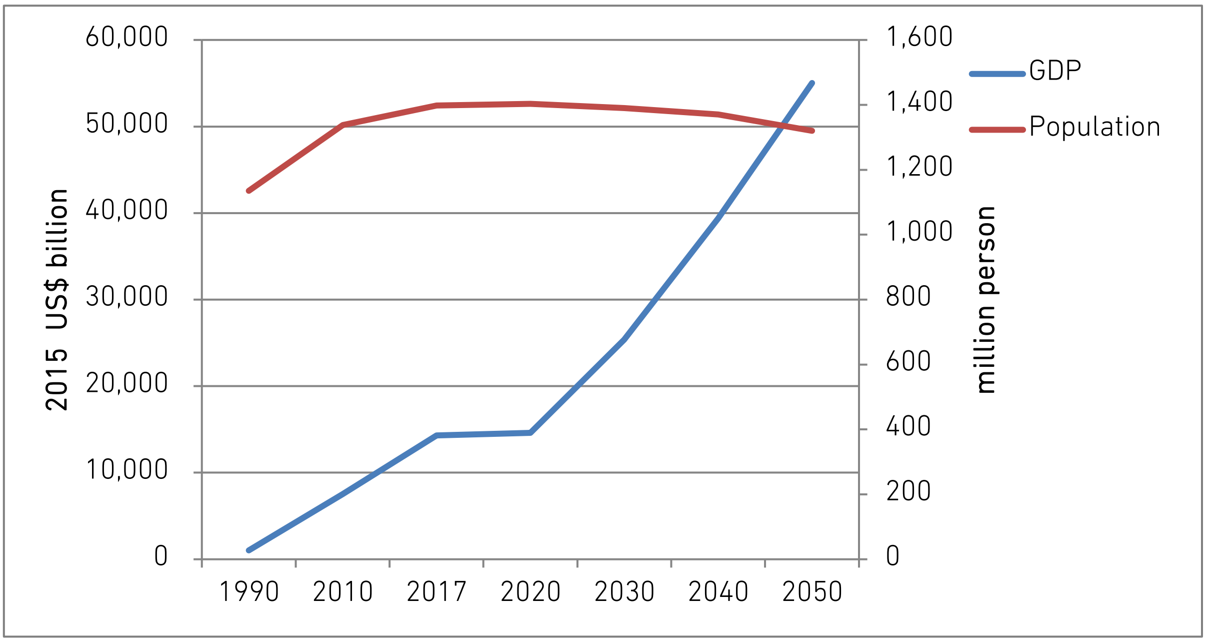
Table 4.1. Annual Growth Rates of Gross Domestic Product and Population

	2019–2020	2020–2030	2030–2040	2040–2050
GDP	2.1%	5.7%	4.5%	3.4%
Population	0.4%	–0.1%	–0.1%	–0.4%

GDP = gross domestic product.
Source: Economic Research Institute for ASEAN and East Asia.

Figure 4.1 shows China's GDP and population assumptions. The population growth rate is projected to decline by 0.1%, 0.1%, and 0.4% throughout the periods of 2020–2030, 2030–2040, and 2040–2050, respectively. The projected population for the year 2050 will be 1.320 billion. The population of China was 1,411.175 million at the end of 2022, which is a decrease of 850,000 from the previous year. This marked the first negative rise in population in over 60 years, and the natural growth rate was –0.60%. Simultaneously, the proportion of the population that is 60 and older has been steadily increasing, reaching 280.04 million, or 19.8% of the total. There were 875.56 million people in the nation who were of working age, making up 62.0% of the total population. The demographic dividend is dwindling for China, and the country will need to make significant adjustments to its growth model to accommodate its ageing population for the foreseeable future.

Figure 4.1. Assumptions of the Average Annual Growth Rate of Gross Domestic Product and Population



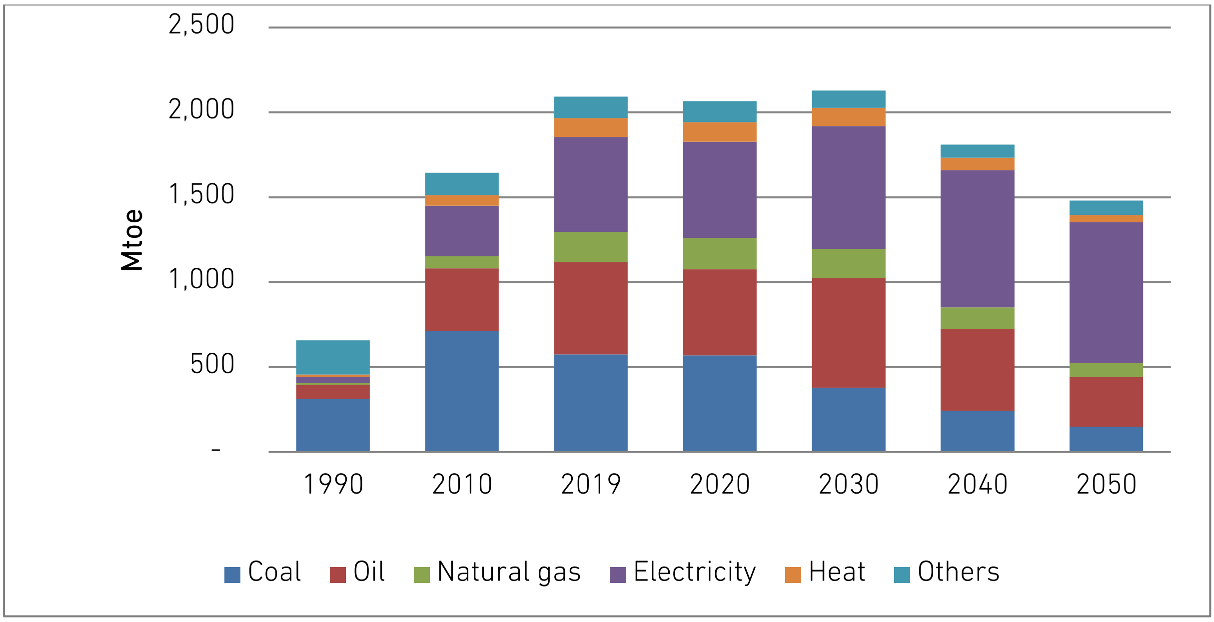
GDP = gross domestic product.
Source: Economic Research Institute for ASEAN and East Asia.

3. Outlook Results

3.1. Total Final Energy Consumption

Figure 4.2 shows total energy consumption by fuel in 1990–2050 under a low-carbon energy transition (LCET) scenario. According to ERIA, China's total final energy consumption (TFEC) has experienced a significant increase, from 658 million tonnes of oil equivalent (Mtoe) in 1990 to 2,067 Mtoe in 2020. Projections indicate that the TFEC will continue to climb, reaching 2,128 Mtoe by 2030. However, it is predicted to gradually fall thereafter, reaching 1,837 Mtoe by 2040 and 1,529 Mtoe by 2050. As for energy type, China is the biggest coal user in the world (BP, 2022). The development of low-carbon energy transition in China has led to a decrease in the share of final coal consumption. Between 1990 and 2020, the proportion of coal in final energy consumption was projected to decrease from 47% to 28%. This will drop to 18% in 2030 and 10% in 2050. The use of coal at terminals increased from 311 Mtoe to 574 Mtoe between 1990 and 2019, and then is expected to decrease to 150 Mtoe in 2050. The consumption of oil and gas is expected to decrease from 646 Mtoe and 173 Mtoe to 292 Mtoe and 82 Mtoe, respectively, from 2030 to 2050. China's electric power infrastructure has experienced rapid growth, bolstered by government laws, positioning it as an exemplar of clean energy and a hallmark of an advanced civilisation. The utilisation of electricity as a final energy source has experienced a significant increase, escalating from 39 Mtoe in 1990 to 568 Mtoe in 2020. Consequently, the level of domestic electricity consumption has been steadily increasing. According to the National Bureau of Statistics (NBS, 2023b), China's whole electricity consumption was projected to reach 8.6 trillion kWh in 2022, with total power generation expected to reach 8.7 trillion kWh. By 2050, it is expected that final electricity consumption will reach 830 Mtoe, or 54% of total final energy, representing electricity as the predominant energy source for final consumption.

Figure 4.2. Final Energy Consumption by Fuel Type, LCET Scenario (1990–2050)

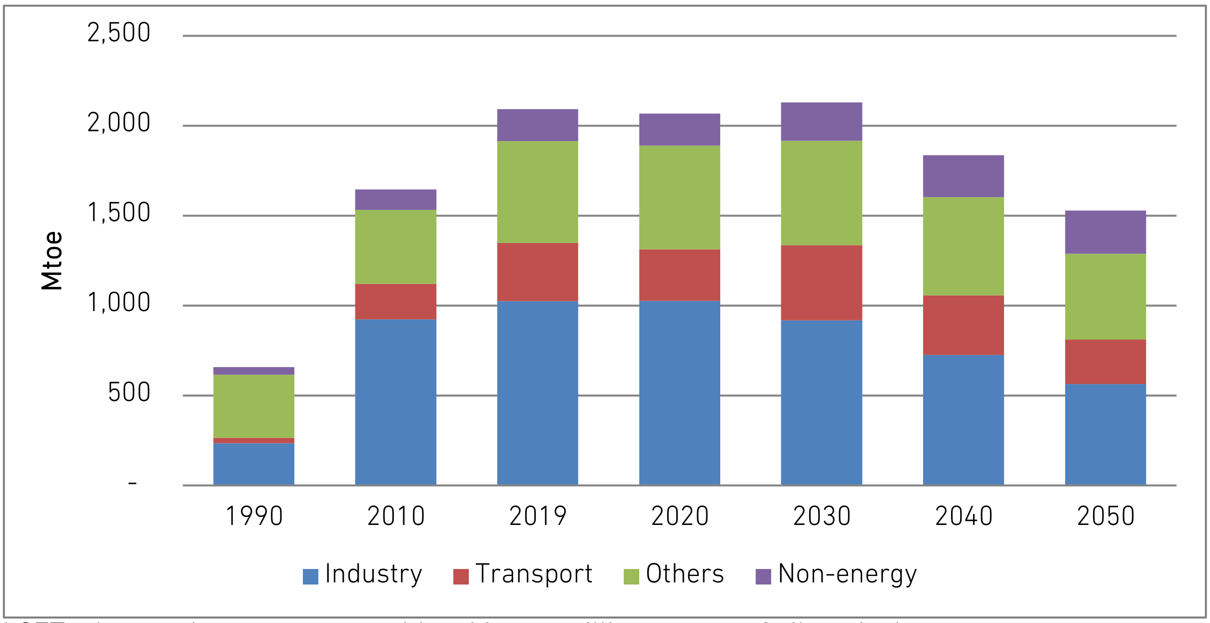


LCET = low-carbon energy transition, Mtoe = million tonnes of oil equivalent.
Source: Economic Research Institute for ASEAN and East Asia.

Figure 4.3 shows the TFEC by sector in 1990–2050 under the LCET scenario. The majority of current energy use is attributed to industry and transportation. Between 1990 and 2020, the proportion of energy consumed by the industrial sector rose from 36% to 50%. China has achieved an average yearly reduction of over 4% in energy consumption per unit of GDP during the past 40 years, resulting in a cumulative decrease of approximately 84% (NBS, 2023b). Significant advancements have been made in the realm of energy conservation and reduction of energy consumption, leading to a rapid improvement in energy efficiency. However, when considering the global context, China's energy consumption per unit of GDP remains 1.5 times higher than the average worldwide. Currently, a sizable share of China's economic structure is devoted to energy-intensive and secondary industries. As part of efforts to expedite the establishment of an energy-efficient society, the 14th Five-Year Plan (2021–2025) in China has incorporated the objective of 'achieving a 13.5% reduction in energy consumption per unit of GDP' as a key benchmark for economic and social progress, which would expedite the process of enhancing the efficiency of traditional energy-intensive sectors and contribute to the growth of low-energy businesses. Projections indicate that the future share of industrial energy consumption will decline to 43% by 2030 and further decrease to 37% by 2050.

China is currently experiencing a period of rapid industrialisation and urbanisation, resulting in an increasing demand for energy in the transport sector. China's transport sector was projected to consume 287 Mtoe in 2020, representing approximately 14% of the total energy consumption. The infrastructure in China is expanding dramatically in terms of both scope and capacity, whilst the use of private vehicles is growing as a result of the social economy's quick expansion. Due to that, energy use in the realm of transport in China has progressively escalated, with an anticipated surge to 417 Mtoe by 2030, constituting 20% of the total. Conversely, the Chinese government has released the China's Green Transport 14th Five-Year Development Plan and other official papers to advance energy preservation, effectiveness, and sustainable growth in the transport industry. According to ERIA, it is anticipated that the share of energy consumption attributed to transportation will diminish to 16% by the year 2050.

Figure 4.3. Final Energy Consumption by Sector, LCET Scenario (2000–2050)

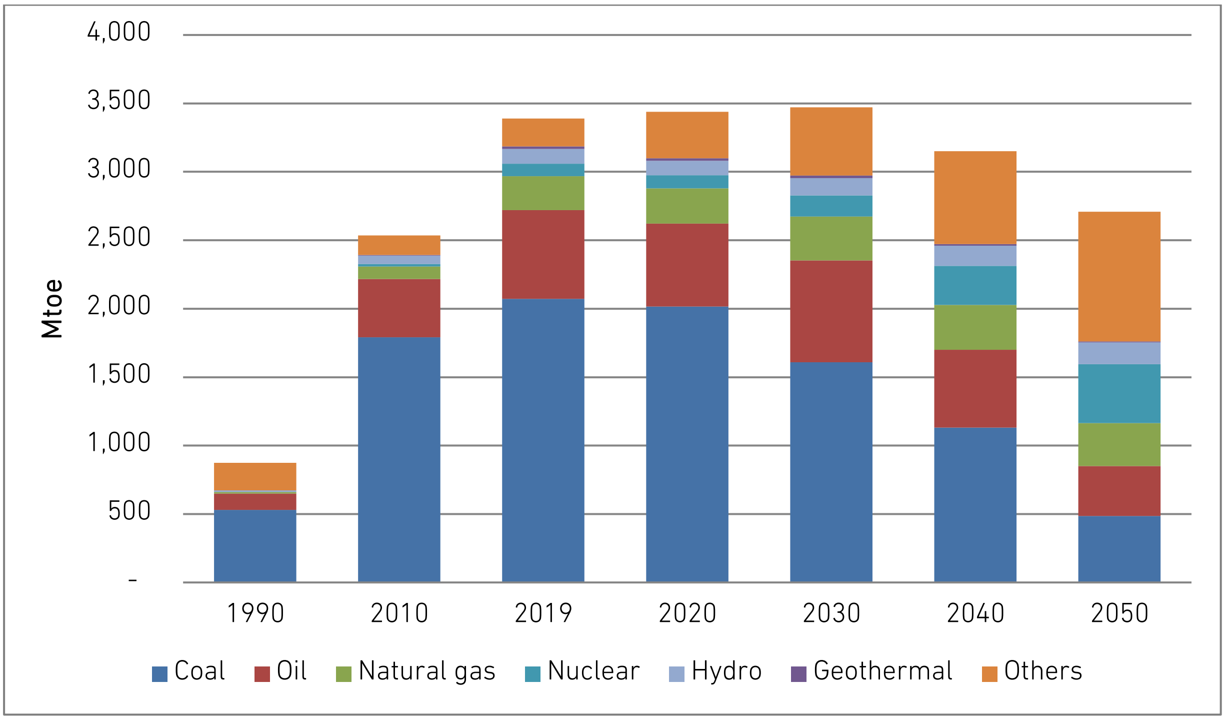


LCET = low-carbon energy transition, Mtoe = million tonnes of oil equivalent.
Source: Economic Research Institute for ASEAN and East Asia.

3.2. Total Primary Energy Supply

Figure 4.4 shows total primary energy supply (TPES) by source in 1990–2050 in the LCET scenario. China possesses abundant coal resources, limited oil reserves, and scarce natural gas. Coal continued to be the predominant source of China's primary energy supply in 2020, representing 59%. Oil is the second largest contributor to primary energy supply, making up 18%, whilst natural gas accounts for 8%. China is heavily dependent on oil and gas imports due to its comparatively limited natural gas and oil resources. According to NBS (2022), China's reliance on imported crude oil stands at 71.2% and its dependence on imported natural gas is 40.5%. Global energy security uncertainties persist due to the impact of geopolitical conflicts, climate change, exchange rate volatility, and other causes. To guarantee energy security, the Chinese government will prioritise the fundamental national coal conditions and encourage the environmentally-friendly utilisation of coal. Simultaneously, the government is actively engaged in the development of renewable energy and enhancing the diverse energy supply. Hydropower is the dominant source of clean electricity, generating 105 Mtoe in 2020 and projected to increase to 159 Mtoe by 2050. Nuclear production, which was 95 Mtoe in 2020, is predicted to more than quadruple to 431 Mtoe in 2050. China has abundant solar and wind energy resources in its northeast, north, and northwest regions. Recent years have seen a rise in the use of solar and wind power by the Chinese government; the share of photovoltaic power generation, wind power, and other energy sources has reached 10% and is predicted to rise to 14% in 2030 and 35% in 2050.

Figure 4.4. Total Primary Energy Supply by Fuel Type, LCET Scenario (1990–2050)



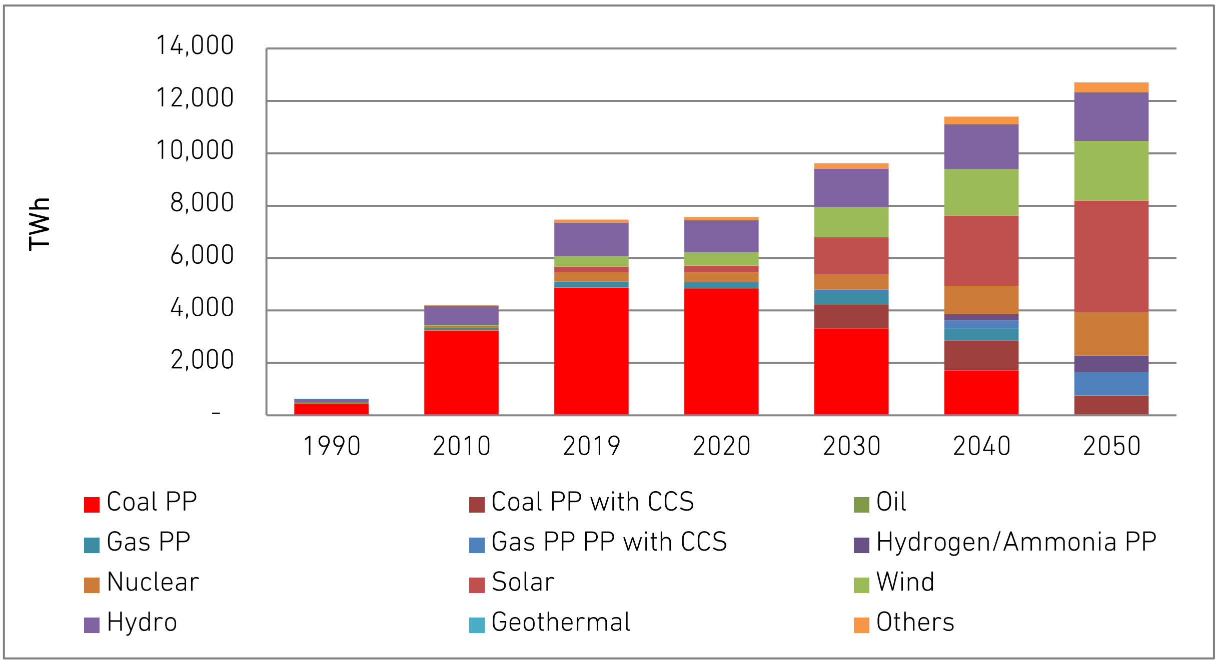
LCET = low-carbon energy transition, Mtoe = million tonnes of oil equivalent.
Source: Economic Research Institute for ASEAN and East Asia.

3.3. Electricity Generation

Figure 4.5 shows historical and future power generation in the LCET scenario. China's power generation has been steadily increasing alongside its economic development. From 1990 to 2020, power generation rose from 621 terawatt-hours (TWh) to 7567 TWh, reflecting an average yearly growth rate of approximately 8.69%. China's reliance on coal as a power source has made it the primary producer of electricity for an extended duration.

By 2020, coal-fired power plants contributed 64% of the overall electricity generation. Nevertheless, as the transition towards clean electricity gains momentum, the proportion of coal-fired power plants in the electricity generation mix is projected to decrease significantly. It is anticipated to decline to 34% by 2030, 15% by 2040, and a mere 0.3% by 2050. However, this does not imply that China will completely forsake coal. Conversely, the Chinese government is actively advocating for the adoption of carbon capture and storage (CCS) technology to facilitate the environmentally-friendly utilisation of coal. By 2030, it is projected that coal-fired power plants incorporating CCS technology will contribute around 10% to the overall electricity supply. Natural gas is considered a comparatively environmentally-friendly energy source. The utilisation of natural gas as a power source is expected to rise to 458 TWh by 2040 and then decline to 44 TWh by 2050. Electricity generation from gas-fired power plants equipped with CCS technology is projected to rise to 842 TWh by 2050, representing approximately 7% of the total. The utilisation of oil and geothermal energy for power generation in China is minimal and ignorable. By 2050, it is projected that nuclear power generation will account for 13% of the total energy produced. Hydropower has historically been the primary source of renewable energy production in China. It generated 711 TWh in 2010, 1216 TWh in 2020, and is projected to reach 1849 TWh in 2050. The progress of hydropower has been largely stable over time. By contrast, the expansion of solar and wind power generation has been swift in recent years. Solar power's share of the energy market was a mere 0.02% in 2010. By 2020, it had increased to 3.4%. Projections indicate that it will reach 14.7% by 2030 and 33.4% by 2050. In 2010, wind power made up only 1.1% of the total energy production. However, it is projected to increase significantly and reach 18% by 2050. Renewable energy generation is projected to become the primary source of electricity generating in the future.

Figure 4.5. Power Generation by Source, LCET Scenario (1990–2050)

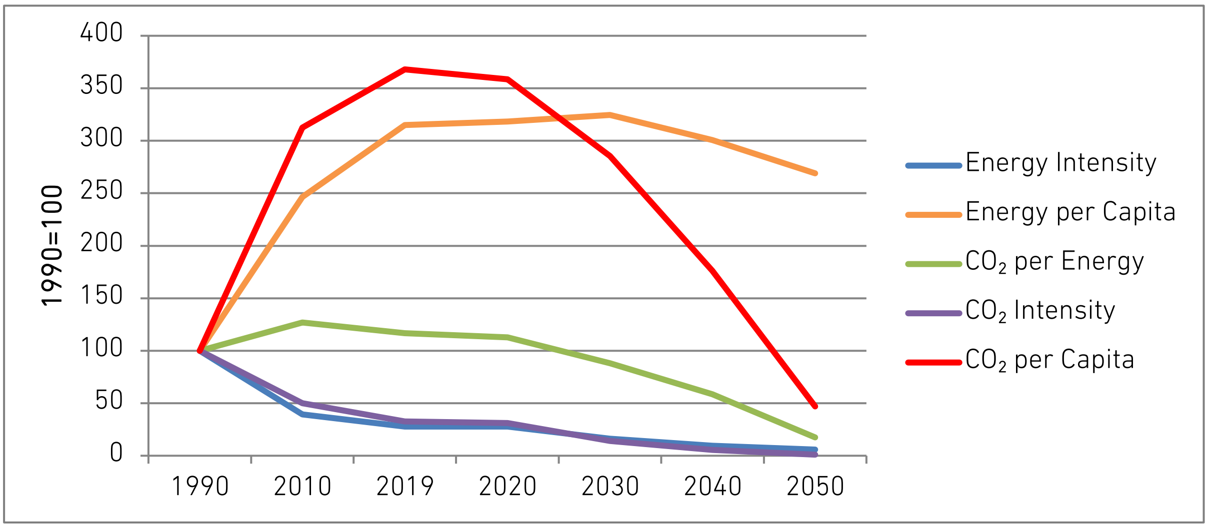


CCS = carbon capture and storage, LCET = low-carbon energy transition, PP = power plant, TWh = terawatt-hour.
Source: Economic Research Institute for ASEAN and East Asia.

3.4. Energy Indicators

Figure 4.6 shows the energy indicators in the LCET scenario. Both the energy intensity and carbon dioxide (CO_2) intensity are expected to decrease steadily from 1990 to 2050. The year 1990 serves as the baseline. By 2050, the energy intensity is projected to decline to around 5.8% of the level observed in 1990. The projected CO_2 intensity will probably drop to around 1% of the level documented in 1990. Energy per capita, CO_2 per energy, and CO_2 per capita are forecast to increase and subsequently decrease between 1990 and 2050. Energy per capita is expected to increase to 325% of the 1990 levels by 2030, and will decrease after that. In 2050, energy per capita is projected to be 269% higher than that in 1990. CO_2 per energy reached their highest level in 2010, at 127% of the level recorded in 1990. However, by 2050, they had decreased significantly to only 17.5% of the 1990 level. The per capita CO_2 emissions reached their highest point in 2019, reaching 368% of the levels recorded in 1990. It is projected that these emissions will gradually decline and are predicted to be at 47% of the 1990 levels by 2050.

Figure 4.6. Energy Indicators, LCET Scenario (1990–2050)

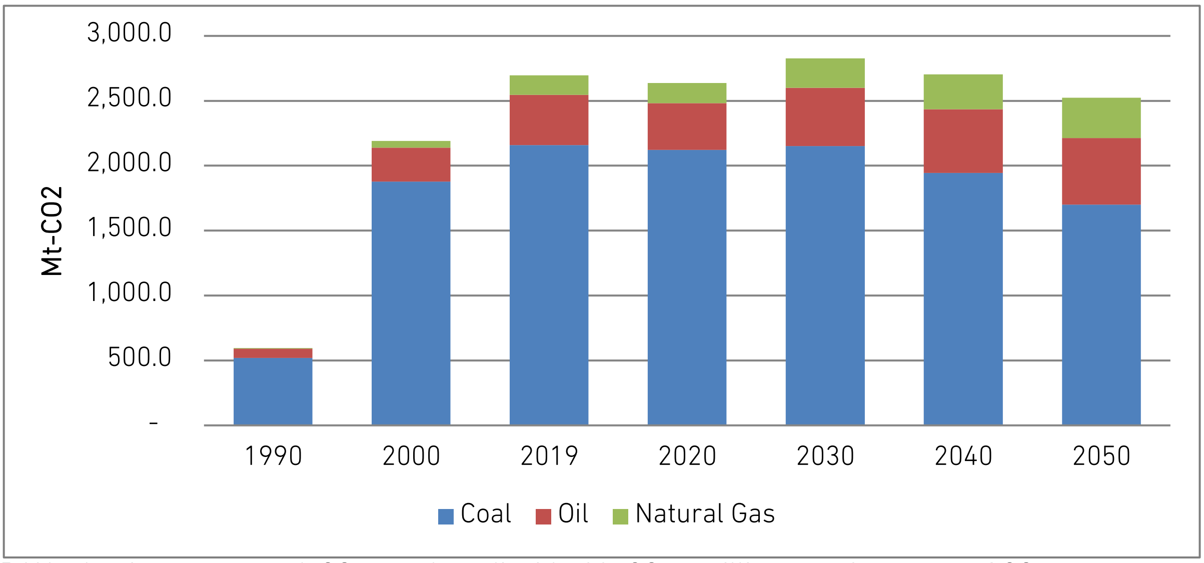


CO_2 = carbon dioxide, LCET = low-carbon energy transition.
Source: Economic Research Institute for ASEAN and East Asia.

3.5. Carbon Dioxide Emissions

Figure 4.7 shows CO_2 emissions in 1990–2050 in the BAU scenario. Under this scenario, the amount of CO_2 emitted from burning fossil fuels is projected to reach its highest point at 2,827 million metric tons of CO_2 (Mt-CO_2) in 2030. By 2030, coal is projected to account for 76% of the total CO_2 emissions, with oil contributing 16%, and natural gas contributing 8%. Projections indicate that there will be a reduction in CO_2 emissions to 2,523 Mt-CO_2 by 2050. Out of this total, coal is responsible for 67.4% of the emissions, crude oil contributes 20.4%, and natural gas accounts for 12.2%.

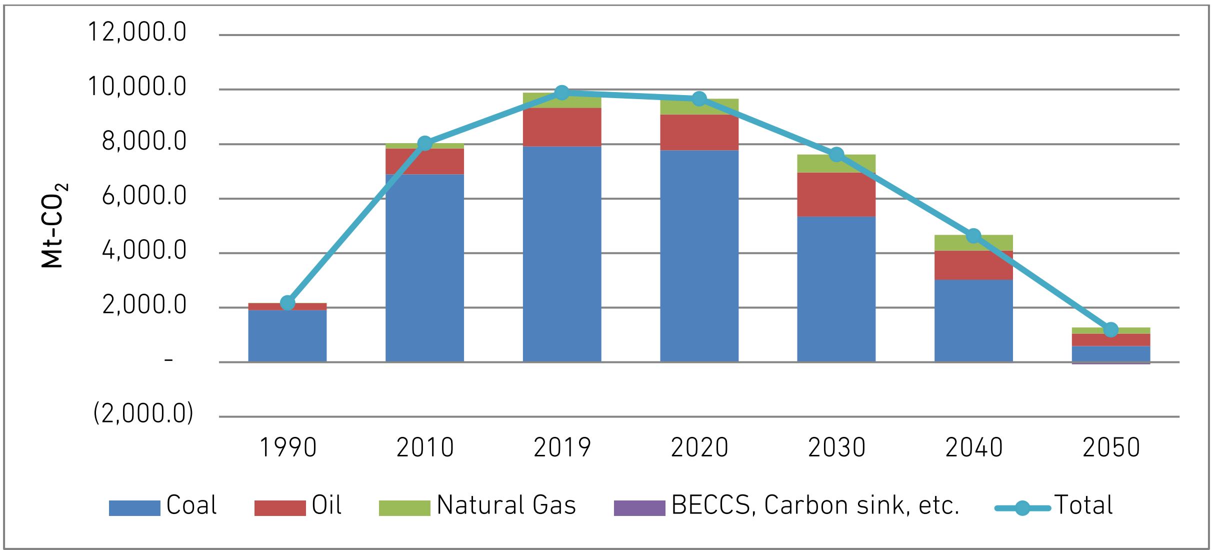
Figure 4.7. CO_2 Emissions by Fossil Fuel Type, BAU Scenario (1990–2050)



BAU = business as usual, CO_2 = carbon dioxide, Mt-CO_2 = million metric tonnes of CO_2.
Source: Economic Research Institute for ASEAN and East Asia.

Figure 4.8 shows CO_2 emissions in 1990–2050 in the LCET scenario. Compared with the BAU scenario, CO_2 is projected to reach its highest point earlier in the LCET scenario. According to ERIA, carbon dioxide would peak in 2019 at 9,882 Mt-CO_2 if it was in the LCET scenario. By 2050, the projected amount of CO_2 is 1191 Mt-CO_2, with coal contributing 590 Mt-CO_2, which represents 50% of the total CO_2 emissions. The CO_2 emissions resulting from the combustion of crude oil amount to 455 Mt-CO_2, representing 38% of the total emissions. Meanwhile, the implementation of bioenergy with carbon capture and storage (BECCS), carbon sinks, and other advanced technologies will effectively decrease carbon emissions by 83 Mt-CO_2.

Figure 4.8. CO_2 Emissions by Fossil Fuel Type, LCET Scenario (1990–2050)



BECCS = bioenergy with carbon capture and storage, CO_2 = carbon dioxide, LCET = low-carbon energy transition, Mt-CO_2 = million metric tonnes of carbon dioxide.
Source: Economic Research Institute for ASEAN and East Asia.

4. Cost Analysis

Increasing investment in clean energy technology is necessary to reach carbon neutrality, but doing so will raise investment costs. This section estimates and calculates final energy consumption costs, construction cost of power plants, and carbon capture and storage cost in both the BAU and LCET scenarios.

4.1. Fuel Cost

Fuel cost assumptions are shown in Table 4.2. Based on the assumption of fuel cost and corresponding final energy consumption, the cost of coal, oil, gas, and hydrogen in 2019 and 2050 in both the BAU and LCET scenarios are estimated and compared.

Table 4.2. Fuel Cost Assumptions

	2019/2020	2050 (2019 Constant Price)	Unit
Coal	80.03	98.00	US$/ton
Oil	41	100	US$/bbl
Gas	7.77	7.50	US$/MMBtu
Hydrogen	0.8	0.3	US$/$Nm^3$

bbl = barrel, MMBtu = metric million British thermal unit, Nm^3 = normal cubic metre.
Source: The Institute of Energy Economics, Japan.

Table 4.3 exhibits the final energy consumption of each fuel and the corresponding cost in 2019 and 2050. From the results, in both the BAU and LCET scenarios, the amount of coal as China's final energy consumption in 2050 will be significantly reduced compared with 2019, and the corresponding fuel cost will also decrease. The cost of coal will be reduced by US$47.6 billion in the BAU scenario and US$67.09 billion in the LCET scenario. The fuel cost for gas and oil as end-energy sources will rise in 2050 compared to 2019 by US$17.29 billion and US$134.3 billion in the BAU scenario and drop by US$27.9 billion and US$172.2 billion in the LCET scenario. Hydrogen consumption in the BAU scenario is zero, compared to 48.16 Mtoe in 2050 in the LCET scenario, at an additional cost of US$18.7 billion. Overall, the total cost of coal, oil, gas, and hydrogen as end-energy fuels in 2050 will decrease by US$248.5 billion compared to 2019 in the LCET scenario and increase by US$ 104 billion in the BAU scenario.

Table 4.3. Fuel Cost in BAU and LCET Scenarios

	Final Energy Consumption (Mtoe), BAU in 2019	Final Energy Consumption (Mtoe), BAU in 2050	Final Energy Consumption (Mtoe), LCET in 2050	Fuel Cost 2050–2019, BAU (US$ million)	Fuel Cost 2050–2019, LCET (US$ million)
Coal	574.20	272.88	149.66	–47,616	–67,087
Oil	542.50	737.75	292.11	134,299	–172,217
Gas	178.96	238.83	82.18	17,285	–27,947
Hydrogen	0	0	48.16	0	18,705
Total	**1295.66**	**1249.46**	**572.11**	**103,968**	**–248,546**

BAU = business as usual, LCET = low-carbon energy transition, Mtoe = million tonnes of oil equivalent.
Note: 2050-2019 means the increased fuel costs in 2050 compared to 2019. If the number of 2050–2019 is less than zero, it means that the cost in 2050 is lower than that in 2019.
Source: Authors' calculations.

4.2. Power Generation Investment

The assumption of construction costs and capacity factors of power plants are shown in Table 4.4. Based on the assumption, the additional capacity and corresponding investment cost of power plants with different fuel types in the scenario of both the BAU and LCET scenarios are calculated.

Table 4.4. Power Plant Assumptions

	Construction Costs of Power Plants		Capacity Factor of Power Plants	
	US$/kW		%	
	2019	by 2050	2019	by 2050
Coal	1,500	1,525	75	80
Oil	--	--	75	80
Gas	700	700	75	80
Hydrogen	--	700	--	80
Nuclear	4,500	3,575	100	80
Hydro	2,000	2,223	50	40
Geothermal	4,000	4,256	50	50
Solar	1,600	307	17	17
Wind	1,600	1,235	40	40
Biomass	2,000	3,019	50	70

kW = kilowatt.
Source: The Institute of Energy Economics, Japan.

Non-fossil fuels will predominate the energy in power plant construction throughout the next 30 years. These coal-fired power plants, equipped with CCS, will increase by 84,130 megawatt (MW) under the BAU scenario, necessitating an extra expenditure of roughly US$128.3 billion. There will be no further expansion of coal-fired power stations in the LCET scenario. Oil-fired power stations are uncommon in China due to the scarcity of oil. Natural gas has the advantages of both stability and cleanliness. Gas-fired power plants will be expanded, with an additional investment of US$81.9 billion under the BAU scenario and an additional US$67.2 billion under the LCET scenario.

The hydrogen generation capacity will see a 90.7 billion MW expansion in the LCET scenario, not an increase in the BAU scenario. Nuclear power plants account for 5% of additional plant capacity over 30 years. However, their investment costs are much higher than other power plants, accounting for 18% of the total investment cost in the BAU scenario and 24% in the LCET scenario. Future investments will primarily focus on solar power generation. The increased solar generation capacity in the BAU scenario amounts to 789,686 MW; in the LCET scenario, it accounts for 71% with 2,700,892 MW. Though not as much as solar power, wind nevertheless will contribute significantly. In the BAU scenario, wind capacity additions made up 16%, whilst in the LCET scenario, they made up 14%.

Table 4.5. Total Investment Cost of Power Plants

	Electricity Generation (TWh)			Additional Capacity (MW)		Total Investment Cost (US$ million)	
	2019	2050					
	BAU	BAU	LCET	BAU	LCET	BAU	LCET
Coal	4,876	5,465	763	84,130	--	128,299	--
Oil	11	4	3	--	--	--	--
Gas	213	1,033	886	117,062	96,067	81,944	67,247
Hydrogen	0	0	636	0	90,690	0	63,483
Nuclear	348	797	1,652	64,007	186,085	228,826	665,255
Hydro	1,273	1,597	1,849	92,527	164,458	205,687	365,590
Geothermal	0	1	1	89	163	378	694
Solar	224	1,400	4,246	789,686	2,700,892	242,434	829,174
Wind	406	1,200	2,286	226,589	536,634	279,837	662,743
Biomass	122	364	389	39,465	43,589	119,145	131,595
Total	**7,472**	**11,861**	**12,711**	**1,413,555**	**3,818,578**	**1,286,549**	**2,785,780**

BAU = business as usual, LCET = low-carbon energy transition, MW = megawatt, TWh = terawatt-hour.
Source: Authors' calculations.

4.3. Carbon Capture and Storage Costs

Carbon capture and storage (CCS) is estimated to cost about US$70/$CO_2$ ton. The overall cost of the CCS investment for coal-fired power plants and natural gas-fired plants in the LCET scenario is assessed based on the assumption that only these plants will be outfitted with CCS technology under LCET scenarios. Ninety-five percent of all gas-fired and coal-fired power plants are predicted to be composed of plants with CCS. Based on that, the total coal consumption of CCS coal-fired power plants is approximately 196.55 Mtoe. Of that, 733.59 Mt CO_2 is produced and 660.23 Mt CO_2 is anticipated to be absorbed by CCS. As a result, the cost of CCS for coal-fired power plants is anticipated to reach US$46.2 billion in 2050. Similarly, it is estimated that in 2050, the cost of CCS for natural gas plants will be US$25.7 billion (Table 4.6).

Table 4.6. Total Investment Cost of CCS, LCET Scenario

	Consumption of Coal or Gas in 2050 (Mtoe)	CO_2 for CCS ($Mt\text{-}CO_2$)	Total Investment Cost of CCS (US$ million)
Coal-fired Power Plant with CCS	196.55	660.23	46,216
Natural Gas-fired Power Plant with CCS	191.55	367.16	25,701
Total	**388.10**	**1027.39**	**71,917**

CCS = carbon capture and storage, LCET = low-carbon energy transition, Mtoe = million tonnes of oil equivalent, $Mt\text{-}CO_2$ = million metric tonnes of CO_2.
Source: Authors' calculations.

4.4. Overall Costs

Based on the results above, the overall costs including additional fuel cost, investment cost of power plants, and CCS cost in 2050 are calculated. As shown in Table 4.7, although the construction of plants using clean energy and CCS are costly, the LCET scenario reduces the use of fossil fuels by a significant amount, resulting in lower overall energy costs in 2050 than in 2019. The overall cost in 2050 is estimated to be US$145.5 billion greater than it was in 2019 under the BAU scenario and US$86.8 billion less than it was in 2019 under the LCET scenario.

Table 4.7. Overall Increased Costs in 2050 Compared to 2019

	BAU	LCET
Total fuel cost investment (US$ million)	103,968	–248,546
Annual investment cost of power plants (US$ million)	41,502	89,864
CCS Cost in 2050 (US$ million)	0	71,917
Total (US$ million)	**145,470**	**–86,765**

BAU = business as usual, CCS = carbon capture and storage, LCET = low-carbon energy transition.
Source: Authors' calculations.

5. Implications and Policy Implications

Global climate change poses a threat to humankind's capacity for long-term prosperity. China has long prioritised combating climate change, has been a leader in green development, and has advocated for the integration of human and environmental well-being. The urgency of the energy transition arises from the increasing unpredictability brought about by climate change. This report primarily predicts the total final energy consumption, total primary energy supply, electricity generation, energy indicators, and carbon emissions on the scenario of low-carbon energy transition. The main findings follow.

First, China's low-carbon revolution has resulted in a decline in the country's terminal coal use share. Coal in TFEC will drop to 18% in 2030 and 10% in 2050. By contrast, electricity consumption is predicted to reach 54% of TFEC, by 2050, making it the main energy source for final consumption. Most energy is used for industry and transport. As China's industrial energy utilisation efficiency improves, future industrial energy consumption is expected to drop to 43% by 2030 and 37% by 2050. As China's transport infrastructure improves and private automobiles become more popular, energy use in the transport sector is predicted to rise to 20% by 2030 and reduce to 16% by 2050.

Second, China's major energy supply continues to rely predominantly on coal. To ensure energy security, the Chinese government will prioritise national circumstances and promote the eco-friendly use of coal. Simultaneously, the government is proactively advancing the development of renewable energy. The share of photovoltaics, wind power, and other energy sources is expected to rise to 35% by 2050 from 14% in 2030.

Third, China's electricity generation climbed 8.7% yearly from 1990 to 2020. The switch to sustainable electricity will see coal's share of electricity fall steadily, to 34% by 2030 and 0.3% by 2050. To reduce CO_2 emissions, China is promoting CCS technology in coal-fired and natural gas-fired power plants. Furthermore, the production of renewable energy is expected to rise quickly and take over as the primary source of electricity. In 2010, the electricity generated by solar and wind sources accounted for only 0.02% and 1.1%, respectively. However, it is projected that by 2050, these percentages will significantly increase to 33.4% and 18.0%, respectively.

Fourth, despite the high cost of building renewable energy power plants and CCS facilities, the LCET scenario lowers the overall costs in 2050 compared to 2019 by reducing the consumption of fossil fuels by a considerable amount on an annual average. The total cost in 2050 is $145.55 billion more than it was in 2019 under the BAU scenario and US$86.8 billion less than it was in 2019 under the LCET scenario.

Given the current status of energy outlook, three policy implications are put forward.

First, enterprises are the primary entities responsible for implementing energy conservation and carbon reduction measures. It is suggested to promote the prominent position of leading companies, implement environmentally-friendly supply chain management, and provide a novel framework for energy efficiency and carbon reduction in small and medium-sized businesses led by more giant corporations. Enterprises in the supply chain that proactively engage in low-carbon technology research and development can receive enhanced policy support from the government, including financial assistance, green procurement, green credit, and tax relief.

Second, it is important to include several socioeconomic aspects when evaluating the benefits and costs of energy transition. Whilst energy transition may have long-term positive impacts on society, it is essential to note that not all groups will see equal gains from it. Conversely, a sizeable portion of the coal industry's workforce is unemployed, and it is challenging for the unemployed to find jobs in the emerging energy sector. Simultaneously, energy transition will cause talent losses in areas rich in coal resources, stalling economic growth. The interests of different groups and areas should be adequately recognised, and policy support should be given to those impaired by the transition to guarantee fairness and justice.

Third, it is also critical to reduce demand-side energy use and carbon emissions. Ecological civilisation education can be incorporated into the national education system to guide young people to establish green, low-carbon environmental protection concepts. It is recommended that the government encourage residents to prioritise the acquisition and utilisation of energy-efficient and water-efficient equipment, whilst also minimising the use of disposable products like plastic shopping bags. The government actively advocates for the implementation of a 'carbon inclusive' system, employing the 'internet + big data + carbon finance' strategy to establish a comprehensive framework for tracking, quantifying, and incentivising citizens' efforts to reduce carbon emissions. This initiative aims to guide the entire society towards adopting a sustainable and environmentally-friendly lifestyle.

References

BP (2022), *Energy Outlook 2022.* London: BP.

National Bureau of Statistics (NBS) (2022), *China Statistical Yearbook 2022*. Beijing: NBS.

National Bureau of Statistics (NBS) (2023a), *Statistical Bulletin of the People's Republic of China on National Economic and Social Development for 2022*. https://www.stats.gov.cn/sj/zxfb/202302/t20230228_1919011.html?eqid=f4fe3a4d0035c38f0000000664578f6a

National Bureau of Statistics (NBS) (2023b), *China Statistical Yearbook 2023*. Beijing: NBS.

National Development and Reform Commission (NDRC) (2023), *Data on China's Energy Production and Consumption in 2022.* https://www.ndrc.gov.cn/fggz/hjyzy/jnhnx/202303/t20230302_1350587.html

Wang, Q. et al. (2023), 'Examining Energy Inequality Under the Rapid Residential Energy Transition in China Through Household Surveys', *Nature Energy*, 8(3), Article 3.

Chapter 5
India Country Report[1]

Atul Kumar

Energy Studies Programme, School of International Studies, Jawaharlal Nehru University, Delhi, India

Adarsh Kumar Singh

Energy Studies Programme, School of International Studies, Jawaharlal Nehru University, Delhi, India

Seiya Endo

Energy Data and Modelling Center, The Institute of Energy Economics, Japan

1. Background

India, now the most populous country globally, surpassing China in 2023, is the seventh-largest nation by area, covering over 3.2 million square kilometres. With a geographic expanse spanning 30° in longitudinal and latitudinal extent, India is a mosaic of diversity. This diversity is evident in its climate, topography, and cultural mosaic. From the majestic Himalayas in the north to the vast coastal plains, India's landscapes include mountains, plateaus, seas, deserts, and islands. These varied landscapes give rise to diverse climatic conditions, influencing regional patterns in diet, clothing, and culture. The Himalayas act as a climatic barrier, shielding the northern regions from extreme winters, whilst the coastal areas experience moderated temperatures due to the sea's influence. However, this diversity also brings challenges, as evident in the stark developmental contrasts between the western and eastern regions and the varying energy demands throughout the year.

Economically, India holds a significant position globally, boasting a gross domestic product (GDP) purchasing power parity of US$10.6 trillion (constant 2017) in 2022 (World Bank, 2023). Despite rapid economic growth, the nation faces challenges such as high inflation, unemployment, and external pressures like the conflict in Ukraine. Yet, India's resilience in economic expansion offers optimism for future growth. Concurrently, the country is tackling socioeconomic issues, including poverty and uneven access to modern energy services.

Since 2000, India's energy consumption has more than doubled, propelled by its burgeoning population and swift economic growth. Remarkably, over 900 million citizens

[1] Based on the Institute of Energy Economics, Japan (IEEJ) model and assumptions.

gained access to electricity in 2 decades, yet per capita energy consumption, at 0.7 toe in 2021, is half the Asian average (Enerdata, 2022). This discrepancy points to a broader issue of development, as reflected in India's Human Development Index (HDI), which stands at 0.633, ranking 132 globally in 2021 (UNDP, 2022). The increasing demand for commercial energy, volatile global fuel prices, and pressure to mitigate greenhouse gas emissions pose significant challenges. Balancing economic growth, enhancing energy infrastructure, and striving for environmental sustainability are critical issues confronting India's policymakers, emphasising the need for sustainable development and improved living standards.

2. Basic Concept of Low-carbon Energy Transition–Carbon Neutral Scenario for India

India is steadfast in its commitment to the international climate agreements, actively pursuing strategies to curtail carbon emissions, augment energy efficiency, and revolutionise energy use patterns. Central to this commitment is the ambitious Panchamrit plan, a quintet of objectives within India's Climate Action Plan. By 2030, the plan envisions achieving 500 gigawatts (GW) of power capacity from non-fossil sources, ensuring 50% of power generation capacity from renewables, reducing the greenhouse gas (GHG) emissions intensity of the economy by 45% by 2030 as compared to 2005 level, slashing carbon emissions by 1 billion tonnes and ultimately attaining net zero by 2070.

A notable endeavour was the introduction of the Lifestyle for the Environment (LiFE) at the United Nations Climate Change Conference in Glasgow (COP26) in November 2021. This initiative aims to foster a global movement towards conscious utilisation of resources, countering the prevailing trend of mindless consumption. It underscores the individual and collective responsibility to adopt lifestyles that minimally impact the Earth. Proponents of this sustainable lifestyle are recognised as 'Pro Planet People' under the LiFE framework.

The energy sector in India was responsible for approximately 75% of total GHG emissions in 2016. India's energy challenges have now got expanded with the need for sustainability and impetus to clean energy deployment becoming important goals to achieve. These include the imperatives of sustainability and a shift towards clean energy. Transitioning to a low-carbon energy system is pivotal for meeting India's net-zero emissions target. The low-carbon energy transition–carbon neutral (LCET–CN) scenario envisages India achieving net-zero emissions by 2070. .

As per the storyline of the LCET–CN scenario for this study, it is envisaged that India will aim for significant energy savings through renewable energy generation and energy efficiency enhancements across various sectors. In the industrial domain, this involves improving efficiency in both small plants and energy-intensive industries. The residential and commercial sectors can achieve substantial savings through efficient end-use technologies and energy management systems. In transportation, enhancing vehicle fuel economy and effective traffic management are crucial for increased efficiency. Additionally, carbon sequestration initiatives, such as forestry, play a vital role in significantly lowering carbon emissions.

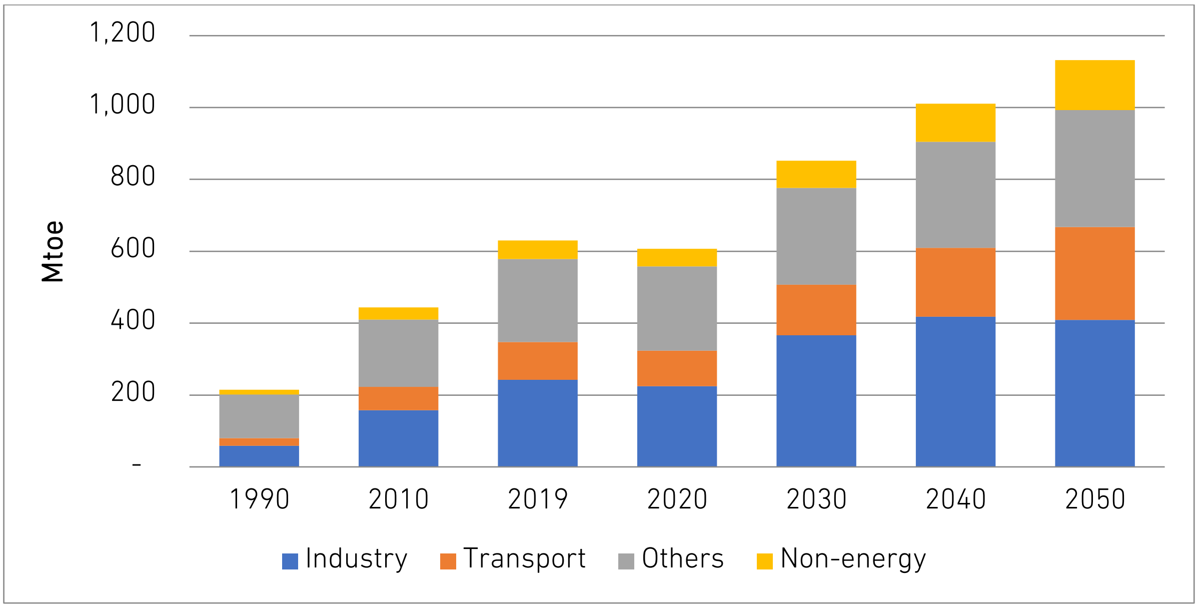
3. Outlook Results – LCET–CN Scenario

3.1. Final Energy Consumption

In the context of the LCET–CN scenario, which assumes robust economic growth and a growing population similar to the business as usual (BAU) scenario, India's total final energy consumption (TFEC) is projected to increase significantly. From around 630 million tonnes of oil equivalent (Mtoe) in 2019, the TFEC is expected to rise to 1132 Mtoe by 2050, growing at an average rate of 1.9% per year (Figure 5.1). This projected increase, whilst substantial, is anticipated to be lower than in the BAU scenario, reflecting the impact of vigorous energy-saving measures, improvements in end-use technology, and the adoption of more efficient energy management systems.

In terms of sector-specific results, the non-energy end-use sector is expected to exhibit the most marked growth, increasing at an average rate of 3.3% annually between 2019 and 2050. The transport and industry sectors also show significant growth, with projected average annual growth rates of 2.9% and 1.7%, respectively. The combined residential and commercial sector ('others') is expected to see modest growth, increasing at an estimated 1.1% per year. However, in terms of share, the energy consumption in the 'others' category is projected to decline from 37% (231 Mtoe) in 2019 to 29% (326 Mtoe) in 2050. By 2050, the industry is continued to be expected to continue holding the highest share of energy demand, although its share is predicted to decrease from 39% in 2019 to 36%. Conversely, driven by the high demand for mobility from the burgeoning population, the transport sector's share is anticipated to increase both in value and proportion, rising from around 17% (105 Mtoe) to 23% (258 Mtoe). Similarly, the non-energy sector's share is projected to grow from about 8% (51 Mtoe) to 12% (139 Mtoe) during the same period. These shifts reflect the evolving landscape of India's energy consumption under the LCET–CN scenario, underscoring the necessity of integrating sustainable and efficient energy practices to meet the country's future energy needs.

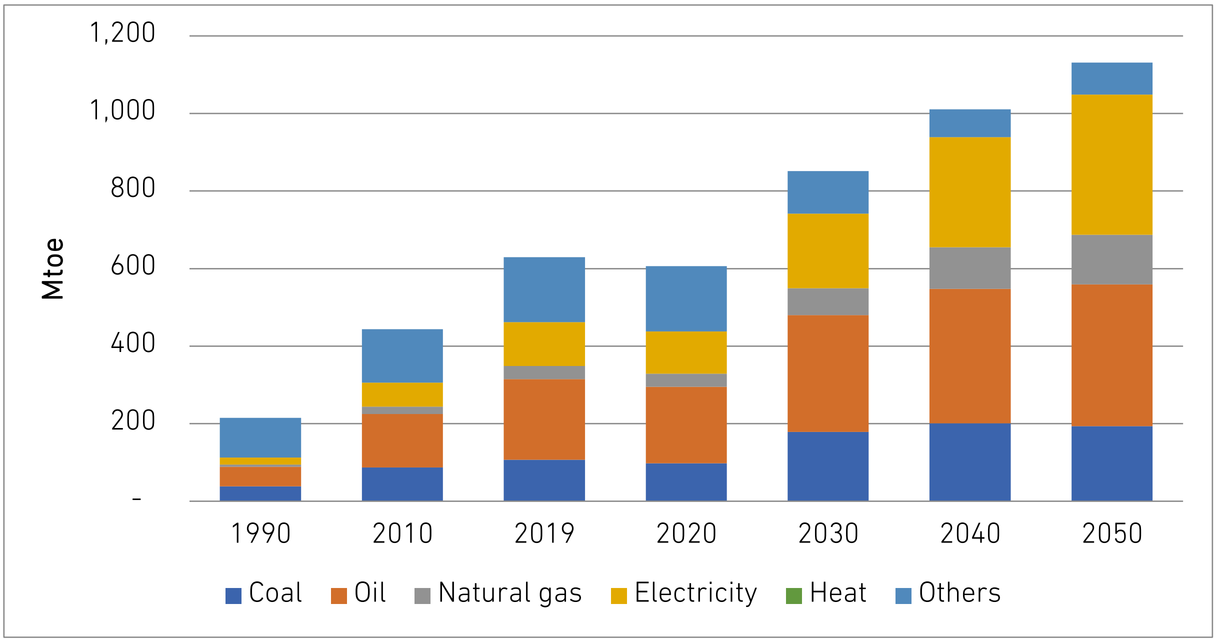
Figure 5.1. Total Final Energy Consumption by Sector, LCET–CN Scenario



Mtoe = million tonnes of oil equivalent.
Note: 'Others' includes residential and commercial sectors.
Source: IEEJ model results.

In the LCET–CN scenario, the analysis of India's final energy demand on a per-fuel basis reveals significant shifts in fuel contributions from 2019 to 2050 (Figure 5.2). Natural gas is projected to experience the most significant increase in its contribution to India's final energy demand, with an annual growth rate of 4.3%. Electricity follows closely, with its contribution expected to grow at an annual rate of 3.8%. This reflects the increasing reliance on electrical power in various sectors of the economy and the ongoing shift towards cleaner energy sources. In contrast, the role of coal in the total primary energy supply is anticipated to decrease by 2050. Whilst still a significant part of the energy mix, coal's contribution in 2050 is projected to be only 17%, equivalent to 193 Mtoe, growing at an annual average rate of 1.9% from 2019 to 2050. This gradual decline indicates a shift away from coal as India progresses towards more sustainable energy sources. The contribution of oil to the energy mix is expected to grow at a relatively modest rate of 1.8% per annum. This slower growth rate reflects the broader global and national trends of reducing dependence on oil for energy, in line with environmental and sustainability goals. Lastly, the end-use sector labelled 'others,' is projected to decrease significantly from 168 Mtoe (26%) in 2019 to 83 Mtoe (7.3%) in 2050. This decline, occurring at an average rate of 2.3% per annum, suggests a substantial reduction in the reliance on traditional biomass sources used for cooking very inefficiently, aligning with the country's transition towards cleaner, more sustainable energy options.

Figure 5.2. Total Final Energy Consumption by Fuel Type, LCET–CN Scenario



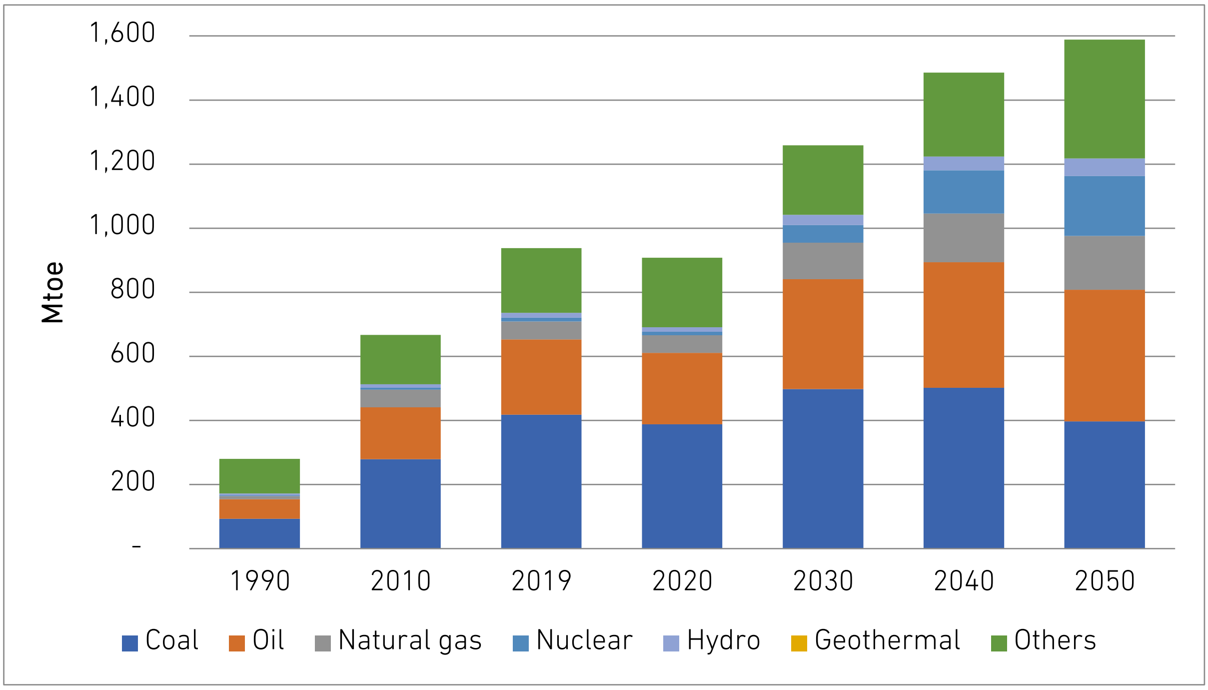
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: IEEJ model results.

Overall, these projections highlight the evolving landscape of India's energy consumption under the LCET–CN scenario, indicating a clear shift towards cleaner energy sources like natural gas and electricity, whilst simultaneously reducing dependence on coal, oil, and traditional biomass.

3.2. Primary Energy Supply

Figure 5.3 illustrates the projected changes in India's primary energy supply under the LCET-CN scenario, spanning from 2019 to 2050. In this scenario, the primary energy supply is projected to increase at a slower pace compared to the BAU scenario. Specifically, it is expected to grow at an average annual rate of 1.7%, reaching 1589 Mtoe by 2050 from 938 Mtoe in 2019. This represents a 30% (578 Mtoe) energy saving relative to the BAU scenario in 2050. The primary drivers behind this reduced consumption are the robust adoption and utilisation of more efficient low-carbon technologies and the implementation of strong energy-saving targets.

Figure 5.3. Total Primary Energy Supply, LCET–CN Scenario



LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: IEEJ model results.

In the LCET–CN scenario, solar and wind energy are projected to see a significant increase, rising from a meagre share of 1.2% of the total primary energy supply (TPES) in 2019 to 14.7% by 2050. This growth translates to an impressive annual rate of 10.2%. Nuclear and hydro energy sources are also expected to grow at a higher rate than under the BAU scenario, with nuclear and hydro increasing by 9.2% and 4.3%, respectively under the LCET–CN scenario.

Oil supply is projected to rise both in value and share. It is expected to grow at an average annual rate of 1.8%, increasing from 235 Mtoe (25.1% share) in 2019 to 412 Mtoe (25.9% share) by 2050. This makes it the second-largest contributor to the primary energy supply mix. Natural gas, growing at a projected 3.6% per year, will see its share increase from 5.9% in 2019 to 10.5% by 2050.

Coal consumption, on the other hand, is expected to decrease both in value and share, declining at a rate of 0.2% per year. From about 418 Mtoe in 2019, coal consumption will drop to 397 Mtoe by 2050. Despite this decline, coal will still account for the second largest share of TPES at 25% in 2050, down from 44.6% in 2019.

Finally, the 'others' category, which includes traditional biomass, is expected to see a significant decrease. Its share of the total primary energy supply is projected to plummet from 20.1% in 2019 to just 0.5% by 2050, representing an annual average decay rate of 9.5%.

These projections under the LCET–CN scenario reflect a decisive shift in India's energy landscape, with a clear movement towards renewable energy, whilst reducing reliance on coal.

3.3. Power Generation

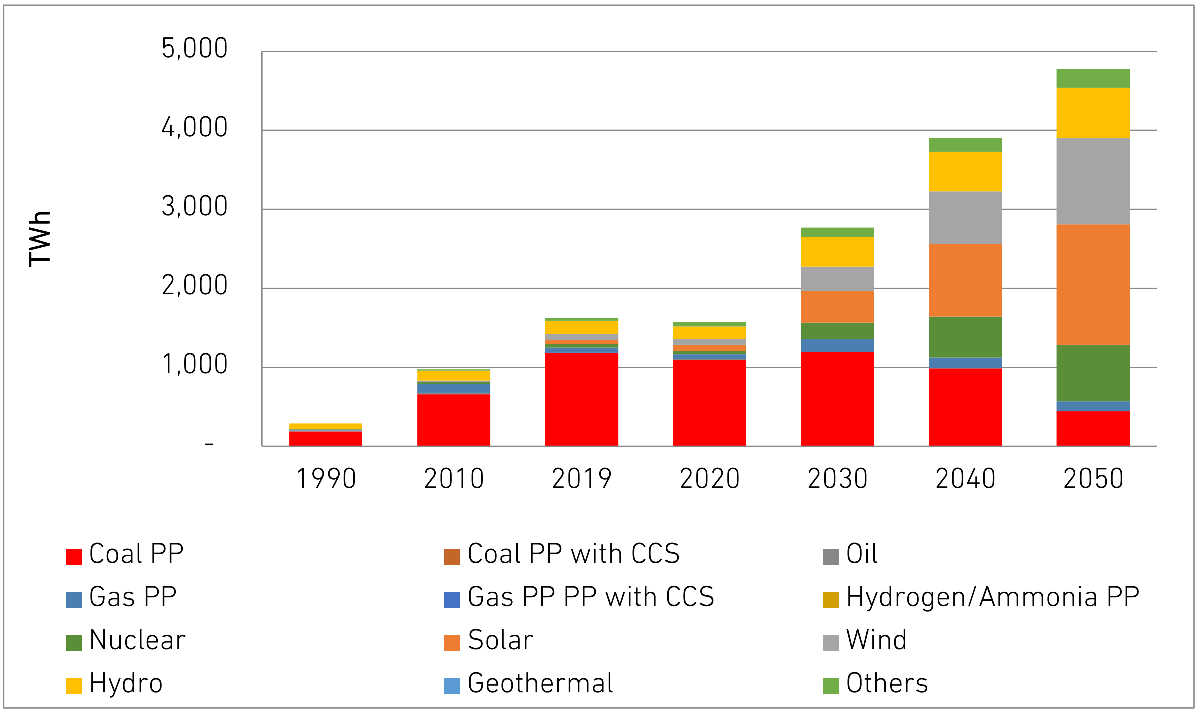
Under the LCET–CN scenario, India's electricity generation is set to undergo significant expansion. From a baseline of 1,624 watt-hours (TWh) in 2019, it is projected to surge to 4,776 TWh by 2050. This increase, at an average growth rate of 3.5% per year, will more than triple the country's power generation, indicating an effort to keep pace with escalating electricity demand.

Central to this expansion is the transition towards low-carbon fuels, leading to a substantial increase in the share of renewable and alternative energy sources. As a result, the proportion of non-fossil-based electricity (comprising renewable and nuclear sources) is anticipated to rise dramatically, from 22.9% in 2019 to 88.1% by 2050.

In this evolving energy mix, solar energy is expected to emerge as the dominant source of power generation, accounting for 31.9% of the total output in 2050. Wind power follows as the second major contributor, with a projected share of 22.8%. The growth rates for these renewable sources are notably high, with solar and wind power experiencing annual increases of 11.6% and 9.3%, respectively between 2019 to 2050. Nuclear power is also on a trajectory of significant growth, with a projected annual increase of 9.2%. Other energy sources, including biomass, imported electricity, natural gas, and hydro, are expected to grow at varying rates of 6.6%, 2.2%, and 4.3%, respectively.

This shift towards renewables, especially wind and solar, is largely attributed to their role in replacing coal in power generation. Consequently, the reliance on coal for electricity is projected to decrease markedly. From a dominant 72.7% share in 2019, coal's contribution to power generation is expected to reduce to just 9.2% by 2050. Figure 5.4 illustrates these projected changes in power generation for India under the LCET–CN scenario from 1990 to 2050.

Figure 5.4. Electricity Generation, LCET–CN Scenario



CCS carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: IEEJ model results.

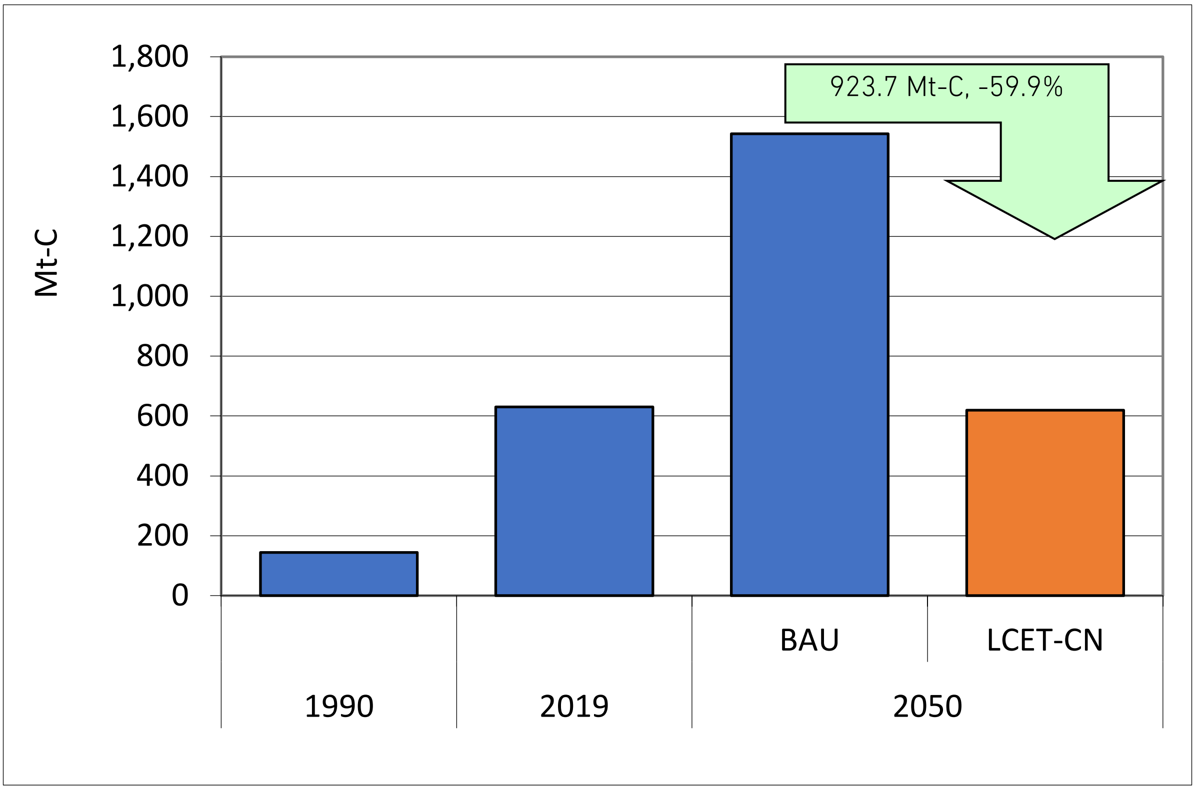
This projection underscores a significant transformation in India's power generation landscape, reflecting a decisive move towards renewable and nuclear energy, in line with global trends and commitments to reduce carbon emissions.

3.4. Carbon Dioxide Emissions

The LCET–CN scenario presents a promising outlook for carbon dioxide (CO_2) emissions in India. In 2019, the total CO_2 emissions stood at 630 million metric tonnes of carbon (Mt-C). Under this scenario, a gradual increase in emissions until 2040 and then a reduction in emissions is projected, leading to a decrease of 1.7% by 2050 as compared to the 2019 level, reaching 619 Mt-C. This decline represents an annual average reduction of 0.1% per year.

In contrast, the BAU scenario paints a different picture. Under BAU, carbon emissions from energy use are expected to rise significantly, with an annual growth rate of 2.9%, culminating in CO_2 emissions of 1543 Mt-C by 2050. Compared to the BAU scenario, the LCET–CN scenario envisages a substantial reduction of 60% (923.7 Mt-C) in CO_2 emissions by 2050, as illustrated in Figure 5.5.

Figure 5.5. CO_2 Emissions Trajectory, BAU vs LCET–CN Scenarios



BAU = business as usual, CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: IEEJ model results.

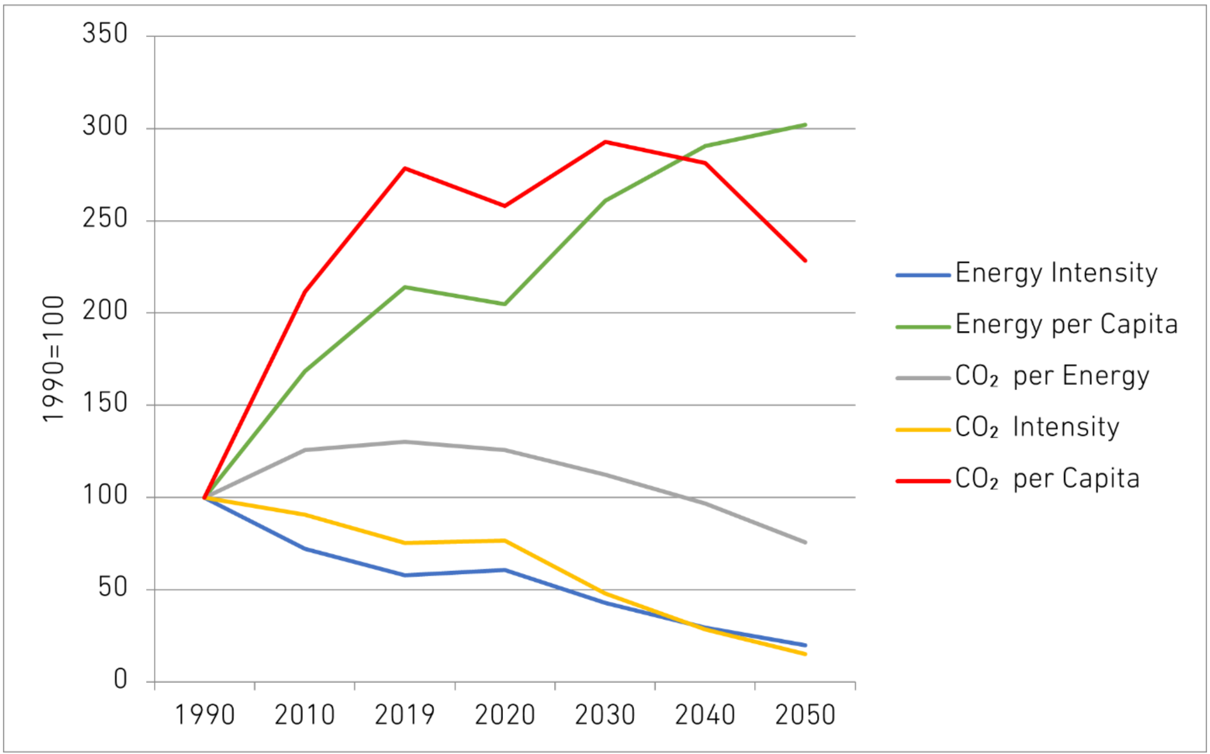
This marked decrease in emissions under the LCET–CN scenario can be attributed to several key factors. Primarily, it is the result of significant reductions in CO_2 emissions due to the vigorous implementation of energy-saving technologies and targets. A notable aspect of this scenario is the projected decrease in coal consumption in industries and power plants, which contributes to the overall reduction in emissions.

Additionally, the transition in the transport sector from oil products to more sustainable alternatives is expected to play a crucial role in lowering carbon emissions. This shift is crucial as it aims to reduce the environmental impact without compromising industrial output or the overall growth trajectory of the nation.

3.5. Energy Indicators

Figure 5.6, based on socioeconomic data projections and energy estimates, illustrates the indices of changes in various projected energy indicators for India under the LCET–CN scenario from 1990 to 2050. The LCET–CN scenario reveals a significant shift in energy efficiency and carbon intensity, driven by the adoption of more energy conservation measures and efficient energy technologies.

Figure 5.6. Energy Indicators, LCET–CN Scenario



CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral.
Source: IEEJ model results.

A notable change is observed in energy intensity, a measure of the primary energy supply per unit of GDP. From US$341 tonnes of oil equivalent (toe)/million 2015 (2015 US dollars) in 2019, it is projected to decrease to US$118 toe/million (2015 US dollars) by 2050. This substantial decrease, representing a negative average annual growth of –3.4%, indicates improved energy efficiency across the economy. In contrast, energy consumption per capita is expected to rise, reflecting the growing energy needs of India's expanding population. The average growth rate of 1.1% per year will see this figure increase from 0.69 toe/person in 2019 to 0.97 toe/person by 2050.

Significant improvements are also projected in terms of CO_2 intensity, which measures CO_2 emissions per unit of GDP. A sharp decline from US$229 t-C/million (2015 US dollars) in 2019 to US$46 t-C/million (2015 US dollars) in 2050 is anticipated, equating to a negative annual average growth rate of –5.0%. This trend is indicative of a notable decrease in CO_2 emissions relative to economic output, largely due to the integration of renewable energy technology into India's energy mix.

Additionally, there is a projected decrease in CO_2 emissions per unit of primary energy consumption, falling from around 0.67 t-C/toe in 2019 to 0.39 t-C/toe in 2050. This change, equivalent to an average annual decline rate of 1.7%, demonstrates an overall reduction in the carbon intensity of the energy sector. Correspondingly, CO_2 emissions per capita are expected to decrease from roughly 0.46 t-C/capita in 2019 to 0.38 t-C/capita in 2050, amounting to an 18% reduction.

These projections under the LCET–CN scenario point towards a future where India not only meets its growing energy demands but does so in a manner that significantly reduces its carbon footprint, aligning with global efforts to combat climate change.

3.5. Green Hydrogen Demand

Hydrogen, recognised as a clean alternative fuel, holds significant potential to replace fossil fuels in various sectors such as industry, transport, power generation, and energy storage systems.

In a strategic move to foster a hydrogen-based economy, India has outlined plans to mandate a compulsory purchase obligation for renewable hydrogen on fertiliser and petroleum companies. This initiative is a testament to the country's commitment to transitioning towards cleaner energy sources. In 2022, India's hydrogen use amounted to 6–7 million tonnes, with the refining sector accounting for 45% of this consumption, followed by the chemicals industry at 35%, and the iron and steel sector at 20%.

A significant policy development in 2023/2024 mandates that refineries must source 10% of their hydrogen demand from renewable sources, a requirement that is set to increase to 25% within the next 5 years. Similarly, fertiliser producers are required to meet 5% of their hydrogen demand with renewable hydrogen starting in 2023/2024, with this proportion rising to 25% in the subsequent 5 years. Plans are also in place to extend these requirements to the steel industry in the near future.

Model results under the LCET–CN scenario project that the consumption of green hydrogen in India will reach approximately 0.54 Mtoe by 2050. This projection underscores India's growing emphasis on green hydrogen as a cornerstone of its sustainable energy strategy, aiming to significantly reduce its carbon footprint and foster a more environmentally-friendly energy sector.

Cost Implications of LCET–CN Scenario

Table 5.1 offers a detailed cost comparison of the BAU and LCET–CN scenarios over the modelling period from 2019 to 2050. This 31-year span exceeds the typical lifetime of power plants, indicating that the entire power generation capacity existing in 2050 will need to be developed in the future. The Institute of Energy Economics, Japan model used for this study does not directly provide outputs for power generation capacity. Therefore, assumptions on normative capacity utilisation factors, along with the model output on annual electricity generation by different power generation technologies, are used to estimate the total installed capacity for these technologies over the respective years.

A key insight from Table 5.1 is the contrast in cost components between the BAU and LCET–CN scenarios. Whilst the BAU scenario is characterised by higher fuel costs, the

LCET–CN scenario incurs substantially higher capital costs. These costs are associated with power plants, energy storage, and energy-saving equipment. Notably, the cost of energy storage is estimated to be particularly significant, reaching approximately US$439 trillion cumulatively over the period from 2019 to 2050. This figure translates to around US$14.16 trillion annually for the next 31 years, an amount several times higher than the current GDP of India.

Such high investment requirements for the LCET–CN scenario, particularly for energy storage, have raised concerns regarding the financial feasibility of achieving ambitious targets for variable renewables. The capital-intensive nature of transitioning to a low-carbon energy system underscores the need for careful financial planning and possibly the exploration of innovative financing mechanisms to support this transition.

Table 5.1. Cost Comparison across the BAU and LCET–CN Scenarios

	BAU (US$ trillion)		LCET–CN (US$ trillion)	
	Cumulative (2019–2050)	Annual Average (2019–2050)	Cumulative (2019–2050)	Annual Average (2019–2050)
Fuel Cost	15.41	0.50	11.81	0.38
Power Plant – Capital Cost	1.39	0.04	1.82	0.06
Energy Storage – Capital Cost	-	-	438.93	14.16
Energy Saving Equipment – Capital Cost	-	-	1.47	0.05
Total	**16.81**	**0.54**	**454.04**	**14.65**

- = very small, BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Authors' estimation based on IEEJ model results.

4. Conclusion and Policy Recommendations

4.1. Conclusion

This chapter has examined India's ambitious journey towards a low-carbon future, as envisioned in the LCET–CN scenario. The focus has been on the transformative changes anticipated in the nation's energy landscape, encompassing shifts in energy consumption, the evolution of primary energy supply, and the dynamic changes in power generation patterns. The projections under the LCET–CN scenario illustrate a significant transition from existing predominant energy supply source coal to an increased reliance on renewable and alternative energy sources, highlighting India's commitment to a sustainable and environmentally responsible future.

A critical aspect of this transition is the projected reduction in CO_2 emissions, a testament to India's efforts in aligning with global climate goals. The shift towards renewable energy, notably solar and wind, signifies a profound change in the energy sector. The move away from coal-fired powered generation and the increasing role of nuclear power further underscore the nation's dedication to reducing its carbon footprint.

Equally significant are the financial implications of this transition. The analysis delves into the capital-intensive nature of shifting to a low-carbon energy system, underlining the need for substantial investments in renewable energy infrastructure, energy storage, and energy-saving technologies. This economic aspect poses both a challenge and an opportunity for India, as it navigates the delicate balance between growth, sustainability, and environmental responsibility.

In essence, the LCET–CN scenario presents a future where India not only meets its burgeoning energy demands but does so through a lens of sustainability and reduced environmental impact. The journey is complex and laden with challenges, but it is also filled with immense potential for innovation, economic growth, and a leading role in the global transition towards cleaner energy.

4.2. Policy Implications

To achieve its ambitious net-zero emissions target, India needs to adopt a holistic approach, encompassing several key strategies:

- Expansion of Renewable Energy: Developing policies to support the growth of renewable energy, enhancing grid flexibility, and focusing on storage technology advancement.
- Energy Efficiency Enhancement: Making significant investments in energy infrastructure across urban and industrial areas, and in appliances and vehicles, to reduce the energy intensity of the economy.
- Transitioning to Renewable and Alternative Energy Sources: Shifting from traditional fossil fuels to renewable sources like wind, solar, and hydro, and exploring nuclear and hydrogen options.
- Promotion of Electric Vehicles: Encouraging the adoption of electric vehicles to lessen oil consumption in the transportation sector, leading to reduced carbon emissions and offering substantial investment opportunities.
- Addressing Energy Storage Costs: Acknowledging the high capital requirements for energy storage technology, a critical factor in achieving variable renewable energy targets. Addressing these costs is essential for the financial feasibility of reaching net-zero emissions.

- Afforestation Initiatives: Implementing substantial afforestation efforts to absorb carbon, balancing emissions from fossil fuel-dependent sectors and rapidly growing industries.
- Hydrogen as Alternative Fuel: Increasing the use of hydrogen, especially in heavy-duty transportation and industrial applications, to reduce reliance on conventional fossil fuels.

Implementing these strategies is pivotal for India to meet its climate commitments and set a precedent for sustainable and eco-friendly growth.

References

Enerdata (2022), India Energy Information | Enerdata. https://www.enerdata.net/estore/energy-market/india/ (accessed 7 December 2023).

World Bank (2023), GDP, PPP (constant 2017 international $) - India | Data. https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.KD?locations=IN (accessed 7 December 2023).

United Nations Development Programme (UNDP) (2022), *Human Development Report 2022*. https://hdr.undp.org/data-center/country-insights#/ranks (accessed 7 December 2023).

Chapter 6
Indonesia Country Report

Suharyati

National Energy Council, Indonesia

1. Basic Concept of Low-carbon Energy Transition–Carbon Neutrality

Net-zero emissions refers to achieving an overall balance between greenhouse gas (GHG) emissions produced and taken out of the atmosphere (Climate Council, 2023).

To achieve net-zero emissions, the use of fossil energy should be reduced and new and renewable energy should be increased. Fossil energy can still be used but is supported by clean technology such as clean coal technology, carbon capture and storage (CCS) and carbon capture, utilisation, and storage (CCUS). Meanwhile, accelerating the use of new and renewable energy is carried out by increasing the use of electricity through the substitution of conventional vehicles for electric vehicles, and the use of biofuels, hydrogen, and batteries. Besides that, new and renewable energy needs to be supported by the application of smart grids and energy conservation to achieve energy security and sustainable development.

Through the Long-term Strategy for Low Carbon and Climate Resilience 2050 (Government of Indonesia, 2021) published by the Ministry of Environment and Forestry, Indonesia wants to reduce GHG emissions to 540 million tonnes of carbon dioxide equivalent (Mt-CO_2e) by 2050 (about 150 million tonnes of carbon [Mt-C]), peaking in 2030. Target emissions in 2050 can be achieved through a net-carbon sink of the forestry and land-use sector. Carbon neutrality can be achieved by reducing emissions in energy, waste, and the industrial processes and product use sector. To reach this goal, the forestry sector must continue efforts to increase the amount of carbon absorbed to achieve and maintain the net-carbon sink, even after 2030. On the other side, significant changes are needed in the energy sector, including increasing the use of renewable energy sources, improving energy efficiency, reducing coal consumption, and implementing CCS and CCUS.

Efforts to reduce emissions in the power sector include a sharp increase in renewable energy (RE) generation such as hydro, geothermal, biomass, wind, and solar. This scenario will also develop nuclear and hydrogen power plants to start production in 2040. Coal-fired power plants will be phased out by 2050, with coal-fired power plants with CCS being developed by 2040. The same scenarios will also be implemented for gas-fired power plants.

2. Indonesian Regulations to Support Net-zero Emissions Target

At the United Nations Climate Change Conference in Glasgow in 2021 (COP26), the President of the Republic of Indonesia conveyed a commitment that Indonesia will be able to reach net-zero emissions by 2060 or sooner if it obtains climate financing support from developed countries. To achieve the net-zero emissions target, it is necessary to develop clean energy so that the primary energy supply of RE must be more dominant than energy from fossil fuels. Whilst in the National Energy Policy, the RE target in primary energy supply is 23% in 2025 and 31% in 2050 (Ministry Energy and Mineral Resources, 2014).

In line with Indonesia's commitment to the Paris Agreement, Indonesia's energy system needs a larger portion of renewable energy. So, in 2022, the National Energy Council revised the National Energy Policy with the ambitious RE target to achieve net-zero emissions by 2060.

To support increasing the RE target, some regulations have been developed to increase the biofuel target, the development of electric vehicles (EV) and rooftop solar photovoltaic (PV) systems, cofiring coal power plants with biomass, electric batteries, low price RE generation, and de-dieselisation. The explanation for each topic follows.

2.1. Biofuel

In 2015, the Ministry of Energy and Mineral Resources published Regulation Number 12 on the Provision, Utilisation and Trading of Biofuels as Other Fuels. Since 2016, biofuel in biodiesel (mix of fatty acid methyl ester and diesel) or B20 has been about 20%. The target implementation of biofuel is shown in Table 6.1.

Table 6.1. Minimum Target of Biodiesel

Sector	2015	2016	2020	2025
Micro Enterprises, Fisheries Enterprises, Agricultural Enterprises, Transport, and Public Services (PSO)	15%	20%	30%	30%
Transport, Non PSO	15%	20%	30%	30%
Industrial and Commercial	15%	20%	30%	30%
Power Generation	25%	30%	30%	30%

Source: Ministry of Energy and Mineral Resources.

Last year the B40 road test was launched successfully and since February 2023, the mandatory programme of B35 started. However, the implementation of bioethanol (mix of gasoline and alcohol) has not been implemented to date, even though there are mandatory requirements (Table 6.2).

Table 6.2. Minimum Target of Bioethanol

Sector	2015	2016	2020	2025
Micro Enterprises, Fisheries Enterprises, Agricultural Enterprises, Transport, and Public Services (PSO)	1%	2%	5%	20%
Transport, Non PSO	2%	5%	10%	20%
Industrial and Commercial	2%	5%	10%	20%

Source: Ministry of Energy and Mineral Resources.

2.2. Electric Vehicles

Since 2019, the government is committed to accelerating the development of the EV industry through Presidential Regulation Number 55 of 2019 (Ministry of State Secretariat, 2019) as steps to stimulate the EV market. To formulate further the above strategies, the government also established Presidential Instructions Number 7 of 2022, which directs the use of battery EVs as operational vehicles and/or individual vehicles in central government agencies and regional governments. The directions include:

- accelerating the production of various types of battery-based electric vehicles (battery electric vehicles), both motorcycles and four-wheeled or more motorised vehicles, to meet the needs of the transformation of fuel-powered vehicles into battery-based electric motorised vehicles (battery electric vehicles);
- providing technical support for deepening the structure of the domestic battery-based electric vehicle industry so that it is able to meet the achievement targets at the domestic component level (TKDN);
- accelerating the development of main components and supporting components for the battery electric vehicle industry; and
- accelerating the production of charging stations and supporting components for the battery-based electric motorised vehicle industry.

To increase the penetration of EVs, the government will offer a subsidy on the sale of all electric motorbikes – incentives will be offered to buyers of electric motorbikes that are manufactured in Indonesia. The subsidy is around Rp7 million. With this incentive, it is hoped that the sales target for electric motorbikes can reach 200,000 units but with the condition that the domestic component level reaches 40%.

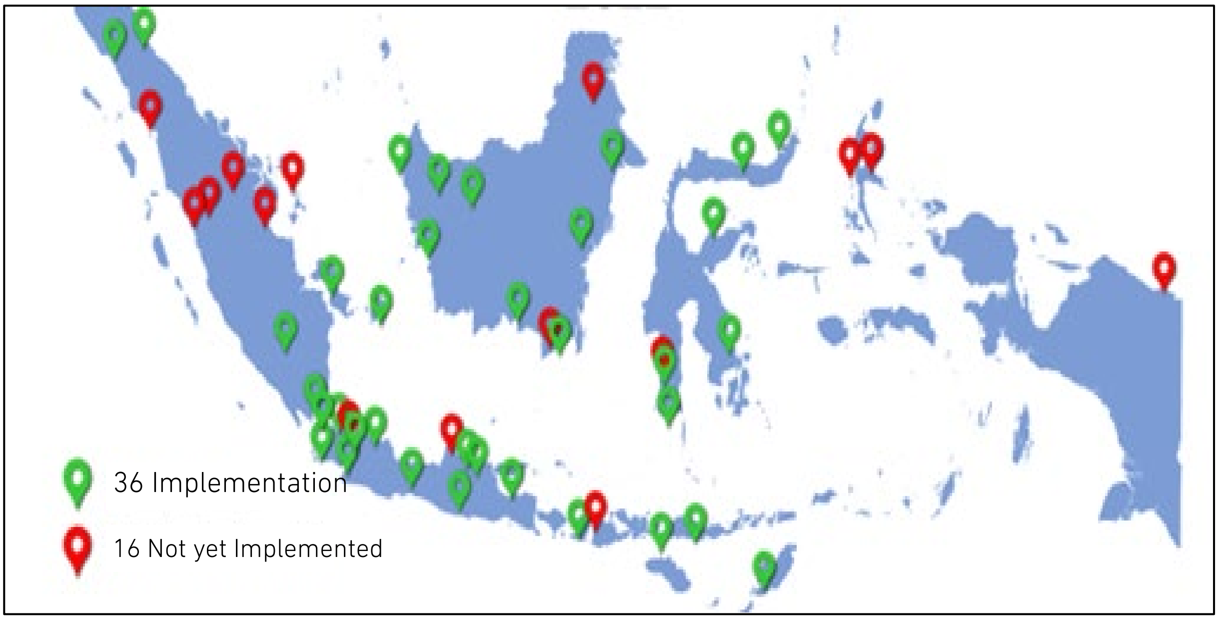
According to data from the Police Department, as of May 2023 there were around 37,000 registered EVs – 30,000 two-wheeled EVs and 7,000 four-wheeled EVs. Meanwhile, according to Statistics Indonesia, the total population of two-wheeled vehicles was around

125 million, and four-wheeled vehicles around 17 million. It means that in 2022, the number of electric motorbikes was only 0.02% and electric cars about 0.04% of the total.

2.3. Cofiring

One programme to support the reduction of emissions is cofiring of coal power by replacing some coal with biomass. The implementation of cofiring is in addition to supporting the recycle, reduce, reuse, and recover (4Rs) energy from waste. Cofiring technology development is low cost because there is no investment needed for the construction of new power plants. Currently, 36 power plants have implemented cofiring commercially (Figure 6.1) in 2023, producing 24 terawatt-hours (TWh) of green energy. The biomass cofiring programme is targeted to use 10.2 million tonnes of biomass in 2025.

Figure 6.1. Cofiring Implementation in Indonesia in 2022



Source: Ministry of Energy and Mineral Resources.

2.4. De-dieselisation

Base on Indonesia's Business Plan for Providing Electricity, there are 5,200 diesel-fired power plants in 2,130 locations (Figure 6.2), which can potentially be included in the de-dieselisation programme. The programme is divided into three schemes: (i) conversion of diesel-fired power plants to RE, (ii) conversion of diesel-fired power plants to gas, and (iii) network expansion to an isolated system to eliminate diesel-fired power plants.

To support the conversion of diesel-fired power plants to gas, the government has set a strategy through the Ministry of Energy and Mineral Resources (MEMR) Decree 249.K/MG.01/MEM/2022 issued in October 2022, which mandated the state oil and gas company Pertamina to supply gas for Perusahaan Listrik Negara (PLN) power generation in 47 power generation dual fuel and mobile power plants.

Figure 6.2. Location of Diesel-fired Power Plants

Source: Business Plan for Providing Electricity PLN 2021–2030 (RUPTL PLN).

2.5. Nuclear Energy Programme Implementing Organisation

One of the programmes to support achieving the net-zero emissions target in 2060 is the construction of a nuclear power plant. Therefore the Minister of Energy and Mineral Resources Decree Number 250.K/HK.02/MEM/2021 has been issued to establish the Nuclear Energy Program Implementation Organization.

2.6. Solar Rooftop

Indonesia has a big potential for solar power. Based on data from the Directorate General of Renewable Energy and Conservation, the potential for solar in Indonesia is about 3,294 GWp (gigawatt peak). The Minister of Energy and Mineral Resources Regulation Number 49/2018 on the Use of Rooftop Solar Power is to encourage domestic use of solar energy. The regulation was amended in 2019 with Regulation Number 13/2019 and Number 16/2019, which address concerns related to licensing and electricity sales to PLN. In 2021, 3,900 customers installed rooftop solar power and in 2023 the number increased to around 8,500 customers This is due to support from the financial sector that provides low-interest loans.

But with an increasing supply of electricity from coal-fired power generation in 2020 and 2021 and electricity consumption growth decreasing due to the COVID-19 pandemic, PLN has limited buying electricity from solar to only 20% of total power generated. It is hoped that the abolition of the export–import provisions for electricity will reduce PLN's financial burden. Currently the capacity of rooftop solar power is 114 megawatts.

2.7. Carbon Capture and Storage, and Carbon Capture, Utilisation, and Storage

Carbon capture, utilisation, and storage (CCUS) refers to a suite of technologies that enable the mitigation of carbon dioxide (CO_2) emissions from large point sources such as power plants, refineries, and other industrial facilities, or the removal of existing CO_2 from the atmosphere.

Indonesia has a CCS plan to be implemented in the oil and gas sector. The government is targeting oil production of 1 million barrels of oil per day and gas production of 12 billion standard cubic feet per day by 2030. On the other hand, Indonesia is committed to supporting the reduction of GHG emissions towards net-zero emissions in 2060 or sooner. CCS and CCUS technology is one of the solutions to achieve these two targets. In the energy transition, natural gas will still play an important role as a bridge to the use of RE.

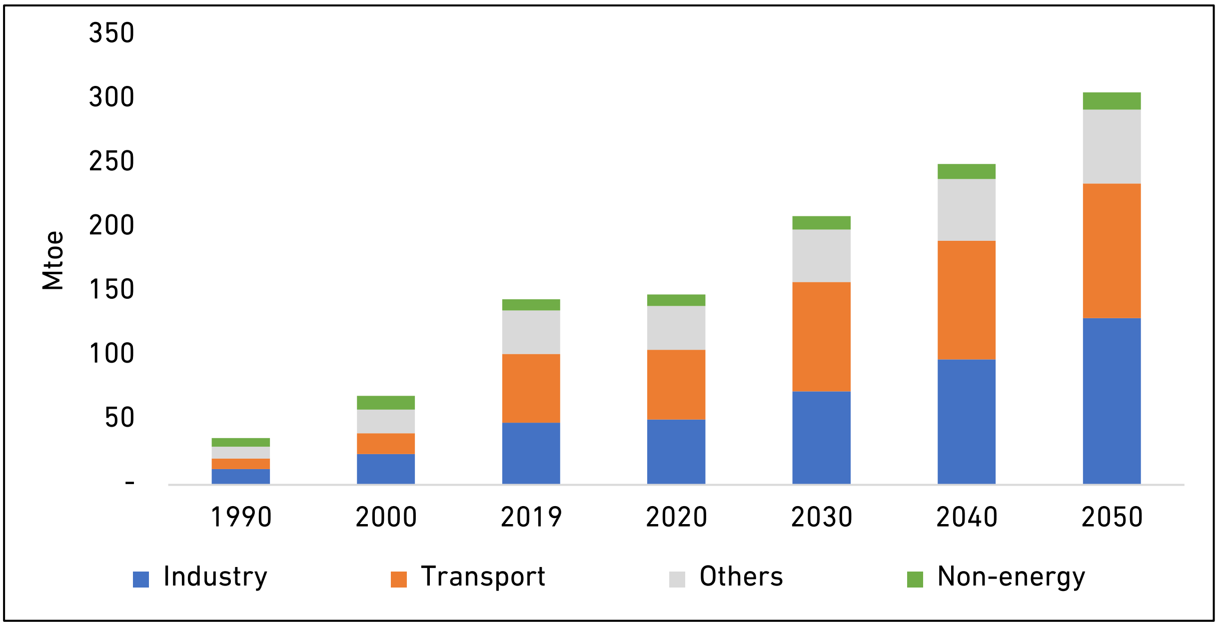
To support emissions reduction, Indonesia published Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 2 of 2023 concerning the Implementation of Carbon Capture and Storage, as well as Carbon Capture, Utilization and Storage in Upstream Oil and Gas Business Activities (MEMR, 2023).

Currently there are 16 CCS and/or CCUS projects in Indonesia that are still in the study and preparation stages, and most of them are targeted to operate before 2030. The CCS/CCUS project that has received a Plan of Development approval is Tangguh BP Berau in Papua. In addition, there is also a huff and puff CO_2 injection pilot test by Pertamina in Jatibarang Field (West Java).

3. Final Energy Consumption

Final energy consumption is projected to increase by an average annual growth rate of 2.4% per year (2019–2050). The final energy consumption in the LCET–CN scenario in 2050 is about 306 million tonnes of oil equivalent (Mtoe), mainly influenced by improving energy efficiency in all sectors.

Figure 6.3. Final Energy Consumption by Sector, 1990–2050



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

Figure 6.3 shows the final energy consumption by sector. Until 2050, the biggest growth rate of energy consumption comes from the industry sector (3.2%), followed by the transport sector (2.2%), whilst the growth rate of the 'others' sector is 1.7% and the non-energy sector is 1.4%. In 2050 the share of final energy consumption will be dominated by the industry sector (42%), which is supported by the economic growth rate increase of about 5% per year.

To achieve emissions reduction according to the LCET–CN scenario, the change that will be made is to replace a portion (10%) of gas and coal consumption in several industrial subsectors with hydrogen. Therefore, in 2050 the share of fossil fuel decreases to 78% from 83% in 2019 and the share of electricity increases from 17% in 2019 to 20% in 2050, and the share of hydrogen will be 3% in 2050 from zero in 2019. Hydrogen as part of clean energy, will start to be used in 2035 for some industries like chemical, non-metallic, and pulp and paper.

In the transport sector, gasoline and diesel consumption that dominated in 2019 will decrease to 37% in 2050 because of the change in the share of electricity (14%), hydrogen (7%), and biofuel (41%).

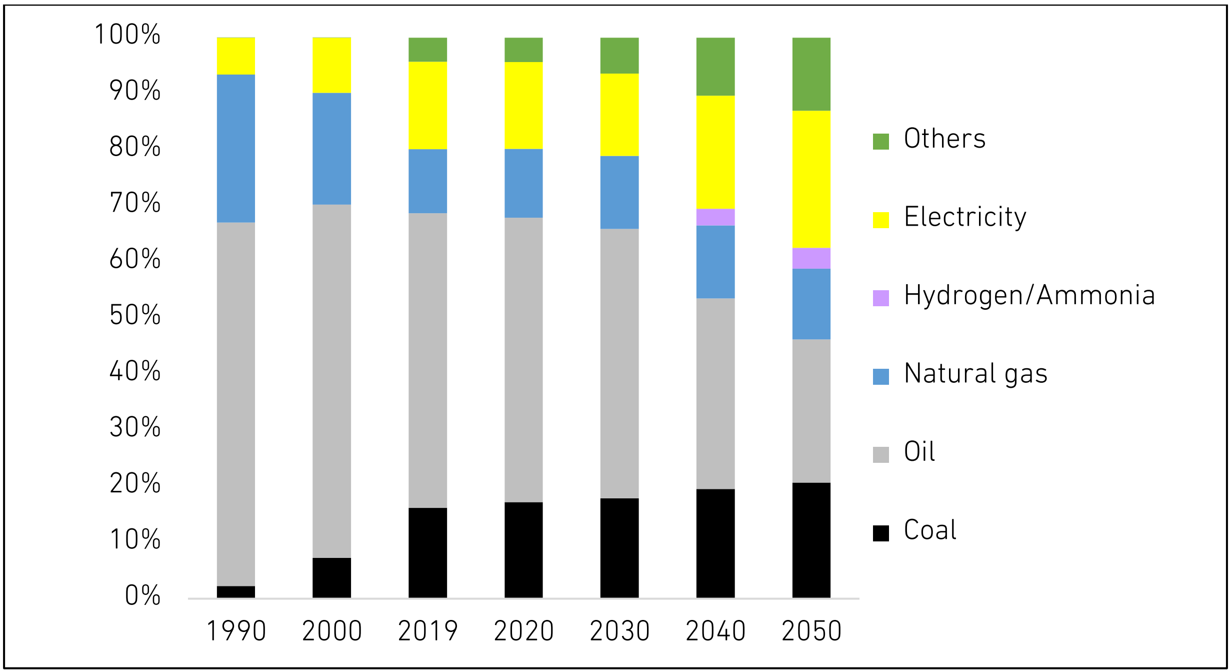
The annual growth rate of biofuel will increase to an average of 6%, in line with biodiesel and bioethanol used, especially in the transport sector. The mix of biofuel in biodiesel and bioethanol projection can reach 40%. In 2023 the content of biofuel in biodiesel was about 35%, but there is no implementation timeline for bioethanol.

Total final energy consumption of electricity 2019–2050 increases with annual growth rate of average 4%. Electricity consumption in 2050 will increase to 75 Mtoe or 884 terawatt-hours (TWh). The biggest growth of electricity consumption comes from the transport sector through the substitution of gasoline and diesel with electricity for cars and motorcycles.

Whilst in the 'others' sector, the reduction in emissions to achieve net-zero emissions concerns the substitution of liquid petroleum gas (LPG) with electricity for cooking, especially in the household sector. The aim this programme, besides the reduction of carbon, is also to reduce dependency on LPG imports. Currently LPG imports have been around 70% of total LPG consumption in Indonesia.

The projection of final energy consumption by type of energy (Figure 6.4) shows that in 2050 the share of fossil fuel will still be 59% because coal and gas will still be used in the industry sector, and oil will be used in the transport sector (with a mix of mix of fatty acid methyl ester to become biofuel). As a result, the share of others (biofuel) will increase from 4% in 2019 to 13% in 2050, whilst the share of electricity will also increase from 7% in 2019 to 24% in 2050 in line with the increasing numbers of EVs and electric stoves.

Figure 6.4. Share of Final Energy Consumption by Energy Type, 1990–2050



Source: Author.

The EV and electric stove programmes will increase electricity consumption, absorbing the current oversupply of electricity in Java Island from the 2015 35 GW coal-fired power plant development programme.

4. Power Generation

Based on projections, the production of electricity in 2050 for the LCET–CN scenario will achieve 1090 TWh, with the growth rate of about 4.3% for 2019–2050. After 2030, a new large-scale RE generation development programme begins with the construction of solar (about 27 MW), geothermal (7 GW), wind (4 GW), and biomass (including municipal solid waste) (about 8 GW). On the other hand, fossil fuel generation will decrease after 2035, with the capacity of coal-fired power plants decreasing from 40 GW in 2030 to zero in 2050, oil-fired power plants decreasing from 4 GW in 2035 to 1 GW in 2050, and gas-fired power plants decreasing from 21 GW in 2035 to 7 GW in 2050.

New technology for power generation projection will develop in 2040 such as coal-fired power plants with CCS, and gas-fired power plants with CCS and hydrogen. Nuclear power is also projected to enter the electricity system starting in 2040 with a capacity of 4 GW.

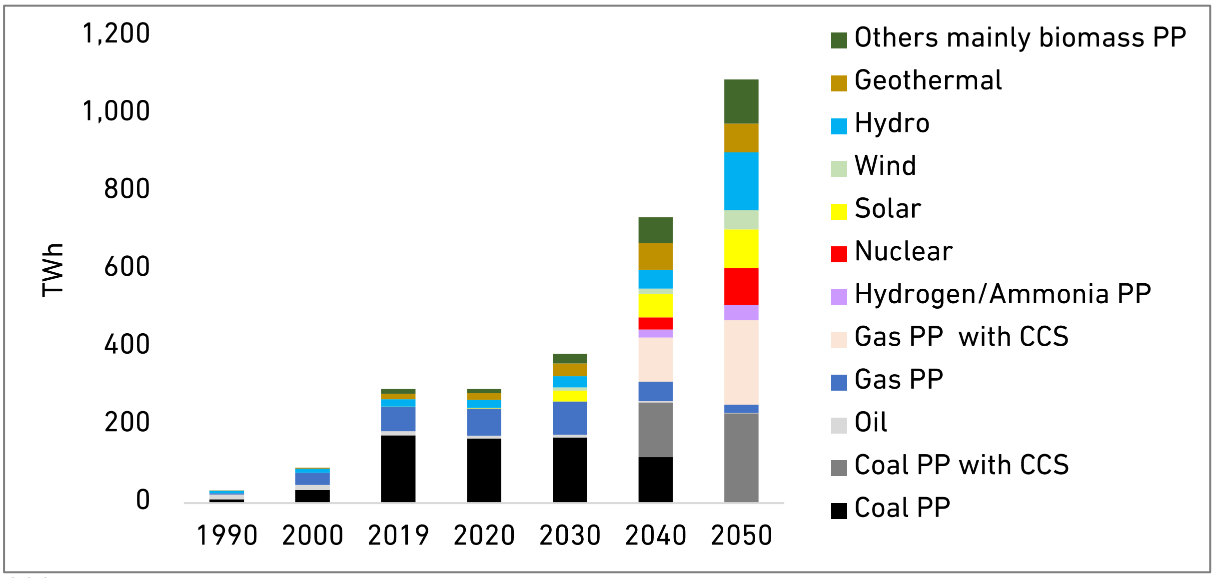
Figure 6.5 shows the production of electricity from 2019–2050. The figure shows that the biggest share of production of electricity comes from coal-fired power plants with CCS (around 21% or 231 TWh) and gas-fired power plants with CCS at about 20% (217 TWh). Coal-fired power plants and gas-fired power plants with CCS are included in the electricity system in Indonesia because coal and gas reserves in Indonesia are large. It is hoped that by 2040, CCS power plants will be economical or can compete with other RE power plants.

Production of electricity from hydro in 2050 is about 14% or 149 TWh. The total hydro potential in Indonesia is around 95 GW and almost half of it is in Kalimantan, about 38% is in Papua, and the rest is spread across Java and Sumatra. Therefore, hydro is expected to be up to 60 GW by 2050.

The production of electricity from solar achieves 99 TWh or 9% from the total production. Even though Indonesia has very large solar potential, due to limited land, solar only around 120 GW can be developed up to 2050.

To build a nuclear power plant requires 10–15 years of preparation so it is estimated that a new nuclear power plant will be able to produce electricity around 2040. The production of electricity from nuclear power plants is projected to be about 32 TWh in 2040, and will increase to 95 TWh in 2050.

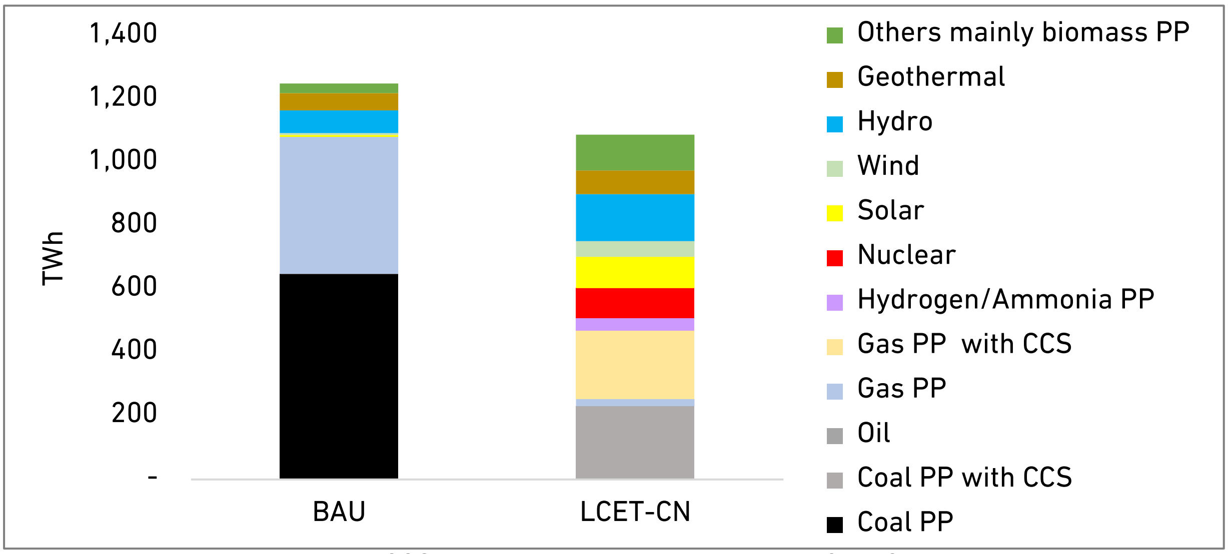
Figure 6.5. Production of Electricity LCET–CN Scenario,1990–2050



CCS = carbon capture storage, PP = power plant, TWh = terawatt-hour.
Source: Author.

When compared with the business as usual (BAU) scenario, the production of electricity from fossil power generation in the LCET–CN scenario is much lower. Electricity production from fossil fuel generation in the BAU scenario is1,038 TWh or 86% from total production electricity in 2050, whilst in the LCET–CN scenario it is only 470 TWh (43%) but using clean technology. The comparison of electricity production in 2050 between the BAU and LCET–CN scenarios is shown in Figure 6.6.

Figure 6.6. Comparison of Electricity Production in BAU and LCET–CN Scenarios, 2050



BAU = business and usual, CCS = carbon capture storage, LCET–CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: Author.

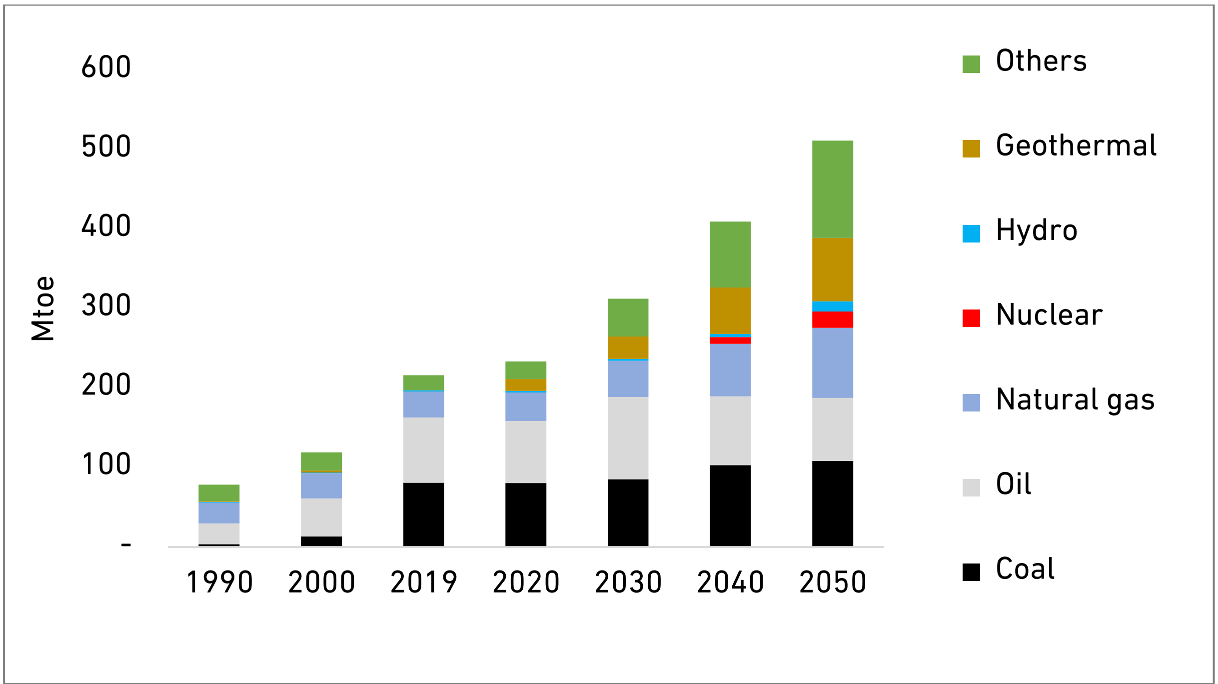
5. Primary Energy Supply

Total primary energy supply (TPES) in the LCET–CN scenario increases by about 3% per year in 2019–2050, so TPES in 2050 will achieve 512 Mtoe. The share of fossil energy in TPES decreases, from 90% in 2019 to 54% in 2050 in line with efforts to reduce emissions to commitment net-zero emissions by 2060. The average coal and gas growth in 2019–2050 is 1% per year and 3% per year, respectively but oil supply shows negative growth, due to the substitution of gasoline and diesel with electricity and biofuel in the transport sector.

In the 2019–2050 period, the growth rate in the primary energy supply of solar is 24% and wind is 16%. Currently, the cost of constructing solar power plants is expensive. However, the cost of installing solar has decreased compared to the previous 5 years so that it is estimated that by 2050, solar can compete with fossil fuel power plants.

Although the growth rate of hydro, geothermal, biofuel, and biomass in 2019–2050 is about 6%, in 2050 the biggest share of TPES from RE is geothermal, because all potential of geothermal will develop in 2050 as the base load of supply electricity. Figure 6.7 shows the primary energy supply in the LCET-CN scenario in 1990–2050.

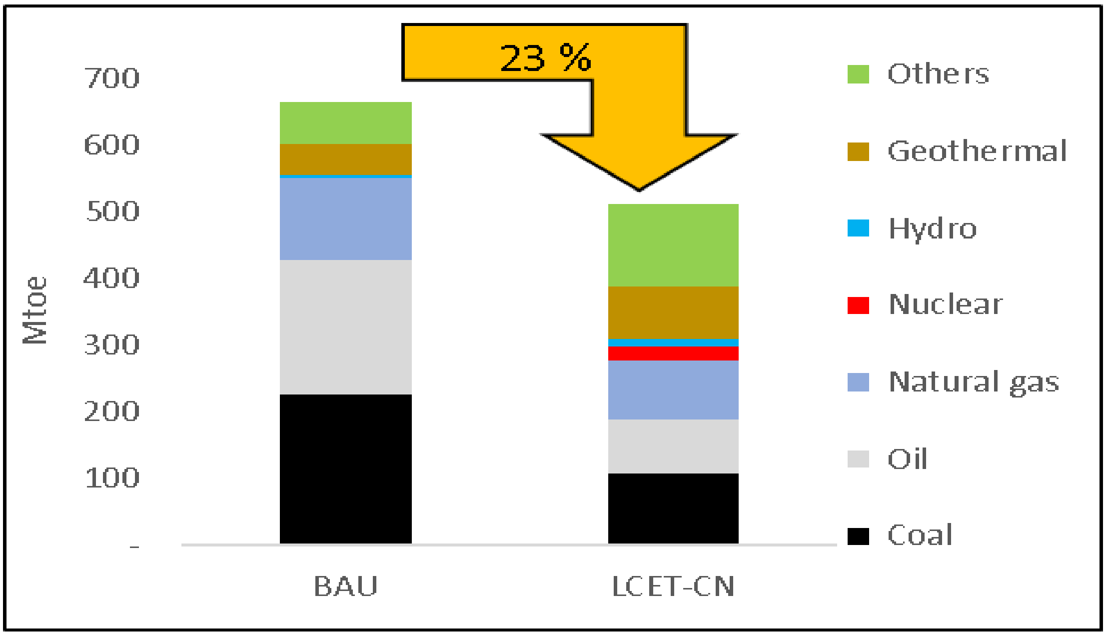
Figure 6.7. Total Primary Energy Supply, LCET–CN Scenario,1990–2050



LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author.

TPES in 2050 in the LCET–CN scenario is 23% lower than the BAU scenario, because of the reduction in primary energy supply of fossil fuels. Primary energy supply of coal in the BAU scenario is 225 Mtoe, but in the LCET–CN scenario it is only 108 Mtoe, because coal in industry is subtitute with hydrogen and coal for generation is limited for coal-fired power plants with CCS. For gas, which is 122 Mtoe in BAU and 88 Mtoe in LCET–CN as a result subtitution gas in the industry sector and limited gas used for electricity generation except for gas-fired power plants with CCS in 2050. Primary energy supply of oil in the LCET–CN scenario is about 79 Mtoe, much lower than the BAU scenario (203 Mtoe) because there is subtitution of oil with hydrogen in industry–and commercial–and subtitution oil with electricity in the transport sector. On the other side, primary energy supply of RE is higer than BAU, due to increasing RE in the power sector, including nuclear. The comparison TPES in 2050 in the two scenarios is shown in Figure 6.8.

Figure 6.8. Comparison Total Primary Energy Supply BAU and LCET–CN Scenarios, 2050



BAU = LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author.

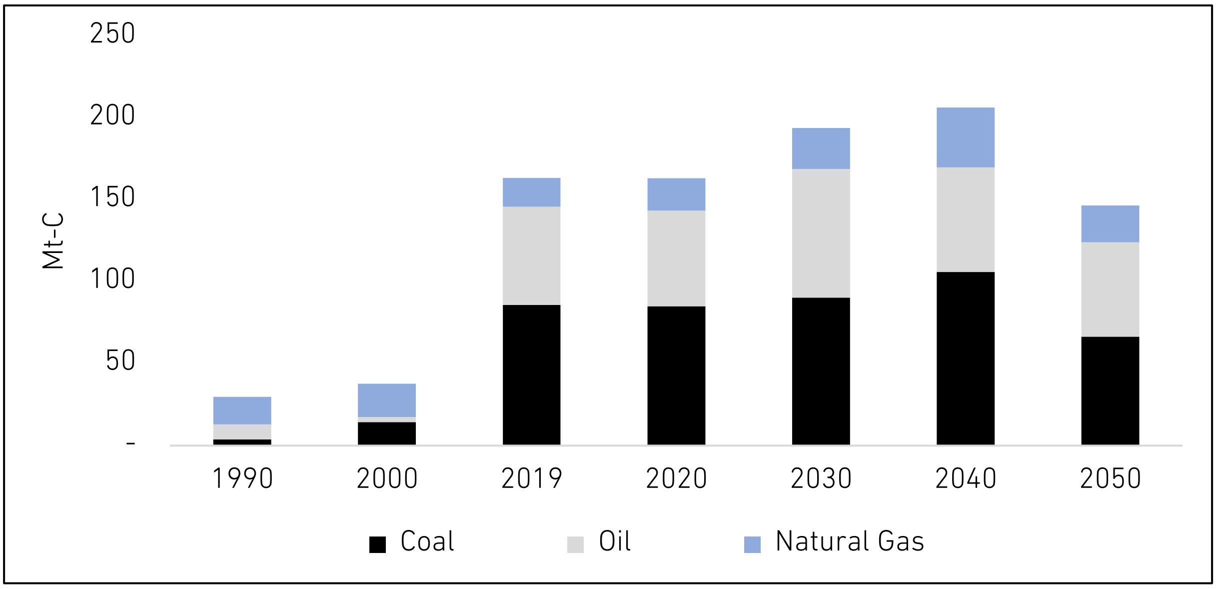
6. Carbon Dioxide Emissions

The CO_2 emissions in the LCET–CN scenario projection increases from 164 Mt-C in 2019 to 207 Mt-C in 2040 (peak emissions) and decreases to 147 Mt-C in 2050. The reduction of carbon is mainly from decreasing the number of coal-fired power plants from 2035 until 2048 and changing them to plants with CCS from 2040, and also decreasing the number of gas-fired power plants from 2036.

In the industry sector, especially iron and steel, coal is still needed for the processing plants and gas is needed for producing feedstock fertiliser. Oil is also used in the transport sector as a mixed biofuel and LPG is still used in the 'others' sector for cooking, so emissions are difficult to reduce.

The biggest emissions in 2050 will come from coal, followed by oil and gas so total emissions will be about 147 Mt-C or 529 Mt-CO_2. These target emissions as mentioned in the Long-term Strategy for Low Carbon and Climate Resilience document, which is set to target a reduction in emissions in 2050 of about 540 Mt-CO_2. The trend of emissions in the LCET–CN scenario 2019–2050 is shown in Figure 6.9.

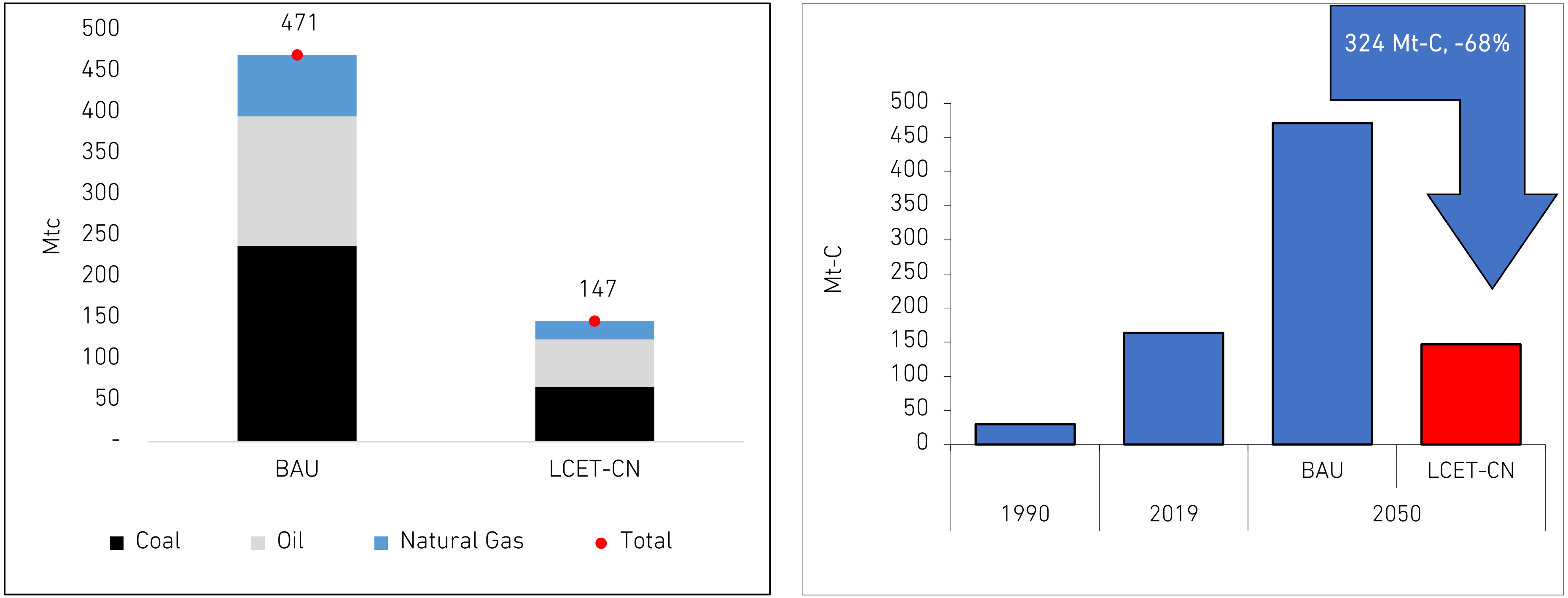
Figure 6.9. CO_2 Emissions in LCET–CN Scenario,1990–2050



CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: Author.

Carbon emissions in the 2050 LCET–CN scenario are much lower than in the BAU scenario as shown in Figure 6.10.

Figure 6.10. Comparison of CO_2 Emissions between BAU and LCET–CN Scenarios, 1990–2050



BAU = business as usual, CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: Author.

7. Cost Benefit Analysis

In this chapter, a cost and benefit analysis will be carried out looking at fuel costs, power plant energy requirements, CCS, energy savings, and total cost benefit analysis for the BAU and the LCET–CN scenarios.

7.1. Fuel Cost Analysis

The fuel cost analysis in both scenarios is calculated based on the primary energy supply for fossil fuel throughout 2019–2050, as well as hydrogen contained in the LCET–CN scenario. The supply of fossil energy is then multiplied by the energy price in 2019/2020 as current condition and for conditions in 2050, the primary energy supply, multiple with the assumed price of each fossil energy in 2050 (Table 6.3).

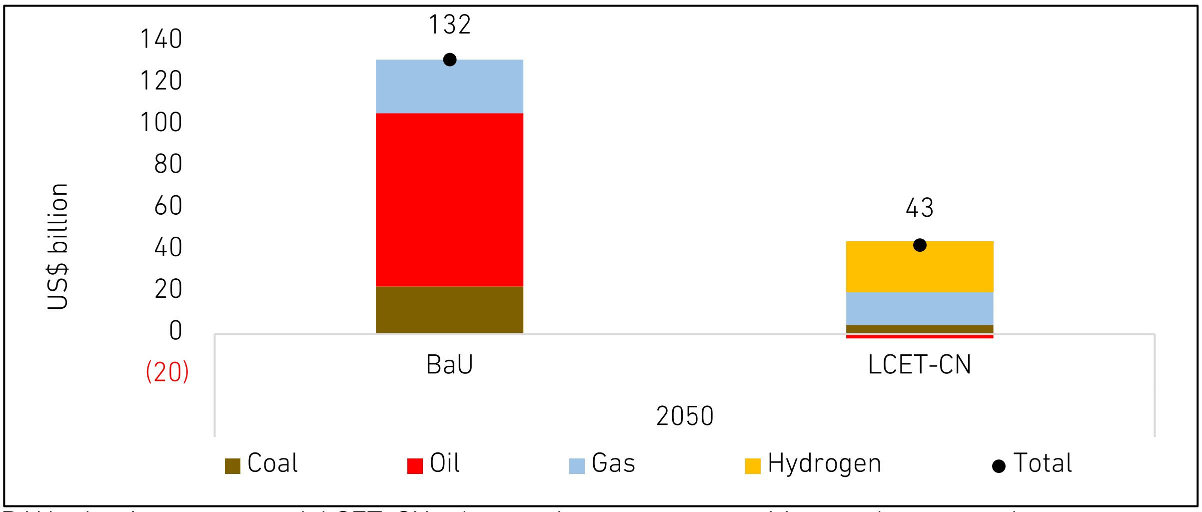
Table 6.3. Assumptions for Fossil Energy Prices in 2019 and 2050

	2019/2020		2050 (2019 constant price)	
Coal	80.03	US$/ton	98	US$/ton
Oil	41	US$/bbl	100	US$/bbl
Gas	7.77	US$/MMBtu	7.5	US$/MMBtu
Hydrogen	0.8	US$/$Nm^3$	0.3	US$/$Nm^3$

bbl = barrel, MMBtu = metric million British thermal unit, Nm^3 = normal metric metre.
Source: ERIA.

From the calculation results, fuel costs until 2050 in the LCET–CN scenario will reach US$34 billion, but fuel costs in the BAU scenario are three times higher than the previous scenario. This condition is mainly influenced by the decrease in oil use in the LCET–CN scenario so that oil fuel costs become negative, or a cost savings of around US$2 billion. However, there are additional fuel costs for hydrogen of around US$25 billion. A comparison of the fuel cost in the BAU and LCET–CN scenarios is shown in Figure 6.11.

Figure 6.11. Comparison of Fuel Cost in BAU and LCET–CN Scenarios

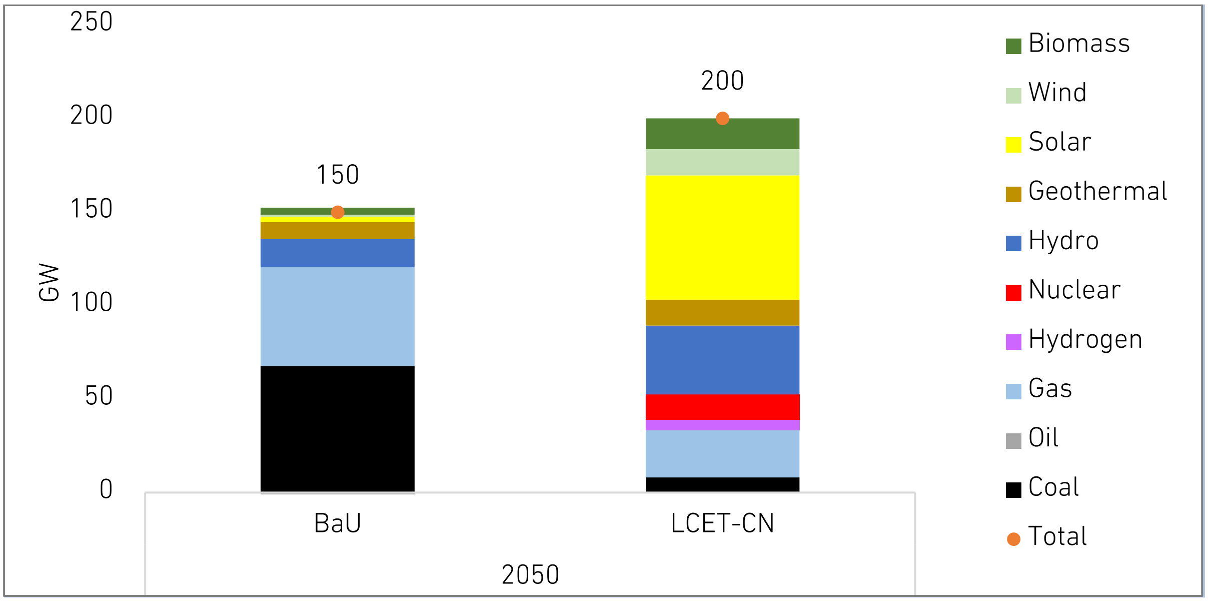


BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Author.

7.2. Power Investment

Based on the projection results for the BAU and LCET–CN scenarios until 2050, 1,253 TWh of electricity are needed for the BAU scenario and 1,090 TWh for the LCET–CN scenario. To meet this electricity production, the generating capacity required for the BAU scenario is around 150 GW and for the LCET–CN scenario is 200 GW in 2050. Projections for additional capacity of generation in each scenario can be seen in Figure 6.12.

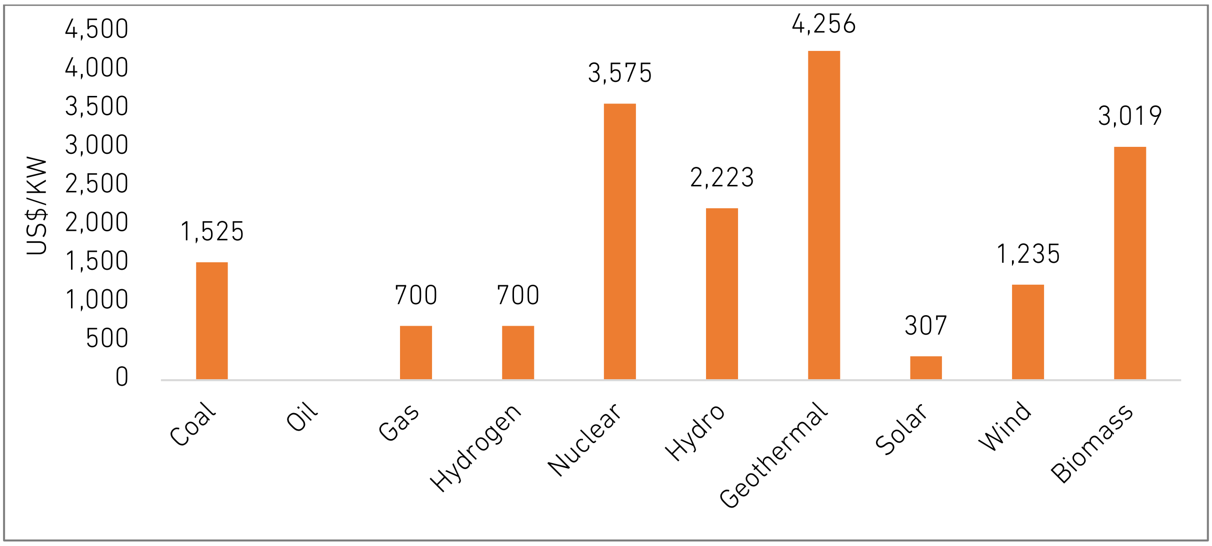
Figure 6.12. Comparison of Additional Capacity of Power Plants in BAU and LCET–CN Scenarios



BAU = business as usual, GW= gigawatt, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Author.

To find out the investment costs of each power plant, the additional power plant capacity during 2019–2050 is multiplied by the assumed construction costs as shown in Figure 6.13.

Figure 6.13. Construction Costs of Power Plants

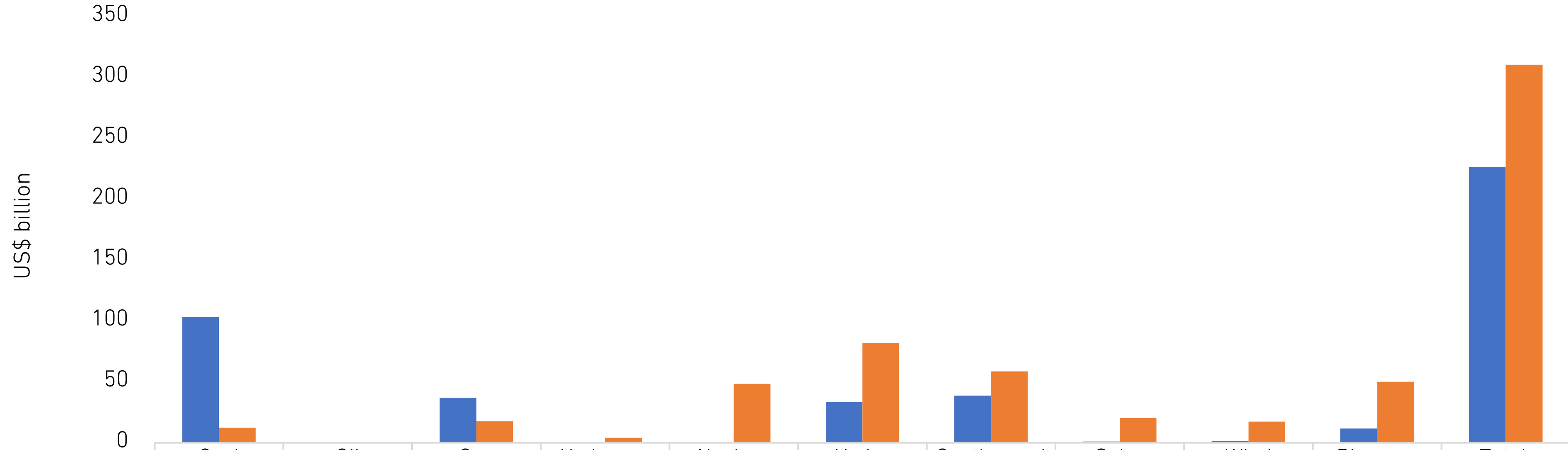


KW = kilowatt.
Source: Author.

Based on Figure 6.13, the most expensive construction cost of power generation in 2050 is geothermal, followed by nuclear, biomass, and hydro.

Investment costs in the LCET–CN scenario are more expensive than the BAU scenario as a result of 83% of electricity generation coming from new and renewable energy which is more expensive than fossil generation, especially geothermal, nuclear, biomass, and hydro. Comparison construction cost between the two scenarios can be seen in Figure 6.14.

Figure 6.14. Construction Cost by Type of Generation



	Coal	Oil	Gas	Hydrogen	Nuclear	Hydro	Geothermal	Solar	Wind	Biomass	Total
2050 BaU	103,257	0	36,926	0	0	33,321	38,770	866	1,339	11,521	225,999
2050 LCET-CN	12,360	0	17,600	3,961	48,263	81,974	58,538	20,414	17,292	50,006	310,408

2050 BaU   2050 LCET-CN

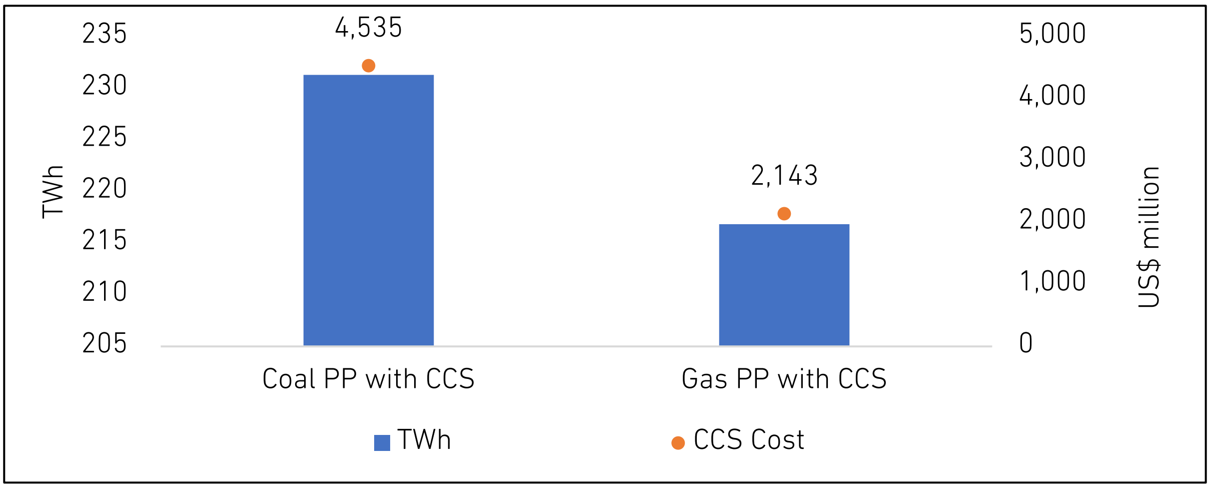
BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral.

Source: Author.

7.3. CCS Cost

CCS is technology for reducing emissions when fossil fuel is used, especially in the power sector. With CCS technology in the LCET–CN scenario, emissions will be reduced to achieve the target. Based on the calculations, in 2050 coal-fired power plants with CCS will produce 231 TWH electricity with coal consumption of about 45 Mtoe and will produce emissions of about 46 Mt-C. If the assumption cost of CCS development is about US$30/$CO_2$ ton, the cost to develop CCS technology is about US$4.5 billion. On the other side, consumption of gas-fired power plants with CCS is about 37 Mtoe and will produce 22 Mt-C or 79 Mt-CO_2. With CCS technology, emissions will decrease to 71 Mt-CO_2 so the cost to develop CCS technology is about US$2.143 million. Total cost CCS development will be about US$6.678 million in 2050 (Figure 6.15).

Figure 6.15. Cost of CCS in LCET–CN Scenario in 2050



CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, TWh = terawatt-hour.
Source: Author.

7.4. Energy Savings

Energy savings are calculated based on energy consumption in 2050 for the BAU scenario compared to the alternative policy (AP) scenario which uses energy savings as one of the assumptions. In the BAU scenario total energy consumption in 2050 is about 448 Mtoe, higher compared to the AP scenario of about 377 Mtoe. Energy saving calculated especially for energy consumption in the industry and 'others' sectors, so total energy saving is about 38 Mtoe (Table 6.4).

Table 6.4. Energy Saving in BAU and AP Scenarios
(Mtoe)

Sector	BAU	AP	Energy Saving
Industry	146	121	25
Others	97	84	13
Total	243	205	38

AP = alternative policy, BAU = business as usual, Mtoe = million tonnes of oil equivalent.
Source: Author.

If the energy savings are equated to crude oil with the assumption that 1 Mtoe is equivalent to 1.09 billion kilolitres (kl), then savings in 2050 will reach 42 million kl. If the energy saving effect is assumed to be US$385/million kl, then the total energy savings cost obtained will be almost US$16 billion.

7.5. Overall Cost

Based on analysis on the overall calculation from Section 7.1 and 7.2, the breakdown of the total investment cost is showed in Table 6.5.

Table 6.5. Overall Cost
(US$ million)

	BAU	LCET–CN
Fuel cost	131,679	42,554
Power capital cost	7,290	10,013
CCS in 2050	0	6,678
Total	**138,969**	**59,245**

BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Author.

8. Conclusion and Recommendations

To achieve the reduction of 540 million Mt-CO2e in emissions by 2050, Indonesia must demonstrate significant commitment and effort. Currently, the renewable energy (RE) share in the primary energy supply is only 12.3%, with 87.7% still reliant on fossil fuels.

Efforts that need to be made by Indonesia include the preparation of a roadmap towards net-zero emissions, such as switching fuel to electricity and hydrogen, increasing the share of biofuel in the transport sector, substituting oil, gas, and coal with hydrogen in the industrial sector, and increasing the use of RE for electricity generation, including nuclear and the use of coal and gas-fired power plants with carbon capture and storage (CCS).

From the overall calculation of the total energy cost, the LCET–CN (Low Carbon Energy Transition–Carbon Neutral) scenario anticipates lower fuel costs compared to the BAU (Business As Usual) scenario. However, the LCET–CN scenario requires larger power investment and CCS costs compared to BAU. This indicates that for Indonesia, the LCET–CN scenario could be one of the pathways to achieving net-zero emissions by 2060.

Other parameters, such as a robust legal framework, knowledge of clean energy technologies, and public awareness, need to be prioritised to implement net-zero emissions. Additionally, cooperation with developed countries is essential to support emissions reduction in areas like investment, technology transfer, and other activities.

References

Climate Council (2023), What Does Net Zero Emissions Mean? 14 April. https://www.climatecouncil.org.au/resources/what-does-net-zero-emissions-mean/

Government of Indonesia (2021), *Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050.* https://unfccc.int/documents/299279

Ministry of Energy and Mineral Resources (2014), Government Regulation of The Republic of Indonesia Number 79 of 2014 on National Energy Policy. Ministry of Energy and Mineral Resources. https://jdih.esdm.go.id/index.php/web/result/1777/detail

Ministry of Energy and Mineral Resources (2015). Regulation Number 12. Provision, Utilisation and Trading of Biofuels and Other Fuels. https://jdih.esdm.go.id/peraturan/Permen%20ESDM%2012%20Thn%202015.pdf (in Bahasa)

Ministry of Energy and Mineral Resources (2023), Jaringan Data Informasi Hukum - Kementerian Energi dan Sumber Daya Mineral. https://jdih.esdm.go.id/storage/document/Permen%20ESDM%20Nomor%202%20Tahun%202023.pdf (in Bahasa)

Ministry of the State Secretariat (2019), Peraturan Presiden Republik Indonesia Nomor 55 Tahun 2019. https://jdih.esdm.go.id/storage/document/Perpres%20Nomor%2055%20Tahun%202019.pdf (in Bahasa)

PLN (2021), *Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) PT PLN (PERSERO) 2021-2030.* PLN. https://web.pln.co.id/statics/uploads/2021/10/ruptl-2021-2030.pdf (in Bahasa)

Chapter 7

Japan Country Report

Seiya Endo and Ryohei Ikarii
The Institute of Energy Economics, Japan

1. Basic Concept of Low-carbon Energy Transition – Carbon Neutrality

Introduction

In October 2020, the Government of Japan declared the target of carbon neutrality by 2050. After that, in 2021, the government updated its nationally determined contribution (NDC) for 2030 to 46% below the 2013 greenhouse gas (GHG) emissions. The government previously declared the emissions target of just 26% below the 2013 level, and the target has been replaced by a far more ambitious one.

The 6th Strategic Energy Plan (METI, 2021a), approved by the Cabinet in 2021, the same year as the NDC update, outlines these quantitative targets and the actions to be taken in each energy sector for carbon neutrality by 2050 and the NDC for 2030.

Whilst Japan is aiming to materialise carbon neutrality, the current energy mix in the country is heavily dependent on fossil fuels. In 2020, fossil fuels made up 85% of primary energy supply (METI, 2021b). Power generation is a relatively decarbonised sector, but generation from coal, oil, and natural gas still covers 74% of total power generation. Japan has to substitute this fossil fuel demand or capture and store the emissions as much as that from fossil fuels in order to neutralise GHG emissions.

To consider energy supply and demand in Japan, this report presents the business as usual (BAU) scenario in which similar energy policies are currently taken, an alternative policy (AP) scenario in which further powerful measures for climate issues are taken from there (these two are forecast scenarios), and the low-carbon energy transition–carbon neutral (LCET–CN) scenario, a back-cast scenario for carbon neutrality. This scenario analysis will show the difference between Japan's carbon neutrality and the forecast scenarios and summarises the challenges to achieving it.

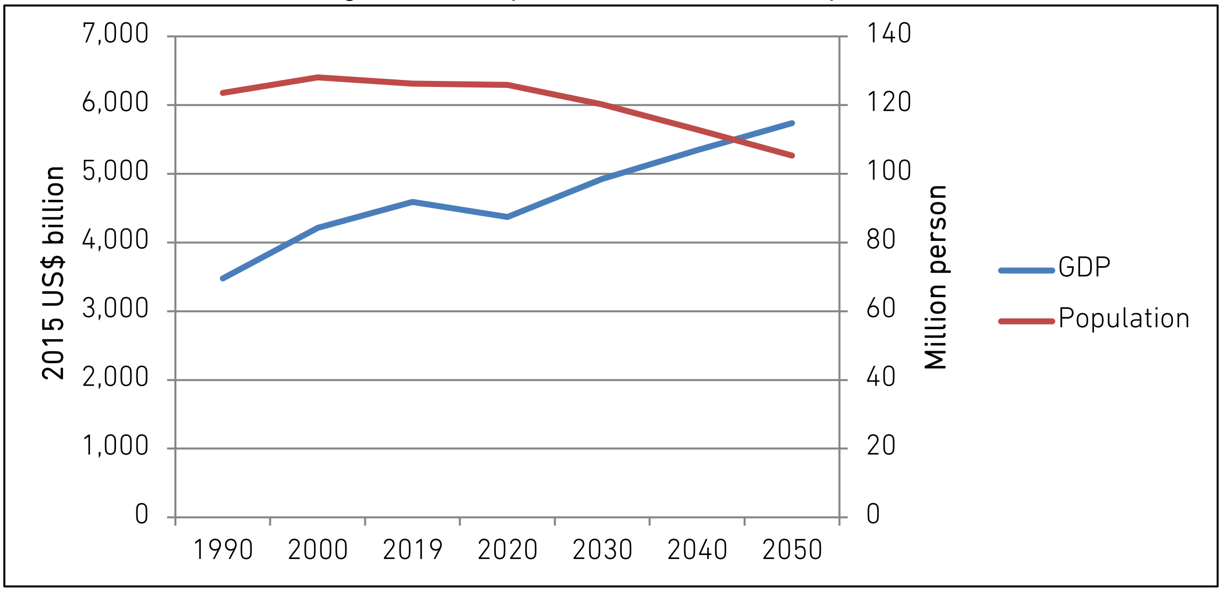
2. Modelling Assumptions

Macroeconomy

The general assumption for the macroeconomy is as described in ERIA (2023). Recently, Japan's gross domestic product (GDP) has continued to moderate and has achieved steady growth at 1.0% per year between 2010 and 2019. On the other hand, in 2020, the GDP declined 4.8% from the previous year due to the economic damage from the novel coronavirus disease (COVID-19) pandemic. In this outlook, the economy is projected to restart a slow and steady growth so that the GDP is assumed to grow at an average annual rate of 0.8% in the outlook period (from 2021 to 2050).

The population in Japan peaked around 2010 and has been declining since then. In the outlook period, the population will decline by about 0.6% per year due to the low birth rate. Consequently, the population is projected to decline from 126 million in 2020 to 105 million in 2050. Figure 7.1 shows the assumptions of GDP and population in this outlook.

Figure 7.1. Population and GDP Prospects



GDP = gross domestic product.

Sources: GDP: IMF (2021) and authors; population: UN DESA (2019).

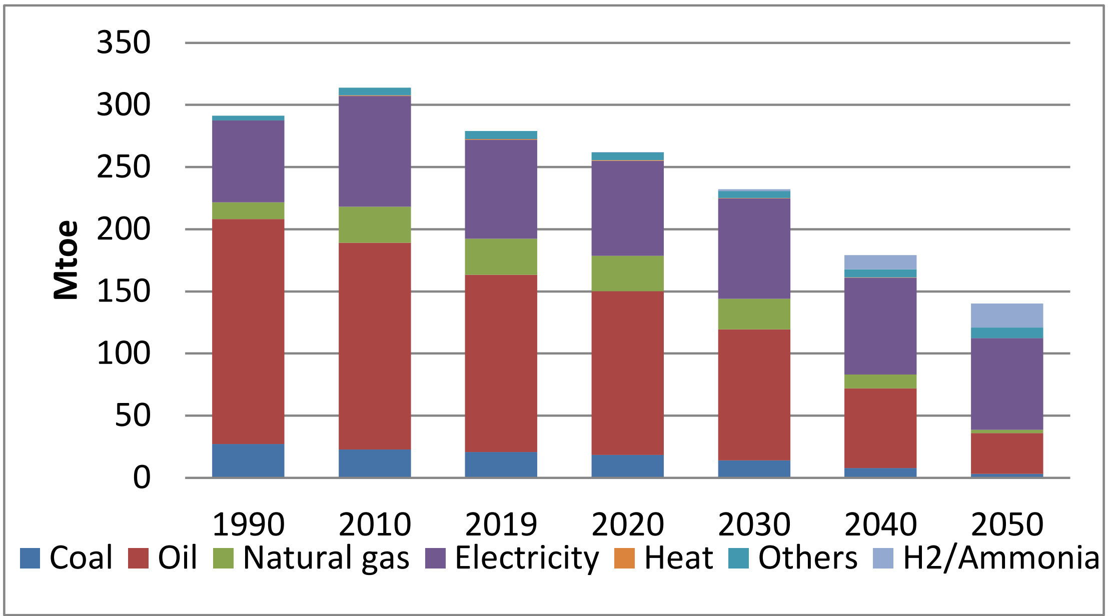
Additionally, the LCET–CN scenario is a back-casting scenario that assumes carbon neutrality in 2050. In the scenario, necessary efforts to achieve it will be made (regardless of cost efficiency). Since Japan has a very limited carbon capture and storage (CCS) potential, it is hardly considered in the BAU and the AP scenarios. However, the LCET–CN scenario assumes CCS penetration into existing thermal power plants and industrial processes due to the need for carbon neutrality.

3. Final Energy Consumption

In the LCET–CN scenario, the final energy consumption will decline approximately 2.5 times faster than in the BAU scenario, falling to 140 million tonnes of oil equivalent (Mtoe) in 2050 (Figure 7.2). The demand is equivalent to 64% of the BAU level.

To achieve carbon neutrality, significant energy transition from fossil fuels to electricity and hydrogen must be made. The fossil-fuel share will decrease drastically, from 69% of energy in 2019 to 27% in 2050. On the other hand, the share of electricity will increase from 29% in 2019 to 52% in 2050. Hydrogen and ammonia consumption starts in 2030 and finally made up 15% of final consumption in 2050.

Figure 7.1. Final Energy Consumption by Source

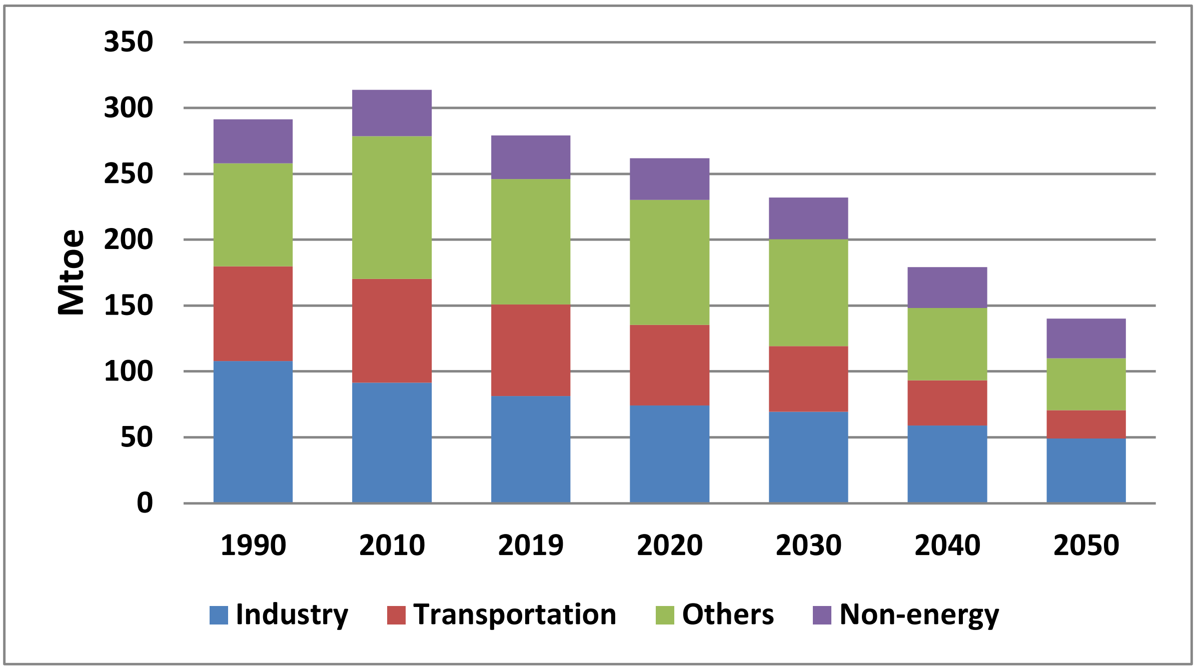


H_2 = hydrogen, Mtoe = million tonnes of oil equivalent.

Source: Authors' calculation.

In the transport and 'others' (residential and service) sectors, demand will be greatly reduced due to intensive energy conservation effort and electrification, which will improve energy efficiency (Figure 7.3). In the transport sector, higher efficiency of electric vehicles and fuel cell vehicles will largely contribute to drastic energy conservation. In the 'others' sector, electrification will significantly progress. In the industry sector, on the other hand, the decline will be limited. In this sector, it will be difficult to substitute all the fossil-fuel demand to electricity or hydrogen, due to the need for high-temperature heat sources and lock-in effect of existing machinery. Instead, CCS is assumed to implement to reduce CO_2 emissions.

Figure 7.3. Final Energy Consumption by Sector



Mtoe = million tonnes of oil equivalent.

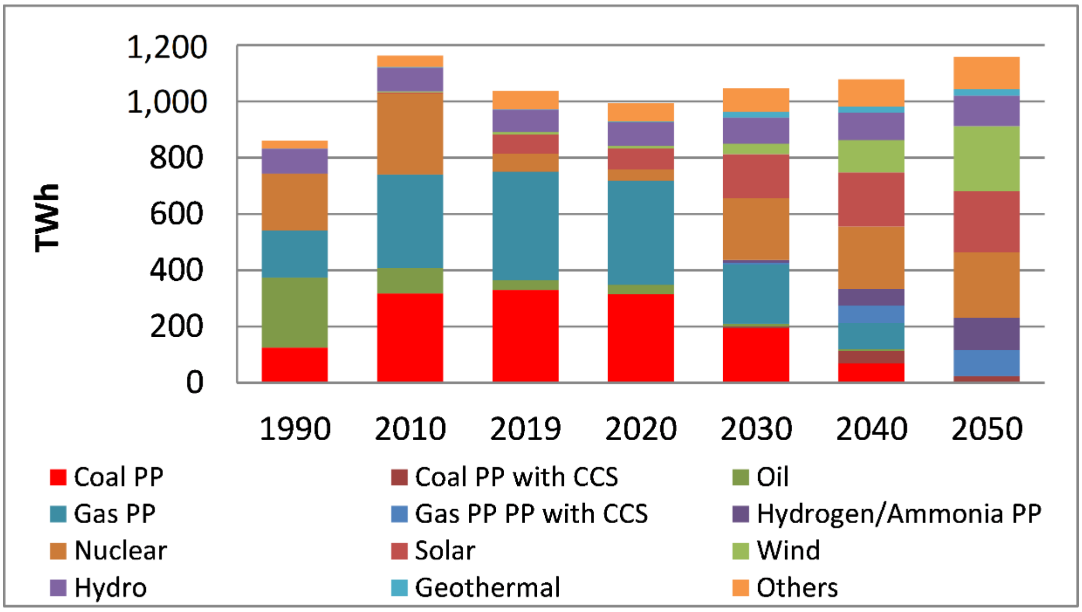
Source: Authors' calculation.

4. Power Generation

Power generation for the LCET–CN scenario in 2050 is projected to be 1,178 terawatt-hours (TWh). Due to rapid progress of electrification and demand for green hydrogen, generation for the LCET–CN scenario in 2050 will be larger than that in 2019, whilst total energy supply will decrease from that of 2019.

About 39% will be from solar photovoltaic (PV) and wind power. Since output from these variable renewable energies is unstable, backup storage and expansion of the grid will be necessary. Other renewables (hydro, geothermal, and biomass) will account for 21%. Nuclear energy covers 20% of total generation. The remaining 20% is thermal power, of which another 10% is hydrogen and 10% is coal and natural gas with CCS.

Figure 7.4. Power Generation, BAU, AP, and LCET–CN Scenarios



AP = alternative policy, BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.

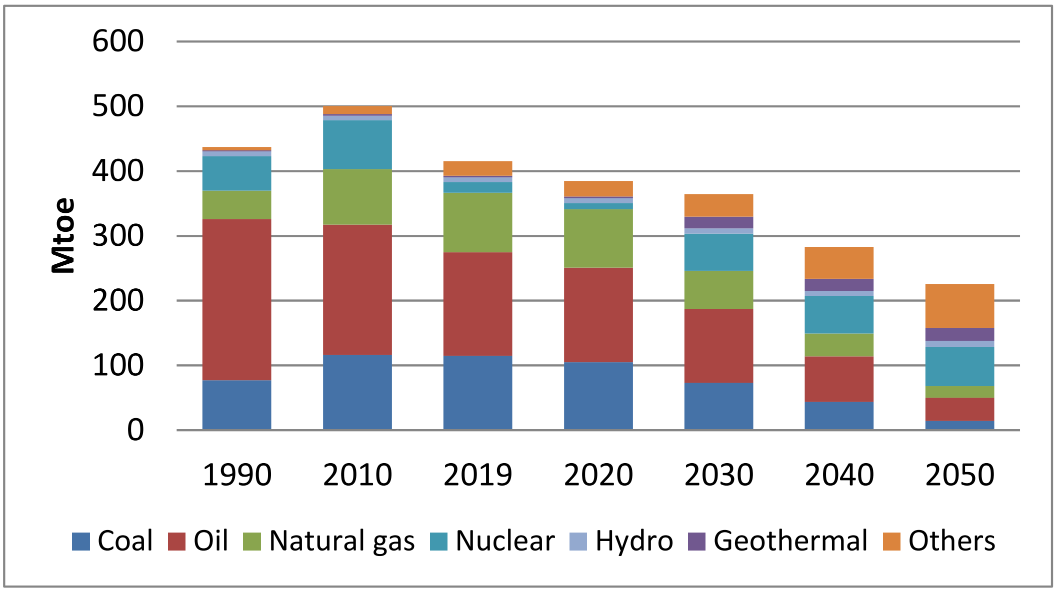
Source: Authors' calculation.

5. Primary Energy Supply

In the LCET–CN scenario, the primary energy supply will decline as significantly as final energy demand declines; the primary supply in 2050 is projected to be 247 Mtoe, 73% of the BAU level (Figure 7.5).

In addition, the share of fossil fuels, which accounted for 88% of the primary energy supply in Japan in 2019, will shrink to 28% in 2050. Nevertheless, even in such a progressively decarbonised scenario, demands for fossil fuels will not disappear, and efforts for stable supply of fossil fuels will remain one of the key energy policies in Japan.

Figure 7.5. Primary Energy Supply, BAU, AP, and LCET–CN Scenarios



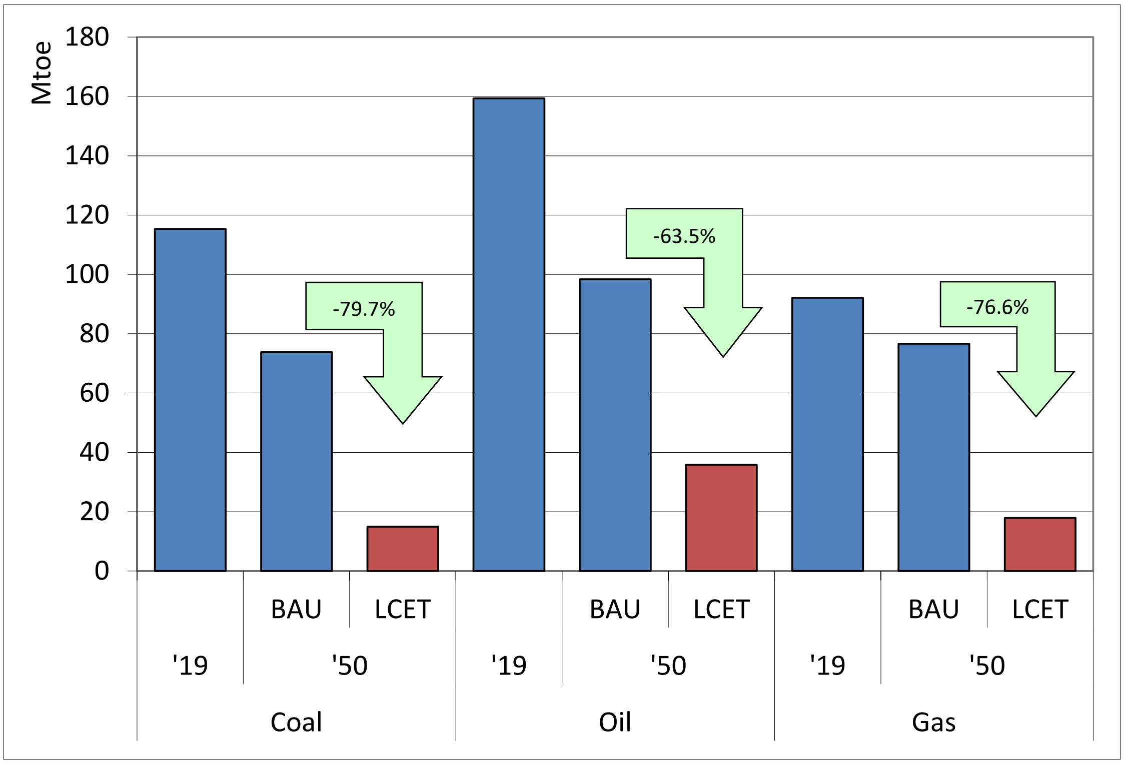
AP = alternative policy, BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.

Source: Authors' calculation.

6. Saving of Fossil Fuel Consumption and CO_2 Reduction

In the LCET–CN scenario, fossil fuel consumption will be about 25% of the BAU scenario, which will reduce 188 Mtoe (Figure 7.6). Amongst fossil fuels, coal is mostly replaced by other energy sources in industry and power sectors, with demand of only 15 Mtoe in 2050. On the other hand, oil demand will linger relatively even in 2050, which is used mainly in the industry and non-energy sectors.

Figure 7.6. Fossil Fuel Reduction in Primary Energy Supply, BAU, APS, and LCET–CN Scenarios

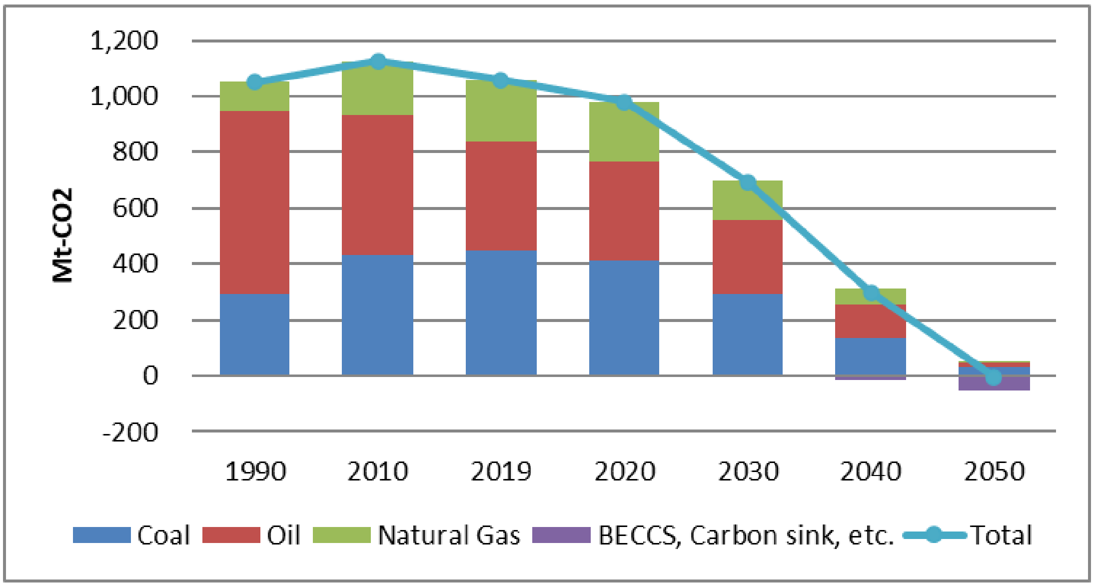


AP = alternative policy, BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, Mt-CO_2 = metric million tonnes of carbon.

Source: Authors' calculation.

Emissions in the LCET–CN scenario show even faster reductions than the trend (Figure 7.7). Japan's NDC target of energy-related CO_2 emissions for 2030 is 185 million tons of carbon (Mt-C), a 45% reduction from the 2013 level. The LCET–CN scenario will be consistent with the NDC target. In 2050, there are small fossil fuel demands that are difficult to substitute to a carbon-free energy source, leaving about 15 Mt-C of emissions from coal and oil. The residual emissions will be offset by negative emissions such as biomass CCS and forestry to achieve carbon neutrality.

Figure 7.7. Carbon Dioxide Emissions from Fossil Fuel Combustion, BAU, AP, and LCET–CN Scenarios



AP = alternative policy, BAU = business as usual, BECCS = bioenergy with carbon capture and storage, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, Mt-CO_2 = metric million tonnes of carbon.

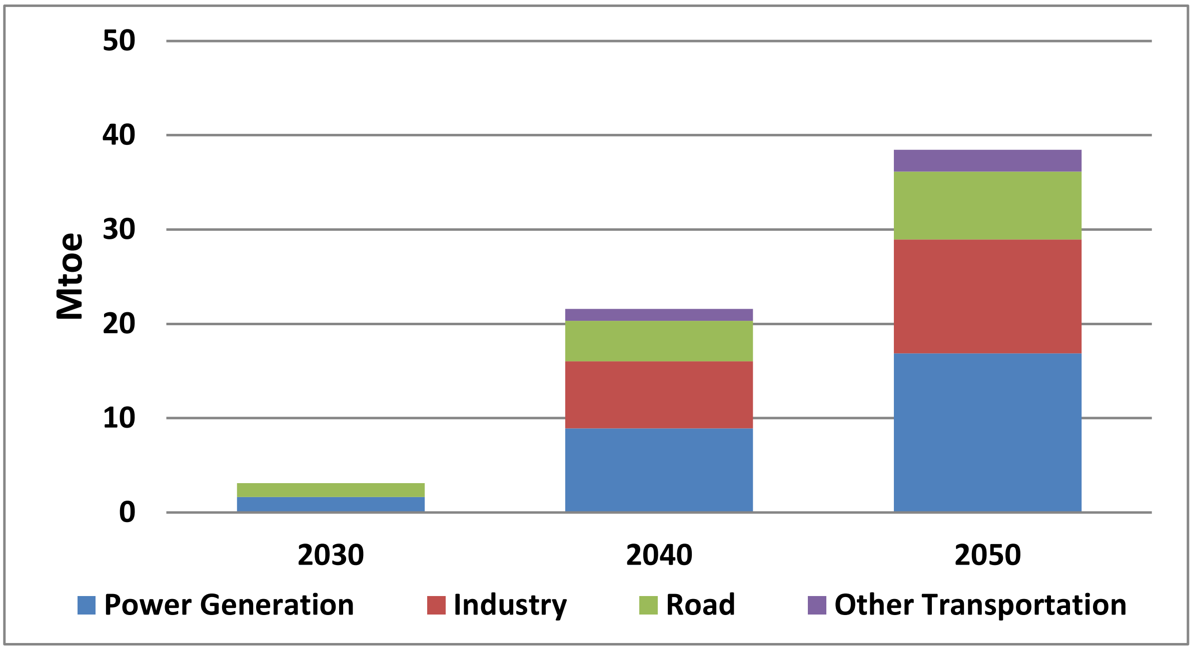
Source: Authors' calculation.

7. Hydrogen Demand across the Sector

In 2030, hydrogen consumption will be limited. Mainly it will be used as fuel for ammonia co-firing in coal-fired power plants and for hydrogen fuel cell vehicles. After 2040, hydrogen will also be used for industrial heating and as a fuel for other transportation (ships).

Consumption in 2050 will be about 40 Mtoe, which will account for 15% of final consumption.

Figure 7.8. Hydrogen Demand



Mtoe = million tonnes of oil equivalent.

Source: Authors' calculation.

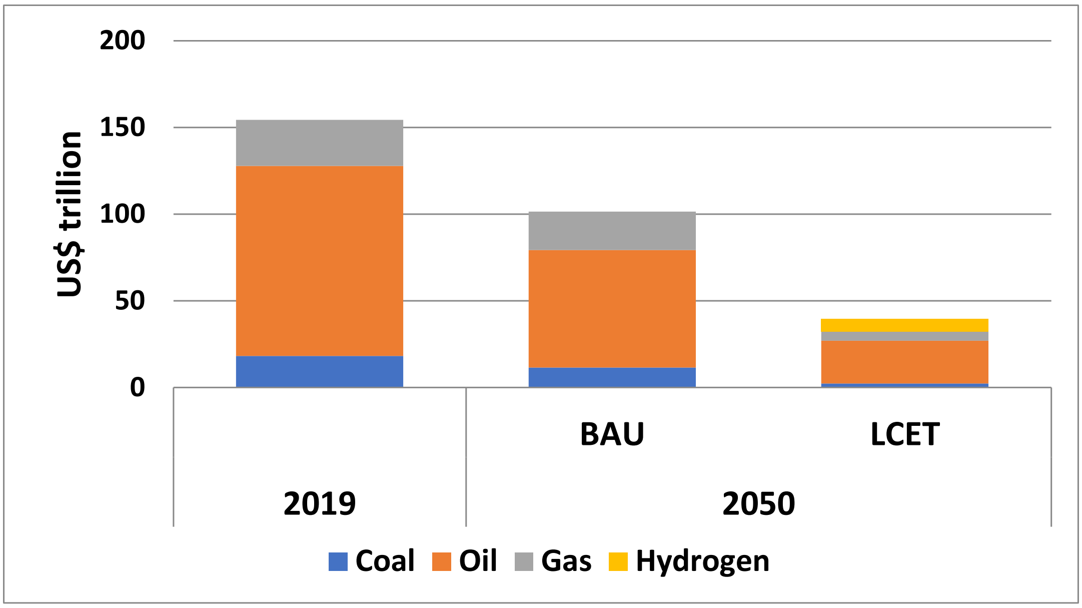
8. Energy Cost Comparison between BAU and LCET–CN Scenarios

In order to evaluate the cost of energy transition, key energy-related costs (fuel, investment for power generation, and CCS) for BAU and LCET–CN scenarios are evaluated based on the outlook results. In this sector, the US dollar means the real price in 2020.

8.1. Fuel Costs

Fuel costs in 2050 are US$39 trillion in the LCET–CN scenario because fossil fuel demand is much lower than in the BAU scenario. Although LCET–CN incurs additional costs due to hydrogen, the total fuel cost is still about 40% of the BAU scenario. We note, however, that this is a cost assessment based on ambitious assumptions regarding hydrogen and ammonia cost reductions, and the total cost may vary depending on the technology progress.

Figure 7.9. Fuel Cost



BAU = business as usual, LCET = low-carbon energy transition.

Note: 'Hydrogen' is only the cost of imported hydrogen and does not include the cost of green hydrogen to avoid double counting with the cost of power generation investment.

Source: Authors' calculation.

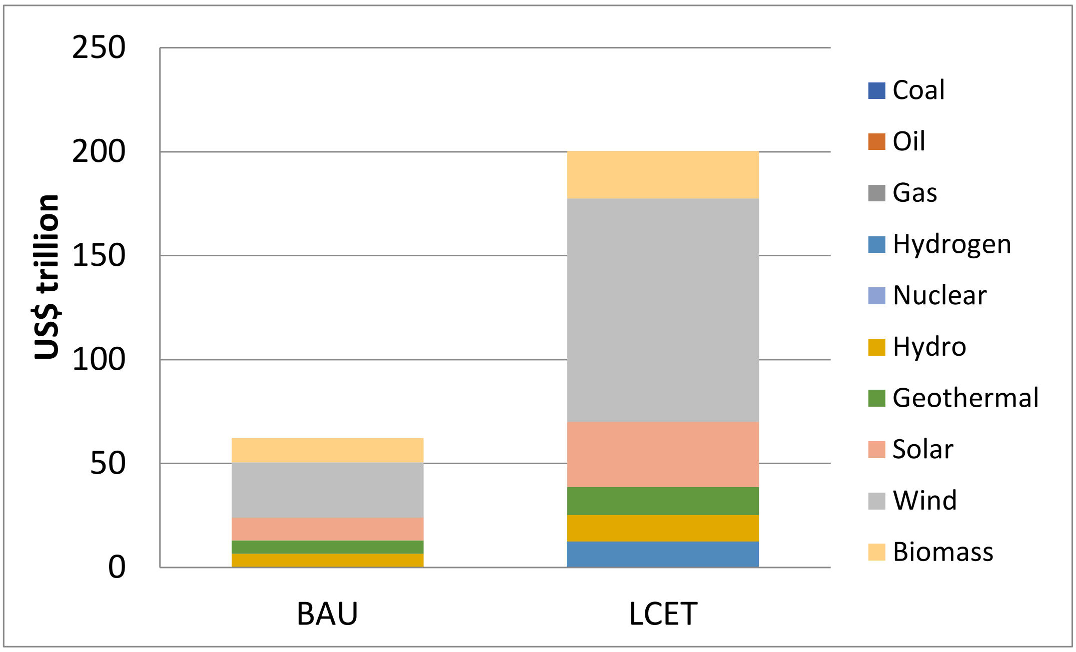
8.2. Power Generation Investment

To estimate the cost of investing in power generation equipment, the unit cost for each power was multiplied by the increase in installed capacity by 2050.

The LCET–CN scenario requires a capital cost of power generation (cumulative from 2020 to 2050) of US$200 trillion, which is more than three times that in the BAU scenario. Especially, large investments are required for solar PV and wind power.

The amount of power generation required in the LCET–CN scenario is 13% larger than that in BAU, so more capital investment is needed to accommodate the additional generation.

Figure 7.10. Power Generation Investment



BAU = business as usual, LCET = low-carbon energy transition.

Source: Authors' calculation.

8.3. CCS Cost

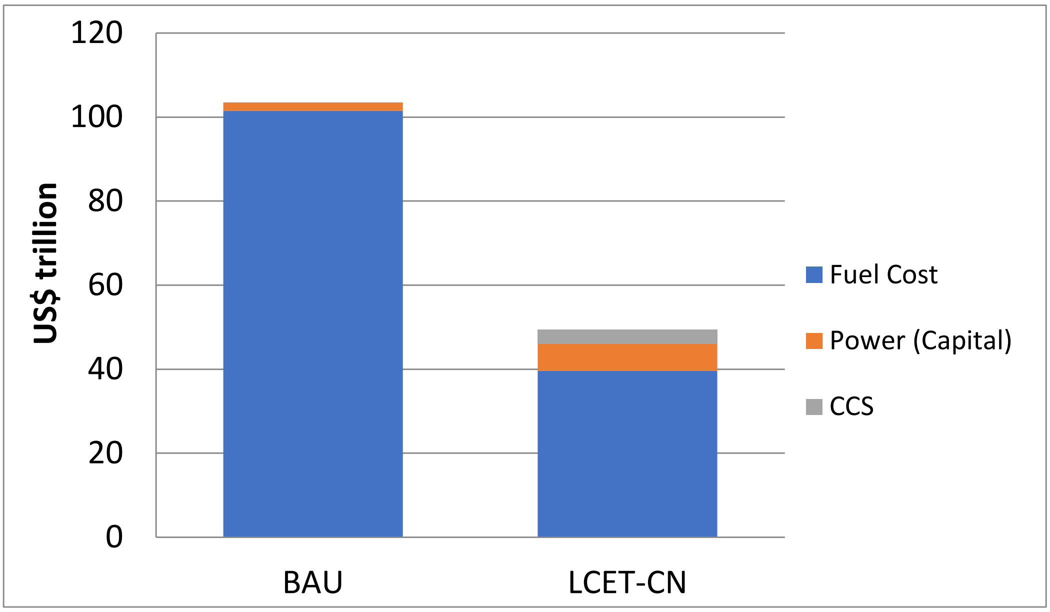
This cost element includes those for CCS implementation into power generation (gas and coal-fired).

The BAU scenario does not consider CCS, so its cost is zero. The LCET-CN scenario assumes that CCS will be incorporated into all coal-fired and gas-fired power plants and is estimated to cost US$3.4 trillion for its capture and storage.

8.4. Overall Cost

So far, costs related to fuels, generation capacities, and CCS have been evaluated. The total in 2050 are shown in Figure 7.11.

Figure 7.11. Cost in BAU and LCET–CN, 2050



BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral.

Notes: All of the costs are converted to an annual basis. This cost evaluation does not include those for energy efficiency improvement, energy storage, distribution, and transmission.

Source: Authors' calculation.

Due to the significant reduction in fuel costs, the cost of the LCET–CN scenario is less than half that of the BAU. Note, however, that this result does not necessarily imply that the cost of carbon neutrality is small.

Importantly, the LCET–CN scenario has significantly reduced energy demand due to energy efficiency improvement and this cost assessment does not include the costs for the efficiency improvement. Such costs vary greatly making them difficult to accurately evaluate them. However, as a rough evaluation, energy savings would cost at least about US$400 per kilolitre oil equivalent as of 2015 (METI, 2015). Furthermore, this cost per unit of energy saved will rise more and more with each increase in energy saved, so this can be a significant additional cost element of the LCET–CN scenario.

9. Conclusions and Policy Recommendations

According to Japan's net-zero policy, energy demand and CO_2 emissions can be reduced, however, net-zero emissions will not be materialised in the BAU and the AP scenarios. In the BAU scenario, CO_2 emissions in 2050 are 65% of 2019 levels. The AP scenario assumes faster energy efficiency improvements than the current trend, progress in restart of nuclear power plants and massive introduction of renewable energy so that CO_2 emissions in 2050 will be reduced to 41% of the 2019 level. Although this is a decent improvement, the results are still far from carbon neutral. They indicate that carbon neutrality requires further CO_2 reduction efforts than assumed in the forecast scenarios such as the BAU and the AP scenarios. In contrast, the LCET–CN scenario will complement this concern, which is a back-casting scenario that assumes carbon neutrality in 2050, as defined.

Nonetheless, CO_2 reduction is not the only focal point of energy policy. '3E+S' (Environment, Energy Security, Economic Efficiency + Safety) is a fundamental –principle in Japan's energy policy. Whilst the LCET–CN is a scenario that pursues environment, the scenario shows some challenges in terms of the remaining other two Es: energy security and economic efficiency.

(i) Energy Security

- Fossil fuels will be reduced to 32% of primary supply in the LCET–CN scenario but remain a necessary energy source. Efforts for a stable supply, from upstream investments to downstream infrastructure maintenance, will be still essential.
- Electricity and hydrogen will be largely deployed to replace fossil fuels. Challenges for energy security for these energies are also inevitable.
  - Electricity must be supplied stably, in greater quantities than at present, and without CO_2 emissions. In the LCET–CN scenario, the amount of power generation in 2050 is about 8% greater than today. Japan's government has already set renewable energy as its main power source. It is essential to develop the dispatchable capacity and adjust the capability for output fluctuation of renewables. Currently, investment in thermal power generation to provide this adjustment is difficult due to volatile wholesale electricity prices and decarbonisation policies, but policy efforts must continue to ensure sufficient capacity through 2050 and in the interim.
  - Hydrogen is expected to be supplied mainly through water electrolysis and imports in Japan, which has scarce fossil-fuel resources. Efforts must be made to build good relationships with hydrogen supplier countries and to form an international market, in the same way Japan currently does for a stable supply of fossil fuels.

- On the other hand, efforts towards carbon neutrality will increase the energy self-sufficiency rate. It will improve from 15% in 2020 to 65% in 2050 under the LCET–CN scenario.

(ii) Economic Efficiency

- Energy costs are also a significant issue. Although the costs of solar PV and wind power, which account for a significant share of electricity, are declining, additional costs will arise for investments in batteries to regulate their output, transmission lines to power generation facilities, and so on. In general, as the variable renewable energies share increases, the cost per kilowatt hour itself increases cumulatively. Therefore, it is necessary to try to utilise other power sources such as nuclear, hydrogen, and fossil fuels with CCS to reduce costs, rather than relying too heavily on renewable energy.
- In addition, the costs of energy efficiency improvement are expected to be enormous. The cost evaluation showed that efforts toward carbon neutrality can lead to reducing fuel and power generation costs. It should be noted, however, that the evaluation does not fully evaluate the costs associated with energy conservation (e.g. from installing high-efficiency equipment or changing operations).

Carbon neutrality is exceedingly difficult to achieve with a combination of existing and mature technologies, and the LCET–CN scenario incorporates developing technologies such as CCS and hydrogen. Financial and technical support from the government for these technologies are significant. In addition, in the transition period around 2040, current technologies and facilities will be mixed with these developing technologies including hydrogen and CCS. It is essential to replace existing technologies with new technologies prudently so that a stable energy supply will not be compromised in the process.

References

Economic Research Institute of East Asia (ERIA) (2023), *Energy Outlook and Energy Saving Potential in East Asia 2023.* Jakarta: ERIA. https://www.eria.org/publications/energy-outlook-and-energy-saving-potential-in-east-asia-2023/ (accessed December 2023).

International Monetary Fund (IMF) (2021), *World Economic Outlook October 2021. Recovery during a Pandemic.* Washington, DC: IMF. https://www.imf.org/en/Publications/WEO/Issues/2021/10/12/world-economic-outlook-october-2021 (accessed July 2023).

Ministry of Economy, Trade and Industry Japan (METI) (2015), 'Relationship Between Energy Saving Effect and Investment'. https://www.meti.go.jp/shingikai/enecho/shoene_shinene/sho_energy/pdf/012_02_00.pdf (accessed July 2023). (in Japanese)

Ministry of Economy, Trade and Industry Japan (METI) (2021a), Strategic Energy Plan. https://www.enecho.meti.go.jp/en/category/others/basic_plan/ (accessed July 2023).

Ministry of Economy, Trade and Industry Japan (METI) (2021b), Energy Balance Table. https://www.enecho.meti.go.jp/statistics/total_energy/ (accessed July 2023).

United Nations Department of Economic and Social Affairs. Population Division (UN DESA) (2019), *World Population Prospects 2019*. New York: United Nations. https://population.un.org/wpp/ (accessed November 2021).

Chapter 8

Republic of Korea Country Report

Kyung-Jin Boo

Seoul National University, Republic of Korea

1. Basic Concept of Low-carbon Energy Transition–Carbon Neutrality

The global effort to achieve net-zero carbon requires innovation in the energy sector. The energy sector accounts for approximately 75% of global carbon emissions. The main levers for the energy sector to achieve carbon neutrality are low-carbon energy transition and carbon neutrality (LCET–CN) including energy reduction through behaviour change, energy efficiency, clean energy, electrification, carbon capture, utilisation, and storage (CCUS), etc. Electrification, which increases the proportion of electricity in final energy consumption, is being considered by countries around the world as a major means of carbon neutrality.

The energy sector is the leading contributor to greenhouse gas (GHG) emissions, making the low-carbon energy transition a global trend since GHG emissions affect global warming and climate change, the most important issues globally. To achieve carbon neutrality in 2050, the overall structure of the energy sector needs to be transformed in addition to reducing the use of fossil fuels. Consequently, most countries are trying to transform their energy systems from the current fossil energy-oriented one to a sustainable green energy-oriented one rested on energy efficiency and renewable energy.

In this context, the Republic of Korea has established and implemented several basic plans and roadmaps including Energy Transition Roadmap, Energy Basic Plans, Renewable Energy Basic Plans, 2050 Carbon Neutral Strategy, Rational Energy Use Basic Plans, Electricity Supply and Demand Basic Plans, and Hydrogen Economy Revitalization Roadmap, to name a few. The government takes these basic plans and roadmaps as stepping stones to mobilise nationwide resources in relevant energy sectors to reduce carbon dioxide (CO_2) emissions in response to the historic Paris Agreement in 2015 as well as the global trend of energy transition to a sustainable energy system. Despite all these efforts and the government's commitment, that is not enough. In order to cost-effectively implement those plans supported by consensus amongst stakeholders and national participants, it would better be preceded or directly followed by technical as well as an economic feasibility analysis based on calculations of investment costs in terms of fuel costs, power generation, carbon capture and storage (CCS), etc.

2. Final Energy Consumption (historical trend: 2019, 2030, 2040, 2050)

This section discusses the LCET–CN scenario developed based on the combination of policy options including efficiency improvement, more efficient thermal power generation along with higher contribution of renewable energy and hydrogen, amongst others.

Historical Trend

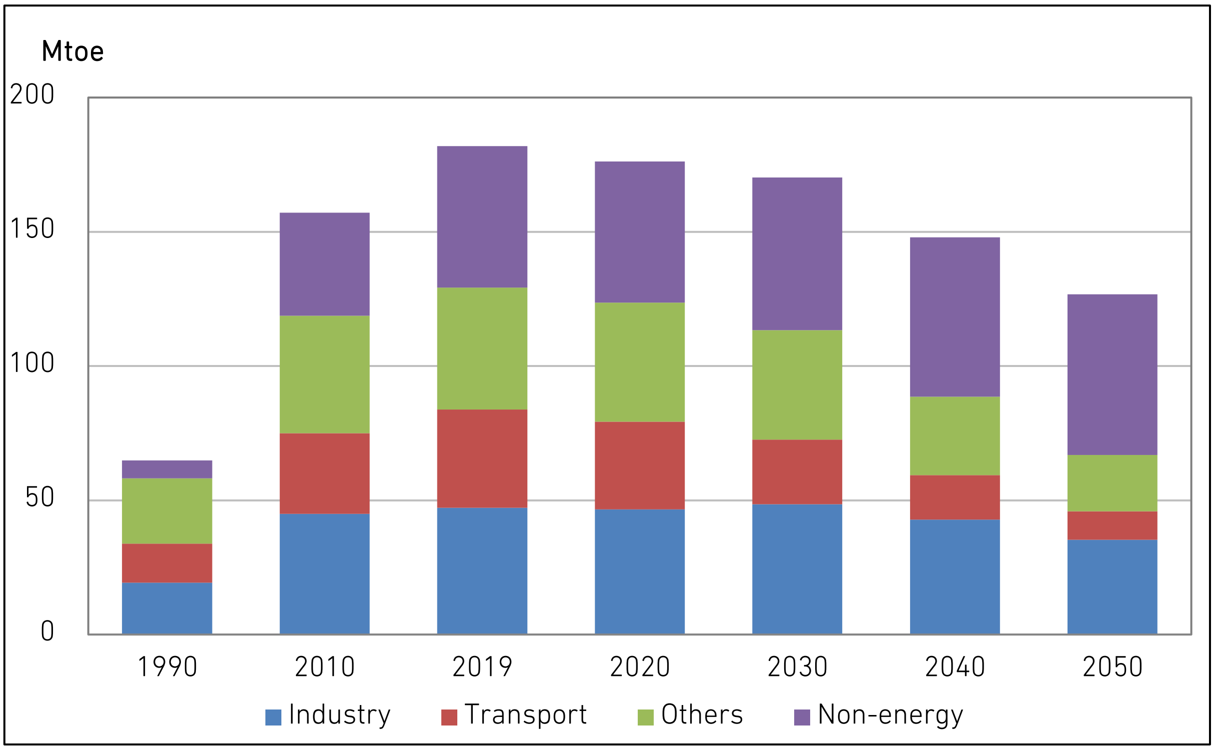
The Republic of Korea's final energy consumption grew 3.6% per year, from 64.9 million tonnes of oil equivalent (Mtoe) in 1990 to 181.9 Mtoe in 2019. The non-energy sector had the highest growth rate during this period at 7.4% per year, followed by the transport sector with 3.2%. Energy consumption in the residential/commercial/public ('others') sector grew at a relatively slow pace of 2.2% per year. Oil was the most consumed product, with a share of 67.3% in 1990, declining to 53.8% in 2019. The share of coal in the final energy consumption declined by 13.7 percentage points between 1990 and 2019, whereas the share of electricity nearly doubled, becoming the second-largest consumed product.

LCET–CN Scenario

The total final energy demand in the LCET scenario is to be reduced to 126.7 Mtoe, decreased by 55.3 Mtoe or 30.4% from 181.9 Mtoe in 2019 at a negative annual average growth rate (AAGR) of –1.2%. Figure 8.1 shows the final energy demand by sector in the LCET scenario. The transport sector shows the fastest decreasing rate at –3.9% per year, followed by the industry sector at –1.2% per year. The share of final energy demand by sector shows a structural change from 2019. The share of transport is forecast to decrease, whilst the share of industry and 'others' sectors will slowly increase at first and decrease later. The share of non-energy sector will increase at a faster speed, reaching 47.2% in 2050.

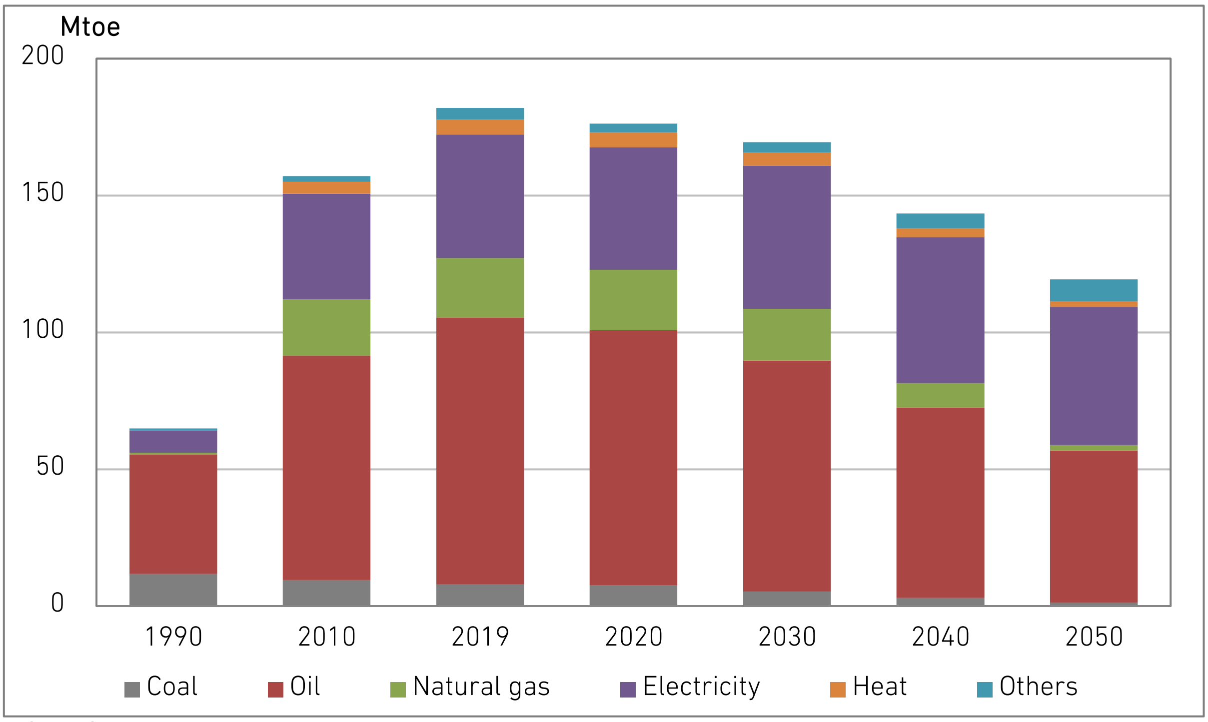
Final energy demand by source is shown in Figure 8.2. Oil will continue to be a dominant energy, accounting for 43.9% of its share, followed by electricity, 39.8%, hydrogen/ammonia, 5.7%, and natural gas, 1.6%. Coal will be marginalised at a share of 0.9% as a minor energy source for industrial, residential, and commercial use. Others such as biomass, heat, and other renewable energies, are expected to be increasing its share from 1.1% in 2019 to 2.3% in 2050.

Figure 8.1. Final Energy Consumption by Sector: LCET–CN Scenario



LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

Figure 8.2. Final Energy Consumption by Energy: LCET–CN Scenario



LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

3. **Power Generation (historical trend: 2019, 2030, 2040, 2050)**

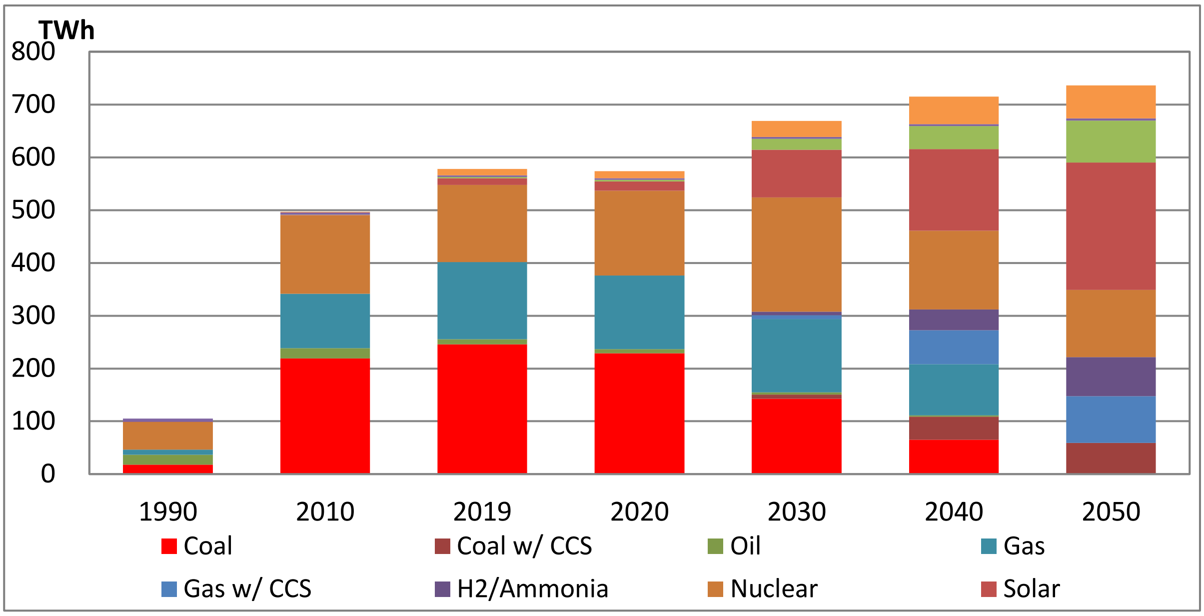
Historical Trend

In 2019, electric power generation in the Republic of Korea amounted to 578.0 terawatt-hours (TWh), with coal providing nearly half of the country's electricity (42.6%), followed by natural gas at 25.3%, and nuclear power at 25.2%. Total electricity consumption grew at an AAGR of 6.0% between 1990 and 2019. When broken down by fuel type, coal increased at an annual rate of 9.5%, natural gas at 9.8%, and nuclear at 3.6% between 1990 and 2019. Over the same period, oil had a negative annual growth rate of –2.4% whilst hydro had –2.8%. Meanwhile, other energy sources such as new and renewable energy has grown rapidly, solar photovoltaic (PV) cells in particular, having grown amazingly fast at an annual rate of 32.8%.

LCET–CN Scenario

As shown in Figure 8.3, electric power generation in the LCET–CN scenario is projected to increase from 578.0 TWh in 2019 to 736.1 TWh in 2050. In terms of fuel mix in the power generation, it is predicted that clean and carbon-free energy sources, such as solar PVs and wind power, will experience a rapid increase. Power generation by fossil fuels equipped with CCS will replace the existing power plants, resulting in 8.0% for coal and 12.1% for natural gas with a total of 20% in the LCET–CN scenario. The fuel mix is expected to include hydrogen, making up approximately 10% of the total. Other fuels, including nuclear and other renewables, are expected to hold higher shares in the fuel mix.

Figure 8.3. Power Generation by Energy Source: LCET–CN Scenario



CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, TWh = terawatt-hour.
Source: Author's calculations.

4. Primary Energy Supply

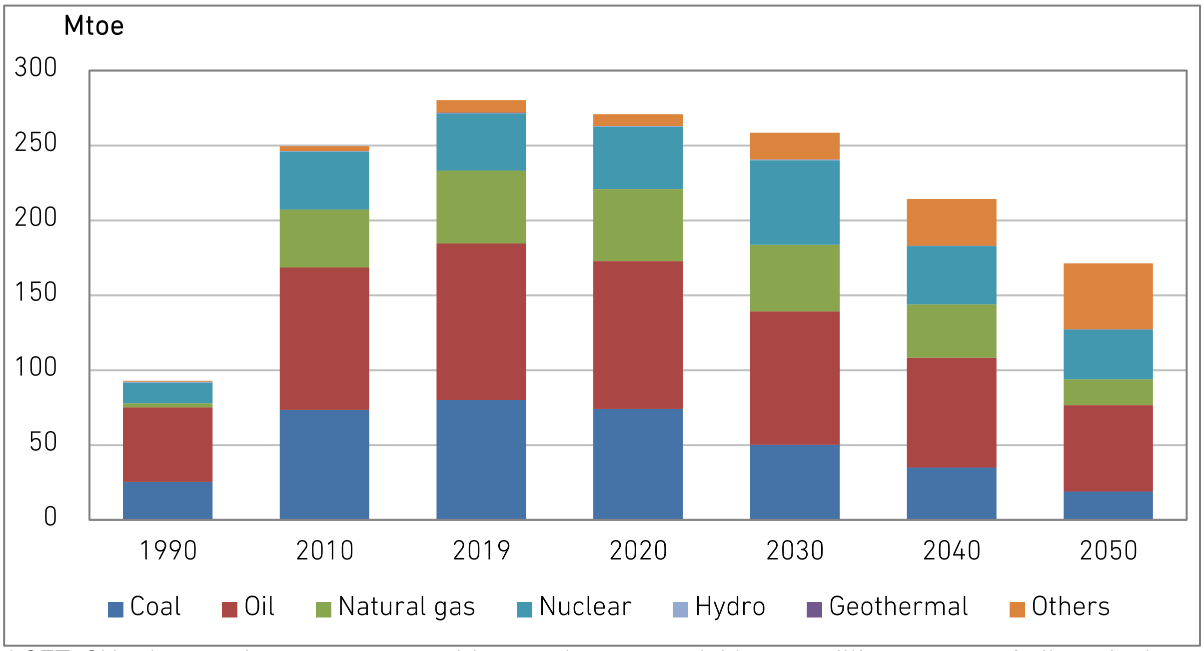
Historical Trend

Primary energy demand in the Republic of Korea had increased at an AAGR of 4.2%, from 92.9 Mtoe in 1990 to 280.2 Mtoe in 2019. Amongst the major energy sources, natural gas grew the fastest at an average annual rate of 10.5%. The next was coal (4.0%), followed by nuclear (3.6%) and oil (2.6%) over the same period. Other energy sources, mainly renewable energy such as solar, wind, biomass, and ocean energy, have been rapidly growing at a rate of 8.7% over the same period. This indicates that the government has been successfully implementing its 'Low Carbon Green Growth' and 'Energy New Industry' policies initiated by the previous two administrations.

LCET«CN Scenario

In the LCET–CN scenario, primary energy supply is projected to decrease at an AAGR of –1.4% per year from 280.2 Mtoe in 2019 to 180.3 Mtoe in 2050. Consumption of fossil fuels, such as coal, oil, and nuclear will gradually decrease in 2019–2050, whereas that of clean energy such as hydro and new and renewable energy will increase by 1.1% and 5.5% per year, respectively, over the projection period (Figure.8.4). Aggressive implementation of energy efficiency and conservation measures on the demand side, along with a larger uptake of renewable energy on the supply side along with accelerated adoption of CCS in power generation by coal and gas, will be the major contributors to reduced fossil fuel consumption.

Figure 8.4. Total Primary Energy Supply: LCET–CN Scenario



LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

5. Carbon Dioxide Emissions

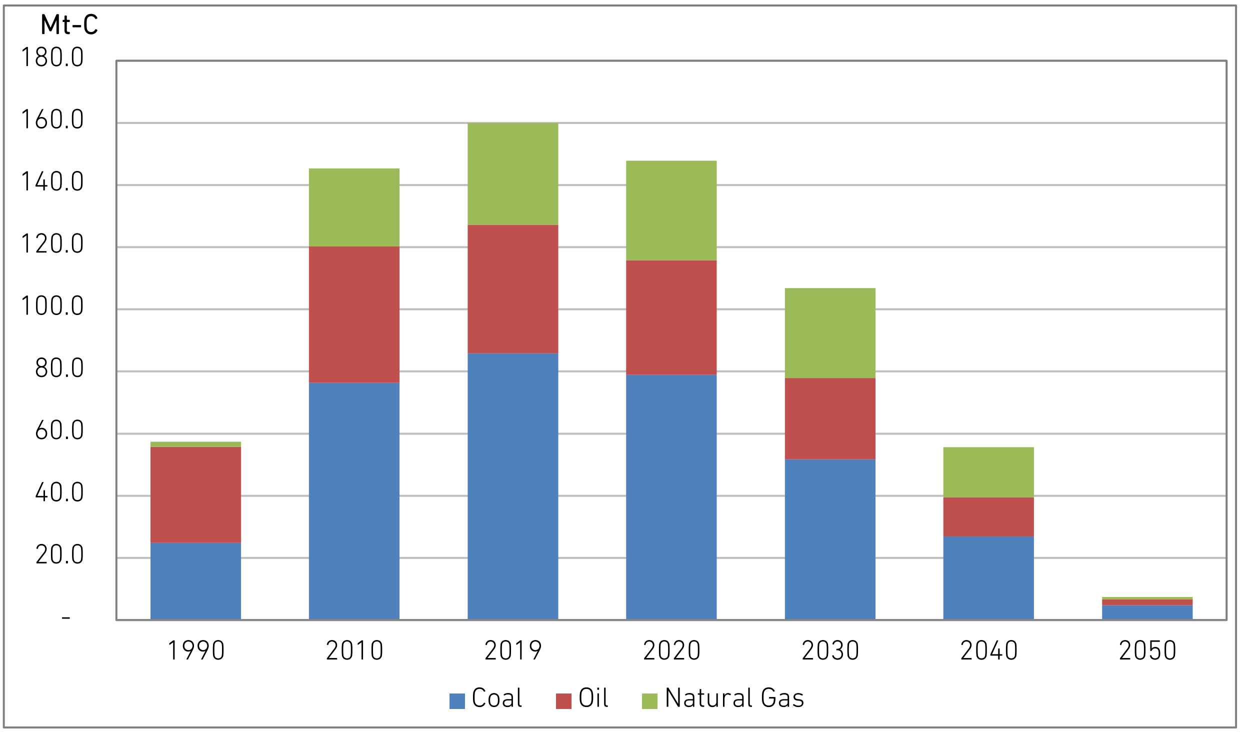
Historical Trend

Carbon dioxide (CO_2) emissions from energy consumption had increased at an AAGR of 3.6%, from 57.4 CO_2 in 1990 to 497.0 million tonnes of carbon (Mt-C) in 2019 due to the continuous increase in fossil fuel consumption during the same period, which used to be explained in terms of coupling between economic growth and energy consumption. Amongst fossil fuels, coal contributes most at 53.6%, oil, 25.9%, and natural gas, 20.5% in the total CO_2 emissions.

LCET–CN Scenario

CO_2 emissions from energy consumption in the LCET–CN scenario are projected to abruptly decrease at an AAGR of –10.4%, from 160.0 Mt-C in 2019 to 5.3 Mt-C in 2050 as shown in Figure 8.5. Such a negative growth rate is much lower than that of primary energy consumption which is estimated to be –1.4% per year. This indicates that the Republic of Korea will be using less carbon-intensive fuels – such as nuclear, natural gas, and renewable energy – and employing more energy-efficient green technologies. To attain such an ambitious target, the government must develop and implement cost-effective and consensus-based action plans to save energy and reduce CO_2 emissions.

Figure 8.5. CO_2 Emissions: LCET–CN Scenario



LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: Author's calculations.

6. Hydrogen Demand across Sectors

Hydrogen is regarded as an energy carrier, playing a key role in energy transition to a future sustainable energy system. The Republic of Korea is no exception in this global trend, it is promoting a large uptake of hydrogen across the sector. One of the key elements of the 2050 Vision of 2050 Carbon Neutrality Strategy is expanding the use of clean power and hydrogen across all sectors.

The Republic of Korea's hydrogen industry is growing rapidly, and in 2021, about 2.4 million tonnes of hydrogen were produced, 53.3% of which was grey hydrogen and 46.6% by-product hydrogen. The goal of domestic clean hydrogen production technology is to develop and indigenise systems, improve alkaline and polymer electrolyte membrane (PEM) water electrolysis, design development of water electrolysis stacks and systems, and research and development of future hydrogen production technologies.

In the logistics sector, policy directions are focused on infrastructure building including hydrogen distribution and charging stations. Hydrogen is being delivered using hydrogen tube trailers – currently there are about 950 hydrogen tube trailers in operation in the Republic of Korea. There are 244 hydrogen charging stations nationwide, with a focus on hydrogen distribution and charging infrastructure development. In the distribution and storage sector, infrastructure development for the overseas introduction of clean hydrogen is underway, and a pilot plant demonstration project for ammonia-based clean hydrogen production is also underway.

The Republic of Korea's 'Hydrogen Economy Revitalization Roadmap' was initially centred on the hydrogen car and hydrogen fuel cell industries, and as of May 2023, 32,168 hydrogen cars had been supplied. By the end of May 2023, about 917.21 megawatts (MW) of power generation fuel cells were supplied in the field of power generation fuel cells, and steady growth was achieved. In the hydrogen utilisation sector, mobility technology development, hydrogen power generation technology development, and infrastructure construction projects are the main areas, and ammonia-based clean hydrogen power generation and hydrogen hybrid power generation demonstration projects using gas turbines are underway. Technology goals include improving the fuel economy and durability of hydrogen vehicles, developing fuel cell capacity and repackaging technology for large-scale mobility, and developing technologies for hydrogen railways, hydrogen ships, and drone fuel cell systems. It is also planned to develop technology for direct hydrogen combustion technology and to build a power generation system using hydrogen and ammonia.

Table 8.1. Hydrogen Roadmap: Targets

		2018	2022	2040
Hydrogen Vehicles (Export) (Domestic)		**1.8 thousand** (0.9 thousand) (0.9 thousand)	**81 thousand** (14 thousand) (67 thousand)	**6,200 thousand** (3,300 thousand) (2,900 thousand)
Fuel Cells	Power Generation (Domestic)	**307 MW** (total)	**1.5 GW** (total)	**307 MW** (total)
	Residential/Buildings	**7 MW**	**7 MW**	**7 MW**
Hydrogen supply		130 thousand/year	470 thousand/year	5,260 thousand/year
Hydrogen price		-	W6,000/kg	W3,000/kg

GW = gigawatt, kg = kilogramme, MW = megawatt.
Source: MOTIE (2019).

The Republic of Korea has set a goal of supplying about 470,000 tonnes of hydrogen per year in 2022, about 1.94 million tonnes per year in 2030, and more than 5.26 million tonnes per year in 2040. In the Hydrogen Economy Revitalization Roadmap in 2019, a supply plan was established in consideration of all forms of hydrogen, including by-product hydrogen and grey hydrogen. The supply of hydro electrolytic hydrogen will begin in 2022, and from 2030 the supply of hydro electrolytic hydrogen and hydrogen produced abroad will be expanded (Table 8.2).

Table 8.2. Hydrogen Production

	2018	2022	2030	2040
Supply (=demand)	130 thousand ton/year	470 thousand ton/year	1,940 thousand ton/year	〉5,260 thousand ton/year
Hydrogen production	① By-product H_2 ② Reformed H_2	① By-product H_2 ② Reformed H_2 ③ Electrolysis	① By-product H_2 ② Reformed H_2 ③ Electrolysis ④ Overseas Production ※①+③+④: 50% ②: 50%	① By-product H_2 ② Reformed H_2 ③ Electrolysis ④ Overseas Production ※ ①+③+④: 50% ②: 30%
Hydrogen price	- (policy pricing)	W6,000/kg (initial market price)	W6,000/kg	W3,000/kg

H_2 = hydrogen, kg = kilogramme.
Source: MOTIE (2019).

7. Energy Cost Comparison between BAU and LCET–CN Scenarios

This section conducts an analysis on energy cost in order to compare the cost difference between the business as usual (BAU) and LCET–CN scenarios. This analysis enables us to estimate the total investment cost in implementing policies and programmes under the LCET–CN scenario in comparison with the BAU scenario. The basic assumptions for this analysis are shown in Table 8.3.

Table 8.3. Assumptions for Fuel Costs

Energy Source (units)	2019/2020	2050[1)]
Coal (US$/tonne)	80.03	98.00
Oil (US$/bbl)	41	100
Gas (US$/MMBtu)	7.77	7.50
Hydrogen (US$/$Nm^3$)	0.8	0.3
CCS (US$/$CO_2$ tonne)	0	30

CCS = carbon capture and storage, bbl = barrel, MMBtu = metric million British thermal unit, Nm^3 = normal cubic metre.
Note: [1)] 2019 constant price.
Source: Author's calculations.

Table 8.4. Assumptions for Construction Cost of Power Plants
(US$/KW)

Fuel Source	2019/2020	2050[1)]
Coal	1,500	1,525
Oil	41	100
Gas	7.77	700
Hydrogen	0.8	700
Nuclear	4,500	3,575
Hydro	2,000	2,223
Geothermal	4,000	4,256
Solar	1,600	307
Wind	1,600	1,235
Biomass	2,000	3,019

KW = kilowatt.
Note: [1)] 2019 constant price.
Source: Author's calculations.

Table 8.5. Assumptions for Capacity Factors of Power Plants
(%)

Fuel Source	2019/2020	2050[1]
Coal	75	80
Oil	75	80
Gas	75	80
Hydrogen	0	80
Nuclear	100	80
Hydro	50	40
Geothermal	50	50
Solar	17	17
Wind	40	40
Biomass	50	70

Note: [1] 2019 constant price.
Source: Author's calculations.

7.1. Fuel Cost

Based on fuel costs assumed for each of energy source in Table 8.1, total investment fuel cost was calculated as shown below in Table 8.6. Primary energy consumption in the LCET–CN scenario will be 102.8 Mtoe which is much lower than that of BAU scenario at 102.8 Mtoe. Consequently, the total investment fuel cost in 2050 in the LCET–CN scenario is estimated to be US$51,141 million, which is a lot lower than that under the BAU scenario at US$89,219 million.

Table 8.6. Total Investment by Energy Source, BAU vs LCET–CN Scenarios

	Primary Energy Consumption (Mtoe)			Total Investment (US$ million)	
	BAU		LCET–CN	BAU	LCET–CN
	2019	2050	2050	2050	2050
Coal	80.04	62.89	18.93	9,939	2,992
Oil	104.43	85.80	57.75	59,017	39,722
Gas	48.87	69.76	17.16	20,145	4,956
Hydrogen	0.0	0.31	8.94	119	3,472
Total	**233.34**	**218.77**	**102.79**	**89,219**	**51,141**

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

7.2. Power Generation Investment

Based on assumptions for power generation investment shown in Table 8.4 and Table 8.5, the total investment cost for power plants was calculated in 2050 for BAU and LCET–CN scenarios shown in Table.8.7. As shown in Table 8.7, the total additional capacity required by 2050 under the BAU scenario is 38,343 MW since 2019. However, the additional capacity under the LCET–CN scenario is estimated to be 160,963 MW which is much bigger than that under the BAU scenario. This is due to more aggressive uptake of renewable energy (RE) for power plant in 2050 under the LCET–CN scenario in pursuit of greater reduction in CO_2 emissions. Accordingly, the total investment for power plants in 2050 under the BAU scenario is estimated to be US$26,081 million whereas it is estimated to be US$30,744 million under the LCET–CN scenario.

Table 8.7. Total Investment in Power Plants, BAU vs LCET–CN Scenarios

	Primary Energy Consumption (TWh)			Additional Capacity (MW)		Total Investment (US$ million)	
	BAU		LCET–CN	BAU	LCET–CN	BAU	LCET–CN
	2019	2050	2050	2050	2050	2050	2050
Coal	246.07	234.48	58.89	–1764	–28,490	0	0
Oil	9.30	0.12	0.00	–1398	–1,416	0	0
Gas	146.10	303.40	88.82	23,943	–8,717	16,760	0
Hydrogen	0.00	0.00	73.61	0	11,204	0	7,843
Nuclear	145.91	68.30	127.32	–11,075	–2,653	0	0
Hydro	2.83	3.56	3.88	138	200	307	444
Geothermal	0.00	0.00	0.00	0	0	0	0
Solar	13.00	48.94	241.58	24,133	153,492	7,409	47,122
Wind	2.68	15.90	79.57	5,032	29,257	6,214	36,133
Biomass	9.32	14.12	62.45	731	8,086	2,207	24,413
Total	**575.20**	**688.82**	**736.11**	**38,343**	**160,963**	**32,897**	**115,955**

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, MW = megawatt, TWh = terawatt-hour.
Source: Author's calculations.

7.3. Carbon Capture and Storage Cost

Power generation, fuel consumption, and investment cost for CCS were calculated for power generation by coal-fired and natural gas-fired power plants equipped with CCS. Assuming that CCS devices can capture up to 90% of CO_2 emissions and the average cost of capture is about US$30/$CO_2$ ton, the total investment for CCS is estimated to be

US$3,257 million for coal-fired power plants and US$1,947 million for gas-fired, respectively, with a total of US$5,204 (Table 8.8).

Table 8.8. Total Investment for CCS under LCET–CN Scenario in 2050

	Power Generation (TWh)	Fuel Consumption (Mtoe)	CO_2 Emissions ($Mt\text{-}CO_2$)	CO_2 Emissions (Mt-C)	Total Investment (US$ million)
Coal-fired Power Plant	58.89	13.85	51.70	14.09	3,257
Gas-fired Power Plant	88.82	14.51	30.91	8.42	1,947
Total	**147.71**	**28.36**	**82.61**	**22.51**	**5,204**

CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent, Mt-C = million tonnes of carbon, $Mt\text{-}CO_2$ = million tonnes of carbon dioxide equivalent, TWh = terawatt-hour.
Source: Author's calculations.

7.4. Overall Cost

Based on the above calculation results, it is possible to compare total costs between the LCET–CN and the BAU scenarios as shown in Table 8.9. Overall investment cost under the BAU scenario in 2050 is projected to be US$90,280 million, whilst the investment cost in the LCET–CN scenario is estimated at US$60,086 million. This result indicates that the total investment in the LCET–CN scenario will save 33.5% of that amount in the BAU scenario, amongst which fuel cost contributes more than 100% to the cost savings in the LCET–CN scenario.

Table 8.9. Cost Comparison: BAU vs LCET–CN Scenarios in 2050 (US$)

	BAU	LCET–CN	LCET–CN vs BAU
Fuel Cost	89,219	51,141	–38,078
Power Capital Cost	1,061	3,740	2,679
CCS	0	5,204	5,204
Total	**90,280**	**60,086**	**–30,194**

BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Author's calculations.

8. Conclusions and Policy Recommendations

Up to now, starting with a series of assumptions on fuel costs and construction costs as well as capacity factors of power plants by energy source, investment costs under the BAU and the LCET–CN scenarios were calculated and compared with each other in terms of primary energy supply, power generation, and CCS.

Conclusions

The total investment cost of the LCET–CN scenario is estimated to be US$60,086 million, which is lower compared to that in the BAU scenario at US$90,280 million, which indicates that the Republic of Korea will be able to attain the target of net zero by 2050 by implementing all policy measures available under the LCET–CN scenario. In addition, it will lead to reduction in the total investment by US$30,194 million as compared to that in the BAU scenario in the energy sector alone.

Amongst investment costs, only the fuel cost, sharing a major portion, 85.1% is estimated to be reduced by US$38,07 million which covers more than increases in power capital cost and CCS. This indicates that fuel cost is critical in terms of share and capital investment. Investment in CCS is estimated to reach US$5,204 million in 2050, with a share of 8.7% in the total investment. If more policy efforts are taken along with technological advancements, the investment cost of CCS is expected to be reduced by a big margin.

Policy Recommendations

As the worldwide economy is quickly entering into a transition to respond to the climate crisis, the importance of climate issues has emerged in the context of strengthening global industrial competitiveness. Under international pressure, in response to the Paris Agreement, the government of the Republic of Korea established the 2030 Nationally

Determined Contribution in June 2015 and prepared the Basic Roadmap for Achieving the 2030 Nationally Determined Contribution at the end of 2016, which embodied the implementation of the goal. As a follow-up to this initiative, specific implementation measures for each sector were presented to achieve the goals, such as the Carbon Neutral Technology Innovation Implementation Strategy (MSIT, 2021) and the Carbon Neutral Industry and Energy R&D Strategy (MOTIE, 2021).

Energy transition and carbon neutrality are becoming an irreversible global trend. The government is currently proactively implementing the Energy Transition, Carbon Neutral, and Green New Deal policies and the Hydrogen Economy Revitalization Roadmap. In this context, the LCET–CN scenario indicates an ambitious CO_2 reduction target compared to the BAU scenario. Investment costs show a big margin between the BAU and LCET–CN scenarios, calling for an exceptional effort in policy development and implementation. The government must develop and implement cost-effective and nation-wide consensus-based action plans to reduce CO_2 emissions by a huge margin. The government should take a more balanced approach in response to addressing the LCET–CN scenario, reviving nuclear power by abandoning the previous denuclearisation policy. It is also necessary to continue the hydrogen economy and Renewable Energy 3020 along with fossil fuels with CCUS.

References

Ministry of Trade, Industry, and Energy (MOTIE) (2019), *Hydrogen Economy Revitalization Roadmap.*

______ (2021), *Carbon Neutral Industry and Energy R&D Strategy.*

Chapter 9
Lao People's Democratic Republic Country Report

Davanhny Xaneth

Ministry of Energy and Mines, Government of the Lao People's Democratic Republic

1. Background

At the United Nations Framework Convention on Climate Change Conference in November 2021, discussions were held on significantly increasing countries' nationally determined contribution (NDC) targets and establishing a carbon credit trading system to accelerate climate-change mitigation measures. All parties to the Paris Agreement are expected to help limit the increase in the global average temperature to well below 2.0° Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5° Celsius. Even developing countries like the Lao People's Democratic Republic (Lao PDR) are expected to declare carbon neutrality targets for 2050.

In the *9th Five-Year National Socio-Economic Development Plan (2021–2025),* the Government of the Lao PDR has made the use of renewable energy and promotion of electric vehicles (EVs) priorities in its efforts to promote green growth and to address climate-change mitigation. In addition, its NDC, which was updated last year, calls for net-zero emissions by 2050. Yet emissions from coal-fired power plants for export and from the transport sector, which consumes crude oil, are challenges.

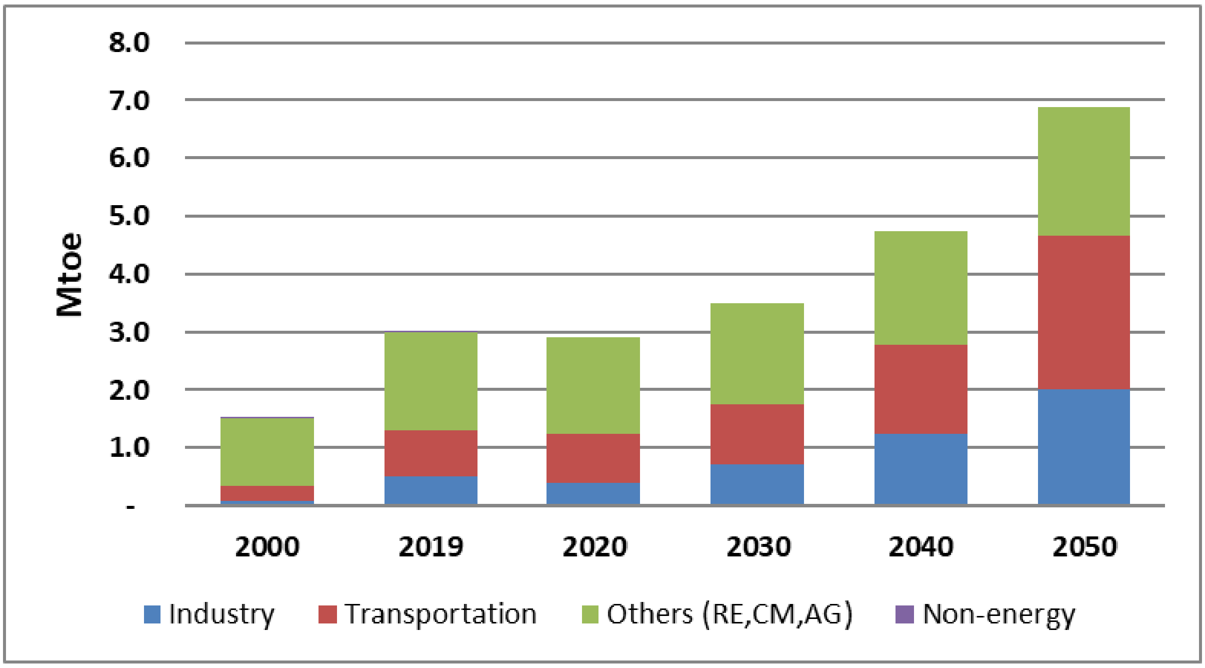
The Lao PDR is rich in clean and renewable hydropower resources, with 80% or 8,924 megawatts (MW) of its 10,971 MW installed capacity in 2021 coming from hydropower. Therefore, since its emissions are lower than those of other countries in Asia, it has the potential to contribute to their decarbonisation targets through the utilisation of existing hydropower and other renewable energy resources of the Lao PDR, taking into account environmental and social impacts.

The power system of the Lao PDR also has a large capacity compared to what is needed domestically; thus, a surplus of electricity during the rainy season has become apparent. This surplus could be used by increasing domestic demand during the rainy season, increasing exports from the domestic power system, and reducing the supply during the rainy season and increasing the supply during the dry season. In addition to exploring potential domestic electricity demand, it is necessary to set up a policy framework with clear goals. Moreover, note that future electricity demand trends will be influenced by the creation of untapped industries in addition to existing industries.

2. Final Energy Consumption (historical trend: 2019, 2030, 2040, 2050)

Under a low-carbon energy transition–carbon neutral (LCET-CN) scenario for the Lao PDR, total final energy consumption (TFEC) is expected to increase 2.7% per year during 2019–2050. This rate is much lower than that under the business-as-usual (BAU) scenario at 3.5% per year. The lower growth rate per year under the LCET-CN scenario would be due to EV use in the transport, 'others', and industrial sectors. The potential energy savings from EVs under the LCET-CN scenario is assumed to be 3.8% from 2040 until 2050. The projection of the TFEC for the BAU scenario until 2050 is based on gross domestic product and population growth assumptions.

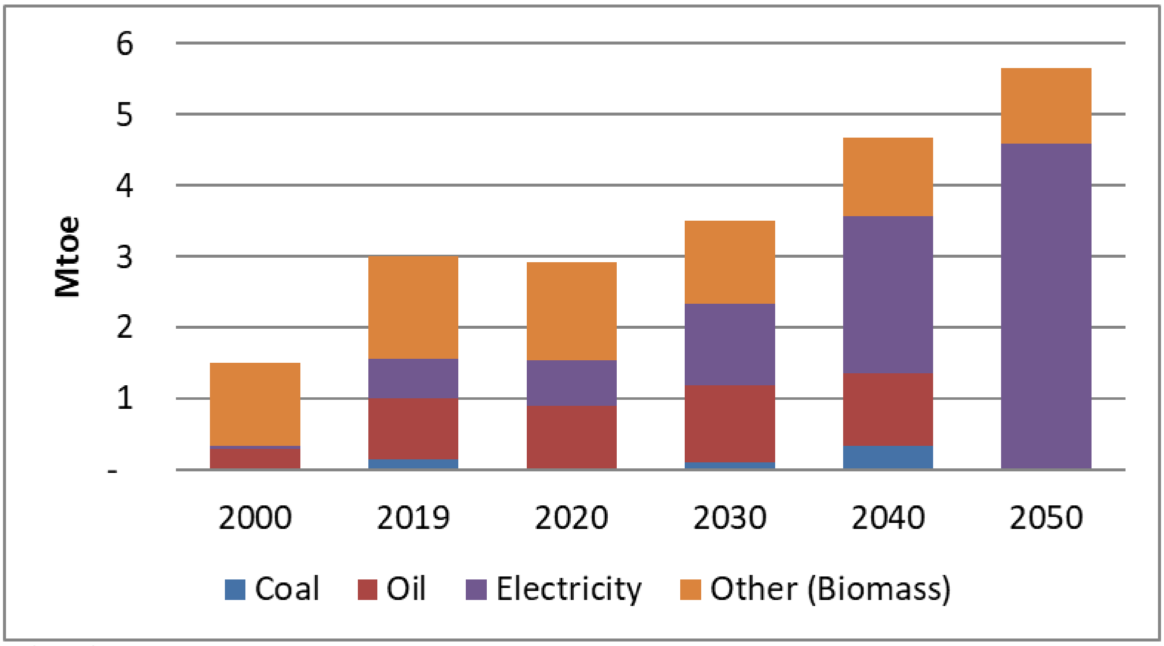
Figure 9.1. Final Energy Consumption by Sector, LCET-CN Scenario, 2000–2050
(Mtoe)



LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: ERIA calculations.

Figure 9.1 shows the final energy consumption by sector under the LCET-CN scenario. In 2050, the TFEC is expected to be 6.86 million tonnes of oil equivalent (Mtoe). The transport sector is expected to remain the dominant sector in 2050, with 38.3% of the total share. The industrial sector would increase at the highest rate per year at 4.6%. 'Others', which is the second-largest final energy consumer, would settle at 2.22 Mtoe or 32.3% of the total share. The increment per year for this sector would only be 4.6% from 2019 until 2050. The transport sector would increase at 3.9% per year from 2019 until 2050, and the non-energy sector would increase 0.9% per year. Although in 2050, the transport sector would have a higher average growth rate than those of the other sectors, during 2019–2050, it would have a higher average rate because the industrial sector would grow rapidly from 2020 to 2040 and then decrease to 2050. The transport sector would grow slowly during 2020–2040 and speed up until 2050.

Figure 9.2. Final Energy Consumption by Fuel, LCET-CN Scenario, 2000–2050
(Mtoe)



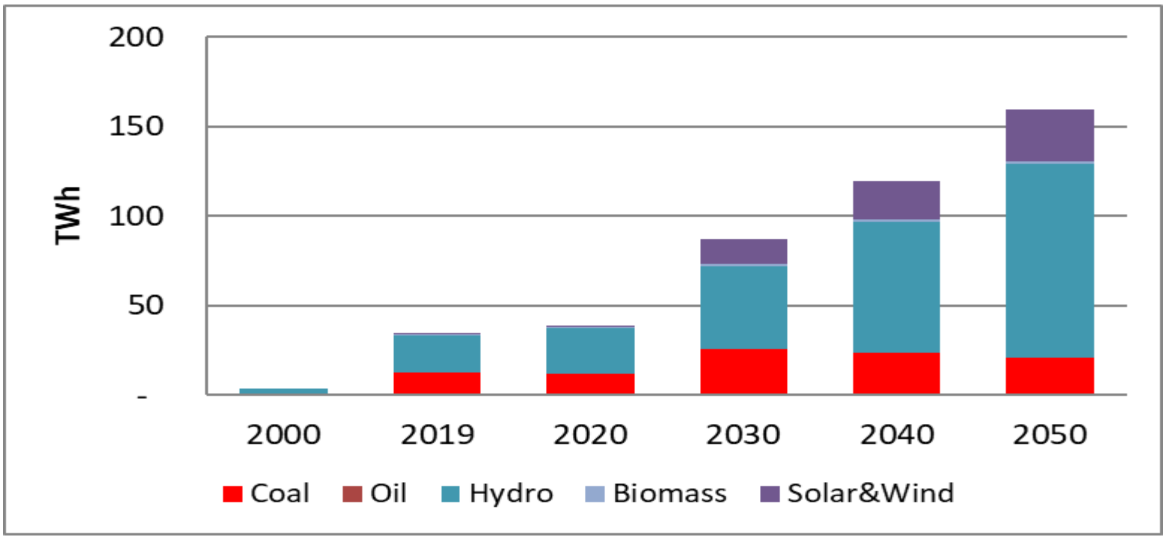
LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: ERIA calculations.

As shown in Figure 9.2, the introduction of EVs would result in a change to the mix of final energy consumption in 2050. The rate of oil consumption would decrease to 10.2% in 2023 and to 0.2% in 2050. This would also be due to the government's policy to increase the consumption of electricity and to reduce the importation of oil.

3. Power Generation (historical trend: 2019, 2030, 2040, 2050)

In 2050, the total power generation is expected to register at 160 terawatt-hours (TWh) under the LCET-CN scenario (Figure 9.4). This figure is higher than those in the BAU scenario and APS 1, at 127.70 TWh and 120.77 TWh, respectively. The LCET-CN scenario would reduce power generation capacity from coal and increase power generation capacity from hydro, solar, and wind.

Figure 9.3. Electricity Generation by Fuel, LCET-CN Scenario, 2000–2050
(TWh)

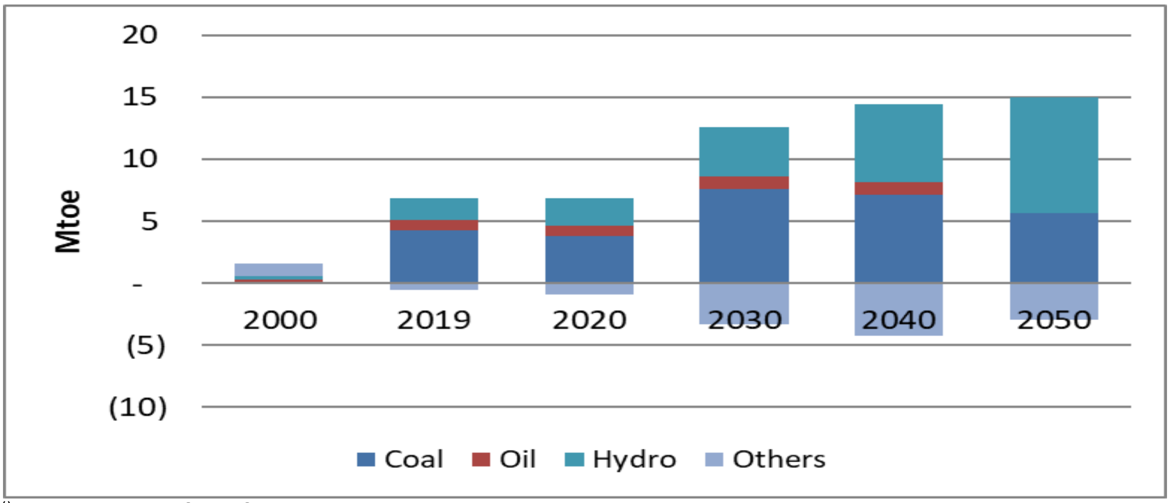


LCET-CN = low-carbon energy transition–carbon neutral, TWh = terawatt-hour.
Source: ERIA calculations.

4. Primary Energy Supply (historical trend: 2019, 2030, 2040 and 2050)

The total primary energy supply (TPES) under the LCET-CN scenario is expected to increase 2.1% per year from 2019 until 2050, a lower rate than those in the BAU scenario at 3.6%.. According to the *National Power Development Strategy of the Lao PDR, 2021–2023,* the country is committed to reducing emissions by 2050. The consumption of coal and oil is expected to fall, and the use of energy from hydro, solar, and wind promoted.

Figure 9.4. Primary Energy Supply by Fuel, LCET-CN Scenario, 2000–2050
(Mtoe)



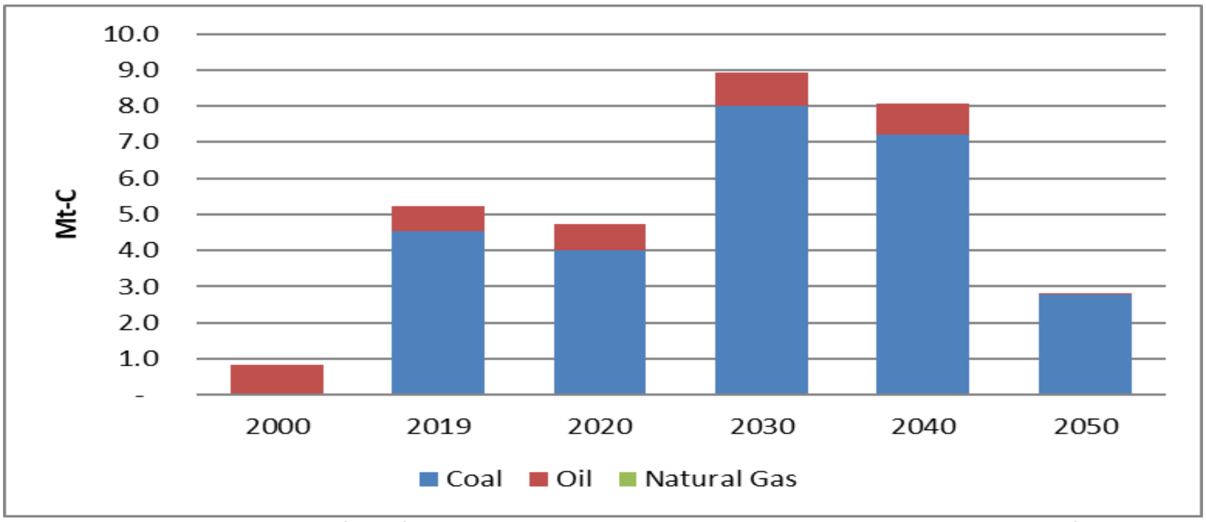
() = negative, LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: ERIA calculations.

According to Figure 9.4, under the LCET-CN scenario, 'others' would have a 5.5% share; solar and wind, a 21.7% share; and electricity, a 3.8% share of the TPES. Hydro would increase 5.6% per year from 2019 until 2050, while oil would fall 14.0%. Overall, the TPES would be expected to register at 12.01 Mtoe in 2050.

5. Emissions

Overall, for 2050, total emissions under the LCET-CN scenario would be 2.8 million tonnes of carbon (MtC), falling 2.0% per year from the 2019 level. Emissions from coal would decrease from 2019 until 2050 at 1.6% per year; likewise, oil emissions would fall 13.9% per year during the same time period. According to the *National Power Development Strategy of the Lao PDR, 2021–2023,* the consumption of coal and oil is set to decrease.

Figure 9.5. Primary Energy Supply, LCET-CN Scenario, 2019–2050
(MtC)



BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, MtC = million tonnes of carbon.
Source: ERIA calculations.

From Figure 9.5, under the LCET-CN scenario, the amount of oil used in 2050 would decrease significantly due to the promotion of clean energy in the transport sector, while the amount of coal would decrease as well. However, this would be a smaller amount due to various concession contracts with coal power plants and the use of coal in cement factories.

6. Power Demand

Currently, electricity generation sources (including exports) are from hydro, accounting for more than 80.41% of the total share. Coal thermal electricity accounts for 18.61%, and solar and biomass electricity account for 0.98% of total installed power. Domestic electricity generation comprises 91.49% hydroelectricity, 3.17% coal-fired power, and 5.34% renewable energy.

Under the LCET-CN scenario, in 2050, hydro would still produce the most energy, with higher demand growth than solar and wind energy. In the transport sector, fuel consumption would be replaced with electric power; the goal is to promote the use of EVs by 2025 to 14% of the total compared to 2017. The percentage of clean energy use in the transport sector should rise to 50% by 2050; there will be 2.63 Mtoe of electricity consumption from road transport. Hydrogen energy will be used in the Lao PDR starting in 2040, with a total consumption of 0.04 Mtoe, growing to 1.20 Mtoe in 2050.

7. Cost Comparison

7.1. Assumptions

An analysis of energy costs was carried between the BAU and LCET-CN scenarios to understand the total investment costs needed to implement all assumptions under the LCET-CN scenario. The basic assumptions for this analysis are in Tables 9.1–9.3.

Table 9.1. Assumed Fuel Costs

Fuel	2019/2020	2050 (2019 constant price)	Unit
Coal	80.03	98.00	US$/tonne
Oil	41.00	100.00	US$/bbl
Gas	7.77	7.50	US$/mmbtu
Hydrogen	0.80	0.30	US$/$Nm^3$
CCS		30.00	US$/$tCO_2$

bbl = barrel, CCS = carbon capture and storage, mmbtu = million British thermal units, Nm^3 = normal cubic metre, tCO_2 = tonne of carbon dioxide.
Source: ERIA calculations.

Table 9.2. Assumed Construction Costs of Power Plants
(US$/kilowatt)

Fuel	2019	by 2050
Coal	1,500	1,525
Oil		
Gas	700	700
Hydrogen		700
Nuclear	4,500	3,575
Hydro	2,000	2,223
Geothermal	4,000	4,256
Solar	1,600	307
Wind	1,600	1,235
Biomass	2,000	3,019

Source: ERIA calculations.

Table 9.3. Assumed Capacity Factors of Power Plants
(%)

Fuel	2019	by 2050
Coal	75	80
Oil	75	80
Gas	75	80
Hydrogen		80
Nuclear	100	80
Hydro	50	40
Geothermal	50	50
Solar	17	17
Wind	40	40
Biomass	50	70

Source: ERIA calculations.

7.2. Fuel Costs

Based on fuel cost assumptions in Table 9.1, fuel costs for both scenarios are shown in Table 9.4.

Table 9.4. Fuel Cost Comparison, BAU and LCET-CN Scenarios, 2050

	Final Energy Consumption, BAU, 2019 (Mtoe)	Final Energy Consumption, BAU, 2050 (Mtoe)	Final Energy Consumption, LCET-CN, 2050 (Mtoe)	Total Investment Cost, BAU, 2050 (US$ million)	Total Investment Cost, LCET-CN, 2050 (Mtoe)
Coal	4.27	13.29	5.69	1,426	226
Oil	0.86	3.56	0.01	1,857	(587)
Gas	0	0	0	0	0
Hydrogen	0	0	1.20	0	1,398
Total	**5.127**	**16.85**	**6.90**	**3,282**	**1,037**

() = negative, BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: ERIA calculations.

From the results above, the fuel costs in 2050 for the BAU scenario would be US$3,282 million, higher than that of the LCET-CN scenario at US$1,037 million.

7.3. Power Generation Investment

Based on the assumptions in Tables 9.2 and Table 9.3, the total investment cost for power plants in 2050 under the BAU and LCET-CN scenarios are in Table 9.5.

Table 9.5. Power Plants Cost Comparison, BAU and LCET-CN Scenarios, 2050

	Electricity Generation, BAU, 2019 (TWh)	Electricity Generation, BAU, 2050 (TWh)	Electricity Generation, LCET-CN, 2050 (TWh)	Additional Capacity, BAU (MW)	Additional Capacity, LCET-CN (MW)	Total Investment Cost, BAU, 2050 (US$ million)	Total Investment Cost, LCET-CN, 2050 (US$ million)
Coal	13	39	21	3,778	1,174	5,762	1,790
Oil	0	0	0	0			
Gas	0	0	0	0	0	0	0
Hydrogen	0	0	0	0	0		0
Nuclear	0	0	0	0	0		0
Hydro	20	79	108	16,893	25,045	37,554	55,674
Geothermal	0	0	0	0	0	0	0
Solar	0	8	19	5,045	12,450	1,549	3,822
Wind	0	0	11	0	3,011	0	3,718
Biomass	1	1	1	124	139	373	418
Total	**34**	**128**	**160**	**25,840**	**41,817**	**45,237**	**65,423**

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, MW = megawatt, TWh = terawatt-hour.
Source: Author's calculations.

From Table 9.5, the total additional capacity needed under the BAU scenario is 25,840 MW more than the 2019 level. The additional capacity under the LCET-CN scenario in 2050 is much greater at 41,817 MW more. This is due to more aggressive assumptions for renewable energy for power plants to reduce emissions. As a result, the total investment for power plants in 2050 under the BAU scenario would be US$45,237 million, while under LCET-CN scenario, it would be US$65,423 million.

7.4. Carbon Capture and Storage Costs

The introduction of carbon capture and storage (CCS) for coal and natural gas power plants would be implemented under the LCET-CN scenario starting in 2041. Based Table 9.1, the CCS cost is around US$30 per tonne of carbon dioxide equivalent. The total investment cost of CCS is shown in Table 9.6.

Table 9.6. Total Investment Cost of Carbon Capture and Storage for the LCET-CN Scenario, 2050

	Consumption in 2050 (Mtoe)	**Emissions** ($MtCO_2$)	**Emissions** (MtC)	**Total Investment Cost** (US$ million)
Coal Power Plant with CCS	5.69	21.2457	5.78901	574
Natural Gas Plant with CCS	0.00	0	0	0
Total	**5.69**	**21.2457**	**5.78901**	**574**

CCS = carbon capture and storage, LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent, MtC = million tonnes of carbon, $MtCO_2$ = million tonnes of carbon dioxide equivalent.
Source: ERIA calculations.

Table 9.6 indicates that the total investment cost of CCS will be US$547 million for coal power plants under the LCET-CN scenario.

7.5. Overall Costs

The breakdown of the total investment costs are shown below.

Table 9.7. Overall Total Investment Cost for BAU and LCET-CN Scenarios, 2050
(US$ million)

Cost	BAU	LCET-CN
Total Fuel Cost Investment	3,282	1,037
Total Power Capital Cost Investment	45,237	65,423
Total CCS Cost Investment	0	0
Total	**48,520**	**66,460**

BAU = business as usual, CCS = carbon capture and storage, LCET-CN = low-carbon energy transition–carbon neutral.
Source: ERIA calculations.

The overall investment cost under the BAU scenario in 2050 is projected to be US$48,520 million, while in LCET-CN scenario, it would be US$66,460 million.

8. Conclusions and Recommendations

From the overall calculation of the total investment costs, the LCET-CN scenario would require higher investment costs than the BAU scenario.

To reach net-zero emissions in 2050, the Lao PDR has increased investment in hydropower, solar power, wind power, and biomass power plants while reducing investment in coal. Regarding its conditional NDC, developed countries will help the Lao PDR achieve it though technology transfer, particularly in the areas of forestry and expanding renewable energy sources such as solar power, hydropower, wind power, and biomass power.

The Lao PDR currently does not have its own methodology for determining emissions, and national emissions reduction targets have been established with assistance from international organisations. Therefore, it is crucial to prioritise the establishment of a national greenhouse gas inventory.

References

Government of the Lao People's Democratic Republic (Lao PDR) (2018), *National Green Growth Strategy of the Lao PDR till 2030*, Vientiane.

––––– (2021), *National Power Development Strategy in the Lao PDR, 2021–2030*, Vientiane.

Government of the Lao People's Democratic Republic, Department of Energy Policy and Planning (2022), *Lao PDR Energy Outlook Result*, Vientiane.

Chapter 10
Malaysia Country Report

Zaharin Zulkifli

Energy Commission of Malaysia

1. Basic Concept of Low-carbon Energy Transition – Carbon Neutrality

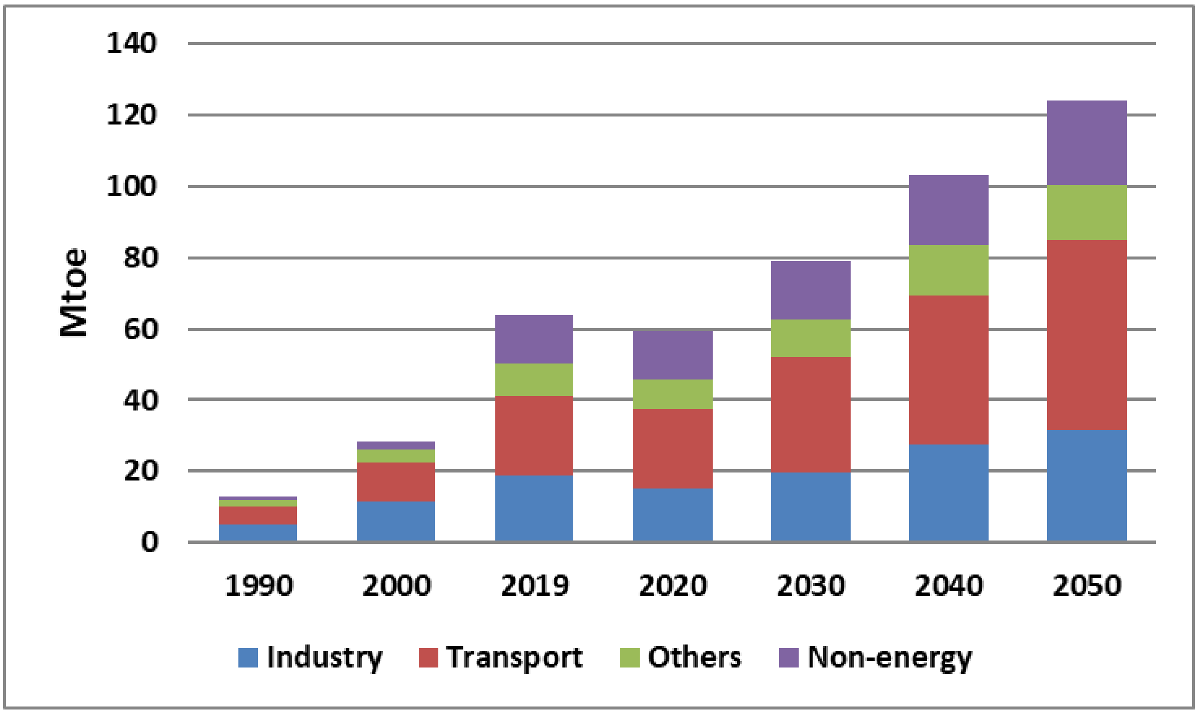
The concept 'low-carbon transition' refers to a shift from an economy that depends heavily on fossil fuels to a sustainable, low-carbon economy. A fundamental change in the way an economy organises energy services is necessary to reduce the risks of catastrophic climate change. Furthermore, a sustainable energy system is likely to offer other significant benefits such as lower resource dependence, technology spillovers associated with the development of alternative energy sources, global access to energy services, and secure and reliable low-carbon energy supplies (Earth System Governance, n.d.).

Carbon neutrality means having a balance between emitting carbon and absorbing carbon from the atmosphere in carbon sinks. Removing carbon dioxide (CO_2) from the atmosphere and then storing it is known as carbon sequestration. To achieve net-zero emissions, all worldwide greenhouse gas (GHG) emissions will have to be counterbalanced by carbon sequestration. A carbon sink is any system that absorbs more carbon than it emits. The main natural carbon sinks are soil, forests, and oceans. To date, no artificial carbon sinks can remove carbon from the atmosphere on a scale needed to fight global warming. The carbon stored in natural sinks such as forests is released into the atmosphere through forest fires, changes in land use, and logging. This is why it is essential to reduce carbon emissions to reach climate neutrality (New European Parliament, 2019).

2. Final Energy Consumption (Historical Trends: 2019, 2030, 2040, 2050)

Under the low-carbon energy transition–carbon neutral (LCET–CN) scenario, the total final energy consumption for Malaysia is expected to increase by 2.2% per year by 2050 from the 2019 level. This rate is much lower compared to the business as usual (BAU) scenario at 2.5% per year and the alternative policy (AP) scenario at 2.4% per year. The lower growth rate per year under the LCET–CN scenario is due to higher potential of savings of energy efficiency that can be obtained from the industry, residential, and commercial sectors. The potential savings of energy efficiency under the LCET–CN scenario is assumed at 16% from 2041 until 2050, whilst only 8% for the AP scenario. The projection of final energy consumption for the BAU scenario until 2050 is based on gross domestic product (GDP) and population growth assumptions.

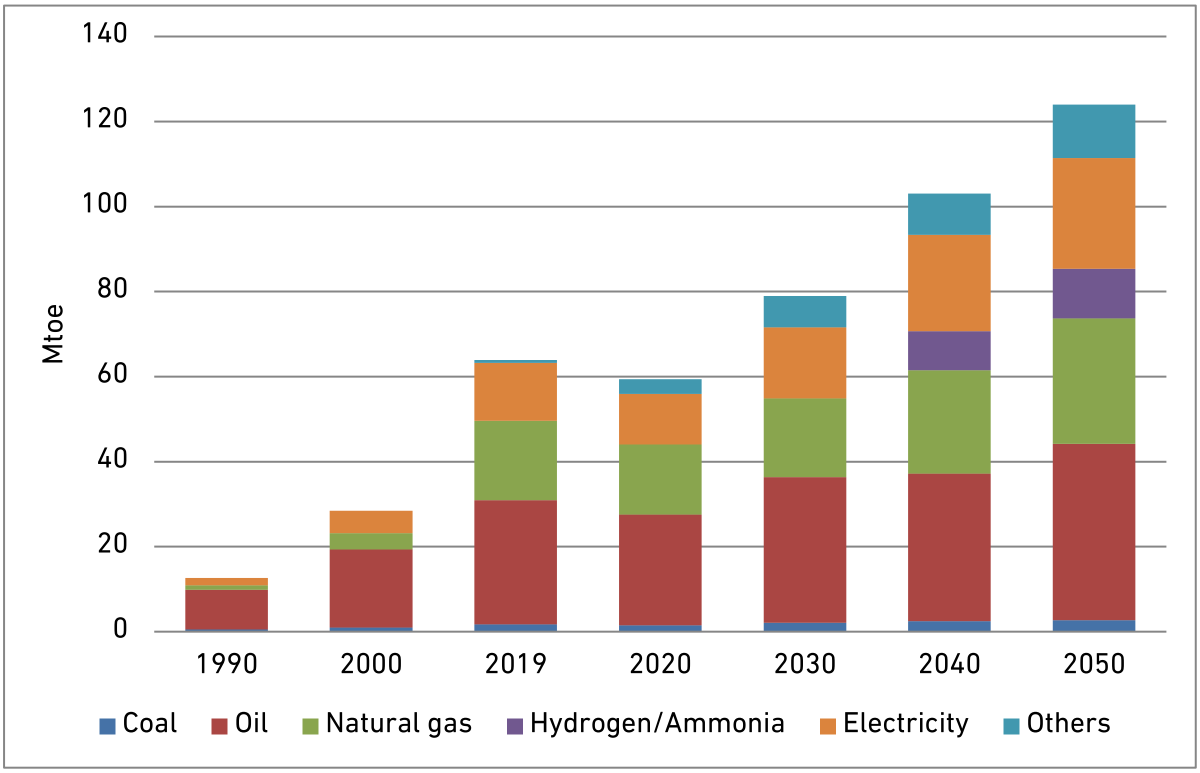
Figure 10.1. Final Energy Consumption by Sector, LCET–CN Scenario (1990–2050)



LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

Figure 10.1 shows the final energy consumption by sector under the LCET–CN scenario. In 2050, the total final energy consumption is expected to register at 124 million tonnes of oil equivalent (Mtoe). The transport sector will be expected to remain as the leading sector in 2050 with 43.3% of the total share. Moreover, the transport sector will be assumed to increase at the highest rate per year at 2.9% compared with the other sectors. The industry sector, which is the second largest of final energy consumed will be expected to settle at 31.42 Mtoe or 25.3% from the total share in 2050. Due to measures to combat energy efficiency in the industry sector, the increment per year is only at 1.6% from 2019 until 2050. Non-energy sector performance will be assumed to increase at 1.8% per year from 2019 until 2050. However, the share of the non-energy sector dropped to 18.9% in 2050 from 21.3% in 2019. Lastly, the 'others' sector (residential, commercial, and agriculture) constituted about 12.4% share from the total final energy consumption in 2050. The 'others' sector posted a positive trend from 2019 until 2050 at a rate of 1.8% per year.

Figure 10.2. Final Energy Consumption by Fuel Type, LCET–CN Scenario (1990–2050)



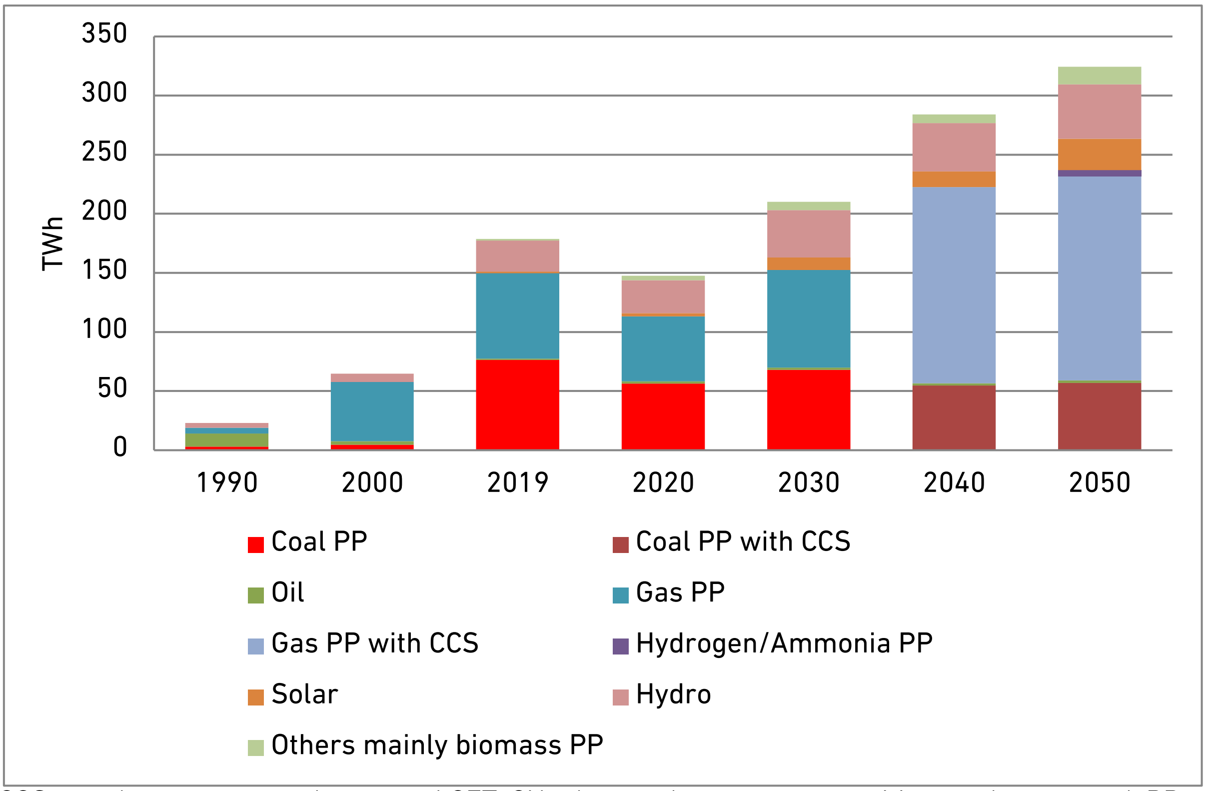
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

The LCET–CN scenario underlines the importance of having clean energy that can contribute to lowering CO_2 emissions. The introduction of hydrogen and biofuel for fuelling vehicles will result in a change in the mix of final energy consumption in 2050. Non-fossil fuels contribute about 19.6% of share from the total final energy consumption in 2050. These contributions come from biofuel at 10.2% and hydrogen at 9.4%. The oil share will be expected to reduce at 33.5% share in 2050 compared to 45.8% share in 2019. The natural gas share also copied the same trend with oil with 23.8% share in 2050 from 2019 level at 29.2% share in 2019. The electricity share remains at same level in 2019 and 2050 with 21.4% and 21.0%, respectively.

3. Power Generation (Historical Trend: 2019, 2030, 2040, 2050)

In 2050, the total power generation is expected to register at 324.29 terawatts per hour (TWh) under the LCET–CN scenario. This figure is lower than in the business as usual (BAU) and alternative policy (AP) scenarios at 412.77 TWh and 379.80 TWh, respectively. The savings generated from electricity consumption in the industry, commercial, and residential sectors has required the power sector to produce less electricity.

Figure 10.3. Electricity Generation by Fuel Type, LCET–CN Scenario (1990–2050)



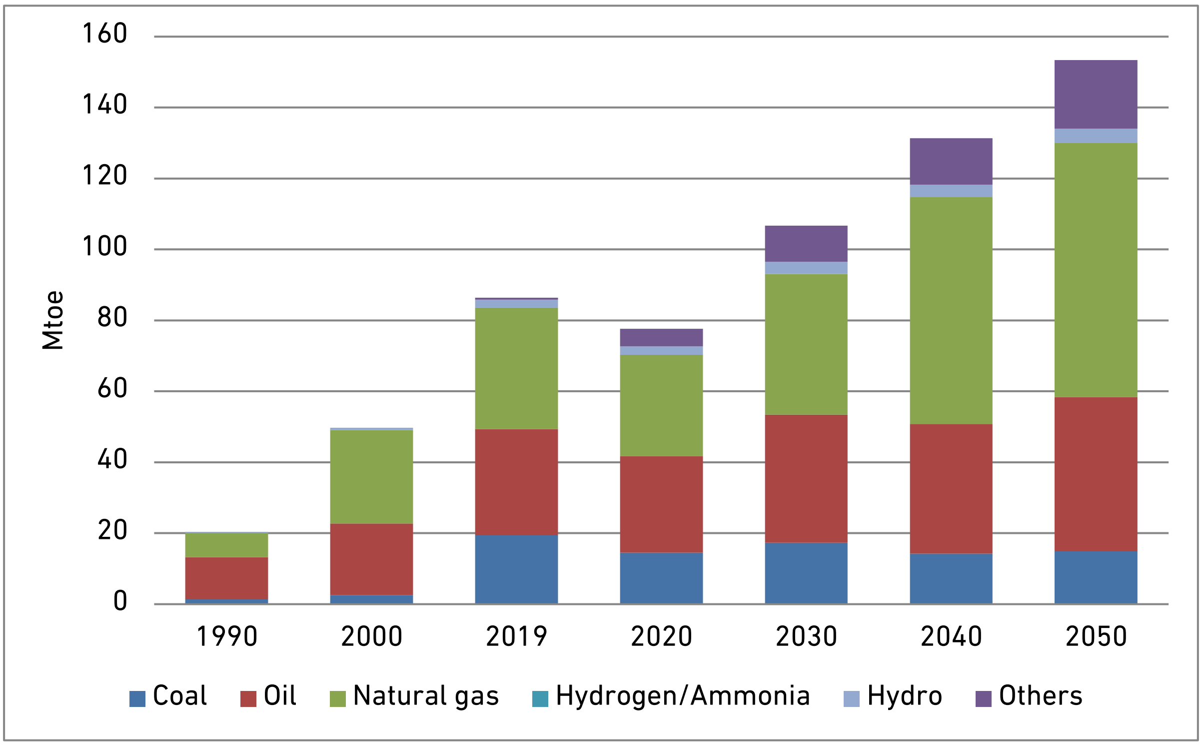
CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: Author's calculations.

Total electricity generation under the LCET–CN scenario is projected to increase at 1.9% per year from 2019 until 2050. Based on Figure 10.3, gas-fired power plants with carbon capture and storage (CCS) register the highest share with 53.3% from the total electricity generation in 2050. This is followed by coal-fired power plants with CCS at 17.5% share. The total renewable energy (RE) share that consist of hydro, solar, and biomass contributes about 27.0% share of total electricity generation in 2050. The higher share of RE generation in 2050 was due to adjusted assumption of RE installed capacity compare with the AP scenario. Under the AP scenario, the RE generation share is 15.7%, whilst in the BAU scenario the share is 9.9%.

4. Primary Energy Supply (Historical Trend: 2019, 2030, 2040, 2050)

The total primary energy supply under the LCET–CN scenario is expected to increase at 1.9% per year from 2019 until 2050. The incremental rate is lower when comparing with the BAU and AP scenarios at 2.6% and 2.1% per year, respectively. This was due to greater assumption of energy savings being inserted into the LCET–CN scenario. Figure 10.4 shows the total primary energy supply by fuel type.

Figure 10.4. Total Primary Energy Supply by Fuel Type, LCET–CN Scenario (1990–2050)



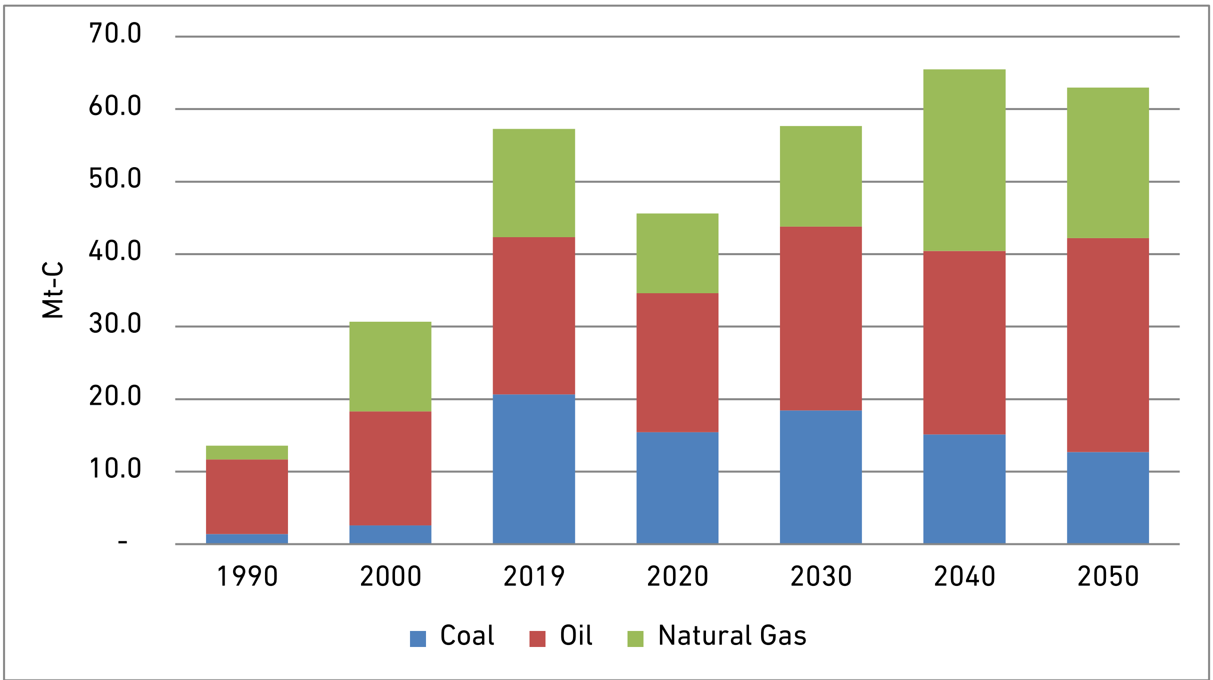
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

'Others' fuel recorded the highest increase amongst fossil fuels at 12.3% per year from 2019 until 2050. This was contributed by biofuel at 10.0% per year in a similar time horizon. The introduction of the National Biofuel Policy and the target of the implementation of biodiesel blending with conventional diesel up by 30% by 2030 in the transport sector have given a significant impact. The assumption of doubling the capacity of RE in the power sector by 2050 has created a bright prospect of RE especially for biomass, biogas, and solar. Solar alone is expected to increase at 9.8% per year from 2019 until 2050 whilst biomass, biogas, and municipal solid waste will grow at 8.7% per year. Natural gas and oil will have minimal growth throughout the projection period at 2.4% per year and 1.2% per year, respectively. Nevertheless, natural gas and oil will still have a significant role for the future energy landscape in the country as they will contribute around 46.8% share and 28.3% share, respectively. This is followed by 'others' at 12.6% share and coal at 9.7% share. The government decision in 2021 that no new coal-fired power plants will be commissioned in the country has contributed to the impact. Overall, the total primary energy supply is expected to register at 153.39 million tonnes of oil equivalent (Mtoe) in 2050.

5. Carbon Dioxide Emissions

Overall, for 2050, the total CO_2 emissions for the LCET–CN scenario is stated at 63.0 million tonnes of carbon (Mt-C), an increase of 0.3% per year from the 2019 level. The total emissions for the LCET–CN scenario in 2050 is much lower compared with the BAU and AP scenarios. In the BAU scenario for 2050, the total CO_2 emissions is registered at 117.9 Mt-C ,whilst in the AP scenario it is 94.1 Mt-C. Between the BAU and LCET–CN scenarios, the highest contribution of CO_2 emissions potential savings will be expected to come from natural gas. Only CO_2 emissions for coal will be expected to have a decreasing trend from 2019 until 2050 with –1.6% per year. This was due to the new policy by the government to stop developing new coal power plants in the future. CO_2 emissions from natural gas will be expected to increase by 1.1% per year from 2019 until 2050 since switching from coal. Natural gas will always be the best option compared to coal, especially in the power sector in generating electricity, because of the stability of supply and the affordability factor. The total emissions from oil will be expected to increase at 1.0% per year to register at 29.5 Mt-C (Figure 10.5).

Figure 10.5. Total CO_2 Emissions by Fuel Type, LCET–CN Scenario (1990–2050)



CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: Author's calculations.

Overall, analysis by share shows that oil will still dominate the total emissions at 46.9% in 2050 followed by natural gas at 33.0%, and lastly coal at 20.1%

6. Hydrogen Demand across the Sectors

Under the LCET–CN scenario assumptions, two sectors will be involved directly for hydrogen utilisation: transport and power. In the transport sector, the assumption was made that gasoline will be replaced with hydrogen. Based on this assumption, the fuel switching between them will start in 2041 until 2050 with a utilisation rate of 50%. This utilisation rate can only be achieved with the proper infrastructure of hydrogen fuelling stations available and affordable hydrogen vehicles in the market. As a result, in 2050, hydrogen consumption will be 11.64 kilotons of oil equivalent (ktoe) coming from road transport. This hydrogen consumption will represent 9.4% of share from the total final energy consumption in 2050.

Hydrogen as a fuel will also be introduced in the power sector beginning in 2041 with total capacity of 720 megawatts (MW). This assumption was made to fully utilise the local supply of hydrogen. In 2050, the total power generation from hydrogen power plants will be expected to generate 5.05 TWh of electricity. This electricity generation will constitute about 1.6% share from the total electricity generation in 2050. In terms of fuel input, the hydrogen share will represent 2.0% from the total fuel input in power generation in 2050.

7. Energy Cost Comparison between BAU and LCET–CN Scenarios

An analysis on energy cost was carried out to see the comparison between the BAU and LCET–CN scenarios. The objective of this analysis is to see the total investment cost needed to implement all assumptions under the LCET–CN scenario and compare with the BAU scenario. The basic assumption for this analysis is stated in Table 10.1.

Table 10.1. Fuel Cost Assumptions

	2019/2020	2050 (2019 constant price)	Unit
Coal	80.03	98.00	US$/ton
Oil	41	100	US$/bbl
Gas	7.77	7.50	US$/MMBtu
Hydrogen	0.8	0.3	US$/$Nm^3$
CCS	0	30	US$/$CO_2$ ton

bbl = barrel, CCS = carbon-capture and storage, MMBtu = metric million British thermal unit, Nm^3 = normal cubic metre.
Source: Author’s calculations.

Table 10.2. Construction Cost of Power Plants Assumptions
(US$/KW)

	2019	by 2050
Coal	1,500	1,525
Oil	0	0
Gas	700	700
Hydrogen	0	700
Nuclear	4,500	3,575
Hydro	2,000	2,223
Geothermal	4,000	4,256
Solar	1,600	307
Wind	1,600	1,235
Biomass	2,000	3,019

KW = kilowatt.
Source: Author's calculations.

Table 10.3. Capacity Factor of Power Plants Assumptions
(%)

	2019	by 2050
Coal	75	80
Oil	75	80
Gas	75	80
Hydrogen	0	80
Nuclear	100	80
Hydro	50	40
Geothermal	50	50
Solar	17	17
Wind	40	40
Biomass	50	70

Source: Author's calculations.

7.1. Fuel Cost

Based on fuel cost assumptions that are stated in Table 10.1, the overall result of total investment fuel cost is shown in Table 10.4.

Table 10.4. Total Investment Fuel Cost Comparison, BAU and LCET–CN Scenarios in 2050

	Final Energy Consumption (Mtoe), BAU in 2019	Final Energy Consumption (Mtoe), BAU in 2050	Final Energy Consumption (Mtoe), LCET–CN in 2050	Total Investment Cost, BAU in 2050 (US$ million)	Total Investment Cost, LCET–CN in 2050 (US$ million)
Coal	192.23	505.12	184.85	49,444	–1,166
Oil	218.49	563.95	262.12	237,609	30,009
Gas	134.83	387.22	269.4	72,878	38,857
Hydrogen	0	0	155.1	0	180,723
Total	**545.55**	**1,456.29**	**871.47**	**359,931**	**248,422**

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

From the results in Table 10.4, the total investment fuel cost in 2050 for the BAU scenario is expected to be US$359,931 million. This total is higher from the total investment fuel cost under the LCET–CN scenario at US$248,422 million.

7.2. Power Generation Investment

Based on power generation investment assumptions stated in Table 10.2 and Table 10.3, analysis on the total investment cost for power plants in 2050 for the BAU and LCET–CN scenarios are shown in Table 10.5.

Table 10.5. Total Investment Power Plants Cost Comparison, BAU and LCET–CN Scenarios in 2050

	Electricity Generation in BAU for 2019 (TWh)	Electricity Generation in BAU for 2050 (TWh)	Electricity Generation in LCET–CN for 2050 (TWh)	Additional Capacity for BAU (MW)	Additional Capacity for LCET–CN (MW)	Total Investment Cost, BAU in 2050 (US$ million)	Total Investment Cost, LCET–CN in 2050 (US$ million)
Coal	76	49	57	–3,871	–2,785	–5,904	–4,248
Oil	1	2	2	124	0	0	0
Gas	72	321	173	35,455	14,332	24,819	10,033
Hydrogen	0	0	5	0	721	0	504
Hydro	26	36	46	2,763	5,659	6,141	12,581
Solar	1	2	27	195	16,821	60	5,164
Wind	0	0	0	0	0	0	0
Biomass	1	3	15	320	2,223	965	6,711
Total	**179**	**413**	**324**	**34,985**	**36,971**	**26,081**	**30,744**

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, MW = megawatt, TWh = terawatt-hour.
Source: Author's calculations.

From Table 10.5, the total additional capacity needed for the BAU scenario is 34,985 MW from the 2019 level. However, the additional capacity for the LCET–CN scenario in 2050 is much greater from the BAU scenario at 36,971 MW. This was due to more aggressive assumptions put RE for power plants in 2050 for the LCET–CN scenario to reduce CO_2 emissions. As a result, the total investment for power plants in 2050 for the BAU scenario is assumed to be US$26,081 million, whilst under the LCET–CN scenario at US$30,744 million.

7.3. Carbon Capture and Storage Cost

The introduction of carbon capture and storage (CCS) is projected to be implemented under the LCET–CN scenario starting from 2041 onwards. The CCS projects will be assumed to be implemented for coal-fired and natural gas-fired power plants. Based on the assumption stated in Table 10.1, the CCS cost is around US$30/$CO_2$ tonne, the total investment for CCS can be calculated. The total investment cost of CCS is shown in Table 10.6.

Table 10.6. Total Investment Cost of Carbon Capture and Storage for LCET–CN Scenario in 2050

	Consumption for LCET–CN in 2050 (Mtoe)	**CO_2 Emissions for LCET–CN** (Mt-CO_2)	**CO_2 Emissions for LCET–CN** (Mt-C)	**Total Investment Cost of CCS for LCET–CN** (US$ million)
Coal Power Plant with CCS	12.31	12.52	45.94	1,240
Natural Gas Plant with CCS	28.9	16.77	61.55	1,662
Total	**41.21**	**29.29**	**107.50**	**2,902**

CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent, Mt-CO_2 = million tonnes of carbon dioxide, Mt-C = million tonnes of carbon.
Source: Author's calculations.

Table 10.6 indicates that the total needed investment cost of CCS will be around US$2,902 million. The total consists of CCS projects for coal-fired power plants at US$1,240 million and US$1,662 million for natural gas-fired power plants with CCS.

7.4. Overall Cost

Based on analysis on the overall calculation from section 1 until section 3, the breakdown of the total investment cost is shown in Table 10.7.

Table 10.7. Overall Total Investment Cost for BAU and LCET–CN Scenarios in 2050

	BAU	LCET–CN
Total Fuel Cost Investment (US$ million)	359,931	248,422
Total Power Capital Cost Investment (US$ million)	26,081	30,744
Total CCS Cost Investment (US$ million)	0	2,902
Total (US$ million)	**386,012**	**282,069**

BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Author's calculations.

The overall investment cost for the BAU scenario in 2050 is projected to be US$386,012 million, whilst in the LCET–CN scenario the cost is projected to be US$282,069 million.

8. Conclusions and Recommendations

From the overall calculation of the total investment cost, the LCET–CN scenario required less investment cost compared with the BAU scenario. This indicates that by implementing all measures under the LCET–CN assumption, Malaysia is not only able to achieve net zero by 2050 but can make a saving of US$103,943 million of investment in the energy sector.

Efforts need to be in place to achieve net-zero emissions by 2050. The government should focus on the availability of new technologies and opportunity of investment. Some other parameters such as legal frameworks, an expert work force, and public awareness also need to be prioritised.

Regional cooperation and understanding between economies in the Asian region need to be strengthened through dialogue, seminars, and workshops so that the target of achieving net zero by 2050 will succeed, not only by country but as a whole region.

References

Earth System Governance (n.d.), Low Carbon Transition. (https://www.earthsystemgovernance.net/conceptual-foundations/?page_id=131#:~:text=The%20concept%20'Low%20Carbon%20Transition,risks%20of%20catastrophic%20climate%20change

New European Parliament (2019), 'What is Carbon Neutrality and How Can it be Achieved by 2050?', 3 October. https://www.europarl.europa.eu/news/en/headlines/society/20190926STO62270/what-is-carbon-neutrality-and-how-can-it-be-achieved-by-2050#:~:text=Carbon%20neutrality%20means%20having%20a,is%20known%20as%20carbon%20sequestration

Chapter 11
Myanmar Country Report

Swe Swe Than

Oil and Gas Planning Department, Ministry of Energy, Government of Myanmar

1. Background

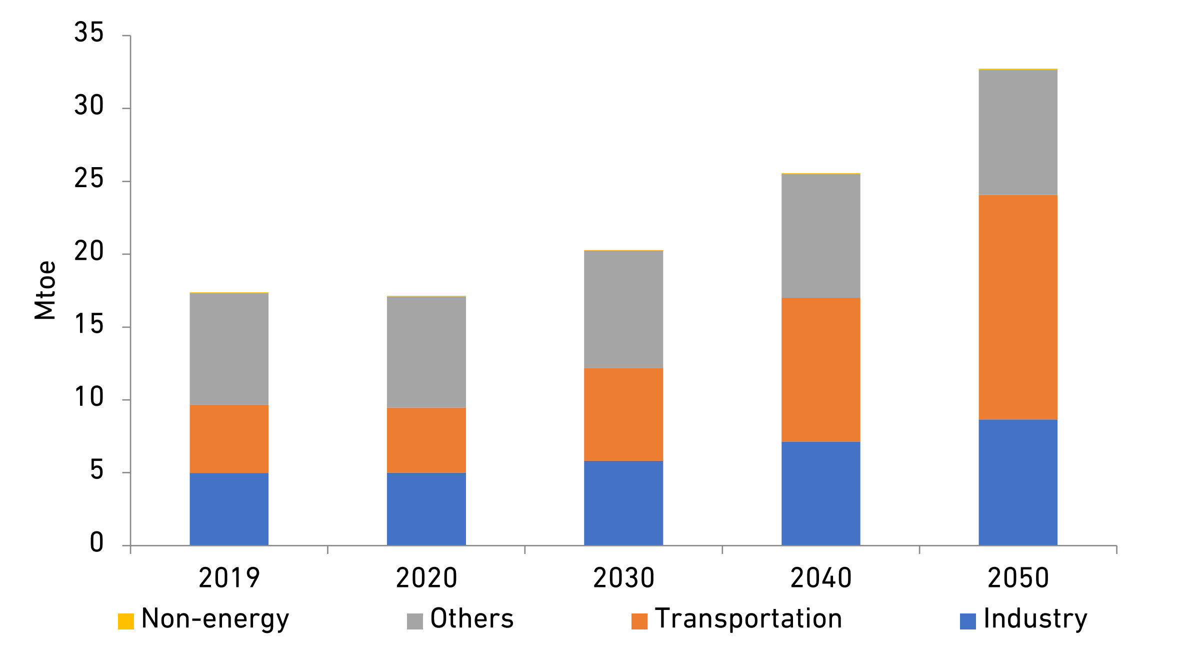
A low-carbon energy transition refers to the shift from high-carbon or fossil fuel-based energy sources to low-carbon or renewable energy sources. The transition involves adopting technologies and practices that produce fewer emissions per unit of energy generated. This can include renewable energy sources such as solar, wind, hydroelectric, geothermal, and biomass, as well as nuclear power, which produces minimal emissions during electricity generation. Additionally, energy-efficiency measures and improvements in energy storage technologies play crucial roles in this transition.

Carbon neutrality or achieving a net-zero carbon footprint entails balancing emissions with carbon removal or offsetting measures. It involves reducing emissions as much as possible and then offsetting any remaining emissions through activities that remove carbon dioxide from the atmosphere or prevent additional emissions. Carbon offsetting can involve activities such as reforestation and afforestation projects, carbon capture and storage (CCS) technologies, and investments in renewable energy projects. This transition requires coordinated efforts from governments, businesses, and individuals to invest in renewable energy infrastructure, adopt energy-efficient technologies, and implement policies that incentivise low-carbon practices. This study aims to describe Myanmar's roadmaps for its energy transition.

2. Final Energy Consumption (Historical Trend: 2019, 2030, 2040, 2050)

Under a low-carbon energy transition–carbon neutral (LCET-CN) scenario, the total final energy consumption (TFEC) for Myanmar is expected to increase 2.1% per year to 2050 from the 2019 level. This rate is much lower compared to the business-as-usual (BAU) scenario at 2.6% per year but higher than the alternative policy scenario (APS) at 2.0% per year. The lower growth rate per year under the LCET-CN scenario would be due to higher energy efficiency in the industrial, residential, and commercial sectors. The potential savings of energy efficiency under the LCET-CN scenario is assumed at 14.1% in the primary energy sector by 2050. The projection of TFEC until 2050 is based on gross domestic product and population growth assumptions.

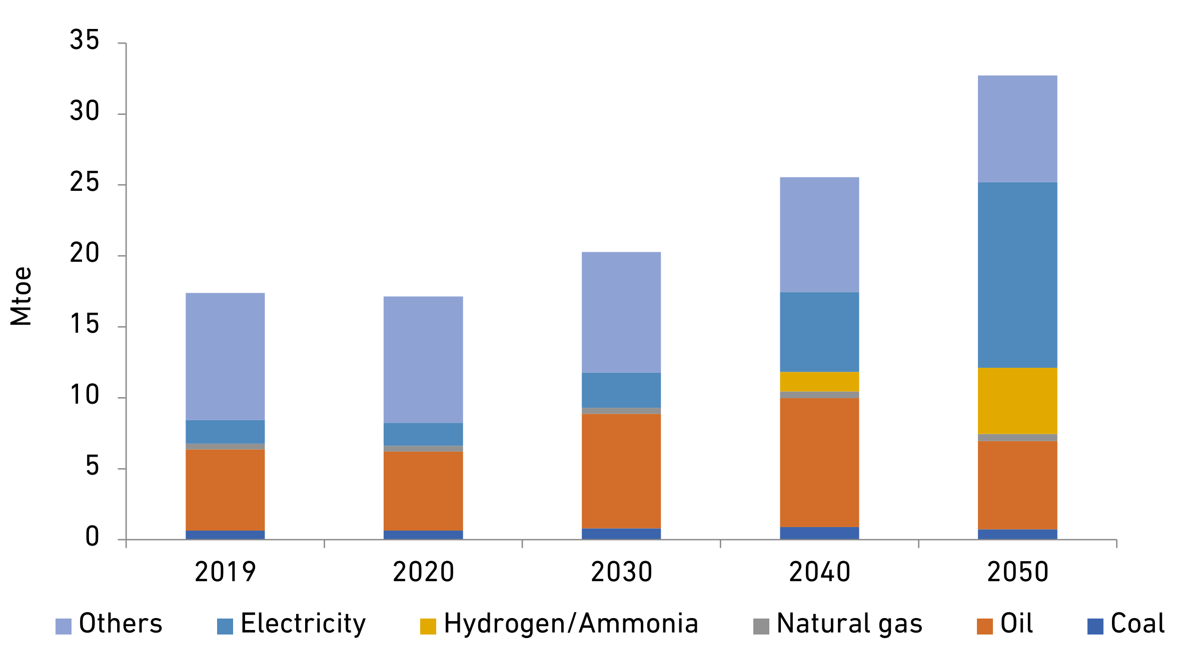
Figure 11.1. Final Energy Consumption by Sector under the LCET-CN Scenario, 1990–2050
(Mtoe)



LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

Figure 11.1 shows the final energy consumption by sector under the LCET-CN scenario. In 2050, the TFEC is expected to be 32.72 million tonnes of oil equivalent (Mtoe). The transport sector would remain the dominant sector in 2050, with 47.1% of the total share. Moreover, the transport sector would increase sharply at 3.9% compared to the other sectors. The industrial sector – the second-largest final energy consumer – is expected to settle at 8.65 Mtoe or 26.4% of the total share by 2050. Due to measures to combat energy efficiency in the industrial sector, the increment per year for the sector would only be 1.8% from 2019 until 2050. Non-energy sector performance would increase 2.0% per year from 2019 until 2050; the share of this sector would remain constant from 2019 to 2050. Lastly, the 'others' sector (i.e. residential, commercial, and agriculture) would constitute about 26.3% of the TFEC in 2050. This sector exhibits a positive trend from 2019 to 2050 at a rate of 0.4% per year.

Figure 11.2. Final Energy Consumption by Fuel under the LCET-CN Scenario, 1990–2050
(Mtoe)



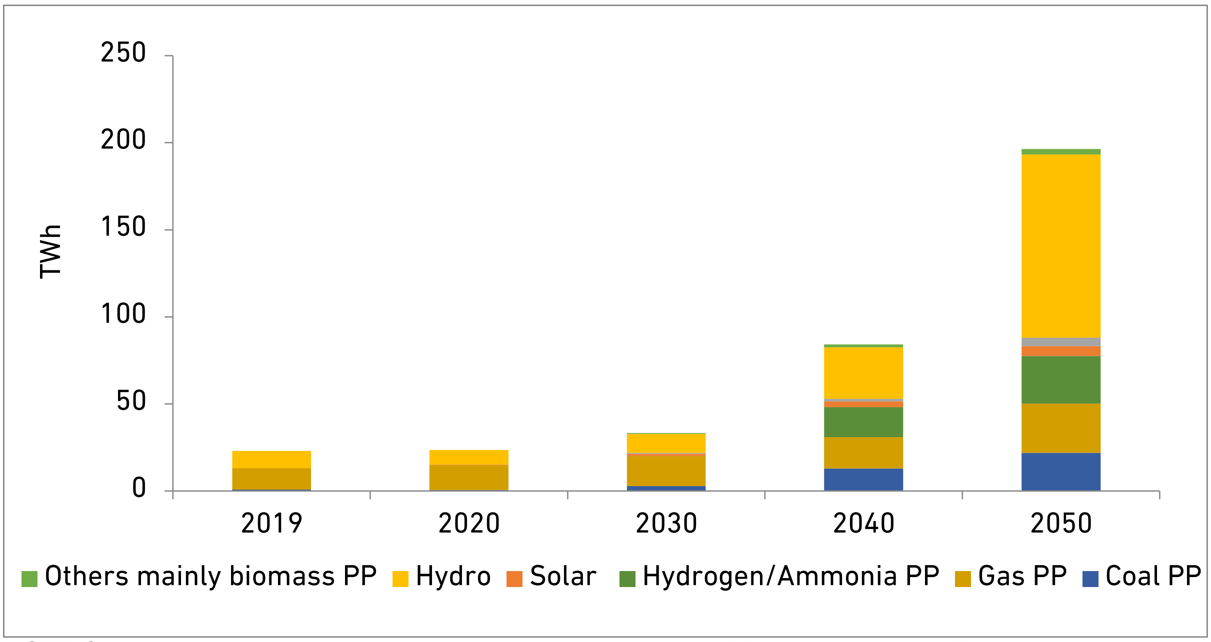
LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

Under the LCET-CN scenario, the introduction of hydrogen and ammonia fuels would increase, and more electric vehicles (EVs) in the transport sector would aid fuel-switching technology to 2050. The share of oil would fall to a 19% share in 2050 compared to a 33% share in 2019. The electricity share would grow from 2019 to 2050 at a rate of 6.9% per year (Figure 11.2).

3. Power Generation (Historical Trend: 2019, 2030, 2040, 2050)

In 2050, total power generation is expected to register at 196.41 terawatt-hours (TWh) under the LCET-CN scenario. This figure is lower than those in the BAU scenario and APS at 81.00 TWh and 69.12 TWh, respectively.

Figure 11.3. Electricity Generation by Fuel, LCET-CN Scenario, 1990–2050



LCET-CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: Author's calculations.

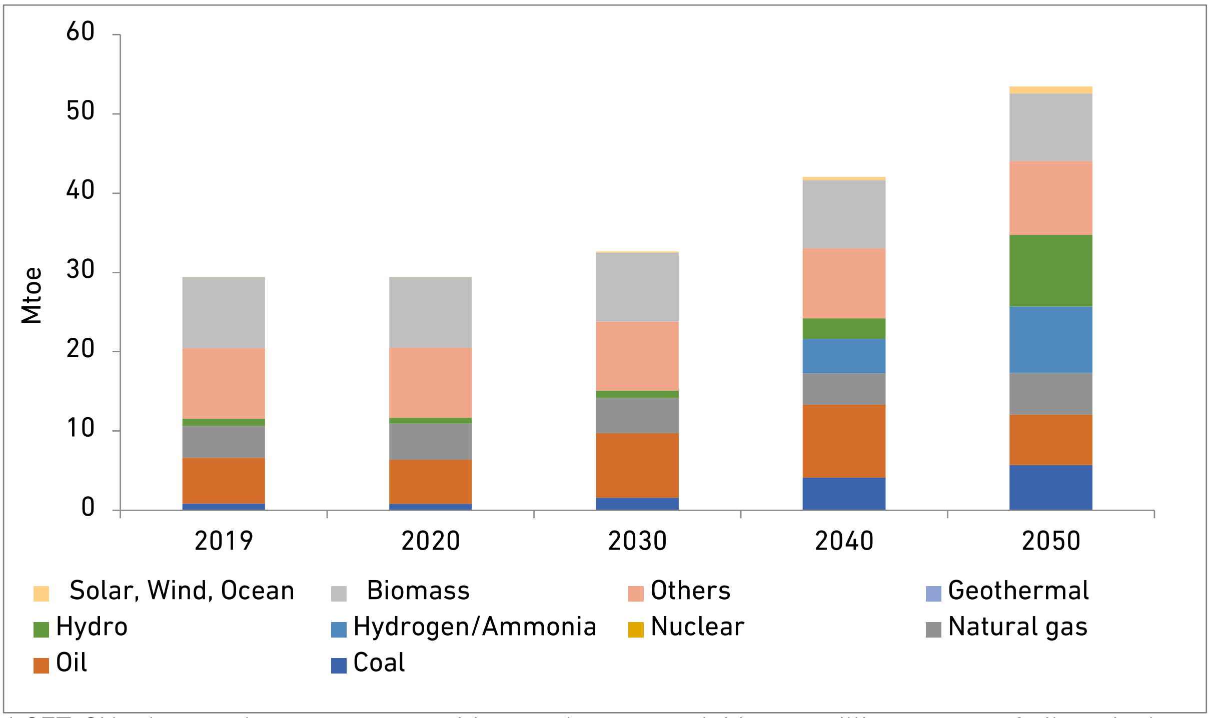
Total electricity generation under the LCET-CN scenario is projected to increase 7.2% per year from 2019 until 2050. Based on Figure 11.3, hydro would comprise the highest share at 53.6% of total electricity generation in 2050, with natural gas following at 14.4%. Both hydrogen and ammonia would increase to 13.9%. The total renewable energy share consists of 2.9% solar, 2.4% wind, 53.6% hydro, and 1.6% others (mainly biomass) of total electricity generation to 2050.

4. Primary Energy Supply (historical trend: 2019, 2030, 2040, and 2050)

The total primary energy supply (TPES) under the LCET-CN scenario is expected to increase 1.9% per year from 2019 until 2050. This incremental rate is lower when compared to the BAU scenario and APS at 2.6% and 2.1% per year, respectively, due to more energy savings under the LCET-CN scenario. Figure 11.4 shows the TPES by fuel type.

Figure 11.4. Total Primary Energy Supply by Fuel Type under the LCET-CN Scenario, 1990–2050

(Mtoe)



LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations

Under the LCET-CN scenario, 'others' fuel would record the highest increase at 25.3% per year from 2019 until 2050. Biomass would decrease 0.2% per year, and natural gas and oil would have minimal growth throughout the projection period at 0.9% per year and 0.3% per year, respectively. This is followed by hydro at 12.5% and coal at 6.3%. Overall, the TPES would register at 44.05 Mtoe in 2050.

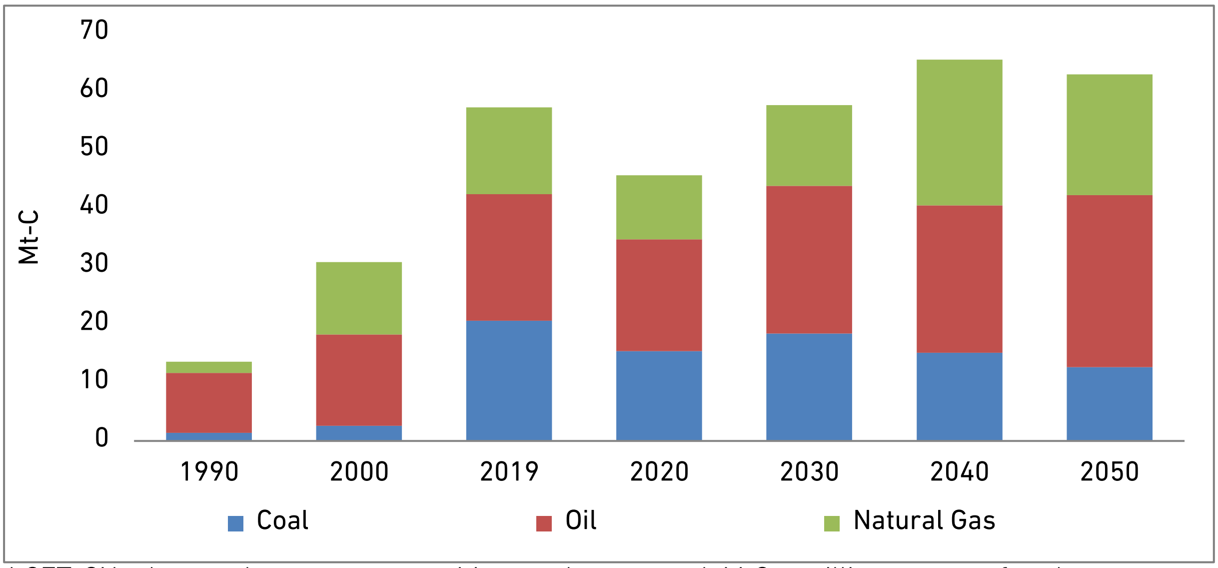
Myanmar has set a conditional target of reducing deforestation by 50% by 2030, resulting in a cumulative emissions reduction of 256.5 million tonnes of carbon dioxide equivalent ($MtCO_2e$) over 2021–2030. The renewable energy share target is 12% of the national energy mix by 2030, which includes small and mini-hydro, biomass, wind, and solar. Finally, it is targeting a 20% electricity-savings potential by 2030 of the TFEC.

Renewable energy would eventually become the main power source under the LCET-CN scenario, accounting for 60.5% in 2050 of the energy mix. Moreover, the efficiency of final energy demand would increase, and thermal power generation would become more efficient.

5. Emissions

Overall, for 2050, total emissions under the LCET-CN scenario would be 14.62 million tonnes of carbon (MtC), an increase of 1.9% per year from the 2019 level. Only emissions for coal would decrease 6.3% from 2019 until 2050, to 6.06 MtC in 2050, due to a new government policy to stop developing new coal power plants. Emissions from natural gas are expected to increase by 0.9% per year from 2019 until 2050 due to the fuel switching from coal. Natural gas is still a better option compared to coal – especially in the power sector – because of the stability of the supply and low cost. Emissions from oil are expected to increase at 0.3% per year, totalling 5.22 MtC in 2050 (Figure 11.5).

Figure 11.5. Total Emissions by Fuel Type under the LCET-CN Scenario, 1990–2050 (MtC)



LCET-CN = low-carbon energy transition–carbon neutral, MtC = million tonnes of carbon.
Source: Author's calculations.

Overall, coal would still dominate total emissions with a 41.5% share in 2050 followed by oil at 35.7% and natural gas at 22.9%.

6. Hydrogen Demand

Under the LCET-CN scenario, two sectors would use hydrogen: transport and industry. In the transport sector, gasoline consumption would decrease due to EVs. Based on this assumption, the fuel switching would result in 2.700 Mtoe in 2041 to 0.389 Mtoe in 2050. The utilisation rate cannot be achieved without hydrogen fuelling stations available as well as affordable hydrogen vehicles on the market. In the industrial sector, hydrogen consumption would represent 13.9% of the TFEC in 2050. In Myanmar, the potential reserve of hydrogen from fossil fuels is 1.7 Mtoe, and hydrogen from renewable energy is 252 Mtoe.

7. Cost Comparison

7.1. Assumptions

An analysis of energy costs was carried out on the BAU and LCET-CN scenarios to examine the total investment costs. The basic assumptions for this analysis are in Tables 11.1–11.3.

Table 11.1. Assumed Fuel Costs

Fuel	2019/2020	2050 (2019 Constant Price)	Unit
Coal	80.03	98.00	US$/tonne
Oil	41.00	100.00	US$/bbl
Gas	7.77	7.50	US$/mmbtu
Hydrogen	0.80	0.30	US$/$Nm^3$
CCS	0	30.00	US$/$tCO^2$

bbl = barrel, CCS = carbon capture and storage, mmbtu = million British thermal unit, Nm^3 = normal cubic metre, tCO_2 = tonne of carbon dioxide equivalent.
Source: Author's calculations.

Table 11.2. Assumed Construction Costs of Power Plants
(US$/kilowatt)

	2019	by 2050
Coal	1,500	1,525
Oil	0	0
Gas	700	700
Hydrogen	0	700
Nuclear	4,500	3,575
Hydro	2,000	2,223
Geothermal	4,000	4,256
Solar	1,600	307
Wind	1,600	1,235
Biomass	2,000	3,019

Source: Author's calculations.

Table 11.3. Assumed Capacity Factors of Power Plants
(%)

Fuel	2019	by 2050
Coal	75	80
Oil	75	80
Gas	75	80
Hydrogen	0	80
Nuclear	100	80
Hydro	50	40
Geothermal	50	50
Solar	17	17
Wind	40	40
Biomass	50	70

Source: Author's calculations.

7.2. Fuel Costs

Based on fuel cost assumptions in Table 11.1, total investments are shown in Table 11.4.

Table 11.4. Total Investments in Fuel under the BAU and LCET-CN Scenarios, 2050

Fuel	Final Energy Consumption, BAU, 2019 (Mtoe)	Final Energy Consumption, BAU, 2050 (Mtoe)	Final Energy Consumption, LCET-CN, 2050 (Mtoe)	Total Investment Cost, BAU, 2050 (US$ million)	Total Investment Cost, LCET-CN, 2050 (US$ million)
Coal	0.85	4.96	5.70	648	766
Oil	5.78	20.93	6.38	10,422	416
Gas	4.03	5.64	5.24	464	350
Hydrogen	0	0	8.37	0	9,757
Total	**10.66**	**31.53**	**25.70**	**11,535**	**11,290**

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

From the results above, the total investment fuel cost in 2050 for the BAU scenario is expected to be US$11,535 million. This total is slightly higher than that under the LCET-CN scenario at US$11,290 million.

7.3. Power Investment

Based on power generation investment assumptions in Table 11.2 and Table 11.3, the total investment cost for power plants in 2050 are in Table 11.5.

Table 11.5. Total Investment in Power Plants under the BAU and LCET-CN Scenarios, 2050

Fuel	Electricity Generation, BAU, 2019 (TWh)	Electricity Generation, BAU, 2050 (TWh)	Electricity Generation, LCET-CN, 2050 (TWh)	Additional Capacity, BAU (MW)	Additional Capacity, LCET-CN (MW)	Total Investment Cost, BAU, 2050 (US$ million)	Total Investment Cost, LCET-CN, 2050 (US$ million)
Coal	0.69	13.29	21.90	1,797	3,031	2,741	4,622
Oil	0.07	0	0	–10	0	0	0
Gas	12.27	23.41	28.20	1,588	2,278	1,112	1,594
Hydrogen	0	0	27.40	0	3,909	0	2,736
Hydro	10.03	44.29	105.30	9,777	27,179	21,735	60,420
Solar	0	0	5.70	0	3,794	0	1,165
Wind	0	0	4.80	0	1,362	0	1,682
Biomass	0.01	0.02	3.20	2	515	5	1,555
Total	**23.07**	**81.01**	**196.00**	**13,145**	**42,067**	**25,593**	**73,773**

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, MW = megawatt, TWh = terawatt-hour.
Source: Author's calculations.

From Table 11.5, the total additional capacity needed under the BAU scenario is 13,145 megawatts (MW) more than the 2019 level. The additional capacity for the LCET-CN scenario in 2050 is much greater – 42,067 MW – due to more aggressive assumptions for renewable energy for power plants to reduce emissions. As a result, the total investment for power plants in 2050 for the BAU scenario is assumed to be US$25,593 million, while under the LCET-CN scenario, it is US$73,773 million.

7.5. Overall Cost

The breakdown of the total investment cost is shown below.

Table 11.6. Overall Total Investment Costs for the BAU and LCET-CN Scenarios, 2050
(US$ million)

Cost	BAU	LCET-CN
Total Fuel Cost Investment	11,535	11,290
Total Power Capital Cost Investment	25,593	73,773
Total CCS Cost Investment	0	0
Total	**37,127**	**85,063**

BAU = business as usual, CCS = carbon capture and storage, LCET-CN = low-carbon energy transition–carbon neutral.
Source: Author's calculations.

Overall investment costs in 2050 are projected to be US$37,127 million for the BAU scenario and US$85,063 million under the LCET-CN scenario.

8. Conclusions and Recommendations

To ensure a more sustainable transition towards cleaner energy sources, Myanmar should foster collaboration and share knowledge on carbon capture, use, and storage technologies, best practices, and experiences. It should also invest in research and innovation for a more sustainable future. Partnerships should be created between academia, industries, and governments to drive innovation in renewable technologies and energy storage solutions.

Future research and development and international collaboration are key factors in accelerating the pace towards carbon neutrality in the Association for Southeast Asian Nations (ASEAN) region, including Myanmar. Cost reduction and international cooperation are vital for achieving carbon neutrality in an affordable manner. Myanmar should formulate a strategic vision to transform into a low-carbon society for the well-being of present and future generations.

In preparing for the changes towards energy transition, Myanmar has been accelerating the development of renewable energy policies, aligning actions and programmes to support climate objectives, and keeping emissions in check by accelerating plans towards reliable and cost-effective renewable energy and reducing energy security risks.

Chapter 12

New Zealand Country Report

Hien Dang
Energy Consultant, New Zealand
Cecilya Malik
ASEAN Expert on Energy Policy Analysis
Seiya Endo
The Institute of Energy Economics, Japan

1. Basic Concept of Low-carbon Energy Transition–Carbon Neutrality

The Low Carbon Energy Transition (LCET) aims to reduce greenhouse gas emissions from energy and to find sustainable ways to remove the use of fossil fuels (primarily coal, oil and natural gas). This includes transformation of the energy structure (e.g. by replacing fossil fuels with renewable energy), decarbonisation of fossil fuel utilisation, and improvement in energy efficiency. The increasing penetration of renewable energy into the energy supply mix, the onset of electrification and improvements in energy storage are all key drivers of the energy transition.

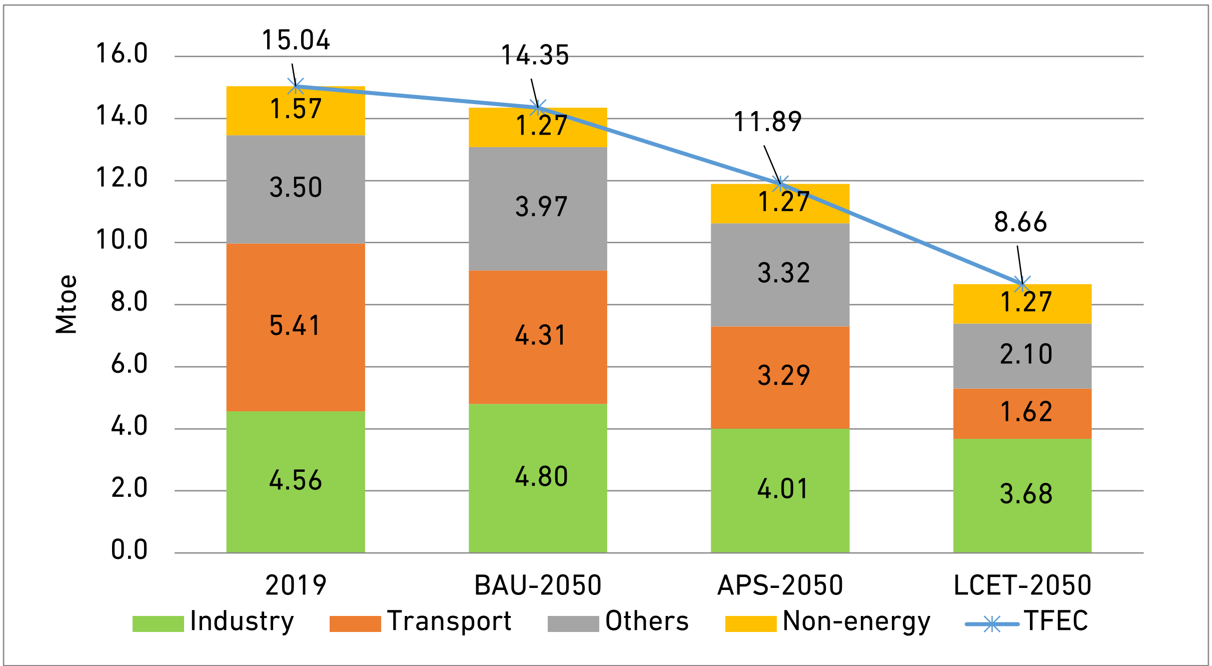
New Zealand enjoys many natural advantages for its energy transition, including an enviable renewable resource base. New Zealand already has a low-emissions electricity system, with significant production from both hydropower and geothermal power, and therefore has an attractive opportunity to leverage this clean electricity to decarbonise end-user sectors. The government has set ambitious targets for reducing greenhouse gas emissions, including achieving net-zero emissions by 2050. This chapter is a revised version of the LCET scenario developed for New Zealand in the Energy Outlook and Energy Saving Potential East Asia (EO&SP) 2023 report. The analysis also includes calculation of the investment costs and emissions reduction benefits of the LCET–CN scenario compared with the business as usual (BAU) scenario.

2. Final Energy Consumption (Historical Trend: 2019, 2030, 2040, 2050)

The low-carbon energy transition–carbon neutral (LCET–CN) scenario, will decrease New Zealand's total final energy consumption (TFEC) at an average rate of 1.8% per year from 15.0 million tonnes of oil equivalent (Mtoe) in 2019 to 8.7 Mtoe in 2050. Throughout this period, the TFEC in LCET–CN will always be lower than the BAU and alternative policy (AP)_ scenarios (40% lower compared with the BAU scenario and 27% lower compared AP scenario).

In 2050, the transport sector in the LCET–CN scenario is expected to decrease by 62% compared to BAU and 51% compared to the AP scenario. The 'others' category (agricultural, residential, and commercial) will decrease by 47% in the BAU scenario and 37% in AP scenario, whilst industry is projected to decrease by 23% in the BAU and 8% in AP scenarios. The LCET–CN's non-energy sector in TFEC is projected to remain unchanged, as shown in Figure 12.1.

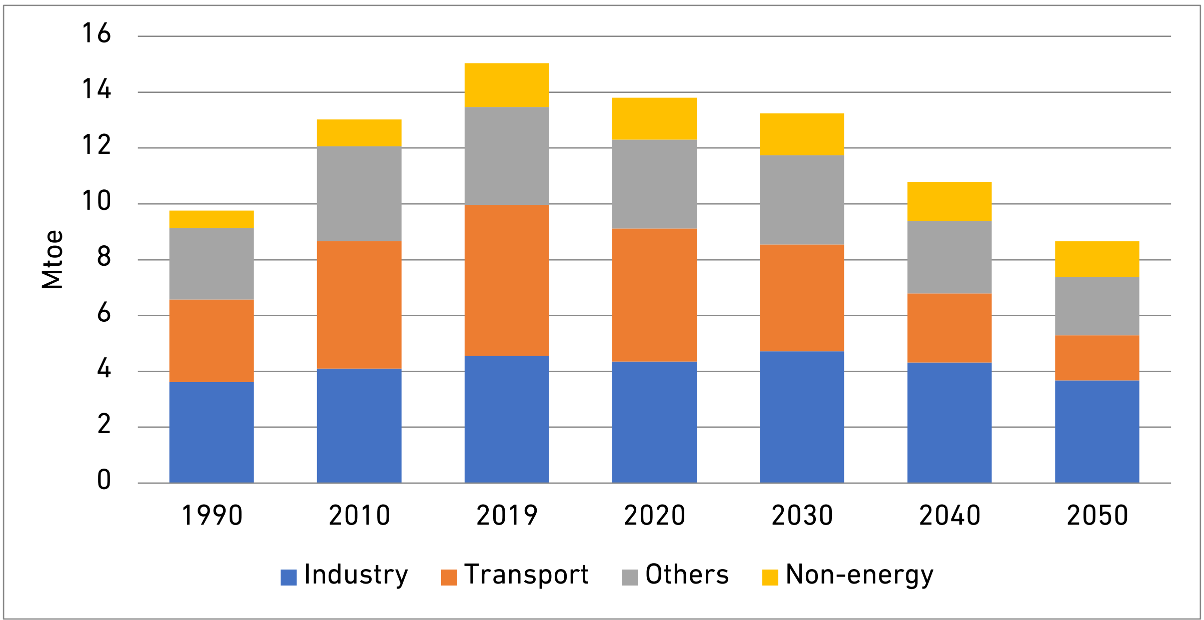
Figure 12.1. Total Final Energy Consumption, BAU, AP, and LCET-CN Scenarios



APS = alternative policy scenario, BAU = business-as-usual, LCET = low-carbon energy transition-carbon neutral, TFEC = total final energy consumption, Mtoe = million tonnes of oil equivalent, TFEC = total final energy consumption.
Note: 'Others' includes agricultural, residential, and commercial sectors.
Source: Authors' calculations.

Figure 12.2 shows the final energy consumption by sector under the LCET–CN scenario. The large reduction of energy consumption in the transport sector from 2019 to 2050 (70%) contributes to the rapid decrease of TFEC in the LCET–CN scenario. The transport sector TFEC decreases from 5.4 to 1.6 Mtoe. The second highest reduction in energy consumption (40% from 2019 to 2050) will be in the 'others' category. Both the industry and non-energy sector energy consumption will decrease only by 19% from 2019 to 2050.

Figure 12.2. Final Energy Consumption by Sector, LCET–CN Scenario (1990–2050)

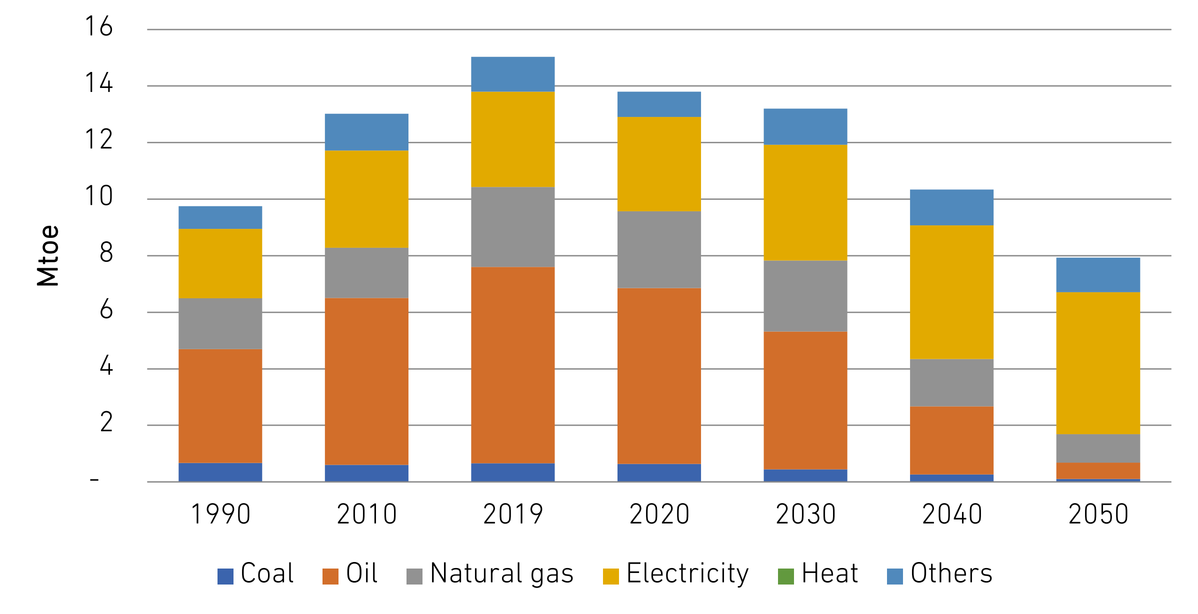


LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Note: 'Others' includes agricultural, residential, and commercial sectors.
Source: Authors' calculations.

The TFEC of the transport sector was the highest in 2019 with a share of around 36%. By 2050, the share of this sector will decline rapidly at an average rate per year of 3.8% compared with the rest of 'others' sector. The high reduction in the transport sector energy consumption is the result of a combined effect in fuel efficiency and substitution. Improved efficiency in the liquid-fuelled internal combustion engine and switching to highly efficient electric vehicles reduces liquid fuel consumption in the country. In addition, behaviour change in the distance travelled (vehicle kilometres travelled) as a result of urban intensification, people will live closer to their work place and choose public transport or other options such as walking and biking.

Considering that oil consumption was the main fuel consumed by the transport sector, oil consumption in the final sector will be reduce from around 6.9 Mtoe in 2019 to 0.6 Mtoe in 2050. This will be a reduction by around 6 Mtoe in 2050 (92% decrease). In case of coal, the reduction from 2019 to 2050 will be at 1 Mtoe (83% decrease), whilst natural gas will be at 2.0 Mtoe (65% decrease). Figure 12.3 shows the final energy consumption by sector under the LCET–CN scenario.

Figure 12.3. Final Energy Consumption by Fuel Type, LCET–CN Scenario (1990–2050)



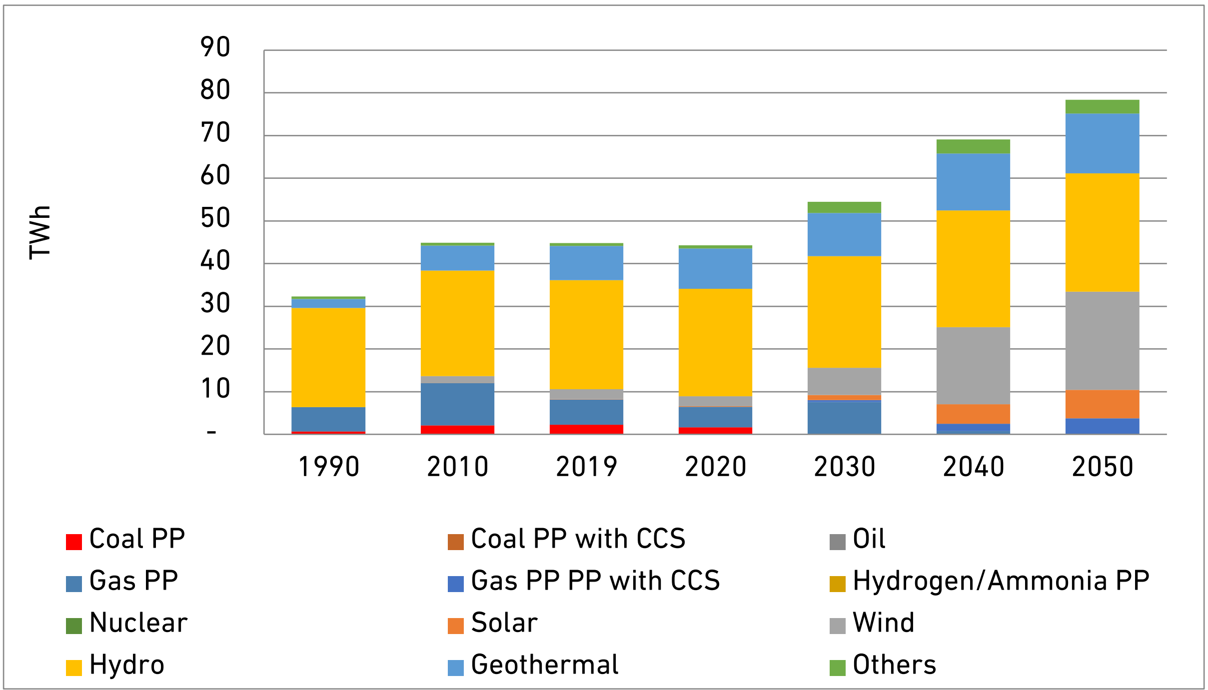
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

These large reductions in fossil fuels consumption of the LCET–CN scenario underline the importance of having clean energy that can contribute to lowering carbon dioxide (CO_2) emissions. As fossil fuel consumption decreases, electricity demand will increase by 49%, from 3.4 Mtoe in 2019 to 5.0 Mtoe in 2050. Hydrogen will start to be consumed from 2030 and hydrogen demand will reach 0.7 Mtoe in 2050. Hydrogen used in the final sector will be in the industry and transport sectors.

3. Power Generation (Historical Trend: 2019, 2030, 2040, 2050)

Power generation in New Zealand is projected to increase over the projection period under the BAU, AP, and the LCET–CN scenarios (Figure 12.4). In the LCET scenario, power generation is projected to grow significantly at 75% in 2019–2050. In comparison to the LCET–CN scenario, power generation increases only by 39.4% in the BAU and by 37.0% in the AP scenario.

Figure.12.4. Electricity Generation by Fuel, LCET–CN Scenario (1990–2050)



CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt hour.
Source: Authors' calculations.

Under the LCET–CN scenario, power generation will reach 78.4 terawatt hours (TWh) in 2050 from 44.8 TWh in 2019, increasing at an average rate of 1.8% per year. Hydropower generation will still be dominant, but the share is decreasing from around 57% in 2019 to 35% in 2050. The share of geothermal power generation remains the same in 2050 as it was in 2019 (18%). Solar photovoltaic (PV) cells, on the other hand, will have an increasing role in the country's power generation. The share of electricity produced by solar PV increased from 0.3% in 2019 to 8.5% in 2050. Similarly with solar PV, wind power generation will also be increasing. The share of wind power generation was 5% in 2019 and has increased to 29% in 2050. Overall, hydro, wind geothermal, and solar PV will constitute more than 90% of power generation in 2050, amounting to around 71 TWh.

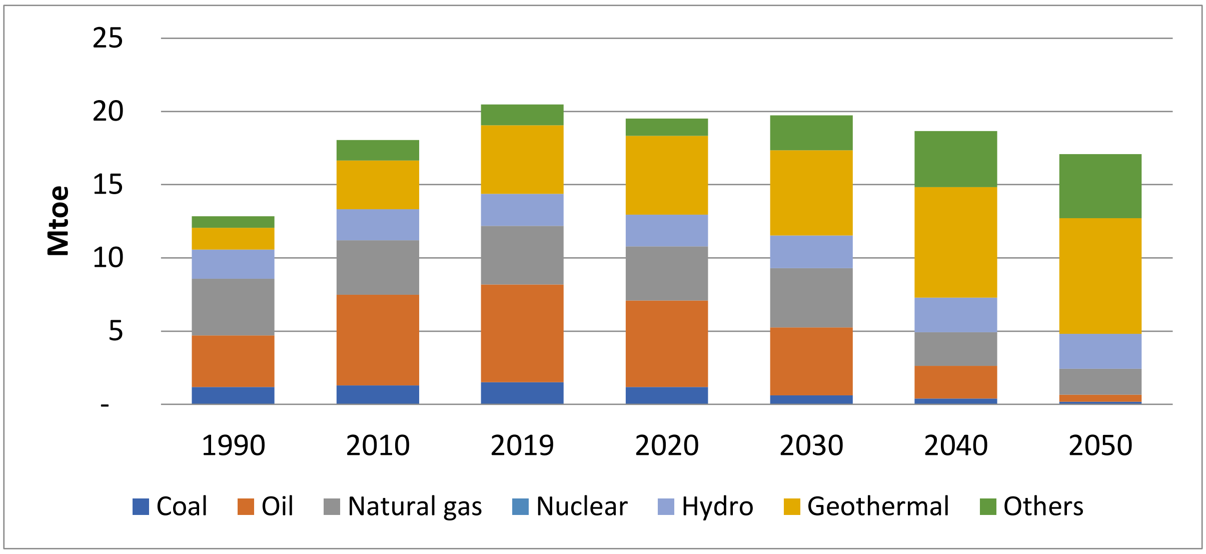
In the case of fossil-based power generation, the percentage of gas and coal will decrease significantly. Specifically, the share of gas, which was 13.1% in 2019, and the share of coal, which was 5.1% in 2019 are both expected to decline to 0.0% in 2050. The LCET–CN scenario projects power generation from natural gas (3.7 TWh in 2050) using carbon capture and storage (CCS). There is no power generated from coal using CCS. The share of total power generated from gas that will utilise CCS under the LCET–CN, accounts for 4.7% in 2050.

4. Primary Energy Supply (Historical Trend: 2019, 2030, 2040, 2050)

The total primary energy supply (TPES) under the LCET–CN scenario is expected to decrease at an average rate of 0.6% per year from 2019 to 2050. Fossil fuel supply will be declining sharply as more sustainable low-carbon fuel will be consumed in the LCET–CN scenario. Oil supply will decrease at an average rate of 8.2% per year, whilst coal supply will decline at an average rate of 6.6% per year. More efficient liquid-fuelled vehicles (including hybrid), switching to electric vehicles, biofuel vehicles, and fuel cell vehicles running on hydrogen will contribute significantly to the rapid decline of oil consumption in the TPES. Coal supply reduction will be both in the industry and power sectors. In the power sector, coal-fired power plants will cease to operate by 2050 and no coal-fired power plant will be operating using CCS.

Natural gas supply is projected to decrease by 2.6% per year, but not as rapidly as oil and coal. Although no gas-fired power plant will be operating in 2050, there will still be gas-fired power plants with CCS in operation from 2030. Other renewable sources, which include hydro, geothermal, wind, biomass, solar, liquid biofuels, and biogas, are projected to increase by an average rate of 1.9% per year in 2019–2050 (Figure 12.5).

Figure 12.5. Total Primary Energy Supply by Fuel Type, LCET–CN Scenario (1990–2050)



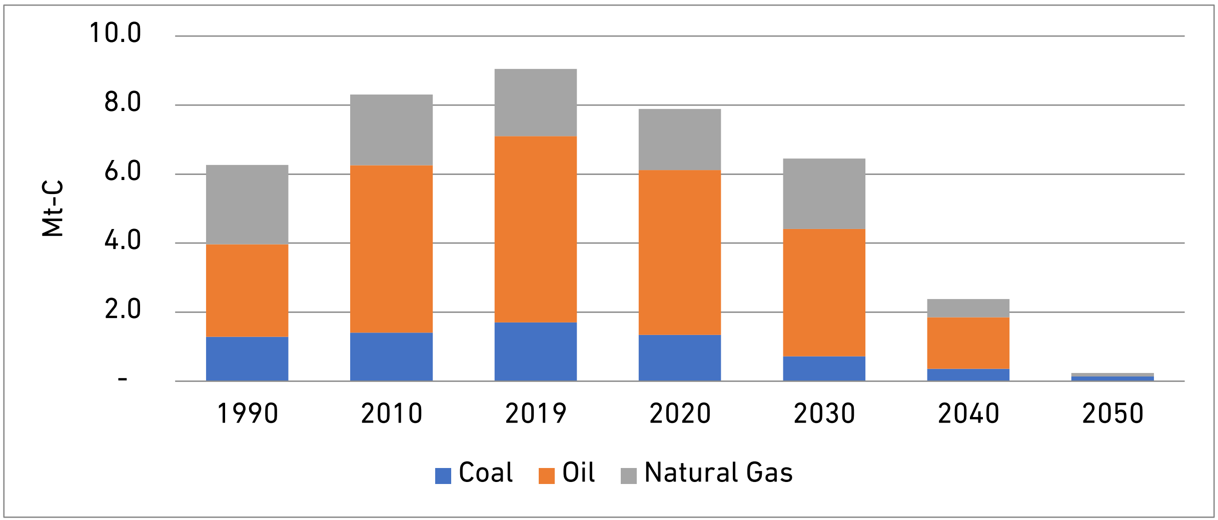
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

5. Carbon Dioxide Emissions

CO_2 emissions are expected to decline from 2019 to 2050 under the BAU, AP, and LCET–CN scenarios. The LCET–CN scenario projects a yearly reduction of 19.4% in CO_2 emissions from 33.2 million tons of carbon dioxide (Mt-CO_2) in 2019 to around 0.88 Mt-CO_2 in 2050

(Figure.12.6). Total reduction of CO_2 from 1990 to 2050 will almost be 100%, which is in line with the country's target of achieving net-zero emissions by 2050. The 2050 CO_2 emissions will be 0.49 Mt-CO_2 for coal and 0.38 Mt-CO_2 for natural gas.

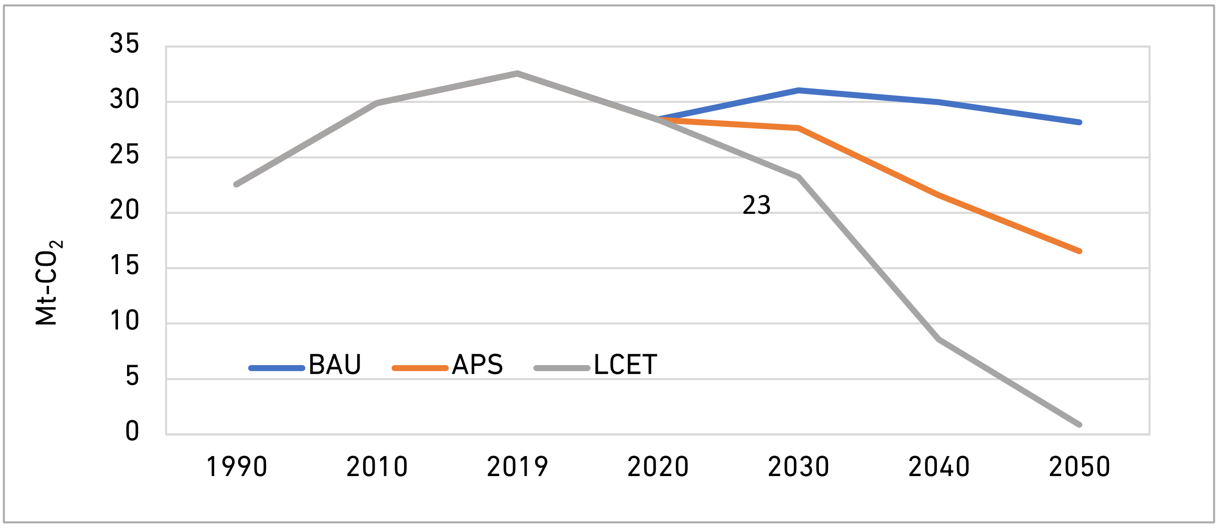
Figure 12.6. Total CO_2 Emissions by Fuel Type, LCET–CN Scenario (1990–2050)



CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: Authors' calculations.

Figure 12.7 shows the history of CO_2 emissions in the three scenarios, with a target to reduce CO_2 emissions by 30% in 2030 from 2005 levels.

Figure 12.7. CO_2 Reduction, BAU, AP, and LCET–CN Scenarios



APS = alternative policy scenario, BAU = business-as-usual, LCET–CN = low carbon energy transition–carbon neutral, Mt-CO_2 = million tonnes of carbon dioxide.
Source: Authors' calculations.

6. Hydrogen Demand Across the Sectors

Under the LCET–CN scenario assumptions, two sectors will be involved directly for hydrogen utilisation – the transport and industry sectors. In these sectors, hydrogen will replace oil consumption with hydrogen. The fuel switching will start in 2030. By 2050, hydrogen consumption will be 582 ktoe in the industry sector and 150 ktoe in the transport sector. Hydrogen consumption from these sectors represent 8.4% of total energy consumption of the final sector.

7. Energy Cost Comparison between BAU and LCET–CN Scenarios

Implementing the LCET–CN scenario implies investing in low-carbon technologies covering energy saving technologies, renewable energy, hydrogen and CCS. An analysis on energy cost was carried out to estimate the total investment cost in implementing policies and programmes under the LCET–CN scenario in comparison with the BAU scenario. The basic assumption for this analysis covers fuel cost (Table 12.1), construction cost of power plants (Table 12.2), and capacity factor of power plants (Table 12.3).

Table 12.1. Fuel Cost Assumptions

	2019/2020	2050 (2019 constant price)	Unit
Coal	80.03	98.00	US$/ton
Oil	41	100	US$/bbl
Gas	7.77	7.50	US$/MMBtu
Hydrogen	0.80	0.30	US$/$Nm^3$
CCS	0	30	US$/$CO_2$ ton

bbl = barrel, CCS = carbon capture and storage, MMBtu = million British thermal unit, Nm3 = normal cubic metre.
Source: Authors' calculations

Table 12.2. Construction Cost of Power Plants Assumptions
(US$/KW)

	2019	by 2050
Coal	1,500	1,525
Oil	0	0
Gas	700	700
Hydrogen	0	700
Nuclear	4,500	3,575
Hydro	2,000	2,223
Geothermal	4,000	4,256
Solar	1,600	307
Wind	1,600	1,235
Biomass	2,000	3,019

KW = kilowatt.
Source: Authors' calculations.

Table 12.3. Capacity Factor of Power Plants Assumptions
(%)

	2019	by 2050
Coal	75	0
Oil	9	9
Gas	30	10
Hydrogen	0	80
Nuclear	100	80
Hydro	55	40
Geothermal	92.5	97
Solar	23	23
Wind	42	40
Biomass	50	70

Source: Authors' calculations.

7.1. Fuel Cost

The fuel cost comparison will be analysed based on the primary energy consumption of the BAU and LCET–CN scenarios. Under the LCET–CN scenario, the primary energy consumption in 2050 will be 2.4 Mtoe, whilst under BAU it will be 10.8 Mtoe. Consequently, the total investment fuel cost in 2050 under the LCET–CN scenario will be lower than that under the BAU scenario, US$863 million compared to US$5,035 million, (Table 12.4).

Table 12.4. Total Investment Fuel Cost Comparison, BAU and LCET–CN Scenarios in 2050

	Primary Energy Consumption (Mtoe), BAU in 2019	Primary Energy Consumption (Mtoe), BAU in 2050	Primary Energy Consumption (Mtoe), LCET–CN in 2050	Total Investment Cost, BAU in 2050 (US$ million)	Total Investment Cost, LCET–CN in 2050 (US$ million)
Coal	1.50	0.87	0.18	138	29
Oil	6.67	5.07	0.47	3,490	322
Gas	4.00	4.87	1.78	1,407	513
Hydrogen	0.00	0.00	0.00	0	0
Total	**12.18**	**10.82**	**2.43**	**5,035**	**863**

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, Mtoe= million tonnes of oil equivalent.
Source: Authors' calculations.

7.2. Power Generation Investment

The construction cost and capacity factor assumptions in Table 12.2 and Table 12.3 will be the basis for calculating the total investment cost for power plants in 2050 for the BAU and LCET–CN scenarios. The capacity factor for each power plant in both scenarios will determine the additional capacity of the power plants to produce the electricity in 2050. The total investment cost to construct these new plants in each scenario is shown in Table 12.5.

Table 12.5. Total Investment Power Plants Cost Comparison, BAU and LCET–CN Scenarios in 2050

	Electricity Generation in BAU for 2019 (TWh)	Electricity Generation in BAU for 2050 (TWh)	Electricity Generation in LCET–CN for 2050 (TWh)	Additional Capacity for BAU (MW)	Additional Capacity for LCET–CN (MW)	Total Investment Cost, BAU in 2050 (US$ million)	Total Investment Cost, LCET–CN in 2050 (US$ million)
Coal	2	0	0	0	0	0	0
Oil	0.004	0.008	0.004	5	0	0	0
Gas	6	15	4	9,977	-2466	6,984	0
Hydrogen	0	0	0	0	0	0	0
Nuclear	0	0	0	0	0	0	0
Hydro	26	23	28	-710	619	0	1,376
Geothermal	8	14	14	712	703	3,030	2,990
Solar	0	3	7	1412	3247	433	997
Wind	2	6	23	1,038	5,927	1,283	7,320
Biomass	1	2	3	229	411	692	1,242
Total	**45**	**63**	**78**	**12,662**	**8,441**	**12,422**	**13,925**

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, Mtoe= million tonnes of oil equivalent, MW = megawatt, TWh = terawatt hour.
Source: Authors' calculations.

As discussed in Section 5 on power generation, electricity generated in 2050 for the LCET–CN scenario will be higher than under BAU, 78 TWh compared to 63 TWh. The type of plants to produce the needed electricity will be gas and renewable energy under BAU. In the LCET–CN scenario, electricity generation from renewable energy power plants will increase significantly since the target of this scenario is to achieve net-zero CO_2 emissions. Based on the capacity factor assumption of each plant, the total additional capacity requirement of BAU will be 12,662 megawatts MW with gas plants being the majority to be constructed (9,977 MW). In the LCET–CN scenario, the total additional capacity requirement will be 8,441 MW, where 5,927 MW will be that from wind power plant and 3,247 MW from solar power plants.

Based on the construction cost assumptions, the renewable energy power plants construction cost is assumed to be higher than the fossil plants (except solar power plants), As a result, the total investment cost for power plants in 2050 for the BAU scenario will be US$12,422 million, lower than in the LCET–CN scenario (US$13,925 million).

7.3. Carbon Capture and Storage Cost

In New Zealand, carbon capture and storage (CCS) technology has been assumed to be introduced under the LCET–CN scenario starting from 2030 onwards. The investment cost for CCS was calculated only for natural gas-fired power plants equipped with CCS since coal-based power plants will not be operating by 2050. If CCS devices can capture up to 90% of CO_2 emissions and the average cost of capture is about US$30/$CO_2$ ton, the total investment for CCS is estimated to be US$37million (Table 12.6).

Table 12.6. Total Investment Cost of CCS for LCET–CN Scenario in 2050

	Consumption for LCET-CN in 2050 (Mtoe)	CO_2 Emissions for LCET–CN (Mt-CO_2)	CO_2 Emissions for LCET–CN (Mt-C)	Total Investment Cost of CCS for LCET–CN (US$ million)
Coal-fired Power Plant with CCS	0	0	0	0
Natural Gas-fired Plant with CCS	0.635	0.37	**1.35**	37
Total	0.635	0.37	**1.35**	37

CCS = carbon capture and storage, LCET–CN = low-carbon energy transition – carbon neutral, Mtoe= million tonnes of oil equivalent, Mt-CO_2 = million tonnes of carbon dioxide, Mt-C= million tonnes of carbon, Mtoe = million tonnes of oil equivalent.

Source: Authors' calculations.

7.4. Overall Cost

Based on the result from the calculations above, the overall total cost comparison between the BAU and LCET–CN scenarios is shown in Table 12.7. The overall investment cost for the BAU scenario in 2050 is projected to be US$5,436 million, whilst in the LCET–CN scenario it will be US$1,349 million. The differences in the total investment of both the BAU and LCET–CN scenarios indicate that there will be a saving in investment of 75% if the LCET–CN scenario is implemented. Fuel costs contribute more than 100% to the cost savings in the LCET–CN scenario.

Table 12.7. Overall Total Investment Cost for BAU and LCET–CN Scenarios in 2050

	BAU	LCET–CN	LCET–CN vs BAU
Total Fuel Cost Investment (US$ million)	5,035	863	–4,172
Total Power Capital Cost Investment (US$ million)	401	449	48
Total CCS Cost Investment (US$ million)	0	37	37
Total (US$ million)	**5,436**	**1,349**	**–4,087**

BAU = business as usual, LCET–CN = low-carbon energy transition – carbon neutral.
Source: Authors' calculations.

8. Conclusions and Recommendations

The total investment cost of the LCET–CN scenario is estimated to be US$1,349 million, which is lower than in the BAU scenario, US$5,436 million. This result indicates that implementing all the measures assumed in the LCET–CN scenario will enable New Zealand to attain net-zero emissions by 2050. This is in line with the government energy strategies being developed to achieve net-zero carbon emissions by 2050. The total investment reduction of the energy sector by implementing LCET–CN scenario will be US$4,087 million compared to implementation of the BAU scenario.

The main reduction in total investment will be that of fuel cost (US$4,172 million) since fuel cost is the major portion of the total investment (93% in BAU and 64% in LCET–CN). Increasing renewable power generation in the LCET–CN scenario and introducing CCS with gas-fired power generation will require additional investment of US$ 85 million in 2050 as compared to the BAU scenario.

Introduction of CCS is assumed to be from 2030, and the investment in CCS will reach US$37 million in 2050. This amount is around 1% of the total investment. If the cost of CCS technology is reduced by 2050, the investment cost of CCS is expected to be reduced significantly.

References

Dang, H. and S. Endo (2023), 'New Zealand Country Report', in Kimura, S., H. Phoumin, and A.J. Purwanto (eds.), Energy Outlook and Energy-Saving Potential in East Asia 2023. Jakarta: ERIA, pp.277–98

Department of Statistics New Zealand (2016), 'Population Projections (Revised) New Zealand (2010-2040)', November. https://newss.statistics.gov.my/newss-portalx/ep/epFreeDownloadContentSearch.seam?cid=300323

Earth System Governance (n.d.), 'Low Carbon Transition,' (https://www.earthsystemgovernance.net/conceptual-foundations/?page_id=131#:~:text=The%20concept%20'Low%20Carbon%20Transition,risks%20of%20catastrophic%20climate%20change

European Parliament (2019), 'What is Carbon Neutrality and How Can it be Achieved by 2050?,' News, 3 October. https://www.europarl.europa.eu/news/en/headlines/society/20190926STO62270/what-is-carbon-neutrality-and-how-can-it-be-achieved-by-2050#:~:text=Carbon%20neutrality%20means%20having%20a,is%20known%20as%20carbon%20sequestration

Ministry of Environment and Water New Zealand (2020), 'New Zealand's Third Biennial Update Report to the UNFCCC', December. (Ministry of Environment and Water New Zealand) https://unfccc.int/sites/default/files/resource/NEW ZEALAND_BUR3-UNFCCC_Submission.pdf

Ministry of Plantation Industry and Commodities New Zealand (2007), New Zealand Biofuel Industry Act. https://www.mpic.gov.my/mpi/images/mpi_polisi_dan_akta/Akta666_BiobahanApiNew Zealand2007_BM.pdf

S&P Global (2021), 'New Zealand's New Energy Transition Plan: Lower Renewable Capacity Addition and a Phase out of Coal Leads to a Sizeable Increase in Gas Requirements and Affordability Concern', June. https://www.spglobal.com/commodityinsights/en/ci/research-analysis/New Zealands-new-energy-transition-plan-lower-renewable-capacity.html

Zhou, P., Y. Lv, and W. Wen (2023), 'The Low-Carbon Transition of Energy Systems: A Bibliometric Review from an Engineering Management Perspective', *Engineering,* 29, 147–58. https://www.sciencedirect.com/science/article/pii/S2095809923001625#:~:text=In%20addition%2C%20we%20define%20the,fossil%20fuel%20utilization%20(e.g.%2C%20by

Chapter 13
Philippines Country Report

Lilibeth T. Morales
Senior Science Research Specialist
Policy Formulation and Research Division,
Energy Policy and Planning Bureau, Department of Energy, Government of the Philippines

1. Background

The energy sector of the Philippines is mandated to ensure sustainable, stable, sufficient, accessible, and reasonably priced energy by formulating and implementing policies and programmes that aim to improve quality of life. Currently, the country's total primary energy supply (TPES) is supported by coal, which is largely used for power generation. In the draft Philippine energy plan for 2023–2050, a clean energy scenario is being considered, which includes decarbonisation targets such as higher renewable energy targets in power generation and inclusion of new and other emerging technologies. It also targets higher electric vehicle (EV) penetration and higher biofuel blends in oil for transport. These plans are in accordance with the country's energy transition strategies towards a low-carbon future and contribute to the achievement of the Sustainable Development Goal 7.

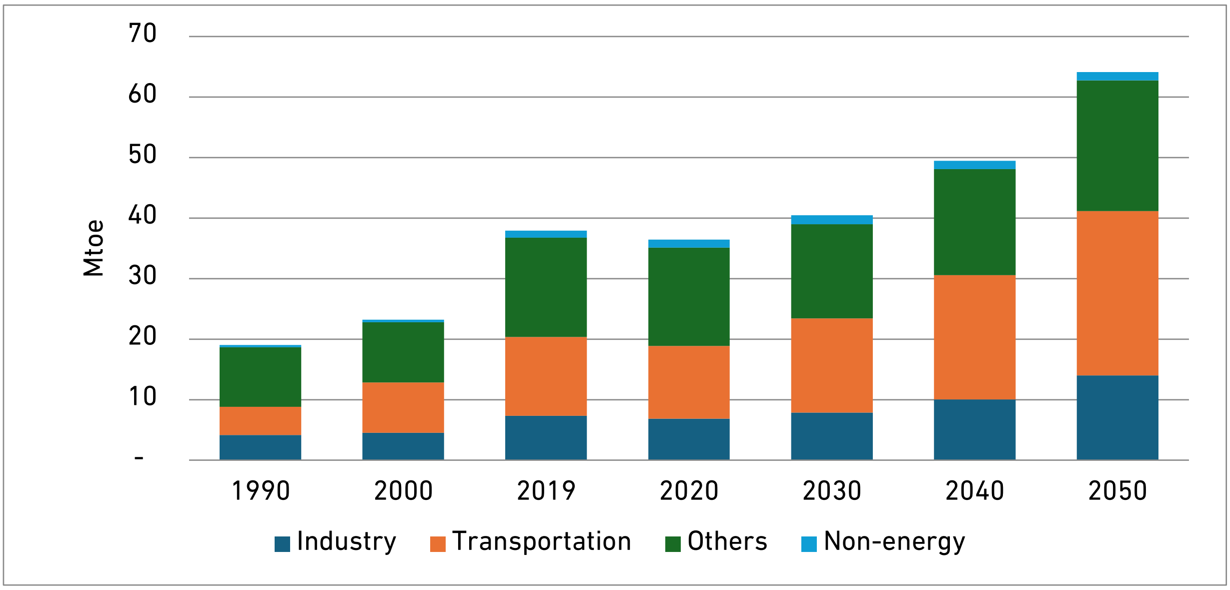
Energy sustainability is the primary factor to reduce the impact of emissions on the environment; as such, a transition towards a clean energy future is being pushed by the global community. The transition is expected to make a significant structural change in the energy sector of the Philippines, which currently dominated by fossil fuels such as coal and oil. Accordingly, a low-carbon energy transition–carbon neutral (LCET-CN) scenario is being studied. An LCET-CN scenario is based on investment in low-carbon technologies such as renewable energy; energy efficiency and conservation; and other new technologies, such as hydrogen and carbon capture, utilisation, and storage (CCUS).

This study develops an LCET-CN scenario, calculates associated energy costs, and records the emissions reduction benefits compared to a business-as-usual (BAU) scenario in the Philippines.

2. Final Energy Consumption (historical trend: 2019, 2030, 2040, 2050)

Under the LCET-CN scenario, the country's total final energy consumption (TFEC) is expected to increase 1.3% per year to 2050 from the 2019 level, much lower than the BAU scenario, which increases 2.9% per year. The lower growth rate under the LCET-CN scenario is due to higher energy efficiency and improved conservation measures in end-use sectors such as industrial, residential, and commercial. The potential savings of energy efficiency under the LCET-CN scenario is assumed at 10% to 2040. The TFEC projection is based on gross domestic product and population growth assumptions.

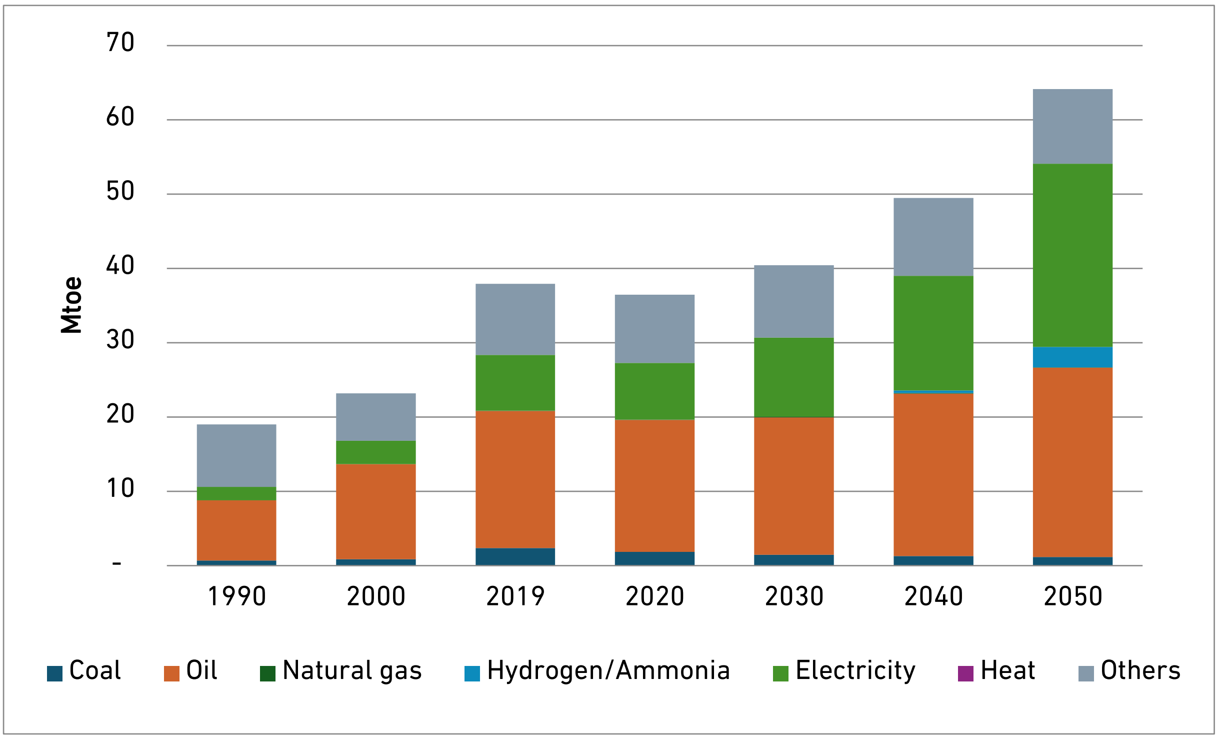
Figure 13.1. Final Energy Consumption by Sector under the LCET-CN Scenario, 1990–2050
(Mtoe)



LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

Figure 13.1 shows the final energy consumption by sector under the LCET-CN scenario. In 2050, the TFEC is expected to reach 64.14 million tonnes of oil equivalent (Mtoe). The transport sector is expected dominate with a share of 42.3% by 2050. The 'others' sector (i.e. combined residential, commercial, and agriculture) would remain second, with a share of 33.7% in 2050, lower than its 43.4% share in 2019. Meanwhile, the industrial sector is expected to increase at an average rate of 2.1%, growing to around 21.0% in 2050 from 19.3% in 2019.

Figure 13.2. Final Energy Consumption by Fuel under the LCET-CN Scenario, 1990–2050
(Mtoe)



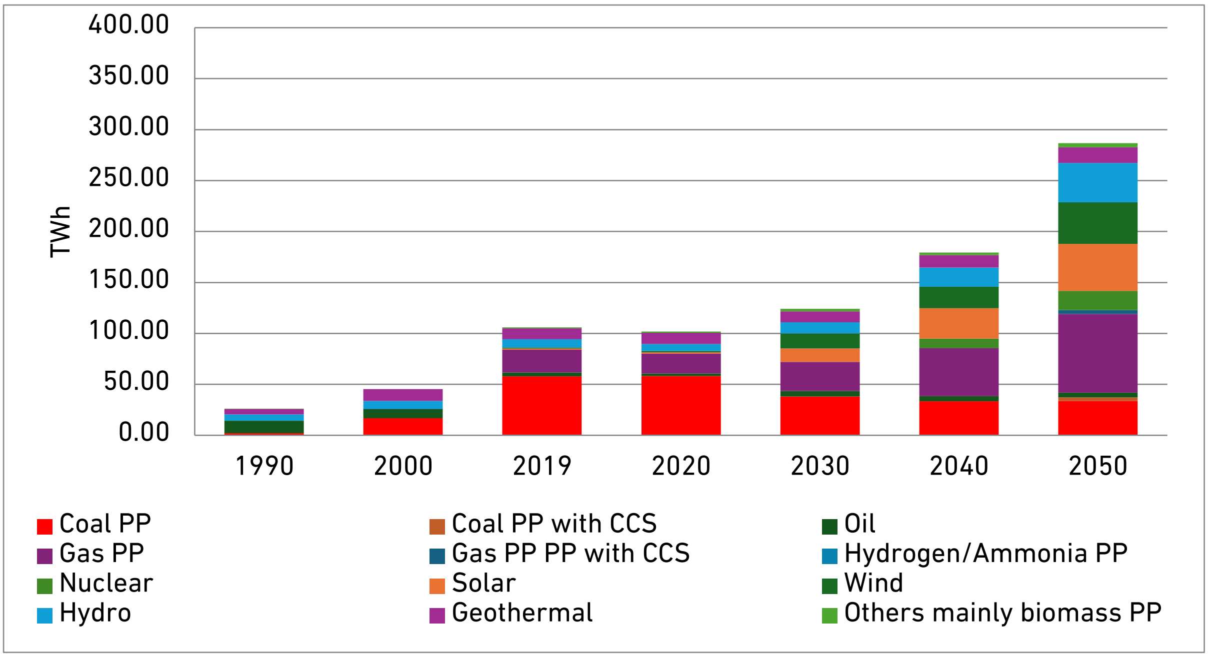
LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

The LCET-CN scenario highlights the importance of clean energy to help lower emissions. According to Figure 13.2, on a per fuel basis, the share of oil would fall from a 45.0% share under the BAU scenario to a 39.7% share under the LCET-CN scenario due to the introduction of energy efficiency and conservation measures, shift to EVs, higher biofuel blends, and introduction of hydrogen in the transport sector. By end of the study period, hydrogen would contribute around 4.3% in the TFEC. Meanwhile, the share of electricity will be 38.3% by 2050 compared to 19.8% in 2019.

3. Power Generation (historical trend: 2019, 2030, 2040, 2050)

In 2050, the total power generation of the Philippines is expected to register at 286.7 terawatt-hours (TWh) under the LCET-CN scenario, 36.5% lower than the BAU scenario of 451.7 TWh. The implementation of energy efficiency and conservation measures in the end-use sectors – specifically oil and electricity – would contribute to the decrease. Moreover, higher power plant efficiency was adopted in the model; more efficient power plants require smaller input compared with less-efficient power plants.

Figure 13.3. Electricity Generation by Fuel under the LCET-CN Scenario, 1990–2050
(TWh)



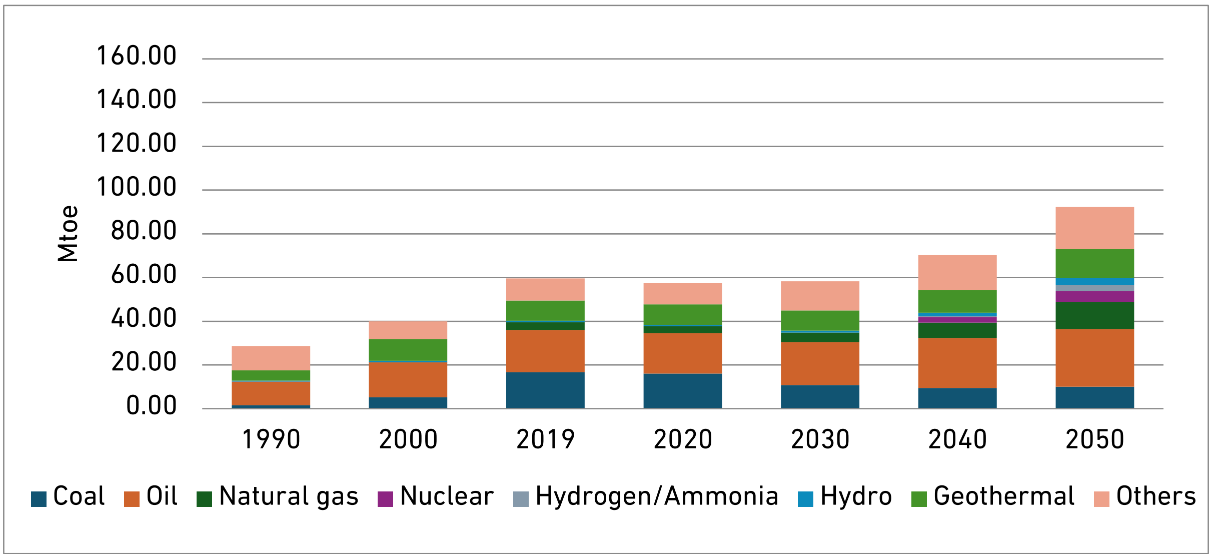
CCS = carbon capture and storage, LCET-CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: Author's calculations.

On a per fuel basis, the combined share of natural gas, including natural gas with carbon capture and storage (CCS), would dominate with a share of 28.2%, reaching 80.8 TWh in 2050 under the LCET-CN scenario. Coal (including coal with CCS) would reach a 13.0% share in 2050 under the LCET-CN scenario compared to a 30.4% share under the BAU scenario.

4. Primary Energy Supply (historical trend: 2019, 2030, 2040, 2050)

The total primary energy supply under the LCET-CN scenario is expected to increase 1.4% per year from 2019 to reach 92.3 million tonnes of oil equivalent (Mtoe) in 2050 under the LCET-CN scenario. The incremental rate is lower when compared to the BAU scenario's 2.8% rate, due to a higher energy savings target of 10% in 2050 (Figure 13.4).

Figure 13.4. Total Primary Energy Supply by Fuel Type under the LCET-CN Scenario, 1990–2050
(Mtoe)



LCET-CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

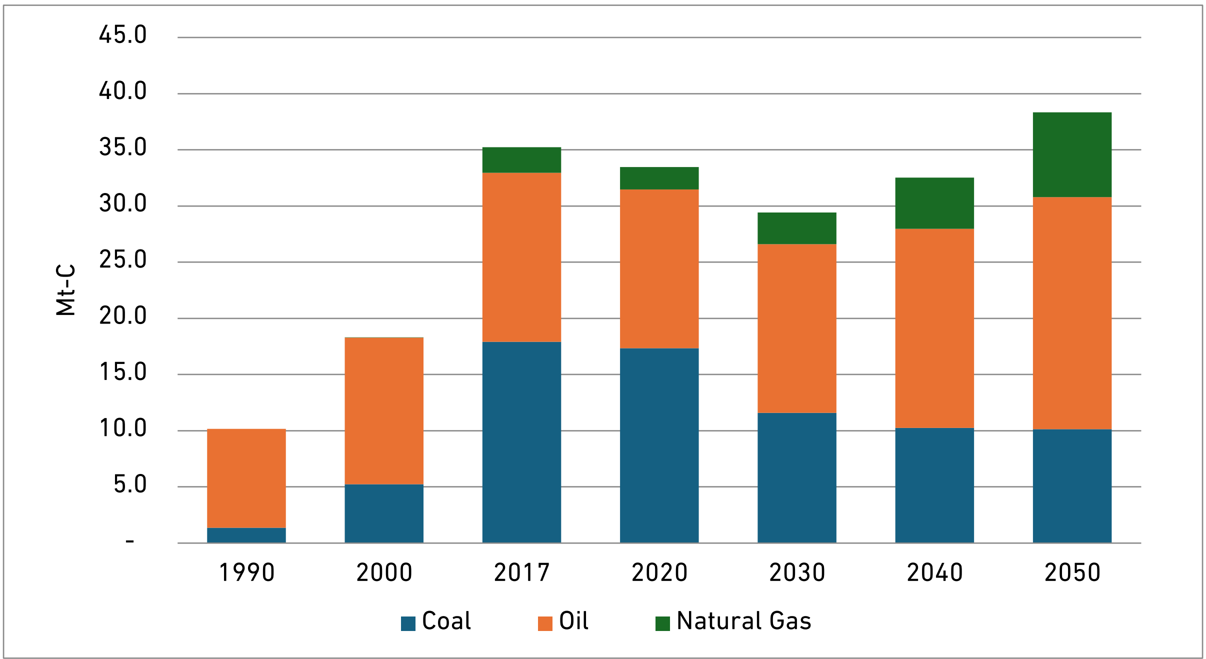
Natural gas fuel would record the highest increase amongst fossil fuels at 4.0% per year from 2019 until 2050 under the LCET-CN scenario. This increase is due to power generation becoming a substitute for coal, whose use would decrease at an annual rate of 1.6%. Meanwhile, the combined contribution of solar, wind, and ocean power would grow quickly at an annual rate of 12.4%. Biofuel would also contribute 10.0% per year during a similar time horizon. By increasing the share of renewable energy to 50.0% by 2040, the share of other renewables such as hydro, geothermal, and biomass would also increase at annual rates of 5.2%, 1.2%, and 0.4%, respectively. Hydrogen would also form part of the mix, contributing 2.7 Mtoe to the TPES by 2050.

As a strategy to reduce emissions, the draft 2023-2050 Philippines energy plan targets 19 gigawatts (GW) and 50 GW onshore and offshore wind power, respectively, to form part of its energy mix.

5. Emissions

Total emissions under the LCET-CN scenario would reach 38.3 million tonnes of carbon (MtC), an increase of 0.3% per year from the 2019 level (Figure 13.5). Emissions from coal are expected to decrease at annual rate of 1.8% from 2019 until 2050 due to repurposing the use of coal for power generation. In December 2022, the Department of Energy (DOE) issued a moratorium on endorsing greenfield coal-fired power projects to improve energy sustainability, reliability, and flexibility by increasing the share of renewable energy in the energy mix; promoting new technologies; increasing system flexibility; and adhering to higher environmental standards. Under the LCET-CN scenario, emissions from natural gas are expected to increase by 3.9% per year from 2019 until 2050 due to this coal moratorium. Similarly, total emissions from oil would increase at an annual rate of 1.0%, reaching 20.7 MtC in 2050.

Figure 13.5. Total Emissions by Fuel Type under the LCET-CN Scenario, 1990–2050



LCET-CN = low-carbon energy transition–carbon neutral, MtC = million tonnes of carbon.
Source: Author's calculations.

By the end of the forecasted period, the share of oil would still dominate total emissions with a 53.9% share of the total, followed by coal at 26.4%, and natural gas at 19.7%.

6. Cost Comparison Analysis

6.1. Assumptions

An analysis of energy costs was carried out to compare the BAU and LCET-CN scenarios (Table 13.1). The objective of this analysis to understand the total energy costs that are needed to implement all assumptions both scenarios.

Table 13.1. Assumed Fuel Costs

Fuel	2019/2020	2050 (2019 Constant Prices)	Unit
Coal	80.03	98.00	US$/tonne
Oil	41.00	100.00	US$/bbl
Gas	7.77	7.50	US$/mmbtu
Hydrogen	0.80	0.30	US$/$Nm^3$
CCS	0	30.00	US$/$tCO^2$

bbl = barrel, CCS = carbon capture and storage, mmbtu = million British thermal unit, Nm^3 = normal cubic metre, tCO_2 = tonne of carbon dioxide.
Source: Author's calculations.

The fuel cost assumptions above were adopted to be consistent with other Association of Southeast Asian Nations (ASEAN) Member States involved in this study.

The assumptions of construction cost per each power source are in Table 13.2.

Table 13.2. Assumed Construction Costs per Each Power Source
(US$/kilowatt)

Power Source	2019	By 2050
Coal	1,500	1,525
Oil		
Gas	700	700
Hydrogen		700
Nuclear	4,500	3,575
Hydro	2,000	2,223
Geothermal	4,000	4,256
Solar	1,600	307
Wind	1,600	1,235
Biomass	2,000	3,019

Source: Author.

6.2. Fuel Costs

Based on fuel cost assumptions in Table 13.1, the overall total fuel costs in 2050 are in Table 13.3.

Table 13.3. Total Fuel Costs
(US$ million)

Power Source	BAU	LCET-CN
Coal	2,876	1,027
Oil	15,751	4,808
Gas	6,237	2,527
Hydrogen	0	3,913
Total	**24,864**	**9,500**

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral.
Source: Author.

From the results above, the total fuel costs in 2050 for the BAU scenario are much higher than those for the LCET-CN scenario due to the high dependency on fossil fuels in 2050 under the BAU scenario. The LCET-CN scenario would incur hydrogen costs at about US$4 billion, but if the Philippines achieves carbon neutrality by 2050, this hydrogen cost would be even higher due to more hydrogen use in the energy sector, especially regarding transport.

6.3. Power Generation Investment

Based on assumptions in Table 13.2, the total investment cost for power plants in 2019–2050 under the BAU and LCET-CN scenarios are shown in Table 13.4.

Table 13.4. Power Plant Costs
(US$ million)

Plant	BAU	LCET-CN
Coal PP	17,278	–4,485
Oil PP	0	0
Gas PP	14,483	5,841
Hydrogen PP	0	0
Nuclear PP	0	9,626
Hydro PP	13,069	19,470
Geothermal PP	6,705	4,538
Solar PV	6,391	9,261
Wind PP	10,926	13,957
Biomass PP	15,410	1,472
Total	**84,262**	**59,682**

BAU = business as usual, LCET-CN = low-carbon energy transition–carbon neutral, PP = power plant, PV = photovoltaic.
Source: Author.

The total additional capacity needed for the BAU scenario is 74,243 megawatts (MW). The additional capacity needed under the LCET-CN scenario in 2050 is much lower at 59,881 MW, as increasing the energy efficiency target as well as using high thermal-efficiency power plants would reduce the need for additional capacity for power generation. The BAU scenario would increase the capacity of thermal power plants and renewable energy plants because of a significant increase in electricity demand. The LCET-CN scenario would increase nuclear and renewable energy power plants, which would reduce emissions as well. As a result, the total investment for power plants during 2019–2050 under the BAU scenario is forecasted to be US$84,262 million, while it would be US$59,682 million under the LCET-CN.

6.4. Carbon Capture and Storage Costs

Under the LCET-CN scenario, the study assumes CCS for coal and natural gas power plants starting in 2040. In 2050, coal power plants with CCS will generate 3.69 TWh and gas power plants 3.69 TWh. Thus, coal consumption by coal power plants with CCS in 2050 would be 10 Mtoe, and gas consumption by gas power plants with CCS would be 8.4 Mtoe. Emissions reduced by CCS would total 39 million tonnes of carbon dioxide ($MtCO_2$) by coal power plants and 18 $MtCO_2$ by gas power plants. Consequently, CCS costs for coal power plants and gas power plants in 2050 are forecasted to be US$1,537 million. If the Philippines achieves carbon neutrality by 2050, it could increase the number of coal power plants with CCS and gas power plants with CCS, and the CCS costs in 2050 would increase rapidly.

6.5. Overall Cost

A breakdown of the total investment costs is shown in Table 13.5.

Table 13.5. Overall Investment Costs
(US$ million)

Cost	BAU	LCET-CN
Fuel Cost, 2050	24,864	9,500
Power Investment, 2019–2050	84,262	59,682
CCS Cost, 2050	0	1,537
Total	**109,126**	**70,719**

BAU = business as usual, CCS = carbon capture and storage, LCET-CN = low-carbon energy transition–carbon neutral.
Source: Author.

The overall investment costs for the BAU scenario are projected to be US$109,126 million, and for the LCET-CN scenario, US$70,719 million. If the Philippines achieves carbon neutrality by 2050, power investment and costs of hydrogen and CCS would increase. In addition, the Philippines will need to own the energy efficiency and conservation costs for achievement of energy savings, especially electricity demand, which are estimated at US$10,000 million. However, it can be claimed that the LCET-CN scenario will contribute to reducing fossil fuel consumption, lessening fossil fuel costs significantly.

7. Conclusions and Recommendations

This study shows that significant energy savings potential of around 33.8% from 2019 levels can be achieved by 2050 with implementation of energy efficiency and conservation standards and measures, higher fuel economy of vehicles, and use of clean and energy-efficient fuel for power generation. Under the LCET-CN scenario, the share of oil in the final energy demand would fall from 45.0% under the BAU scenario to 39.7%. Moreover, the Electric Vehicle Industry Development Act (EVIDA) would complement the reduction of the share of oil in the transport sector. Note that to increase the penetration rate of EVs in the market, necessary infrastructure must be in place; the government should help encourage investment in this regard. It should also focus on intensifying the targets and promotion of alternative fuels in the transport sector to substitute the use of oil.

The TPES is expected to double from the 2019 level of 59.6 Mtoe to 139.5 Mtoe by 2050 under the BAU scenario, which will require more investment until 2050. Under the LCET-CN scenario, the TPES would decrease to around 92.3 Mtoe, and the share of coal in the TPES would fall to 10.9% from 25.0% under the BAU scenario as a result of fuel switching in end-use sectors; entry of more renewables, natural gas, and nuclear for power generation; and improved efficiency of fossil fuel-based power plants. The reduction of coal in the TPES would contribute to decreased emissions levels of 73.3%.

The LCET-CN scenario would also entail lower energy costs. If the Philippines achieves carbon neutrality by 2050, it would save US$43,042 million in energy sector costs compared to the BAU scenario.

To achieve the goal of transitioning to a clean energy future, the government must encourage investment, establish needed frameworks, develop an expert workforce, and raise public awareness. Regional cooperation and understanding between economies should be strengthened through dialogues, seminars, and workshops.

The Philippines has already established strategies for a low-carbon future in the *Philippine Energy Plan (PEP) 2020–2040* and draft 2023–2050 plan. Meanwhile, a net-zero emissions target for the Philippines has yet to be established compared with other ASEAN Member States like Malaysia (2050) and Indonesia (2060 or sooner). The Philippines should evaluate the advantages and disadvantages of technologies to help the country adopt and not sacrifice supply, security, affordability, and sustainability of energy. After identifying the most suitable technologies, a roadmap should be developed for each strategy.

References

Congress of the Philippines (2007), Republic Act No. 9367, Biofuels Act of 2006, Manila.

––––– (2008), Republic Act No. 9513, Renewable Energy Act of 2008, Manila.

––––– (2019), Republic Act No. 11285, Energy Efficiency and Conservation Act, Manila.

––––– (2022), Republic Act No. 11697, Electric Vehicles Industry Development Act, Manila.

Government of the Philippines, Department of Energy, Philippine Energy Supply and Demand Outlook, https://doe.gov.ph/energy-supply-and-demand-outlook

––––– (2020), *2019–2020 Energy Sector Accomplishment Report 2020,* Manila.

––––– (2021), *Philippine Energy Plan (PEP) 2020–2040*, Manila.

Government of the Philippines, Department of Energy, Energy Policy and Planning Bureau (2019), *Philippine Energy Situationer 2019*, Manila.

International Monetary Fund (IMF), World Economic Outlook Databases, https://www.imf.org/en/Publications/SPROLLs/world-economic-outlook-databases#sort=%40imfdate%20descending [accessed 3 February 2023]

Philippine Statistics Authority, (2019), *Philippine Statistical Yearbook 2019*, Manila.

World Bank, International Comparison Program, https://www.worldbank.org/en/programs/icp

–––––, World Development Indicators, https://databank.worldbank.org/source/world-development-indicators [accessed 3 February 2023]

World Energy Council, https://www.worldenergy.org/

Chapter 14

Singapore Country Report

Zhong Sheng

Energy Studies Institute, National University of Singapore

1. Background of Singapore's Low-carbon Energy Transition–Carbon Neutrality

In 2022, Singapore submitted the second update of its Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (Government of Singapore, 2022). This provided enhanced climate targets compared to the first update of the NDC released in 2020 (Government of Singapore, 2020). In this second update, Singapore lowered its emissions target in 2030 to 60 metric tonnes of carbon dioxide equivalent ($MtCO_2e$). More importantly, in 2022 Singapore has announced the target of achieving net-zero emissions by 2050, which is addressed in its Long-Term Low-Emissions Development Strategy.

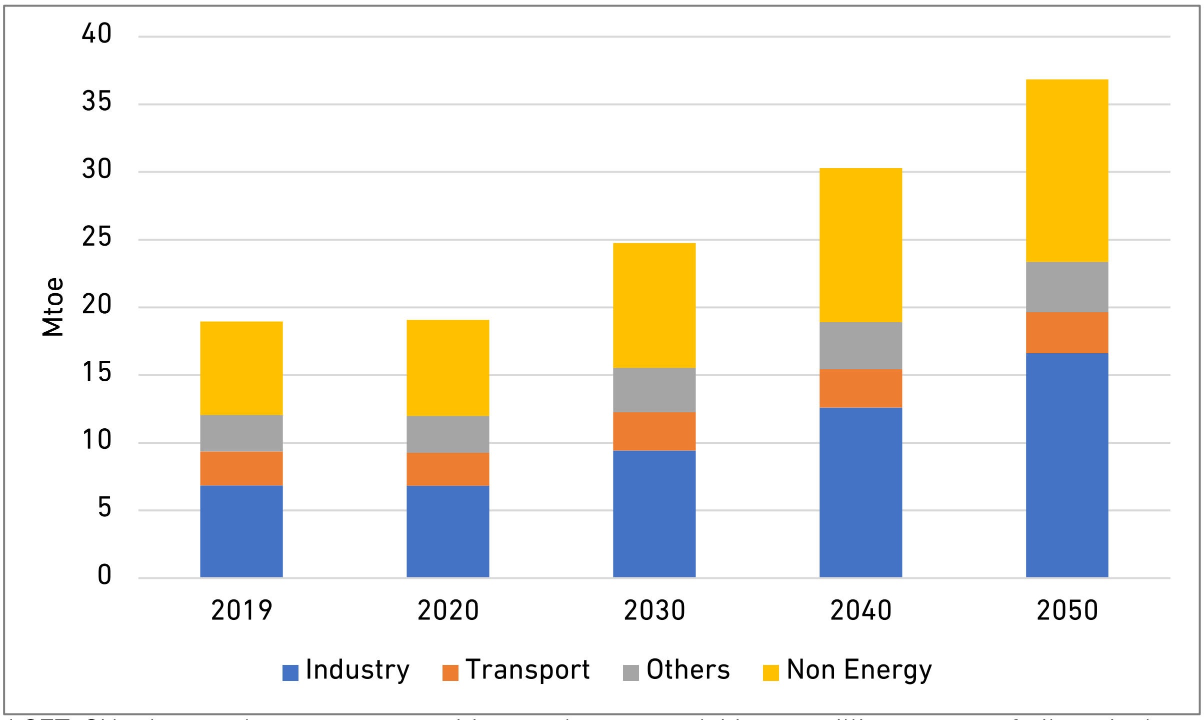
To achieve the NDC and net-zero emissions targets, Singapore has committed to accelerate the low-carbon transition for industry, economy, and society through various measures, including regional power grids, solar energy, emerging low-carbon technologies (i.e. carbon capture and storage [CCS], and hydrogen), and natural gas. This report will present Singapore's energy outlook results under the low-carbon energy transition–carbon neutral (LCET–CN) scenario.

2. Final Energy Consumption, 2019–2050

Under the LCET–CN scenario, the total final energy consumption of Singapore is projected to grow to 36.86 million tonnes of oil equivalent (Mtoe) in 2050 from 18.95 Mtoe in 2019 (about a 94.47% growth over the entire period), meaning an increase of 2.19% per year by 2050 from the 2019 level. As a comparison, the total final energy consumption under the LCET–CN scenario is slightly higher than that under the business as usual (BAU) scenario (i.e. 35.76 Mtoe). This is because the application of CCS in the LCET–CN scenario leads to efficiency loss and additional electricity use. In the LCET–CN scenario, CCS can be applied to the industry sector (i.e. the use of natural gas and refinery gas). This study assumes a 20% increase in electricity in the industry sector by 2050.

Figure 14.1 shows the final energy consumption by sector of Singapore under the LCET–CN scenario. In 2050, the total final energy consumption is projected to be 36.86 Mtoe. The industry sector will be expected to be the sector consuming the most energy in 2050 (about 45.09% of the total). Moreover, the industry sector has the higher annual growth rate as compared to other sectors (i.e. about 2.9% per year over 2019–2050). The non-energy sector, which will be the second largest energy consuming sector in 2050, will consume 13.5 Mtoe (or 36.63% from the total share) in 2050. The annual growth rate of the non-energy sector is about 2.19%. The 'others' sector (i.e. residential and commercial sectors) is projected to consume 3.71 Mtoe (or about 10.07% of the total) in 2050. The annual growth rate of the 'others' sector is about 1.02%. Lastly, the transport sector is projected to consume 3.03 Mtoe (about 8.21% of the total), with an annual growth rate of 0.61%. This is because the number of vehicles is regulated in Singapore.

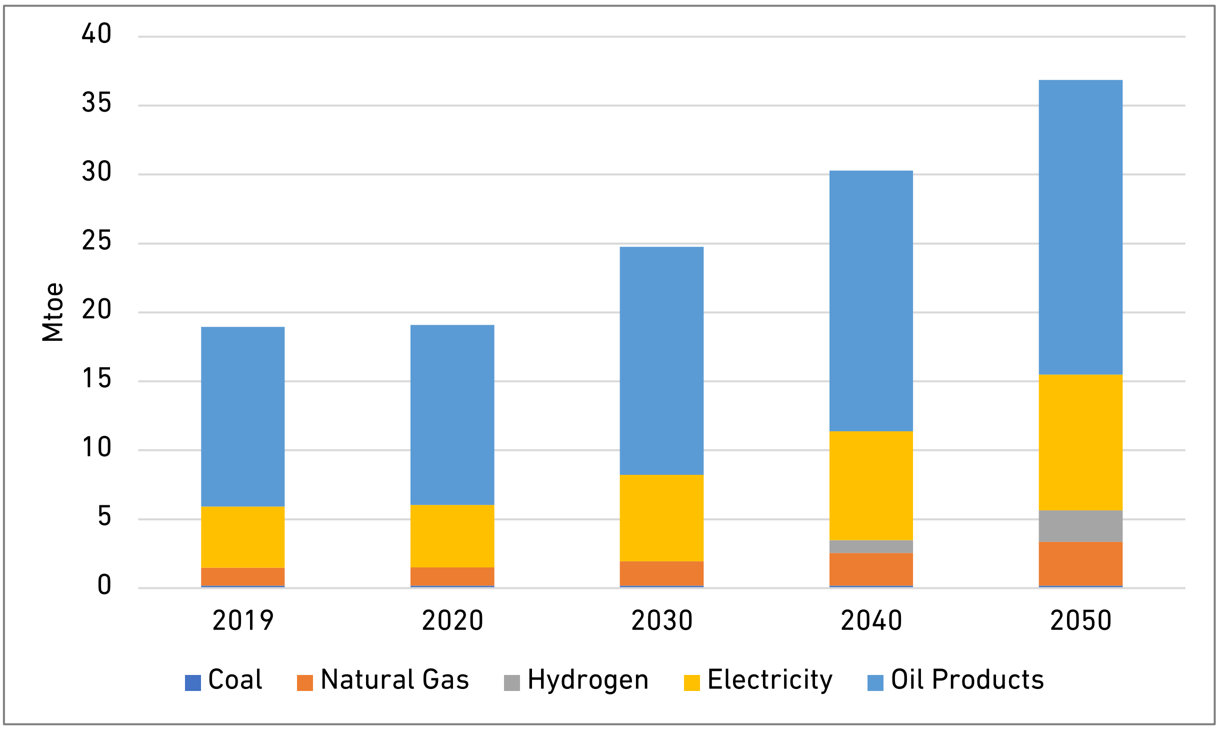
Figure 14.1. Final Energy Consumption by Sector, LCET–CN Scenario (2019–2050)



LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

Figure 14.2 shows the final energy consumption by fuel under the LCET–CN scenario. In this scenario, hydrogen is introduced and will change the energy consumption structure of Singapore in 2050. Hydrogen and electricity together will contribute about 32.95% of the total final energy consumption in 2050, i.e. 6.19% for hydrogen and 26.76% for electricity, respectively. The oil share will be expected to reduce to 57.96% in 2050 from 68.75% in 2019. The share of natural gas share is projected to grow from 6.81% in 2019 to 8.6% in 2050.

Figure 14.2. Final Energy Consumption by Fuel, LCET–CN Scenario (2019–2050)



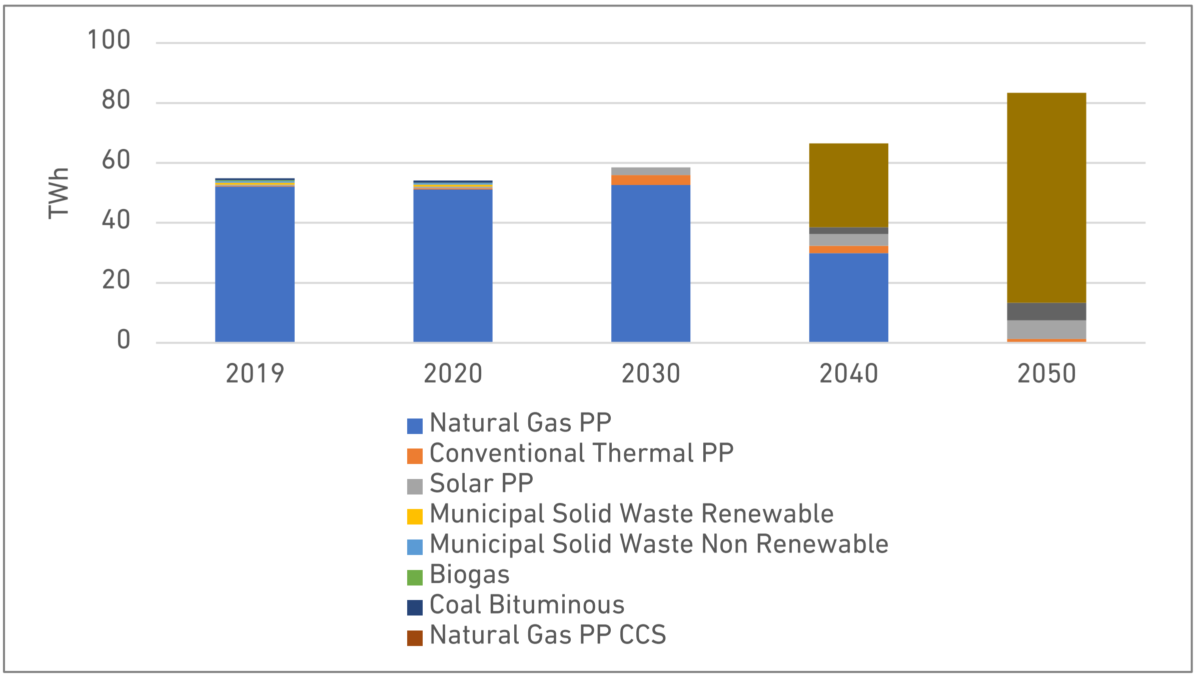
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

3. Power Generation, 2019–2050

In 2050, the total power generation is projected to be 83.43 terawatt-hours (TWh) under the LCET–CN scenario. This is lower than those under the BAU scenario, which is 88.61 TWh. Due to the applications of CCS in the industry sector, there would be additional consumption under the LCET–CN scenario, compared to the BAU scenario. The LCET–CN scenario assumes electricity imports, which will increase from 0% to 33% of domestic electricity demand by 2035, and this import share is assumed to be unchanged over 2035–2050.

The electricity generation mix under the LCET–CN scenario is shown in Figure 14.3. Total electricity generation under the LCET–CN scenario is projected to increase at 1.36% per year from 2019 until 2050. As shown in Figure 14.3, hydrogen (100% volume hydrogen using combined-cycle gas turbines) is projected to have the highest share with 84% in the total electricity generation in 2050. This is followed by solar PV with a share of 7.4% in generation mix in 2050. Biomass with CCS will account for 7% in generation mix. Conventional thermal power plants will contribute to the remaining generation (about 1.6% in the total). In the LCET–CN scenario, natural gas, coal, and biogas will be phased out by 2050.

Figure 14.3. Electricity Generation by Fuel Type, LCET–CN Scenario (2019–2050)

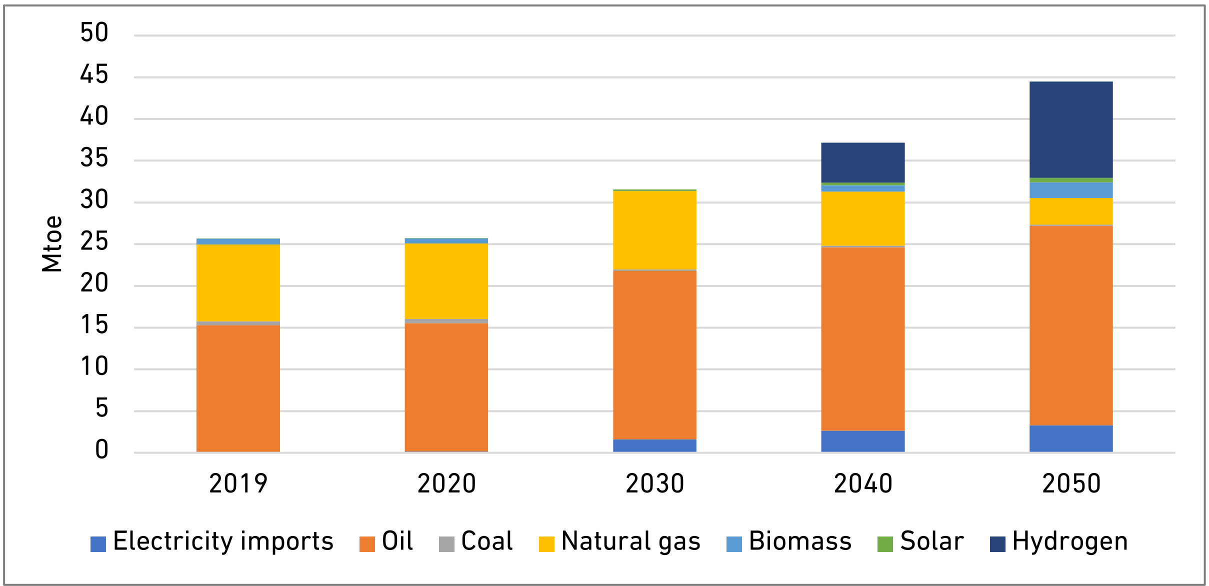


CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: Author's calculations.

4. Primary Energy Supply, 2019–2050

The total primary energy supply under the LCET–CN scenario is projected to increase by about 1.79% per year over the period 2019–2050. This annual growth rate is lower than that under the BAU scenario (i.e. 1.94% per year).

Figure 14.4. Total Primary Energy Supply by Fuel Type, LCET–CN Scenario (2019–2050)



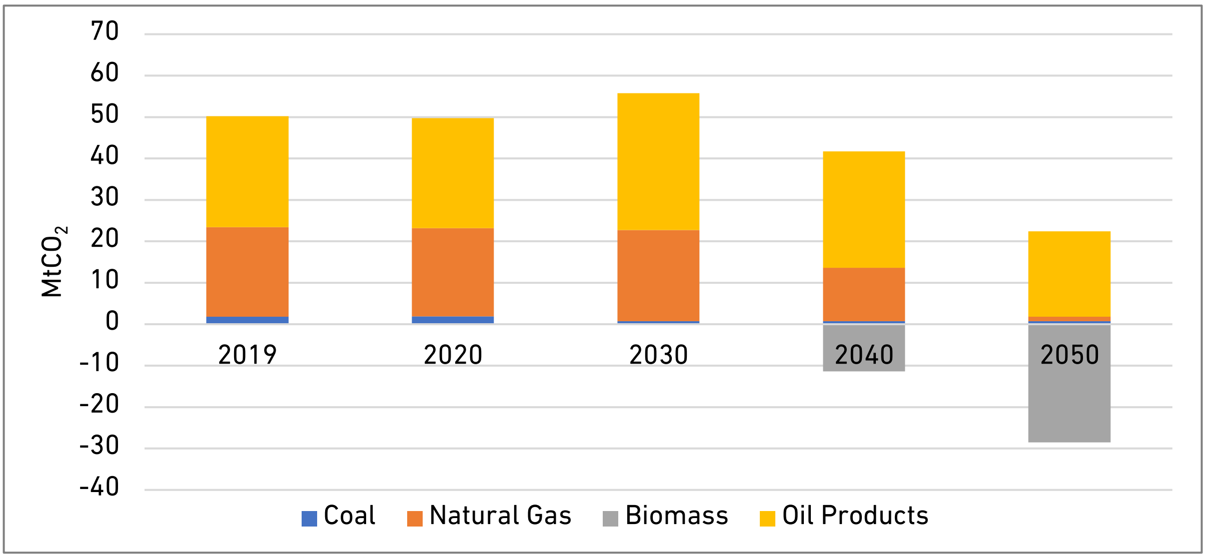
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

Across all years, oil products still account for the highest share (59.54% in 2019 and 53.7% in 2050). In the LCET–CN scenario, electricity imports and hydrogen are becoming more important. In 2050, electricity imports and hydrogen account for 7.39% and 25.97% in total primary energy supply, respectively, which increase from 0% in 2019. The share of renewable energy would also significantly increase. Biomass and solar energy will contribute to 4.21% and 1.19% in total primary energy supply, respectively. The other fossil fuels, natural gas and coal, are expected to decline in total primary energy supply. Specifically, the amount of coal would decrease from 0.46 Mtoe in 2019 to 0.18 Mtoe in 2050, with an annual growth rate of 2.93%. The amount of natural gas would decrease from 9.21 Mtoe in 2019 to 3.17 Mtoe in 2050, with an annual growth rate of 3.38%.

5. Carbon Dioxide Emissions

Overall, in 2050, the total carbon dioxide (CO_2) emissions under the LCET–CN scenario are projected to be about –6.1 $MtCO_2$. In the LCET–CN scenario, biomass with CCS is introduced to the electricity generation. This is a carbon-negative electricity generation technology (i.e. with a negative grid emission factor), and thus biomass with CCS can lead to negative emissions, which can offset the emissions from other sectors or sources (Sanchez, et al., 2015). In 2019, natural gas and oil contribute to the most emissions. Emissions from natural gas greatly drop from 21.64 $MtCO_2$ in 2019 to 1.11 $MtCO_2$ in 2050. In 2050, emissions from oil products still account for the most emissions, decreasing from 26.78 $MtCO_2$ in 2019 to 20.61 $MtCO_2$ in 2050.

Figure 14.5. Total CO_2 Emissions by Fuel Type, LCET–CN Scenario (2019–2050)



CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral, $MtCO_2$ = million tonnes of carbon dioxide.
Source: Author's calculations.

6. Hydrogen Demand across the Sector

In the current analysis, hydrogen will be introduced to two sectors under the LCET–CN scenario, i.e. transport and electricity. In the transport sector, hydrogen is expected to replace diesel used in vehicles. Such a fuel switching is assumed to start in 2031, and hydrogen is assumed to replace all diesel vehicles by 2050. This needs to be supported by proper hydrogen infrastructure (e.g. hydrogen fuelling station, transportation, and storage) and supporting policies and regulatory framework. In 2050, final consumption of hydrogen in the transport sector is projected to be 2.28 Mtoe, accounting for 87.69% of total final energy consumption in the transport sector.

In the LCET–CN scenario, hydrogen as a fuel (100% volume with combined-cycle gas turbines) is also introduced to electricity sector from 2031 and onwards. This assumes sufficient hydrogen supply to Singapore. In 2050, the total power generation from hydrogen power plant is projected to be 70.08 TWh, accounting for 84% in electricity generation.

7. Energy Cost Comparison between BAU and LCET–CN Scenarios

In addition, the current analysis compares the energy costs between the BAU and the LCET-CN scenarios. The comparison can provide useful information about the investment needed to achieve the climate targets in the LCET–CN scenario. Tables 14.1–14.3 present the basic techno-economic assumptions used in such a comparison. Note that not all technologies are applicable to Singapore.

Table 14.1. Fuel Cost Assumptions

	2019–2020	2050 (2019 constant price)	Unit
Coal	80.03	98.00	US$/ton
Oil	41	100	US$/bbl
Gas	7.77	7.50	US$/MMBtu
Hydrogen	0.8	0.3	US$/$Nm^3$
CCS	0	70	US$/$CO_2$ ton

bbl = barrel, CCS = carbon capture and storage, CO_2 = carbon dioxide, MMBtu = metric million British thermal units, Nm^3 = normal cubic metre.
Source: Author's calculations.

Table 14.2. Construction Cost of Power Plants Assumptions
(US$/KW)

	2019	by 2050
Coal	1,500	1,500
Oil	1,310	1,310
Gas	700	700
Hydrogen	0	700
Nuclear	4,500	4,500
Hydro	2,000	2,000
Geothermal	4,000	4,000
Solar	1,600	960
Wind	1,600	960
Biomass	2,000	2,000

KW = kilowatt.
Source: Author's calculations.

Table 14.3. Capacity Factor of Power Plants Assumptions
(%)

	2019	by 2050
Coal	90	90
Oil	4.5	4.5
Gas	54	54
Hydrogen	54	54
Nuclear	100	100
Hydro	50	50
Geothermal	50	50
Solar	12	19.6
Wind	40	40
Biomass	62.5	62.5

Source: Author's calculations.

7.1. Fuel Cost

Based on fuel cost assumptions shown in Table 14.1, Table 14.4 shows the comparison of total fuel cost between the two scenarios of interest. As shown in Table 14.4, the total fuel cost of the BAU scenario is projected to be US$10,593 million in 2050, whilst the fuel cost in the LCET–CN scenario will be US$17,585 million in 2050. This is driven by the great increase in hydrogen consumption in the LCET-CN scenario.

Table 14.4. Comparison of Total Fuel Cost, BAU and LCET–CN Scenarios in 2050

	Final Energy Consumption (Mtoe), BAU in 2019	Final Energy Consumption (Mtoe), BAU in 2050	Final Energy Consumption (Mtoe), LCET–CN in 2050	Total Investment Cost, BAU in 2050 (US$ million)	Total Investment Cost, LCET–CN in 2050 (US$ million)
Coal	0.46	0.63	0.18	27	-44
Oil	13.98	26.89	22.58	8,880	5,915
Gas	9.21	15.05	3.17	1,686	–1744
Hydrogen	0	0	11.55	0	13,458
Total	**23.65**	**42.57**	**37.48**	**10,593**	**17,585**

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

7.2. Power Generation Investment

According to Table 14.2 and Table 14.3, total investment costs in the BAU and LCET–CN scenarios are presented in Table 14.5.

Table 14.5. Comparison of Total Investment in Power Plants, BAU and LCET–CN Scenarios in 2050

	Electricity Generation in BAU for 2019 (TWh)	Electricity Generation in BAU for 2050 (TWh)	Electricity Generation in LCET–CN for 2050 (TWh)	Additional Capacity for BAU (MW)	Additional Capacity for LCET–CN (MW)	Total Investment Cost, BAU in 2050 (US$ million)	Total Investment Cost, LCET–CN in 2050 (US$ million)
Coal	1	1	0	52	–82	78	–124
Oil	0	2	1	0	0	0	0
Gas	52	80	0	5,837	–11,022	4,086	–7,716
Hydrogen	0	0	70	0	14,815	0	10,370
Hydro	0	0	0	0	0	0	0
Solar	0	3	6	1,514	3,355	1,454	3,221
Wind	0	0	0	0	0	0	0
Biomass	0	0	6	29	1,019	58	2,038
Total	**54**	**86**	**83**	**7,432**	**8,084**	**5,676**	**7,790**

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, MW = megawatt, TWh = terawatt-hour.
Source: Author's calculations.

As shown in Table 14.5, the total additional capacity under the BAU scenario is 7,432 MW from the 2019 level. The additional capacity under the LCET-CN scenario in 2050 is larger than that in the BAU scenario, i.e. 8,084 MW. This is due to more radical expansions in hydrogen, solar, and biomass. Total investment in 2050 under BAU is US$5,676 million, whereas the investment needed for the LCET–CN scenario in 2050 is higher at US$7,790 million.

7.3. Overall Cost

With the results obtained from Section 7.1 and Section 7.2, the breakdown of the total investment cost in 2050 is showed in Table 14.6. Note that in current assumptions of LCET-CN, CCS applications in fossil fuel-based electricity generation will be phased out in 2050, and the electricity generation mix will be dominated by hydrogen.

Total investment cost for the BAU scenario in 2050 is projected to be US$16,269 million. This is lower than that in the LCET-CN scenario, i.e. US$25,375 million.

Table 14.6. Total Investment Cost under BAU and LCET–CN Scenarios in 2050

	BAU	LCET–CN
Total Fuel Cost Investment (US$ million)	10,593	17,585
Total Power Capital Cost Investment (US$ million)	5,676	7,790
Total CCS Cost Investment (US$ million)	0	0
Total (US$ million)	**16,269**	**25,375**

CCS = carbon capture and storage, BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Author's calculations.

8. Concluding Remarks

This study presents a scenario of net-zero emissions for Singapore. Based on the assumptions specified in the current study, the target of net-zero emissions is achievable for Singapore, whilst the investment needed in 2050 would be higher than that under the BAU scenario.

To achieve net-zero emissions, there are several strategies, including electricity imports through cross-border grids, applications of emerging decarbonisation technologies (i.e. CCS and hydrogen), and more expansions in renewable energy (i.e. solar and biomass). Under the current scenario settings, natural gas would be a transition fuel, and hydrogen is expected to play an important role. In addition, carbon-negative technologies, for example, biomass with CCS, is a necessary component for achieving net-zero emissions.

A greater effort from government, industry, the academic community, and society is needed for the net-zero pathways. The key role of the emerging decarbonisation technologies should be recognised, and policy support (e.g. regulatory frameworks for CCS and hydrogen applications, research and development support) should be in place. Regional cooperation and integration through regional power grids should be further enhanced as well. The results presented in the current study show a pathway for net-zero emissions, whilst this is not the only definite one. Future studies are also needed to explore those alternative pathways.

References

Government of Singapore (2020), 'Singapore's Update of its First Nationally Determined Contribution (NDC) and Accompanying Information'. https://unfccc.int/sites/default/files/NDC/2022-06/Singapore%27s%20Update%20of%201st%20NDC.pdf

______ (2022), 'Singapore's Second Update of its First Nationally Determined Contribution (NDC) and Accompanying Information'. https://unfccc.int/sites/default/files/NDC/2022-11/Singapore%20Second%20Update%20of%20First%20NDC.pdf

Sanchez, D. L., J. H. Nelson, J. Johnston, A. Mileva, and D. M. Kammen (2015), 'Biomass Enables the Transition to a Carbon-Negative Power System across Western North America', *Nature Climate Change, 5*(3), pp.230–34. doi:10.1038/nclimate2488

Chapter 15

Thailand Country Report

Supit Padrem, Vichien Tantiwisarn, and Surasit Tanthadiloke

Energy Policy and Planning Office, Thailand

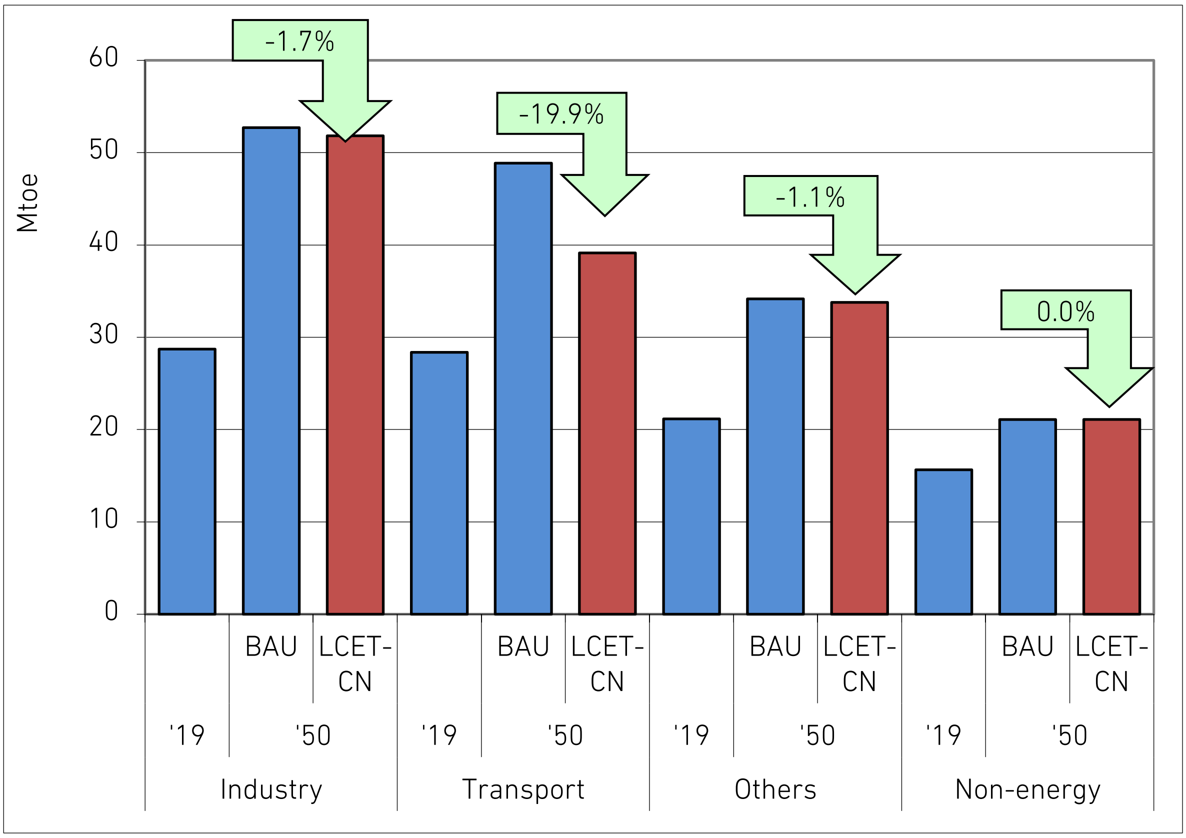
1. Basic Concept of Low-carbon Energy Transition–Carbon Neutrality

Thailand targets to achieve carbon neutrality in 2050. For the energy sector, the Office of Natural Resources and Environmental Policy and Planning set the carbon dioxide (CO_2) offset to be within 100 million tonnes of CO_2 (Mt-CO_2) in 2050. The low-carbon energy transition–carbon neutral (LCET–CN) scenario focuses on how to achieve this target in 2050. The low-carbon technology of carbon capture and storage (CCS) and low-carbon energy (blue and green hydrogen) will be assumed to replace the conventional fossil fuels in use today. In the case of Thailand, the LCET–CN scenario assumes hydrogen will be used in the industry sector but not in the transport and 'others' sectors.

2. Final Energy Consumption

In the LCET–CN scenario, final energy consumption is projected to grow by 1.4% per year, from 93.9 million tonnes of oil equivalent (Mtoe) in 2019 to 145.8 Mtoe in 2050. This is around 7.0% lower than in the business as usual (BAU) scenario. The increasing stock of electric vehicles will lower the use of oil. Consumption is different from BAU in the transport and 'others' sectors, but much greater in transport at –19.9%, in industry –1.7%, and in the 'others' only –1.1%, as shown in Figure 15.1.

Figure 15.1. Final Energy Consumption by Sector, BAU and LCET–CN Scenarios

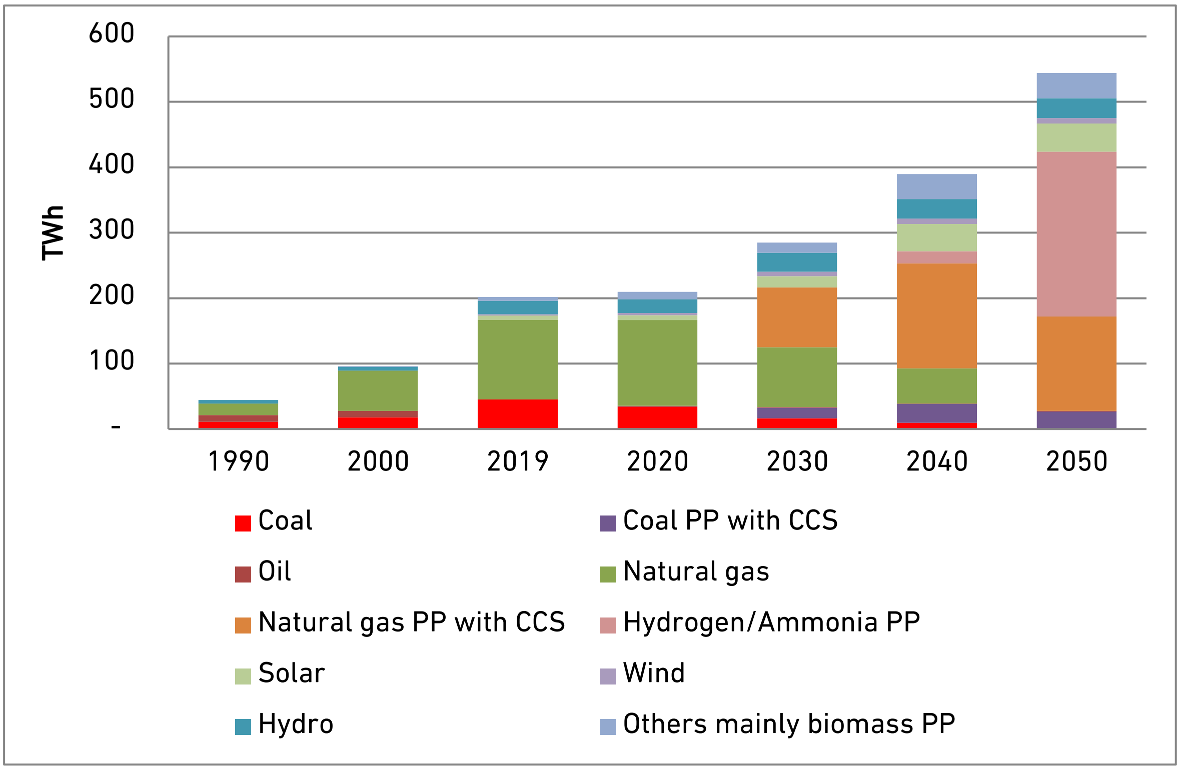


BAU = business as usual, LCET–CN = low-carbon energy transition scenario–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

3. Power Generation

In the LCET–CN scenario, power generation is expected to grow at around 3.3% per year from 2019 to 2050 and will reach 544.2 terawatt-hours (TWh) in 2050. In 2050, hydrogen will be the dominant fuel used in power generation with the highest share of 46.4% or 252.3 TWh. The second largest source of power generation will be natural gas with CCS, a share of 26.5% (144.2 TWh) in 2050. The rest will be solar photovoltaic (PV), biomass, hydro, coal with CCS, wind, and oil, with shares of 7.8%, 7.1%, 5.5%, 4.9%, 1.6%, and 0.2%, respectively (Figure 15.2).

Figure 15.2. Power Generation by Fuel Type, LCET–CN Scenario



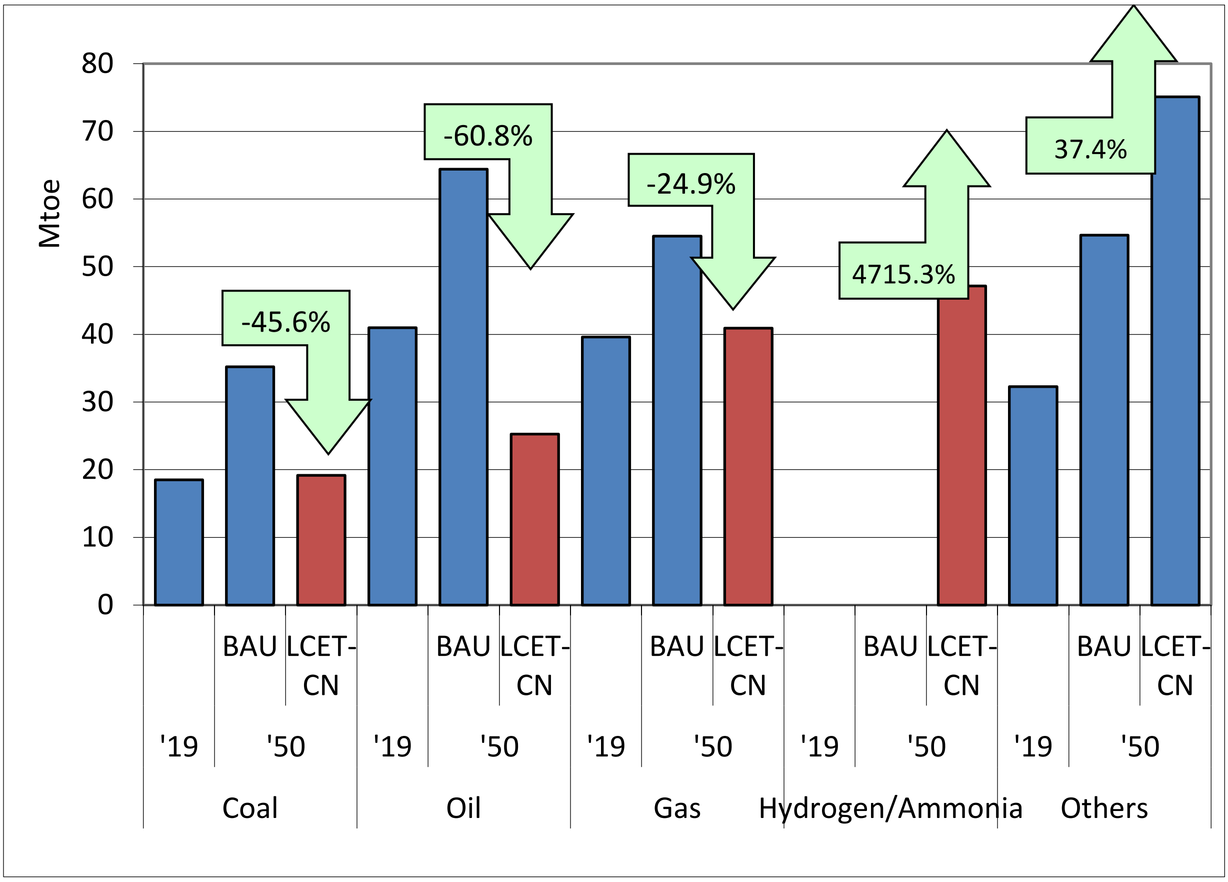
CCS = carbon capture and storage, LCET–CN = low-carbon energy transition scenario–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: Authors' calculations.

4. Primary Energy

The growth rate of the primary energy supply in the LCET–CN scenario is projected to be the same as that in the BAU scenario, increasing at 1.5% annually and reaching 210.2 Mtoe in 2050. However, the primary energy supply in the LCET–CN scenario has a different fuel mix from the BAU scenario.

To achieve carbon neutrality in 2050, fossil fuels (coal, oil, and natural gas) must be replaced by alternative fuels, new energy sources such as hydrogen and ammonia, and renewable energy. In the LCET–CN scenario, the consumption of coal, oil, and natural gas is projected to be lower compared to the BAU scenario by 45.6%, 60.8%, and 24.9%, respectively. However, they are expected to increase in the 'others' category by 37.4% and hydrogen/ammonia (from 0 Mtoe in 2019 to 47.2 Mtoe). The differences in the projections between the two scenarios are shown in Figure 15.3.

Figure 15.3. Primary Energy Supply by Source, BAU and LCET–CN Scenarios

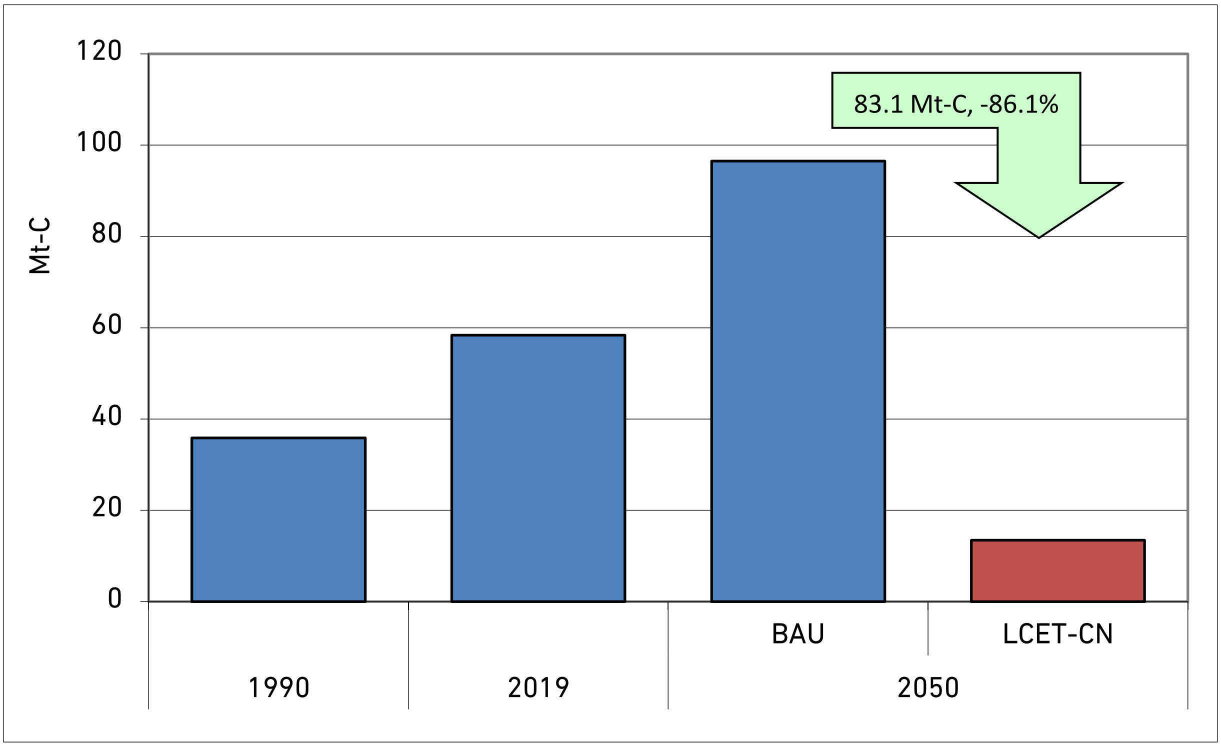


BAU = business as usual, LCET = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent. Source: Authors' calculations.

5. Carbon Dioxide Emissions Reduction

Under the LCET–CN scenario, the average annual growth in CO_2 emissions from 2019 to 2050 is projected to be –4.6%, with an emissions level of 13.5 million tonnes of carbon (Mt-C) in 2050. The difference in CO_2 emissions between the BAU and the LCET–CN scenarios is 83.1 Mt-C, or 86.1%. This can achieve carbon neutrality, which is less than the offset capability in Thailand in 2050 of 27 Mt-C. The reduction in CO_2 emissions highlights the range of benefits that can be achieved through energy efficiency improvements and savings via action plans, environmentally-friendly fuels, and CCS in industry and in power generation for coal and natural gas (Figure 15.4).

Figure 15.4. Carbon Dioxide Emissions from Energy Consumption, BAU and LCET–CN Scenarios

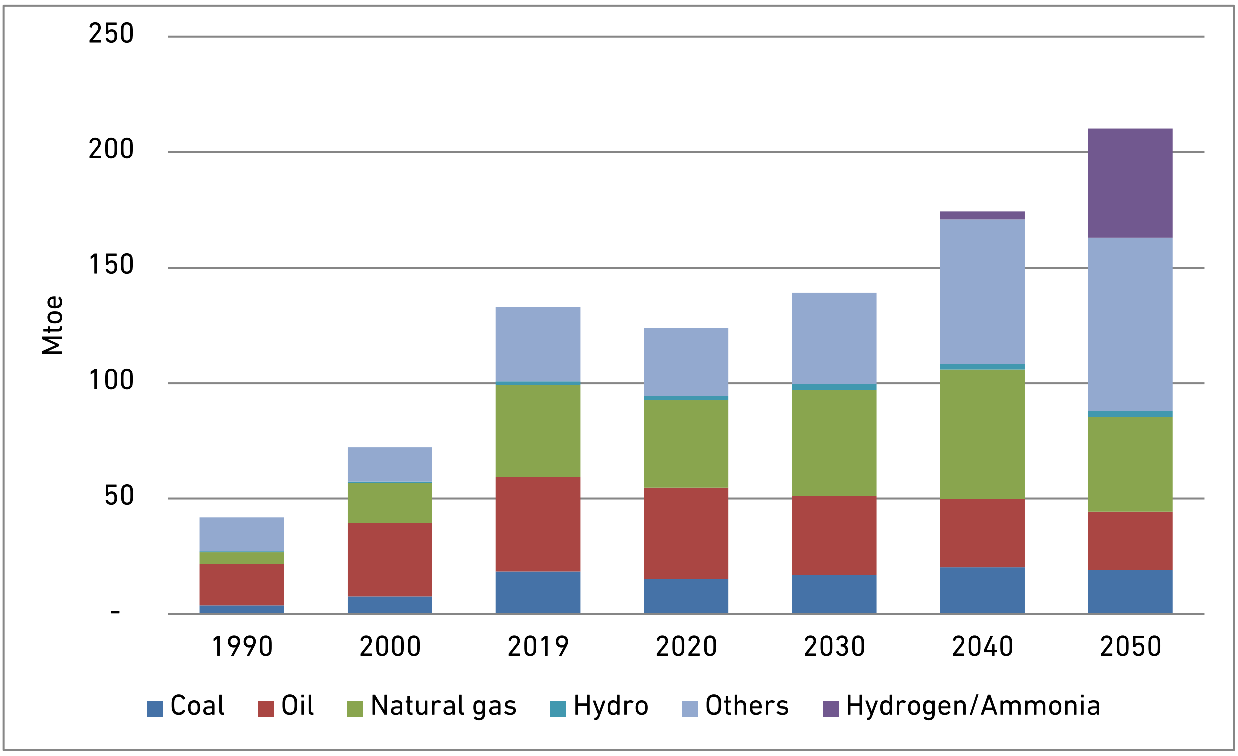


BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: Authors' calculations.

6. Hydrogen Demand across Sectors

In the 2050 LCET–CN scenario, the total hydrogen supply of 47.15 Mtoe is expected to come from imports. Natural gas from indigenous sources may no longer exist in 2050, thus, domestic blue hydrogen will not be produced. Hydrogen will be consumed in the power generation sector (45,265.3 ktoe) and the industry sector (1,887.9 ktoe). Hydrogen's share in the primary energy supply will be 22.4% (Figure 15.5).

Figure 15.5. Hydrogen Demand



Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

7. Energy Cost Comparison between BAU and LCET–CN Scenarios

The energy cost is the estimation that covers the cost of fuel, power generation investment, and CCS. A comparison will be made to see the difference of primary energy and power generation of 2019 to 2050, and it will compare the BAU and LCET–CN scenarios. This cost comparison will be a helpful tool for making a final decision. Tables 15.1, 15.2, and 15.3 show the assumptions for fuel cost, construction cost and capacity factor of power plants.

Table 15.1. Fuel Cost Assumptions

	2019/2020	2050 (2019 constant price)	Unit
Coal	80.03	98.00	US$/ton
Oil	41	100	US$/bbl
Gas	7.77	7.50	US$/MMBtu
Hydrogen	0.8	0.3	US$/Nm^3
CCS	0	30	US$/$CO_2$ ton

bbl = barrel, CCS = carbon-capture and storage, CO_2 = carbon dioxide, MMBtu = metric million British thermal units, Nm^3 = normal cubic metre.
Source: Authors' calculations.

Table 15.2. Construction Cost of Power Plants Assumptions

(US$/KW)

	2019	by 2050
Coal	1,500	1,525
Oil	0	0
Gas	700	700
Hydrogen	0	700
Nuclear	4,500	3,575
Hydro	2,000	2,223
Geothermal	4,000	4,256
Solar	1,600	307
Wind	1,600	1,235
Biomass	2,000	3,019

KW = kilowatt.
Source: Authors' calculations.

Table 15.3. Capacity Factor of Power Plants Assumptions

(%)

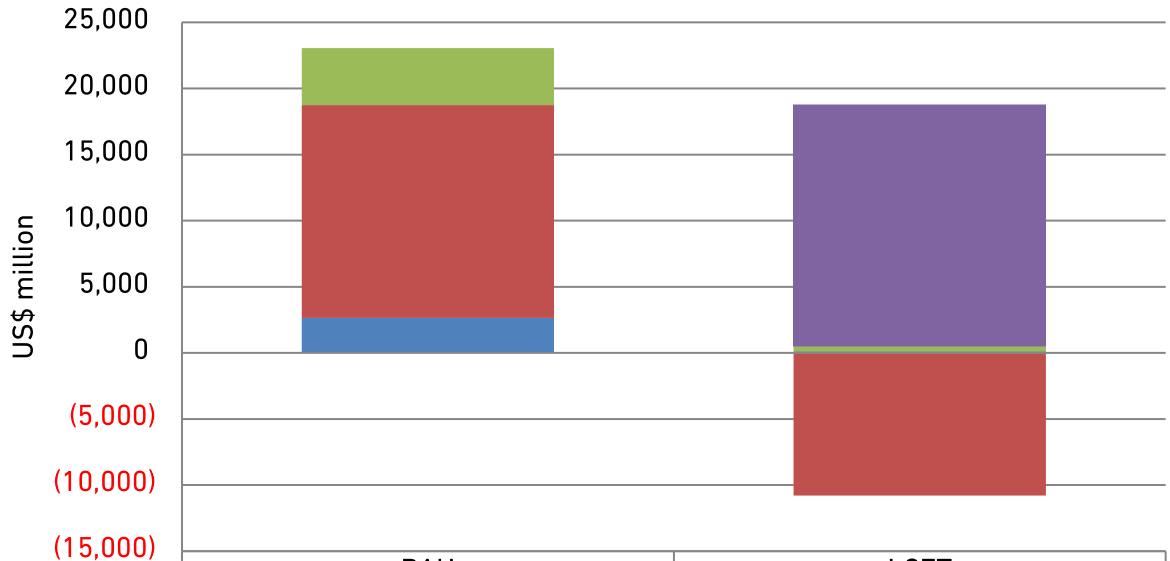
	2019	by 2050
Coal	75	80
Oil	75	80
Gas	75	80
Hydrogen	0	80
Nuclear	100	80
Hydro	50	40
Geothermal	50	50
Solar	17	17
Wind	40	40
Biomass	50	70

Source: Authors' calculations.

7.1. Fuel Cost

Thailand's fossil fuel cost (coal, oil, and natural gas) and hydrogen cost from primary energy in 2019 and 2050 in the BAU scenario is around US$23,052 million, and in the LECT–CN scenario it is around US$8,000 million. In comparison between 2019 to 2050, the increases in the cost in the BAU scenario is much greater than the LCET–CN scenario (Figure 15.6). The LCET–CN scenario can save in the use of fossil fuels, especially oil, although the cost of hydrogen will be high. In terms of fuel cost, Thailand might be in a better situation.

Figure 15.6. Change of Fuel Cost 2019 to 2050, Comparison between BAU and LCET–CN Scenarios



	BAU	LCET
Hydrogen	0	18,314
Gas	4,302	382
Oil	16,109	(10,803)
Coal	2,641	106

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Authors' calculations.

7.2. Power Generation Investment

According to the BAU and LCET–CN scenarios from 2019 until 2050, the difference of the installed capacity of power generation, Thailand might increase capacity to 81,265 MW in the BAU scenario and 122,251 MW in the LCET–CN scenario. The investment in new additional power generation of both cases expects to be US$113,821 million in the BAU scenario and US$131,545 million in the LCET–CN scenario. In the case of the LCET–CN scenario, the cost soars by new investment in hydrogen power plants (Table 15.4).

Table 15.4. Total Investment Power Plants Cost Comparison, BAU and LCET–CN Scenarios in 2050

	Electricity Generation in BAU for 2019 (TWh)	Electricity Generation in BAU for 2050 (TWh)	Electricity Generation in LCET–CN for 2050 (TWh)	Additional Capacity for BAU (MW)	Additional Capacity for LCET–CN (MW)	Total Investment Cost, BAU in 2050 (US$ million)	Total Investment Cost, LCET–CN in 2050 (US$ million)
Coal	133	216	71	11,843	–8,834	18,060	–13,471
Oil	1	2	3	89	0	0	0
Gas	253	381	269	18,070	2,205	12,649	1,544
Hydrogen	0	0	526	0	75,119	0	52,583
Hydro	200	30	30	2,709	2,746	6,021	6,104
Solar	6	43	43	24,319	24,319	7,466	7,466
Wind	2	9	9	1,835	1,835	2,267	2,267
Biomass+ Municipal Solid Waste	32	169	184	22,311	24,860	67,358	75,052
Total	**448**	**847**	**1,135**	**81,265**	**122,251**	**113,821**	**131,545**

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, MW = megawatt, TWh = terawatt-hour.
Source: Authors' calculations.

CCS Cost

In the case of the LCET–CN scenario, Thailand can be expected to use CCS in coal-fired plants at 26.5 TWh and natural gas-fired plants at 144.2 TWh. It is assumed to capture and store CO_2 at approximately 19.7 Mt-C. If the cost of CCS is US$70/$CO_2$ tonne, the total cost for CCS of 19.7 Mt-C or 72.3 Mt-CO_2 in 2050 will be approximately US$4,553 million (Table 15.5).

Table 15.5. Total Investment Cost of CCS for LCET–CN Scenario in 2050

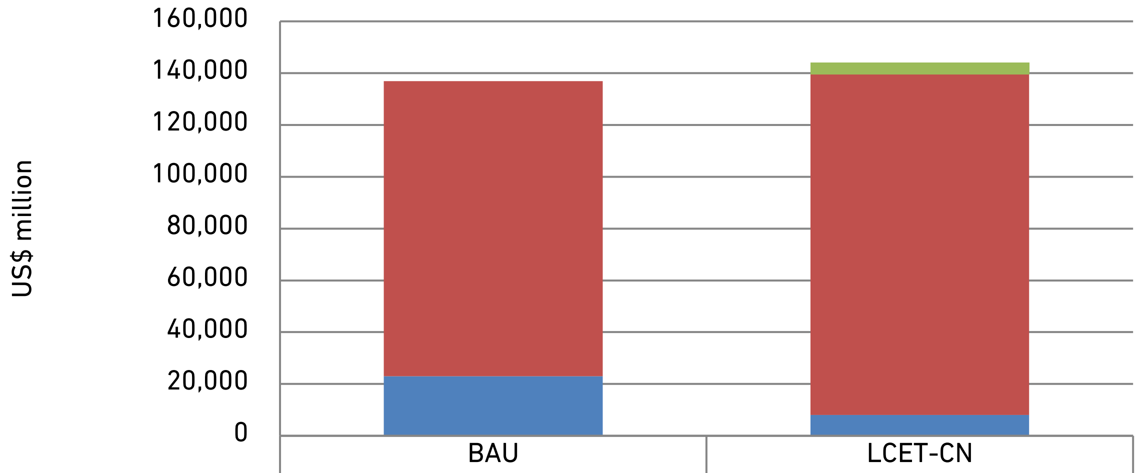
	Consumption for LCET–CN in 2050 (Mtoe)	CO_2 Emissions for LCET–CN (Mt-CO_2)	CO_2 Emissions for LCET–CN (Mt-C)	Total Investment Cost of CCS for LCET–CN (US$ million)
Coal Power Plant with CCS	6.1	22.8	6.2	1,438
Natural Gas Plant with CCS	23.2	49.4	13.5	3,115
Total	**29.3**	**72.3**	**19.7**	**4,553**

CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon, Mt-CO_2 = million tonnes of carbon dioxide, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

Overall Cost

When fuel cost, power generation investment, and CCS cost are combined together, in 2050 the approximate overall cost will be US$136,873 million in the BAU scenario and US$144,097 million in the LCET–CN scenario. The different amount between these two cases is around US$7,224 million, but higher in the LCET–CN scenario (Figure 15.7).

Figure 15.7. Overall Cost Comparison between BAU and LCET–CN Scenarios



	BAU	LCET-CN
CCS	0	4,553
Power capital cost	113,821	131,545
Fuel Cost	23,052	8,000

BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Authors' calculations.

8. Conclusions and Recommendation

Hydrogen/ammonia and CCS might help Thailand to transition to low-carbon energy. The use of hydrogen and CCS will cut CO_2 emissions from 96.5 Mt-C in the BAU scenario to 13.5 Mt-C in the LCET-CN scenario, which is lower than the carbon neutrality target of 27 Mt-C or 100 Mt-CO_2 (carbon offset) in the energy sector in 2050. However, when cost is considered, power generation investment cost and CCS cost drive the cost of low carbon higher than in the BAU scenario at around US$7,224 million. The extra cost for environmentally-friendly energy would be around 0.7% of GDP (US$1,092.5 billion) in 2050. Policymakers will need to make hard decisions to choose whether to pay more money for the environment. Moreover, carbon neutrality will impact the way of using energy. It will change the use of conventional energy, coal, natural gas, and oil to new energy types, and hydrogen in particular.

Chapter 16
Viet Nam Country Report

Nguyen Minh Bao

Independent Energy Consultant, Viet Nam

1. Introduction

1.1. Basic Concept of Low-carbon Energy Transition–Carbon Neutrality

The energy sector is the primary source of greenhouse gas (GHG) emissions in Viet Nam, accounting for approximately 65% of the country's total emissions by 2016 (MONRE, 2020). Thus, a transition to a low-carbon energy system is necessary to reduce the energy-related carbon dioxide (CO_2) emissions from fossil fuels and can make a significant contribution to achieve a carbon neutral target in Viet Nam by 2050.

Low carbon energy transition-carbon neutrality (LCET–CN) is a significant structural change in an energy system regarding energy supply and consumption to achieve carbon neutrality or to a balanced state between emitting carbon and absorbing carbon from the atmosphere.

LCET–CN can be done through investment in low-carbon technologies such as renewable energy, energy efficiency and conservation (EE&C), and other new technologies such as hydrogen and carbon capture and storage (CCS).

Investment in renewable energy and energy efficiency will be strongly implemented from 2020 to 2050, whilst hydrogen and CCS technologies will consider implementation when these technologies are mature enough and widely commercialised. It is expected to apply hydrogen by 2035 and CCS by 2040.

Investments in low-carbon technologies will increase costs due to the high cost of new technologies, but benefit from energy savings and reduced CO_2 emissions.

This study will develop a LCET–CN scenario and calculate the investment costs and emissions reduction benefits of the LCET–CN scenario compared with the BAU scenario.

1.2. Energy Policies to Achieve LCET–CN Scenario

Viet Nam has committed to develop and implement strong emissions reduction measures to achieve net-zero emissions by 2050 using its own resources, along with cooperation and support from the international community.

The Government of Viet Nam recently implemented a series of strategies and policies in the energy sector to fulfil its commitment of increasing the share of renewable energy sources in power generation, enhancing energy efficiency, and promoting fuel switching to reduce GHG emissions. The targets for reducing GHG emissions, conserving energy, promoting fuel switching, and advancing renewable energy development, as outlined in legal documents, are summarised in Table 16.1.

Table 16.1. Mitigation Targets and Related Legal Documents

Legal Document	Mitigation Targets and Actions
National Climate Change Strategy, Vision to 2050	Targets: Viet Nam will strive to achieve net-zero emissions by 2050. • By 2030: GHG emissions in the energy sector decreases by 43.5% from BAU and emissions do not exceed 457 $MTCO_2e$. • By 2050: Total national GHG emissions reach net zero, GHG emissions in the energy sector reduces by 91.6% from BAU, and emissions do not exceed 101 million tonnes of CO_2 equivalent.
National Power Development Plan period 2021–2030, with Outlook to 2050 (PDP VIII)	Targets: • Increase the share of renewable energy in power generation to 49.6% in 2030 and from 82.0% to 91.8% in 2050 in term of installed capacity. • Increase the share of electricity generated from renewable resources from 30.9% to 39.2% in 2030 and from 67.5% to 71.5% in 2050.
MOIT's Action Plan for Implementing the Viet Nam's Commitments at COP26	• Strengthen implementation of energy efficiency measures by improving Minimum Energy Performance Standards (MEPS). • Phase out the use of fossil fuels in the energy sector. • Apply CCS in industry fields such as cement, steel, and chemical industries. • Develop renewable energy projects such as solar PV, wind power, hydropower, hydrogen, CCS, and energy storage technologies. • Promote electrification and energy efficiencies in residential, transport sectors.
Action Plan on Green Energy Transition GHG Emissions Reduction in Transport Sector	Target: Develop a green transport system towards net-zero emissions by 2050. • By 2030: Promote energy efficiency and encourage the switch to electricity and green energy in fields where technologies, institutions, and resources are available to fulfil the country's commitments in its NDC. • By 2050: Prioritise the development of sustainable modes of transport and achieve net-zero emissions by transitioning all transportation means, equipment, and infrastructure to use electricity and green energy.

BAU= business as usual, CCS = carbon capture and storage, COP26 =26th Session of the Conference of Parties, GHG = greenhouse gas, MOIT = Ministry of Industry and Trade, NDC = nationally determined contribution, PV = photovoltaic.
Source: Compiled by author.

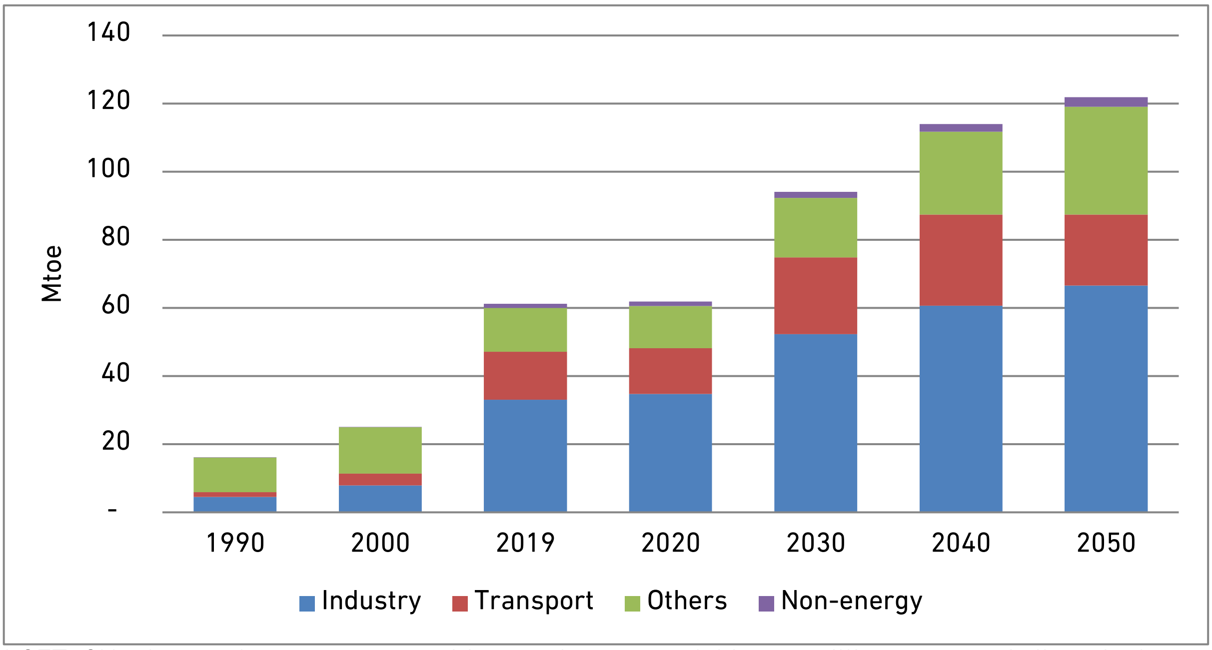
2. Analysis of LCET–CN Results

2.1. Total Final Energy Consumption

Viet Nam's total final energy consumption (TFEC) in 2019 was 61.3 million tonnes of oil equivalent (Mtoe), which has increased by 4.7% per year, 3.8 times more than its 1990 level of 16.1 Mtoe. On a per sector basis, the fastest growth occurred in the transport sector (8.3% per year), followed by the industry sector (7.1%), and the residential/commercial ('others') sector (0.9% per year). Non-energy use is expected to grow at 13.9% per year.

For 2019–2050, the TFEC is projected to increase at an average rate of 2.2% per year under the LCET–CN scenario. The increase is driven by strong economic growth, which is assumed to be at an average annual growth rate of 5.2% and the rising population with an average annual growth rate of 0.4%. On a per sector basis, the 'others' sector is expected to exhibit the strongest growth in energy consumption, with an annual increase of 2.9%. This is followed by the industry sector with an annual growth of 2.3% and the transport sector with 1.3%. Non-energy use is expected to grow at 2.8% per year. Figure 16.1 shows the final energy consumption by sectors from 1990 to 2050.

Figure 161. Final Energy Consumption by Sector, LCET–CN Scenario, 1990–2050



LCET–CN = low carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Note: 'Others' includes residential and commercial sectors.
Source: Author's calculations.

The 'others' sector was the primary source of the country's energy consumption in 1990, accounting for around 63%. This was mainly due to the use of biomass fuel used for residential cooking. This share decreased to 21.1% by 2019 due to the growing economy, which led to the substitution of biomass fuels with more efficient commercial fuels. Economic growth is expected to continue improving the standard of living, thus increasing the transition from biomass to modern fuels such as liquefied petroleum gas.

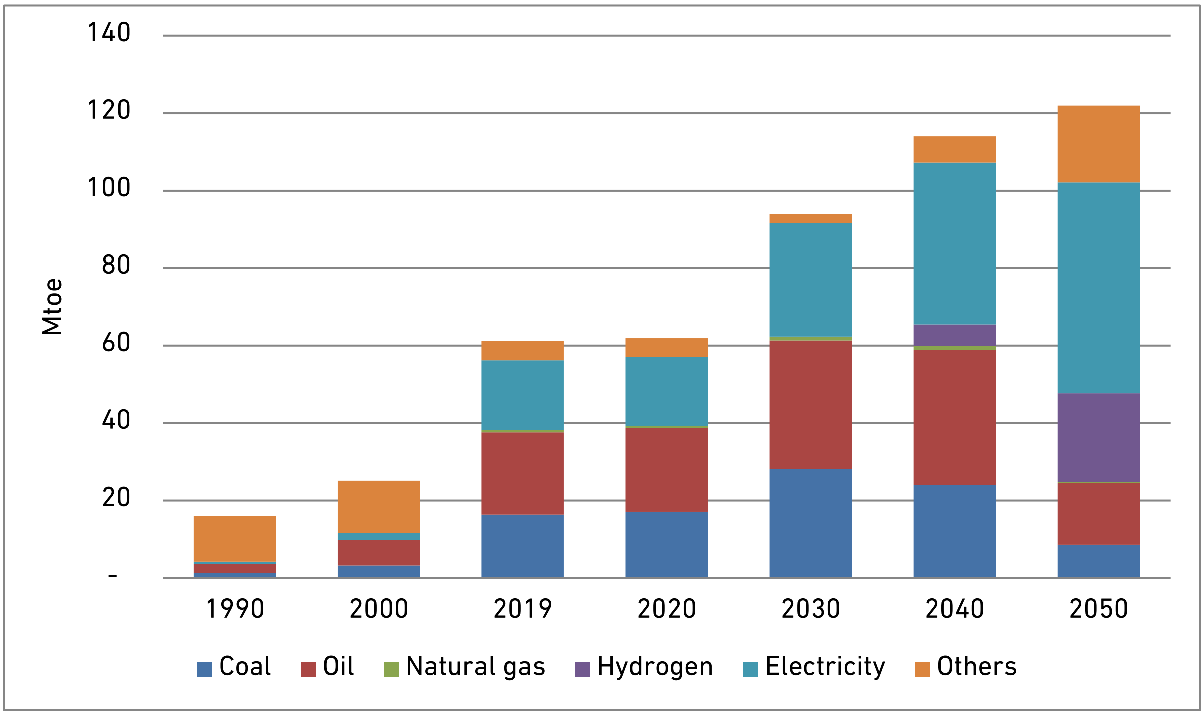
During 2019–2050, the industry sector is expected to remain the largest consumer of energy in Viet Nam. However, its share of energy consumption will increase from 54.0% in 2019 to 56.2% in 2020, before slightly declining to 54.6% in 2050. Meanwhile, the 'others' sector will become the second largest consumer, with its share increasing slowly from 21.1% in 2019 to 26.0% in 2050.

In 1990, other fuels – mainly biomass – had the highest consumption rate, accounting for 73.9% of the TFEC. However, this share decreased dramatically to 8.3% in 2019. Oil was the second most consumed product, making up 14.5% of the TFEC in 1990 and increasing to 34.7% in 2019. Coal consumption increased from 8.3% in 1990 to 26.7% in 2019. Electricity had a small share of 3.3% in 1990 but increased to 29.4% in 2019.

On a per fuel basis under the LCET–CN scenario, other fuels (mainly biomass) are projected to exhibit the fastest growth in final energy consumption, increasing at 4.5% per year between 2019 and 2050. Electricity was the second-highest growth rate of 3.6% per year, due to the increasing use of electricity in transport. The remaining fuels are projected to be decreased, due to fuel switching from fossil fuel to clean energy such as hydrogen, electricity and biomass. Coal is projected to decrease at the highest annual rate of 2.0% per year, followed by natural gas with 1.3% and oil with 1.0%.

In 2019, oil products held the largest share of energy at 34.7%. This share is projected to decrease to 13.0% in 2050. The second-largest share of demand is electricity, which is projected to increase from 29.4% in 2019 to 44.6% in 2050. By 2050, coal will decrease from 26.7% in 2019 to 7.1% in 2050, whilst other fuels (mainly biomass) will increase from 8.3% in 2019 to 16.2% in 2050. However, natural gas is expected to decrease from 0.9% in 2019 to 0.3% in 2050. (Figure 16.2).

Figure 16.2. Final Energy Consumption by Fuel Type, LCET–CN Scenario, 1990–2050



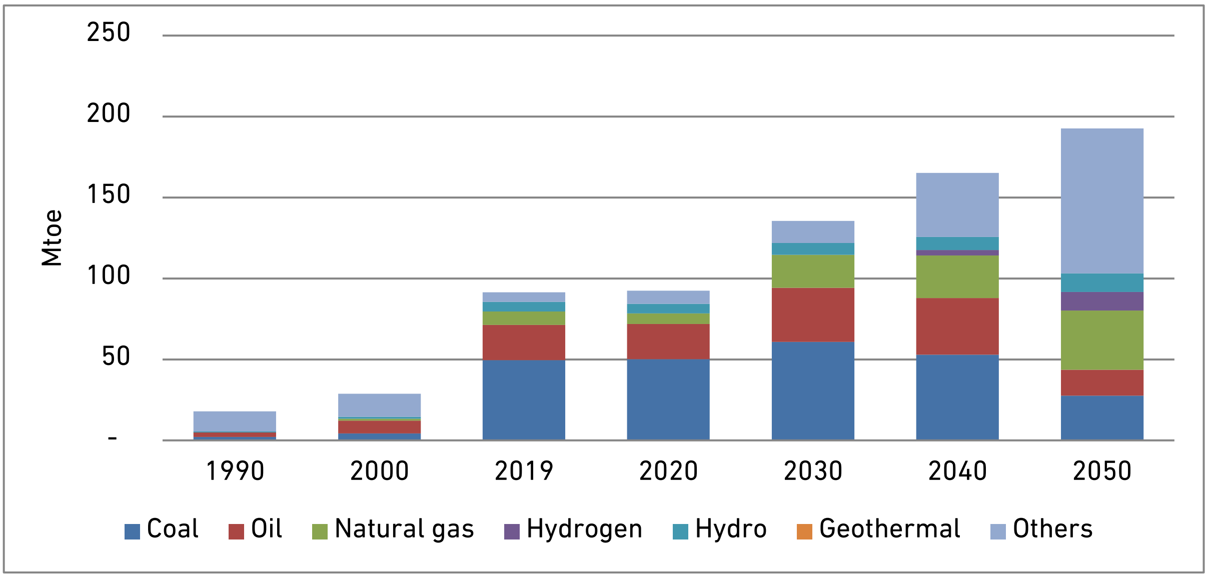
LCET–CN = low carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Note: 'Others' is mainly biomass.
Source: Author's calculations.

2.2. Total Primary Energy Supply

The total primary energy supply (TPES) of Viet Nam grew at a higher rate than the TFEC. It increased by 5.8% per year, from 17.9 Mtoe in 1990 to 91.4 Mtoe in 2019. Also, between 1990 to 2019, natural gas consumption grew at an average annual rate of 31.3%, coal at 11.3%, hydropower at 9.2%, and oil at 7.5%.

In the LCET–CN scenario, Viet Nam's TPES is projected to increase at an annual rate of 2.4%, from 91.4 Mtoe in 2019 to 192.6 Mtoe in 2050. The fastest growth is expected in other fuels (mainly biomass), increasing at an annual average rate of 9.1% between 2019 and 2050, followed by natural gas at 5.0% and hydro at 2.1%. Meanwhile, coal and oil will decrease at 1.9% and 1.0% per year, respectively. Figure 16.3 shows the primary energy supply by source in for 1990–2050.

Figure 16.3. Primary Energy Supply, LCET–CN Scenario, 1990–2050



LCET–CN = low carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Note: 'Others' is mainly biomass.
Source: Author's calculations.

In 2019, other sources accounted for the smallest share of TPES at 6.5% and is expected to increase strongly to be the largest share at 46.5% in 2050, whilst natural gas would increase from 8.9% to 19.0%. This growth is due to the projected decline of coal from 54.2% in 2019 to 14.4% in 2050, oil from 23.9% to 8.2%, and hydro from 6.5% to 5.9%.

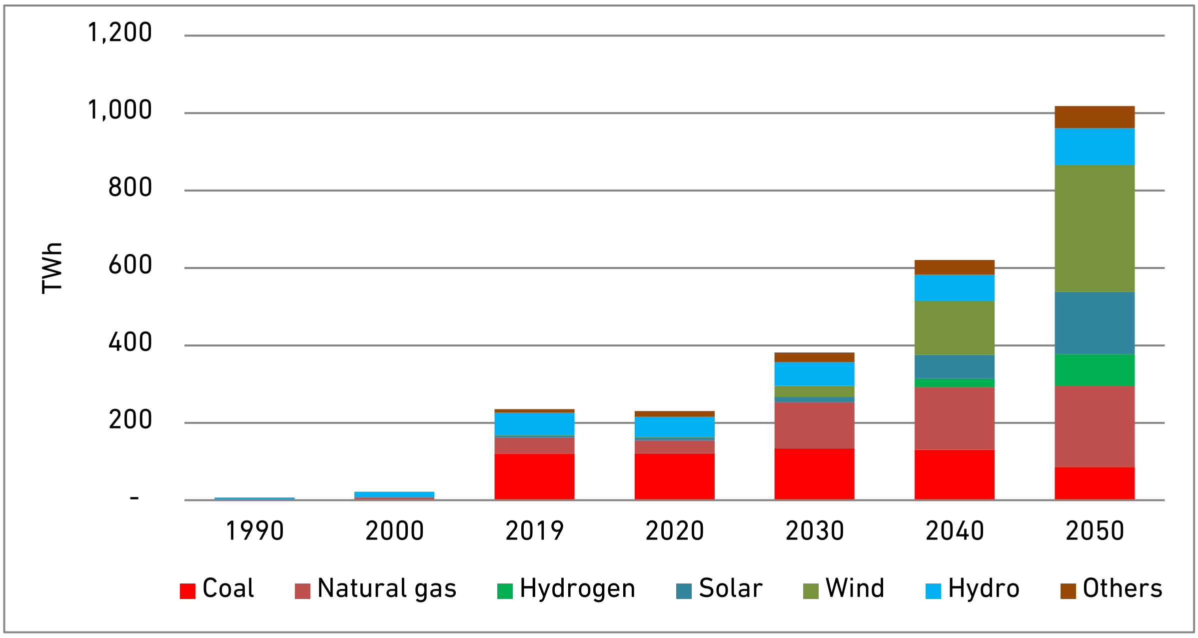
2.3. Power Generation

Power generation output increased at 12.1% per year, or 27.3 times, from 8.7 terawatt-hours (TWh) in 1990 to 236.9 TWh in 2019. The fastest growth occurred in natural gas power generation (35.8% per year), followed by coal (15.2%), hydro power (8.5%), and oil power (1.7%).

Under the LCET–CN scenario, power generation is projected to increase by an average of 4.8% per year, or 4.3 times between 2019 and 2050, to meet electricity demand. Wind power generation is projected to experience the highest growth rate of 21.8% per year, followed by solar (12.0%), others, including biomass, small hydro and imported electricity (6.2%), natural gas (5.3%) and hydro (1.6%). The high growth rates of wind and solar are due to their substitution for coal, which are projected to decrease at an annual rate of 1.1%.

Figure 16.4 shows the power generation output by type of fuel under the LCET–CN scenario from 1990 to 2050.

Figure 16.4. Power Generation by Fuel Type, LCET–CN Scenario, 1990–2050



LCET–CN = low carbon energy transition–carbon neutral, TWh = terawatt hour.
Note: 'Others' includes biomass, wind, solar and imported electricity.
Source: Author's calculations.

By the end of 2019, most of Viet Nam's power came from coal, which comprised about 50.7% of the total power generation mix. The share of hydro power generation was around 24.3%, whilst the rest was from natural gas (18.0%), solar (2.0%), oil (0.9%), wind (0.3%), and 'others' (around 3.8%).

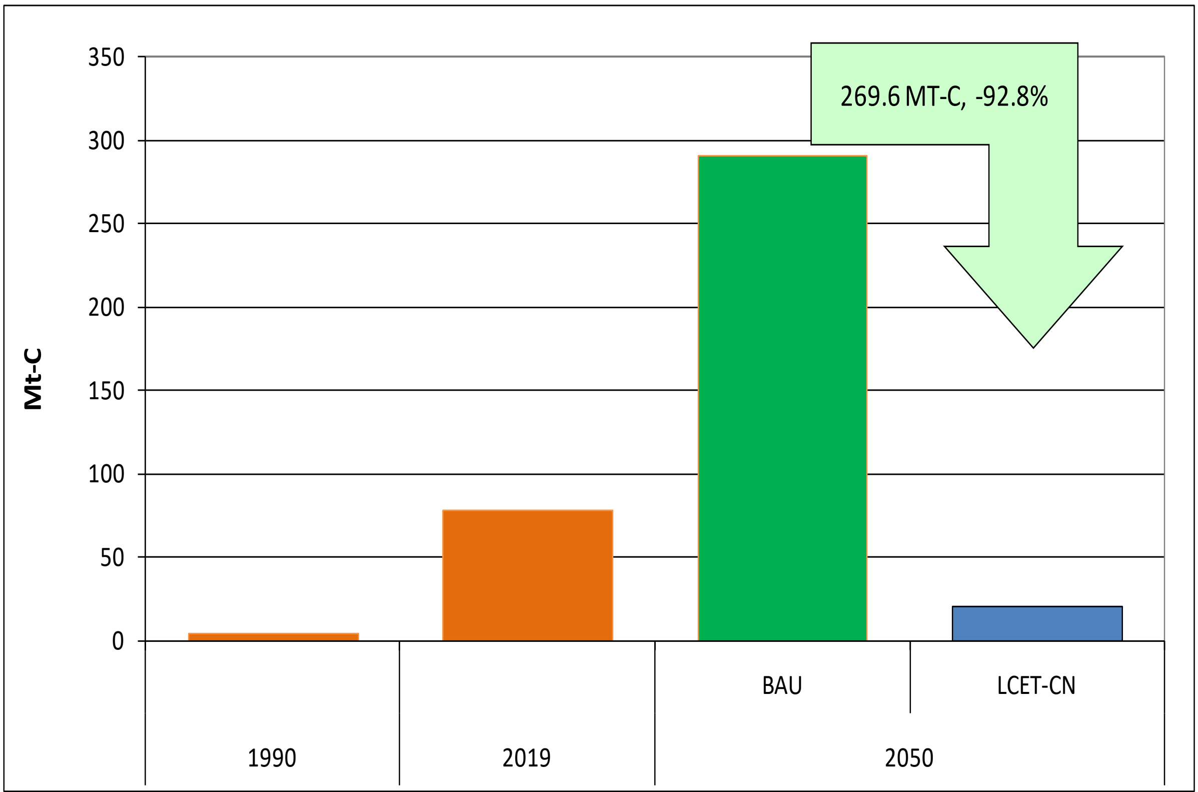
From 2020 to 2050, wind is projected to be the highest energy transition to replace coal for power generation under the LCET–CN scenario with its share growing from the smallest share of 0.5% in 2020 to the largest share of 32.2% in 2050. Natural gas is anticipated to be the second highest energy transition from natural gas without CCS (with its share increasing from 14.5% in 2020 to 31.2% in 2030) to natural gas with CCS with the second largest share of 20.8% in 2050. The third highest energy transition is solar, with its share increasing from 3.4% in 2020 to 15.8% in 2050. These high growth rates are due to the projected decline of coal with the highest energy transition from 52.6% (without CCS) in 2020 to 8.3% (with CCS) in 2050 and the share of hydro in the total power generation will decline from 22.4% in 2020 to 9.3% in 2050.

2.4. Carbon Dioxide Emissions

The total CO_2 emissions under the LCET–CN scenario is projected to decrease by 4.2% per year from 78.5 million tonnes of carbon (Mt-C) in 2019 to 20.9 Mt-C in 2050, which is lower than CO_2 emissions in 2019 at 57.7 Mt-C. In 2050, CO_2 emissions in the BAU scenario is projected at 290.5 Mt-C, thus the reduction in LCET–CN scenario, compared to BAU is about 269.6 Mt-C, or 92.8% (Figure 16.5).

The above calculation results show that Viet Nam could achieve carbon neutrality by 2050 because LCET scenario can achieve 20.9 Mt-C that is lower than the potential of carbon sink by forest with 27.5 Mt-C until 2050. The LCET scenario includes EE&C measures and significant use of variable renewable energy, such as solar PV and wind. It also integrates new energy technologies, such as hydrogen from national grid and CCS applied to coal and gas power plants. Implementing ambitious EE&C measures, renewable energy development, and new technologies will be crucial for reducing CO_2 emissions across various sectors. There are lots of challenges ahead of Viet Nam, but if the country could tackle these challenges, the LCET–CN scenario suggests it can achieve carbon neutrality by 2050.

Figure 16.5. Evolution of Carbon Dioxide Emissions, BAU and LCET–CN Scenarios, 1990, 2019, and 2050



BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: Author's calculations.

2.5. Hydrogen Demand Across the Sectors

Hydrogen is a clean alternative fuel, which has the potential to provide for energy in transportation, distributed heat, power generation, and energy storage systems. Hydrogen fuel can be produced through several methods. The most common methods today are natural gas reforming (a thermal process) and electrolysis.

In Viet Nam, hydrogen can be produced from a domestic resource with electrolysis technology using the national grid and partly imported. Because Viet Nam's power source to 2050 is mostly produced from renewable energy (RE) sources and gas with the use of CCS, therefore, there are a little carbon emissions and could be critical for achieving LCET–CN.

Hydrogen is expected to start using from 2035 for industrial production, transportation and power generation. By 2050, the total demand for hydrogen is about 34.5 Mtoe, in which around 11.6 Mtoe, accounting for 33.5% of total demand, will be used for power generation.

On the demand side, by 2050, the total hydrogen is expected to reach about 22.9 Mtoe, accounting for 66.5% of total demand. Hydrogen consumption demand in industry sector will be the higher with 12.0 Mtoe (or 52.4%), which are mainly used for the production of iron and steel and other industries. The remained amount of hydrogen with 10.9 Mtoe (or 47.6%) will be used to replace diesel oil and fuel oil in transport.

3. Cost Comparison between BAU and LCET–CN Scenarios

3.1. Introduction

To achieve the target of carbon neutral by 2050, investing in energy-saving technologies, RE, hydrogen, and CCS in the LCET–CN scenario will reduce energy consumption and reduce emissions but will increase investment costs compared to BAU. This section will focus on cost calculation and comparison between the two scenarios – BAU and LCET–CN.

Because the cost calculation for the cost of scenarios is complicated, whilst the input data are limited or not available, then in this study, the calculations are based on the available calculation results on the consumption of the types of fuel in different sectors, input fuel for power generation and electricity produced from different power generation technologies in the base year of 2019 and 2050. It is assumed that the difference in energy use between 2050 and 2019 will be an effort on energy efficiency and energy transition for the whole period of 2019–2050.

3.2. Cost Comparison

Fuel Cost

Applying energy efficiency measures on the demand side and a strong shift from fossil fuels to clean fuels, especially using RE and hydrogen in power generation, will significantly reduce primary energy demand in the LCET–CN scenario. Based on the assumption of fuel prices of each type, it is possible to calculate and compare fuel costs in the two scenarios – BAU and LCET–CN.

Assumptions on Fuel Costs

The assumptions on fuel costs in physical units at the 2019 constant prices are presented in Table 16.2.

Table 16.2. Assumptions on Fuel Costs

Fuel	2019/2020		2050 (2019 constant price)	
Coal	80.03	US$/ton	98	US$/ton
Oil	41	US$/bbl	100	US$/bbl
Gas	7.77	US$/MMBTU	7.5	US$/MMBtu
Hydrogen	0.8	US$/Nm^3	0.3	US$/Nm^3
CCS		US$/$CO_2$ ton	30	US$/$CO_2$ ton

bbl = barrel, CCS = carbon-capture and storage, CO_2 = carbon dioxide, MMBtu = metric million British thermal unit, Nm^3 = normal cubic metre.
Source: ERIA.

The calculation results show that coal demand in the BAU scenario during the period of 2019-2050 increases to 124.9 Mtoe at a cost of US$19,739.0 million, followed by the oil increased to 63.4 Mtoe at a cost of US$43,601.5 million and natural gas, increased to 29.4 Mtoe at a cost of US$8,497.4 million. The total incremental cost in the BAU scenario is US$7,1837.9 million (Table 16.3).

Table 16.3. Fuel Costs in BAU Scenario

Fuel	Primary Energy Consumption			Fuel Cost (US$ million)
	2019	2050	2050–2019	2050–2019
Coal	49.5	174.4	124.9	19,739.0
Oil	21.8	85.2	63.4	43,601.5
Gas	8.1	37.5	29.4	8,497.4
Hydrogen	0.0		0.0	0.0
Total	79.5	297.2	217.7	71,837.9

BAU = business as usual, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Author's calculations.

In the LCET–CN scenario, the highest decrease in coal demand by 2050 is 21.8 Mtoe compared to 2019, equivalent to a reduced cost of US$3,451.7 million, followed by oil with a decrease of 6.0 Mtoe with a decrease in cost compared to 2019 of US$4,102.3 million due to the strong use of renewable energy replacing coal for power generation, and the use of clean fuels (electricity and hydrogen) to replace oil in transportation. Meanwhile, natural gas increased by 28.5 Mtoe with an additional cost of US$8,224.4 million and hydrogen increased by 11.6 Mtoe, with an additional cost of US$13,480.3 million. The total additional cost compared to 2019 in the LCET–CN scenario is US$14,150.8 million (Table 16.4).

Table 16.4. Fuel Costs in LCET–CN Scenario

Fuel Type	Primary Energy Consumption			Fuel Cost (US$ million)
	2019	2050	2050–2019	2050–2019
Coal	49.5	27.7	–21.8	–3,451.7
Oil	21.8	15.9	–6.0	–4,102.3
Gas	8.1	36.6	28.5	8,224.4
Hydrogen	0.0	11.6	11.6	13,480.3
Total	79.5	91.7	12.2	14,150.8

LCET–CN = low-carbon energy transition–carbon neutral.
Source: Author's calculations.

Power Generation Investment

Investment costs for power generation technologies are calculated based on input data such as investment cost per unit of capacity, capacity factors, and corresponding power output of each power plant.

Table 16.5 shows investment costs and capacity factors of power generation technologies in 2019 and 2050.

Table 16.5. Investment Cost and Capacity Factors

	Investment Cost (US$/KW)		Capacity Factors (%)	
	2019	2050	2019	2050
Coal	1,500	1,525	75	80
Oil			75	80
Gas	700	700	75	80
Hydrogen		700		80
Hydro	2,000	2,223	50	40
Solar	1,600	307	17	17
Wind	1,600	1,235	40	40
Biomass	2,000	3,019	50	70

KW = kilowatt.
Source: Author's calculations.

Based on data on investment cost per unit of capacity, capacity factor, output difference between the years 2050 and 2019, we can calculate the additional capacity in the period of 2019–2050 and then calculate the investment cost for power generation for the period 2019-2050 of the BAU and LCET–CN scenarios, as shown in Table 16.6.

Table 16.6. Power Generation Investment Costs – BAU Scenario

	Generation Outputs (TWh)			Additional Capacity (MW)	Costs (US$ million)
	2019	2050	2050–2019	2019–2050	2019–2050
Coal	120.2	536.8	416.6	59,452	90,665
Oil	2.1	0.0	–2.1	0	0
Gas	42.6	220.9	178.3	25,445	17,812
Hydrogen	0.0	0.0	0.0	0	0
Hydro	66.1	91.1	24.9	7,116	15,819
Solar	4.8	6.1	1.3	894	275
Wind	0.7	0.7	0.0	7	9
Biomass	0.4	1.0	0.7	114	344
Total	236.9	856.73	619.8	92,428	124,922

BAU = business as usual. MW = megawatt, TWh terawatt-hour.
Source: Author's calculations.

In the BAU scenario, the power output from coal-fired power plants in 2050 increases significantly with 416.6 TWh compared to 2019, equivalent to an additional capacity of 59,452 MW and an additional investment cost of US$90,665 million. This is followed by gas with an increase in power output of 178.3 TWh, equivalent to a capacity of 25,445 MW and an additional investment cost of US$ 17,812 million and hydro with an increase of 24.9 TWh, equivalent to a capacity of 7,116 MW and an additional investment cost of US$15,819 million. Whilst renewable power sources (solar, wind, biomass) increased insignificantly to about 2 TWh, equivalent to a capacity of 1,015 MW and an additional investment cost of US$627 million.

In the LCET–CN scenario, due to a strong shift from coal power to clean energy sources such as RE and hydrogen, the electricity output from coal-fired power in 2050 will decrease significantly by 35.0 TWh compared to 2019, equivalent to a reduced capacity of 4,996 MW and a reduced investment cost of US$7.619 million. Meanwhile, renewable power sources (solar, wind, biomass) increased significantly. The highest is wind power, increased by 326.8 TWh, equivalent to a capacity of 93,264 MW and additional investment cost of US$115,181 million, followed by solar power, increased by 156.3 TWh, equivalent to a capacity of 104,968 MW and additional investment cost is US$32,252 million, and biomass power, increased by 27.3 TWh, equivalent to a capacity of 4,452 MW and an additional investment cost of US$13,439 million.

In addition, the electricity output from natural gas increased by 168.8 TWh, equivalent to a capacity of 24,081 MW and additional investment costs of US$16,857 million, followed by hydrogen, increased to 80.7 TWh, equivalent to a capacity of 11,521 MW and an additional investment cost of US$ 8,065 million, and hydropower increased by 58.2 TWh, equivalent to a capacity of 16,609 MW and additional investment costs of US$36,922 million (Table 16.7).

Table 16.7. Power Generation Investment Costs – LCET–CN Scenario

	Generation Outputs (TWh)			Additional Capacity	Costs
	2019	2050	2050–2019	2019–2050	2019–2050
Coal	120.2	85.1	–35.0	–4,996	–7,619
Oil	2.1	0.0	–2.1	0	0
Gas	42.6	211.4	168.8	24,081	16,857
Hydrogen	0.0	80.7	80.7	11,521	8,065
Hydro	66.1	124.3	58.2	16,609	36,922
Solar	4.8	161.1	156.3	104,968	32,225
Wind	0.7	327.5	326.8	93,264	115,181
Biomass	0.4	27.6	27.3	4,452	13,439
Total	236.9	1,017.9	781.0	249,899	215,071

LCET–CN = low-carbon energy transition–carbon neutral, TWh = terawatt-hour.
Source: Author's calculations.

Carbon Capture and Storage Cost

CCS will be calculated mainly for power generation using fossil fuels including coal and natural gas.

The cost of CCS is mainly calculated for coal and gas power plants with CCS equipment installed. With assuming that CCS devices can capture up to 90% of CO_2 emissions and the average cost of capture is about US$30/$CO_2$ ton, the total cost for CCS can be calculated by US$3,962 million, of which US$2.049 million for gas power and the remaining US$1,913 million is for coal power.

Overall Cost

Based on the above calculation results, it is possible to compare costs between the LCET–CN and BAU scenarios as presented in Table 16.8.

Table 16.8. Cost Comparison between LCET–CN and BAU Scenarios in 2050

(US$ million)

	BAU	LCET–CN	LCET–CN vs. BAU
Fuel Cost	71,838	14,151	–57,687
Power Capital Cost	124,922	215,071	90,148
CCS	0	3,962	3,962
Total	196,760	233,183	36,423

BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral.

Source: Author's calculations.

From Table 16.8, it is shown that investing in clean energy sources such as RE and hydrogen to replace coal for power generation and oil products for transportation in the LCET–CN scenario leads to higher costs than BAU by US$90,148 million, but reduces the fuel costs by US$57,687 million. However, even though the investment costs in RE and hydrogen are high, there still be a great benefit to reducing CO_2 emissions and therefore, if carbon prices are taken into account, the costs in the LCET–CN scenario can be significantly reduced.

In addition, the cost for CCS in the LCET–CN scenario is about US$3,962 million. The total cost in the LCET–CN scenario is US$36,423 million higher than the BAU.

4. Conclusions and Recommendations

4.1. Conclusions

- Energy transition in energy use and power generation are important activities to achieve the carbon neutral in Viet Nam by 2050. The increasing investment costs for energy transition, especially investment in RE and hydrogen will reduce the cost of using fossil fuels such as coal and oil products as well as reduce CO_2 emissions.
- The total cost in the LCET–CN scenario is US$36,423 million higher than the BAU scenario, mainly due to the higher investment costs in RE sources. However, if carbon prices are included in the calculation, the costs in the LCET–CN scenario can be significantly reduced.
- The additional cost due to investment in CCS is US$3,962 million. Due to the assumption that CCS starts to invest in 2040 and will be widely used by 2050, if the cost of CCS technology is reduced by 2050, the investment cost for CCS may decrease accordingly.

4.2. Recommendations

To achieve the goal of net-zero emissions by 2050, Viet Nam must reduce its reliance on fossil fuel quickly – especially coal-fired power – and switch to renewable energy sources and low greenhouse gas emissions technologies such as CCS and hydrogen. However, whilst the cost of solar and wind energy has been decreasing rapidly, their reliability depends on the weather and time of day. Further, CCS and hydrogen technologies are still in their early stages and require substantial financial investments. Therefore, promoting EE&C measures is essential for Viet Nam in the coming years to reduce overall energy consumption, especially in using fossil fuel. Therefore, the Government of Viet Nam should:

- further improve standards and technical regulations on energy consumption norms in different sectors, strengthening the implementation of energy efficiency measures.
- issue policies on the development and application of energy service companies, enabling assessment of energy efficiency potential and external investment in EE&C measures, and
- enhance the implementation of solutions for the efficient use of energy and promote the transition to clean energy and electrification in industry, transport, services, trade, etc.

Coal thermal power plants play a significant role in meeting Viet Nam's growing electricity demand. However, because of the goal of achieving net-zero emissions, the country is transitioning from coal to natural gas for power generation and exploring options for natural gas or LNG imports. The development of transparent markets in Asia will enhance Viet Nam's LNG supply security.

The demand for petroleum products in Viet Nam will increase in the coming years. Whilst Viet Nam is a net exporter of crude oil, it relies on petroleum product imports due to limited oil refinery capacity for domestic needs. Efforts will be made to expand its refinery capacity, but petroleum product imports will still be needed until 2040. To reduce dependence on energy imports, Viet Nam is implementing policies focused on fuel switching from oil to electricity and hydrogen, especially for road transport.

As renewable energy sources will expand rapidly in the coming years, ensuring a safe and stable electricity supply system is crucial for Viet Nam. Therefore, it is necessary to develop a well-balanced power generation portfolio that maximises the use of hydropower resources, prioritise the development of wind and solar power, whilst ensuring safety at reasonable prices, and develop natural gas power as an important source of power supply.

Shifting energy towards net zero emissions by 2050 is a big challenge for Viet Nam, especially the challenges on finance, technology, policy institutions, and regulatory framework for the energy transition. In order to overcome these policy challenges, some recommendations are proposed as follows:

- Formulation of the Law on Renewable Energy, in support of RE manufacturing industry development, RE deployment, electricity transmission and storage improvement, green hydrogen production and use, etc.
- Develop policy on cooperation in research and development (R&D) between public and private sector entities, focusing on R&D of technological innovations in solar and wind power, energy storage, energy efficiency, green hydrogen and derivatives, and CCS, as well as information technology applications in the power sector, as appropriate.
- Develop a long-term legal framework to achieve net-zero emissions and ensure the transition from fossil energy to low-emissions energy.
- Complete the legal framework on green credit, mechanisms and policies and sanctions to create favourable conditions for credit growth for projects on the list of green classification, response to climate change and energy transition.

References

General Statistics Office, Government of Viet Nam (2020), *Statistical Yearbook of Viet Nam*. Ha Noi: General Statistics Office.

Government of Viet Nam (2017), Decision No. 60/QD-TTg dated 16 January 2017 of the Prime Minister for Approving the Development Plan of the Gas Industry of Vietnam by 2025, with Vision to 2035. Ha Noi: Government of Viet Nam.

Government of Viet Nam (2019), Decision 280/QD-TTg dated 13 March 2019 of the Prime Minister on Approval for National Program for Thrifty and Efficient Use of Energy for the Period of 2019 -2030. Ha Noi: Government of Viet Nam.

Government of Viet Nam (2022a), Decision No. 876/QD-TTg dated 22 July 2022 of the Prime Minister on Approving the Action Plan on Green Energy Transition and Mitigation of Carbon Dioxide and Methane Emissions from Transportation. Ha Noi: Government of Viet Nam.

Government of Viet Nam (2022b), Decision No. 896/QD-TTg dated 26 July 2022 of the Prime Minister on Approving the National Strategy for Climate Change until 2050. Ha Noi: Government of Viet Nam.

Government of Viet Nam (2023), Decision No. 500/QD-TTg dated 15 May 2023 of the Prime Minister on Approving the National Power Development Plan for the Period 2021–2030, with Vision to 2050. Ha Noi: Government of Viet Nam

Ministry of Industry and Trade (2022), Decision No. 626/QD-TTg dated 05 April 2022 on Approving the Action Plan of Ministry of Industry and Trade for Implementing Viet Nam's Commitments at COP26. Ha Noi: Ministry of Industry and Trade.

Ministry of Natural Resources and Environment (MONRE) (2020), *Viet Nam – Report on National GHG Inventory for 2016*. Ha Noi: Ministry of Natural Resources and Environment.

Viet Nam Electricity (2018), *Annual Report*, *2018*. Ha Noi: Viet Nam Electricity.

Viet Nam Electricity (2021), *Annual Report*, *2021*. Ha Noi: Viet Nam Electricity.

Chapter 17
United States Country Report[1]

Clara Gillispie

National Bureau of Asian Research, United States

Seiya Endo

Energy Data and Modelling Center, the Institute for Energy Economics, Japan

1. Introduction

The United States (US) is the fourth largest country in the world by total area and the third largest by population. As of 2023, it was home to approximately 333.5 million people, of which more than 80% live in urban areas (US Census Bureau, n.d.; World Bank, 2024a).

The US is the world's first or second largest economy (depending on the metric), with a gross domestic product (GDP) of $25.44 trillion and per capita income of $77,950 as of 2022 (World Bank, 2024b, 2024c). By sector of origin, roughly 77% of the US gross domestic product (GDP) can be linked to services, whilst around 18% is linked to industry including construction (World Bank, 2024d, 2024e). Agriculture, forestry, and fishing collectively make up just 1% (World Bank, 2024f). More broadly, international trade also plays a crucial role in the overall strength and health of the US economy, with data from the World Bank suggesting that roughly one-quarter of US GDP is linked to trade (World Bank, 2024g).

1.1. Energy Situation

The United States is the world's second largest consumer of energy (first on a per capita basis) but its consumption growth rate has slowed significantly in recent years. To that end, in 1990 US final energy consumption was 1,293.54 million tonnes of oil equivalent (Mtoe). Over the following decade, consumption increased by nearly 20% (reaching 1,546.28 Mtoe in 2000), and then grew by less than 3% over the next 2 decades (reaching 1,588.48 Mtoe in 2019).

In terms of how the United States might meet its demand for energy, the country has long had abundant, diverse resource potential, including substantial natural endowments in fossil fuels such as coal, oil, and natural gas; geothermal and hydroelectric potential; and good conditions for wind and solar energy. Yet up until recently, significant portions of this

[1] Unless otherwise cited, all data in this report can be attributed to the Institute of Energy Economics Japan's economic modelling results for the United States, which are included in full as an appendix to this publication.

potential were not considered technically or economically viable; coal alone thus often accounted for a sizeable share of all domestic energy production on an annual basis until well into the early 2000s. However, since then, breakthroughs in technology, declining production costs, and generally favourable environments for development and investment have contributed to a surge of interest in domestic oil, natural gas, and wind and solar energy production. Consequentially, US natural gas production has roughly doubled since 2005, as has domestic crude oil production (US EIA, 2022a). Meanwhile, in the past 10 years alone, US wind power capacity has more than doubled – whilst solar power capacity has increased twentyfold (US EIA, 2022b).

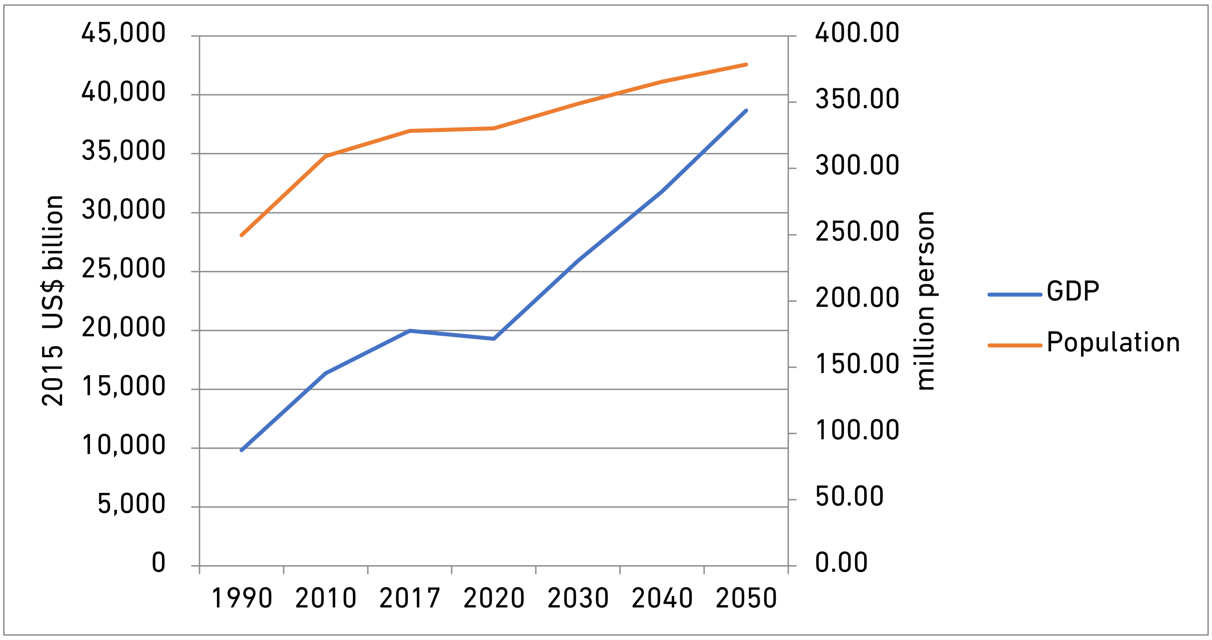
Such developments have had at least two ripple effects on the US energy outlook. The first is accelerating the United States' ongoing shift towards cleaner consumption patterns, given the now wider range of available lower- and zero-carbon supply options. To that end, in 2014 natural gas surpassed coal as the single largest share of US power generation and, since then, has further increased its share. Consumption of wind and solar has also continued to hit new record highs (US EIA, 2022c, 2022d, Gillispie, 2022). Collectively, these shifts have also had a knock-on effect of offsetting otherwise anticipated growth in US carbon dioxide (CO_2) emissions – such that, despite the rise in total final energy consumption since 1990, CO_2 emissions in 2019 were only 0.1 million tonnes of carbon (Mt-C) higher than levels in 1990 (i.e. 1,293.6 Mt-C vs. 1,293.7 Mt-C).

The second major impact of these shifts is in reshaping the United States' otherwise expected outlook for trade in energy. Increased US oil and natural gas production has contributed to not only backing out US requirements for relevant Canadian and other imports, but also bolstered the country's potential to serve as an important global energy supplier. This includes as a supplier of natural gas where, as of 2023, notable volumes of US liquefied natural gas exports have already been delivered to Japan, Taiwan, India, the Republic of Korea, and China (US EIA, 2022e). Meanwhile, reduced requirements for coal at home has also translated into a greater emphasis on export markets for US coal producers, with India, Japan, and the Republic of Korea accounting for three of the US' top five steam coal export markets (US EIA, 2022f). Whilst these trends suggest a number of ways in which US energy production might be able to contribute to regional energy security outlooks—not to mention to US trade balances – several factors may nonetheless curtail interest in otherwise available US supplies and technologies. These include potential bottlenecks in relevant energy export and import infrastructure as well as intense competition between the United States and other economies for global market share – all amidst rising domestic and global concerns around climate change.

2. Modelling Assumptions

Over this study's outlook period of 2019–2050, both overall GDP and population counts are projected to grow, though at markedly different rates – resulting in a trend of an overall rising per capita GDP (Figure 17.1). Whilst US birth rates are projected to remain below replacement levels during the outlook window, the population continues to grow overall due to expectations for sustained immigration and improved life expectancies. However, at 0.5% per year, the population growth rate for the outlook period is still at a notably slower pace than the 0.9% per year of the 1990–2019 period.

Figure 17.1. Gross Domestic Product and Population



GDP = gross domestic product.
Source: Authors' calculations.

Between 1990 and 2019, the United States' GDP grew at an average annual rate of 2.5%. Despite significant disruption during the 2007–2008 global economic crisis and once again during the 2020–2021 novel coronavirus disease (COVID-19) crisis, the US economy has generally been able to realise steady (albeit relatively modest) growth.[2] Hence, this model projects that the US GDP growth rates will re-stabilise over the outlook period at an annual average growth rate of 2.2% per year. This estimate aligns with expectations of continued efficiency and productivity gains coupled with modest yet sustained population growth. It also assumes continued US leadership on innovation and strong global industrial competitiveness.

[2] For more on this, see Gillispie (2022).

With these conditions in mind, this study estimates the US' energy saving and CO_2 emissions reduction potential as well as select costs of such shifts by comparing the results of a business as usual (BAU) scenario with the cumulative impact of several alternative policy (AP) scenario and a low-carbon energy transition (LCET–CN) scenario. In the BAU scenario, numerous longstanding market trends are expected to continue to hold true. Such trends include weakening outlooks for coal and nuclear energy, given unfavourable economics and social license in the United States when compared with non-hydro renewables and natural gas. Coal in particular is expected to undergo a dramatic decline, given the growing market competitiveness of alternative generation options (as described above) as well as the expected retirement of a number of older, less efficient coal-fired plants during the outlook period. Meanwhile, despite a projected uptick in the use of alternative fuels and in the pace of electric vehicle adoption, the US transport sector is also anticipated to remain heavily reliant on oil in this scenario – at least in part due to relatively more modest means and incentives for sparking large-scale switching when compared with the tools available within the power sector.

The AP scenario, in contrast, examines what a country's energy outlook might look like assuming the full implementation and realisation of a range of policy efforts that are already underway as of 2022. This includes greater progress in established efforts to strengthen efficiency of final energy demand; improve efficient thermal power generation; sustain a robust role for nuclear energy as a source of baseload power generation; and realise a higher contribution from renewable energy in total supply. For the United States, calculations here are modelled based on a review and assessment of US laws and policies in place at the national- and state-level as of 2021. Importantly, this cut-off date means that the potential impacts of the United States' Inflation Reduction Act, which was signed into law in August 2022, are not covered by the AP scenario findings.

Finally, the LCET–CN scenario models what shifts (if any) might enable a country to reach net-zero CO_2 emissions on an annual basis by 2050. In the case of the United States, such shifts include the adoption of specific new incentives, tools, and approaches that are more aggressive in prioritising decarbonisation than those in the AP scenario but that nonetheless remain technically feasible and at least *potentially* socially acceptable.[3] Here, the United States' *Pathways to Net-Zero Greenhouse Gas Emissions by 2050* serves an important basis for such scenario modelling, as do the various executive orders issued by the Biden administration related to decarbonising power-, transport-, and industry-sector energy demand. However, in some cases, divergences between the findings of these official reviews and this report do occur, given modest differences in methodologies (including assumptions about likely economic conditions and technological advances between 2019 and 2050).

[3] E.g. more aggressive dates for phasing out combustion engines, but not the suggestion of eliminating all motorised vehicles.

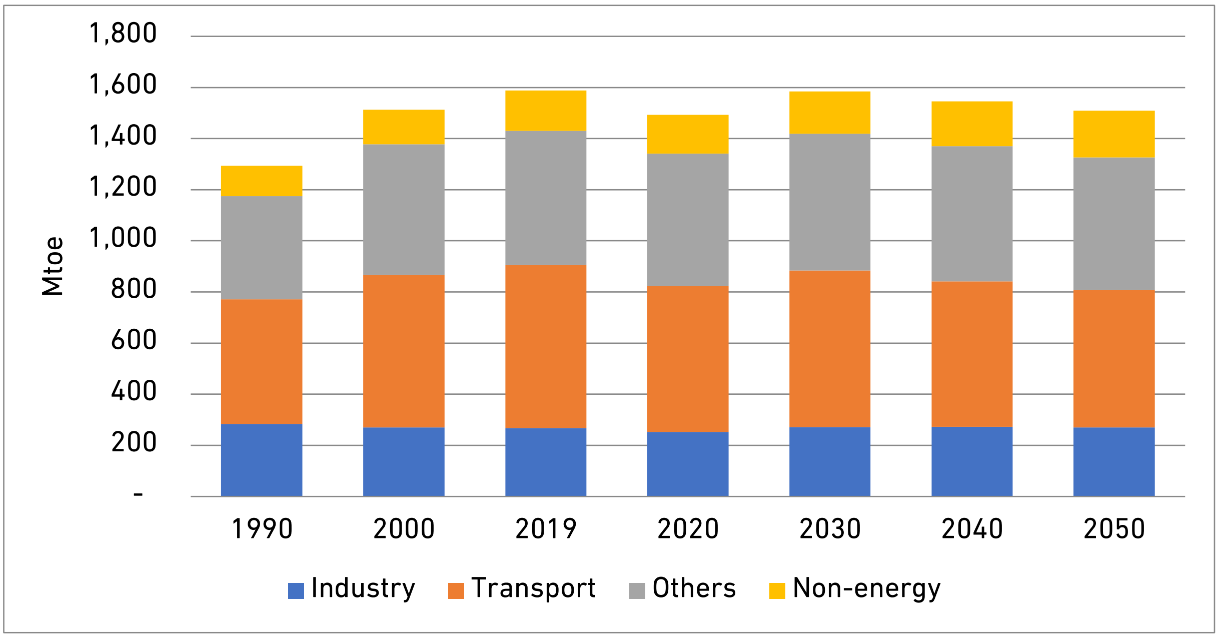
3. Outlook Results

3.1. Business as Usual Scenario

Final Energy Consumption

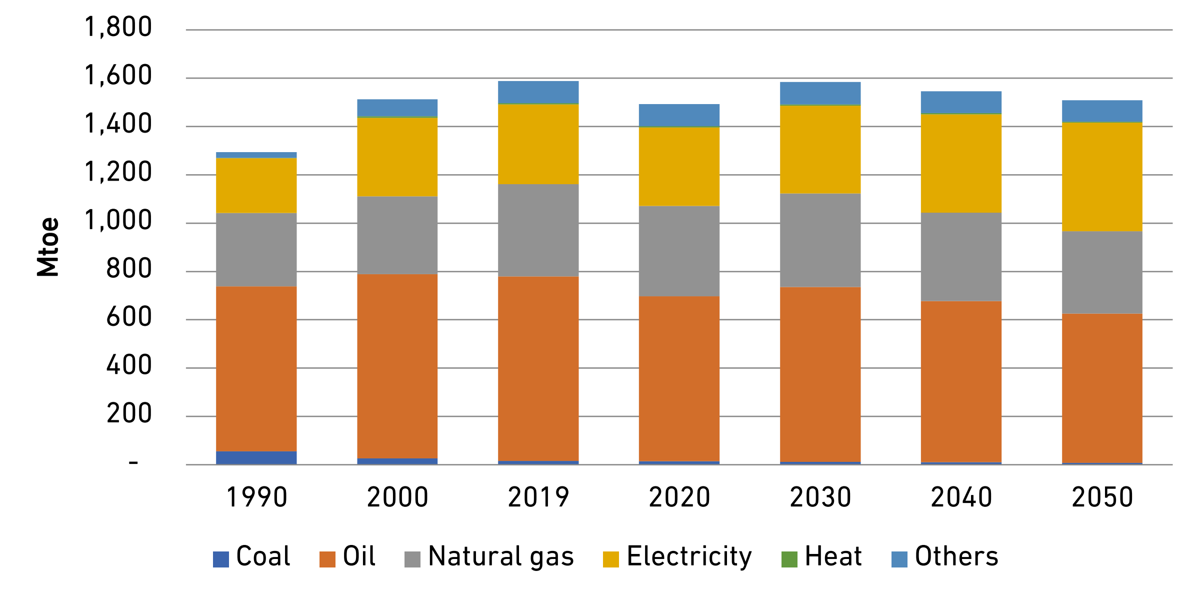
Under the BAU scenario, total final energy consumption is anticipated to decline slightly between 2019 and 2050, at an average annual rate of decrease of 0.2% (Figure 17.2). The transport sector is a key driver of this decline, as otherwise expected growth linked to a modest rise in vehicle ownership and utilisation is more than offset by increased switching to cleaner, more efficient vehicles as well as other structural changes within the sector. However, an otherwise steeper decline in total US energy consumption is offset by a rise in non-energy sector consumption, which is expected to see average annual growth of 0.5%. Meanwhile, both industry and others are expected to see relatively flat growth during the outlook period.

Figure 17.2. Final Energy Consumption by Sector under BAU Scenario



BAU = business as usual, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

Figure 17.3. Final Energy Consumption by Fuel Type under BAU Scenario



BAU = business as usual, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

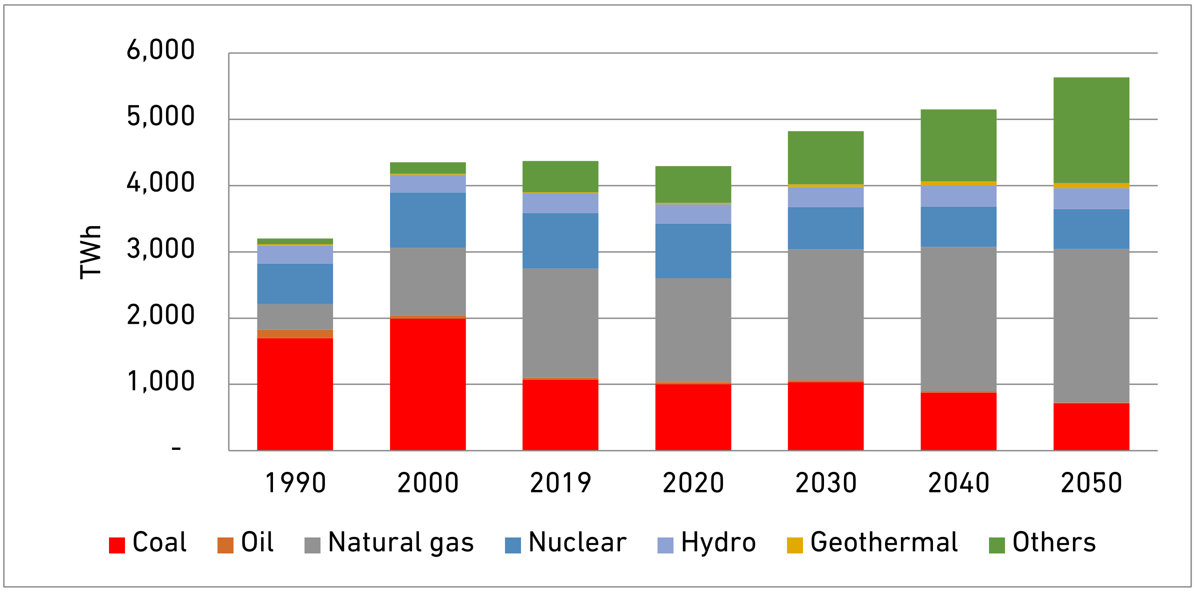
In this context, oil consumption declines and by 2050, is anticipated to fall to 616.91 Mtoe (roughly 10% below levels in 1990). Coal consumption also declines and does so consistently throughout the entire 2019–2050 period. In contrast, electricity consumption grows (from 329.32 Mtoe in 2019 to 448.68 Mtoe in 2050), which (amongst other things) reflects headwinds in newly electrifying various sectors of the US economy (e.g. transport as well as industry). Natural gas consumption likewise grows overall but shows signs of a potential peak and then subsequent decline after 2030 as the fuel faces additional competition from other energy types in multiple end-use sectors.

Primary Energy Consumption

Under the BAU scenario, total primary energy consumption is anticipated to decline from 2,212.75 Mtoe in 2019 to 2,082.97 Mtoe in 2050, with an average annual rate of decrease of 0.2%. Coal consumption is anticipated to decline at a rate of 1.6% during this period, whilst nuclear declines by 1.1%. In contrast, non-hydropower renewables experience the largest growth in consumption this period at 4.8%, followed by geothermal at 4.6%.

Power Generation

Figure 17.4. Power Generation under the BAU Scenario



BAU = business as usual, TWh = terawatt-hour.
Source: Authors' calculations.

Electricity generation in the United States, under BAU, is project to increase over the outlook period, although at a modestly slower pace than the previous 25 years. Generation output increases from 4,370.99 terawatt-hours (TWh) to 5,634.40 TWh between 2019 and 2050 (Figure 17.4), for an average annual growth rate (AAGR) of 0.8%. The retirement of older, less efficient coal-fired plants, as well as ongoing technological improvements promoting more efficient consumption are assumed to play important roles in shaping this outlook, alongside broader market and policy forces that incentivise input switching. In line with this, coal declines steadily – at 1.3% a year – and by 2050 is anticipated to account for only 12.7% of all US power generation (down from 24.5% in 2019). Meanwhile, natural gas is expected to gain in relative competitiveness and, by 2050, represents 41.1% of the overall mix. Even so, the largest average annual growth rates are seen in non-hydro renewables, most prominently solar and wind. When combined with shares for nuclear and hydro, these growth rates suggest that by 2050, roughly 46% of US power generation output may come from zero-carbon energy sources.

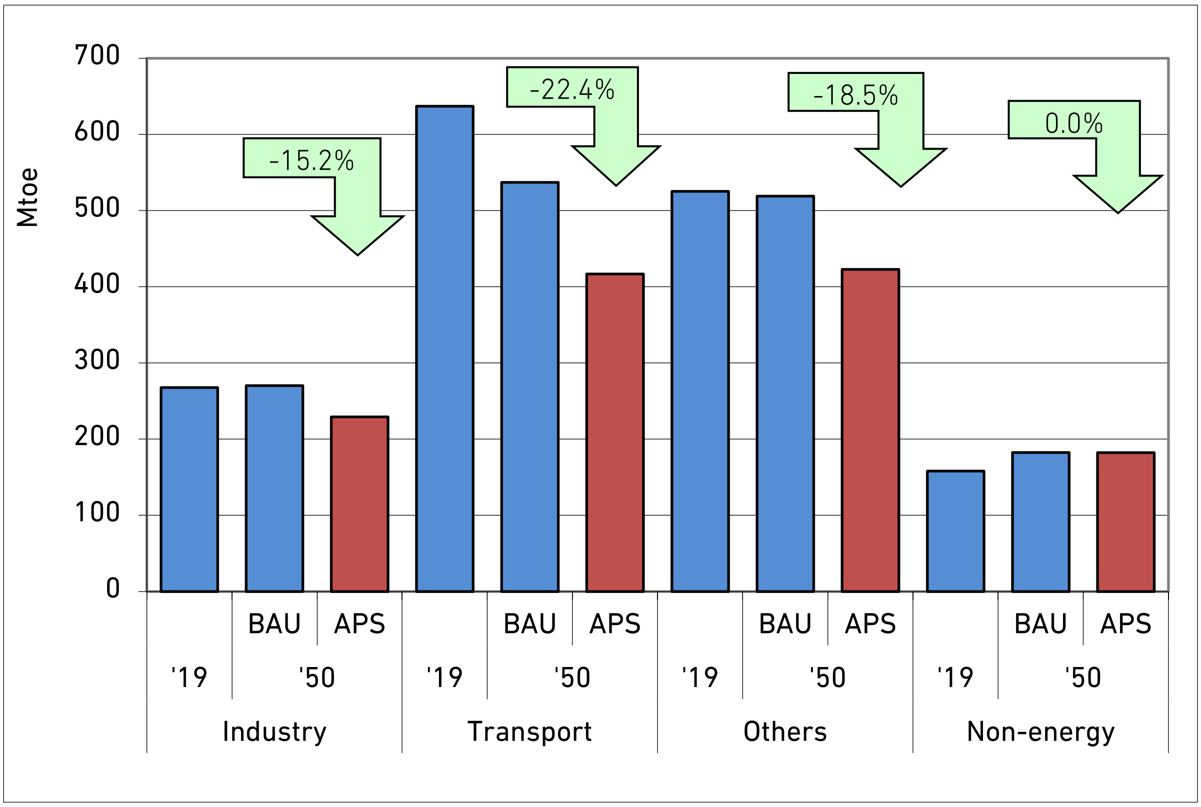
3.2. Alternate Policy Scenario

Final Energy Consumption

Under the AP scenario, this study projects that an even more dramatic decline in total final energy consumption will occur in the United States. To that end, under the AP scenario such consumption is expected to decline from 1,588.48 Mtoe to 1,251.43 Mtoe during the 2019–2050 period. When compared with the BAU scenario, this shows an energy savings of roughly 258 Mtoe or 17.1% during the outlook period. Transport realises a saving of 120 Mtoe (22.4%), industry saves 41 Mtoe (15.2%), and residential and commercial (others) saves 96 Mtoe (18.5%) (Figure 17.5). Meanwhile, in contrast to expectations under BAU, both industry *and* residential and commercial now realise some level of declining overall consumption.

The impacts of this decline are not evenly distributed across fuel type. Whilst coal, oil, and natural gas all realise even faster rates of decline over the outlook period under the AP scenario, the difference between the AP and BAU scenarios is sharpest for natural gas. Meanwhile, electricity consumption is still anticipated to grow – and, indeed, is modestly higher than in BAU – given factors such as an increased uptake in electric vehicles.

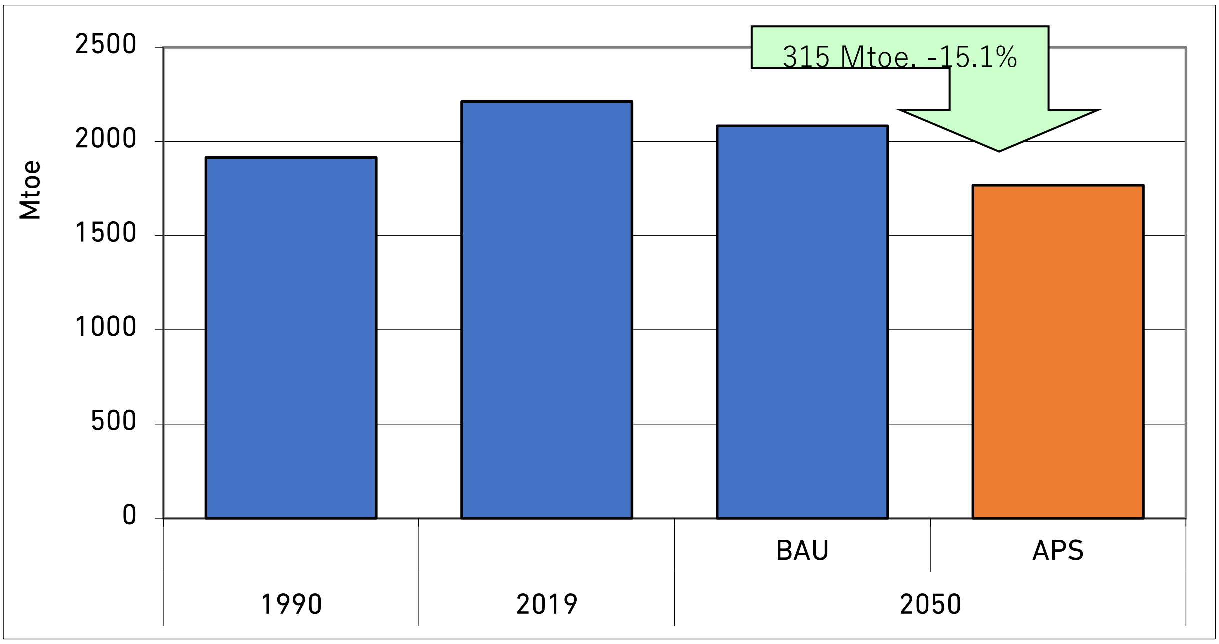
Figure 17.5. Final Energy Consumption by Sector in BAU vs. AP Scenarios



AP = alternative policy, BAU = business as usual, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

Primary Energy Consumption

Figure 17.6. Total Primary Energy Consumption in BAU vs. AP Scenarios

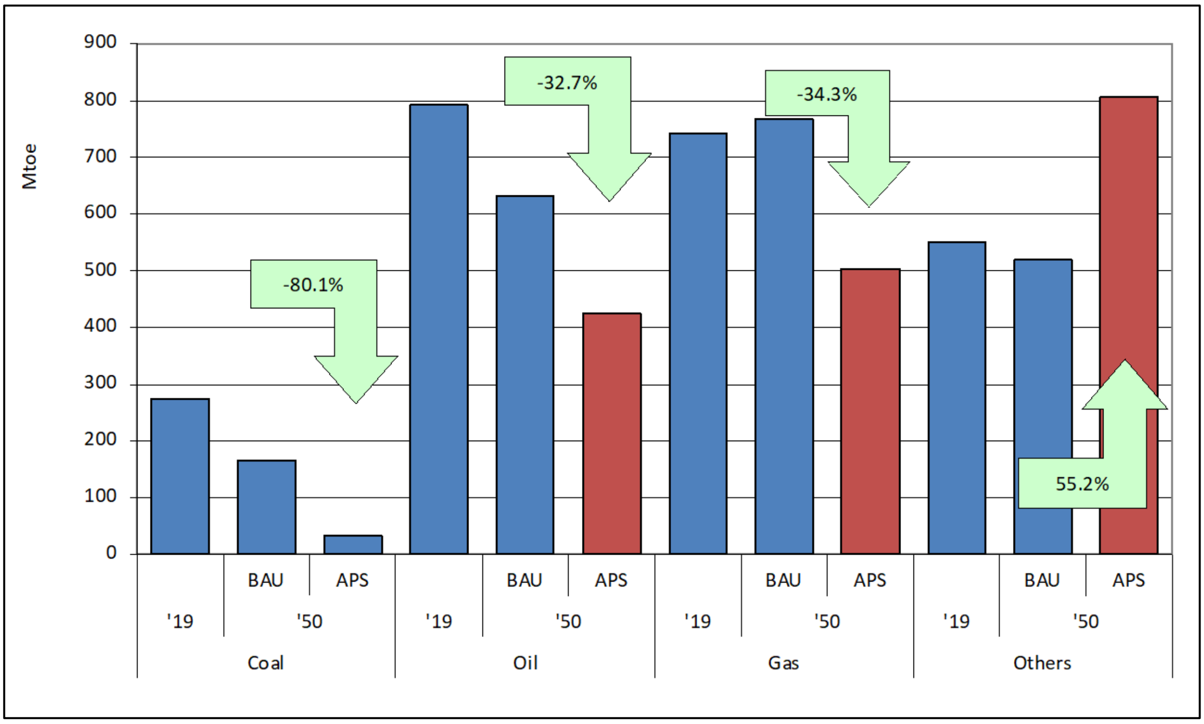


AP = alternative policy, BAU = business as usual, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

Under the AP scenario, the United States' primary energy consumption is anticipated to decrease from 2,212.75 Mtoe in 2019 to 1,767.98 Mtoe in 2050. This implies that in 2050, primary energy consumption under the AP scenario will be around 315 Mtoe or 15.1% lower than BAU (Figure 17.7).

Primary energy demand in the AP scenario is expected to decline for coal to 32.80 Mtoe. This represents a total energy saving of 132.4 Mtoe (or 80.1%) in 2050 compared with BAU. Oil consumption is also anticipated to decline compared to BAU, with a potential saving of 206.6 Mtoe (or 32.7%) by 2050, whilst natural gas is anticipated to see an even more pronounced level of decline at 263.0 (or 34.3%). In contrast, the combined demand for all others is anticipated to increase about 286.98 Mtoe (55.2%) compared to BAU in 2050.

Figure 17.7. Total Primary Energy Consumption by Fuel in BAU vs. AP Scenarios

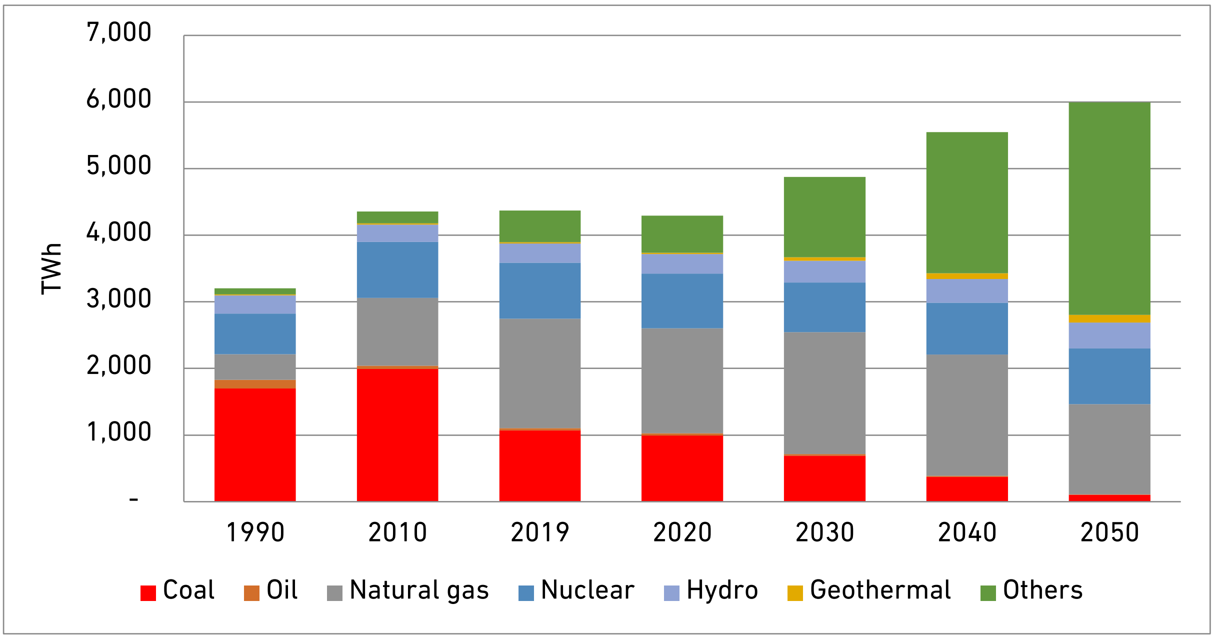


AP = alternative policy, BAU = business as usual, Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

Power Generation

In line with rising demand for electricity, power generation under the AP scenario rises to 5,997.37 TWh in 2050 under the AP scenario – an increase of 362.97 (or 6.4%) over BAU in that same year (Figure 17.8). Yet this modest increase belies larger changes in the US power mix that occur in this scenario. Critical in this context is thus expectations that the full implementation of policies already in place as of 2021 supports more aggressive switching to wind, solar, and geothermal sources in the United States through 2050, as well as the country's ability to maintain nuclear energy output at roughly 2019 levels. This, in turn, produces a scenario where zero-carbon energy sources come to account for roughly 75.6% of US electricity generation by 2050. Consequentially, and in contrast to BAU, zero-carbon generation now backs out not just coal- but also gas-fired power – such that output from natural gas in 2050 is 960.74 TWh less under APS when compared with BAU for the same year. Even so, at 22.5% of total US power generation output, natural gas still represents a significant share of the power mix of 2050.

Figure 17.8. Power Generation under AP Scenario



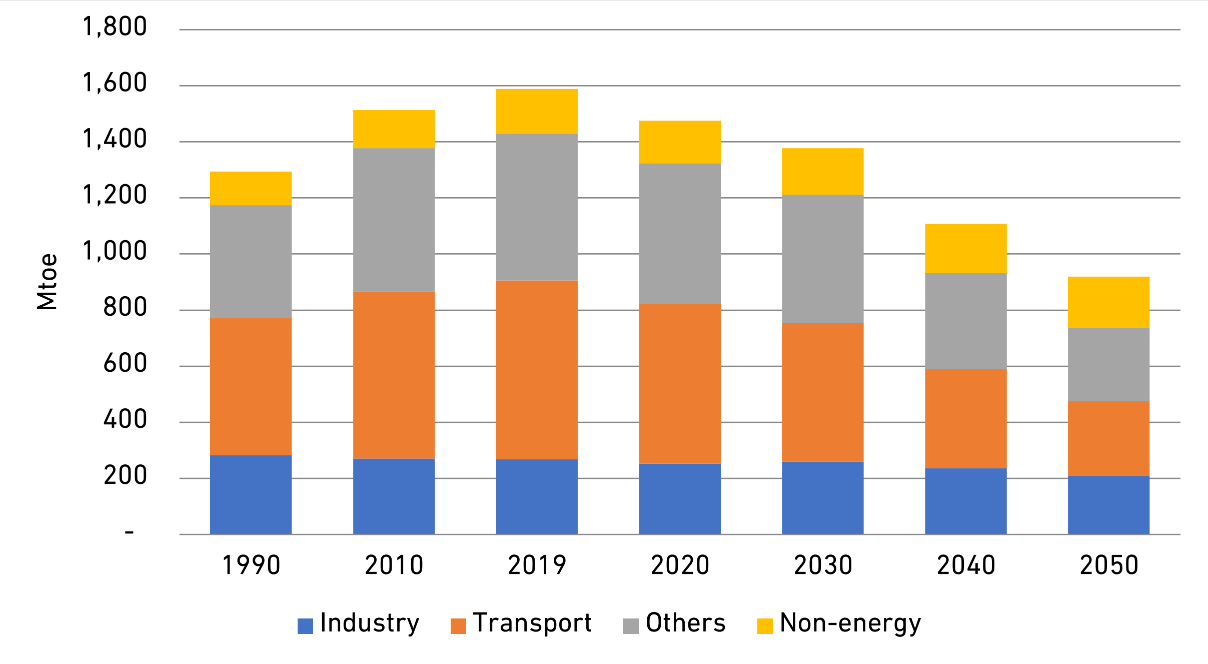
AP = alternative policy, TWh = terawatt-hour.
Source: Authors' calculations.

3.3. Low-carbon Energy Transition Scenario

Final Energy Consumption

Under the LCET–CN scenario, final energy consumption falls from 1,588.48 Mtoe to 918.89 Mtoe during the 2019–2050 period. This suggests a savings in 2050 that is an additional 332.53 Mtoe (or 27%) lower than in the AP scenario – and a full 590.15 Mtoe (or 39%) lower than BAU. Residential and commercial (others) is now 161.36 Mtoe (38.2%) lower than the AP scenario, whilst transport also realises a significant additional saving of 152.24 Mtoe (36.5%). Although the saving under the LCET–CN scenario relative to the AP scenario is less pronounced for industry, it is nonetheless notable at an additional decline of 18.93 Mtoe (8.3%) (Figure 17.9).

Figure 17.9. Final Energy Consumption by Sector



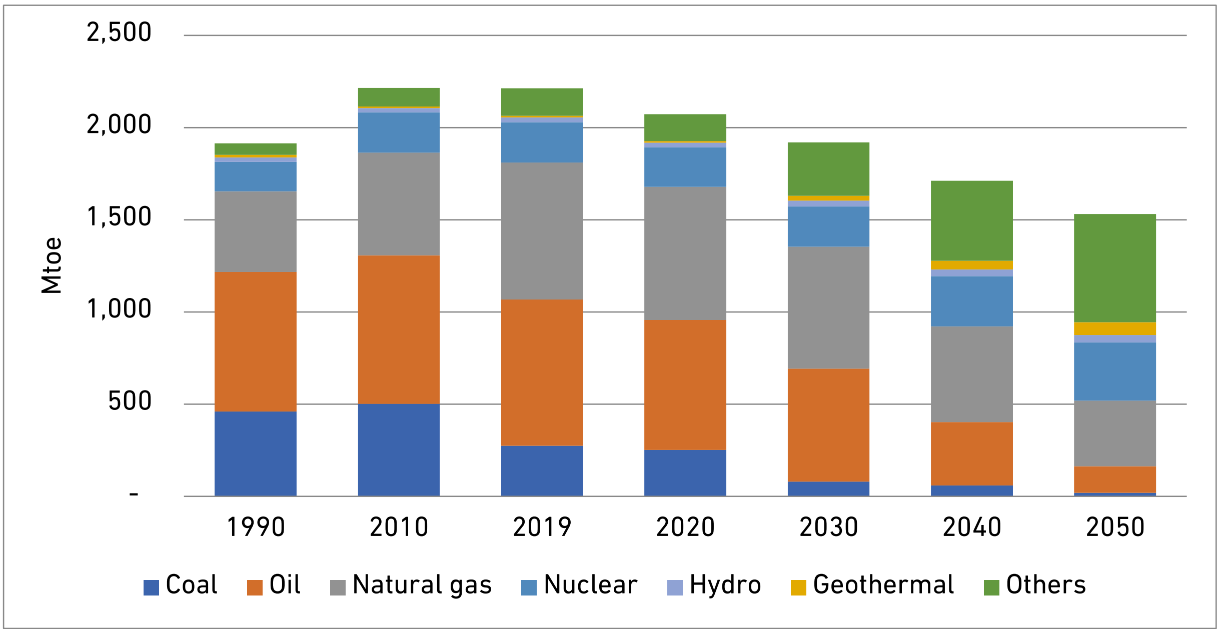
Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

Primary Energy Consumption

Under the LCET–CN scenario, the United States' primary energy consumption is anticipated to decrease from 2,212.75 Mtoe in 2019 to 1,530.65 Mtoe in 2050. This implies that in 2050, under LCET–CN savings of primary energy consumption will be around 237.33 Mtoe (13.4%) lower compared with the AP scenario (Figure 17.10).

As part of this, primary energy demand for coal declines to 19.67 Mtoe. This represents an additional energy saving of 13.13 Mtoe (or 40%) in 2050 over the already dramatic decline in APS. Oil consumption is also anticipated to decline compared to the AP scenario, with a potential saving of 281.14 Mtoe (or 66.2%) by 2050, whilst natural gas declines by 147.71 Mtoe (or 29.3%).

Figure 17.10. Total Primary Energy Supply



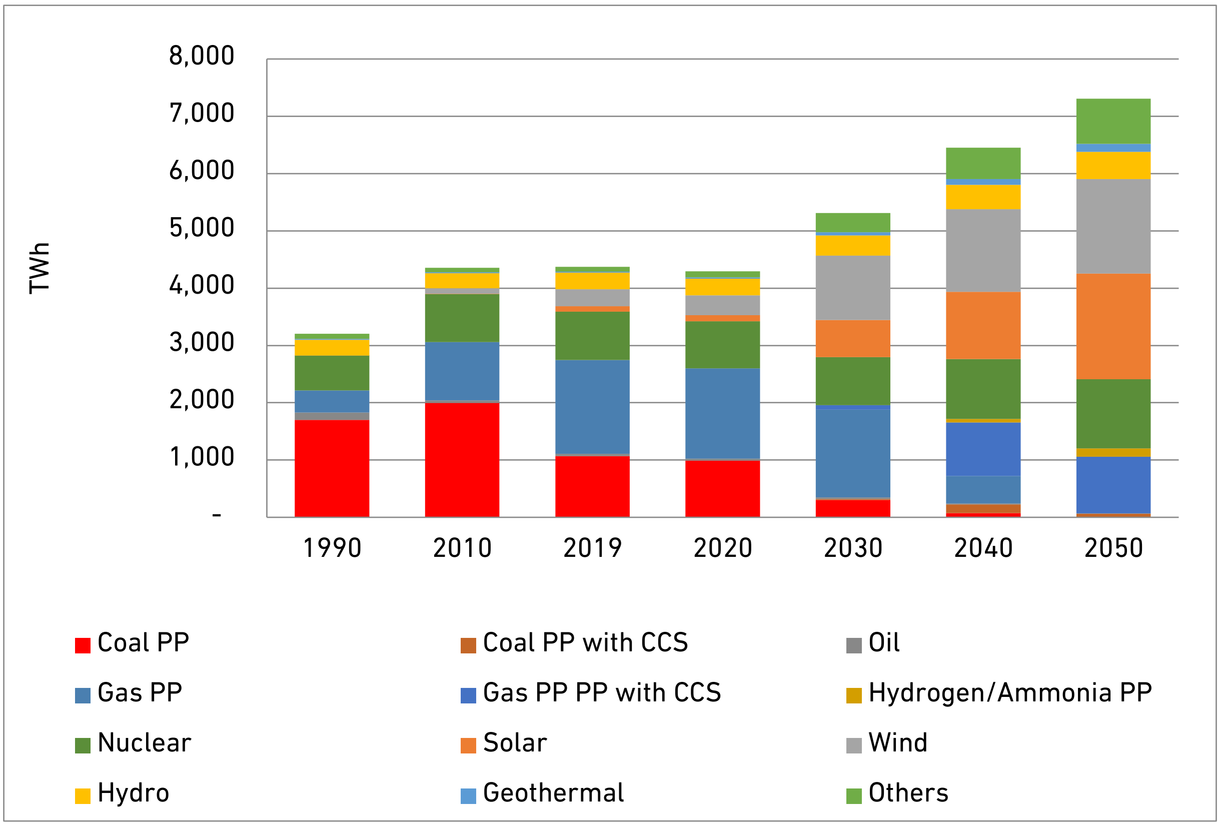
Mtoe = million tonnes of oil equivalent.
Source: Authors' calculations.

Power Generation

The LCET–CN scenario anticipates even greater progress towards the goal of electrifying the US economy as well as the build-out of relevant infrastructure. Thus, and perhaps not surprisingly, this scenario sees a significant increase in power generation output – by 1,311.08 TWh (or nearly 22%) more than under the AP scenario.

A key assumption under the LCET–CN scenario is that market and policy breakthroughs increase the attractiveness of technologies that support the decarbonisation of coal and natural gas. To that end, in 2050 all generation from coal and from natural gas are now paired with carbon capture and storage (CCS). Even so, non-fossil sources remain highly competitive and capture an even larger share of total power generation output in 2050 under the LCET–CN scenario relative to the AP scenario. Notable here is not only new growth in wind and solar but also an uptick in generation from nuclear power (as a result of both technological breakthroughs and new construction). Meanwhile, the collective impact of these trends is even more pronounced – suggesting a scenario where in 2050, virtually of all US power generation output is fully decarbonised.

Figure 17.11. Power Generation



CCS = carbon capture and storage, PP = power plant, TWh = terawatt-hour.
Source: Authors' calculations.

3.4. Carbon Dioxide Emissions

All scenarios in this report project that US CO_2 emissions will decline during the outlook period, although at markedly different rates. Under BAU, US CO_2 emissions from energy consumption are anticipated to decline an annual average rate of decrease of 0.7% – going from 1,293.7 Mt-C in 2019 to 1,043.6 Mt-C in 2050. This level of decline reflects both the decline in total US energy consumption, as well as continued switching in the US power sector – particularly decreases in coal consumption and increases in consumption of non-fossil sources. However, a decline in generation from nuclear energy offsets what might otherwise be even steeper power sector reductions.

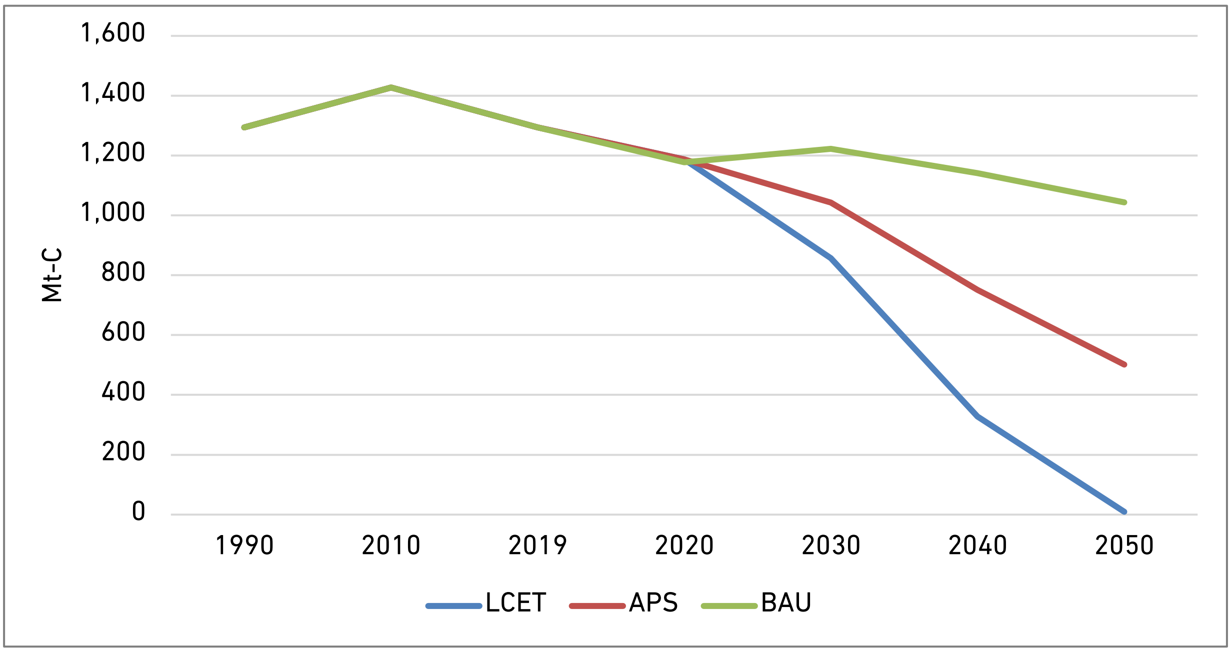
In the AP scenario, CO_2 emissions are projected to decrease at an average annual rate of 3% from 1,293.7 Mt-C in 2019 to 501.4 Mt-C in 2050. Emissions savings in the AP scenario are thus 51.95% compared to the BAU in 2050. The most dramatic shifts between the BAU and AP scenarios link to absolute reductions in emissions from natural gas (an additional 228.2 Mt-C in savings), though both coal and oil also see significant additional new reductions, at a further 157.6 Mt-C and 156.4 Mt-C, respectively. However continued uncertainties in investments and in progress towards strengthening existing, ageing grid infrastructure (so that it can better manage variable renewable energy sources) are likely to continue to challenge efforts to bring new zero-carbon generation capacity online in ways that maximise potential energy savings and CO_2 reductions.

In the LCET–CN scenario, CO_2 emissions are anticipated to decrease at an average annual rate of 14.7% – nearly five times faster than the AP scenario and roughly 21 times faster than BAU. Even so, the rate of decrease does not ensure that the United States' energy system is 'carbon-emission free' by 2050, as roughly 21.8 Mt-C is still emitted annually in this scenario. Key to this picture is lingering emissions from natural gas – which make up over three-quarters of remaining emissions – as well as from coal. Encouraging, though, emissions from oil *do* reach zero by mid-century in this scenario, despite expectations for continued consumption of this fuel in the United States. This suggests the enormous potential of various tools to support cleaner consumption of this fossil fuel when well-aligned with other decarbonisation efforts.

In its revised Intended Nationally Determined Contributions submission, the United States pledged to reduce its greenhouse gas emissions by 50%–52% from 2005 levels by 2030 and to reach net-zero emissions by 2050.[4] The above modelling suggests that the US is already making encouraging progress in taming its emissions and, even under BAU, is likely to see further reductions. However, only under the LCET–CN scenario is the United States anticipated to come close to (although not quite meet) the country's targets for 2030. Meanwhile, the LCET–CN scenario *does* see a pathway for the United States to reach 'carbon neutrality' by 2050 – but only through a combination of both aggressive systemic transformation *and* leveraging bioenergy with carbon capture and storage, carbon sinks, and other tools to deliver 'negative emissions.' As suggested by Figure 17.12, even a relatively modest valuation of US efforts in this space is likely to deliver net-negative emissions by 2050. However, scaling up efforts here is not expected to act as a full- or partial-alternative to the more aggressive transformations of US energy systems that will need to be done.

[4] For more on this, see US Department of State and the United States Executive Office of the President (2021).

Figure 17.12. CO_2 Emissions Trends in BAU, AP, and LCET–CN Scenarios



AP = alternative policy, BAU = business as usual, CO_2 = carbon dioxide, LCET–CN = low-carbon energy transition–carbon neutral, Mt-C = million tonnes of carbon.
Source: Authors' calculations.

3.5. Hydrogen Demand

As of 2019, all three models register US final energy demand for hydrogen at 0 Mtoe. Over the outlook period, neither the BAU nor AP scenarios project any additional US demand for hydrogen. This is largely due to their assumptions that necessary market-creation steps – such as large-scale buildouts of enabling infrastructure and greater harmonisation of various industry standards – are unlikely to occur during this period absent additional, targeted policy support. Thus, even to the extent that hydrogen production costs could come down (another important consideration), the BAU and AP scenarios find wider conditions as continuing to limit hydrogen's competitiveness relative to other fuels and technologies.

The LCET–CN scenario, in contrast, examines what might be possible if some of these initial market conditions could be addressed through enhanced policy support (with key assumptions here including robust coordination amongst both US and international stakeholders, given aims to minimise market fragmentation). With such efforts in place, the LCET–CN scenario sees US demand for hydrogen as well-positioned to take off within the 2020s, reaching 11.03 Mtoe by 2030. Over the next decade, it then continues to increase at an AAGR of 18.9% – reaching 62.10 Mtoe in 2040 – before slowing to an AAGR of 5.6% between 2040 and 2050. The result is that the LCET–CN scenario sees US final energy demand for hydrogen as reaching 106.63 Mtoe in 2050.

Such demand for hydrogen in the LCET–CN scenario is underpinned by usage in multiple sectors. As suggested in Figure 17.11, hydrogen is expected to play a role in US power generation in 2050, albeit a relatively modest one – accounting for only 2% of the overall mix. Hydrogen is also anticipated to play a role in backing out demand for other fuels in both the transport and industry sectors. Ultimately, though, as of this writing in 2024 many US energy strategy documents continue to assume a wide range of potential futures around US final energy demand for hydrogen, given its complex relationship with other elements of net-zero planning. To that end, the US' *Pathways to Net-Zero Greenhouse Gas Emissions by 2050* notes that scenarios that utilise large volumes of hydrogen also see large increases in electricity use (US Department of State and US Executive Office of the President, 2021); something that would then have additional implications for infrastructure and capital investment requirements.

3.6. Energy Cost Comparisons between the BAU and LCET–CN Scenarios

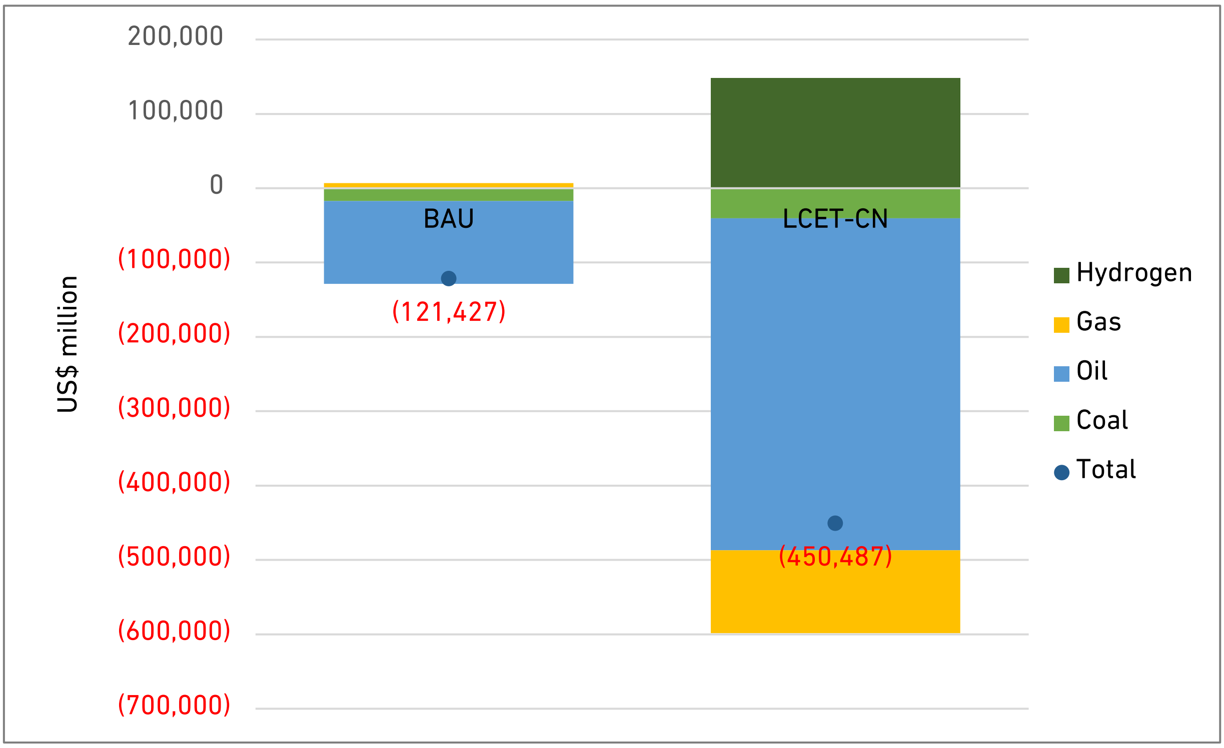
Fuel Costs

Given the scale of US demand for energy generally and for oil, natural gas, and coal specifically, current US spending on fuel is considerable. This study estimates that in 2019 alone, US fuel costs totalled US$803,128 million. Roughly 68% of these costs were connected to oil, whilst natural gas accounting for additional 27%. Meanwhile, coal accounted for roughly 5%.

All scenarios project that US fuel costs will decline over the outlook period – although do so with very different rates. Under BAU, an overall trend of declining oil and coal consumption combined with some modest growth in natural gas consumption supports a decline in fuel costs to US$681,701 million in 2050 (a savings of US$121,427 million, relative to 2019).

Under the LCET–CN scenario, US fuel costs in 2050 are expected to decline to US$253,964 million – US$450,487 million lower than in 2019 and an additional US$329,060 million in savings beyond BAU (Figure 17.13). This is primarily driven by the scenario's steep decline in oil consumption, followed by a (relatively) more modest decline in natural gas. Alongside this, although the LCET–CN scenario does envision that US spending on hydrogen will grow sharply over the outlook period, reaching $148,015 million a year in 2050. In contrast, US spending on hydrogen in 2050 under BAU is zero, given the absence of demand for this fuel in that scenario. Even so, US spending on hydrogen in 2050 under the LCET–CN scenario is equivalent to only 69% of US spending on natural gas in just 2019.

Figure 17.13. Fuel Costs Savings in 2050 in BAU vs. LCET–CN Scenarios

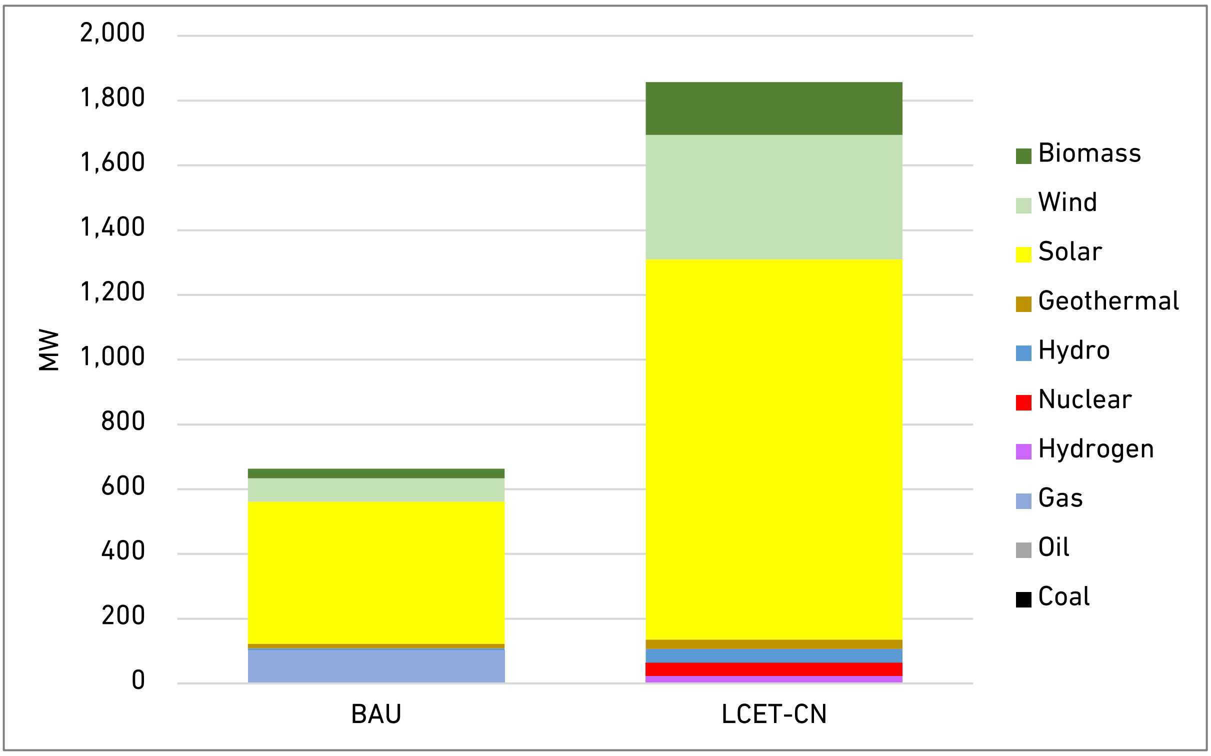


BAU = business as usual, LCET = low-carbon energy transition – carbon neutral.
Source: Authors' calculations.

Power Generation Investment

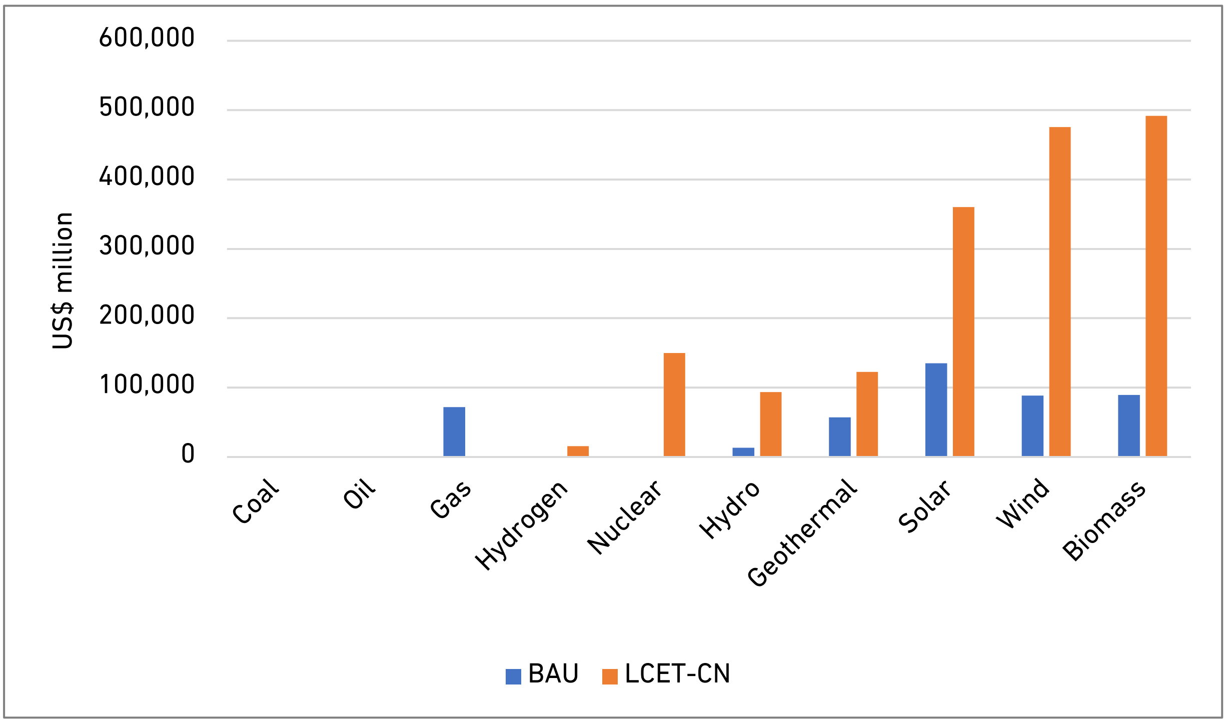
In contrast with the savings observed in fuel costs, US power plant construction costs are significantly higher under the LCET–CN scenario compared to the BAU scenario. Key to this picture is the significant additional power generation capacity requirements of the LCET–CN scenario (1,629,149 MW) vs BAU (662,810 MW). However, scenario variations in the kinds of new capacity coming online – as shown in Figure 17.14 – also contribute to further widening cost differences, given the relatively higher per KW construction costs of wind, nuclear, and biomass projects (which are relatively more prominent under the LCET–CN scenario) versus natural gas projects (which is more prominent under the BAU scenario). The net impact of these trends is that between 2019 and 2050, power plant construction costs are projected to be roughly US$1,709,809 million under the LCET–CN scenario versus US$455,455 million in BAU – or roughly 3.8 times higher under LCET–CN than under BAU (Figure 17.15).

Figure 17.14. Power Plant Capacity Additions under BAU vs. LCET–CN Scenarios



BAU = business as usual, LCET = low-carbon energy transition, MW = megawatt.
Source: Authors' calculations.

Figure 17.15. Power Plant Construction Investment under BAU vs. LCET–CN Scenarios

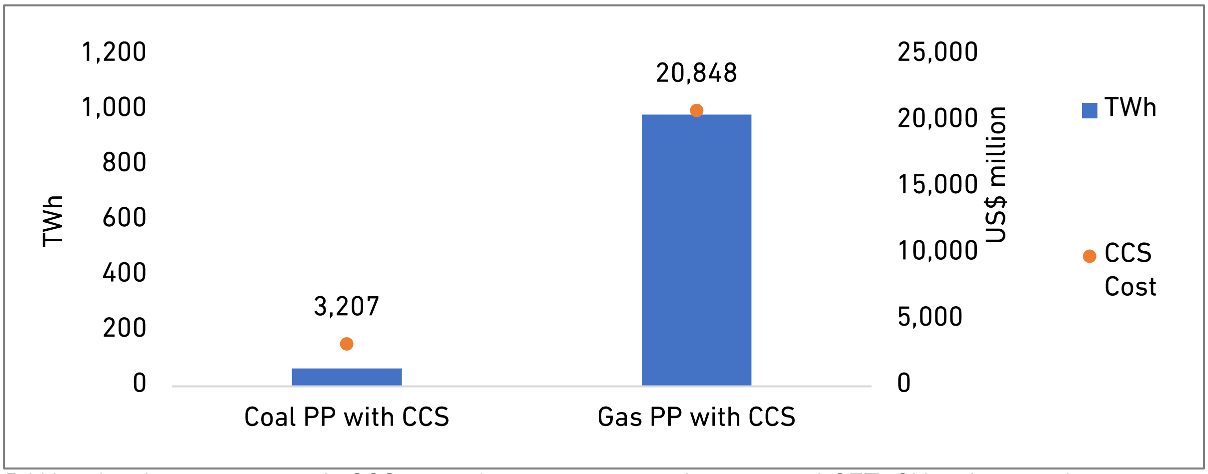


BAU = business as usual, LCET–CN = low-carbon energy transition – carbon neutral.
Source: Authors' calculations.

Carbon Capture and Storage Cost

Spending on CCS is also assumed to be higher under the LCET–CN scenario than BAU; unsurprising given the technology's prominence in the LCET–CN scenario and absence in BAU. As shown in Figure 17.16, the vast majority of these costs are associated with the substantial applications of CCS technologies in gas-fired power plants, with relevant costs in 2050 alone amounting to US$20,848 million. However, spending associated with the country's increasingly modest fleet of coal-fired power plants is also significant, at US$3,207 million in 2050.

Figure 17.16. CCS Costs under BAU vs. LCET–CN Scenarios in 2050



BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: Authors' calculations.

Overall Cost

Table 17.1 summarises the overall differences in costs between the BAU and LCET–CN scenarios in 2050. It suggests that, over time, the LCET–CN scenario's higher costs in terms of power plant construction requirements and spending on CCS are offset by significant savings on fuel costs; such that in 2050, the cost of the LCET–CN scenario is roughly 47.8% of that for BAU. That being said, it should be noted that over the outlook period, the LCET–CN scenario envisions a faster rate of growth in power capacity needs in the first half of the period and a faster rate of decline in fuel requirements during the second half of the outlook period. This is something that could undermine the narrative of LCET–CN's 'economic benefits' in individual years, given when new spending will be required verses when savings will be realised.

Table 17.1. Cost Comparison of BAU vs. LCET–CN Scenario

(US$ millions)

	BAU	LCET–CN
Fuel Costs in 2050	681,701	253,964
Power Plant Construction Costs (Average Annual Cost for 2019–2050)	14,692	55,155
CCS Costs in 2050	0	24,055
Total	696,393	333,174

BAU = business as usual, CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral.
Source: Authors' calculations.

4. Implications

- In both the LCET–CN and AP scenarios, zero-carbon sources are now anticipated to account for most of the US electricity generation mix by 2050, and under the LCET–CN scenario, variable renewable energy sources alone are expected to represent more than 50% of the total mix. Yet to sustain such switching, greater attention to bolstering enabling infrastructure as well as advancing new breakthroughs in storage technologies will be crucial.
- Continued efforts to strengthen the transport sector are envisioning as a critical opportunity for energy saving under all scenarios. In addition to accelerated deployment of electric vehicles, greater attention to fuel efficiency and technologies for overall cleaner consumption will be critical. Hydrogen, too, has a potentially prominent role to play.
- Even amidst the changes above, oil and natural gas are anticipated to represent a sizeable share of the United States' energy mix in both the BAU and AP scenarios and are still relatively prominent under the LCET–CN scenario. To get to 'net-zero' by 2050, finding ways to radically decarbonise the consumption of these fuels is thus an important imperative alongside switching to renewable and other alternative energy sources. In turn, leading on these efforts could also bolster the long-term competitiveness of US fossil fuel exports as a means of how Asia might advance its own energy and environmental security goals.
- Pursuing a 'carbon neutral' energy mix is likely to dramatically reduce US expenditures on fuel – especially, but not only, on oil. However, it will also require substantial new investment in power plant infrastructure and, at least in some individual years in the outlook period, is expected to have higher associated costs

than BAU. Whilst this study finds the LCET–CN scenario ultimately producing strong environmental and economic benefits for the US, clear communication and ongoing engagement with key stakeholders and the public will be essential to sustaining support for what, at times, is expected to be a challenging transformation. Alongside this, continued US–Asia dialogue can also play an important role in helping to support these efforts and share lessons learned.

References

Gillispie, G. (2022), 'Low-carbon Green Recovery from the Pandemic in the United States'. In V. Anbumozhi, K. Kalirajan, and X. Yao (eds.), *Assessing the Impacts of COVID-19: Regional Policies and Practices for Green Recovery*. Jakarta: ERIA, pp.229–51. https://www.eria.org/uploads/media/Books/2022-Assessinng-theImpact-of-COVID-19-for-Green-Recovery/16_Chapter-12_United-States.pdf (accessed 7 February 2024).

United States (US) Census Bureau (n.d.), 'US and World Population Clock'. https://www.census.gov/popclock (accessed 7 February 2024).

US Department of State and the United States Executive Office of the President (2021), *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*. Washington, DC: United States Department of State and the United States Executive Office of the President. https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf (accessed 7 February 2024).

US Energy Information Administration (US EIA) (2022a), 'Monthly Energy Review – September 22', https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf accessed 7 February 2024).

_____ (2022b), 'New Renewable Power Plants are Reducing US Electricity Generation from Natural Gas', https://www.eia.gov/todayinenergy/detail.php?id=50918 (accessed 7 February 2024).

_____ (2022c), 'Record Numbers of Solar Panels were Shipped in the United States during 2021', https://www.eia.gov/todayinenergy/detail.php?id=53679 (accessed 7 February 2024).

_____ (2022d), 'Solar Power will Account for Nearly Half of New US Electric Generating Capacity in 2022', https://www.eia.gov/todayinenergy/detail.php?id=50818 (accessed 7 February 2024).

_____ (2022e), 'US Natural Gas Exports and Re-Exports by Country', US Energy Information Administration, Washington, DC. https://www.eia.gov/dnav/ng/ng_move_expc_s1_a.htm (accessed 7 February 2024).

_____ (2022f), 'Coal Explained: Coal Imports and Exports. Washington, DC: EIA. https://www.eia.gov/energyexplained/coal/imports-and-exports.php (accessed 7 February 2024).

World Bank (2024a), 'Urban Population (% of total population) - United States,' https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=US (accessed 7 February 2024).

______ (2024b), 'United States,' https://data.worldbank.org/country/united-states (accessed 7 February 2024).

______ (2024c), 'GNI per capita, PPP (current international $) - United States,' https://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD?locations=US (accessed 7 February 2024).

______ (2024d), 'Services, Value Added (% of GDP) – United States,' https://data.worldbank.org/indicator/NV.SRV.TOTL.ZS?locations=US (accessed 7 February 2024).

______ (2024e), 'Industry (including construction), Value Added (% of GDP) - United States,' https://data.worldbank.org/indicator/NV.IND.TOTL.ZS?locations=US (accessed 7 February 2024).

______ (2024f), 'Agriculture, Forestry, and Fishing, Value Added (% of GDP),' https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=US (accessed 7 February 2024).

______ (2024g), 'Trade (% of GDP),' https://data.worldbank.org/indicator/NE.TRD.GNFS.ZS?locations=US (accessed 7 February 2024).