Chapter 1
Australia Country Report

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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.

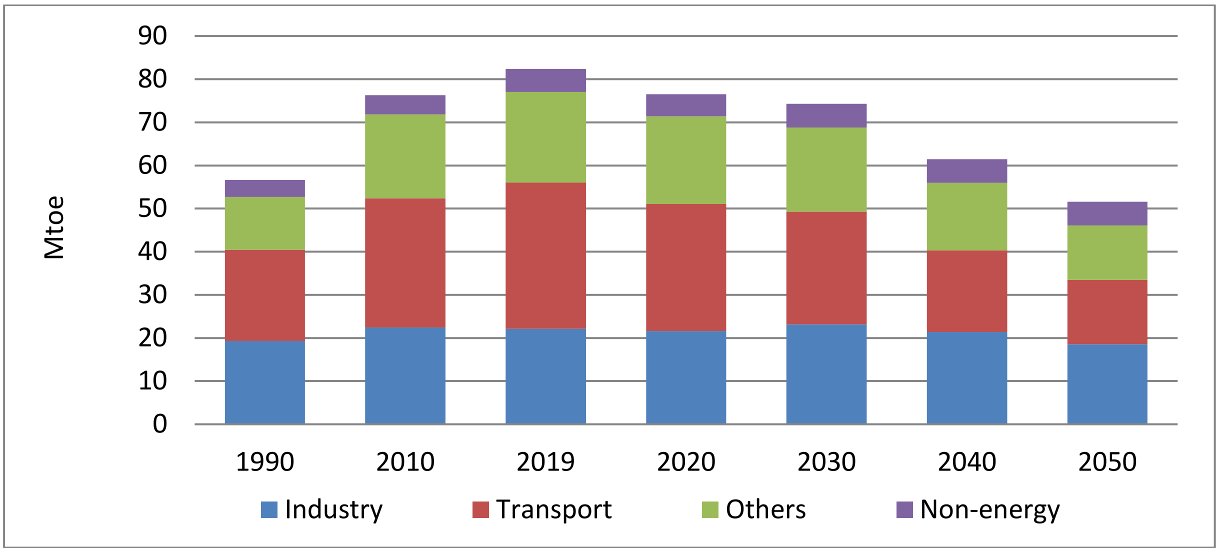
Achieving the LCET–CN scenario requires major structural changes of energy systems. However, mapping a single pathway for net-zero targets involves a high level of uncertainty.

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

2.1. Final Energy Consumption

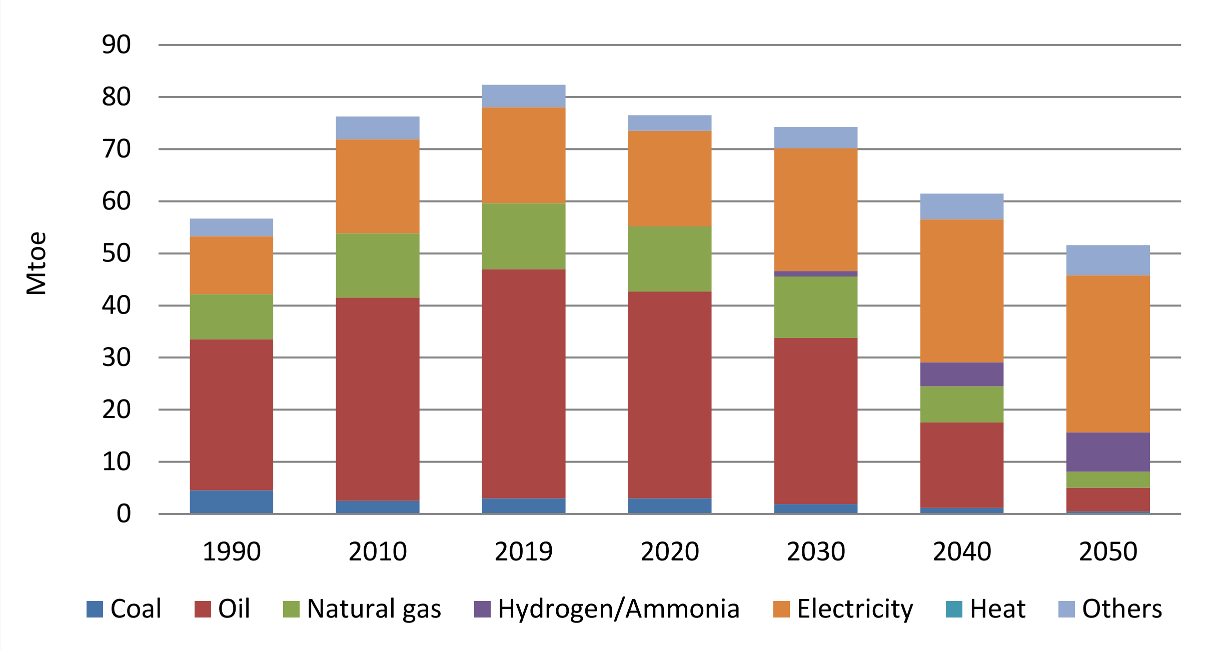
In the LCET–CN scenario, total final energy consumption will decrease from 82.3 million tonnes of oil equivalent (Mtoe) in 2019 to 51.6 Mtoe in 2050, or by about 37.4% or an average of 1.5% per year. Energy consumption in the transport sector will decline strongly (55.9%) because of efficiency improvements 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)



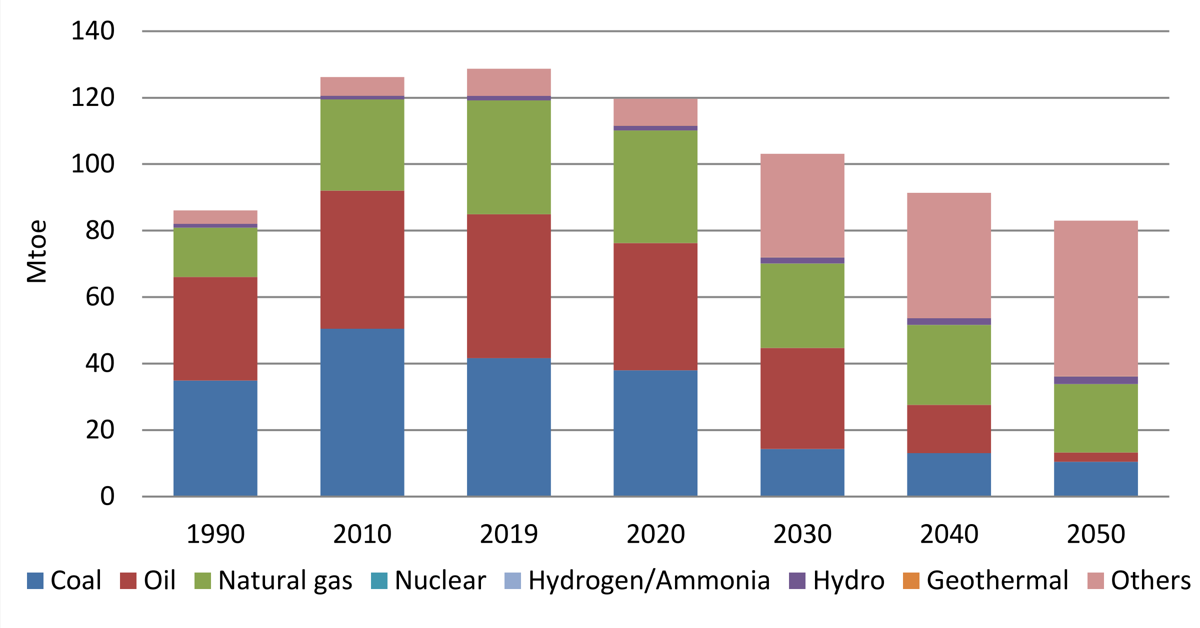
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Authors.

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)

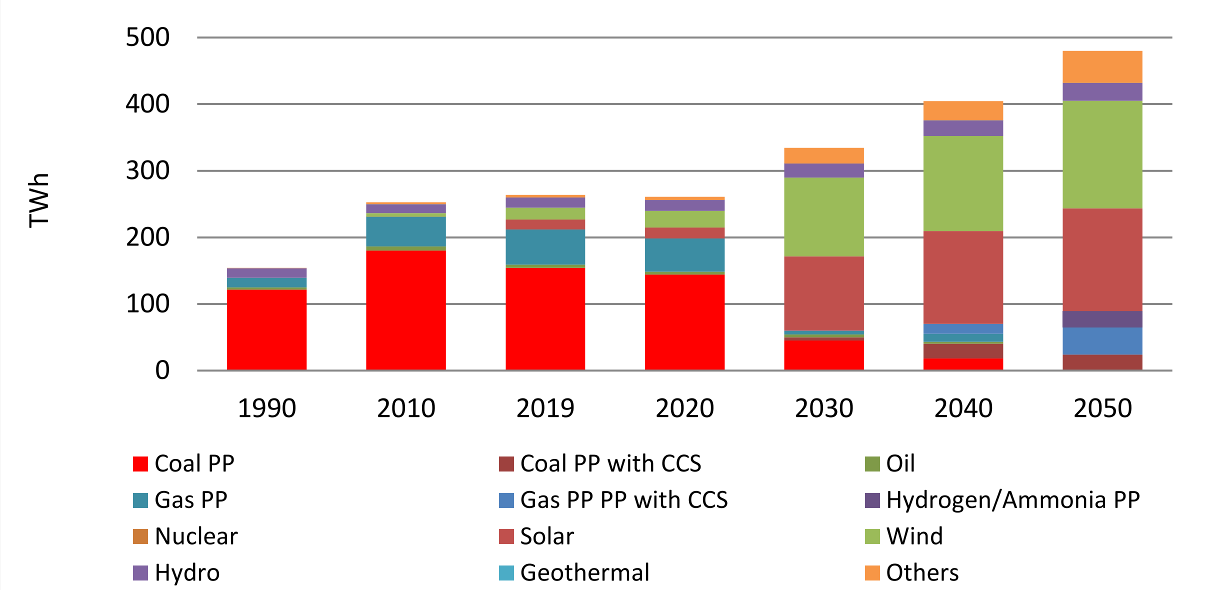


LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Authors.

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.

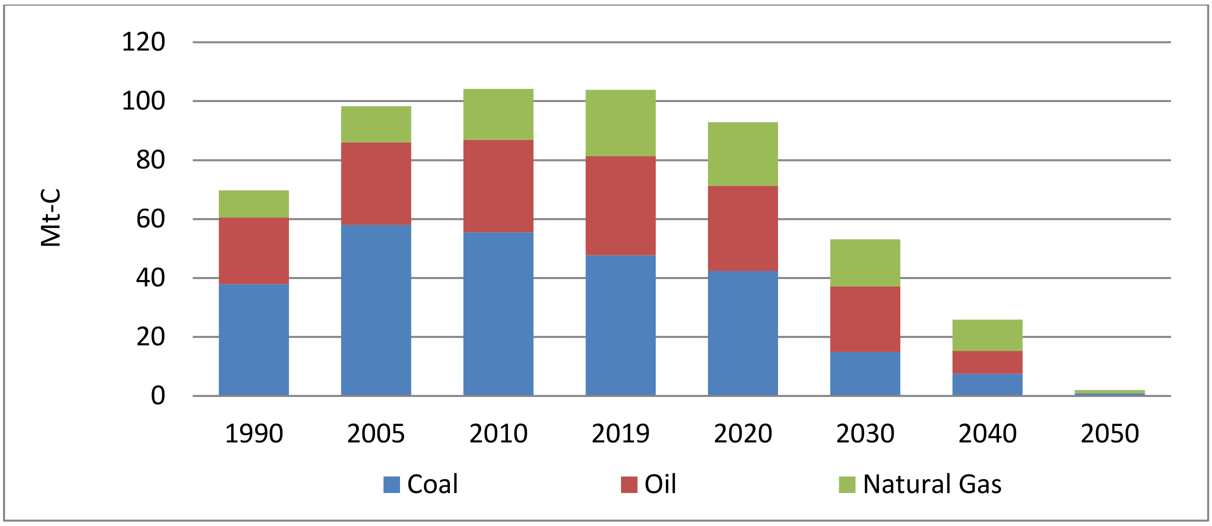
2.4. Carbon Dioxide Emissions

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.

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