Chapter 14

Singapore Country Report

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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.

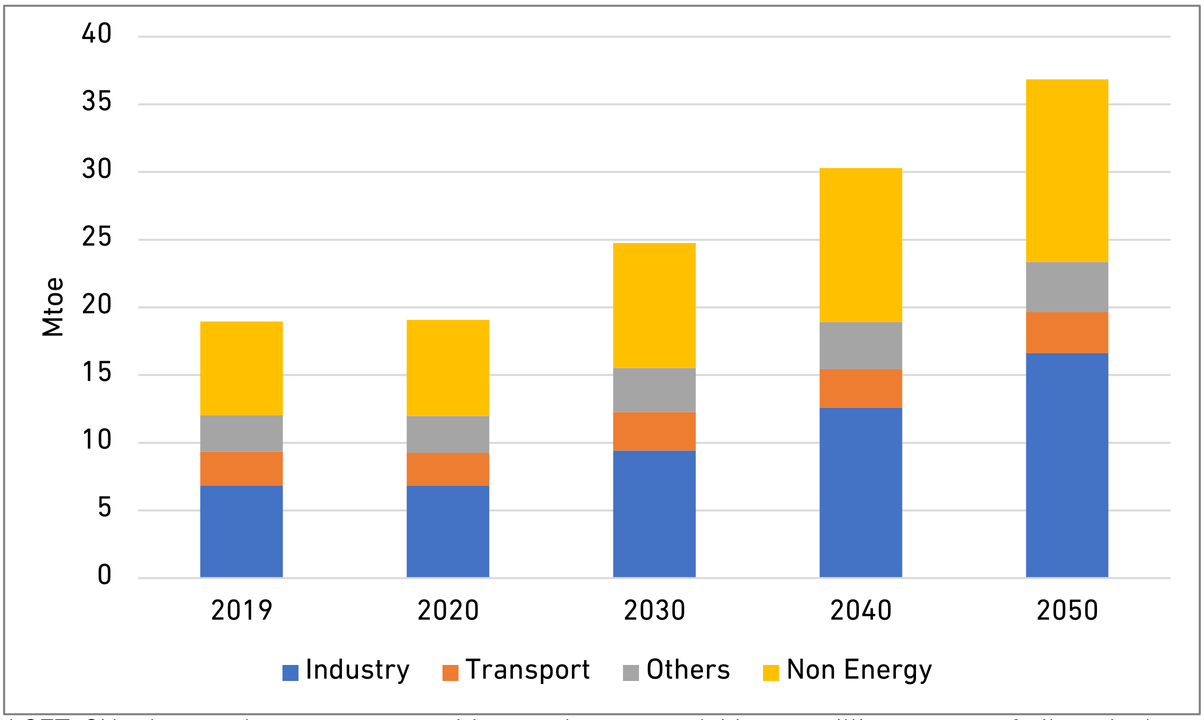
To achieve the NDC and net-zero emissions targets, Singapore has committed to accelerate the low-carbon transition for industry, economy, and society through various measures, including regional power grids, solar energy, emerging low-carbon technologies (i.e. carbon capture and storage [CCS], and hydrogen), 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.

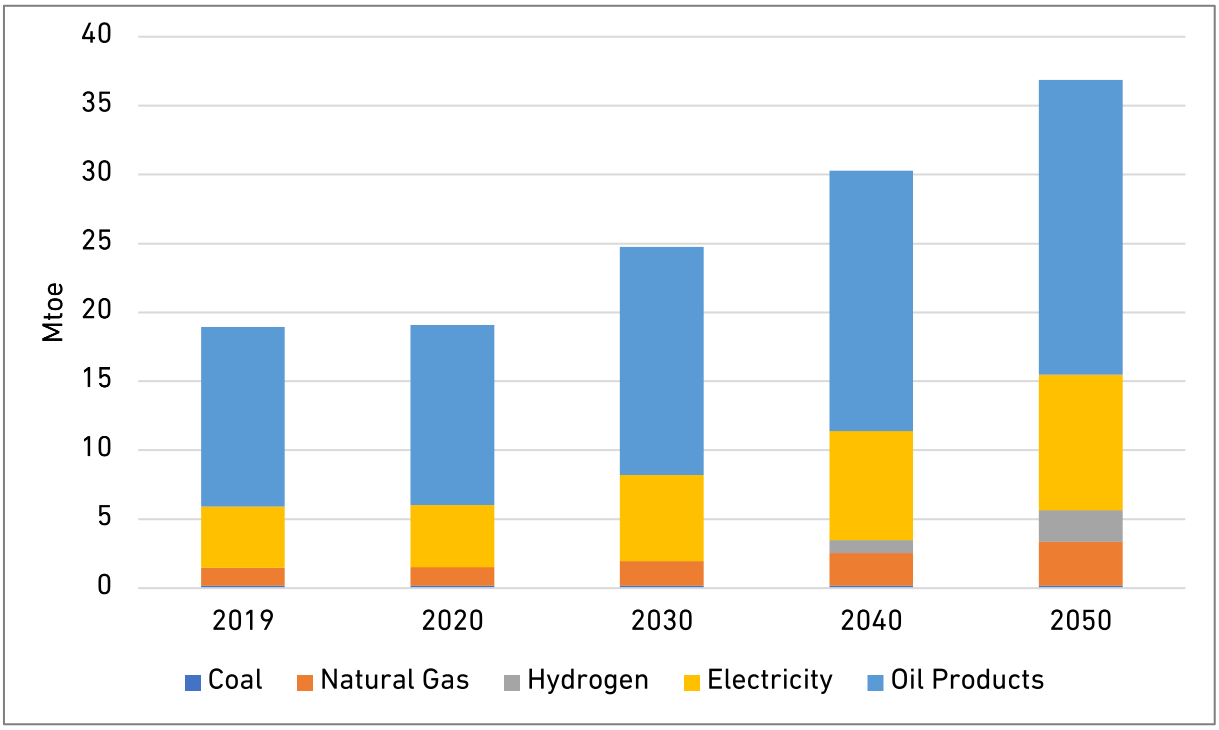
Figure 14.1. Final Energy Consumption by Sector, LCET–CN Scenario (2019–2050)



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)



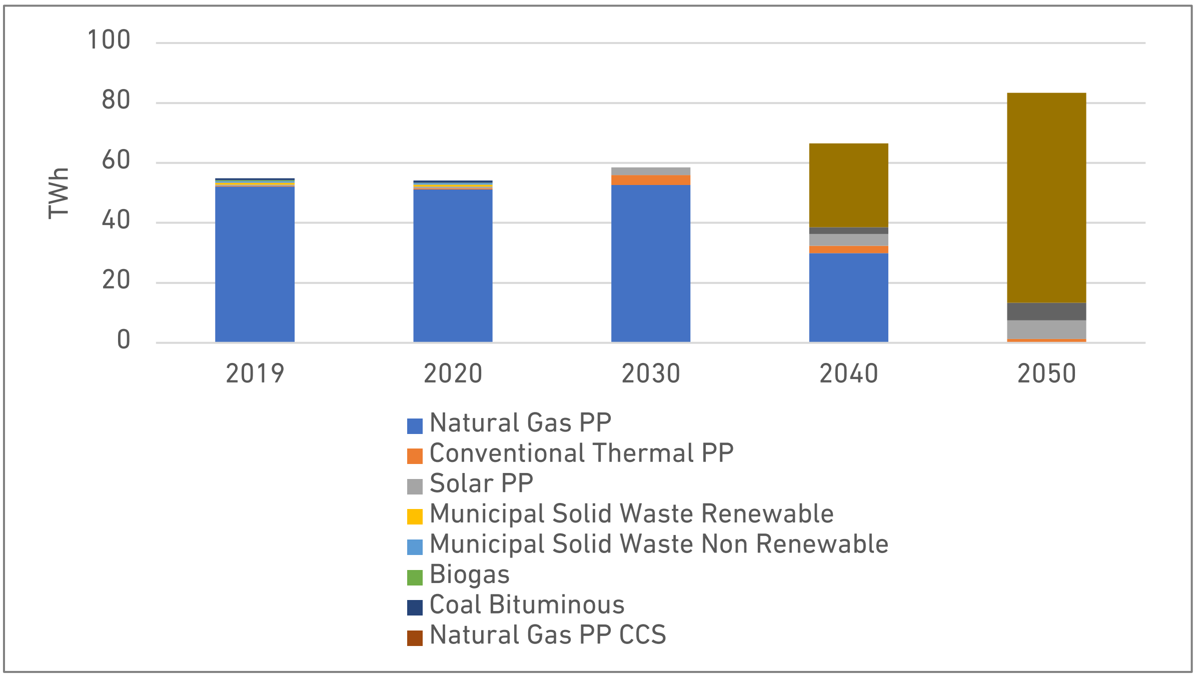
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

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)

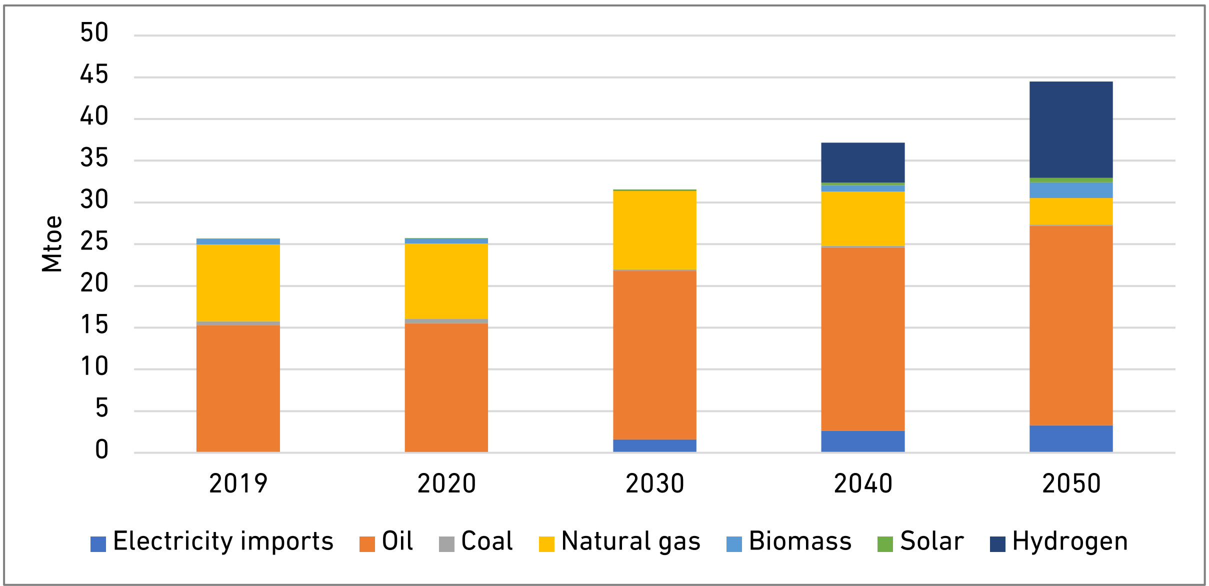


CCS = carbon capture and storage, LCET–CN = low-carbon energy transition–carbon neutral, PP = power plant, TWh = terawatt-hour.
Source: Author's calculations.

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)



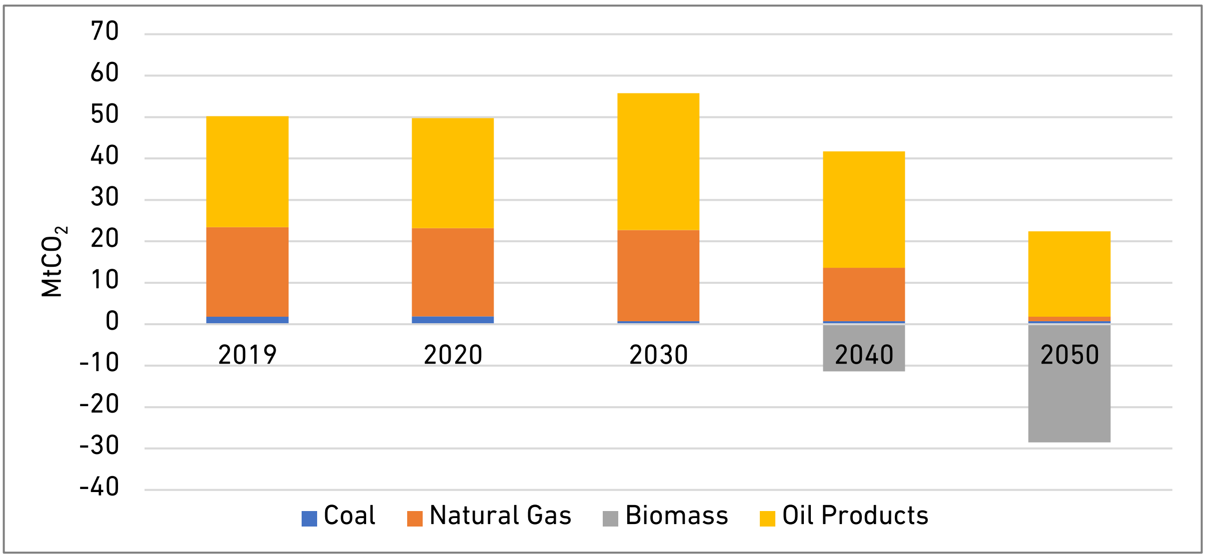
LCET–CN = low-carbon energy transition–carbon neutral, Mtoe = million tonnes of oil equivalent.
Source: Author's calculations.

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

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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