Chapter 3

Result for ASEAN

July 2022

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Chapter 3
Results for ASEAN

1. Results for CN2050/2060

CN2050/2060 reflects nationally declared carbon-neutral target years and considers carbon sinks in Indonesia, Malaysia, Myanmar, Thailand, and Viet Nam based on discussions with each country.

Table 3.1. Target Year and Assumptions of Carbon Sink in CN2050/2060

Country	CN Target Year	Energy-related CO_2 Emission Reduction Target from 2017	Note
Brunei Darussalam	2050	100%	・ Target year: No CN target. Set to 2050, considering income level ・ Sink: Not considered
Cambodia	2050	100%	・ Target year: 2050 CN declaration (CAA member country) ・ Sink: Not considered
Indonesia	2060	50%	・ Target year: 2060 CN declaration ・ Sink: 2050 value of the LCCP scenario in the LTS. Although original target is calculated to be 39%, set to 50% as the minimum requirement
Lao PDR	2050	100%	・ Target year: 2050 CN declaration (CAA member country)

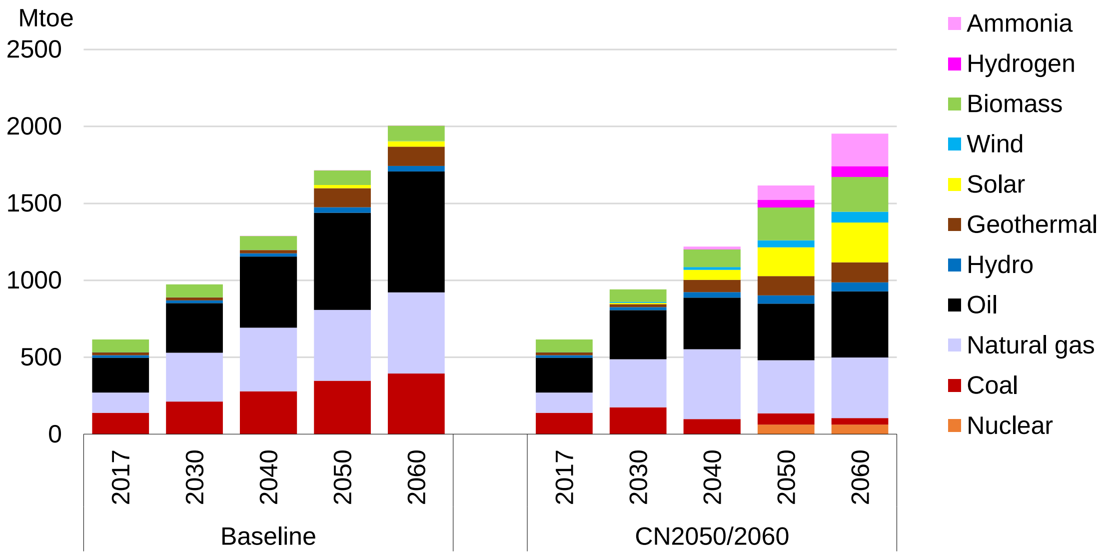
			• Sink: Not considered
Malaysia	2050	50%	• Target year: Referred to 2050 CN by Prime Minister • Sink: 2016 value of the inventory. Although original target is calculated to be -14%, set to 50% as the minimum requirement
Myanmar	2060	60%	• Target year: 2060 CN (requested by Myanmar) • Sink: 2030 target of the unconditional NDC
Philippines	2060	100%	• Target year: No CN target. Set to 2060 • Sink: Not considered
Singapore	2050	100%	• Target year: No CN target. Set to 2050, considering income level • Sink: Not considered
Thailand	2050	50%	• Target year: 2050 CN (requested by Thailand) • Sink: Use values provided by Thailand
Viet Nam	2050	70%	• Target year: 2050 CN declaration • Sink: 2030 target of the unconditional NDC

CAA = climate ambition alliance, CN = carbon neutral, LTS = long-term strategy, LCCP = low-carbon scenario compatible with Paris Agreement target, NDC = nationally determined contribution.
Source: Author.

1.1. Primary Energy Supply

Figure shows the primary energy supply in Baseline and CN2050/2060. Primary energy supply in 2060 substantially increases to about 3.3 times the 2017 level in Baseline, and to about 3.2 times in CN2050/2060. In Baseline, primary energy supply from fossil fuels such as coal, natural gas, and oil continues to increase in 2060. However, promoting decarbonisation towards carbon neutrality requires a broad range of technologies, such as renewable energy, nuclear, CCS, and H_2 and NH_3 imports. In CN2050/2060, the share of these technologies goes up to 51% of primary energy supply in 2050 and 56% in 2060.

Figure 3.1. Primary Energy Supply in ASEAN (CN2050/2060)

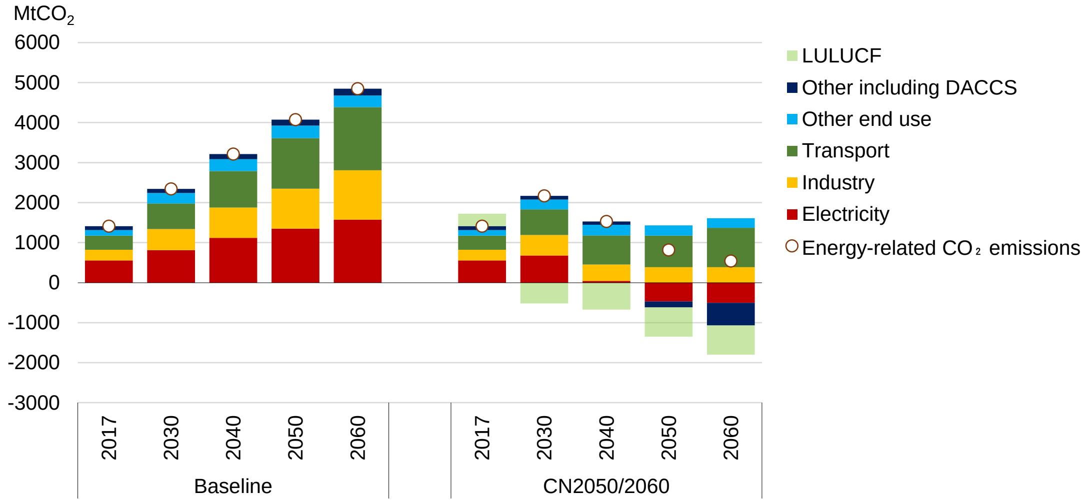


Mtoe = million tonnes of oil equivalent.
Source: Author.

1.2. Sector Carbon Dioxide Emissions

Figure 3.2 illustrates sector CO_2 emissions in Baseline and CN2050/2060. In Baseline, CO_2 emissions increase mainly in electricity and transport with the growth of final energy consumption. In CN2050/2060, CO_2 emissions from transport, particularly buses and trucks, remain whilst the power sector is fully decarbonised by 2050 because the costs of alternative vehicles, specifically battery electric vehicles and fuel cell vehicles, are high. End-use CO_2 emissions are offset through not only decarbonisation of power but also a combination of negative-emission technologies such as BECCS and DACCS. Integrating negative-emission technologies with end-use emission reduction is estimated to be a cost-effective strategy to achieve carbon neutrality.

Figure 3.2. Sector Energy-related Carbon Dioxide Emissions in ASEAN (CN2050/2060)

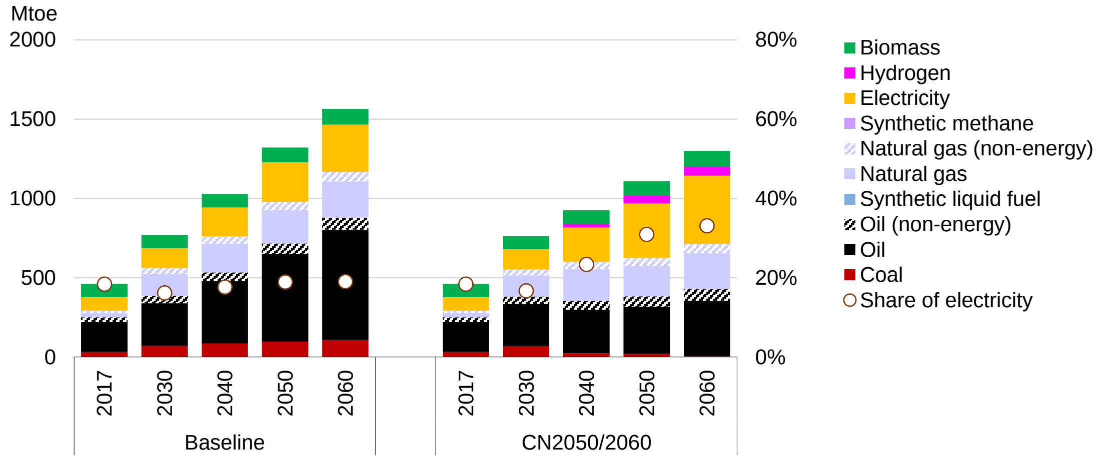


CO_2 = carbon dioxide; DACCS = direct air capture with carbon storage; LULUCF = land use, land-use change, and forestry; $MtCO_2$ = million tonnes of carbon dioxide.
Source: Author.

1.3. Final Energy Consumption

Figure 3.3 shows final energy consumption in Baseline and CN2050/2060. In CN2050/2060, final energy consumption in 2060 decreases by 17% compared with Baseline. In CN2050/2060, the share of electricity increases to 33% by 2060. The changes suggest that advancing energy efficiency and electrification is a core strategy to decarbonise end-use sectors.

Figure 3.3. Final Energy Consumption in ASEAN (CN2050/2060)

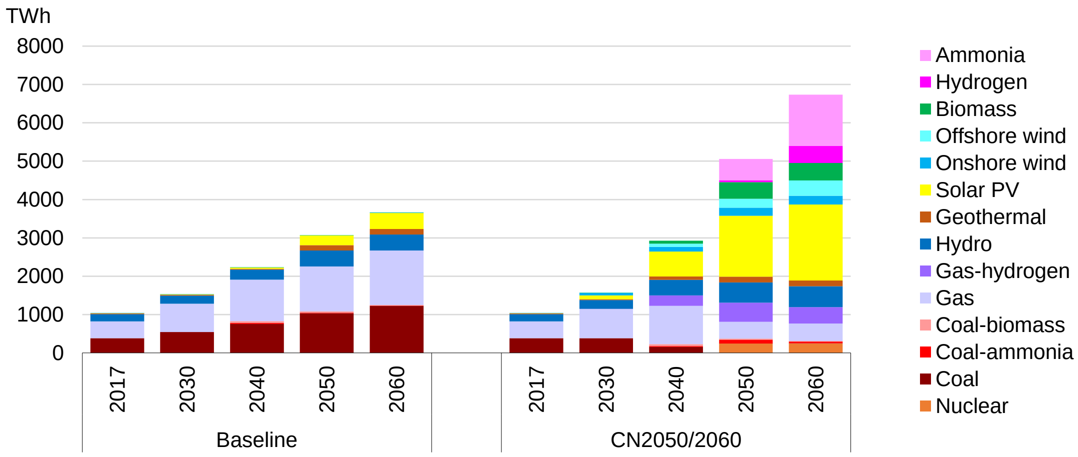


Mtoe = million tonnes of oil equivalent.
Source: Author.

1.4. Power Generation

Figure 3.4 describes the power generation in Baseline and CN2050/2060. In Baseline, coal-fired power generation and natural gas-fired power generation account for most of the electricity mix even in 2060. In CN2050/2060, renewable energy is a major power source, accounting for 56% in 2060. H_2- and NH_3-fired power generation follow renewables, accounting for 26%. The share of solar PV power generation is 53% of electricity generation from renewables.

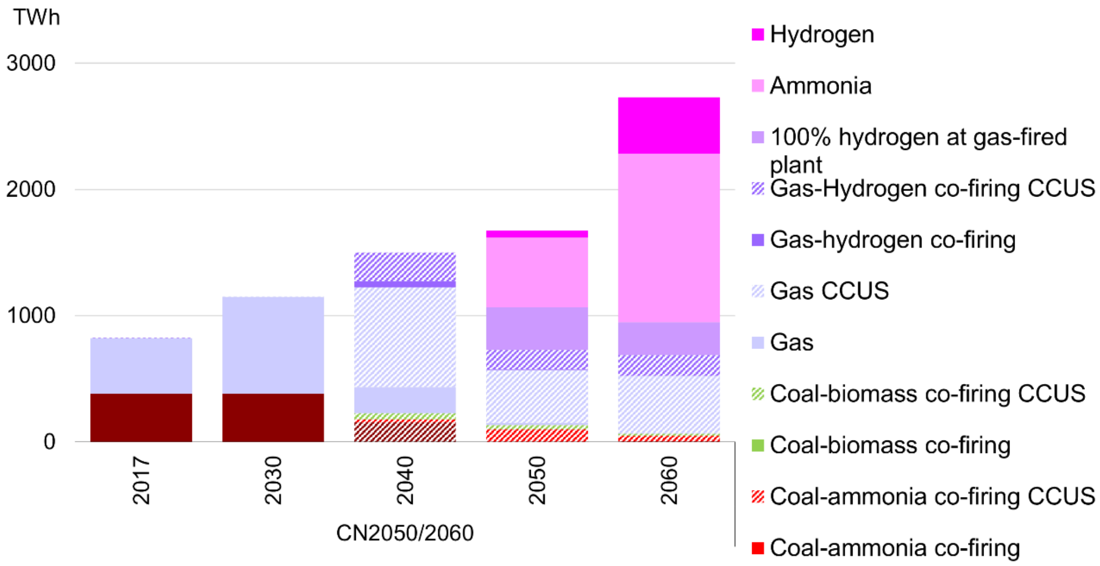
Figure 3.4. Power Generation in ASEAN (CN2050/2060)



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

Figure 3.4 shows that H_2 and NH_3, including co-firing, play roles in the electricity mix in CN2050/2060. Figure 3.5 shows the transition of thermal power generation (coal, natural gas, NH_3, H_2) in total electricity generation. In the near term, for example, up to 2030, highly efficient gas-fired power generation is estimated to contribute to curbing CO_2 emissions from power generation. In the medium to long term, gas-fired power generation with CO_2 capture, utilisation, and storage (CCUS), co-firing with NH_3 or H_2, and 100% NH_3- or H_2-fired power generation are the candidates. From 2040 to 2050, co-firing at existing coal- and gas-fired power stations, gas-fired power generation with CCUS, and 100% NH_3-fired power generation are expected to be pursued, and a major share of thermal power generation shifts to 100% NH_3-fired power generation by 2060.

Figure 3.5. Generated Electricity from Coal, Gas, Ammonia, and Hydrogen in ASEAN (CN2050/2060)

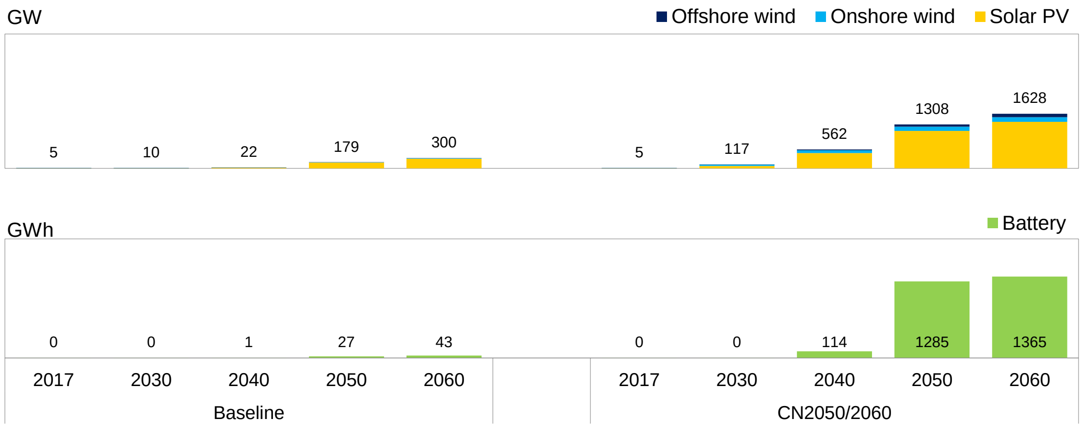


CCUS = carbon dioxide capture, utilisation, and storage; TWh = terawatt-hour.
Source: Author.

1.5. Variable Renewable Energy and Battery

In CN2050/2060, variable renewable energy (VRE), such as solar PV and wind power generation, is expected to be deployed. Installed capacity of solar PV power generation is estimated to account for a large share, and that of all VRE reaches about 1,628 GW by 2060 (Figure 3.6). The cost of batteries and VRE significantly decreases and the mass deployment of VRE is expected to accelerate after 2040 (Figure 2.5, Figure 2.6). The study considers sodium-sulphur, lithium-ion, and redox flow batteries as storage technologies.

Figure 3.6. Variable Renewable Energy and Battery Capacity in ASEAN (CN2050/2060)

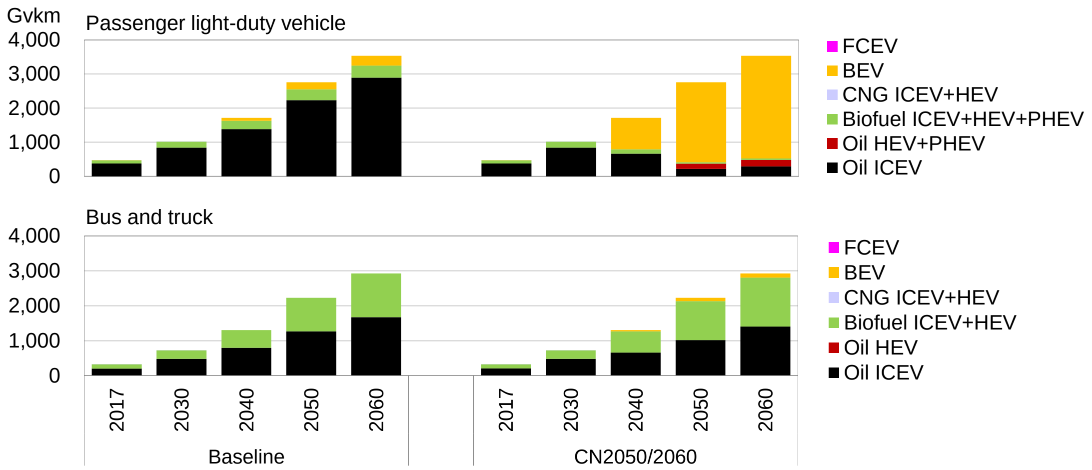


GW = gigawatt, GWh = gigawatt-hour, PV = photovoltaic.
Source: Author.

1.6. Road Transport

Transport contributes greatly to the growth of final energy consumption in Baseline. Figure 3.7 shows travel distance of passenger light-duty vehicles in the upper graph and that of buses and trucks in the lower graph and demonstrates that the use of oil persists in short- and long-distance transport in Baseline. By contrast, a major share of passenger vehicles are electrified by 2050 in CN2050/2060. However, long-distance alternative vehicle technologies, such as battery electric vehicles and fuel cell vehicles, are expensive and, therefore, oil consumption is expected to remain until 2060. The use of biofuels in internal combustion engines and hybrid vehicles is expected to expand.

Figure 3.7. Travel Distance by Vehicle Technology in ASEAN (CN2050/2060)

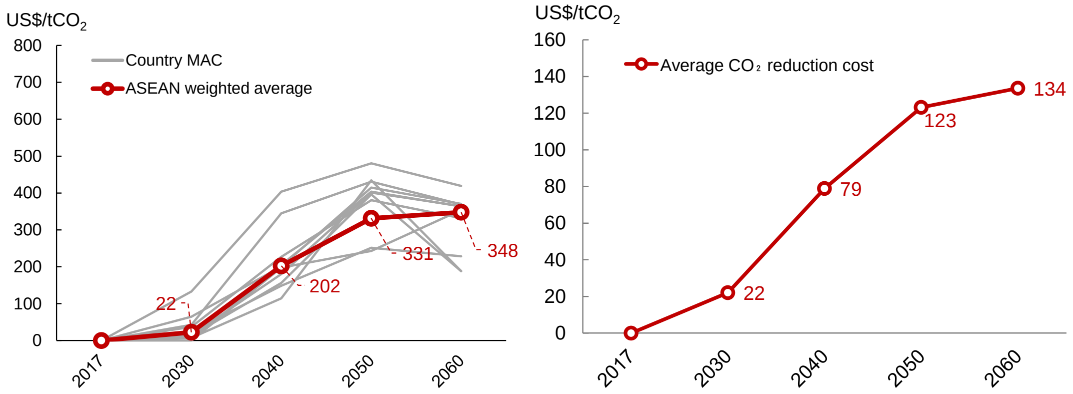


BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, Gvkm = 10^9 vehicle-km, PHEV = plug-in hybrid electric vehicle.
Note: Biofuel includes bioethanol and biodiesel mixed with petroleum fuel.
Source: Author.

1.7. Costs for Reducing Carbon Dioxide and Energy Prices

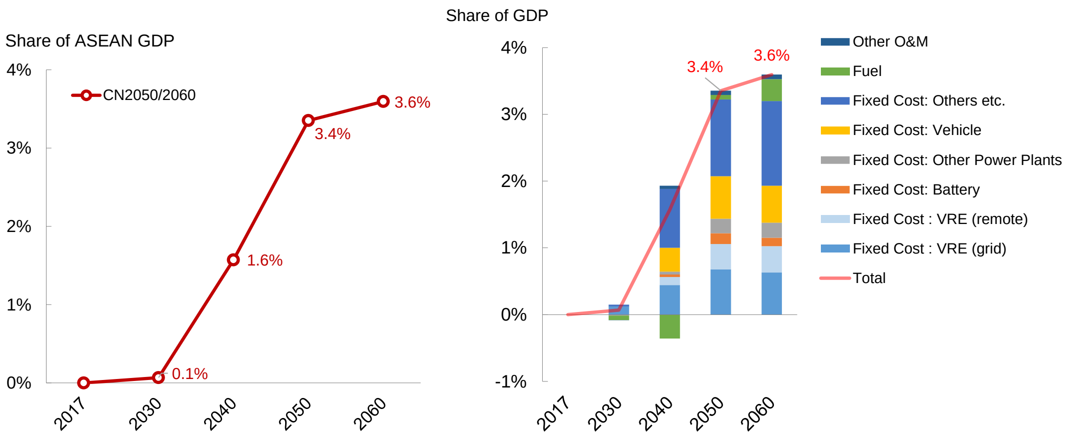
The marginal CO_2 abatement cost (MAC) is the cost required for the entire energy system to reduce marginally 1 ton of CO_2, as yielded by the model simulation (see Enkvist et al. [2007]). Figure 3.8 illustrates the weighted average of MAC in ASEAN. In CN2050/2060, the MAC rises to US$348/t$CO_2$ in 2060, implying an economic challenge to decarbonisation. In CN2050/2060, the MAC increases only slightly during 2050 and 2060 because CO_2 emissions constraints are moderate. The additional annual cost in CN2050/2060 compared with Baseline is estimated at about 3.6% (US$0.58 trillion) of ASEAN’s gross domestic product (GDP) in 2060.

Figure 3.8. Marginal Carbon Dioxide Abatement Cost (Left), Average Carbon Dioxide Reduction Cost (Right) (CN2050/2060)



CO_2 = carbon dioxide, MAC = marginal CO_2 abatement cost, tCO_2 = tonne of carbon dioxide.
Source: Author.

Figure 3.9. Additional Annual Cost (Left), Composition of Additional Annual Cost (Right) (CN2050/2060)

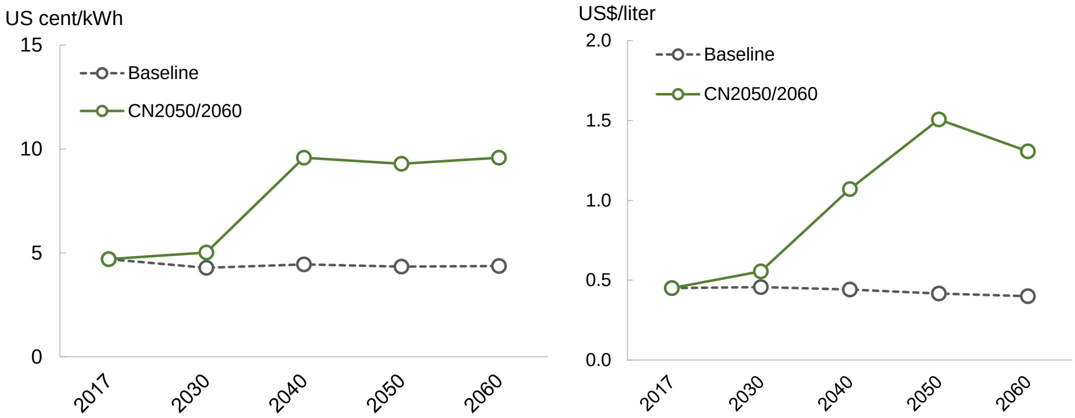


GDP = gross domestic product, O&M = operation and maintenance, VRE = variable renewable energy.
Source: Author.

The costs presented here do not include costs to enhance emission reductions in the land use, land-use change, and forestry (LULUCF) sector, such as afforestation. The Intergovernmental Panel on Climate Change (2018) estimates the cost of afforestation and reforestation at US$5–US$50/tCO_2. In addition to the cost assessment and setting of certain assumptions for baseline LULUCF sector emissions,[4] additional annual costs are estimated at 0.2%–0.7% of ASEAN GDP in 2030 and 0.1%–0.3% in 2060. However, the marginal abatement costs of LULUCF and setting of the baseline are subject to large uncertainties.

Electricity and diesel prices are estimated to rise two- to four-fold in CN2050/2060. Whilst the rise of energy prices is considered inevitable to achieve carbon neutrality, policymakers must minimise the economic impact of decarbonisation on end users. The diesel end-use price increases because a carbon price is imposed in the future.

Figure 3.10. Electricity Price (Left), Diesel End-use Price (Right) (CN2050/2060)



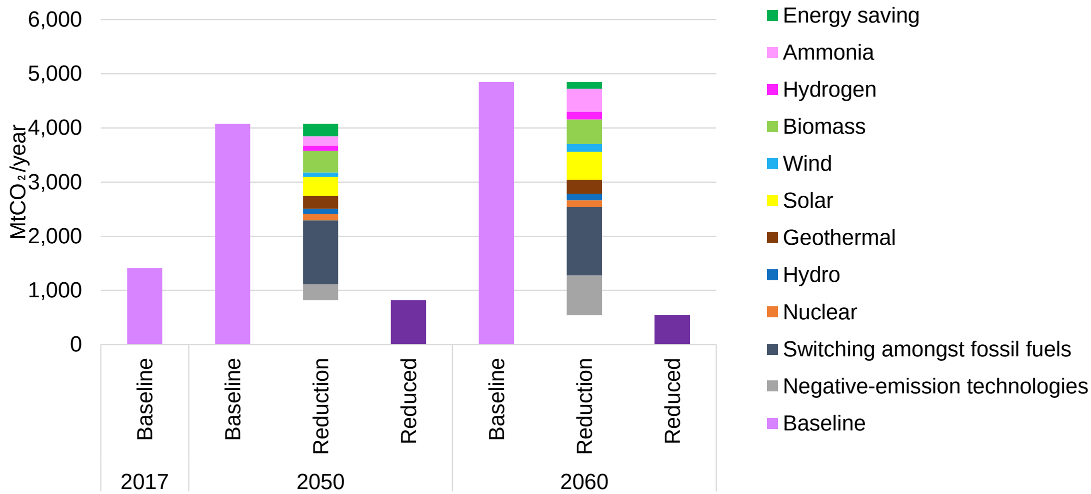
kWh = kilowatt-hour.
Source: Author.

1.8. Contribution of Mitigation Measures

Figure 3.11 shows the contributions of technologies to reducing energy-related CO_2 emissions in CN2050/2060. Carbon neutrality cannot be achieved solely by VRE but by combinations of reduction technologies. In addition to energy efficiency, imported H_2 and NH_3, and negative-emission technologies, switching amongst fossil fuels can play important roles in the ASEAN region.

[4] The MAC was set at US$25 and US$50 per ton-CO_2. Baseline emissions in the LULUCF sector were assumed to remain unchanged. However, since Indonesia's current emissions are positive, a case with a linear decrease towards zero in 2050 was also considered.

Figure 3.11. Contribution of Mitigation Measures (CN2050/2060)



$MtCO_2$ = million tonnes of carbon dioxide.
Source: Author.

1.9. Sensitivity Analysis 1: Technological Innovation

In the first sensitivity analysis, five cases of technological innovation were set to analyse the impact of the innovation on energy mix and mitigation costs (MAC and additional annual cost). 3.2 shows the assumptions of the cases.

Table 3.2. Key Technology Assumptions for Technological Innovation Cases

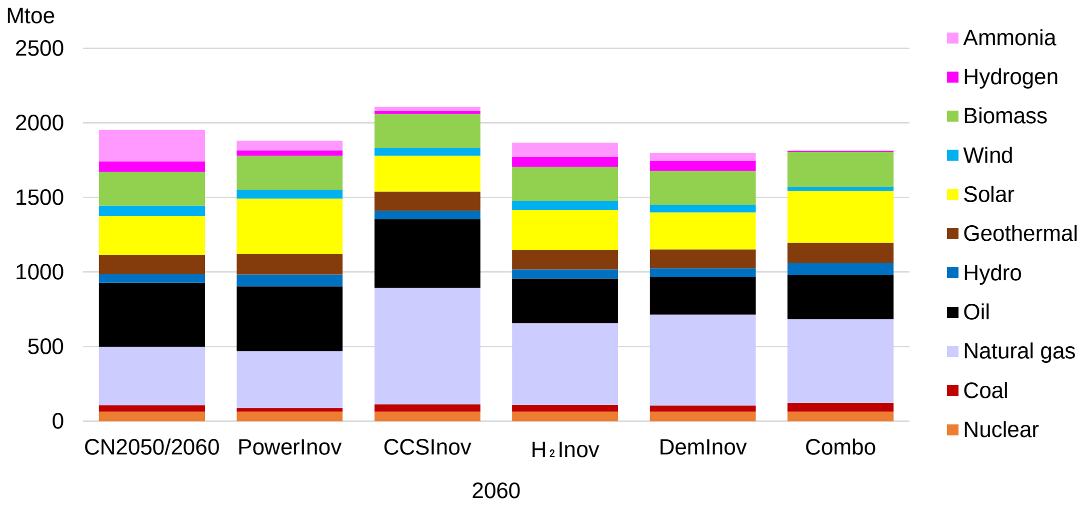
Case	Net-zero Year	Key Technology Assumptions
CN2050/2060	2060	Reference technology cost International power grid extension constrained by planned ASEAN power grid capacity CO_2 storage up to 1.6 $GtCO_2$/year in 2060
PowerInov	2060	Cost reduction of lithium-ion battery (-25% in 2040 and -50% after 2050, from the reference level) and international grid extension No upper limit for international power grid extension Large-scale electricity exports from Myanmar to Thailand

CCSInov	2060	Cost reduction of direct air capture (-25% in 2040 and -50% after 2050) CO_2 storage up to 2.7 $GtCO_2$/year in 2060
H_2Inov	2060	Cost reduction of coal gasification and methane reforming (-25% in 2040 and -50% after 2050), electrolyser (-22% in 2040 and 2050, -35% in 2060) Cost reduction of H_2 consumption: H_2 based DRI-EAF and fuel cell ship (-25% in 2040 and -50% after 2050), FCEV (comparable to hybrid electric vehicle price in 2060)
DemInov	2060	Cost reduction of advanced end-use technologies (-50% in and after 2040)
Combo	2060	Combined the assumptions of four innovation cases mentioned above

CO_2 = carbon dioxide, DRI-EAF = direct reduced iron–electric arc furnace, FCEV = fuel cell electric vehicle, $GtCO_2$ = gigatonnes of carbon dioxide, H_2 = hydrogen.
Source: Author.

Figure 3.12 shows the primary energy supply for each case in 2060. The overall energy mix seems not to differ significantly from case to case. In CCSInov, more natural gas and oil supplies remain than in other cases in 2060 because of large CO_2 storage capacity and large negative-emission potential (e.g. DACCS).

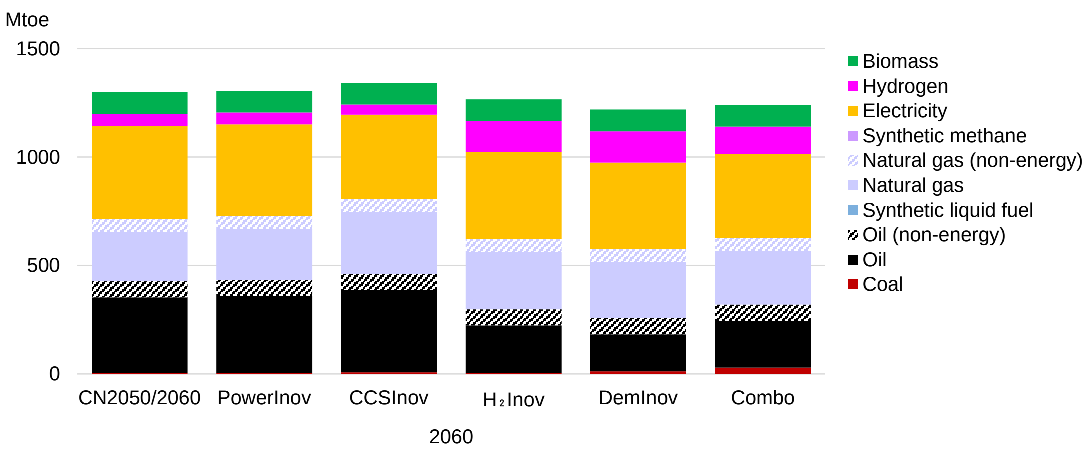
Figure 3.12. Primary Energy Supply in 2060 (Sensitivity Analysis 1)



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

Figure 3.13 shows final energy consumption for each case in 2060. In CCSInov, more fossil fuel consumption, such as oil and natural gas, remains than in other cases. In H2Inov and DemInov, fossil fuel and electricity consumption decrease due to growth of H_2 consumption. The increase in H_2 consumption in H2Inov and DemInov is caused mainly by demand for fuel cell buses and trucks. In both cases, 40%–45% of buses and trucks in ASEAN are expected to be fuel cell vehicles in 2060.

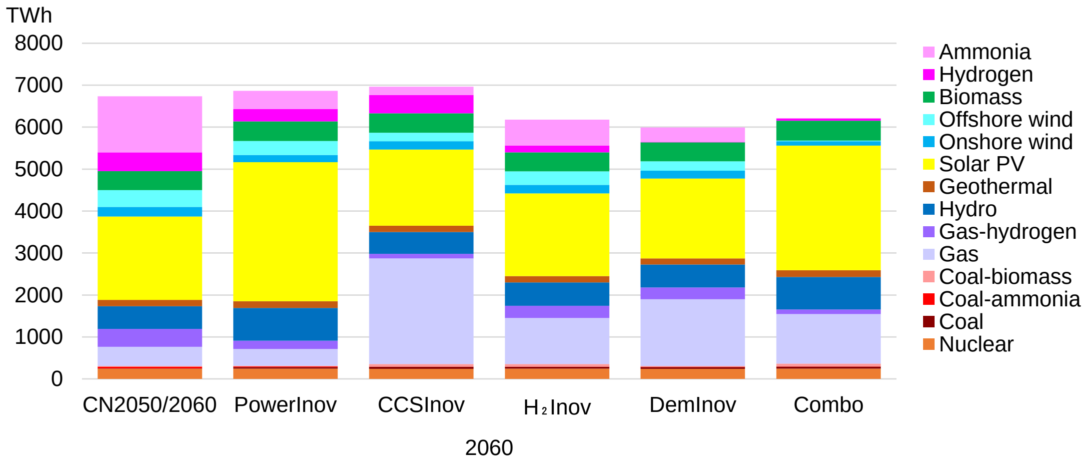
Figure 3.13. Final Energy Consumption in 2060 (Sensitivity Analysis 1)



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

Figure 3.14 shows the electricity mix for each case in 2060. PowerInov suggests that the ASEAN region enables the introduction of low-cost renewable energy sources by extending grid interconnections, for example, by introducing solar PV in place of offshore wind. Total electricity generation in H2Inov and DemInov is about 10% less than total electricity generation in CN2050/2060 since end-use electricity consumption declines.

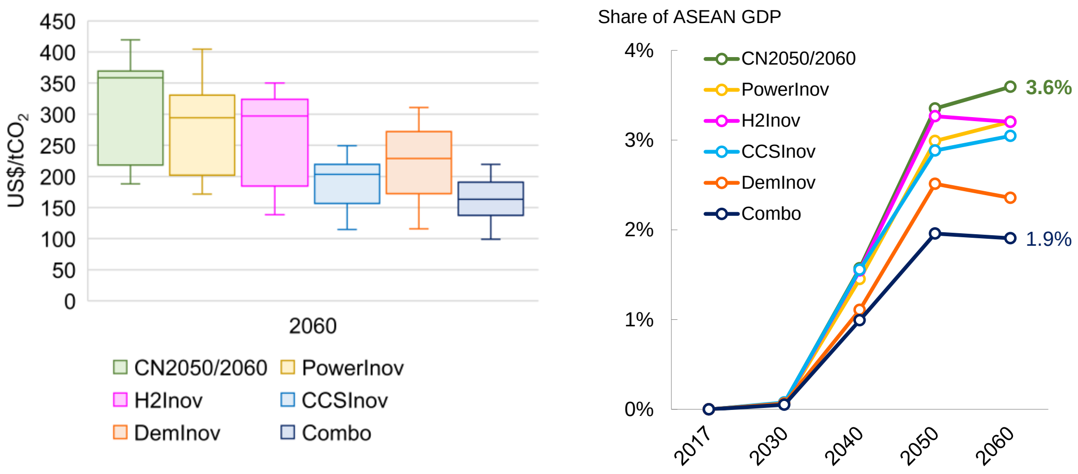
Figure 3.14. Generated Electricity in 2060 (Sensitivity Analysis 1)



Mtoe = million tonnes of oil equivalent, PV = photovoltaic.
Source: Author.

Figure 3.15 illustrates the mitigation costs for each case in 2060. A comparison of CN2050/2060 with the technological innovation cases shows that energy cooperation in ASEAN, such as cost reduction of each technology through innovation and expansion of grid interconnections, substantially reduces mitigation costs. Mitigation costs as of 2060 in Combo are about half or less than that for CN2050/2060, indicating that research and development and international collaboration are essential to achieve carbon neutrality. Technological innovation is especially important because it not only lowers the cost of the carbon-neutral scenario but also leads to early carbon neutrality. Therefore, rather than promoting individual efforts, all countries should pursue international cooperation to accelerate innovation that leads to cost reduction.

Figure 3.15. Marginal Abatement Cost (Left), Additional Annual Cost (Right) (Sensitivity Analysis 1)



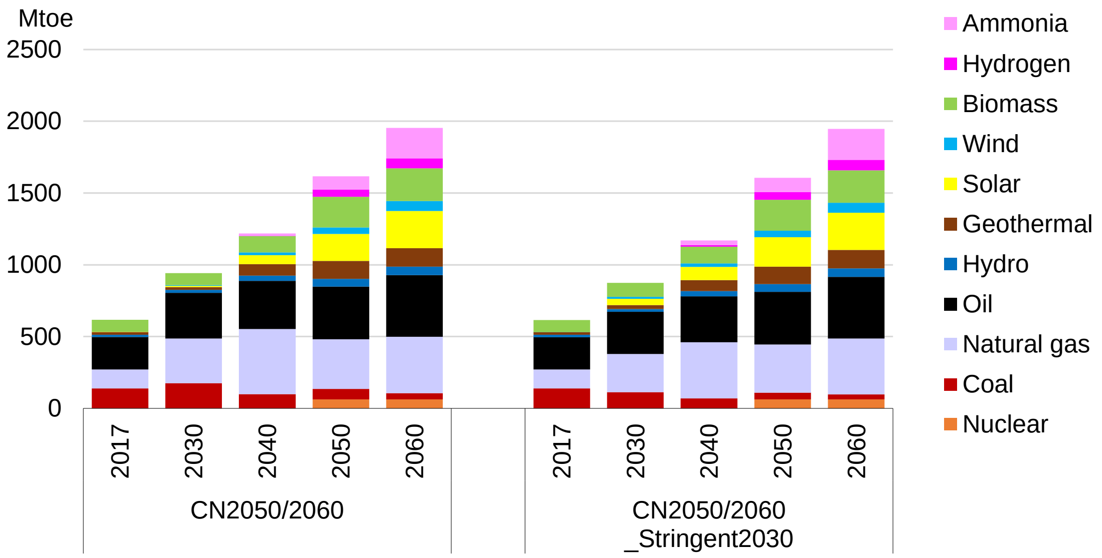
GDP = gross domestic product, tCO_2 = tonne of carbon dioxide.
Source: Author.

1.10. Sensitivity Analysis 2: Strengthen Carbon Dioxide Emission Constraints in 2030

The second sensitivity analysis presents the results of CN2050/2060_Stringent2030, which tightens emission constraints in 2030 in CN2050/2060 to the same level as the IEA Sustainable Development Scenario.

Figure 3.16 shows the primary energy supply in CN2050/2060 and CN2050/2060_Stringent2030. In CN2050/2060_Stringent2030, strengthened emission constraints reduce the share of fossil fuels and increase that of solar PV in 2030. The share of H_2 and NH_3 increases slightly from 1% to 4% in 2040 in CN2050/2060_Stringent2030.

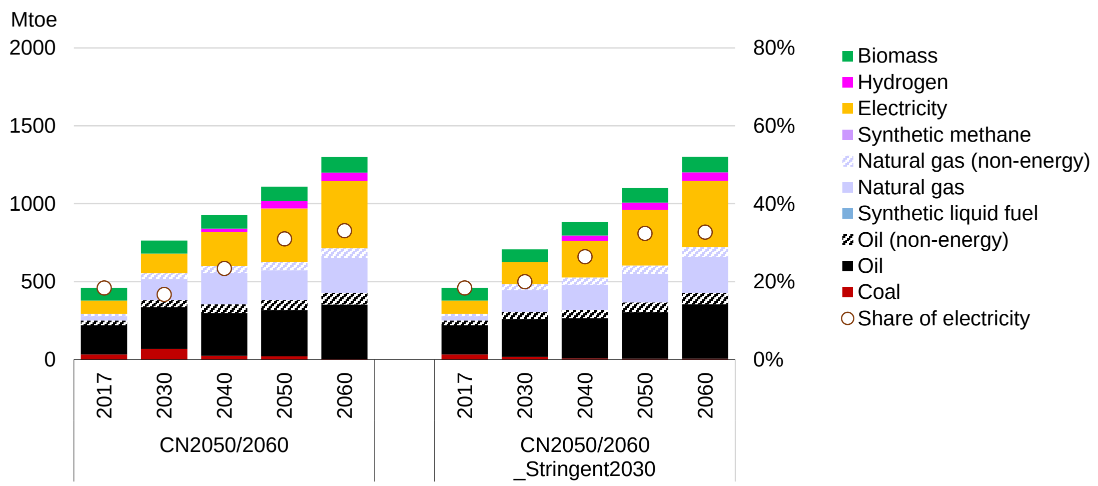
Figure 3.16. Primary Energy Supply (CN2050/2060_Stringent2030)



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

Figure 3.17 illustrates final energy consumption in CN2050/2060 and CN2050/2060_Stringent2030. Final energy consumption in 2060 is the same for both cases, but CN2050/2060_Stringent2030 lower than CN2050/2060 by 7% in 2030 and 5% in 2040. The share of electricity in CN2050/2060_Stringent2030 increases slightly in 2030 and 2040.

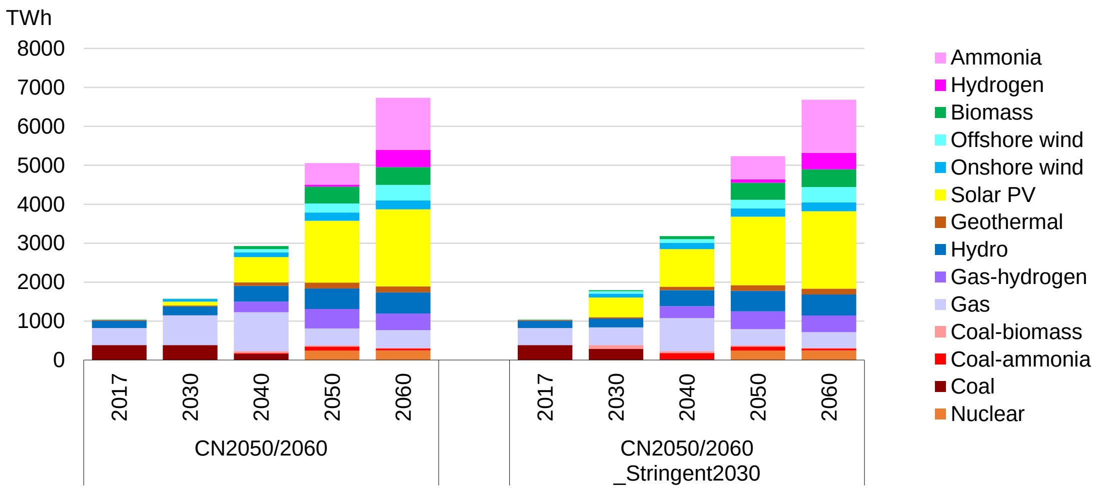
Figure 3.17. Final Energy Consumption (CN2050/2060_Stringent2030)



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

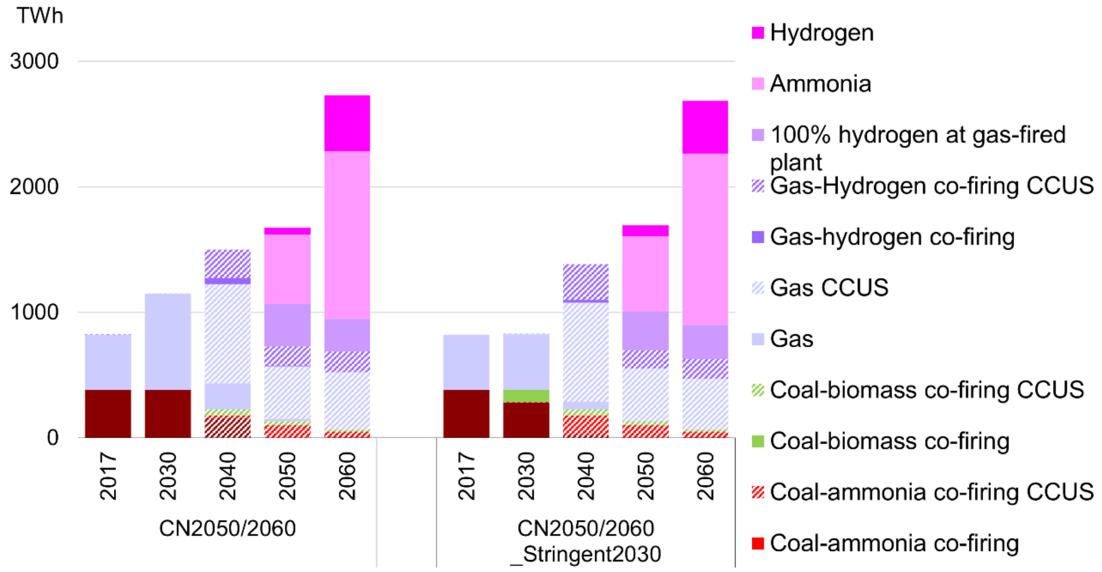
Figures 3.18–3.19 describe power generation in CN2050/2060 and CN2050/2060_Stringent2030. In CN2050/2060_Stringent2030, solar PV is introduced on a large scale from 2030. Looking at electricity generated by thermal power (coal, natural gas, NH_3, and H_2), gas-fired power generation decreases in 2030 whilst coal–biomass co-firing is introduced. There is no significant difference in transition in thermal power generation after 2040, but in CN2050/2060_Stringent2030, coal–NH_3 co-firing replaces coal-fired power generation in 2040.

Figure 3.18. Power Generation (CN2050/2060_Stringent2030)



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

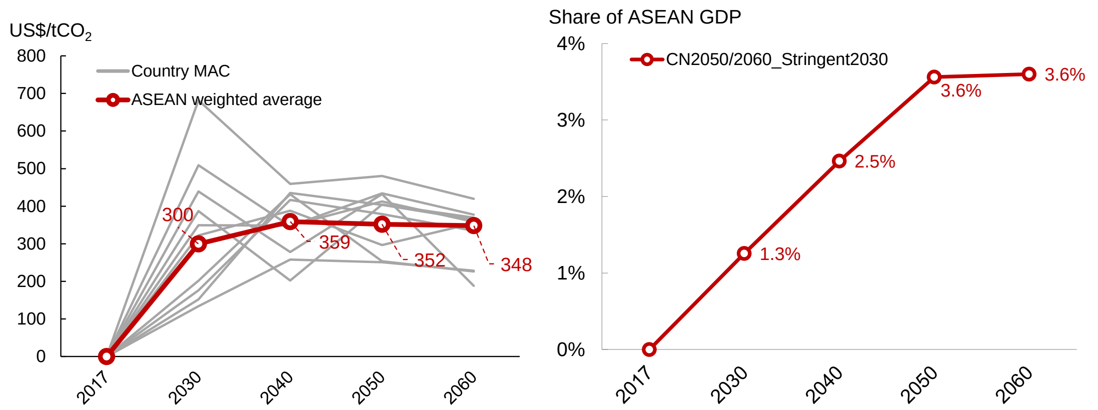
Figure 3.19. Generated Electricity from Coal, Gas, Ammonia, and Hydrogen in ASEAN (CN2050/2060_Stringent2030)



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

In CN2050/2060_Stringent2030, the MAC in 2030 increases significantly to US$300/t$CO_2$ due to enhanced CO_2 emission constraints. The MAC and additional annual cost for CN2050/2060_Stringent2030 are higher than that for CN2050/2060 in 2030 and 2040 but show no significant difference after 2040. The value of the objective function is larger in CN2050/2060_Stringent2030 than in CN2050/2060.

Figure 3.20. Marginal Carbon Dioxide Abatement Cost (Left), Additional Annual Cost (Right) (CN2050/2060_Stringent2030)



GDP = gross domestic product, MAC = marginal carbon dioxide abatement cost, tCO_2 = tonne of carbon dioxide.
Source: Author.

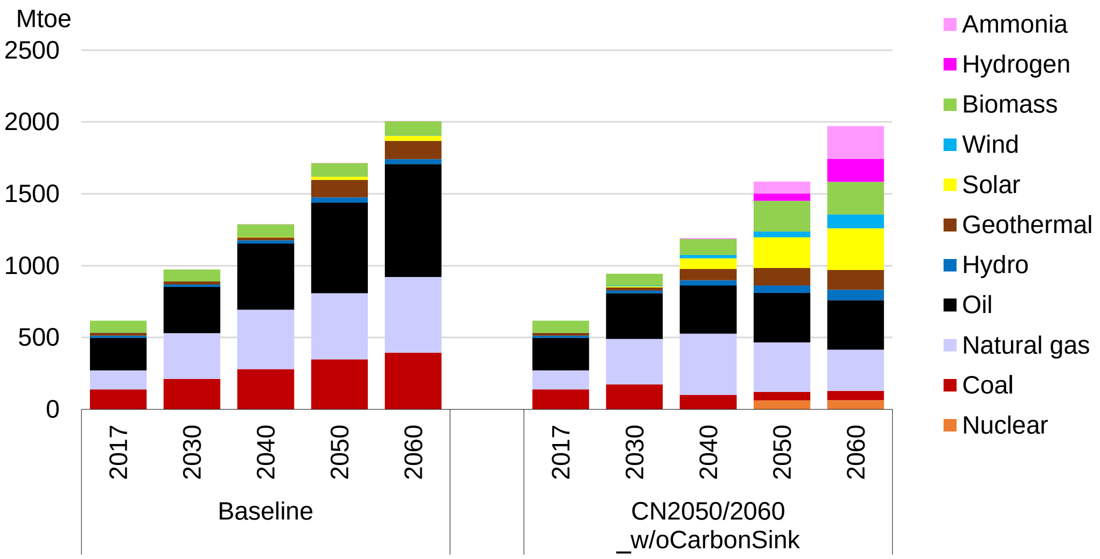
2. Results of CN2050/2060_w/oCarbonSink

CN2050/2060_w/oCarbonSink assumes that energy-related CO_2 emissions become net zero by 2060 and does not consider carbon sinks (Figures 3.21–3.31).

2.1. Primary Energy Supply

Figure 3.21 shows the primary energy supply in Baseline and CN2050/2060_w/oCarbonSink. Primary energy supply in 2060 substantially increases by 3.2 times in CN2050/2060_w/oCarbonSink. The share of a broad range of technologies, e.g. renewable energy, nuclear, CCS, and H_2 and NH_3 imports, goes up to 65% of the primary energy supply in 2060.

Figure 3.21. Primary Energy Supply in ASEAN (CN2050/2060_w/oCarbonSink)

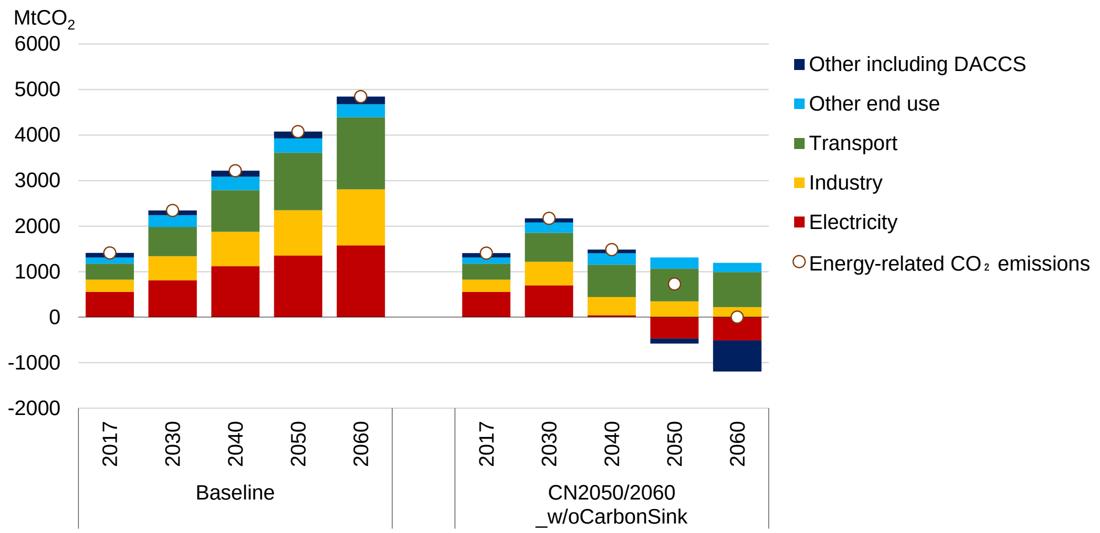


Mtoe = million tonnes of oil equivalent.
Source: Author.

2.2. Sector Carbon Dioxide Emissions

Figure 3.22 illustrates sector CO_2 emissions in Baseline and CN2050/2060_w/oCarbonSink. In CN2050/2060_w/oCarbonSink and CN2050/2060, CO_2 emissions from transport, particularly buses and trucks, remain whilst power is fully decarbonised by 2050. CN2050/2060_w/oCarbonSink does not consider carbon sinks; therefore, negative-emission technologies such as BECCS and DACCS contribute more than in CN2050/2060.

Figure 3.22. Sector Energy-related Carbon Dioxide Emissions in ASEAN (CN2050/2060_w/oCarbonSink)

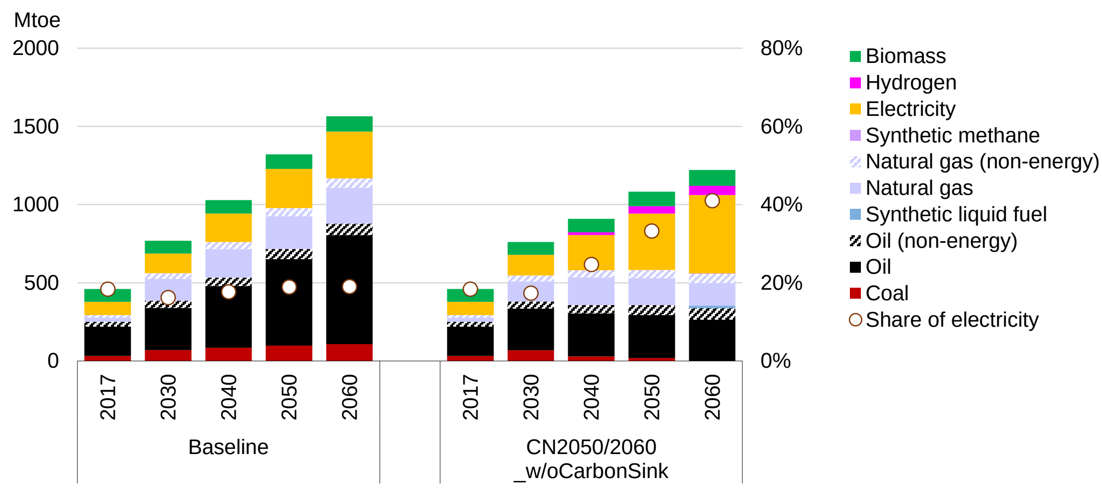


CO_2 = carbon dioxide, DACCS = direct air capture with carbon storage, MtCO2 = million tonnes of carbon dioxide.
Source: Author.

2.3. Final Energy Consumption

Figure 3.23 shows final energy consumption in Baseline and CN2050/2060_w/oCarbonSink. Final energy consumption in 2060 decreases by 22% in CN2050/2060_w/oCarbonSink, more than in other cases, such as CN2050/2060 and CN2050/2060_Stringent2030. In CN2050/2060_w/oCarbonSink, the share of electricity increases to 41% by 2060.

Figure 3.23. Final Energy Consumption in ASEAN (CN2050/2060_w/oCarbonSink)

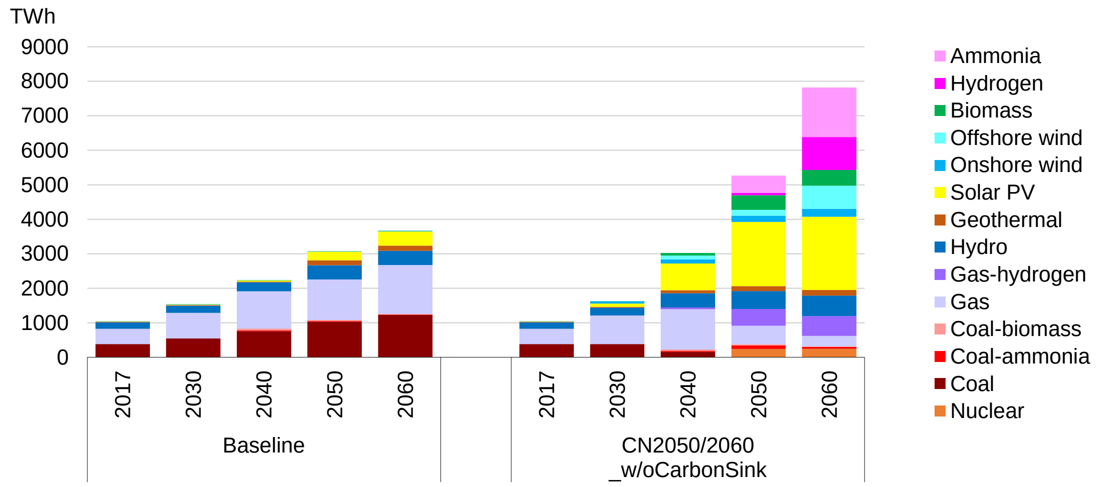


Mtoe = million tonnes of oil equivalent.
Source: Author.

2.4. Power Generation

Figure 3.24 illustrates power generation in Baseline and CN2050/2060_w/oCarbonSink. In CN2050/2060_w/oCarbonSink and other cases, renewable energy is a major power source, accounting for 54% in 2060. H_2- and NH_3-fired power generation account for 31%. The share of solar PV power generation is 50% of electricity generation from renewables.

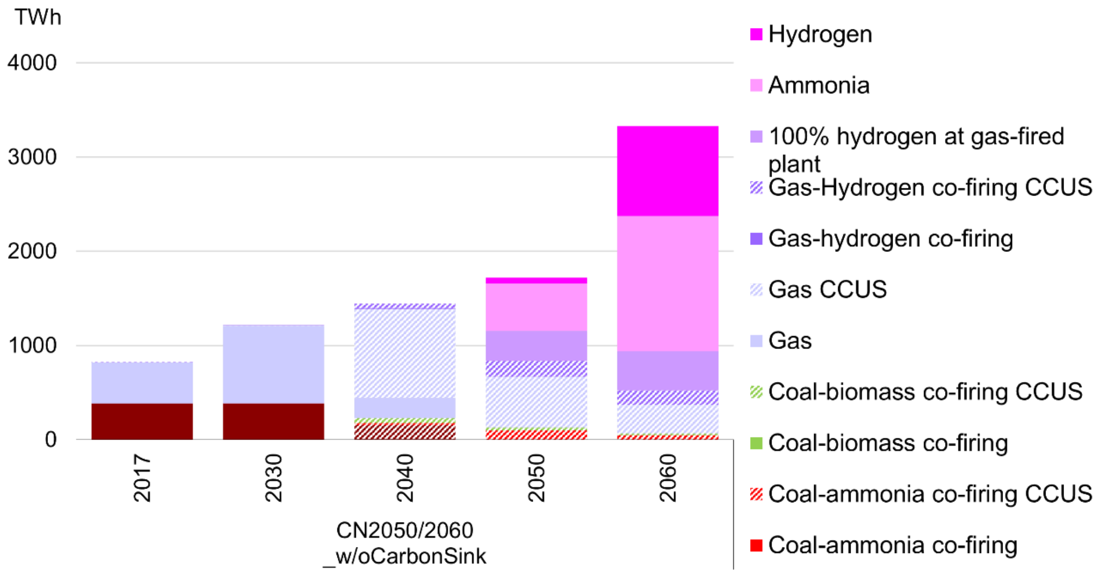
Figure 3.24. Power Generation in ASEAN (CN2050/2060_w/oCarbonSink)



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

H_2 and NH_3, including co-firing, play roles in the electricity mix in CN2050/2060_w/oCarbonSink. CN2050/2060 and CN2050/2060_w/oCarbonSink do not show significant differences in the transition of thermal power generation technologies after 2030. The amount of electricity by thermal power generation in 2060 increases 22% compared with CN2050/2060 and the introduction of H_2-fired power generation progresses.

Figure 3.25. Generated Electricity from Coal, Gas, Ammonia, and Hydrogen in ASEAN (CN2050/2060_w/oCarbonSink)

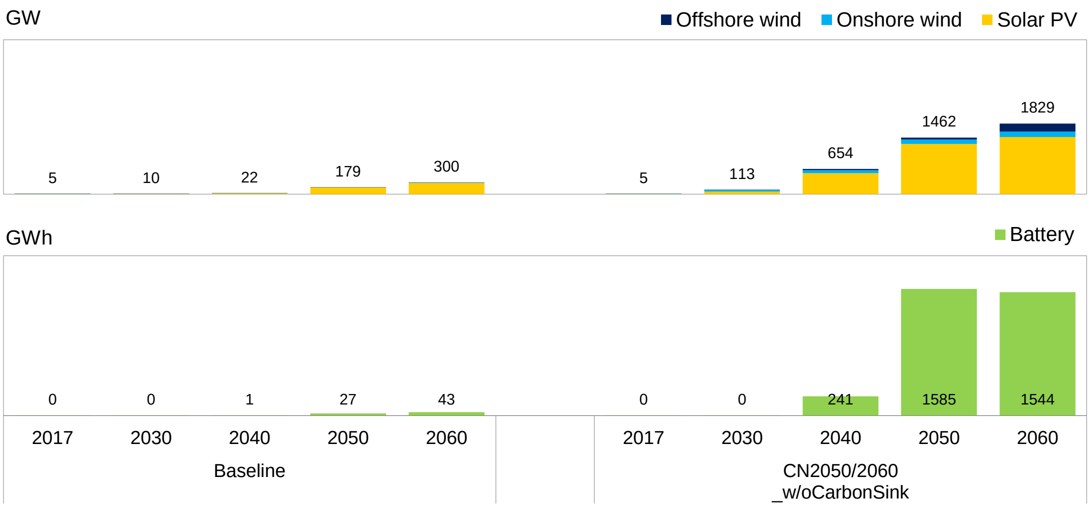


CCUS = carbon dioxide capture, utilisation, and storage; TWh = terawatt-hour.
Source: Author.

2.5. Variable Renewable Energy and Battery

Variable renewable energy (VRE), such as solar PV and wind power, is expected to be deployed in CN2050/2060_w/oCarbonSink. The installed capacity of solar PV power generation is estimated to account for a large share and that of all VRE is about 1,829 GW by 2060.

Figure 3.26. Variable Renewable Energy and Battery Capacity in ASEAN (CN2050/2060_w/oCarbonSink)

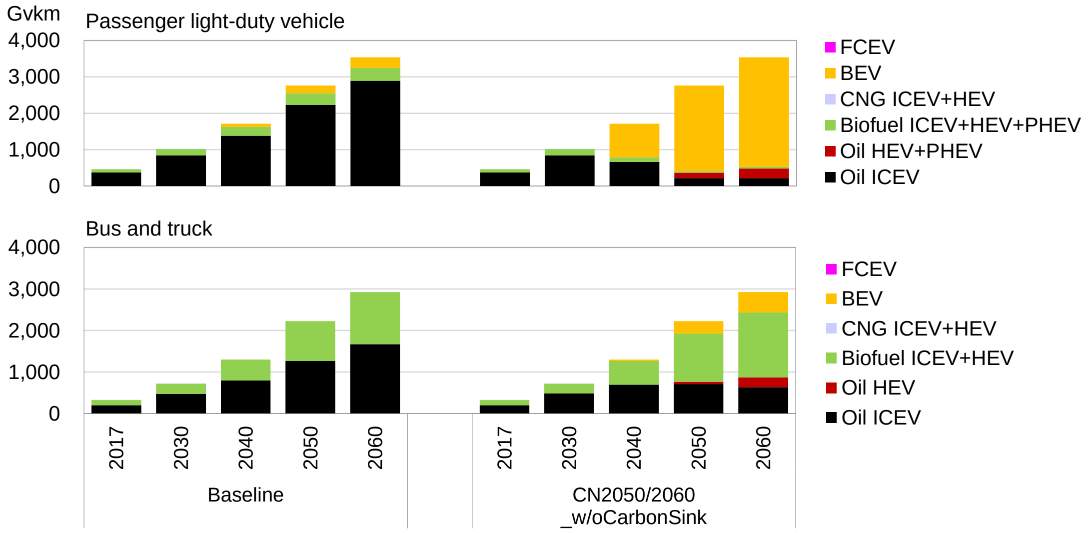


GW = gigawatt, GWh = gigawatt-hour, PV = photovoltaic.
Source: Author.

2.6. Road Transport

Figure 3.27 shows passenger light-duty vehicles in the upper graph, and buses and trucks in the lower graph. In CN2050/2060_w/oCarbonSink, a major share of passenger vehicles are electrified by 2050. Comparing CN2050/2060 and CN2050/2060_w/oCarbonSink, the share of battery electric vehicles increases and that of biofuels decreases in long-distance transport. Oil consumption is expected to remain until 2060 in buses and trucks.

Figure 3.27. Travel Distance by Vehicle Technology in ASEAN (CN2050/2060_w/oCarbonSink)



BEV = battery electric vehicle, CNG = compressed natural gas, FCEV = fuel cell electric vehicle, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, Gvkm = 10^9 vehicle-km, PHEV = plug-in hybrid electric vehicle.

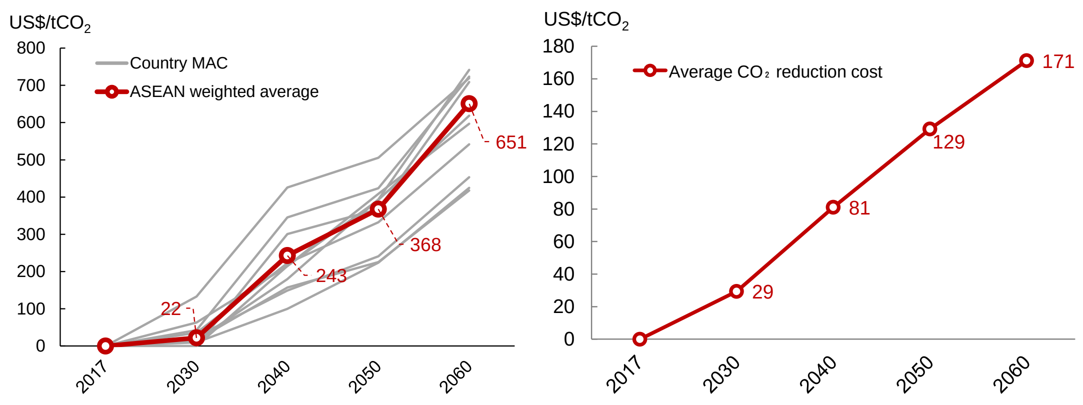
Note: Biofuel includes bioethanol and biodiesel mixed with petroleum fuel.

Source: Author.

2.7. Costs of Reducing Carbon Dioxide and Energy Prices

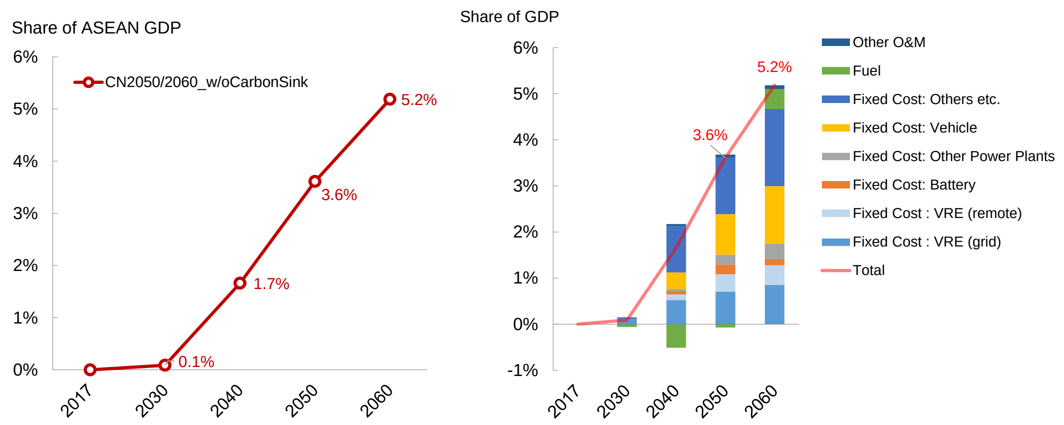
In CN2050/2060_w/oCarbonSink, the MAC rises sharply from 2050 to US$651/t$CO_2$ in 2060, implying a major economic challenge to decarbonisation. Increase in the MAC is derived from more stringent constraints on CO_2 emissions from 2050 to 2060. The additional annual cost in CN2050/2060_w/oCarbonSink compared with Baseline is estimated at about 5.2% (US$0.83 trillion) of ASEAN's GDP in 2060.

Figure 3.28. Marginal Carbon Dioxide Abatement Cost (Left), Average Carbon Dioxide Reduction Cost (Right) (CN2050/2060_w/oCarbonSink)



CO_2 = carbon dioxide, MAC = marginal carbon dioxide abatement cost, tCO_2 = tonne of carbon dioxide.
Source: Author.

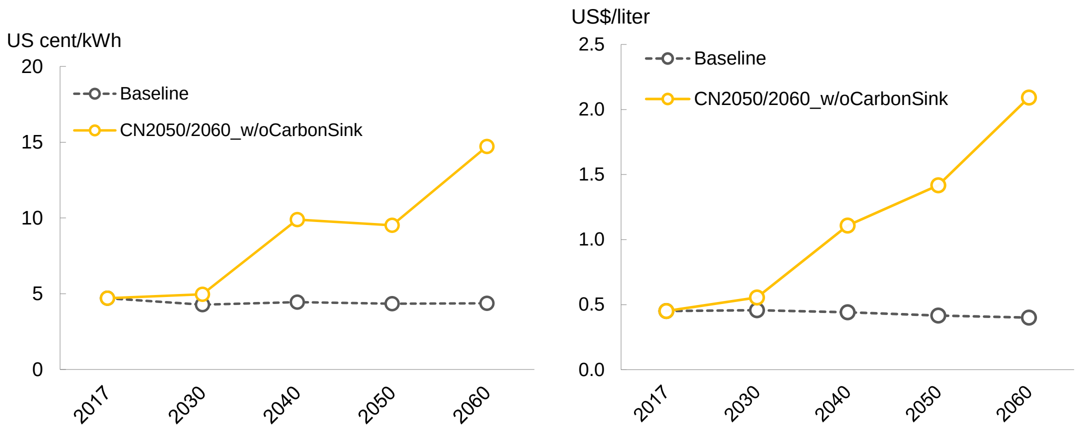
Figure 3.29. Additional Annual Cost (Left), Composition of Additional Annual Cost (Right) (CN2050/2060_w/oCarbonSink)



GDP = gross domestic product, O&M = operation and maintenance, VRE = variable renewable energy.
Source: Author.

Electricity and diesel prices are estimated to rise two- to five-fold in CN2050/2060_w/oCarbonSink.

Figure 3.30. Electricity Price (Left), Diesel End-use Price (Right) (CN2050/2060_w/oCarbonSink)

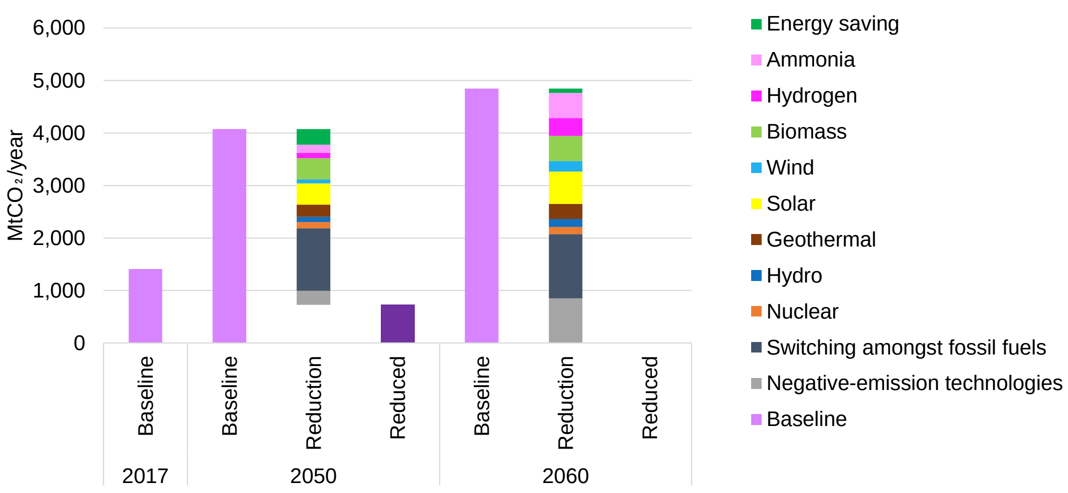


Source: Author.

2.8. Contribution of Mitigation Measures

Figure 3.31 shows the contribution of technology to the reduction of energy-related CO_2 emissions in CN2050/2060_w/oCarbonSink.

Figure 3.31. Contribution of Mitigation Measures (CN2050/2060_w/oCarbonSink)



$MtCO_2$ = million tonnes of carbon dioxide.
Source: Author.