Decarbonization of ASEAN energy systems: Optimum technology selection model analysis up to 2060

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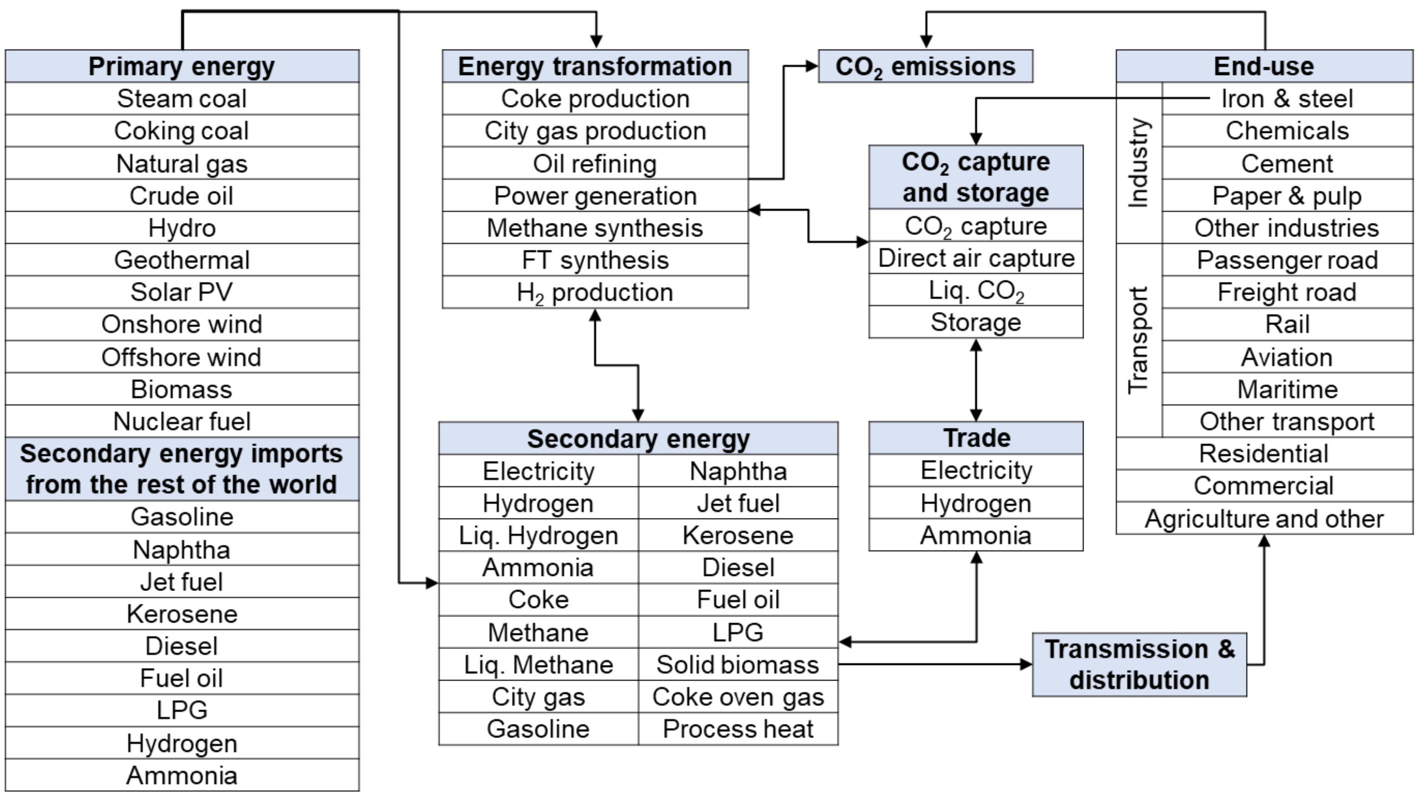
Outline

- **Methodology**
- Results for ASEAN
- Conclusions

IEEJ-NE_ASEAN model

- IEEJ-NE (NE: New Earth) is a linear programming model that simulates the cost-optimal deployment of energy technologies under technical constraints.
- It encompasses the total energy system. Power supply and demand are temporally disaggregated to incorporate the costs for integrating variable renewable energy.

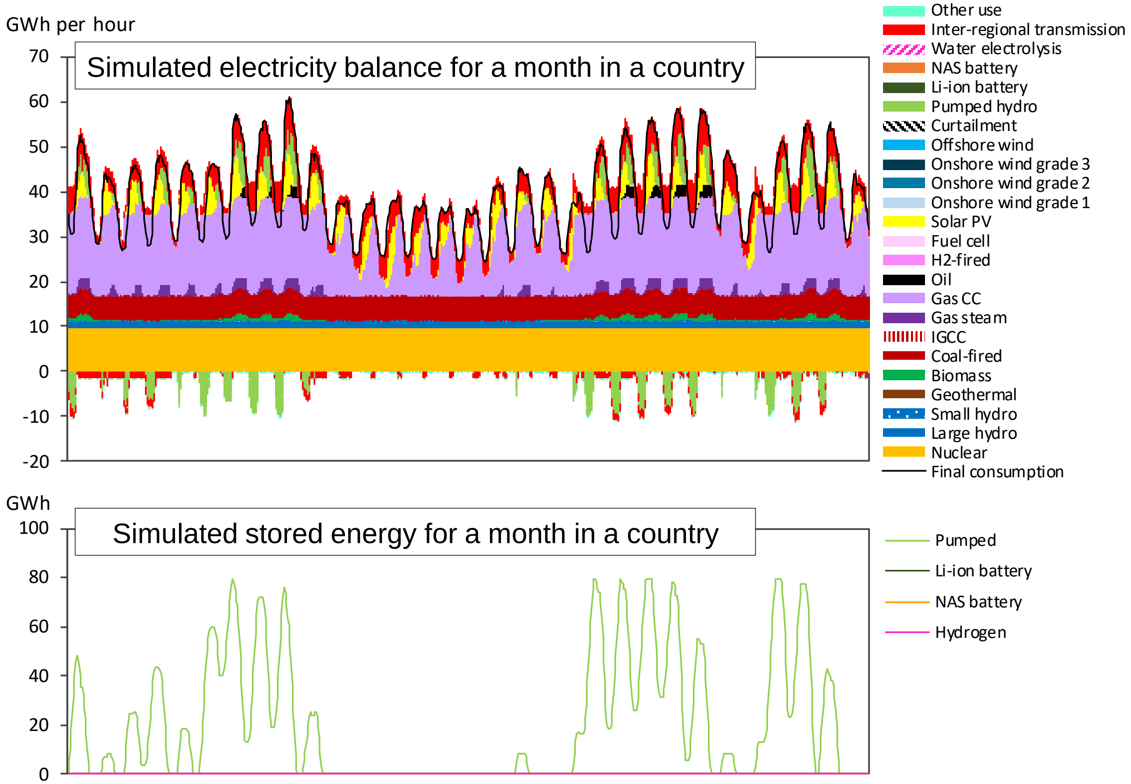
Modeled energy system



Modeling of electricity supply and demand

- Temporally disaggregated (2910 time slices per year) to capture the variability of renewable energy and system integration cost.
- Co-firing at both existing and newly installed power plants are explicitly modeled.

Modeled technologies	
Coal-fired	Geothermal
Coal-Ammonia co-firing (20%)	Solar PV
	Onshore wind
IGCC	Offshore wind
Gas-fired	Biomass-fired
Gas combined	Nuclear
Gas-Hydrogen co-firing（H_2 20%, 40%, 60%, 80%)	Hydrogen-fired
	Ammonia-fired
	Pumped hydro
	Li-ion battery
Hydro	H_2 tank



Model overview

Regional division	10 ASEAN countries (10 nodes)
Time period	2017-2060 with representative years of 2017, 2030, 2040, 2050 and 2060
Objective function	Discounted total system cost for ASEAN
Discount rate	8%
Temporal resolution	2190 time slices (4-hourly resolution) per year for electricity supply and demand balance
Number of technologies	350+ technologies
End-use sector	**Industry**: Iron & Steel, Cement, Chemicals, Paper & pulp, Other industries **Transport**: Light-duty vehicle, Bus & truck, Rail, Aviation, Navigation, Other transport **Residential**: Light and appliances, Space cooling, Water heating, Kitchen **Commercial**: Light and appliances, Space cooling, Water heating & Kitchen **Other**: Agricultural and other energy demand

Selected low-carbon technologies in the model

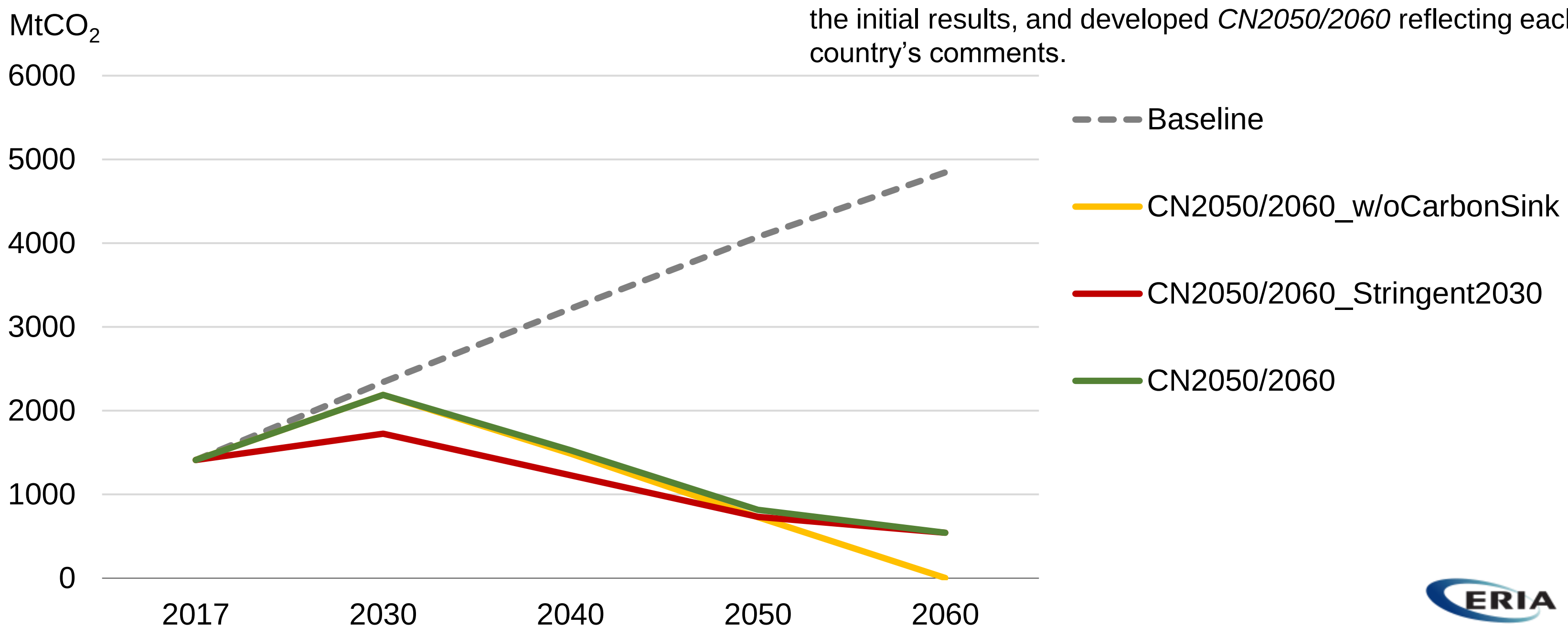
Renewables	Solar PV, Onshore wind, Offshore wind, Hydro, Geothermal, biomass
Nuclear	Light water reactor
CCUS	**CO_2 capture**: Chemical absorption, Physical absorption, Direct air capture **CO_2 utilization**: Methane synthesis, FT liquid fuel synthesis **CO_2 storage**: Geological storage
Hydrogen	**Supply**: Electrolysis, Coal gasification, Methane reforming, H_2 separation from Ammonia, H_2 trade among ASEAN countries, H_2 imports from non-ASEAN countries **Consumption**: H_2 turbine, Natural gas-H_2 co-firing, FCEV, H_2 based DRI+EAF, Fuel cell ship, H_2 aviation, H_2 heat for industries, Fuel synthesis (methane, FT liquid fuel, ammonia)
Ammonia	**Supply**: Ammonia synthesis, NH_3 trade among ASEAN countries, NH_3 imports from non-ASEAN countries **Consumption**: Ammonia turbine, Coal-ammonia co-firing, H_2 separation
Negative emissions	Direct air capture with CCS (DACCS), Biomass-fired power generation with CCS (BECCS)

Case settings

- ***Baseline*** does not assume any emission constraints by 2060.
- ***CN2050/2060*** assumes energy-related CO_2 emission constraints by country and achieves net zero CO_2 emissions with natural carbon sink by 2060 in ASEAN.
  - ***CN2050/2060_Innovation cases*** are for evaluating the impact of technological innovation in the *CN2050/2060*. **(sensitivity analysis 1)**
  - ***CN2050/2060_Stringent2030*** puts more stringent emission constraints by 2030 in the *CN2050/2060*. The emission in 2030 is consistent with IEA SDS. **(sensitivity analysis 2)**
- ***CN2050/2060_w/oCarbonSink*** assumes net zero energy-related CO_2 emissions by 2050 in BRN and SGP and by 2060 in the rest of the countries. This is the case we initially assumed.

Energy-related CO_2 emission constraints in ASEAN

Note: *CN2050/2060_w/oCarbonSink* is the case we initially assumed. We had discussions with ASEAN countries based on the initial results, and developed *CN2050/2060* reflecting each country's comments.



Country emission reduction targets in the *CN2050/2060*

The CN2050/2060 reflects nationally declared CN target years and considers carbon sinks in Indonesia, Malaysia, Myanmar, Thailand, and Vietnam.

Energy-related CO_2 emission reduction targets by country in the *CN2050/2060*

Country	CN target year	Energy-related CO2 emissions reduction target from 2017	Note
Brunei	2050	100%	Target year: No CN target. Set to 2050 considered 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: The 2050 value of the LTS LCCP scenario. Although original target is calculated to be 39%, set to 50% as the minimum requirement
Laos	2050	100%	Target year: 2050 CN declaration (CAA member country) Sink: Not considered
Malaysia	2050	50%	Target year: Reffered to 2050 CN by prime minister Sink: The 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: The 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 considered income level Sink: Not considered
Thailand	2050	50%	Target year: 2050 CN (requested by Thailand) Sink: Use values provided by Thailand
Vietnam	2050	70%	Target year: 2050 CN declaration Sink: The 2030 target of the unconditional NDC

Key assumptions

ASEAN Power Grid

- Int'l grid extension is constrained with currently planned capacities, totaling 55GW.

Hydrogen imports from non-ASEAN countries

- Volume: max. 203Mtoe/year in 2040, 540Mtoe in 2050, 638Mtoe in 2060. The volume after 2050 is equivalent to 30% of baseline total primary energy.
- Price: 30 cent per Nm^3-H_2 in 2030, 20 cent in 2050 and 17.5 cent in 2060 based on Japanese Government's long-term hydrogen supply chain target.

Annual CO_2 storage capacity

- Max. 687MtCO_2/year in 2040, 1138MtCO_2 in 2050 and 1610MtCO_2 in 2060
- The capacity is equivalent to 25% of baseline CO_2 emissions in 2050, 30% in 2060.

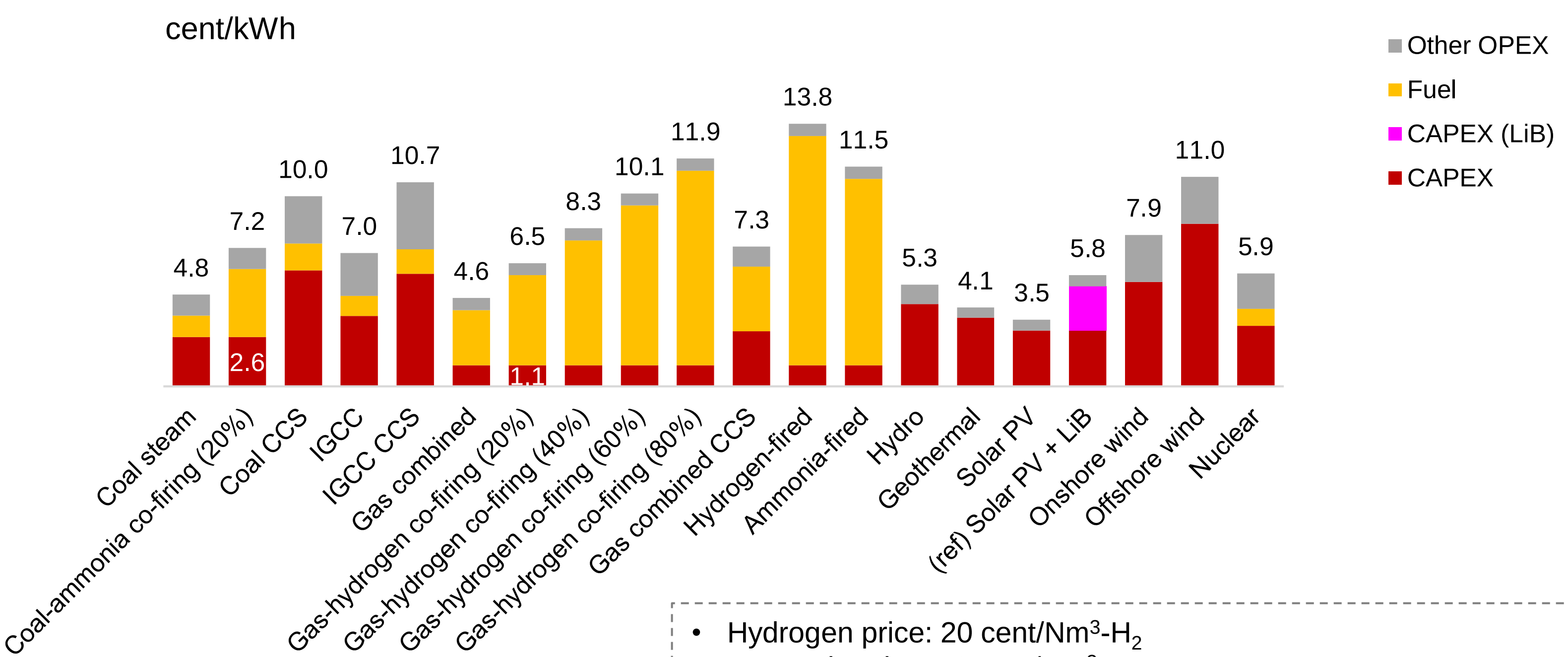
Biofuel supply potential for road transport grows in proportion to road transport demand.

Power generation cost

Assumptions for power generation cost are obtained from publicly available reports or ASEAN countries.

Assumed levelized Cost of Electricity (LCOE)

Indonesia, 2050



- Hydrogen price: 20 cent/Nm^3-H_2
- Ammonia price: 16 cent/Nm^3-H_2
- Capacity factor: 40% for hydro, 80% for geothermal, 15% for solar PV, 20% for onshore wind, 30% for offshore wind, 80% for nuclear, 60% for the rest of the technologies

(source) Danish Energy Agency (2021), etc.

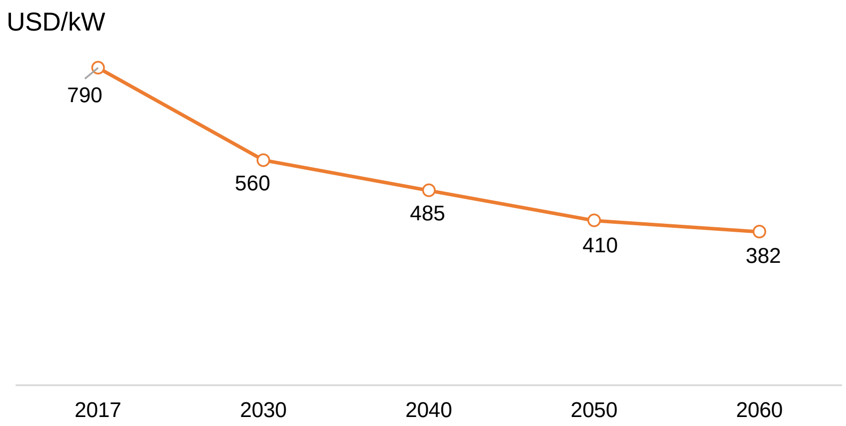
Cost reduction of variable renewables and battery

Cost of solar PV, wind turbines and battery are assumed to largely decrease by 2060

- Note that pumped hydro, Li-ion battery and compressed hydrogen tank are modeled.
- Capacity of pumped hydro is exogenous in this study, while Li-ion battery and hydrogen tank are determined endogenously

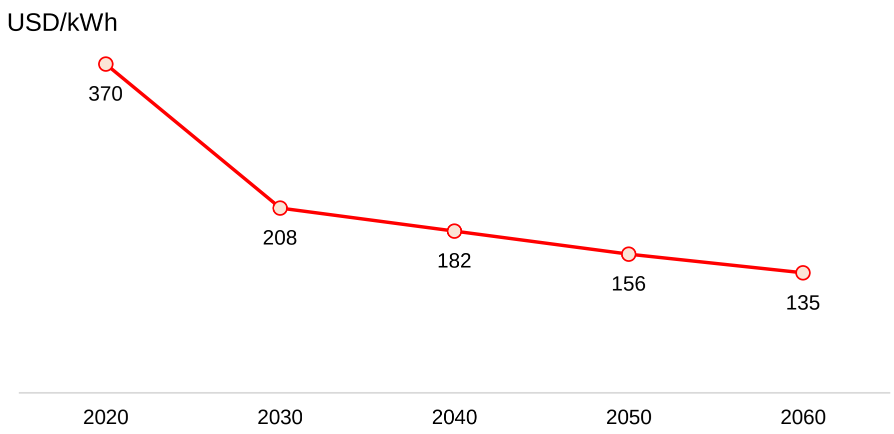
Solar PV capital cost

Indonesia



Li-ion battery cost

ASEAN

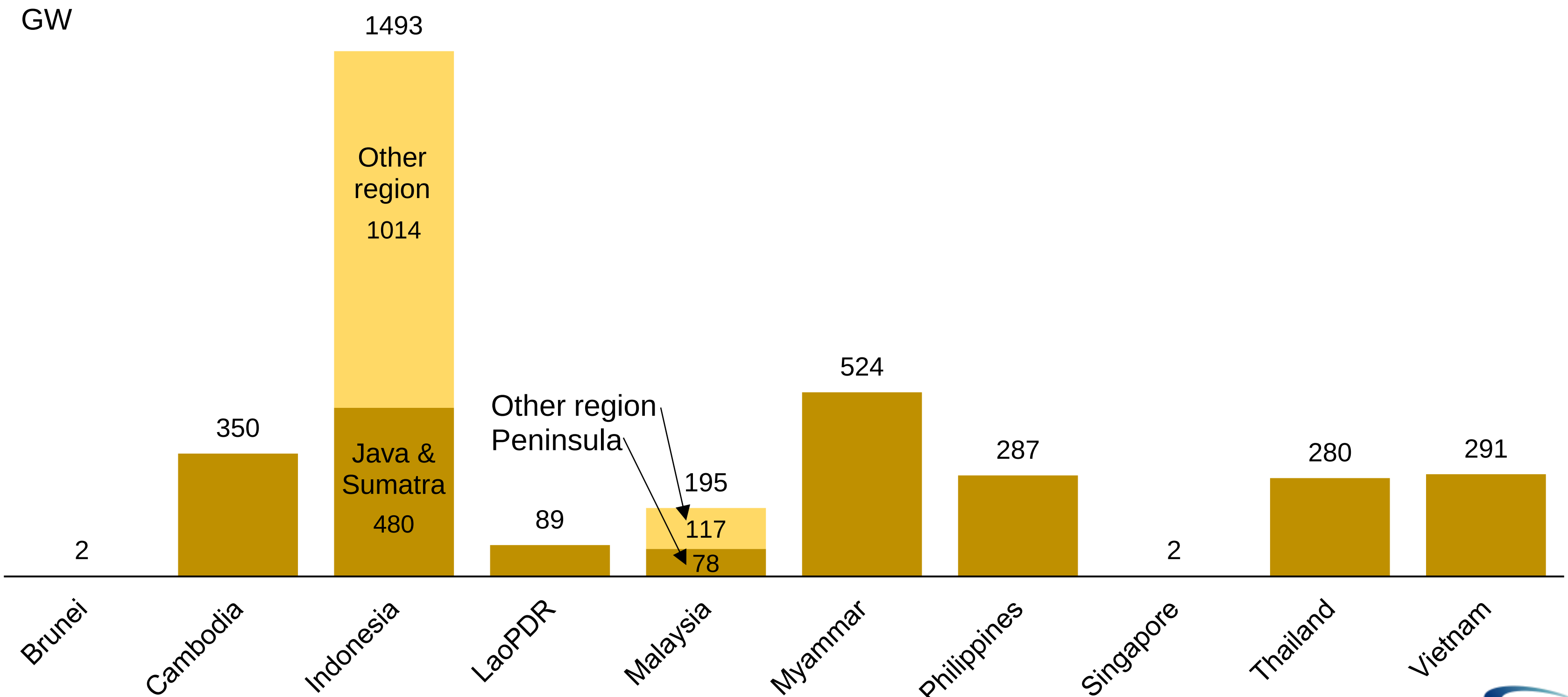


(source) Danish Energy Agency (2021); NREL (2020)

Solar PV potential

- Total 3513 GW in ASEAN, estimated by the IEEJ based on GIS data
- Solar PV potential in Indonesia is divided into “Java & Sumatra” and “other” to reflect regional imbalance of electricity demand and renewable energy
  - Solar PV in the “other” region is assumed for hydrogen production
- Potential in Malaysia is also divided into “peninsula” and “other” in this model

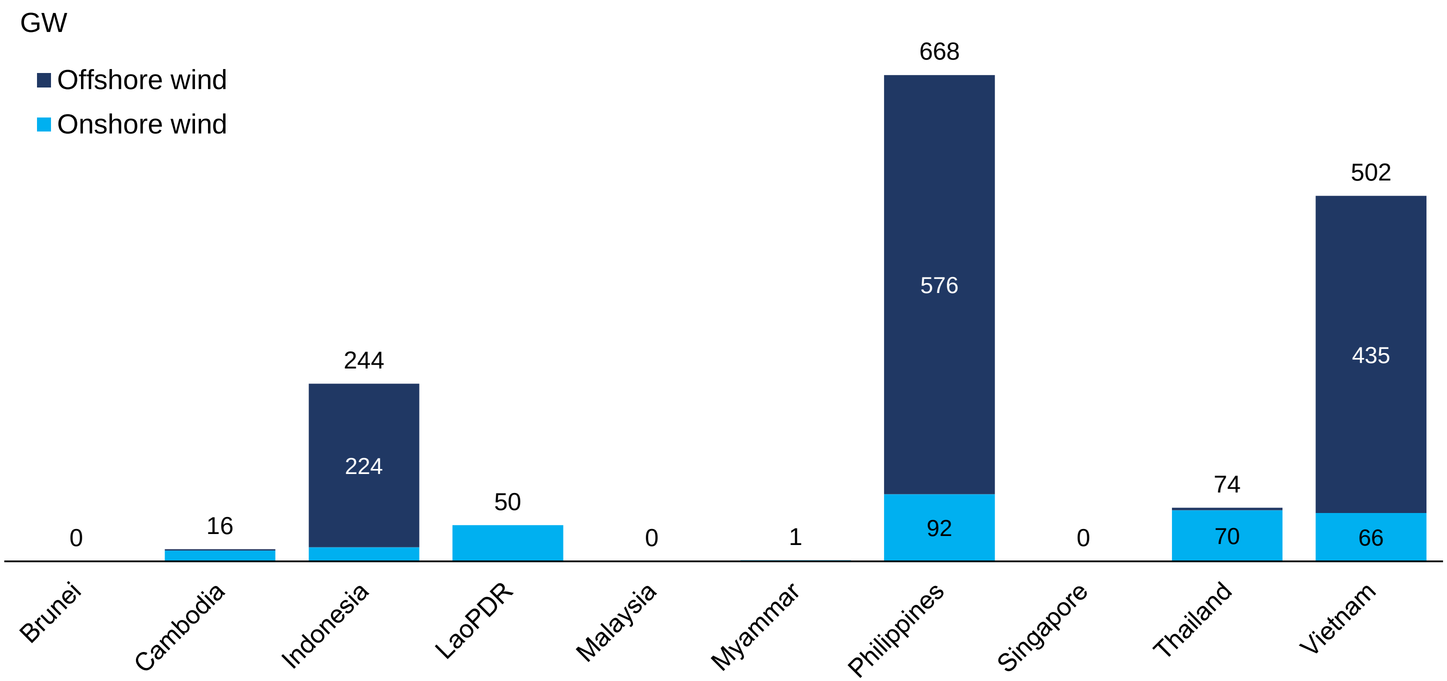
Solar PV potential assumption



Wind power potential

- Assumed onshore wind potential is 313GW and offshore wind is 1241GW in ASEAN, estimated by the IEEJ based on GIS data
- Onshore wind and offshore wind in Indonesia is divided into "Java & Sumatra" and "other region" to reflect regional imbalance of demand and resources
  - Wind power in the "other region" is assumed for hydrogen production

Wind power potential



Note: Potential data will be revised based on comments from each country

Outline

Methodology

Results for ASEAN

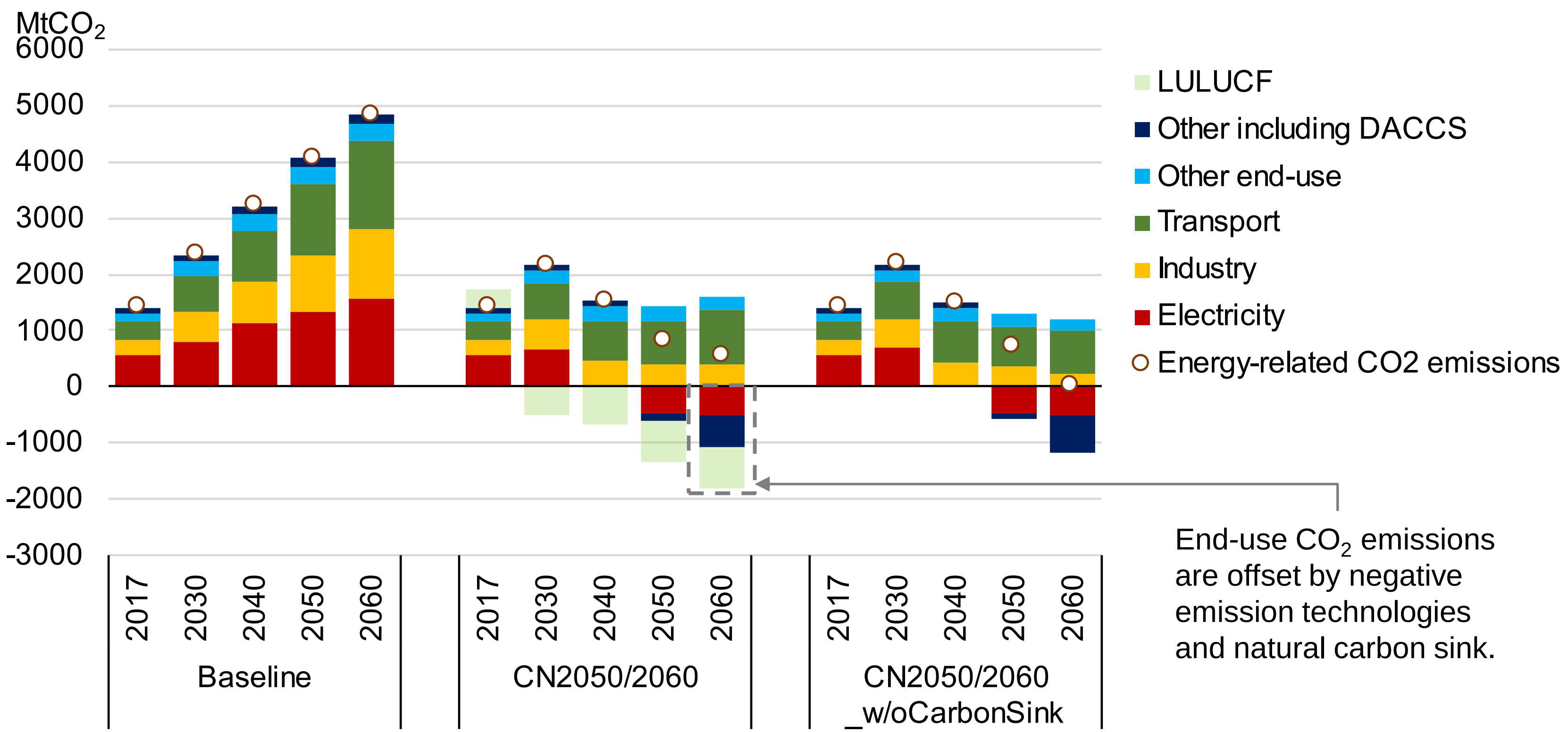
- **Energy mix for decarbonizing ASEAN by 2060**
- Sensitivity analysis 1: Technological innovation
- Sensitivity analysis 2: Strengthen CO_2 emissions constraints in 2030

Conclusions

Sectoral CO_2 emissions

- End-use emissions reduction, combined with negative emission technologies[1], is estimated to be a cost-efficient strategy for ASEAN carbon neutrality.
- Power sector is almost decarbonized by 2040, while the CO_2 from the transport, especially bus and truck, remain in the *CN* cases because of high costs of alternative vehicles.

Sectoral energy-related CO_2 emissions in ASEAN

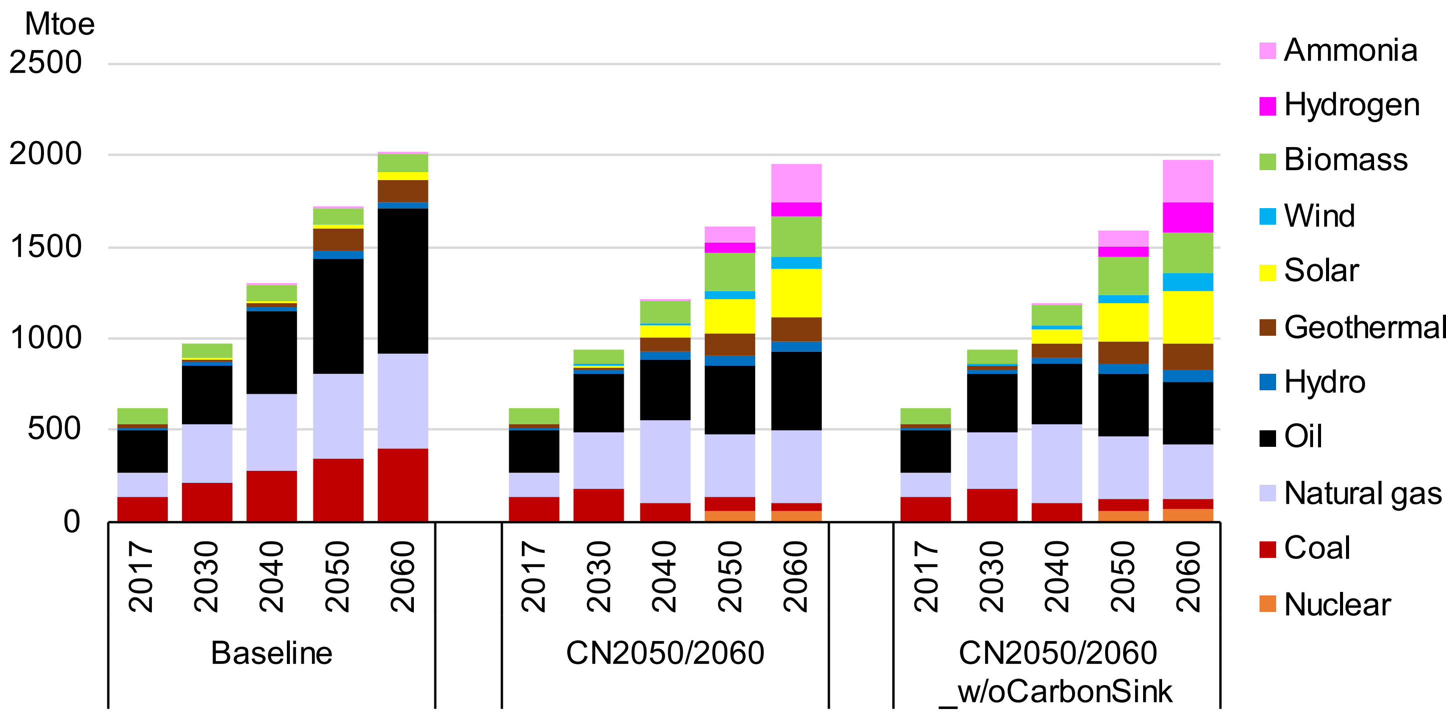


1 BECCS and DACCS

Primary energy supply

- A wide range of technologies, including renewables, nuclear, CCS and import of hydrogen and ammonia, are necessary for deep decarbonization.
- Zero emission energies together contribute to 56% of primary energy in 2060 in the *CN2050/2060,* and 65% in the *CN2050/2060_w/oCarbonSink*.

Primary energy supply in ASEAN



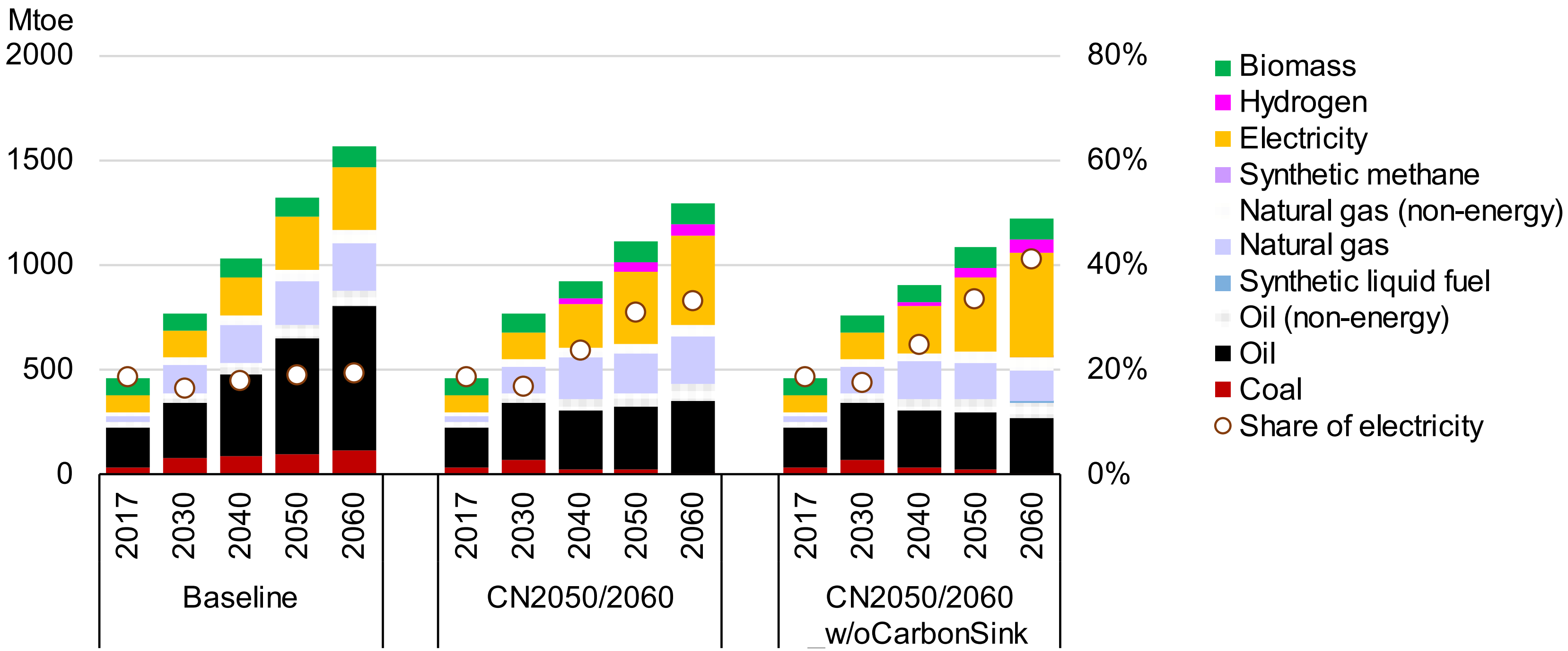
1 NETs = Negative Emissions Technologies

Fossil fuels include non-energy use. CO_2 from fossil fuel combustion in 2060 in CN2050/2060 is offset by NETs and natural carbon sink.

Final energy consumption

- Energy saving and electrification are core strategies for decarbonizing end-use sectors.
- Electricity becomes the largest end-use energy source by 2050.

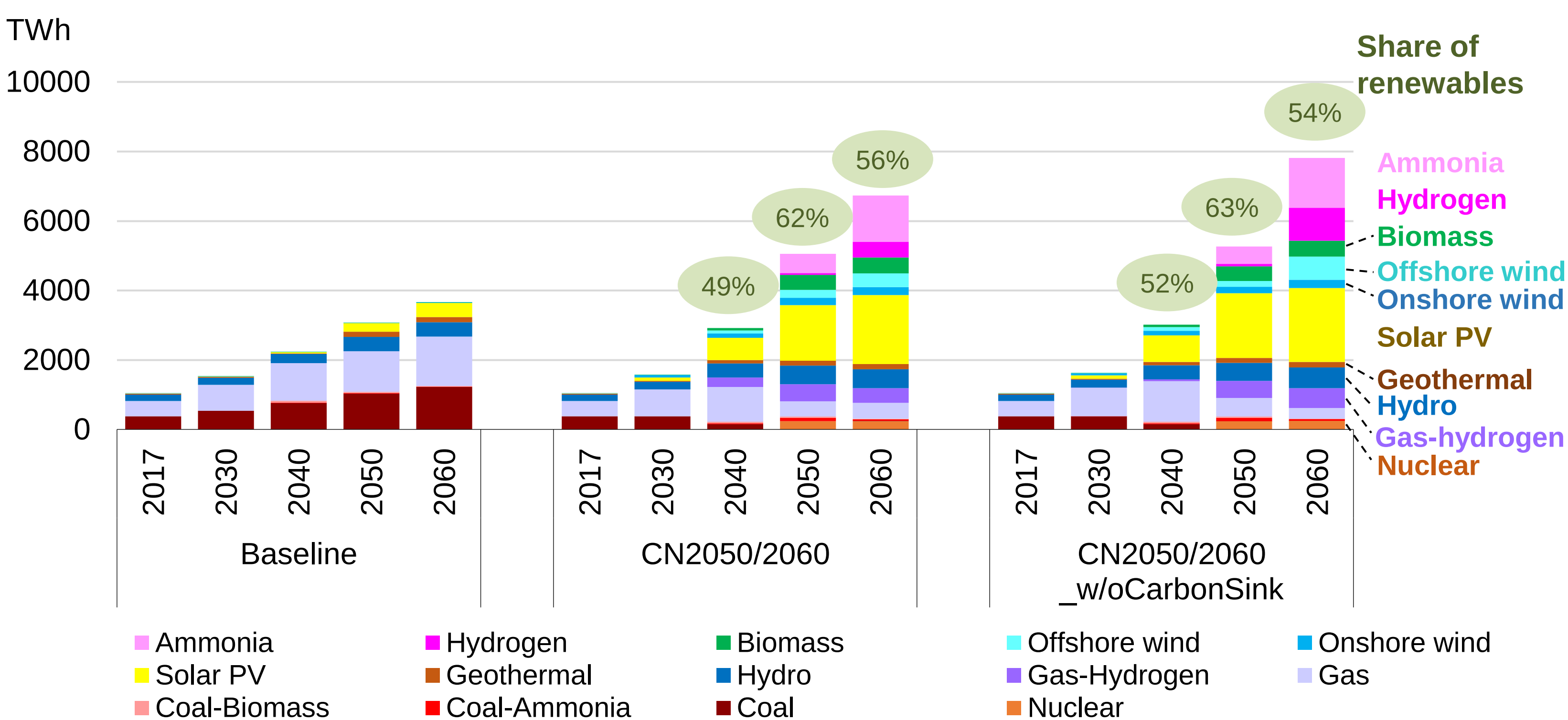
Final energy consumption in ASEAN



Power generation

- Renewables become the main power source in the *CN* cases.
- Hydrogen and ammonia, including co-firing, are also projected to be a part of the power generation mix for net zero emissions by 2060.

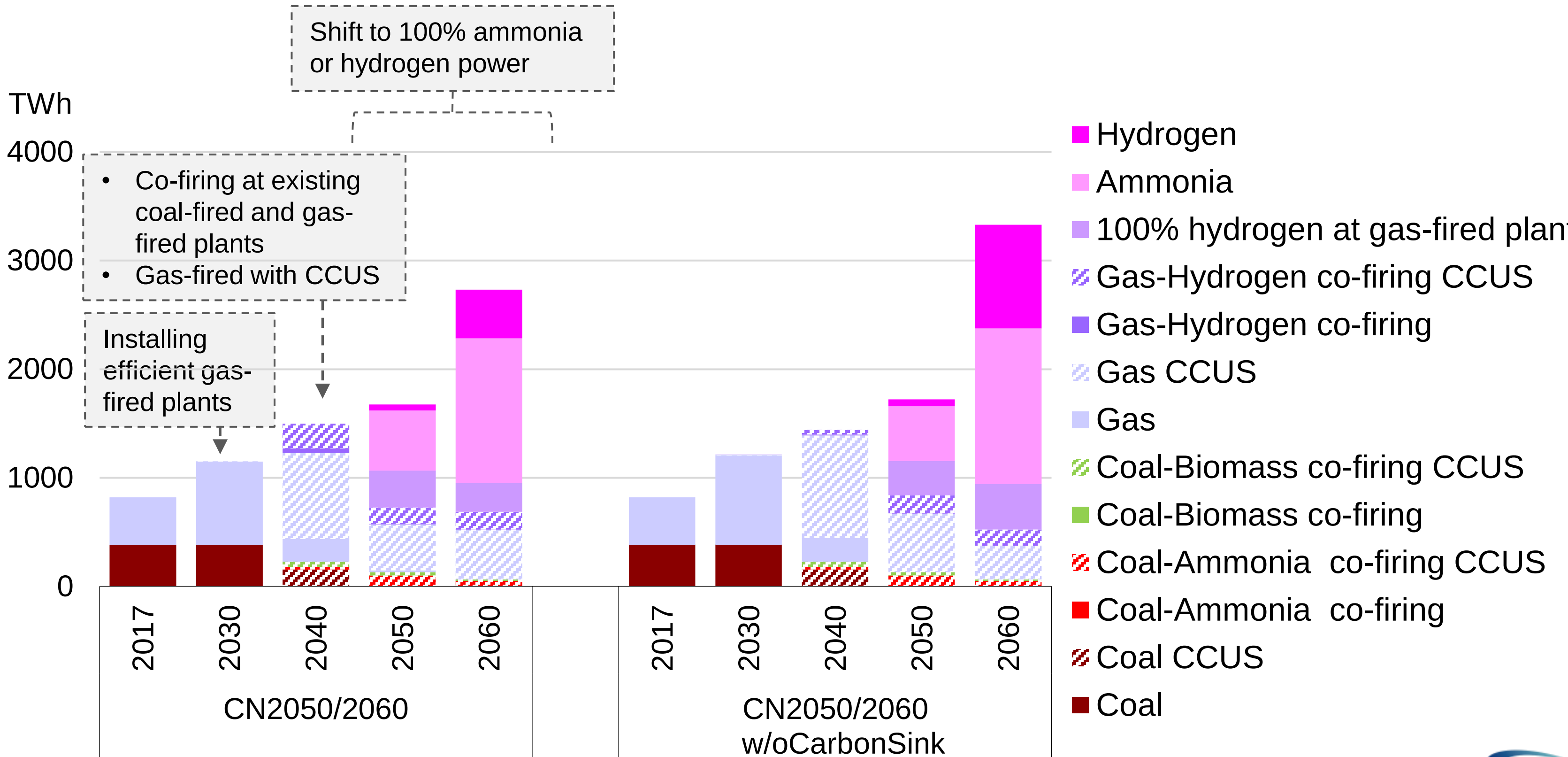
Power generation in ASEAN



Transition from fossil fuels to NH_3 & H_2 power generation

- In the short- to medium-term, such as 2030~40, efficient gas-fired plants is estimated to contribute to curbing CO_2 emissions from power generation.
- In the longer-term, gas-fired with CCUS, co-firing with ammonia or hydrogen, and 100% ammonia and hydrogen power would be candidates.

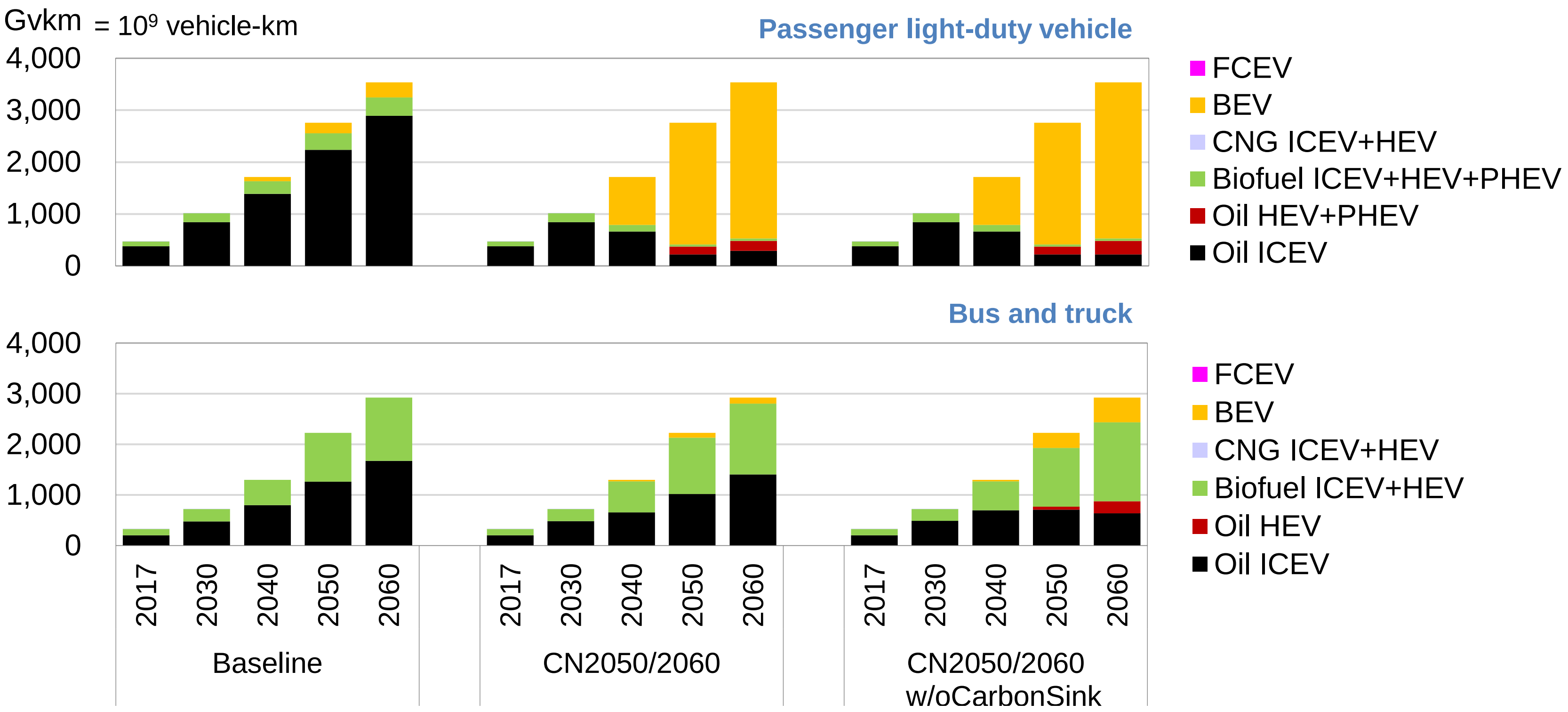
Power generation from coal, gas, ammonia and hydrogen in ASEAN



Road transport vehicle

- Passenger light-duty vehicles are projected to be largely electrified by 2050.
- Oil consumption remains in bus and truck transport in the *CN* cases mainly due to high price for alternative vehicle technologies.

Travel distance by vehicle technology in ASEAN

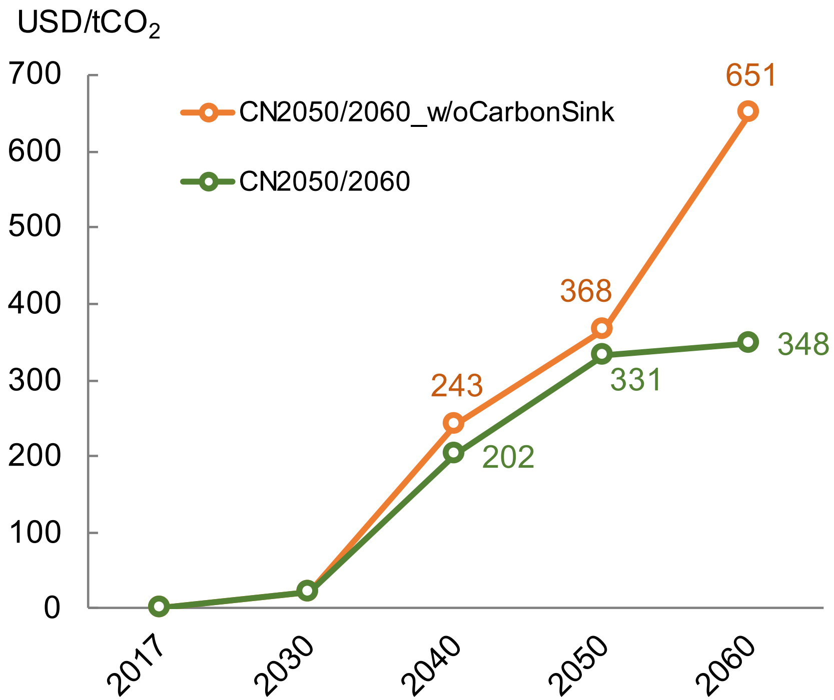


Note: biofuel includes bioethanol and biodiesel mixed with petroleum fuel.

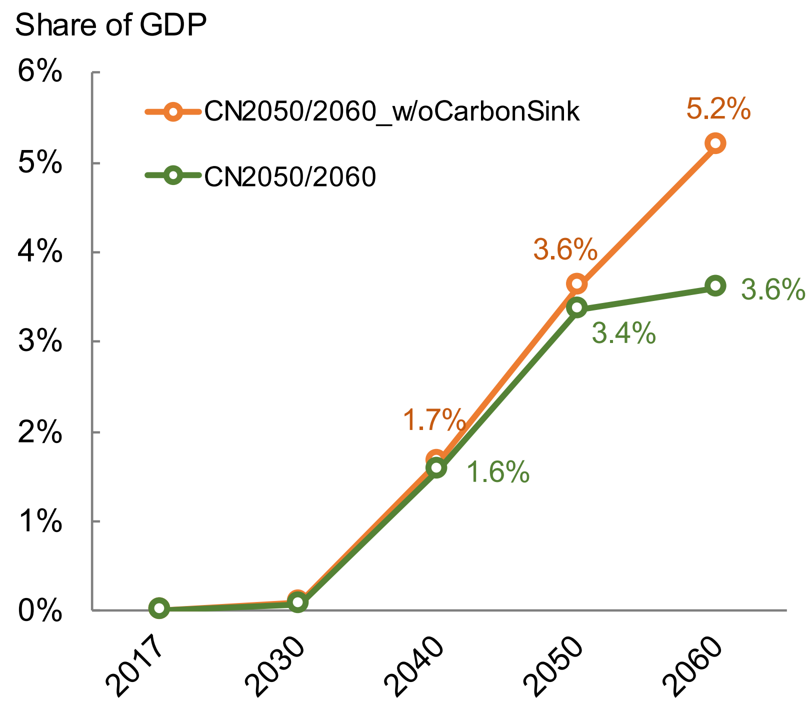
Costs for reducing CO_2

- Marginal abatement cost, which represent the intensity of decarbonization policies, would be 348 USD per tCO_2 in the *CN2050/2060*, and 651 USD in the *CN2050/2060_w/oCarbonSink*, implying economic challenges for net zero emissions.
- Additional annual cost from the *Baseline* to the *CN2050/2060* and the *CN2050/2060_w/oCarbonSink* is estimated to be about 3.6% and 5.2% of ASEAN GDP in 2060.

Marginal CO_2 abatement cost (MAC)
ASEAN weighted average



Additional annual cost
ASEAN total



Note: The costs presented here do not include costs to enhance emissions reductions in the LULUCF sector.

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Sensitivity analysis 1

Impacts of technology innovation

Five technology innovation cases (*PowerInov, CCSInov, H2Inov, DemInov and Combo*) to investigate their impacts on energy mix and mitigation costs.

Case	CN year	Key technology assumptions
CN2050/2060	2060	• Reference technology cost • International power grid extension is constrained by planned ASEAN Power Grid capacity • CO_2 storage up to 1.6GtCO_2/year in 2060
PowerInov	2060	• Cost reduction of Li-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 DAC (-25% in 2040 and -50% after 2050) • CO_2 storage up to 2.7GtCO_2/year in 2060
H2Inov	2060	• Cost reduction of coal gasification, methane reforming and electrolyzer (-25% in 2040 and -50% after 2050) • Cost reduction of hydrogen consumption: H_2 based DRI-EAF and FC 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	• Combination of all the above

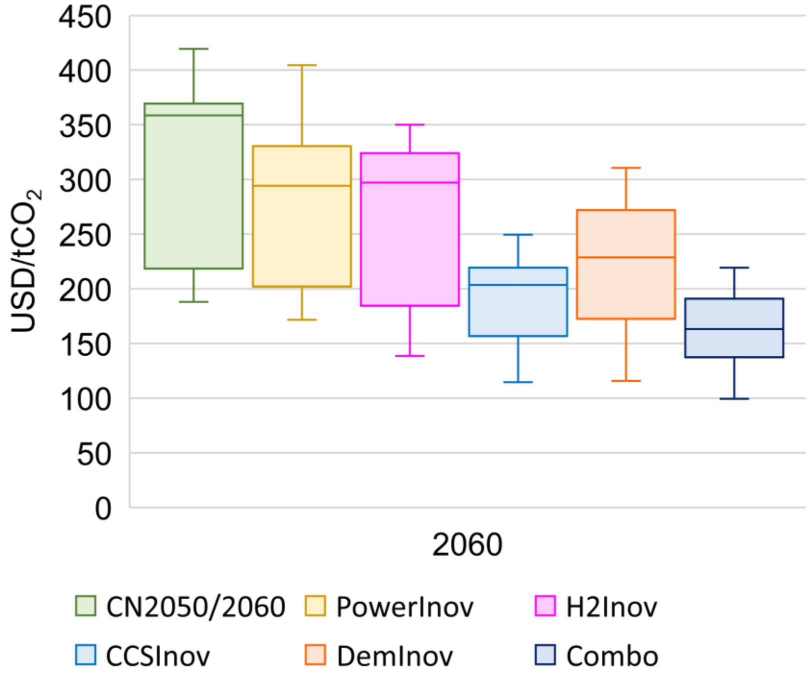
DRI-EAF: Direct Reduced Iron-Electric Arc Furnace, FC: Fuel Cell, FCEV: Fuel Cell Electric Vehicle

Innovation and mitigation costs

- Technology innovation, as well as ASEAN energy cooperation such as APG, significantly reduce marginal abatement costs and additional annual costs.
- Future research & development and cooperation is crucial for realizing net zero emissions.

Marginal CO_2 abatement cost (MAC)

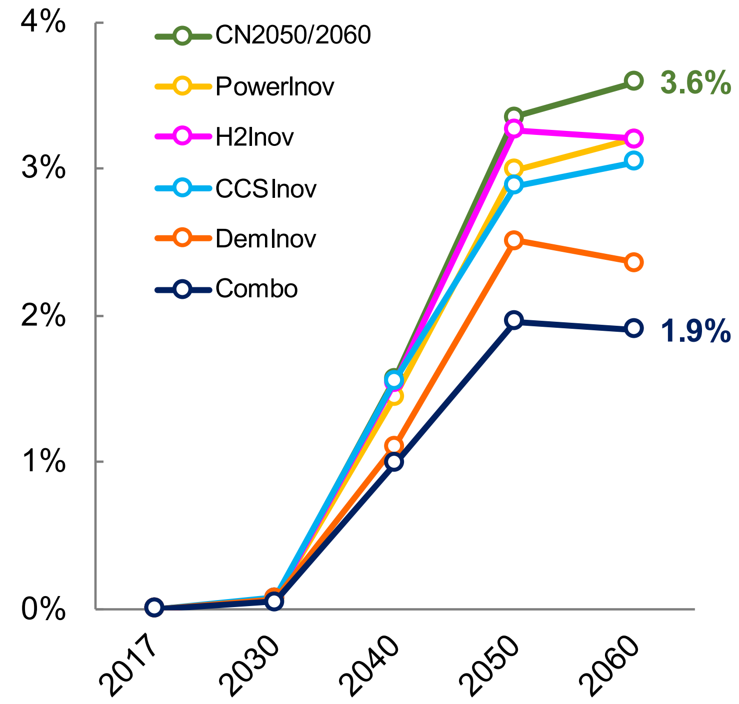
Range of country marginal cost in 2060



Additional annual cost

ASEAN total

Share of ASEAN GDP



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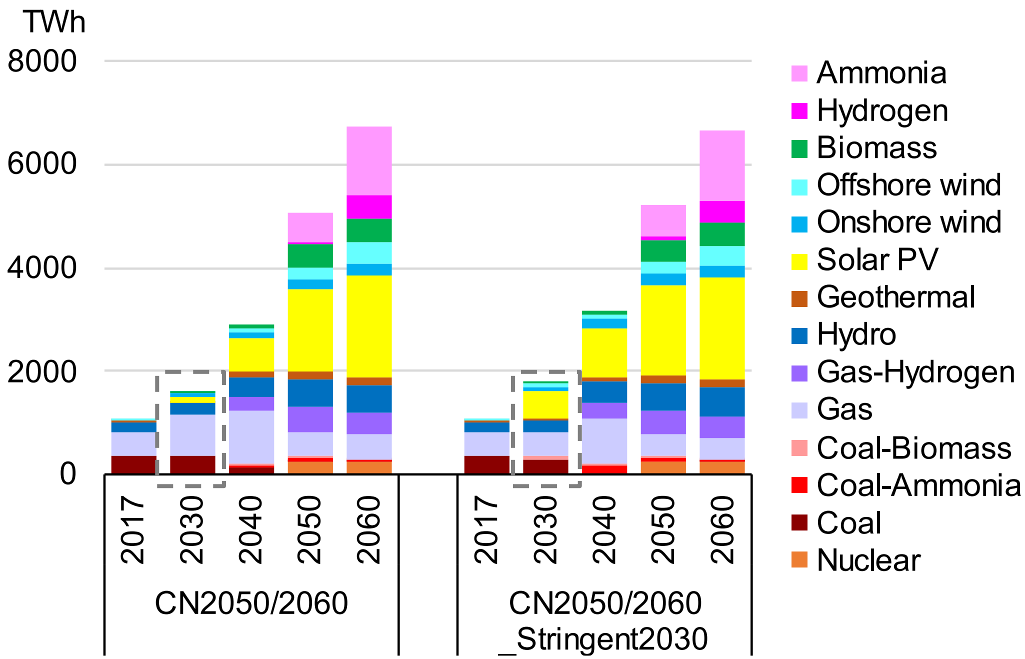
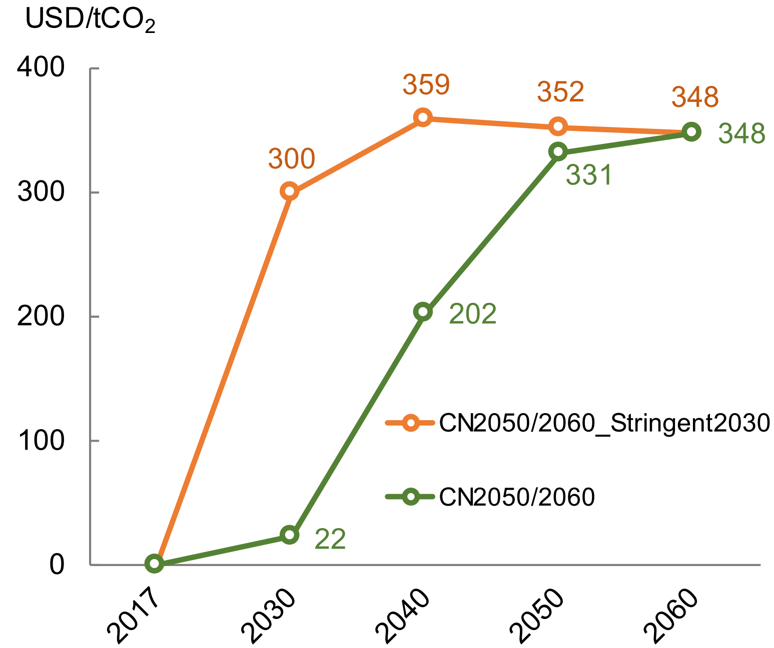
Impacts of strengthening short-term emission constraints

- As for the power generation mix, solar PV increases while gas-fired decreases in 2030 in the *CN2050/2060_Stringent2030* by strengthening short-term emission constraints.
- MAC in 2030 increases significantly to 300 USD/tCO_2, implying the cost hurdle to achieve short-term emission reductions.

Power generation in ASEAN



Marginal CO_2 abatement cost (MAC)
ASEAN weighted average



Note: The value of the objective function is larger in the *CN2050/2060_Stringent2030* than in the *CN2050/2060*.

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Conclusions (1)

- Energy saving and electrification in end-use sectors, combined with low-carbon power supply, would be core strategies for decarbonizing ASEAN energy systems.
  - Not only VRE, but also other carbon-free technologies including hydro, geothermal, biomass, and nuclear can contribute to carbon neutrality.
  - CO_2-free hydrogen supply, CCS, and negative emission technologies are also important.

- During transition periods, various kinds of “low-carbon” technologies can reduce CO_2 emissions effectively.
  - In the power sector, fuel switching from coal to natural gas, deployment of more efficient turbines, co-firing with hydrogen or ammonia, as well as fossil-fuel fired power generation with CCS can contribute to following paths towards deep decarbonization.
  - Affordable technologies are likely to be introduced in the mid-term. Deployment of more expensive technologies would be required in the last stage of complete decarbonization.

Conclusions (2)

Simulation results would imply significant economic challenges associated with decarbonization.

- Mitigation costs and energy prices may increase in the *CN* cases.

Cost reduction and international cooperation would be the key to achieve carbon neutrality in an affordable manner.

- Technology innovation and scale merits are essential for cost reduction.
- Regional cooperation would contribute to more efficient deployment of low carbon technologies.
- Future research & development, in cooperation with advanced economies, is crucial for achieving carbon neutrality in the long term.