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Renewable pathways to climate-neutral Japan

Study results

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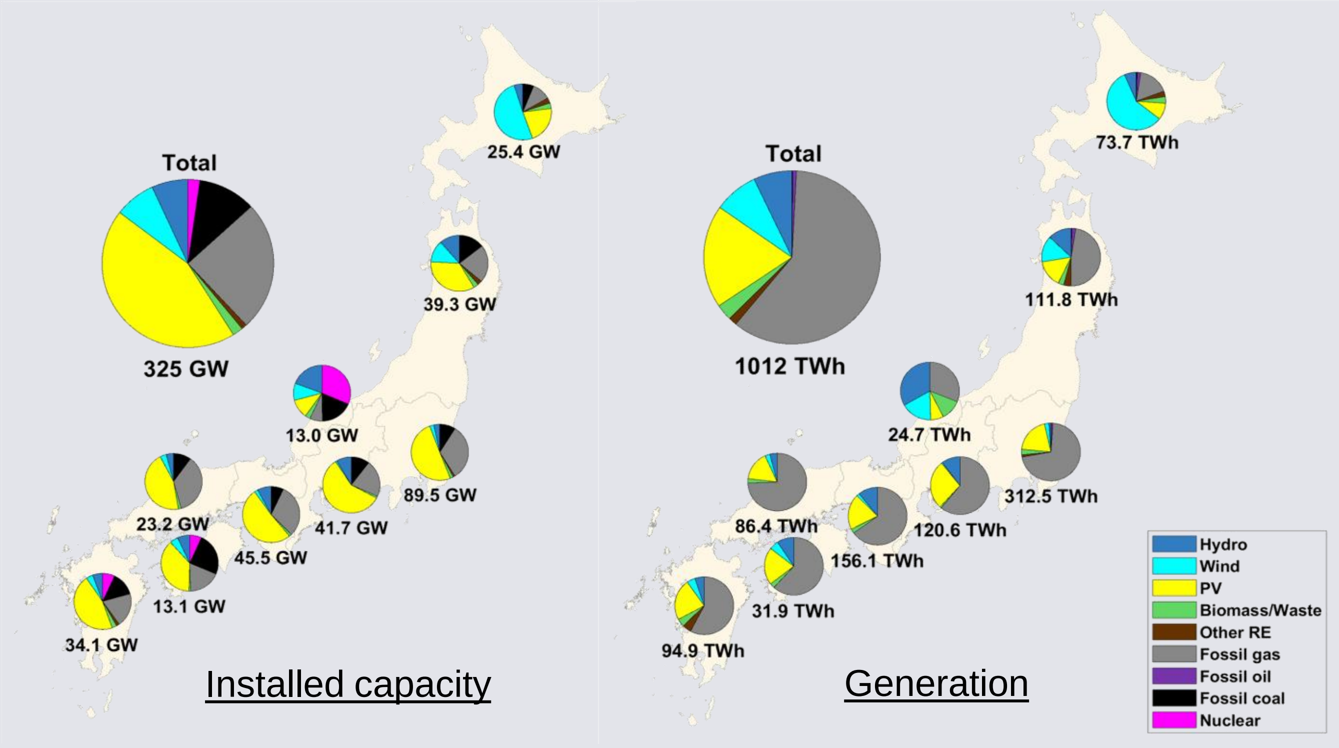
LUT University performed a first of its kind modelling of the Japanese energy system, across sectors, across regions and at a one-hour time resolution

LUT Energy model	Setting
→ Modelling of an optimally structured energy system: • optimal set of technologies, best adapted to the availability of the country's resources • optimal mix of capacities for all technologies • optimal operation modes for every element of the energy system • least cost energy supply for the given constraints → Key features of the model: • linear optimization model • hourly resolution • 5-year step • multi-node approach: 9 grid regions for Japan • flexibility and expandability	→ Modelled sectors • Power sector • Heating & Cooling • Transport sector → Japanese specificities: • Japan is an island without power grid interconnections today • Limited land availability for RES • Technology cost overall higher than global benchmark

Step 1: -45% GHG by 2030. Coal phase-out and at least 40% renewable electricity contributes the lion's share of emission reduction

Installed capacity & generation in 2030



Agora-REI-LUT (2021)

Power sector:

- Coal & nuclear phase out
- Electrification: +5% power demand
- Solar PV capacity more than doubles, onshore wind quadruples (144 GW solar PV and 25 GW wind installed capacity by 2030)*
- Half of PV capacity from prosumers
- RE generation: 400 TWh (185 TWh today)

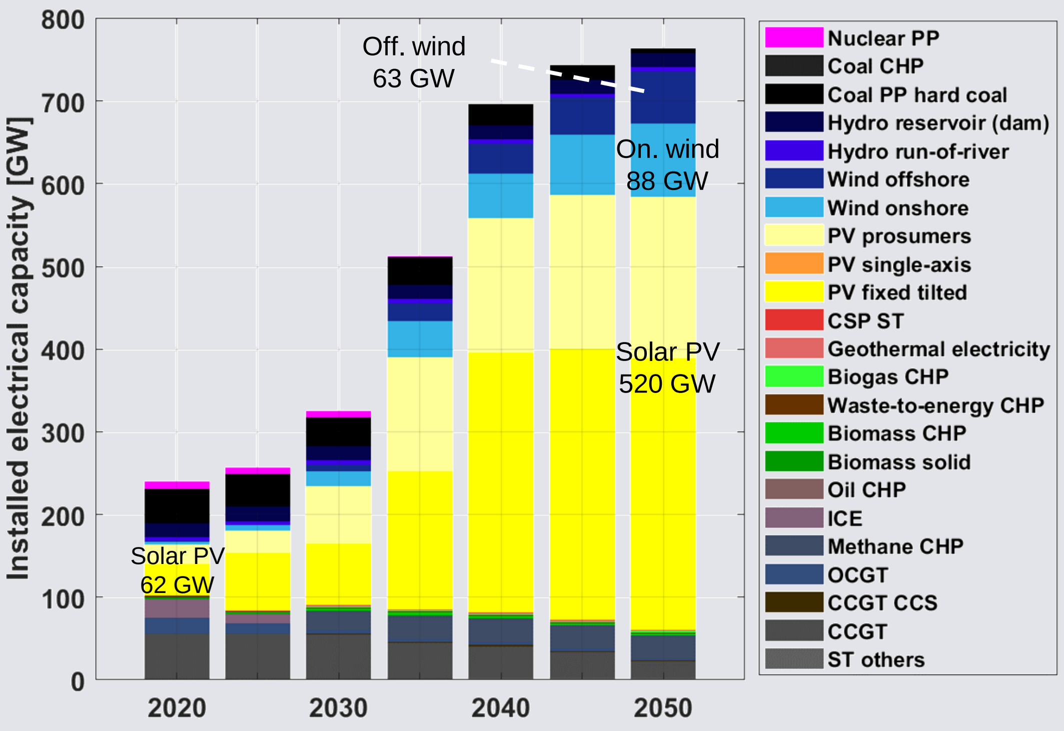
Building, Transport, industry:

- Direct electrification
- Energy efficiency

*This amounts to an annual installed capacity of 8.4 GW of solar PV, 1.5 GW of onshore wind, and 0.7 GW of offshore wind between 2021 and 2030.

Step 2: -90% GHG by 2045 relative to 2010

Installed capacity between 2020 and 2050 towards a RES-based energy system



Agora-REI-LUT (2021)

Power sector:

- Electrification: +30% power demand, ~1300 TWh (mostly for heat)
- RE generation: 97% of power mix
- RE capacity*:
  - Solar PV 3.5x (almost max potential)
  - Onshore wind 3x mostly in Eastern regions, supplies power for H_2 production
  - Offshore wind close to load centers (H_2): 44 GW

Buildings: decarbonized by 2040 – heat pumps

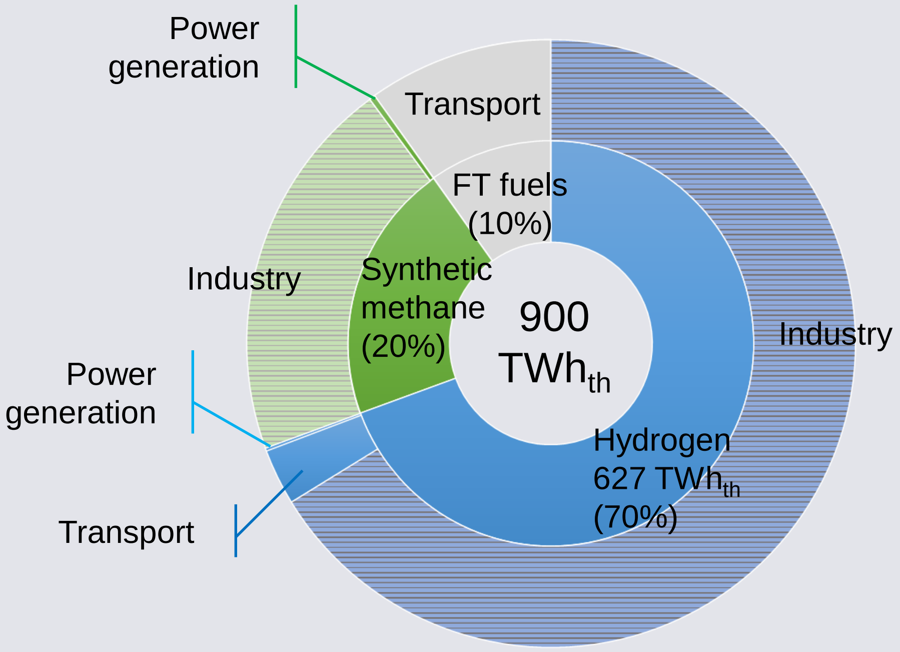
Transport, industry:

- Direct electrification
- Energy efficiency
- Synthetic fuels: Fischer-Tropsch for transport, H_2 & methane for industry

*This amounts to an annual installed capacity of 18.5 GW of solar PV, 2.8 GW of onshore wind, and 2 GW of offshore wind between 2031 and 2045.

Step 3: By 2050: Increased use of green synthetic fuels in the last step to eliminate residual emissions

Green synthetic fuels demand in 2050 in the BPS scenario with imports



Agora-REI-LUT (2021)

→ Variable RE reach 670 GW in 2050 (10x). Max potential set in study exhausted for solar PV

→ Deep electrification: +50% power demand (1,430 TWh)

→ Green synthetic fuels demand: 900 TWh_{th}
- Largely for industry and H_2
- 50% of H_2, most synthetic methane and FT fuels imported
- Almost no synfuels for power generation

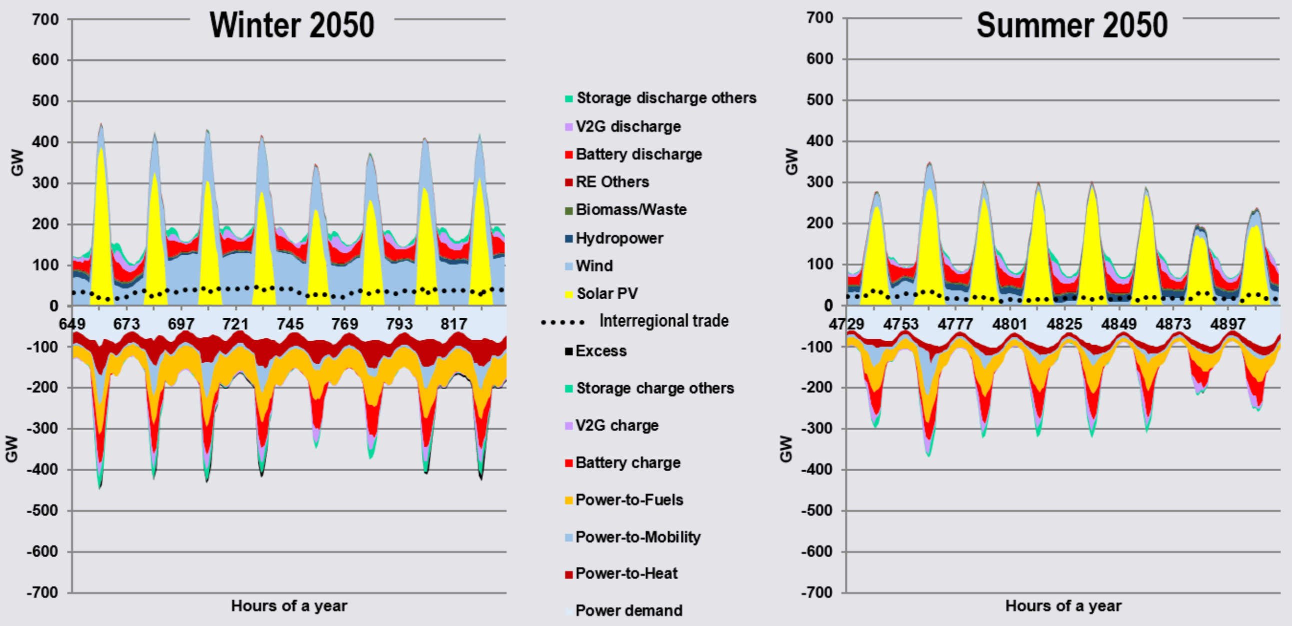
→ H_2 production:
- Electrolyzers: 73 GW
- Power for H_2: 430 TWh_{el} (30% of demand) Mostly by wind (off & onshore ~140 GW)

→ System dependency on import: 32%
Without imports of syn fuels:
- + 190 GW wind
- + ~100 GW transm. grid (4x instead of 2x)

* International maritime transport and aviation are not included in this study.

System stability is achieved throughout the year thanks to flexible demand, flexible energy sources and e-fuel imports

Typical weeks during winter and summer in 2050

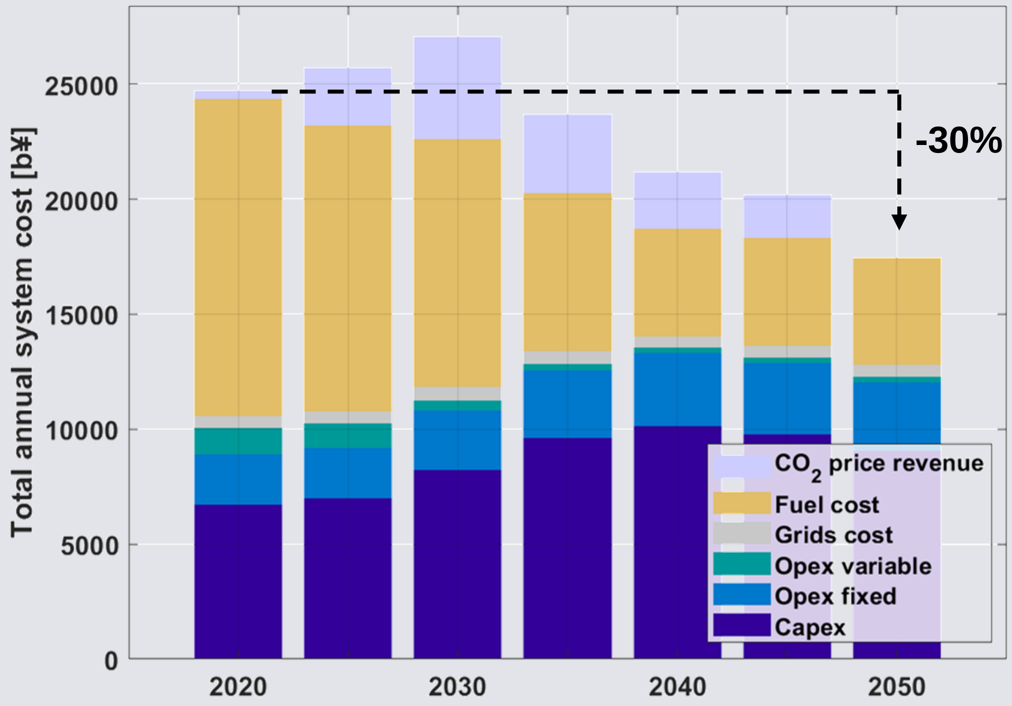


Agora-REI-LUT (2021)

- System capacity > 750 GW
- Peak load: 84 - 490 GW (summer night – winter midday)
- Flexible demand activated when high RE feed-in: storage, V2G charging, power-to-mobility, power-to-heat, power-to-fuels
- Flexible energy sources available in sufficient amounts when low RE feed-in: hydro dams, pumped-hydro storage, gas turbines and gas CHP running on biogas and e-fuels, biomass power plants and CHP, battery storage, as well as some wind capacity generating during every hour of the year (> 200 GW)
- Curtailment: 1.1%

This renewable decarbonized energy system can be built by 2050 at a reasonable cost, with total system cost about 30% lower in 2050 than in 2020

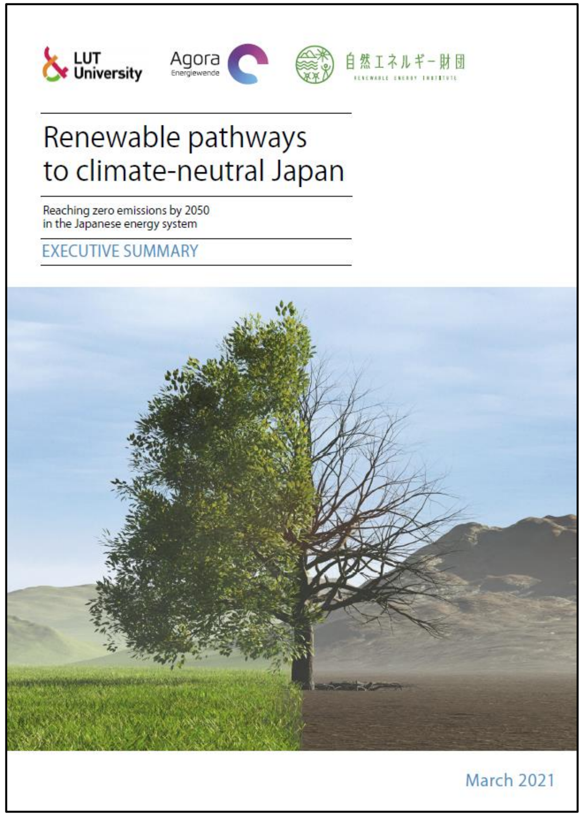
Total annual system cost per cost component (in b¥)



Agora-REI-LUT (2021)

- Total system cost
  2020: 24.7 trillion ¥ (224 b$) 4.4% of GDP
  2050: 17.4 trillion ¥ (158 b$) 3% of GDP
- Heat sector becomes the main cost driver by 2050 (synthetic fuels)
- Important investments required: CAPEX-related system costs increase throughout the transition, compensated by the decline of fossil fuel imports
- Investments: mostly in PV, followed by wind energy – about 1.4%-3.2% of current gross investment levels
- As a comparison: fossil fuel imports currently ~17 trillion ¥ (154 b$) yearly, representing 22% of Japanese imports in value

Key findings



1. **Net zero emissions can be achieved in Japan at reasonable costs based on renewables deployment and electrification.** An interim target of at least 40% renewables in power generation is required in 2030 to transition towards a 100% objective in 2050. Electrification of heat, transport and industry, as well as various flexibility options (such as grid reinforcement, storage and demand-side flexibility) will facilitate the integration of renewables, while bringing down emissions to net zero in 2050.

2. **A three-step roadmap is needed to achieve climate neutrality by 2050.** The first step consists of a 45% reduction in greenhouse gas emissions by 2030 (relative to 2010). Second, emissions must decline by at least 90% by 2045 (relative to 2010). Finally, green synthetic fuels eliminate residual emissions, mostly from high-temperature heat generation in industry.

3. **Hydrogen will be used sparingly, even if it is imported, as direct electrification is more efficient and less expensive.** Direct electrification should therefore be prioritized wherever possible in transportation, space heating and low and mid-temperature heat in industry. Domestic production of green hydrogen will also put considerable pressure on the power system.

4. **Nuclear power is not necessary to achieve the long-term decarbonization target at lower cost.** Renewables will outcompete nuclear new build and lifetime extension projects already by 2025, leading to a gradual phase-out of nuclear power plants at the end of their technical lifetime if not stopped earlier.

5. **Japan has to kick-start enhanced climate action as soon as possible and increase its interim sectoral targets to reach 45% lower GHG emissions and at least 40% renewables in power generation by 2030.** The upcoming discussions on the 6th Strategic Energy Plan and concrete regulatory measures, such as an effective carbon pricing mechanism, will be crucial to determine how Japan goes about achieving those interim 2030 targets and climate neutrality by 2050.

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Thank you for your attention!

Questions or Comments? Feel free to contact me:

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