Computational simulation of nationwide high-voltage power grid in Japan under large-scale renewable integration

(再エネ大量導入下での全国の電力基幹系統の数値シミュレーション)

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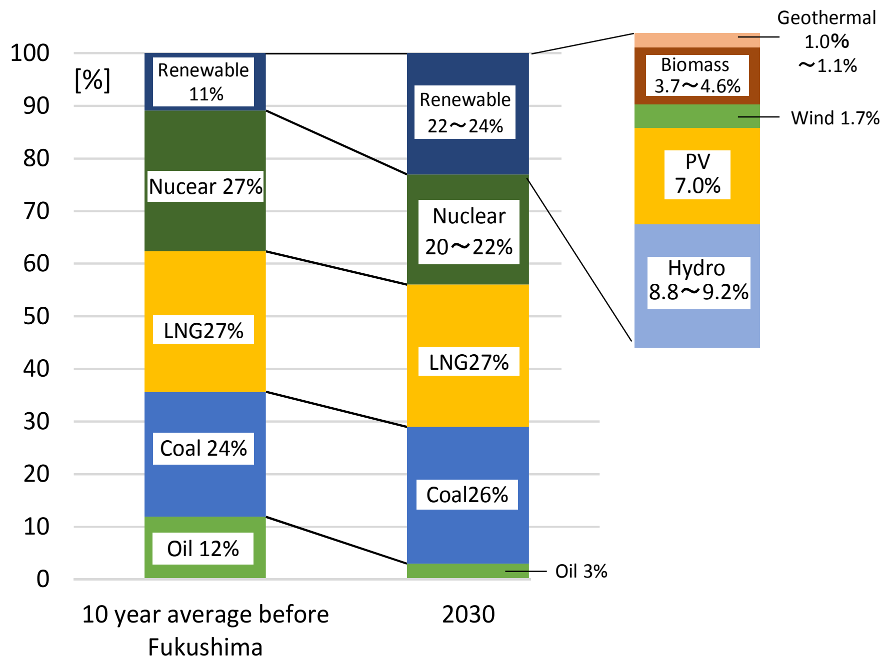
Outline

- **RES Integration & Optimal Power Generation Mix (最適電源構成モデルによる再エネ導入評価)**
- **Renewable-Hydrogen (再エネ水素電力貯蔵)**

Official Target of Optimal Power Generation Mix in 2030

- Long-term energy outlook to 2030 of Japan was published in July 2015 by Ministry of Economy, Trade and Industry (METI).
- The most important agenda consists in the maximization of the fraction of renewable energy (22～24%) after the Fukushima nuclear accident.

Outlook of Power Generation Mix in 2030



(Source) METI(Ministry of Economy, Trade and Industry)

Optimal Power Generation Mix (OPGM) Model in Japan

(Source) Sugiyama, T., Komiyama, R. and Fujii, Y, ***IEEJ Transactions on Power and Energy***, in Japanese, Vol.136, No.12, 2016 (to be published)

Optimizes the set of endogenous variables which minimizes the objective function under the given constraints

Objective Function

＝ **Fixed Cost** (power sources, storages, transmission lines ＋ **Fuel Cost** (thermal, nuclear) ＋ **Power Storage Cost***

* Power Storage Cost = Capacity Cost + Energy Cost + Cost of consumable parts

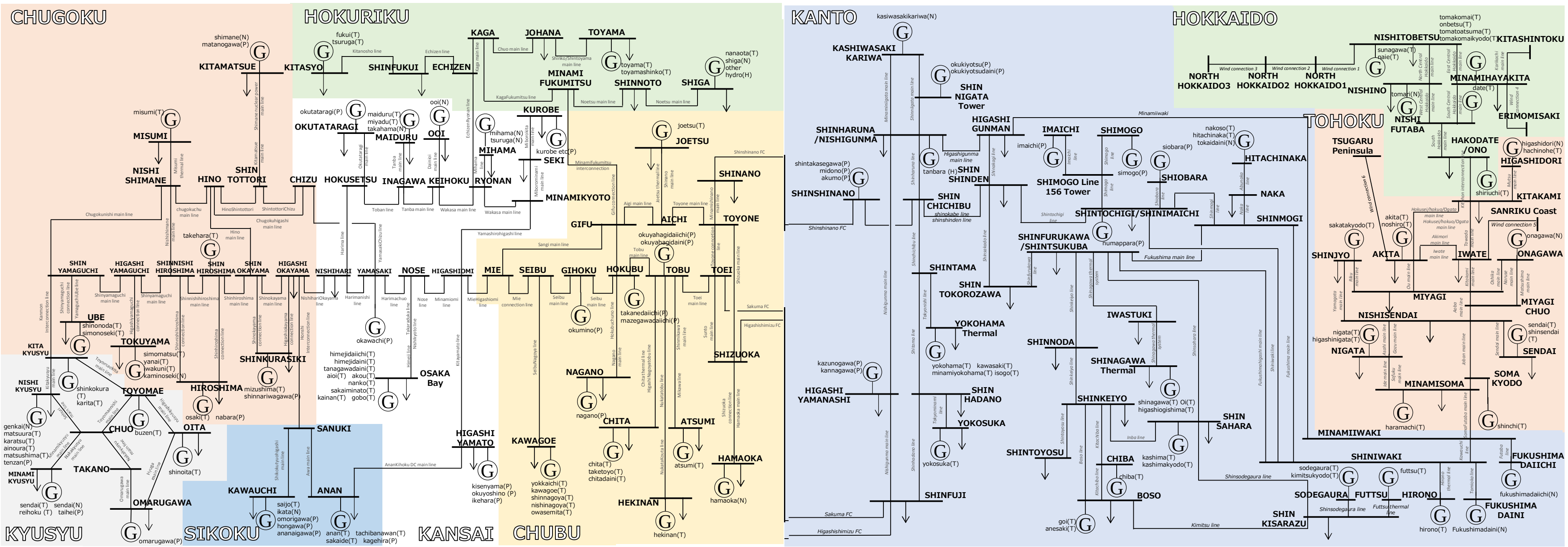
Constraints

supply-demand balances, capacity constraints, power supply reserve constraints, load following capability constraints, CO_2 emission constraint, power transmission capacity constraints, charge and discharge balance of power storage, C-rate constraints, ………………

Power Line Network of OPGM model in Japan

(135 nodes, 166 transmission lines)

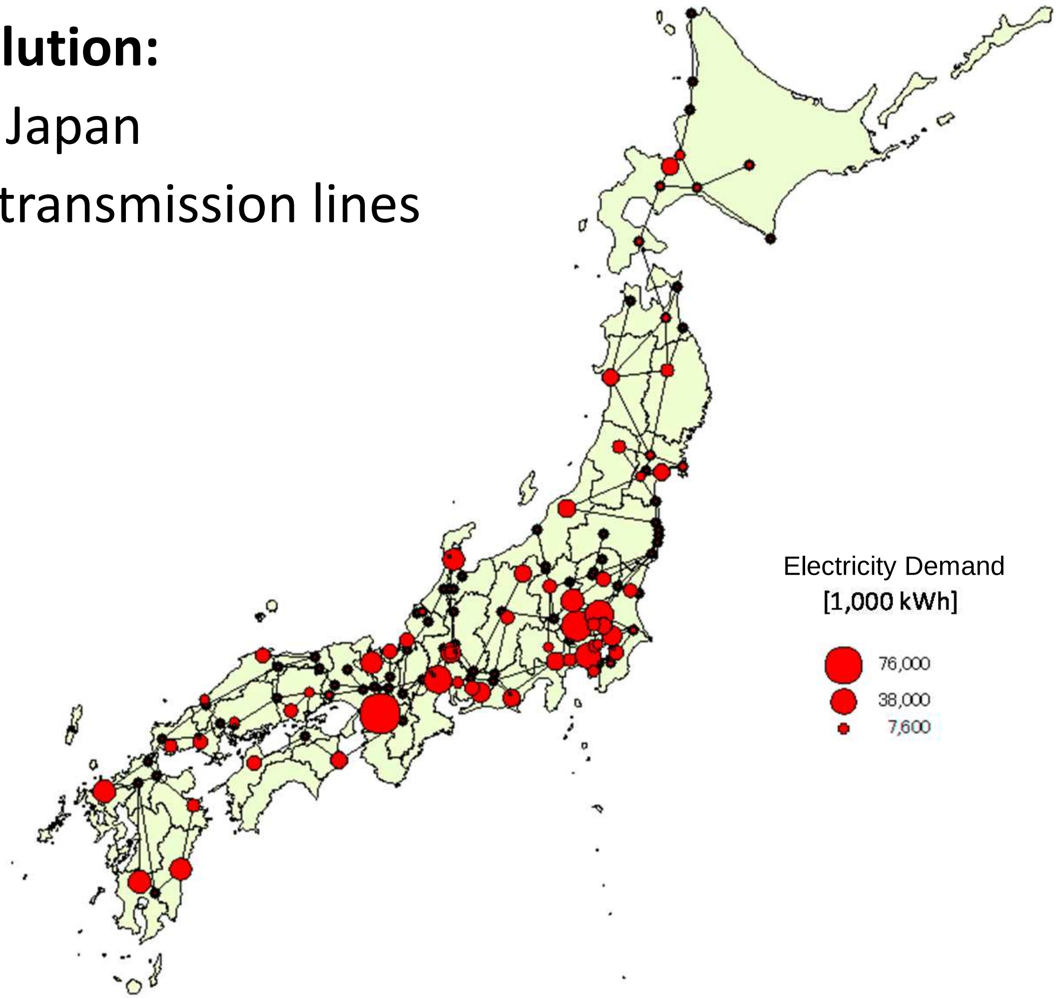
Western Japan (60Hz) *Eastern Japan (50Hz)*



Network Topology and Electricity Demand

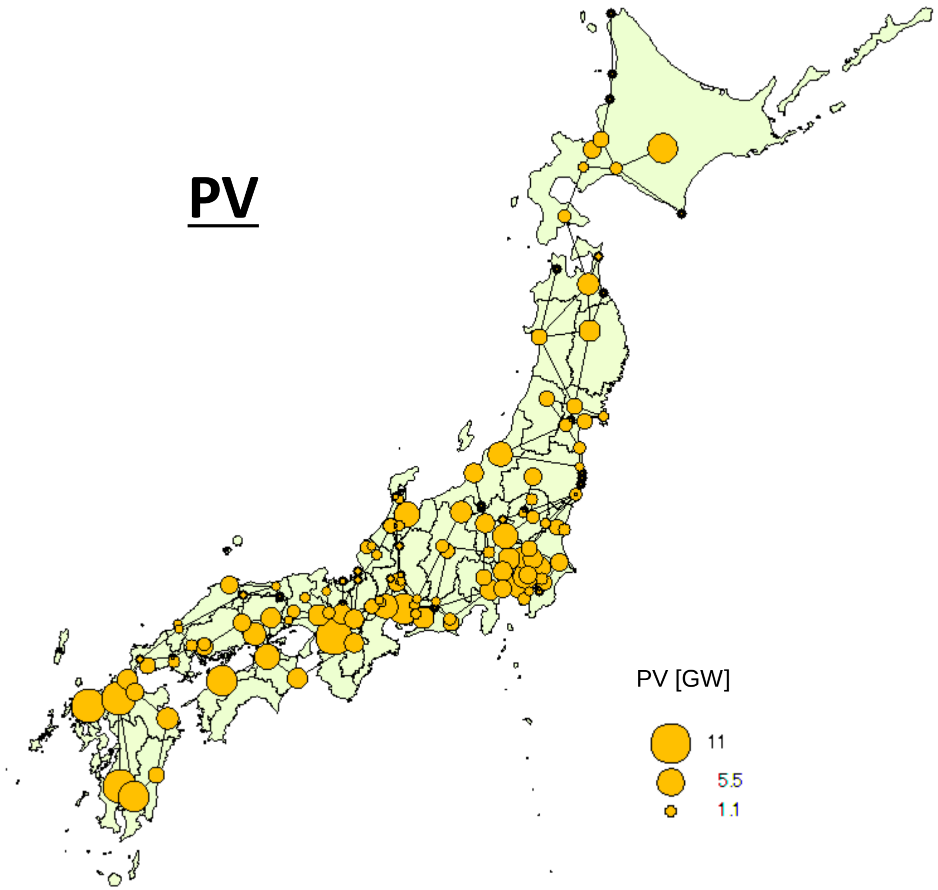
Geographical Resolution:

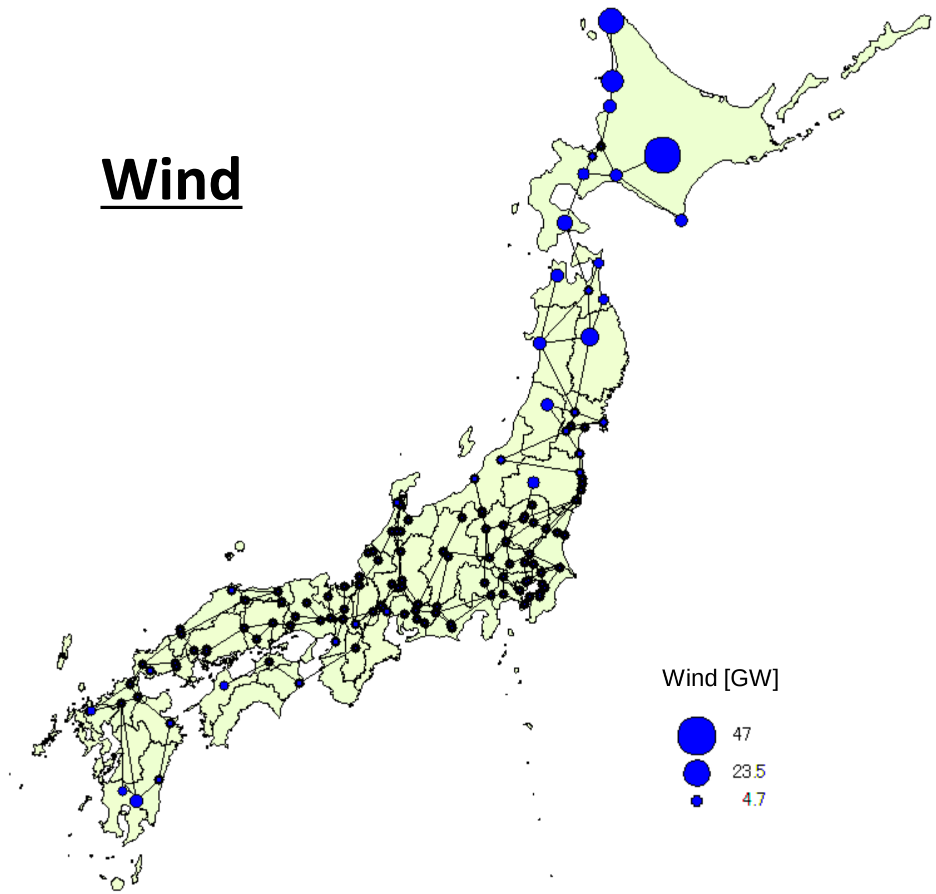
- whole region of Japan
- 135 nodes, 166 transmission lines



PV and Wind Potential

estimated by Ministry of Environment, Japan

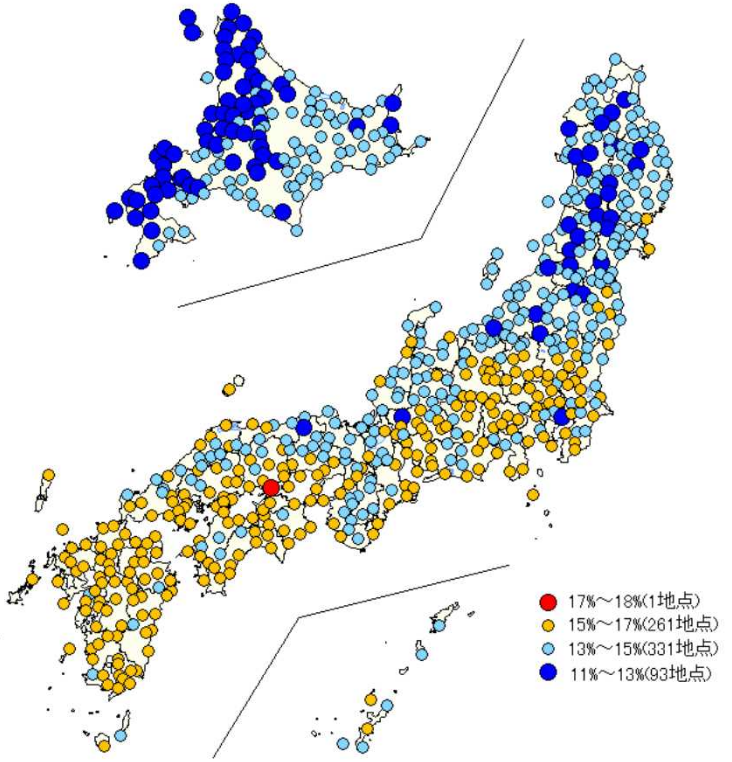




PV Output in Japan

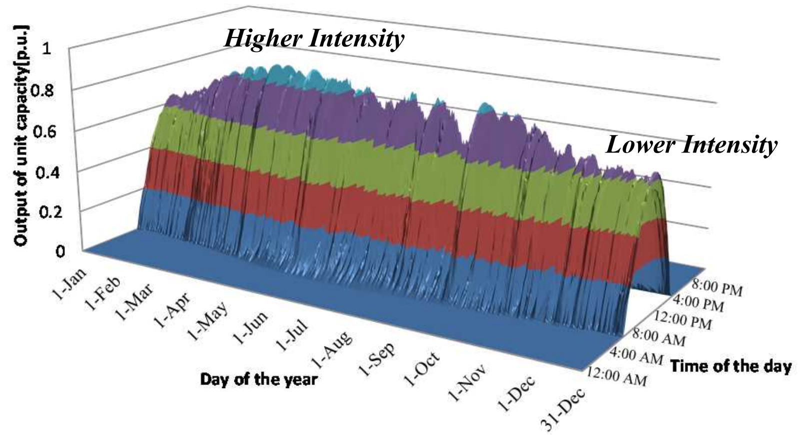
- The yearly 10-min. profile PV and wind output are estimated, using the Japanese meteorological database (AMeDAS)
- AMeDAS has around 1,300 climate observation point, which provides observed climate data on every 10 min.
- Solar insolation is higher intensity in summer and lower intensity in winter.
- Coping with its seasonal imbalance are important under large-scale introduction of PV.

PV capacity factor estimated from AMeDAS

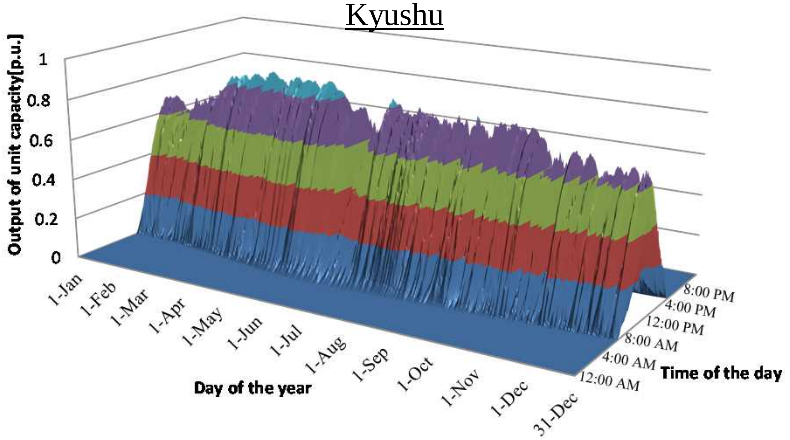


(Source) Y.Fujii, Potential Evaluation of Rooftop Photovoltaic Systems on the Basis of Nationwide Meteorological Data, JSER Conference, Osaka, June 2008

Kanto (Tokyo)



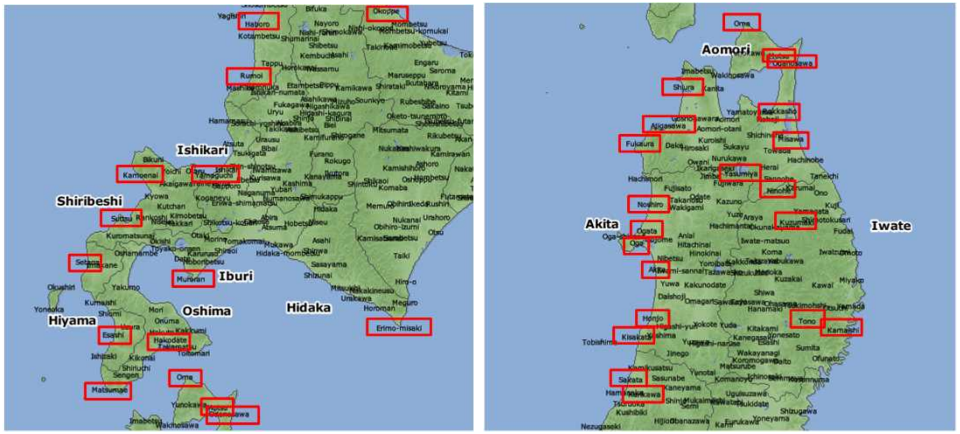
Kyushu



Wind Output in Japan

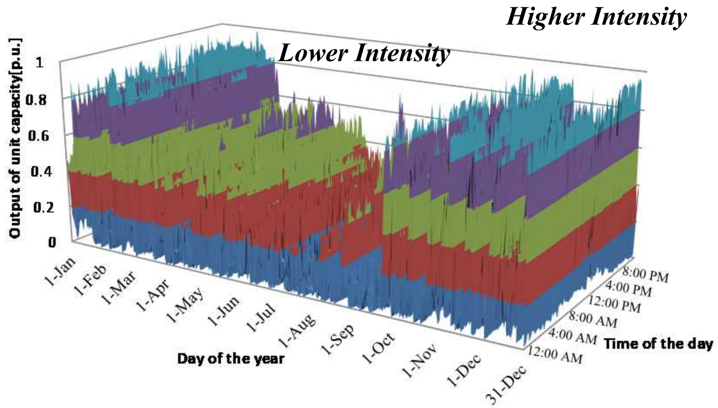
- Operating time of wind is higher than PV, but its output is more intermittent than PV.
- Wind velocity is higher in winter and lower in summer.

Location of AMeDAS in Hokkaido and Tohoku

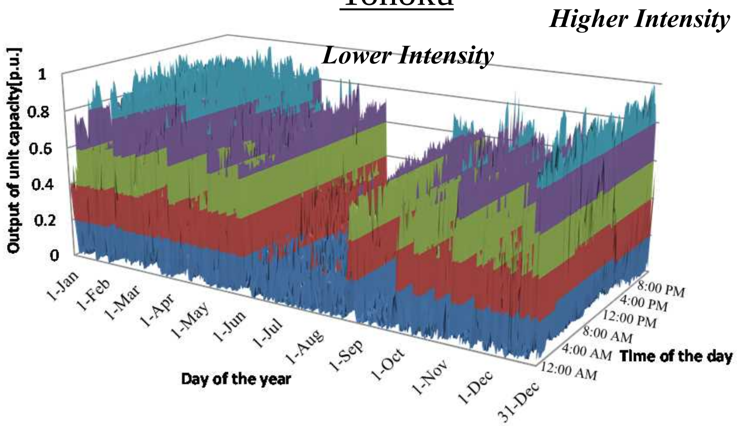


In the model, PV and wind outputs can be **curtailed**, if necessary.
(The model determines the optimal operation of PV & wind outputs among direct grid integration, storage and curtailment)

Hokkaido



Tohoku



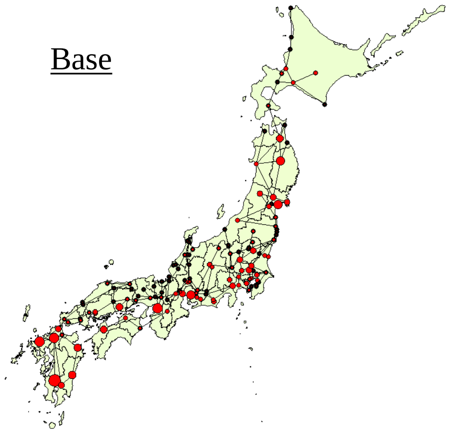
RES Scenario

RES capacity（total in 9 utility service regions）

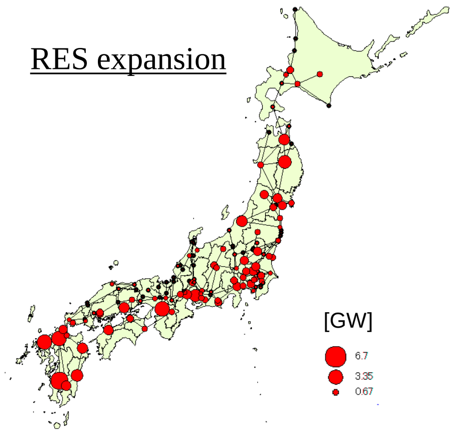
	Base case (RES fraction: 23%)	RES expansion case (RES fraction: 32%)
PV	64 GW	128 GW
Wind	10 GW	20 GW
Hydro	23 GW	23 GW
Geothermal	1.5 GW	3 GW
Biomass	6 GW	6 GW
Marine	（None）	1 GW
Total	104.5 GW	181 GW

PV

Base

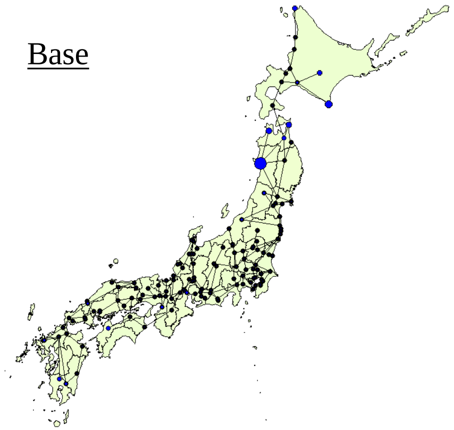


RES expansion

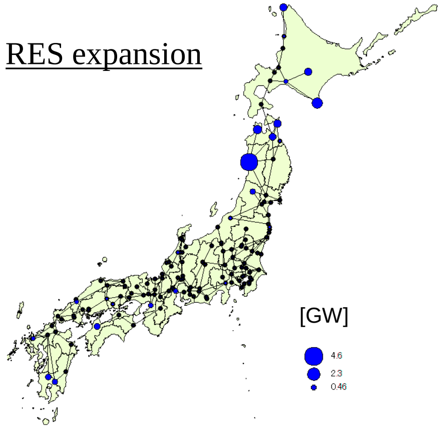


Wind

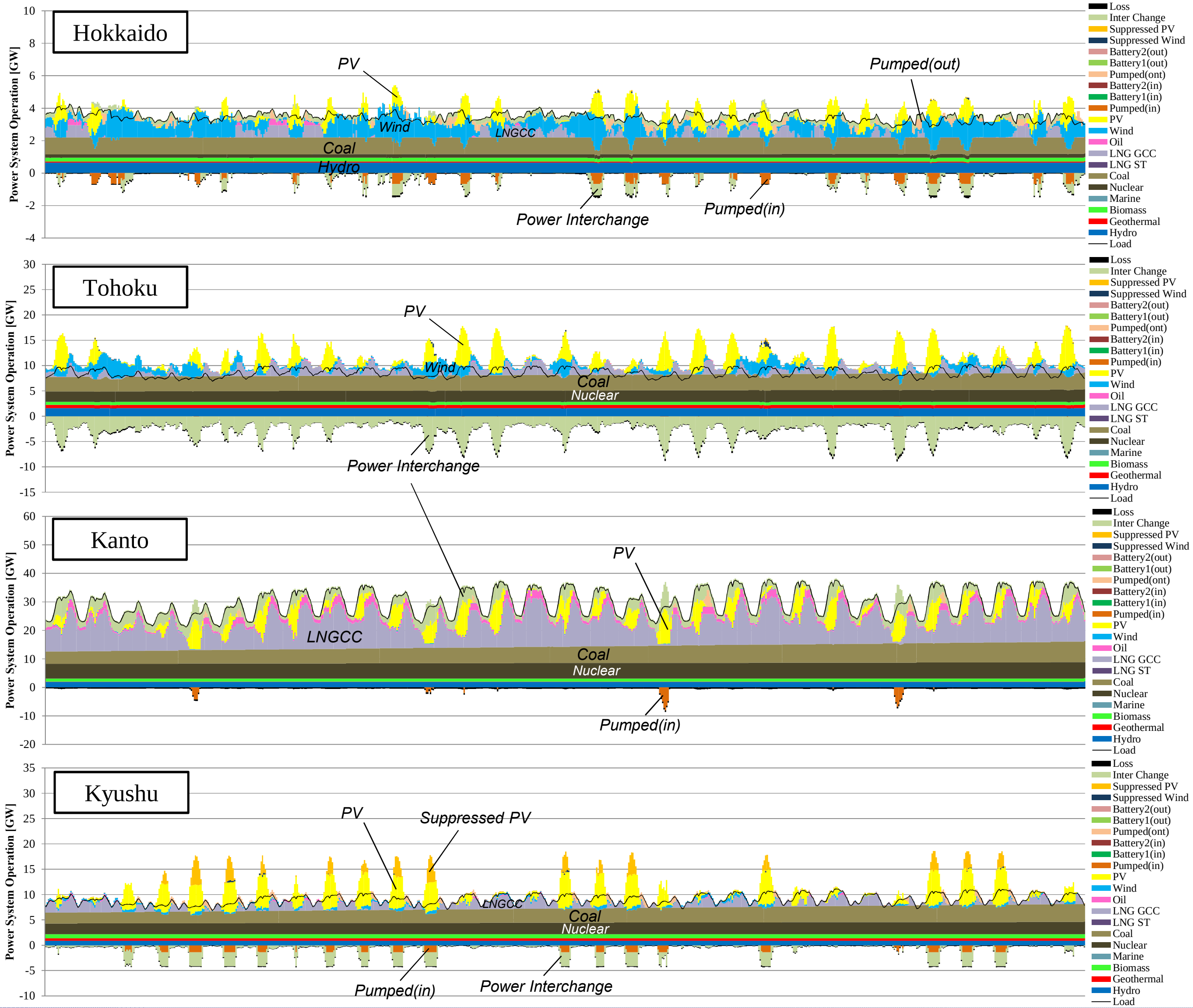
Base



RES expansion

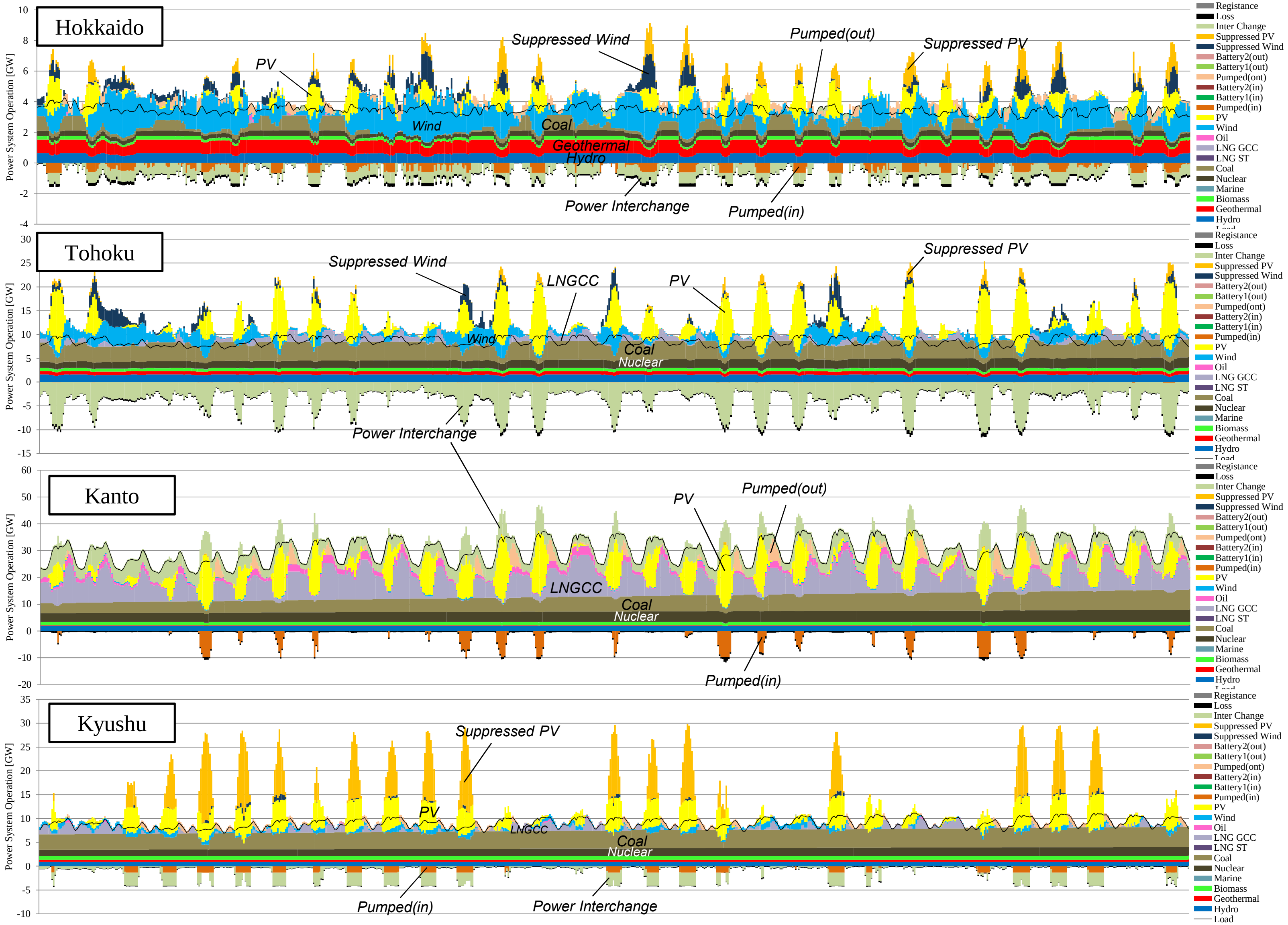


Optimal Power Dispatch (in May, Base case)



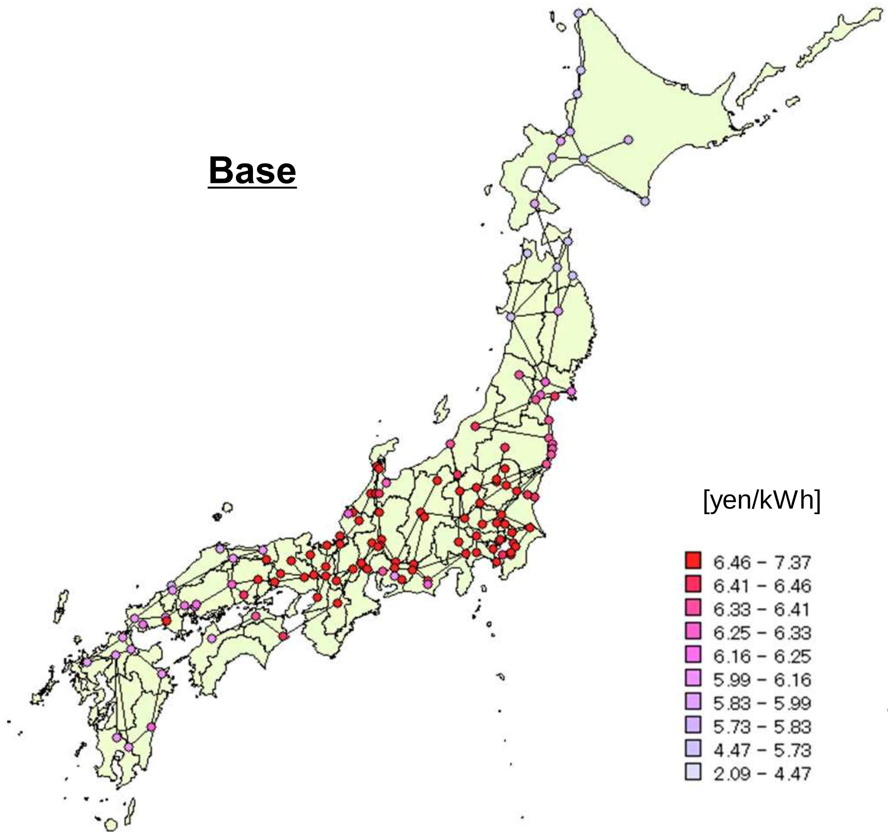
Wind

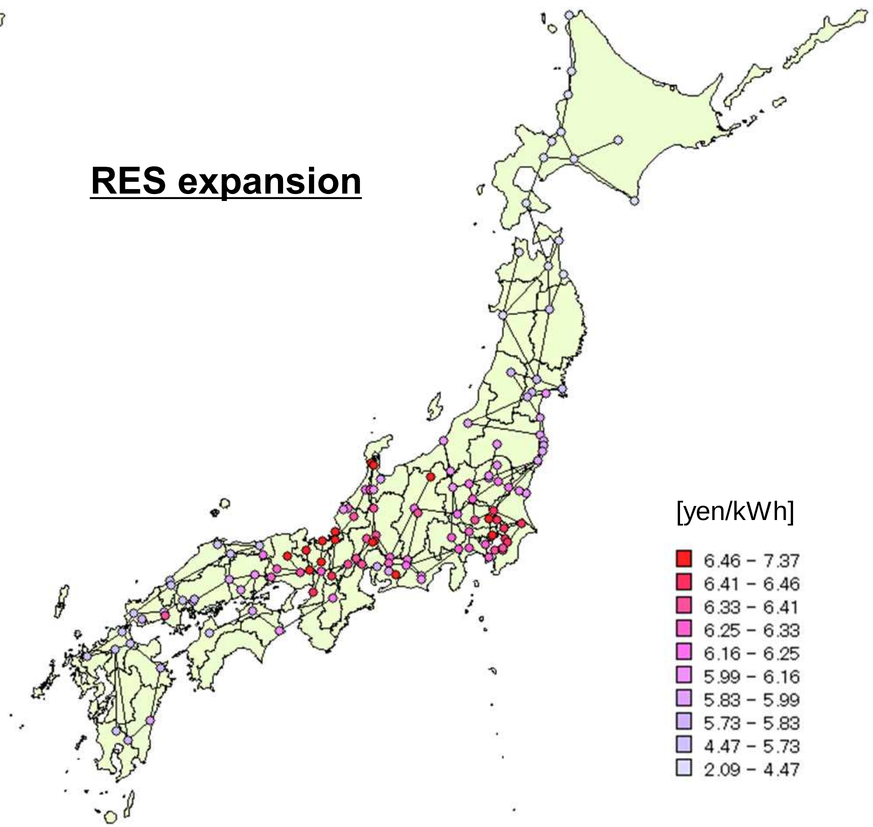
Optimal Power Dispatch (in May, RES exp. case)



Locational Marginal Price (Nodal Price)

In RES expansion case, nodal price decreases due to the surplus RES output

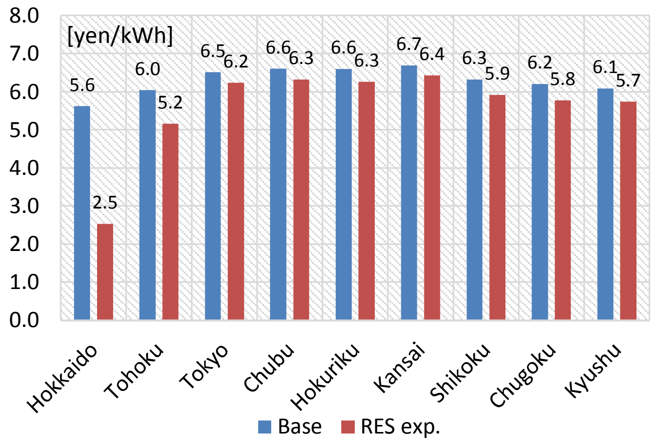




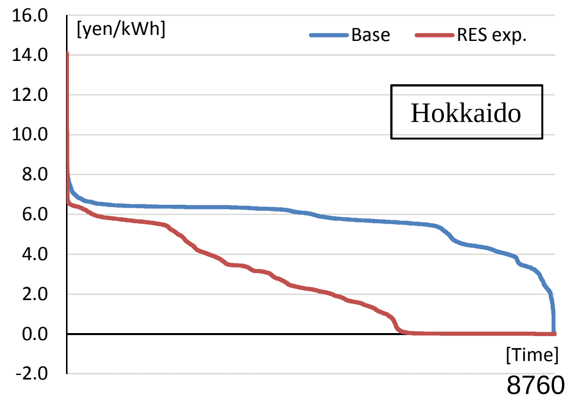
Locational Marginal Price Curve

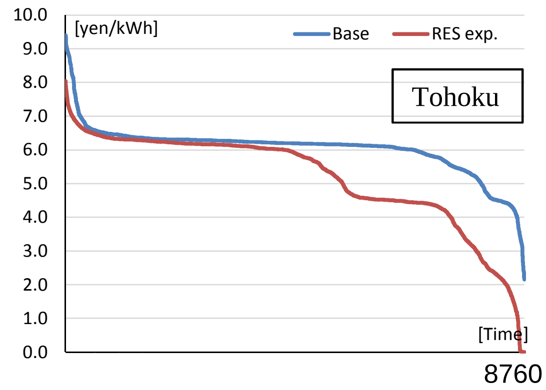
In RES expansion case, nodal price drops in a longer term in Hokkaido and Tohoku where large-scale intermittent renewables are installed.

Annual-average nodal price
in each electricity service area



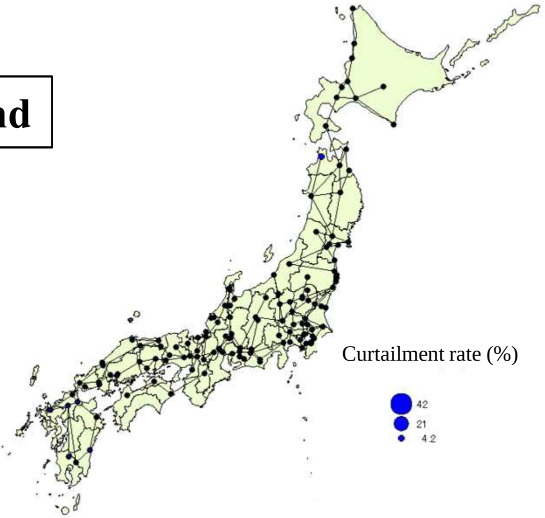
Nodal price curve in Hokkaido and Tohoku



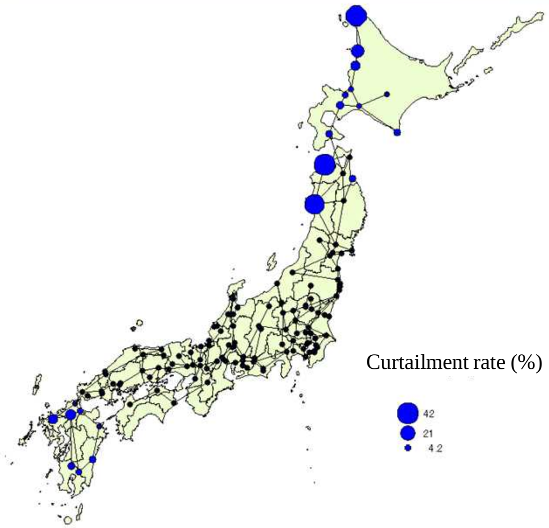


Curtailment Rate of Wind and PV Outputs

Wind

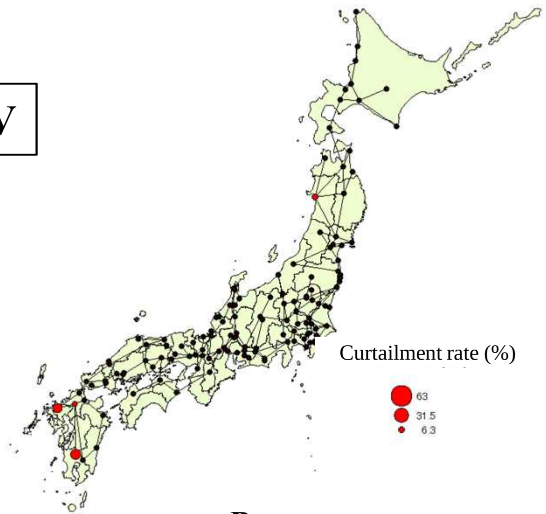


Base case

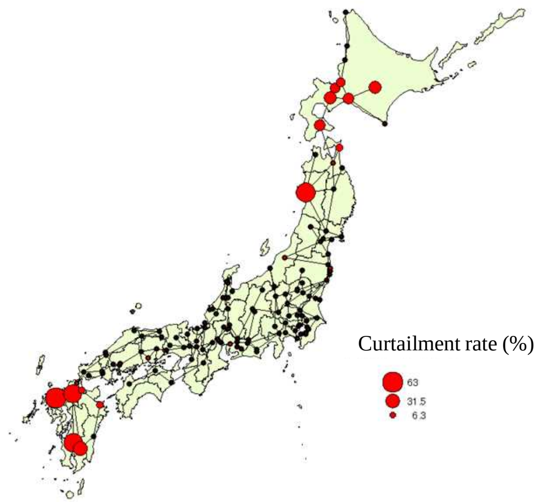


RES expansion case

PV



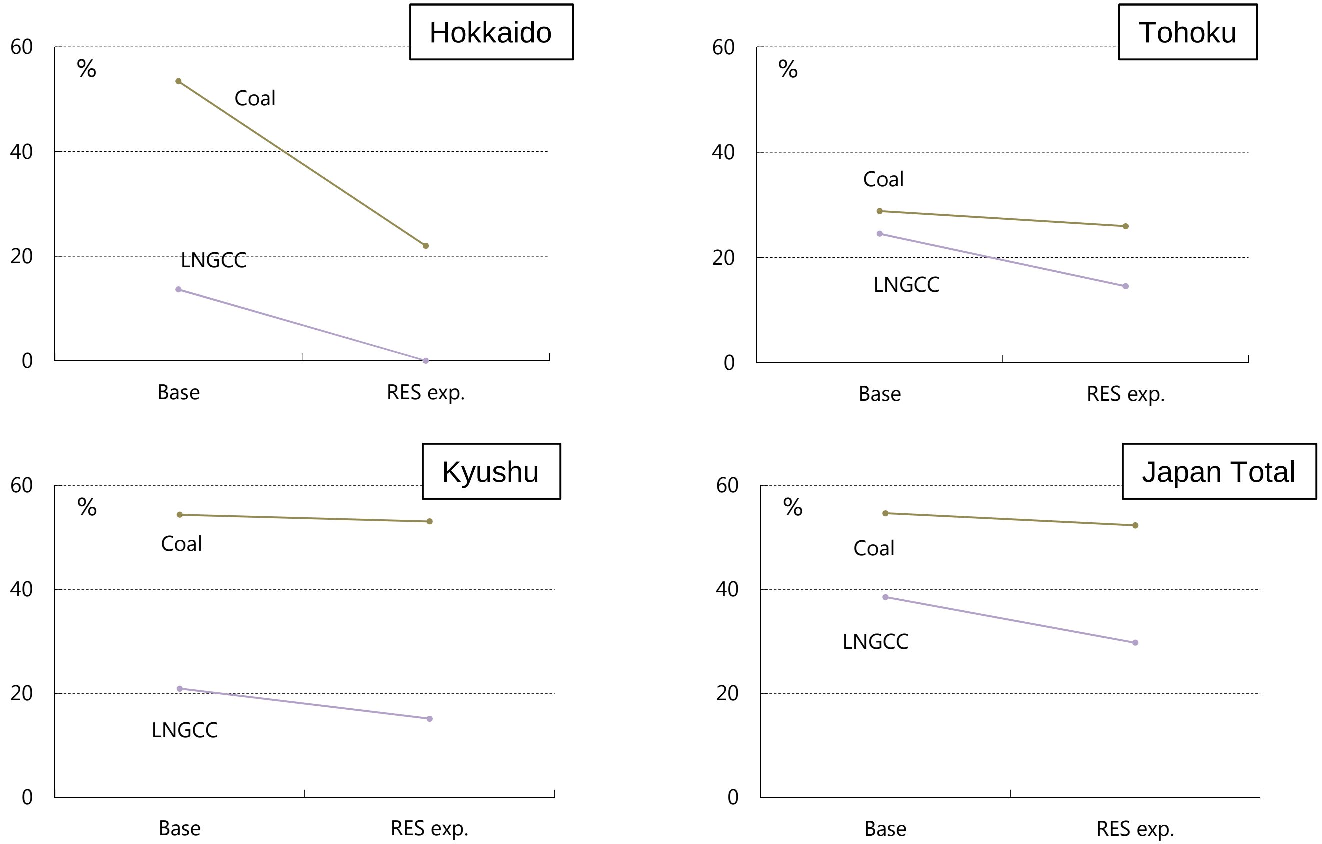
Base case



RES expansion case

Capacity Factor of Coal and LNGCC

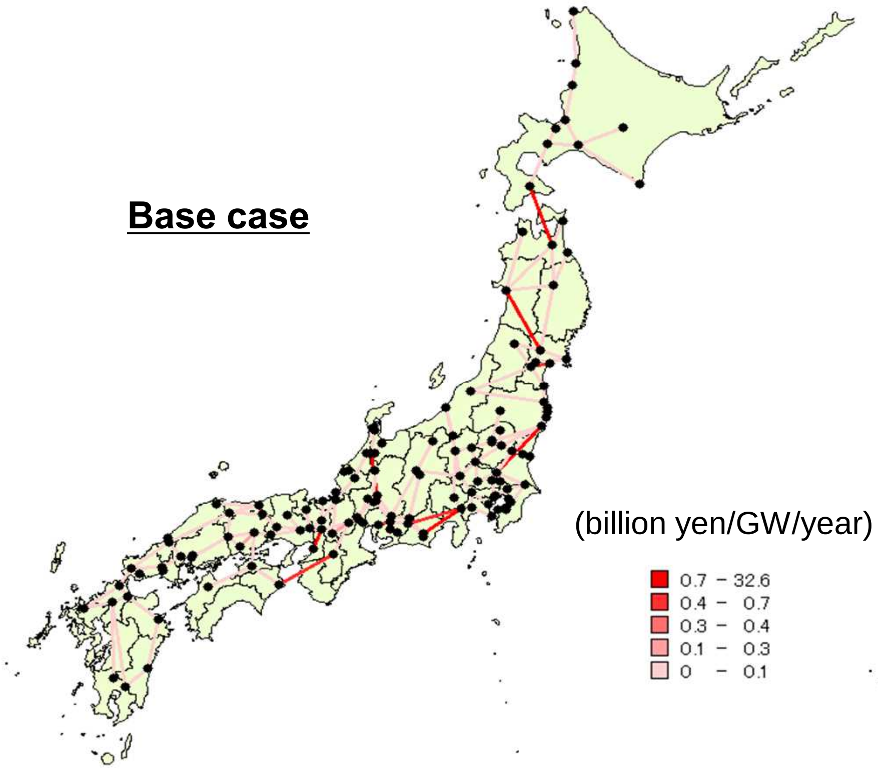
Capacity factor of thermal power plant will decline through large-scale RES integration



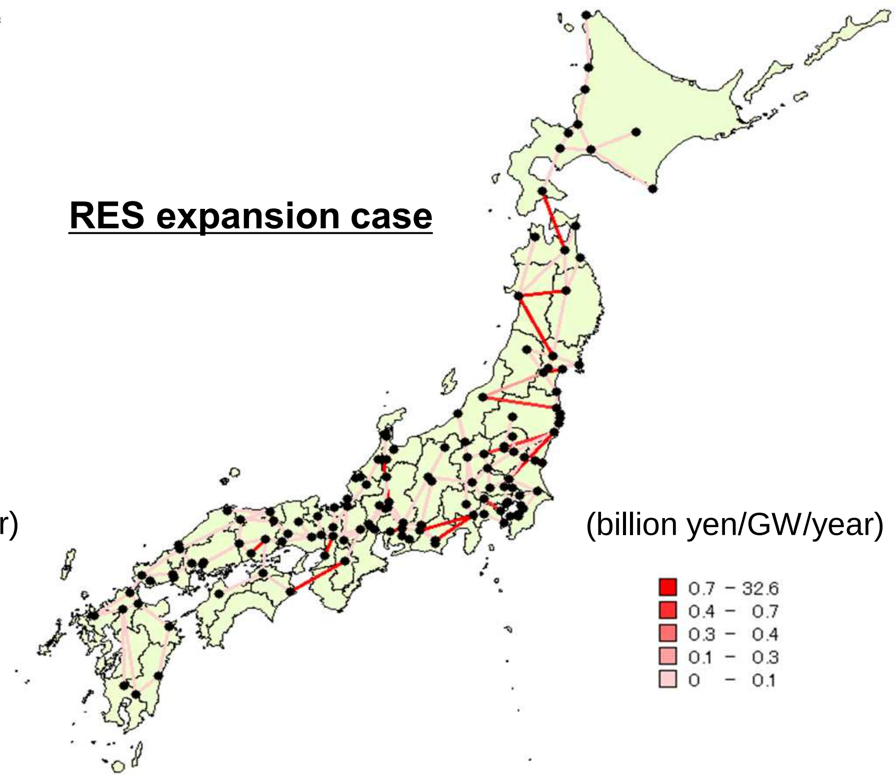
Shadow Price of Transmission Line Expansion

More reduction of power system cost by unit capacity expansion of power line is expected in RES expansion case, owing to the nation-wide power exchange caused by massive renewable integration.

Base case



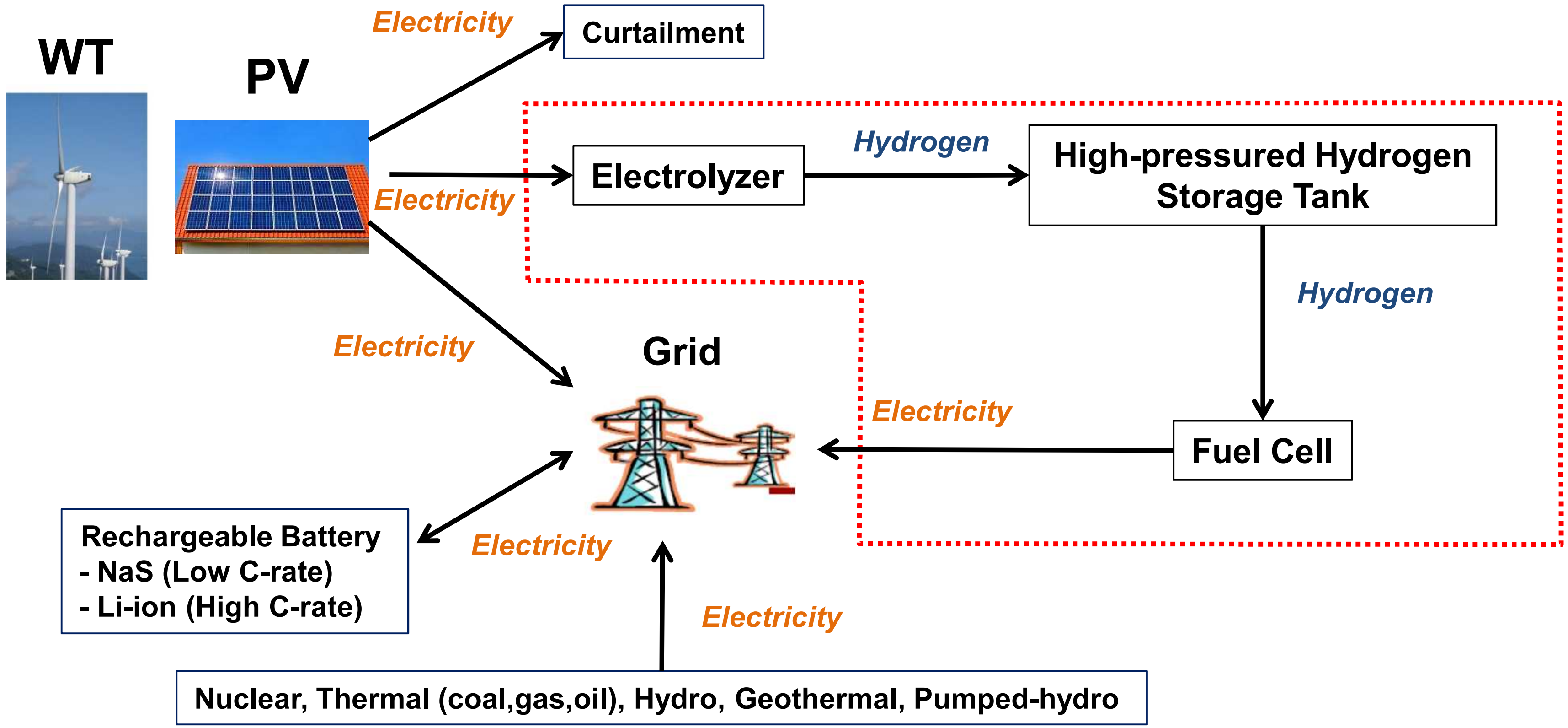
RES expansion case



Modelling of Renewable-Hydrogen System

(Source) Komiyama,R. and Fujii,Y., ***Energy***, Vol.81, pp.537–555, 2015

- Wind and PV outputs are into grid, electrolyzer and suppression control (curtailment).
- Electrolyzer system converts electricity from wind and PV into hydrogen, which is stored in compressed hydrogen tank for later combustion in fuel cell or hydrogen gas turbine.
- Hydrogen system is assumed to be installed onsite in wind and PV.



Case Setting

■ **CO_2 Regulation**

Base Case(No Regulation), -60%, -70%, -80%

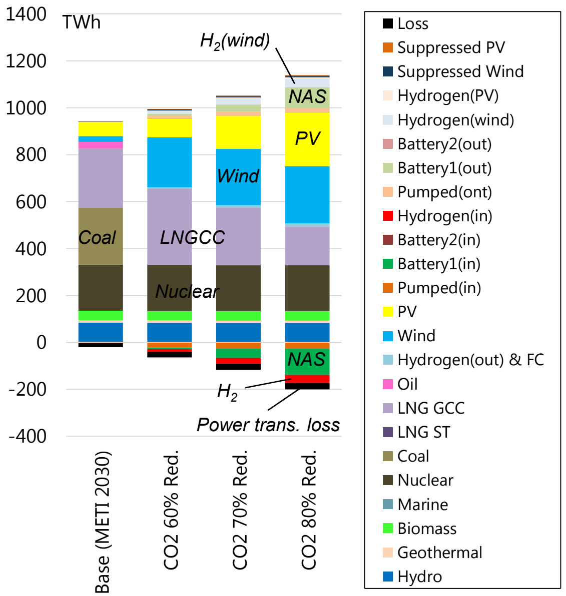
- Cost of H_2 technology (electrolyzer, hydrogen storage, fuel cell) is assumed as -80% reduction from reference values.
- Nuclear, thermal, hydro, pumped, electricity demand etc. are assumed on the basis of METI's energy outlook in 2030.

Power Generation Mix in Japan

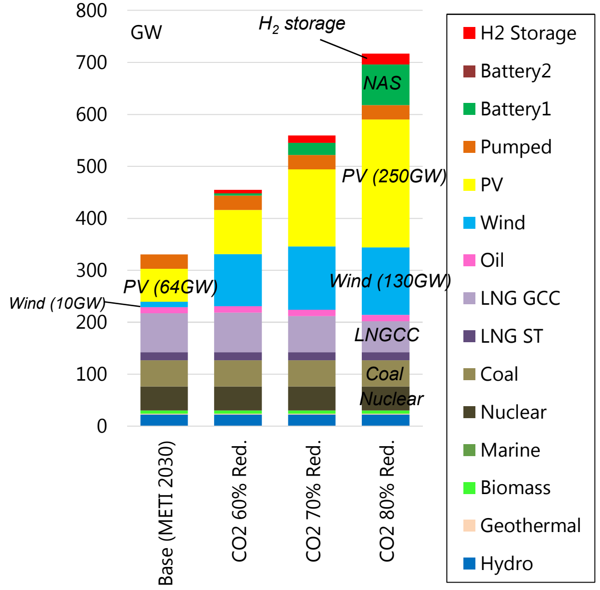
(Note) Cost of Hydrogen System: -80%

- Strict CO_2 regulation policy accelerates the installations of PV, wind and energy storage system, such as NAS battery and hydrogen storage, which replace carbon-intensive thermal power plants.
- Power transmission loss increases, due to nation-wide power exchange caused by massive RES integration.
- Despite the reduced cost assumption of hydrogen system (-80% reduction), installation of hydrogen storage is smaller than that of NAS battery

Power Generation



Capacity

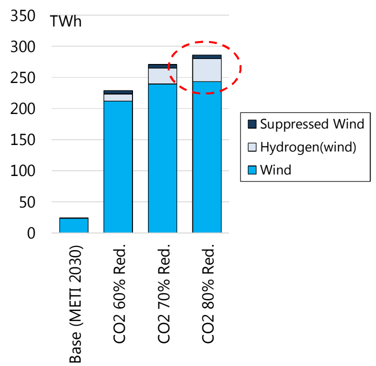


Hydrogen Production from PV & Wind

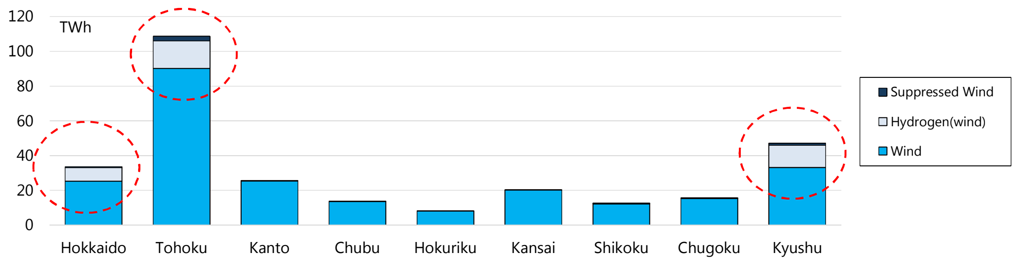
(Note) Cost of Hydrogen System: -80%

- In CO_2 80% reduction case, 10% of wind output is utilized for hydrogen production.
- Wind-based hydrogen is observed in Tohoku, Kyushu and Hokkaido.
- Hydrogen is not so much produced from PV output. Hydrogen goes well with wind rather than PV
- In Kyushu, however, 30% of PV output is utilized for hydrogen production.

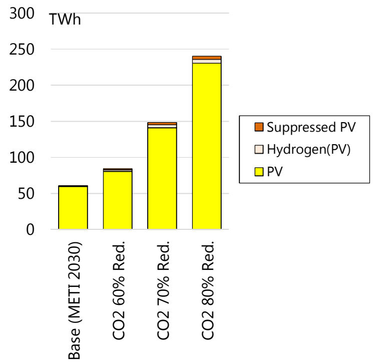
Wind (Japan)



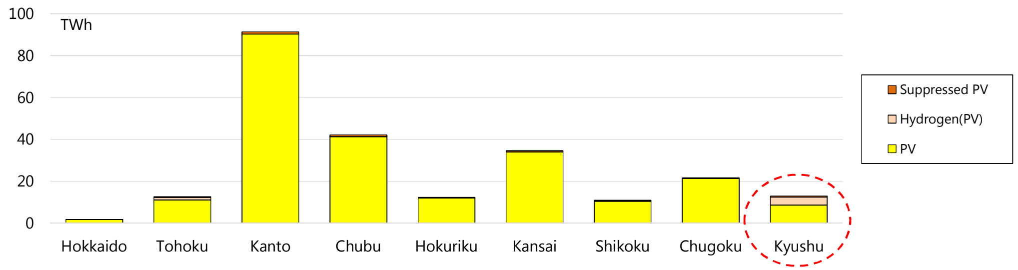
Wind (by region, CO_2 -80%)



PV (Japan)



PV (by region, CO_2 -80%)



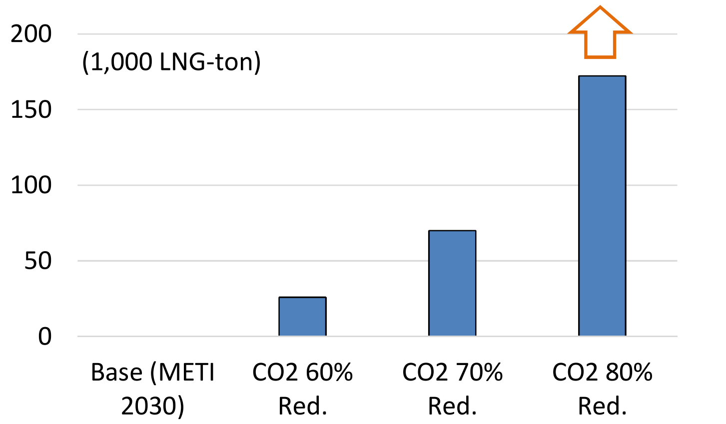
Hydrogen Storage Installation

(Note) Cost of Hydrogen System: -80%

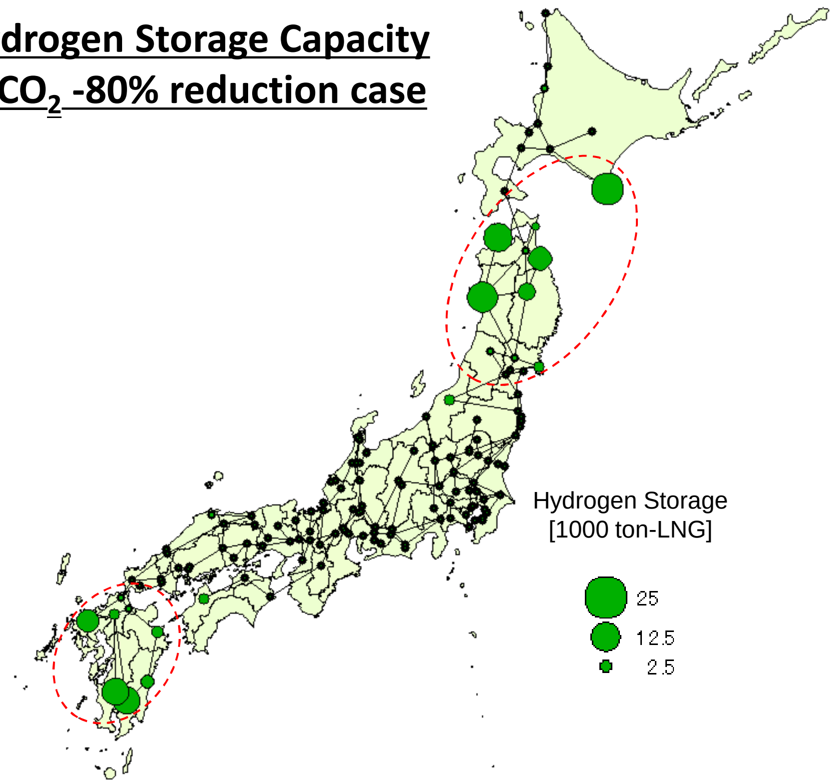
CO_2 regulation and hydrogen cost reduction are required to accelerate the introduction of renewable-based hydrogen storage system.

Hydrogen Storage Capacity

170,000 ton is equal to two units of LNG bulk storage tank.

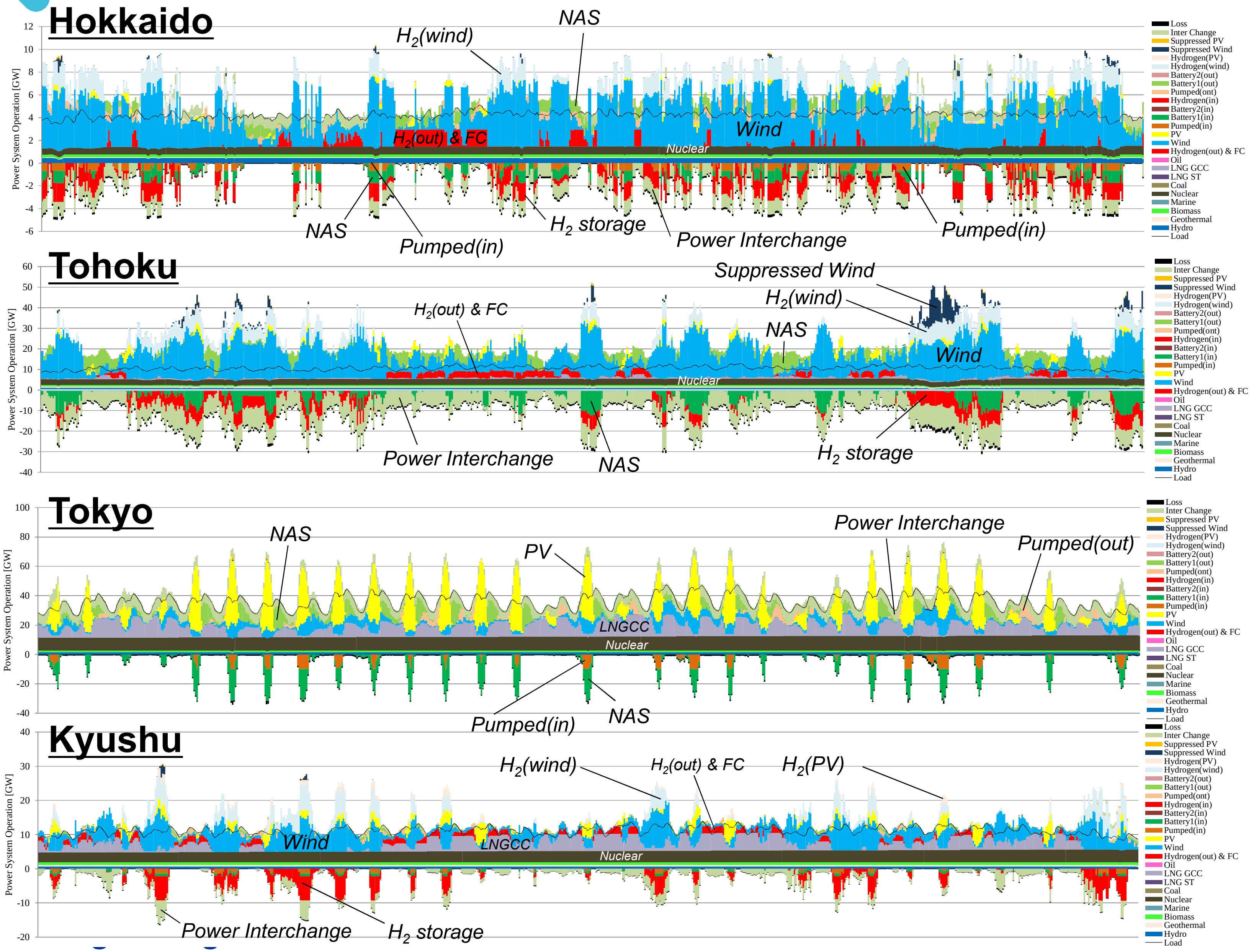


Hydrogen Storage Capacity in CO_2 -80% reduction case



Optimal Power Dispatch in December

(Note) Cost of Hydrogen System: -80%, CO_2: -80%

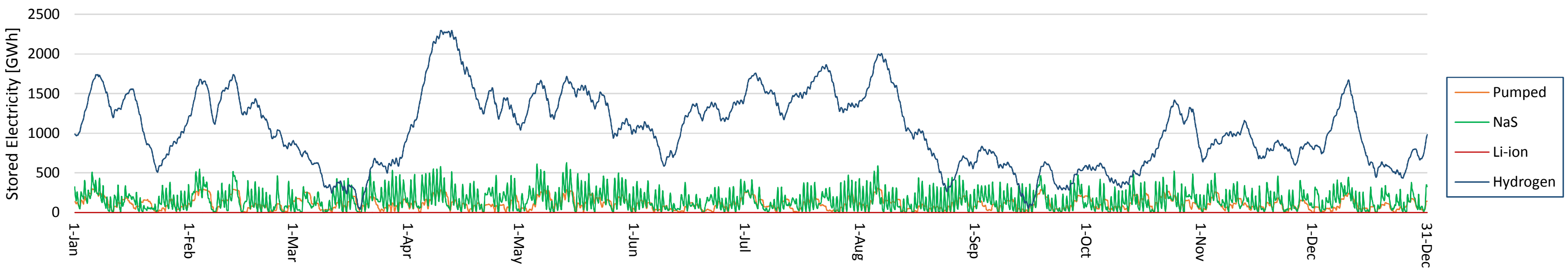


Annual SOC of Storage Facility in Japan

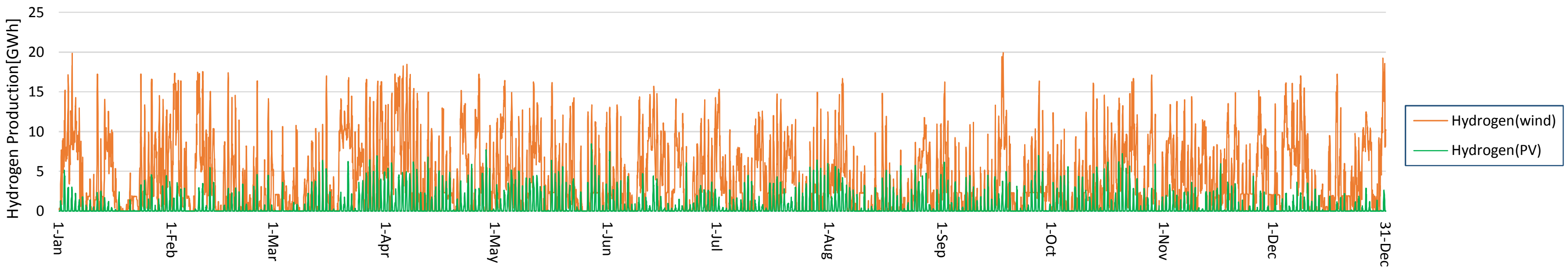
(Note) Cost of Hydrogen System: -80%, CO_2: -80%

- Charge and discharge of hydrogen storage tank shows a monthly or seasonal cycle, while that of NAS battery exhibits a daily cycle .
- Since a storage loss of hydrogen in compressed tank is very low, the model selects a long-term hydrogen storage of surplus renewable output as an optimal solution under strict CO_2 regulation.

SOC of H_2 storage tank and battery



H_2 produced from wind & PV



Summary

RES Integration

- **Observation and challenges implied by power grid modelling simulation**
  - Unconventional operation such as daylight power charging in pumped-hydro
  - Decreased capacity factor of thermal generator including base-load generator
  - Large-scale RES output curtailment
  - Nationwide grid operation
  - Decline of nodal electricity price
  - Cost-effective grid expansion

Renewable-Hydrogen

- **Hydrogen storage is a suitable option for storing RES energy in a monthly or seasonal scale.**
- **Dramatic cost reduction of hydrogen system and severe CO_2 regulation are prerequisite for promoting renewable-hydrogen**
- **Hydrogen goes well with wind rather than PV**

Thank you for your kind attention.

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Relevant Papers:

- Komiyama,R. and Fujii,Y., ***J. Energy Eng.***, April 2016
- Komiyama,R. and Fujii,Y., ***Energy***, Vol.81, pp.537–555, 2015
- Komiyama,R. and Fujii,Y., ***Energy Policy***, Vol.83, pp.169-184, 2015
- Komiyama,R.,Fujii,Y., ***Energy Policy***, Vol.66, pp.73-89, 2014

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