Power supply and demand for decarbonized society:

Development of AIM/MOGPM (Multi-regional Optimal Generation Planning Model)

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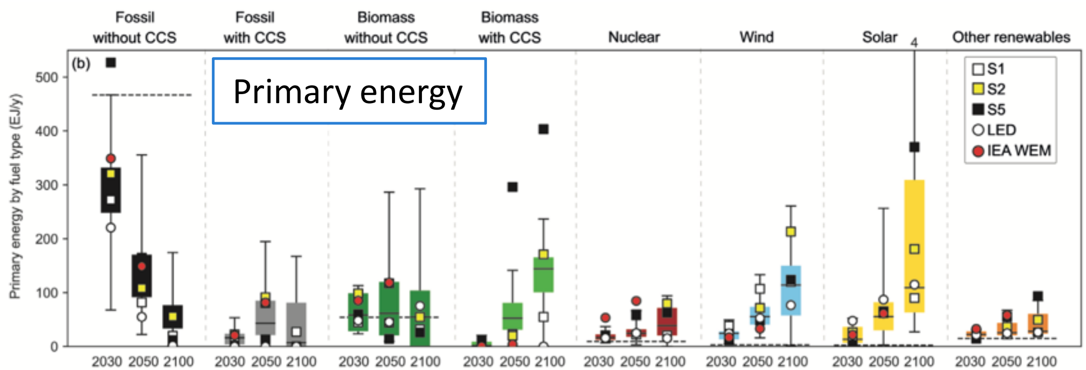
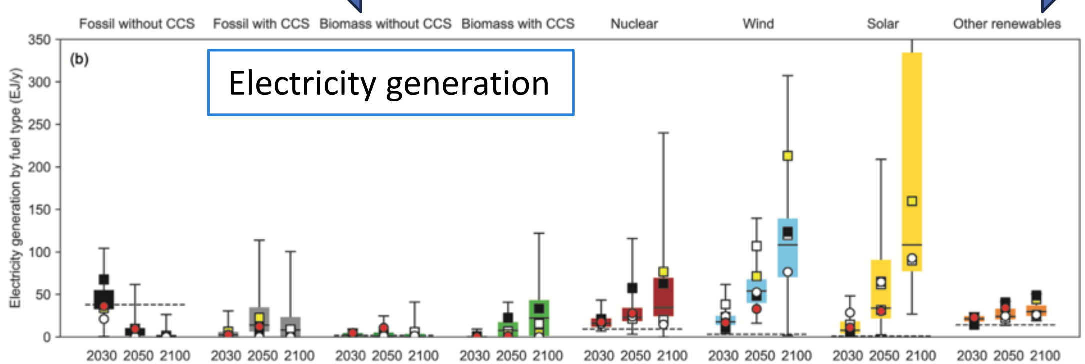
Renewables will be a main source of electricity supply in 2050

- Decarbonized society (carbon neutral society) requires large penetration of renewable energies.
- Around 60% of primary supply and **80% of electricity generation** comes from renewables **in global scale**, and **75% of electricity generation** is renewables **in AIM analysis of Japan carbon neutral scenario**.

Global: Ranges for pathways limiting warming to 1.5°C with no or limited overshoot

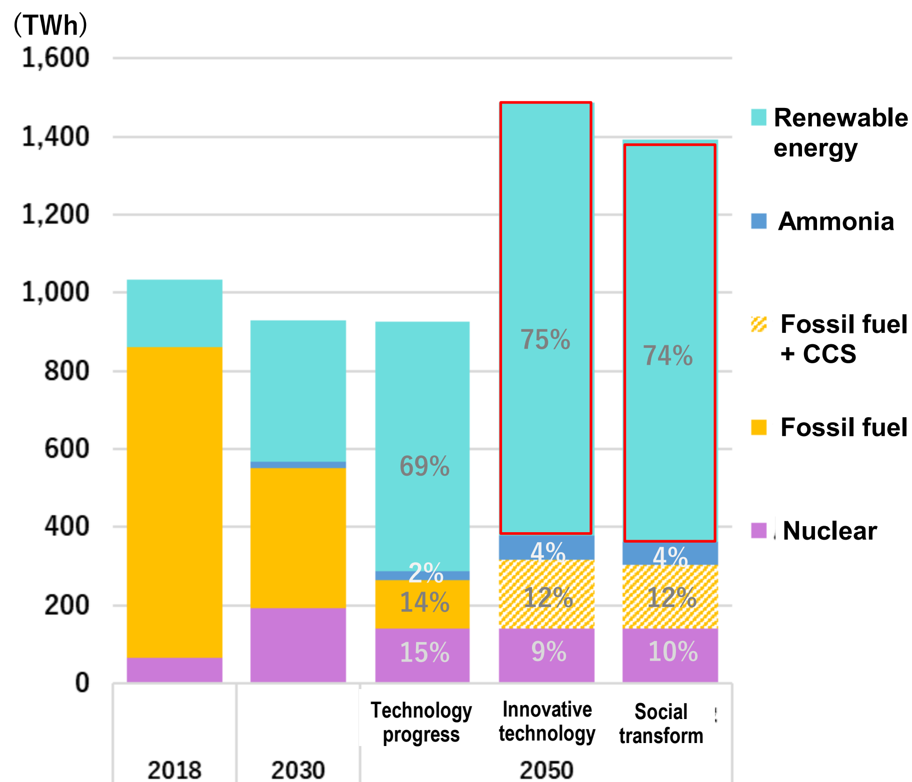


Renewables + Nuclear



Source: IPCC SR15 (Figure 2.15(b) and 2.16(b))

Japan: Energy mix of electricity generation in AIM's analysis



Source: Results from our analysis

Issues for designing renewable-based electricity system

[Balancing of electricity demand and supply in every hour]

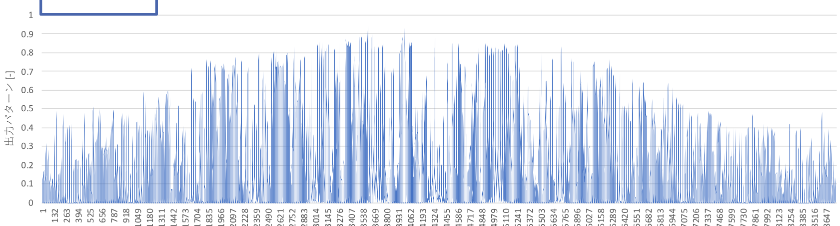
- Electricity supply should match demand at any given time; however, generations of renewables, esp. variable renewable energies (VREs), are intermittent, and have little relationship with electricity demand patterns.

[Delivering renewables from potential rich area to less potential area]

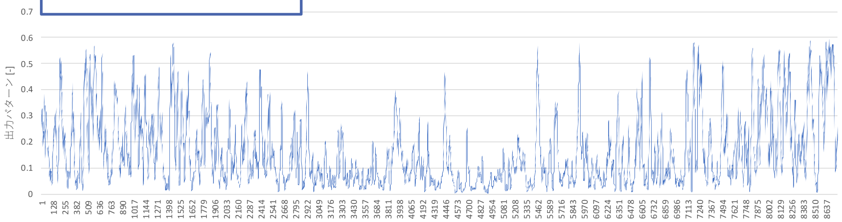
- Available types and amount (potential) of renewables differ region by region (unevenly distributes among country); electricity transmission network among regions is crucial for future grid system.

Example of hourly outputs in VREs

Solar



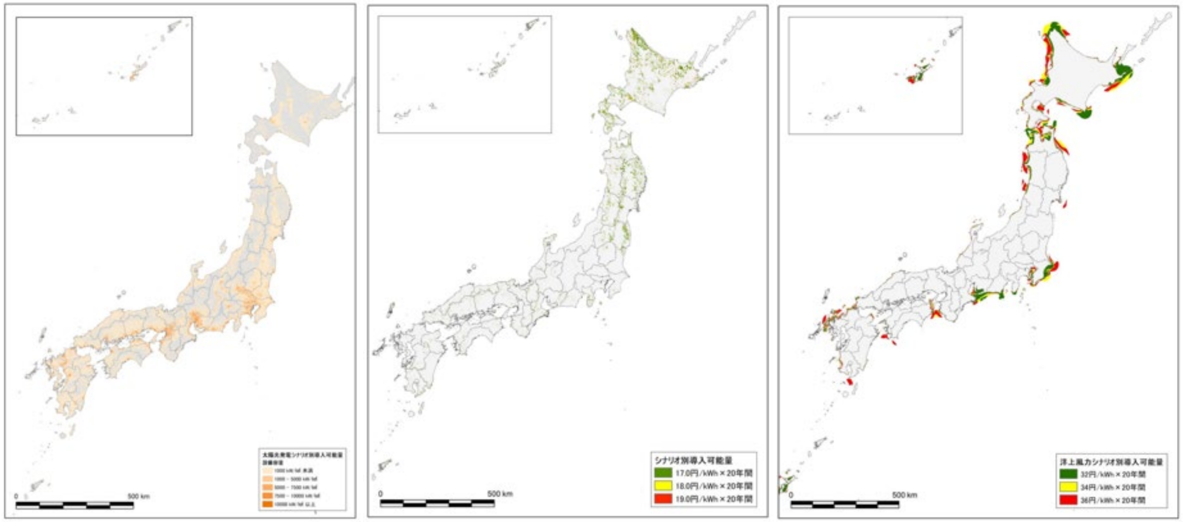
Onshore Wind



(From January 1 to December 31)

Geographical distribution of Renewable Potentials

<PV for houses> <Onshore wind> <Offshore wind>



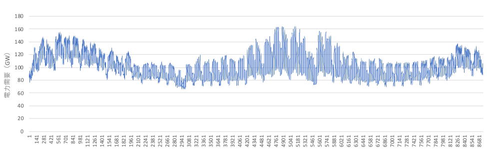
Source: Renewable Energy Potential System (REPOS), Ministry of the Environment, Japan.

Overview of AIM's Power Plant Model (AIM/MOGPM) (1)

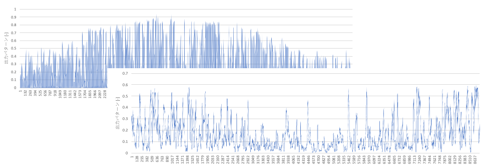
- The model designs long-term electricity generation (**capacity expansion**) and **grid planning** as well as **system configuration and their dispatches** with renewables while maintaining supply and demand on an hourly basis.
- **Key features** of the model:
  1) **Hourly-basis**: the model finds hourly operation of power plants as well as storages (batteries).
  2) **Grid network (Location)**: The model analyzes required capacity and investment plan of grid network to encourage use of renewables.
  3) **Determining optimal timing of hydrogen production**: The model can determine timing of hydrogen production based on annual required amount of hydrogen.

Key inputs of the AIM/MOGPM

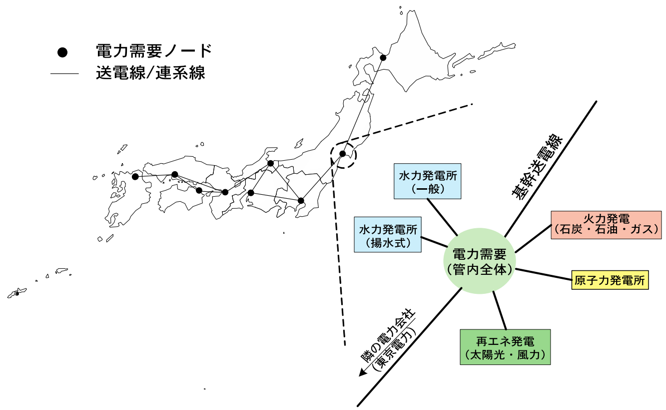
Hourly Demands



Hourly Outputs of Renewables



Grid Network / Power Plant Location



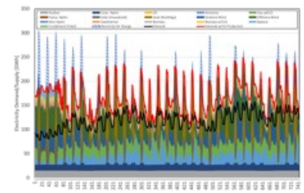
Other Parameters

Efficiency, Ownuse, Capital and O&M costs, Fuel costs etc.

Cost Min.

Outputs

- Hourly demand-supply Balance



- Annual generation
- Capacities of power plants
- Capacities of grids and configuration of network
- GHG emissions
- Costs for power plants and generations

Refs of the model: Gao and Ashina (2022) https://doi.org/10.1016/j.jclepro.2021.129828 / Shiraki et al. (2015) https://doi.org/10.1016/j.jclepro.2015.09.079

Overview of AIM's Power Plant Model (AIM/MOGPM) (2)

- The problem defines as **Linear Programming (LP)** model.
- The model solves problem period-by-period by minimizing objective function (**dynamic recursive**) every each 5 year from 2015 to 2050.
- **Objective function is minimizing a total cost of the system**: Capital cost/CAPEX both for power plants and transmission lines, Operating costs (OPEX) and fuel costs of power plants, Carbon/Energy tax(es) for GHG emissions and fuel use.
- Model implemented in Python+GAMS/CPLEX and Python+Gurobi.

[Objective Function]

$$\min TC_t = CN_{t,p} * VR_{t,p} + CN_{T,t} * VR_{T,t}$$ <- Capital Cost

$$+C_{FOM,t,p} * (VS_{t,p} + VZ_{t,p})$$ <- Fixed O&M

$$+GN_{t,k} * VE_{t,k}$$ <- Fuel + Var. O&M

$$+TAXE_{t,k} * VE_{t,k} + TAX_{t,m} * VQ_{t,m}$$

<- Carbon/Ene Tax

[List of Indexes]
t: Period, *p*: Type of Plant, *k*: Type of Fuel,
m: Type of Gas

[List of Variables]
VS: Total Capacity (Stock) of Plant
VR: Capacity of Recruited Plant
VR_T: Capacity of Recruited Transmission Line
VZ: Removed Capacity
VE: Energy Consumption
VQ: Gas Emission

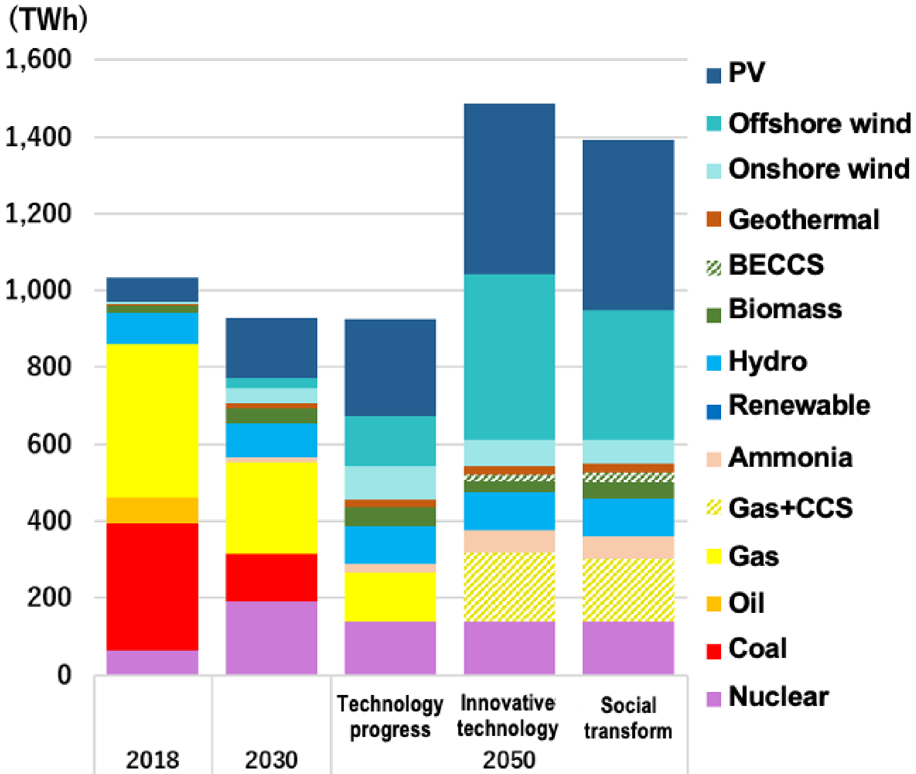
[List of Parameters]
CN: Annualized Capital Costs of Plant
CN_T: Annualized Capital Costs of Transmission Line
C_{FOM}: Fixed O&M Cost
GN: Variable Cost (Variable O&M and Fuel Cost)
TAXE / *TAX*: Energy Tax / Carbon Tax

AIM ASIA-PACIFIC INTEGRATED MODEL

Example of Model Application: Japan 2050 CN scenario

- In the Innovative Technology and Social Transformation scenarios, the amount of electricity generated increases with the demand for electricity for new fuel production.
- **Decarbonized power sources account for 100% of power generation**: nuclear power, thermal power with CCS, new-fuel thermal management, and renewable energy generation. Offshore wind and solar power are huge, generating 338~432 billion kWh and 444 billion kWh, respectively.

<Energy mix of electricity generation: detailed class.>



<Energy mix of electricity generation: coarse class.>