第2回　再エネ講座シンポジウム2021

# THE AGENT-BASED ELECTRICITY SYSTEM MODELING AND ITS POTENTIAL FOR POLICY ASSESSMENT ON THE JAPANESE POWER MARKETS


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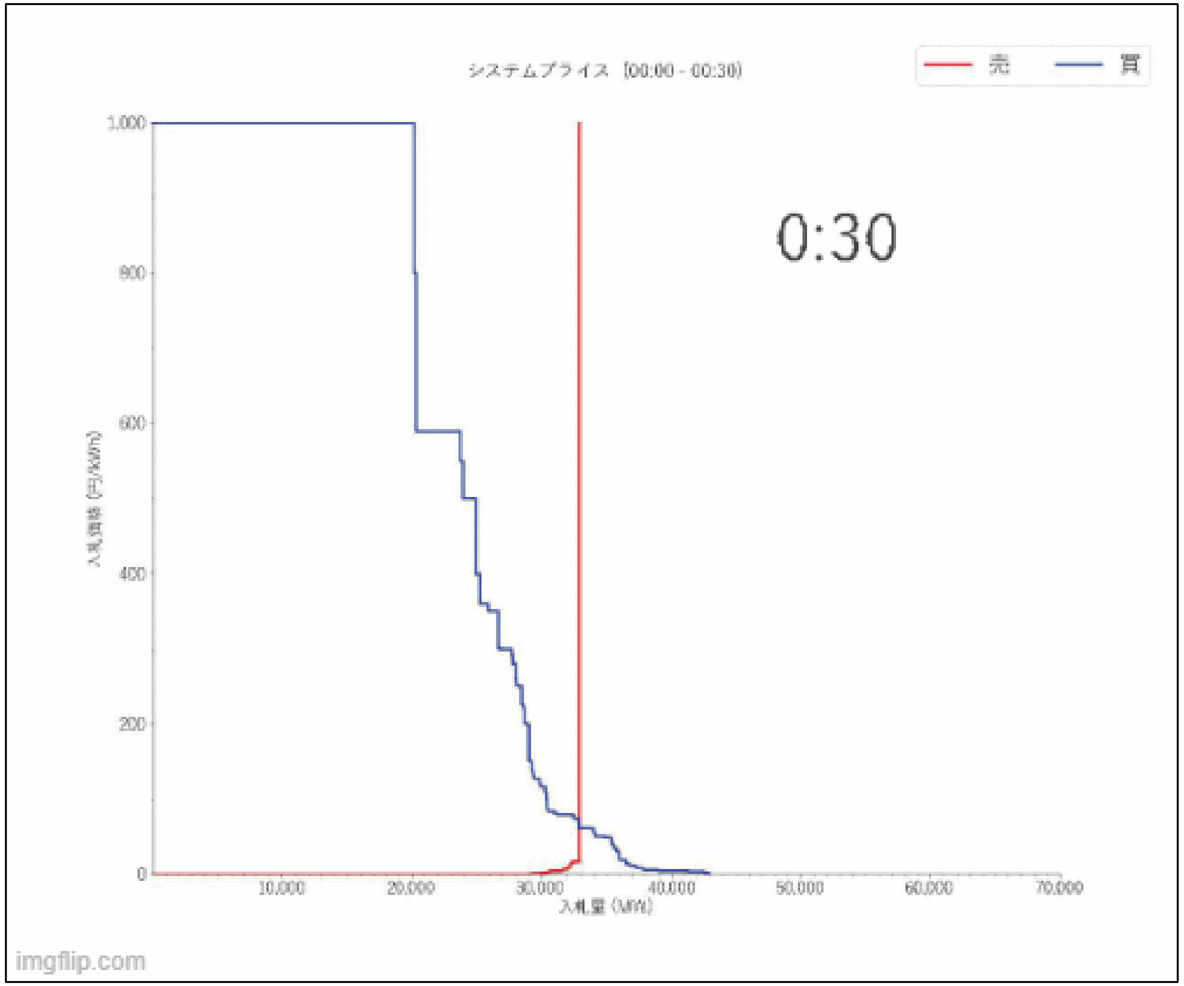
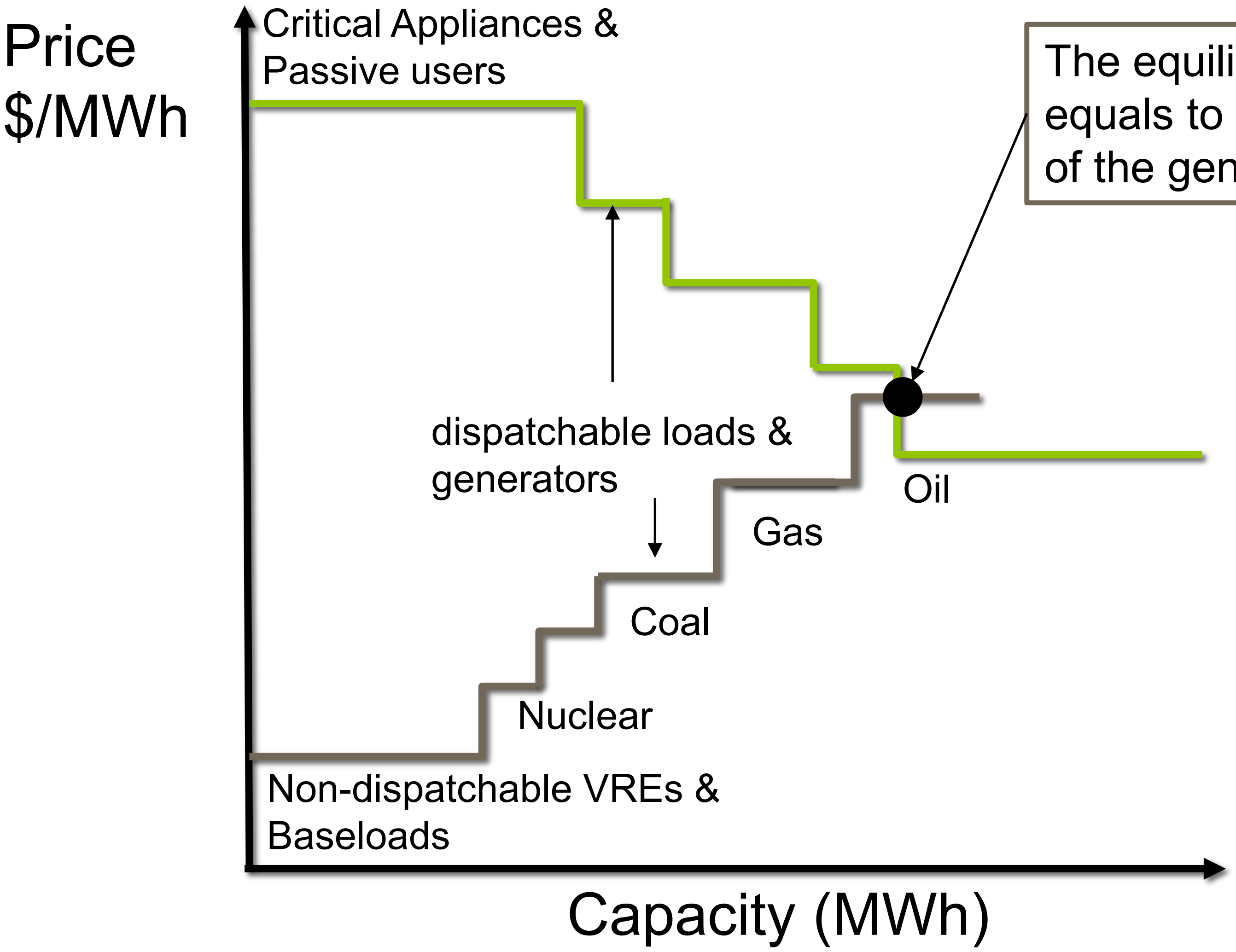
# 1 Introduction:
# Price Spike and the Theory of Electricity Pricing

# The Price Spike at Wholesale Market: JPEX on 15th Jan, 2021




- The bid and offer curves as shown
- Three approaches on the impacts of Renewables
  - Merit Order Curve Approach in the competitive markets
    - The electricity price is decreased significantly by the penetration of renewables, but fluctuates more.
  - Price manipulation in the monopolistic markets
    - Due to RE’s variability, the fossil plants are easier to manipulate the market during the demand peak.
  - Electricity Pricing in the power system

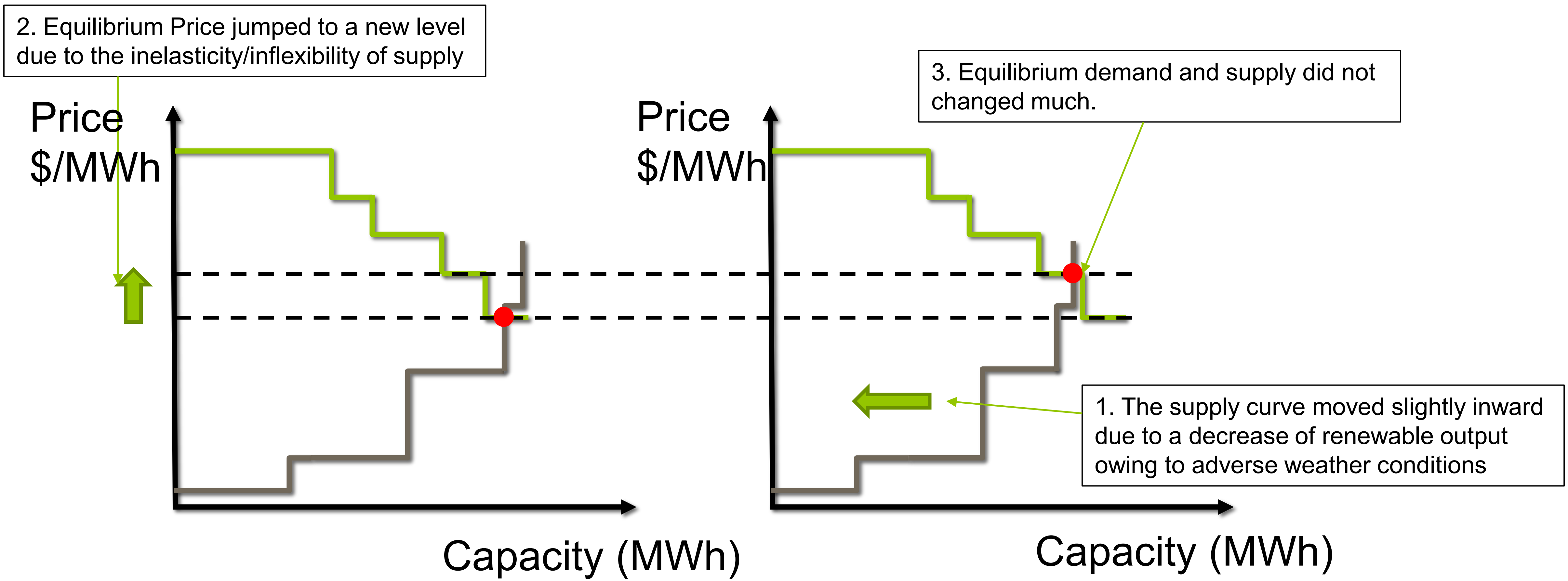
# The Power Pricing at a Competitive Wholesale Market




The equilibrium electricity price equals to the highest marginal cost of the generator at serving

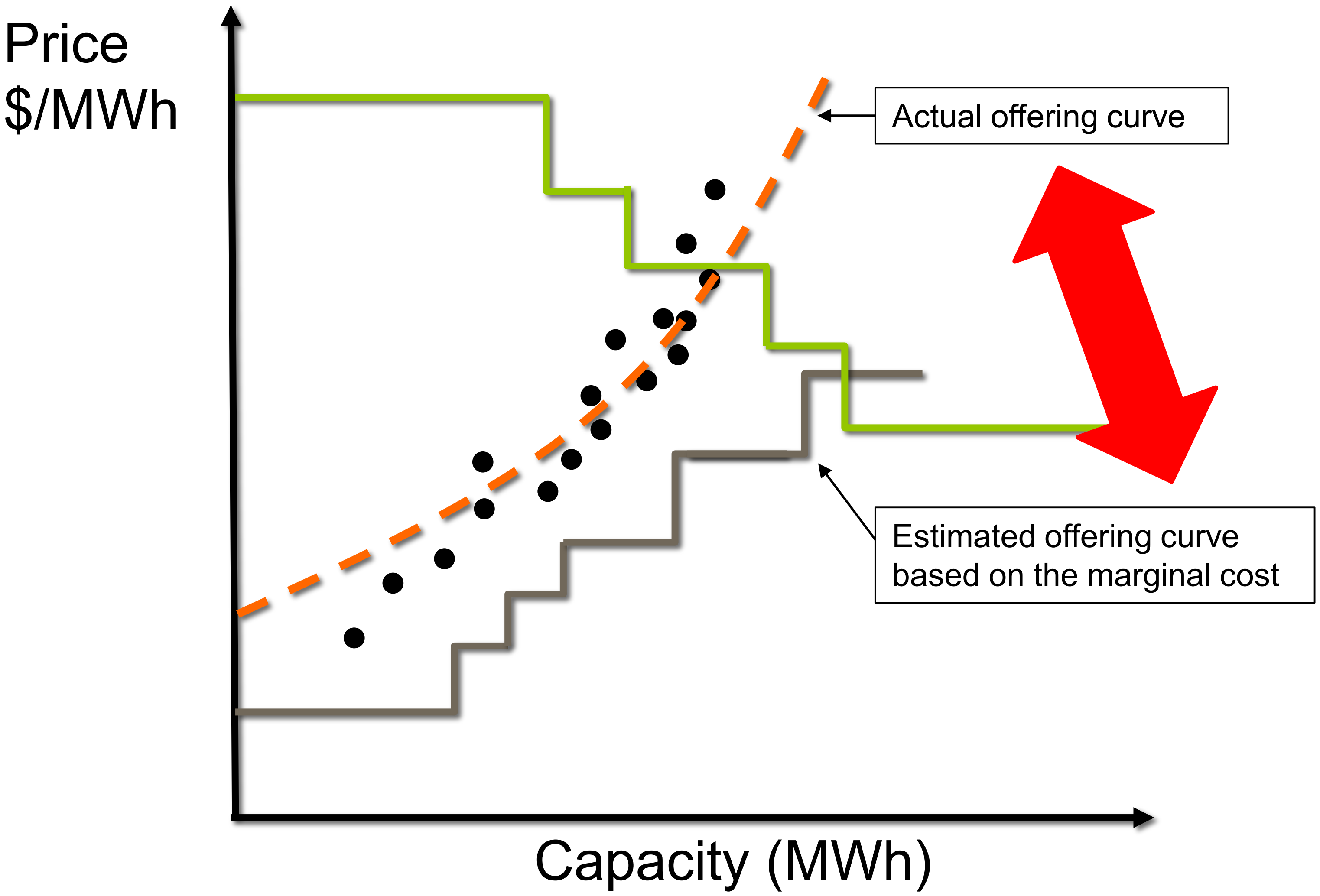
The Impacts of renewable energy on electricity price will depends on its impacts on the serving power plants. For example, the oil generators which has the highest marginal costs will retire due to the renewables, then the electricity price will decrease to the marginal costs of the gas generators.

# The Power Price at Competitive Wholesale Market: Small changes may lead to a price spike.

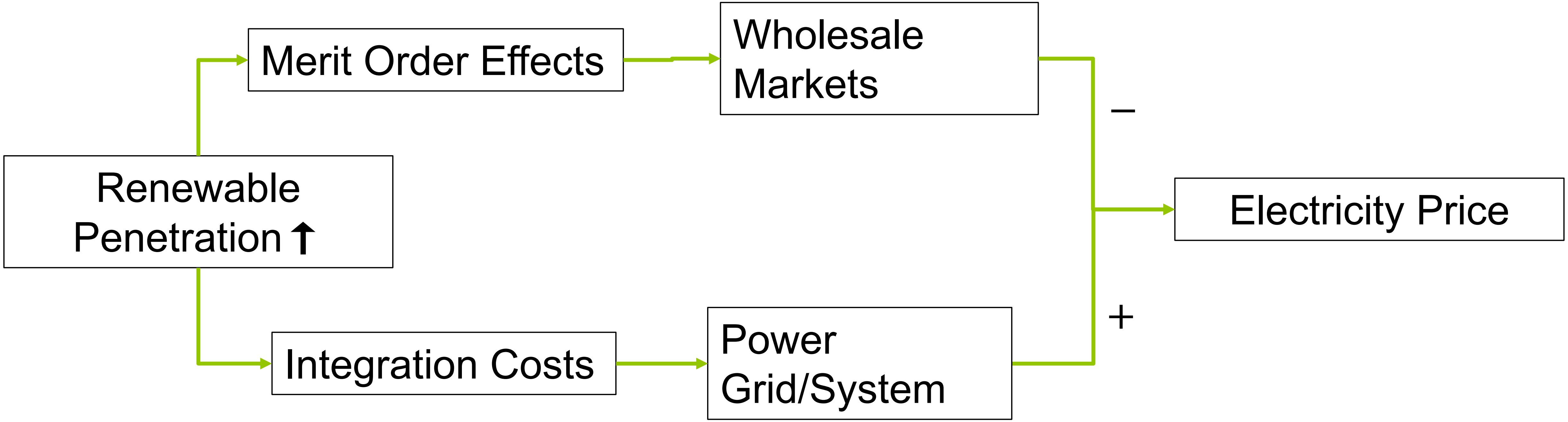


# The Power Price at Monopolistic Wholesale Market

- The auction mechanism in the wholesale market is equivalent to the free market price, only if there is no market power.
- However, when we consider the market power and information asymmetry among the traders in the repeated auctions, then the equilibrium will be complicated.
- The equilibrium price is be higher than the price in the free markets.



# Beyond the Merit Order Effects:
# The Role of Power Grids & Theory of Electricity Pricing

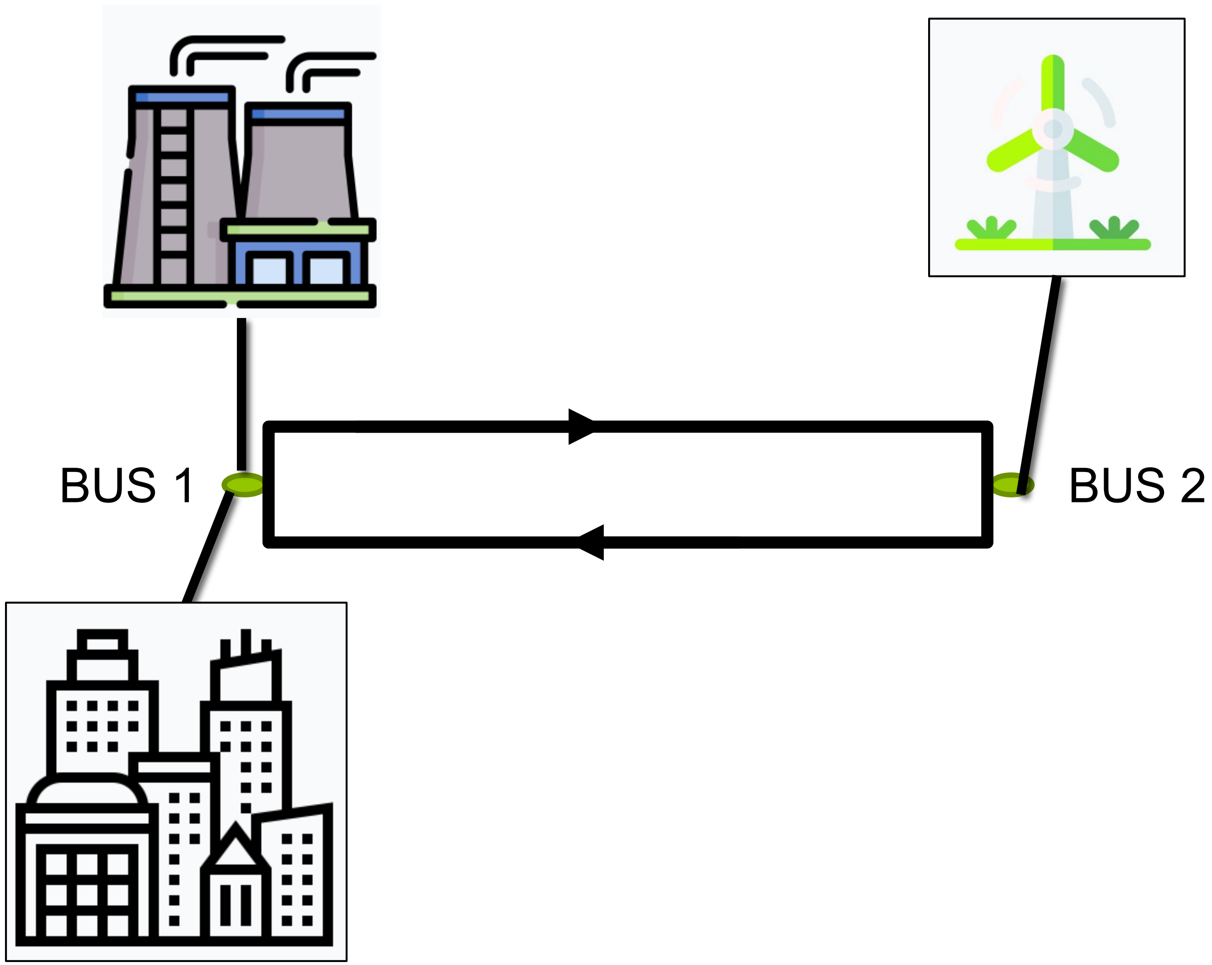



In UK, network costs 27.59 percent, while wholesale or energy costs 36.30 percent; In Australia, for instance, network costs are as high as 48 percent, whereas generation costs represent 25 percent of the bill.

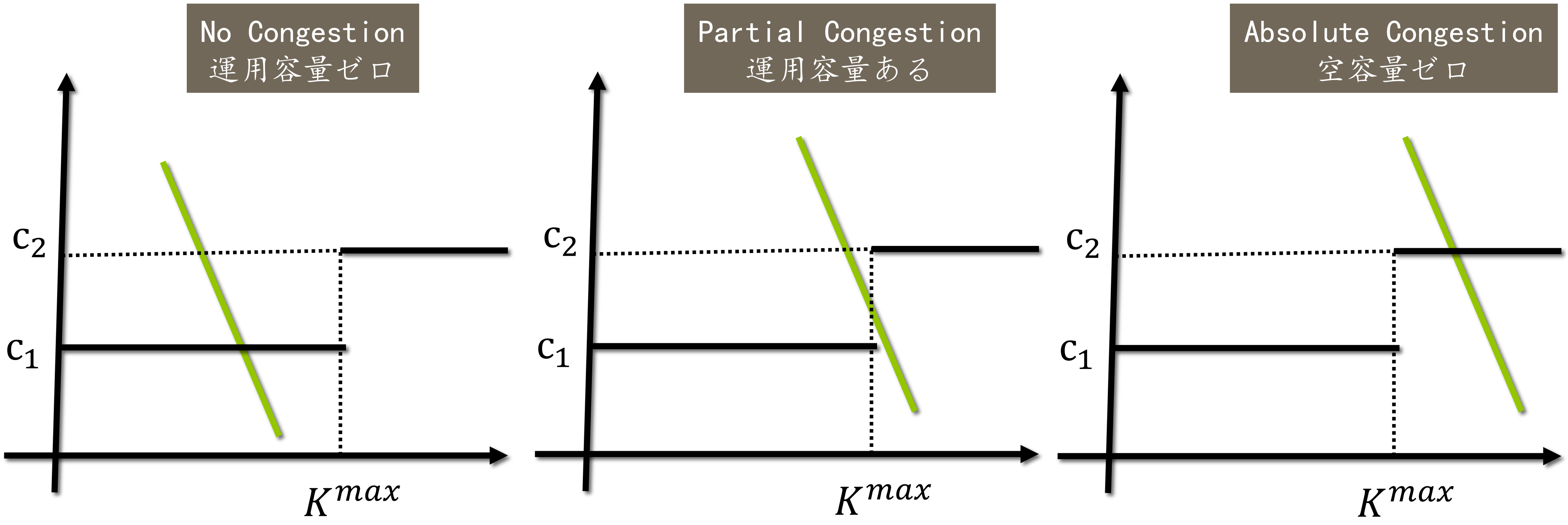
# 2 Example: A Two-Node Dispatching model

# A Two-Node Dispatching model

- (Joskow & Tirole, 2000): *Transmission Rights and Market Power on Electric Power Networks*
- Two-Nodes Model
  - Bus 1: Load & Fire Power Plant
  - Bus 2: A wind turbine with no load
- The pricing will be determined by:
  - The marginal costs of both generators, including the fossil fuel plant and the wind turbine
  - The capacity of the transmission line
  - The quantity of the demand(load)



# A Price Spike from no congestion to Absolute Congestion



# 3. The Security Constraint Economic Dispatch Model

# Security Constrained Economic Dispatch Problem

- ISO's Objective function: Minimizing the generating costs of all **dispatchable** plants

$$\min \ TC = \sum_{t=1}^{24} \sum_{i=1}^{n} \text{Generation } costs\ of\ individual\ dispatchable\ plants$$

- Note: The Renewables are regarded as non-dispatchable. Therefore, wind and solar power in the optimal dispatching model is sometimes called "negative loads".

# Constraints for Economic Dispatch

- Power demand and supply balances

$$\sum Demand_{it} = \sum Supply_{it} \quad for\ Node\ i\ at\ Time\ t$$

- Power transmission constraints

$$\sum flow_i \leqslant Tranmission\_Capacity_t \;\; for\ each\ branch\ t$$

- Capacity reserve constraints
- Minimum output threshold of thermal power plant
- Charge and discharge balances of energy storage
- …

# Lagrange multipliers methods & Kuhn-Tucker Conditions

$$\min_{\{Outputs\ of\ dispatchable\ Plants\ i\}} TC = \sum_{t=1}^{24}\sum_{i=1}^{n} costs\ of\ individual\ dispatchable\ plants$$

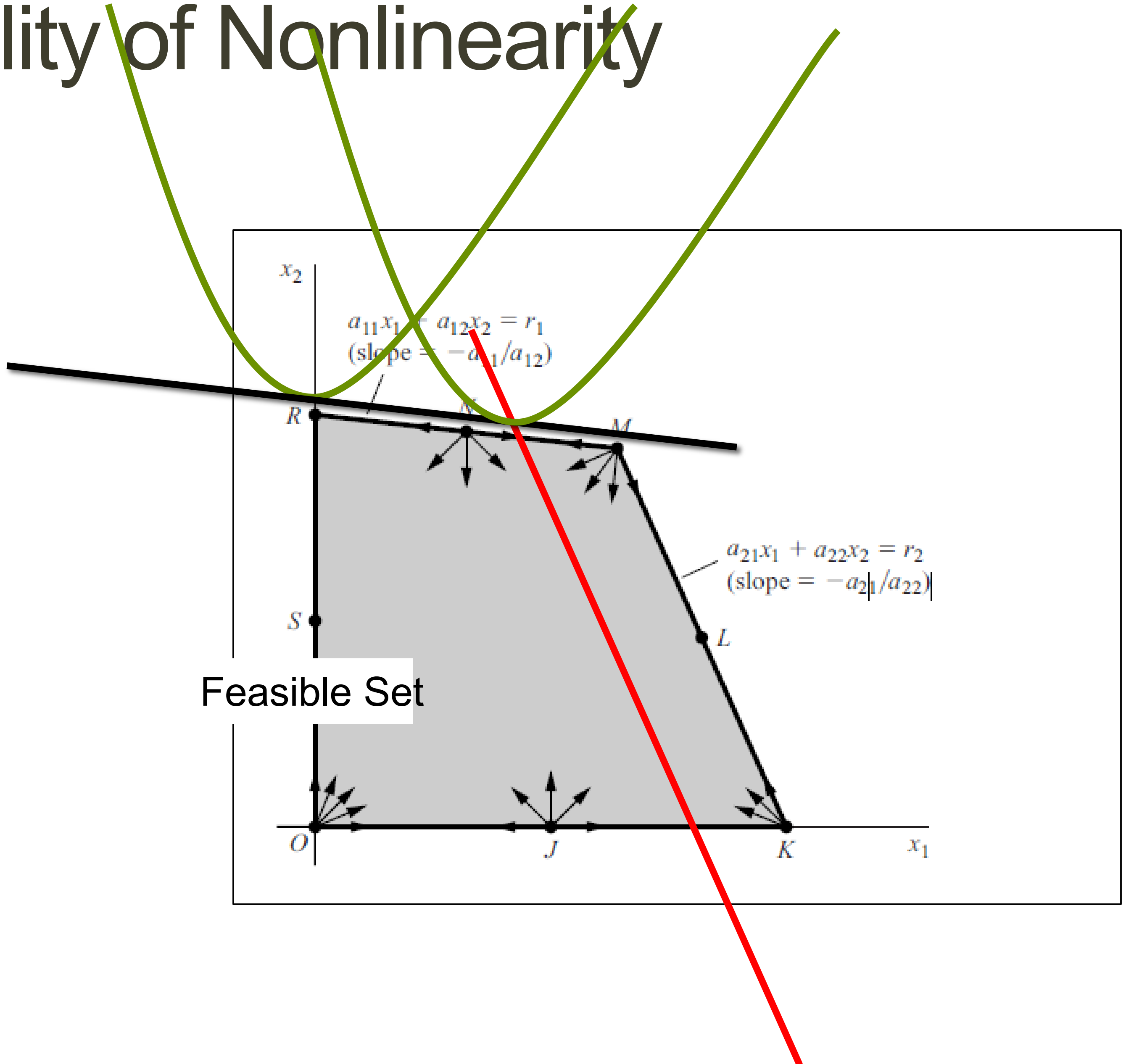
$$subject\ to \begin{cases} \sum Demand_m = \sum Supply_n \quad for\ Node\ i & (1) \leftarrow \lambda \\ \sum flow_i \leqslant Tranmission\_Capacity_t \quad for\ each\ branch\ t & (2) \leftarrow \mu \\ Other\ Constraints... \end{cases}$$

- (1) is Equality Constraint; (2) is Inequality Constraint
- The existence and the uniqueness of the solution are ensured by the convex conditions for the generating cost functions, and the decreasing marginal utility assumptions for the demand functions

# The Shadow Prices: $\lambda$ *and* $\mu$

- $\lambda$ is the shadow price of an incremental amount of supply.
  - Known as the “Locational Marginal Price” or “Nodal Price”: the least cost to service the next increment of demand at that location consistent with all power system operating constraints
  - $\lambda$ could be zero, positive or even negative.
  - “Nodal Price” *vs* “Zonal Price”: The economic scarcity of the transmission capacity within the “zone”
- $\mu$ is the shadow price of the transmission
  - Inequality Constraints and the complimentary slackness
  - If the inequality is not bunding, which means that there are still room for increase the power flow in this branch, then $\mu$=0(no economic scarcity
  - Otherwise, $\mu$ >0

# Originality of Nonlinearity



# Realization of the Optimal Dispatching Simulation

- Simulations are based on the Theory of linear and integer programming.
- International Projects
  - AMES(Prof. Tesfatsion, Iowa State University) – ISO-New England
  - PyPSA(Schlachtberger, Frankfurt Institute for Advanced Studies) – EU countries
  - …
- Simulation Projects in Japan
  - IEEJ-NE(東京大学藤井・小宮山研究室)
  - 三菱総合研究所（MRI）
  - PROMOD(IGES)
  - AIM/Enduse(国立環境研究所)
  - …
- This is an incomplete and growing list considering the importance of the renewable penetration in many economies. To my knowledge, lots of literature in this field relies their study on the optimal dispatching approach.

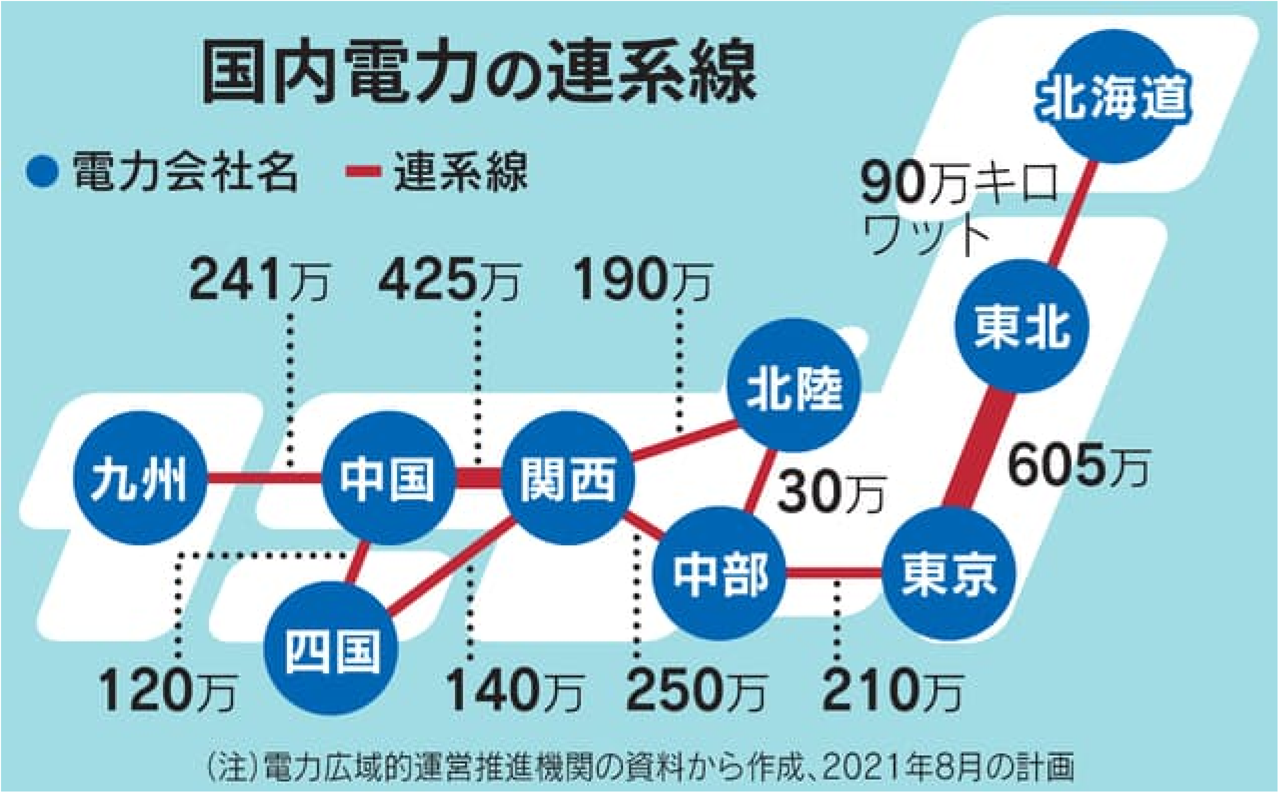
# 4. Very Preliminary Results

# Nine Buses Model for the Japanese Cross-regional Dispatch

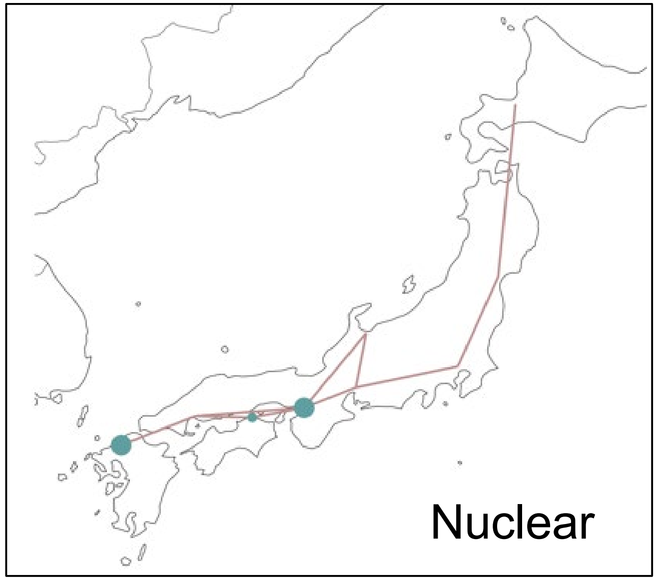
**These slides are ONLY intended to demonstrate the capabilities of the optimal dispatching model and is NOT (yet) accurate enough to be used for research or policy purposes.**

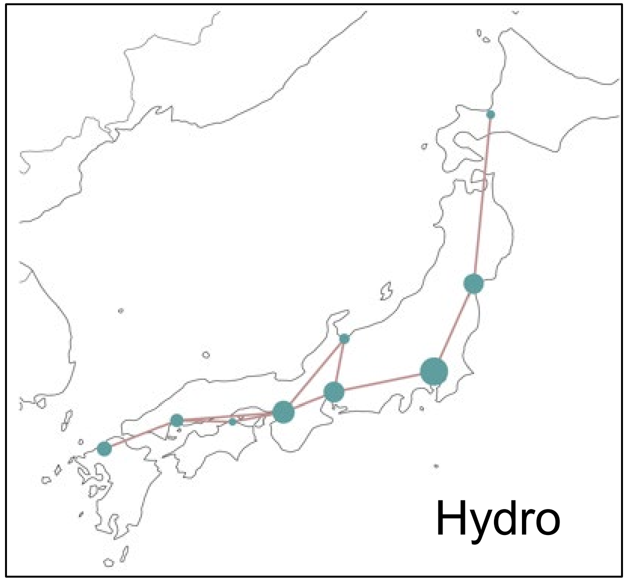
# The Nine-Bus model: 国内電力の連系線と地域(沖縄除く)

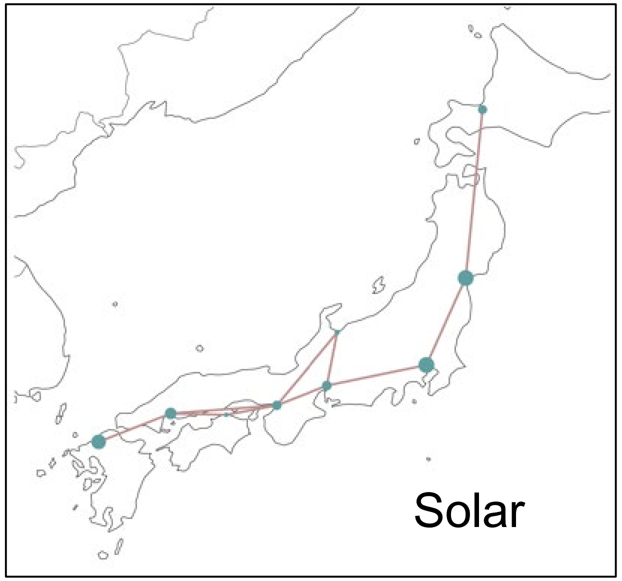
- Based on the PyPSA (PyPSA: Python for Power System Analysis) package
- Meshed network contains:
  - 9 buses represents the nine major dispatching regions in
  - 10 cross-regional lines with different transmission capacity
- Targets: to study the cross-regional interactions on regional price, RE curtailment, grid congestion,…

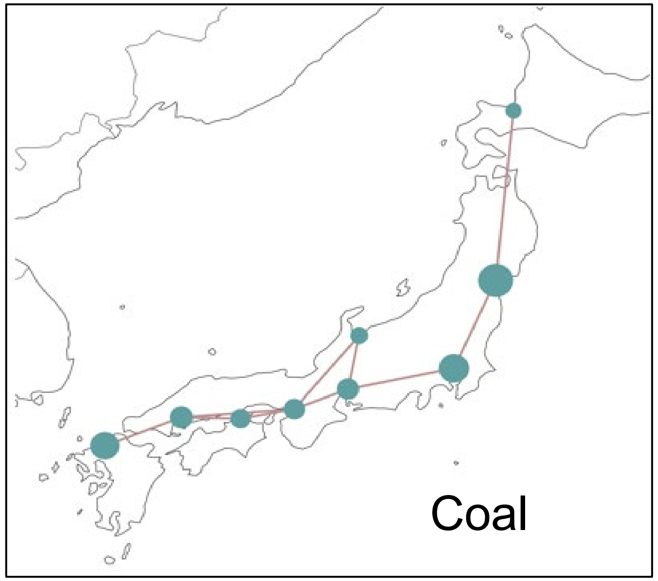


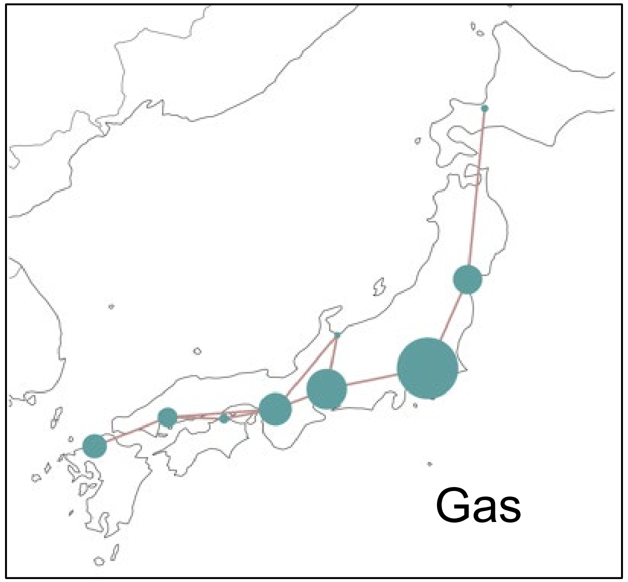
# Model input: 国内電力供給

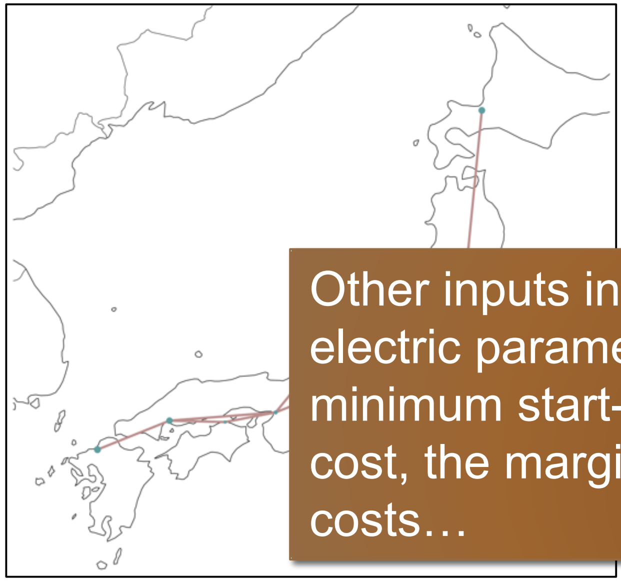


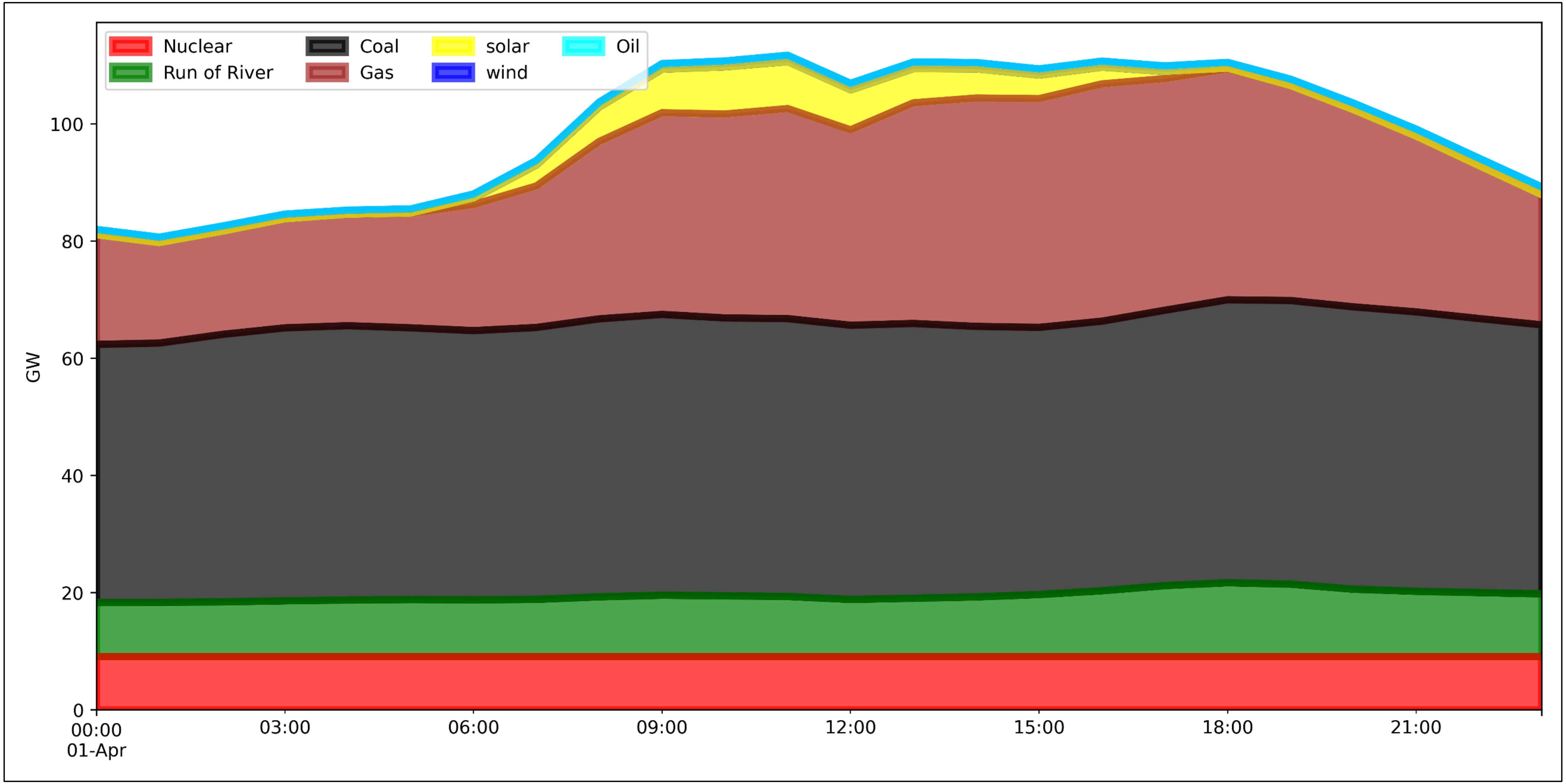



Other inputs includes many electric parameter, including the minimum start-up time, start-up cost, the marginal generation costs…

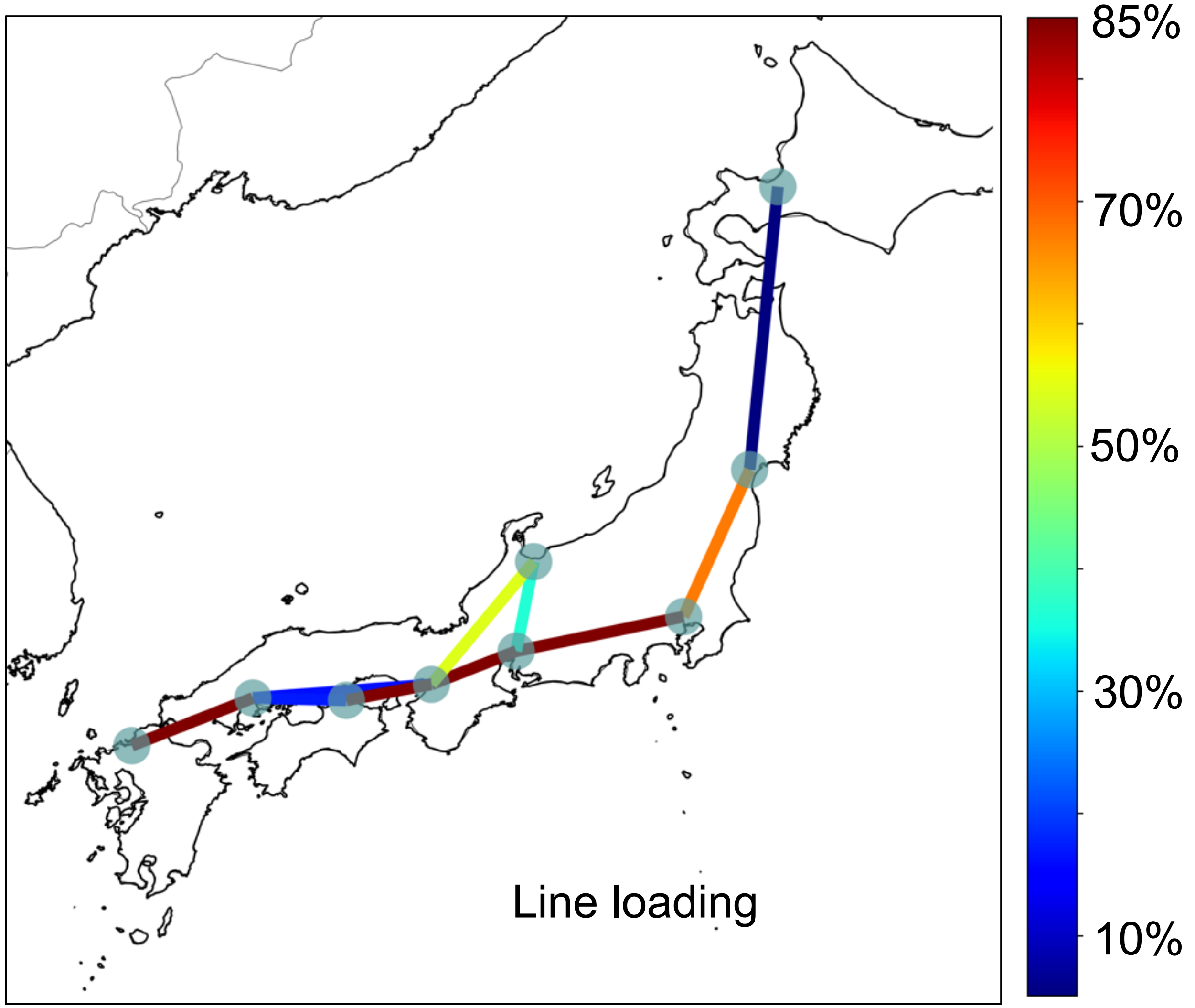
# Result Ⅰ: Output by Energy on April 1st, 2020



# Result Ⅱ: Line loading at 12pm, on April 1st, 2020

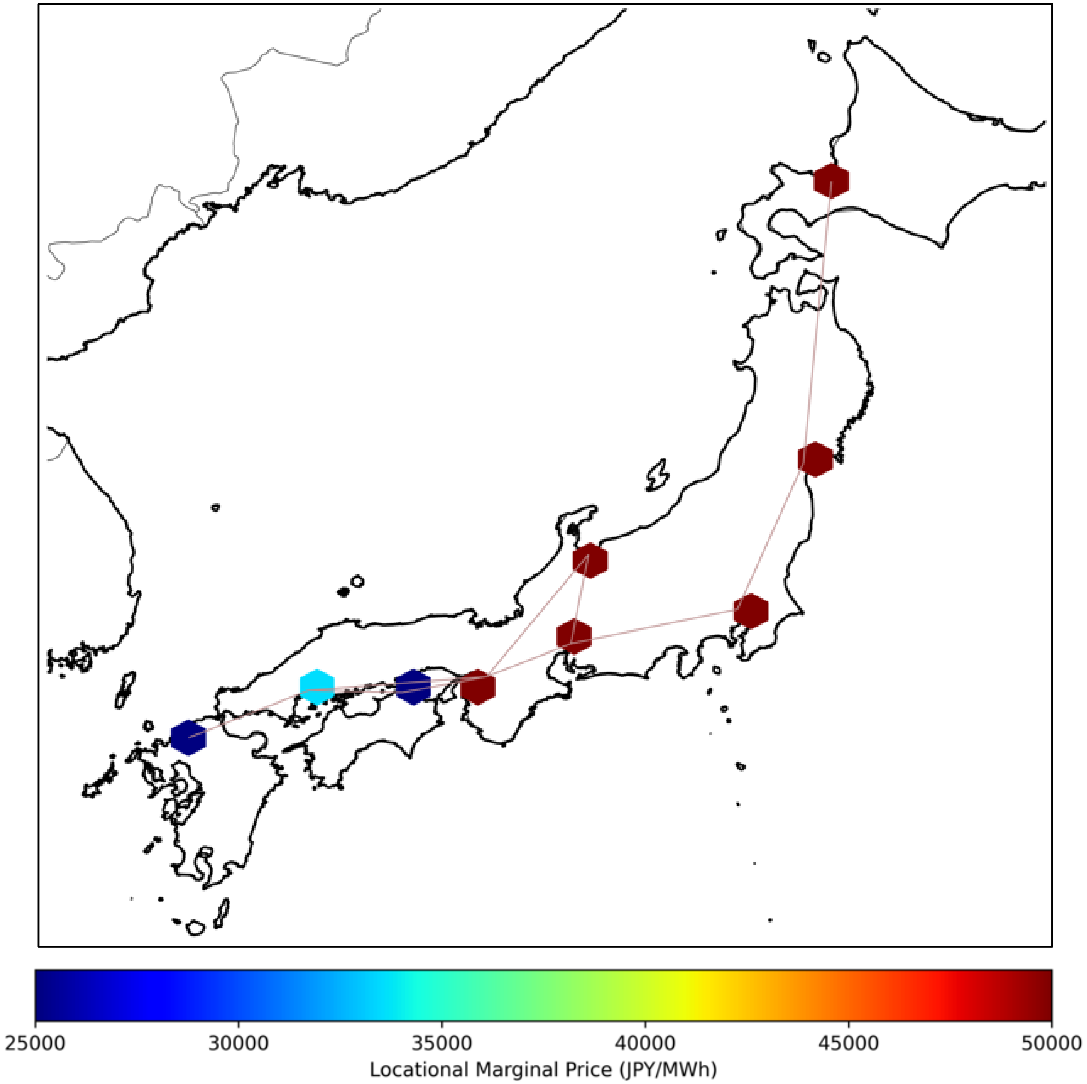
$$line\ loading = \frac{transmission\ power}{transmission\ capacity}$$

- The congested lines:
  - Kyushu → Chugoku
  - Chubu → Tokyo
  - Shikoku → Kansai
- Lines with spare capacity:
  - Hokuriku → Chubu
  - Chugoku → Kyushu



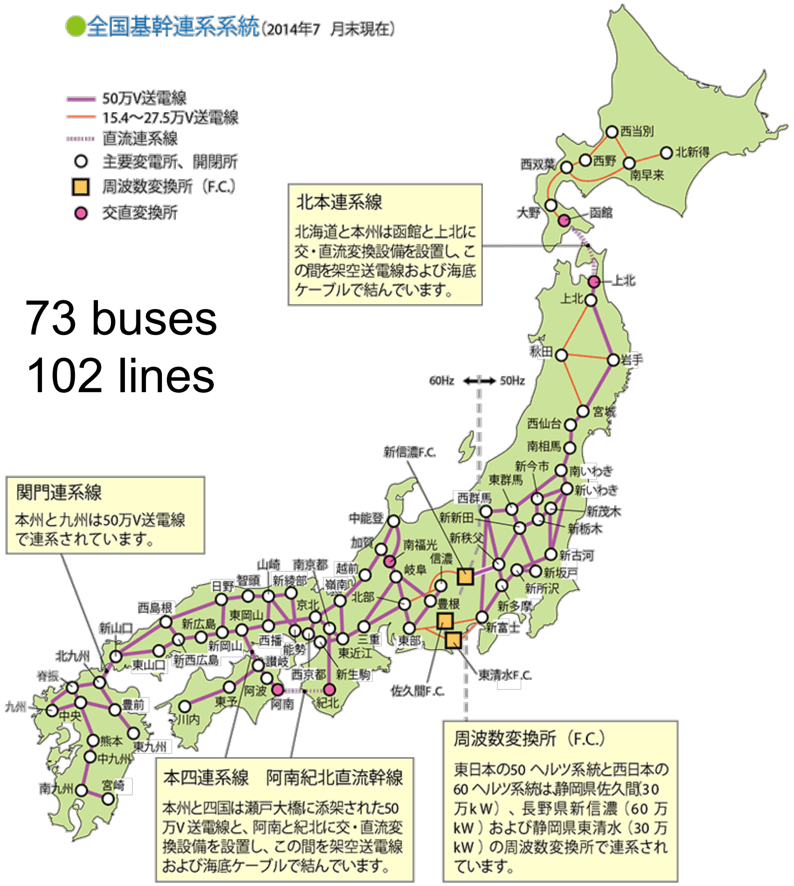
# Result Ⅲ: Locational Marginal Price at 12pm, on April 1st

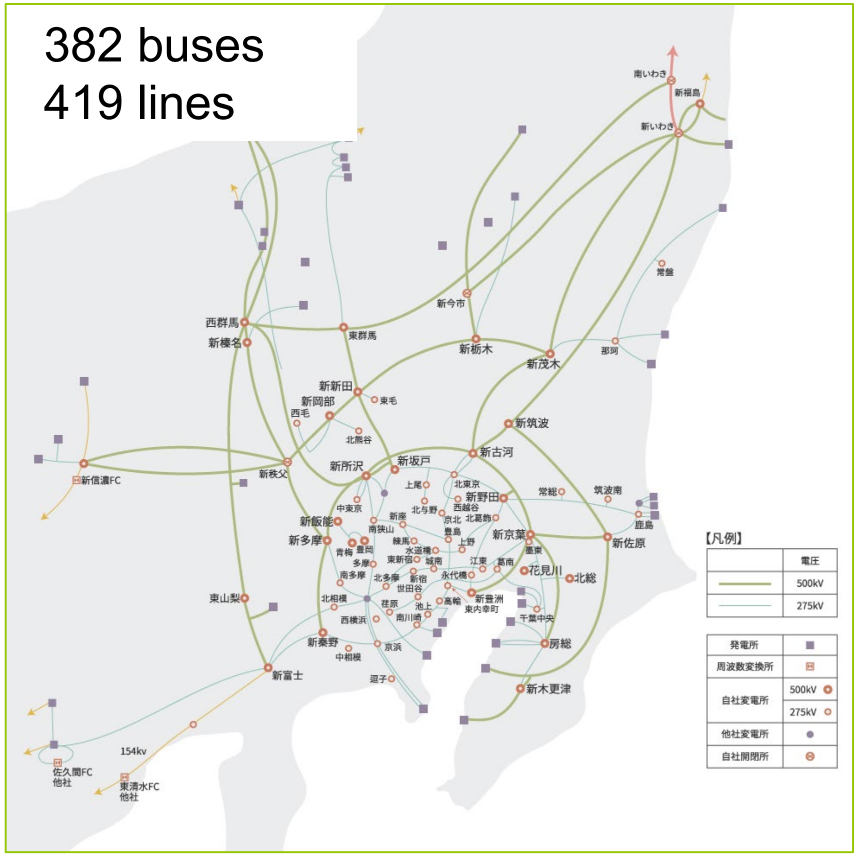
- Kyushu Area & Chugoku Area have the lowest LMP, due to the restoration of nuclear stations and high penetration of renewables.
- LMPs in the East Japan and Northwest Japan are the highest, due to the termination of nuclear power.
- **Still need calibration of parameters, such as** the marginal generation cost, the mini start-up cost & time…
- Moreover, scenario analysis will be conducted.



# Simulation:

## 全国基幹連系系統　　地域間連系線や地内基幹系統



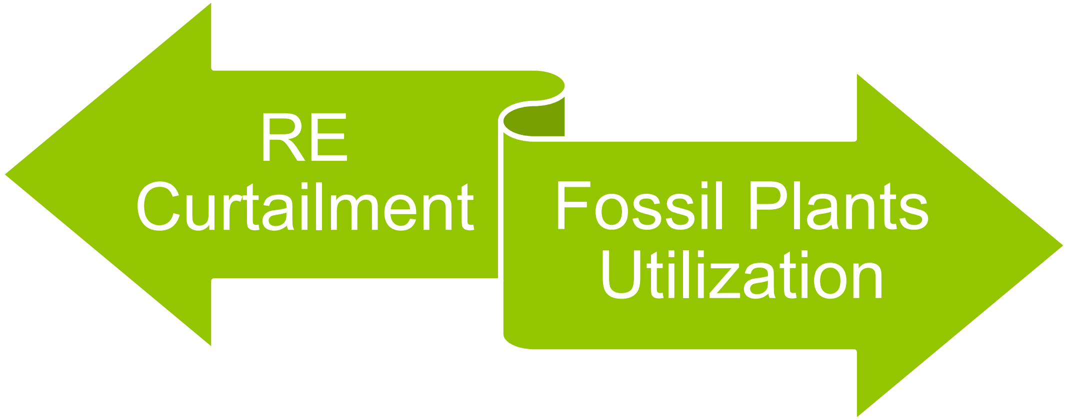
# 5. Future Studies:
# Possible Scenario Analysis

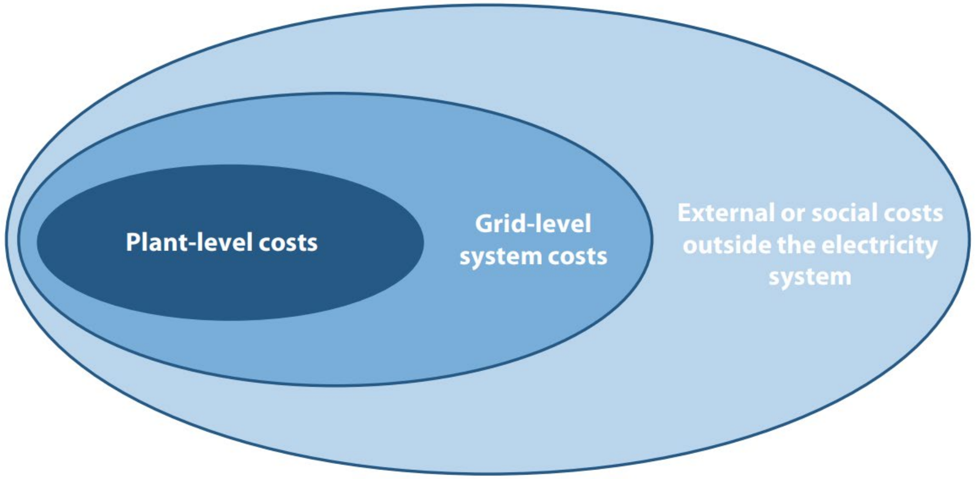
# Possible Scenario Analysis

- 市場高騰
- 統合コスト
- RE Curtailment
- 空容量ゼロ
- EV Adoption
- …

# Integration Costs & RE Curtailment (統合コスト)

- A wide range of costs across the literature that depend largely on the price and availability of flexible system operation(Heptonstall & Gross, 2021)
- Not easy to estimate the integration cost through the partial equilibrium model such model on
- Therefore, this model provides promising results.



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