COST EVALUATION CONSIDERING TIME-SHIFTED ELECTRICITY DEMAND OF INDUSTRIAL SECTOR IN ENERGY-CHAIN MODEL IN JAPAN

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The 1st IAEE Online Conference

June 8th, 2021

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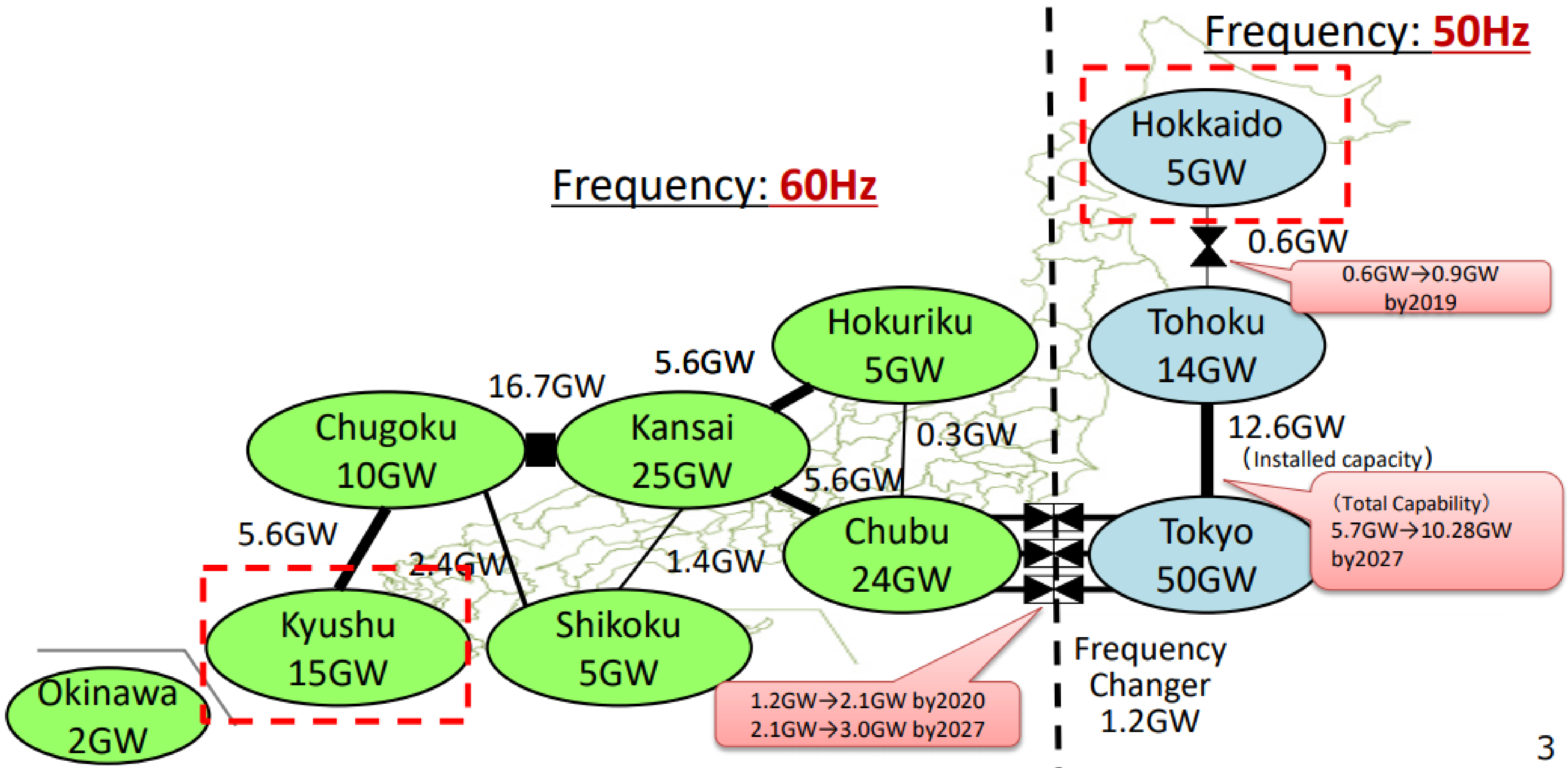
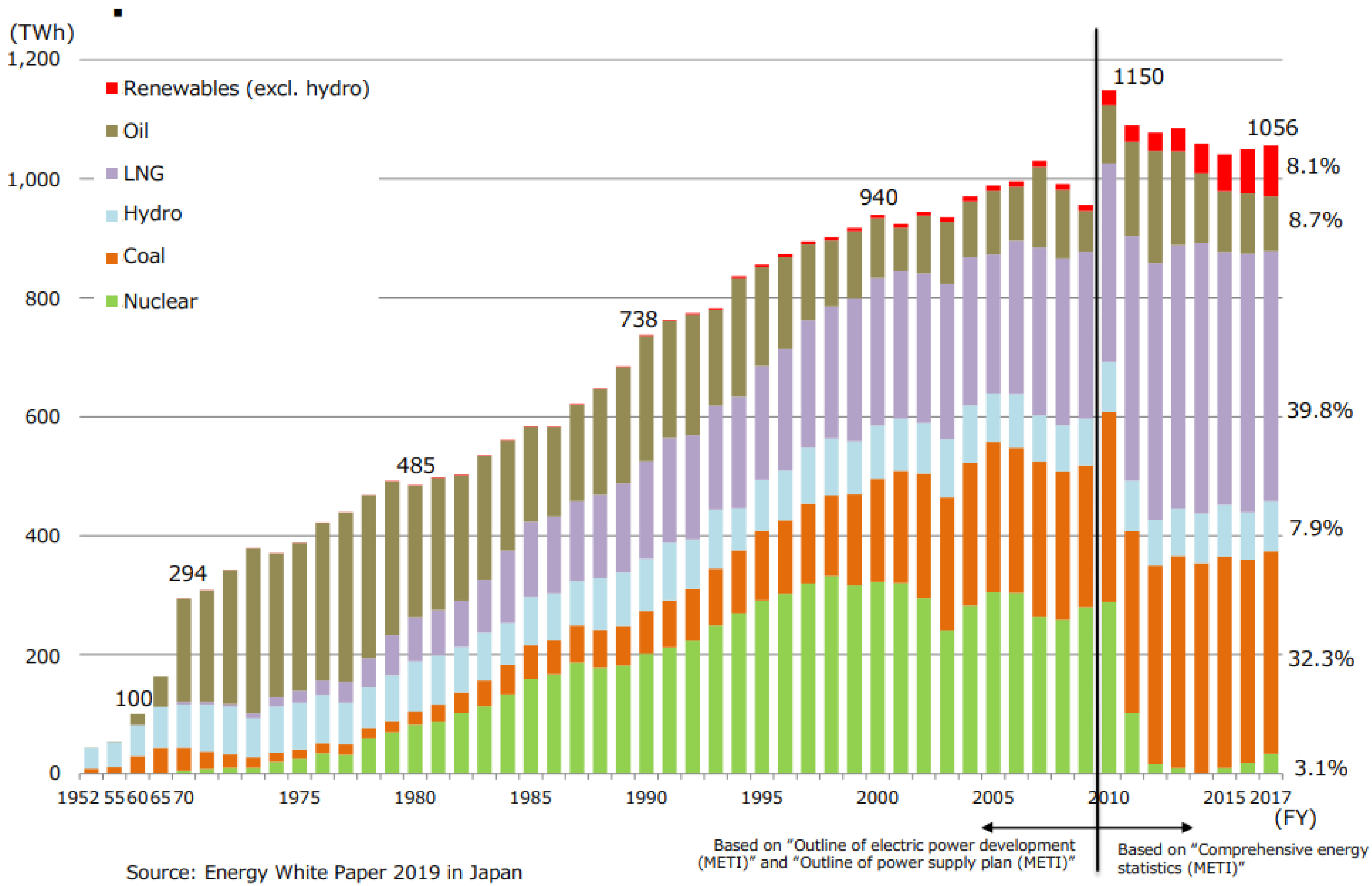
Power Grid in Japan



*The figures below indicates the maximum electricity demand in 2016.

Source: METI, Electricity and Gas Market Surveillance Commission

Power generation and Power supply composition

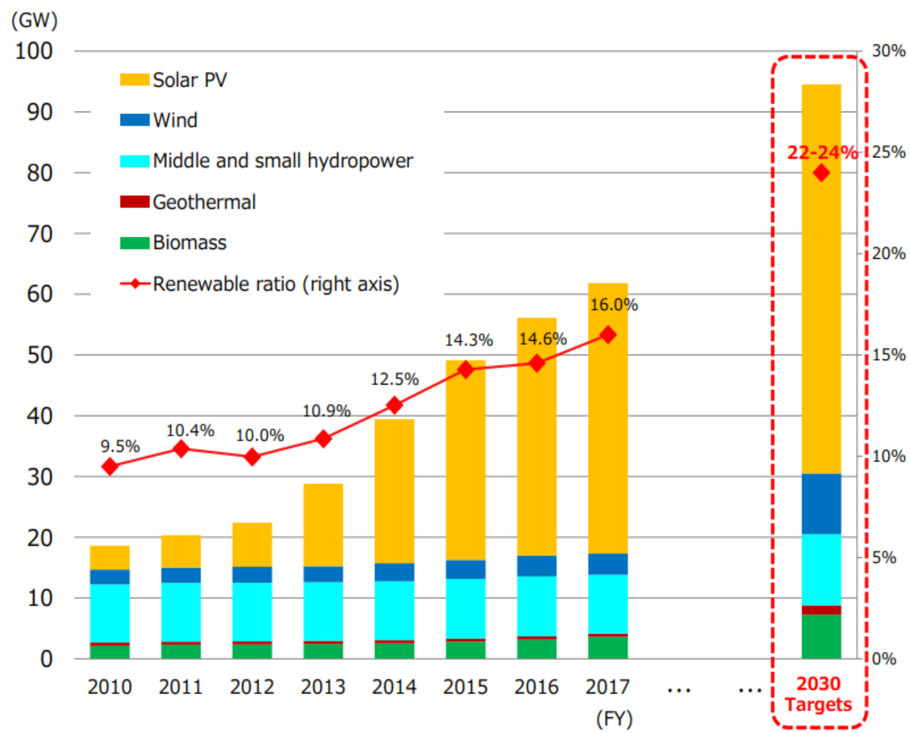


Source: Energy White Paper 2019 in Japan, NEDO

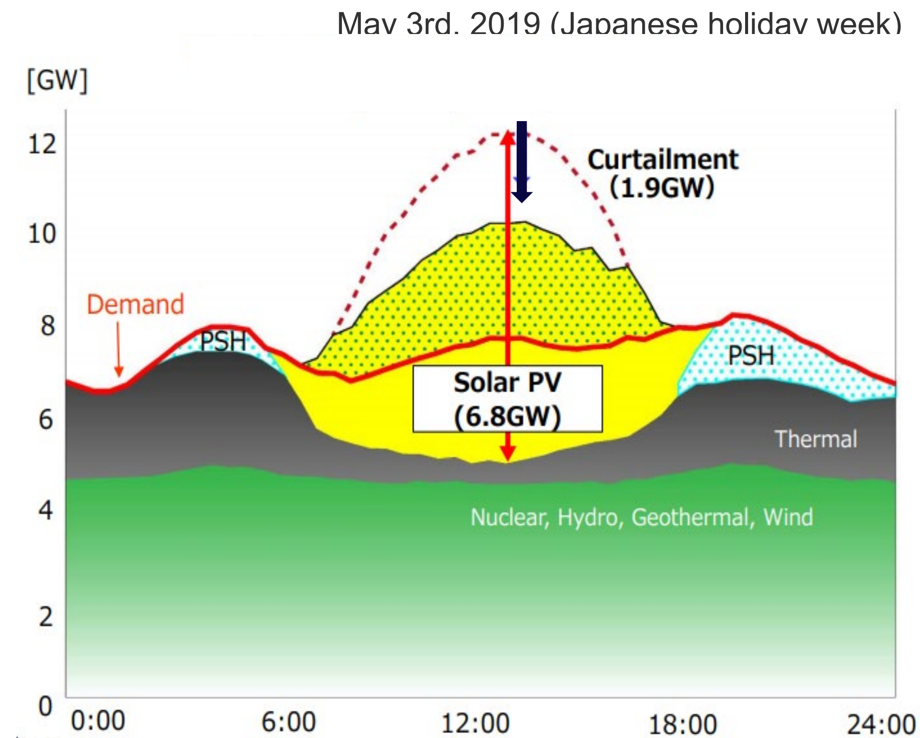
Due to the rapid PV penetration, duck curve is going deeper.

- Japanese government aims to install 64 GW of solar generation capacity (7.0% of total electricity generation) and 10 GW wind (1.7% of that) by 2030.
- Japanese government raised emissions reduction target to from 26% to 46% by 2030

Renewable electricity introduction[1)]



Supply & Demand in Kyushu Electric Area[2)]

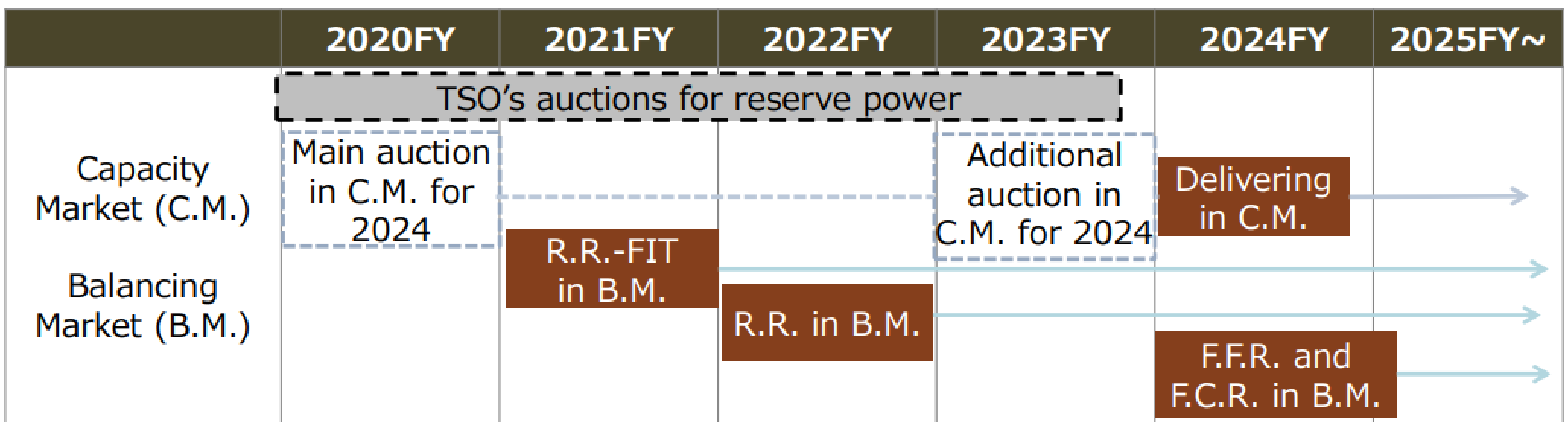


Source 1: Ministry of Economy, Trade and Industry (METI) & NEDO, 2: Kyushu Electric Power Company & NEDO

Balancing Market is going to be established

- From 2021, RR-FIT (Reserve Replacement Process to deal with forecast error of renewable energy by FIT) category in Balancing Market has began.
- In 2022 and 2024, additional categories of balancing market will be established.

Plan to establish Capacity Market and Balancing Market



R.R. : Reserve Replacement Process, F.R.R.: The Frequency Restoration Process, FCR: The Frequency Containment Process

Source: METI, Electricity and Gas Market Surveillance Commission

Research Issue and Objective

Background

- Due to the rapid PV penetration, duck curve is going deeper.
- Balancing market has established from 2021. Large-scale demand resources are hopeful for DSR utilization.

Issue

- **How much impact will DSR (demand side resources) have to the whole energy system in Japan in 2030, if they are utilized for demand time-shifting?**

Objective

- To incorporate **time-shifting** of industrial electricity demand into the energy system model of whole Japan.
- To analyze how it affects the entire Japanese energy system, and to evaluate its system cost.

Energy chain model (Energy System Model for whole Japan)

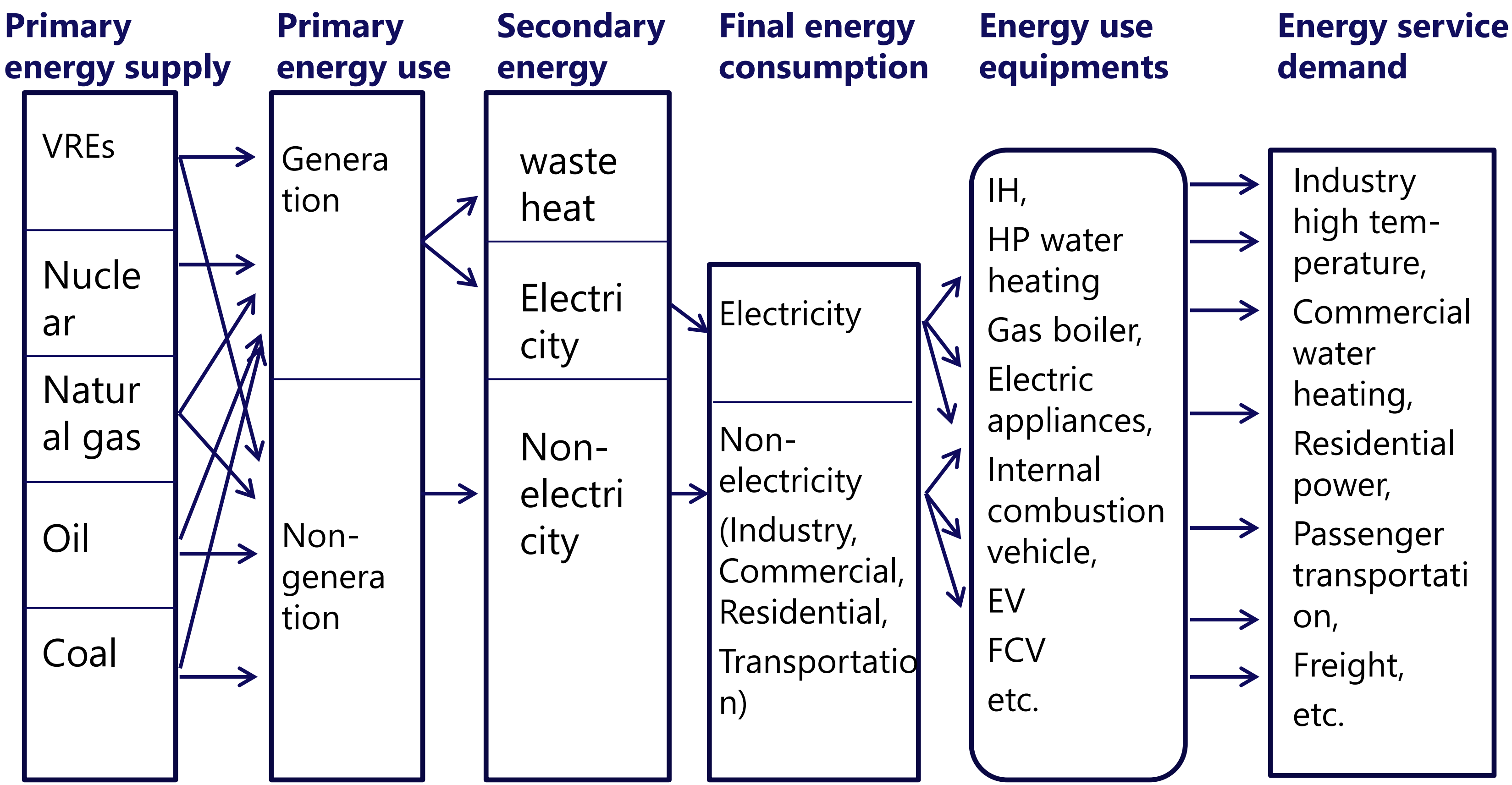
- An energy-chain model which is developed by Hiromi Yamamoto [1] simulates the entire energy-chain from primary energy supply to supply-demand balance and final service demand in Japan.

- Characteristics of **Energy Chain Model**
  - To consider the national energy chain from primary energy supply to final energy use.
  - It includes power sector detailed model (MM-OPG)
  - The objective function is to minimize the cost of the total system cost, including equipment cost, fuel cost, and operation and management cost, from the primary energy supply to the final service demand.
  - It covers not only the power sector but also the non-power sector, from upstream of energy supply to end-use equipment and energy services.
  - One-region model for Japan.
    - It does NOT cover regional issues (i.e. Transmission lines, Uneven distribution of VREs)

Source: [1] Hiromi Yamamoto, "An Effect of Electrification and Active Operation Time-Patterns of Electric Appliances Calculated by an Energy-Chain Model in Japan", Journal of Japan Society of Energy and Resources, Vol. 40, No.6, 2019

Structure of Energy Chain Model

- Energy conversion process from primary supply to final service demand is modeled as chained as soft link. Below is the structure overview.



Source: [1] Hiromi Yamamoto, "An Effect of Electrification and Active Operation Time-Patterns of Electric Appliances Calculated by an Energy-Chain Model in Japan", Journal of Japan Society of Energy and Resources, Vol. 40, No.6, 2019

Calculation assumptions of Energy Chain Model

- **Calculation target year:** 2030
  - The cost is minimized for a single year.
  - The installed capacity of the previous year is transferred to the next year in consideration of the service life.

- **The energy service demand** in the target year is given as an exogenous scenario with reference to the long-term energy supply and demand outlook by Japanese government.

- **Calculate the cost-minimizing energy chain** that satisfies the given service demand. The optimization calculation is performed using the linear programming method.

- For the electricity sector, we consider the hourly coincidence of electricity demand and supply for each hour of the year, the constraint on securing LFC reserve, and the loss of efficiency due to partial loading of generating facilities.

- **The temporal pattern of electricity demand** (Electric vehicle and Heat-pump water heater for commercial and residential use) are incorporated as flexible.

Source: [1] Hiromi Yamamoto, "An Effect of Electrification and Active Operation Time-Patterns of Electric Appliances Calculated by an Energy-Chain Model in Japan", Journal of Japan Society of Energy and Resources, Vol. 40, No.6, 2019

Examples of DSR (demand side resources) which may be time-shifted

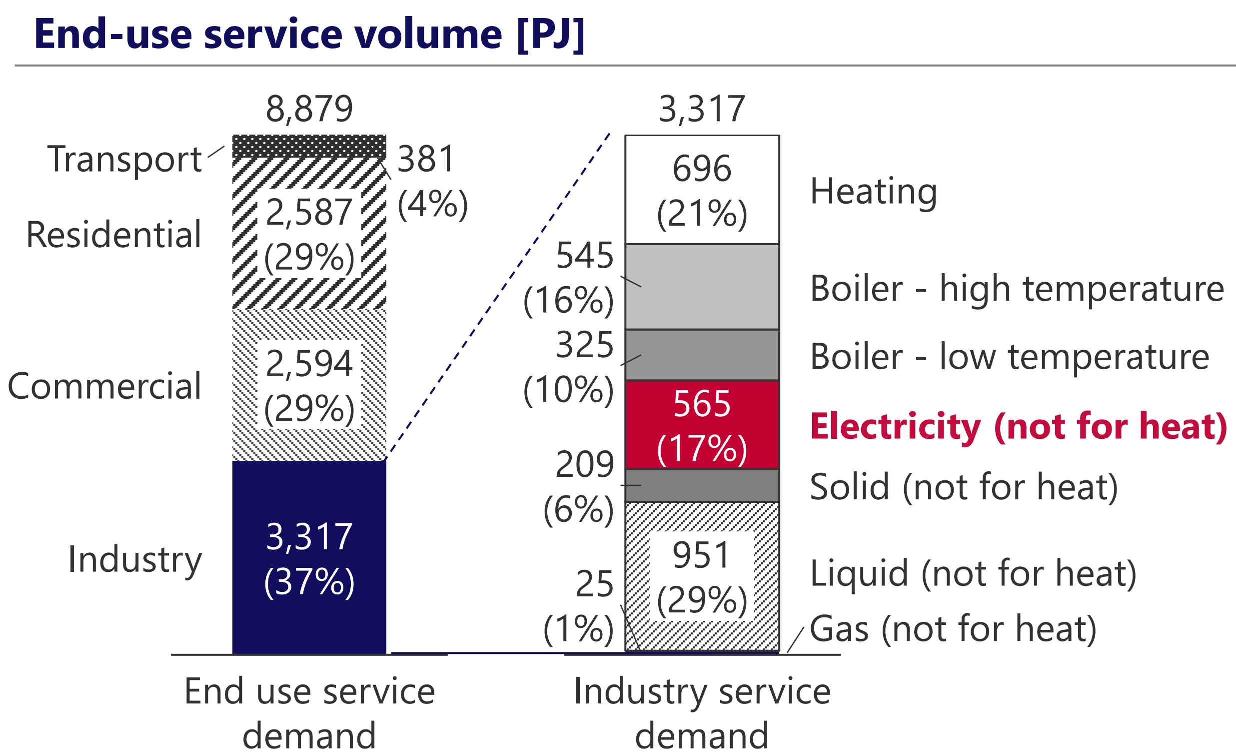
- **We don't specify the kinds of DSR to be utilized for demand time-shifting.**

- **Industrial DSR**
  - **Industrial demands**
    - Agricultural pumps, plant factories
    - Industrial robots (e.g., automated guided vehicles in warehouses)
    - Data centers
    - Electric carts / forklifts for industrial use

  - **Appliances**
    - Equipment with batteries
      - Computers & related equipment
      - Drones
      - Robots (for cleaning, nursing care, patrolling, etc.)
    - IoT-enabled electrical equipment
      - Washing machines and dryers, dishwashers
      - Refrigerators, Freezers

Time-shifting targets among end-use technologies

- Electricity usage (excl. for heat) in industrial sector are assumed to be time-shifted.
  - Electricity usage (excl. for heat) in industrial sector is 37% × 17% = 6.3% of total end-use service.
  - Small part of it is assumed as the target to be time-shifted.



Potential percentage of industrial demand to be time-shifted

- According to a report by the Oak Ridge National Laboratory in the United States, "Assessment of Demand Response for Industrial Loads of the Western U.S. Grid," [2]
  - 2.2% of the total industrial load can realistically be utilized for time shifting
  - 10.4% of the total industrial load can be maximally utilized for time shifting.
- According to Takahashi et al., "Evaluation of the potential of demand response with reserve power supply in the industrial and business sectors," [3]
  - Potential in the case of previous-day notification is approx. 3.3 GW ~ 4.1 GW. This means approx. 3-4% of electricity usage.

Time shift percentage case setting for industrial electricity demand
Leave deactivated: Base case
Three cases: **1%, 3%, and 10%** time-shifted case

Where
- We assume a manufacturing firm that manufactures mainly using electricity and can accumulate inventory.
- We assume that the weekly electricity consumption does not vary with the presence or absence of activation so as not to affect the weekly product output of manufacturing firms.

[2] Oak Ridge National Laboratory, "Assessment of Industrial Load for Demand Response across U.S. Regions of the Western Interconnect", 2013
[3] Takahashi, et.al., "Potential Estimation of Reserve-type DR Resources in Japanese Industrial Sector", CRIEPI Research Report Y15013, 2016/04

Case setting

- **Base case**
  - Electric vehicles and water heaters for business and residential use are operated in a time-shifted manner to optimize the power system.

- **3 Simulation case**
  - As an additional small-scale DSR equivalent, we assume that some portion of the total electricity demand (excluding heat demand) can be time-shifted.
  - The percentage of time-shifted electricity is assumed to be **1%, 3%, and 10%**.
    - We call them the 1% time shift case, the 3% time shift case, and the 10% time shift case, respectively.

Assumptions

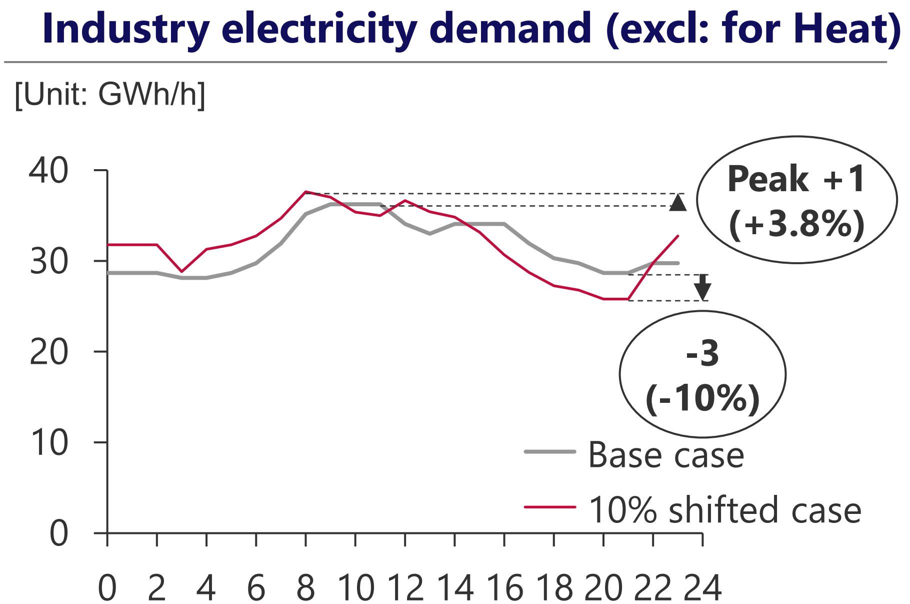
- **Thermal power generation**
  - The cost of power generation, generation efficiency, and service life were set based on the Agency for Natural Resources and Energy (part of METI) in 2014.
  - The partial load efficiency of power generation and the amount of LFC reserve by load factor were considered.
- **PV and wind**
  - The installed capacity and generation cost of photovoltaic (PV) and wind power in 2030 are based on “the Long-Term Energy Supply and Demand Outlook” by METI.
  - 64 GW of solar generation capacity (7.0% of total electricity generation) and 10 GW wind (1.7% of that) by 2030.
- **Base-load generation and pumped water generation**
  - The amount of power generation in 2030 for nuclear power, hydropower, and other power generation (geothermal, biomass, etc.) was given as an exogenous scenario with reference to the Long-Term Energy Supply and Demand Outlook from METI.
- **Energy service demand**
  - Proportional distribution of energy service demand in the base year (2010) by service.
  - The energy service demand in 2030 is 1.00 in total for industry, 1.11 in total for business, 0.95 in total for households, and 0.90 in total for transportation, compared to 2010.

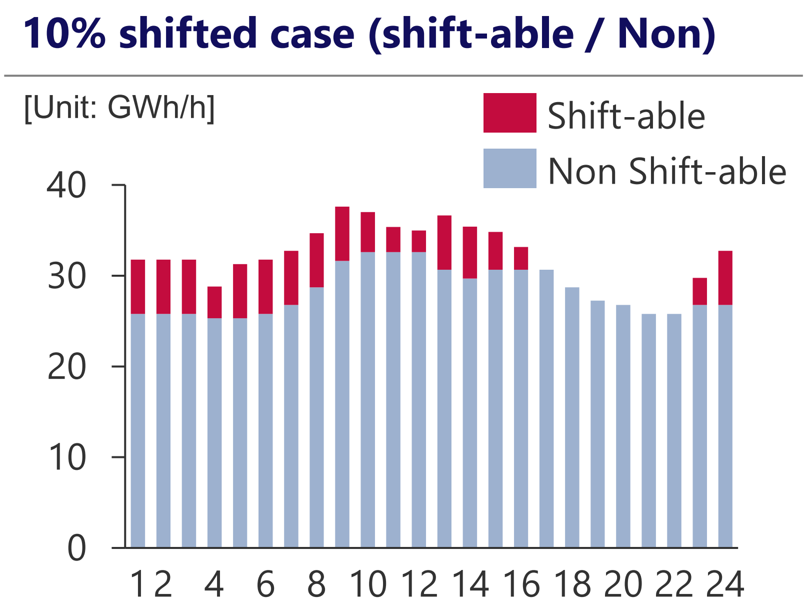
Source: [1] Hiromi Yamamoto, “An Effect of Electrification and Active Operation Time-Patterns of Electric Appliances Calculated by an Energy-Chain Model in Japan”, Journal of Japan Society of Energy and Resources, Vol. 40, No.6, 2019

Result (1/6): On a day with light electricity demand; Industry electricity demand time-shift

- Industry electricity demand in the evening hours are reduced by 10%.
- As shown in the figure on the right, the demand that could be shifted moved from the evening hours to other hours.

Temporal pattern of electricity demand on a day with low demand and high PV/wind generation (May 4)



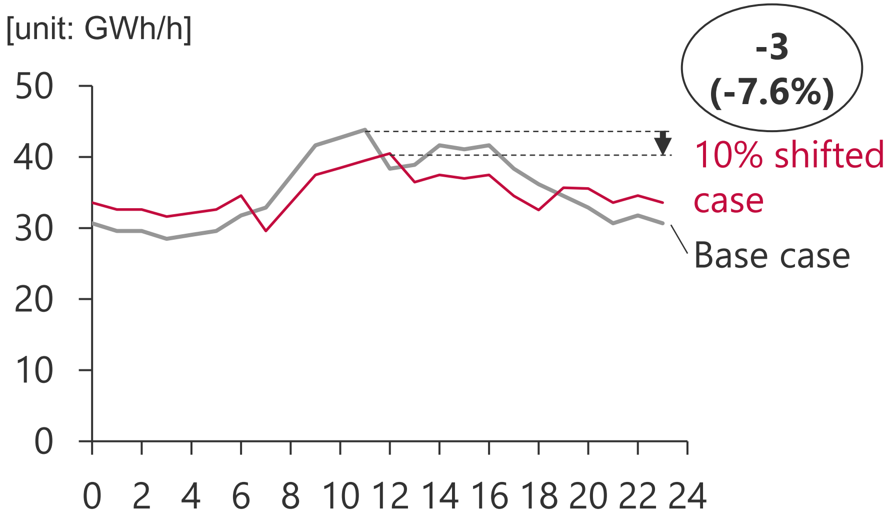


Result (2/6): On a day with heavy electricity demand Peak reduction

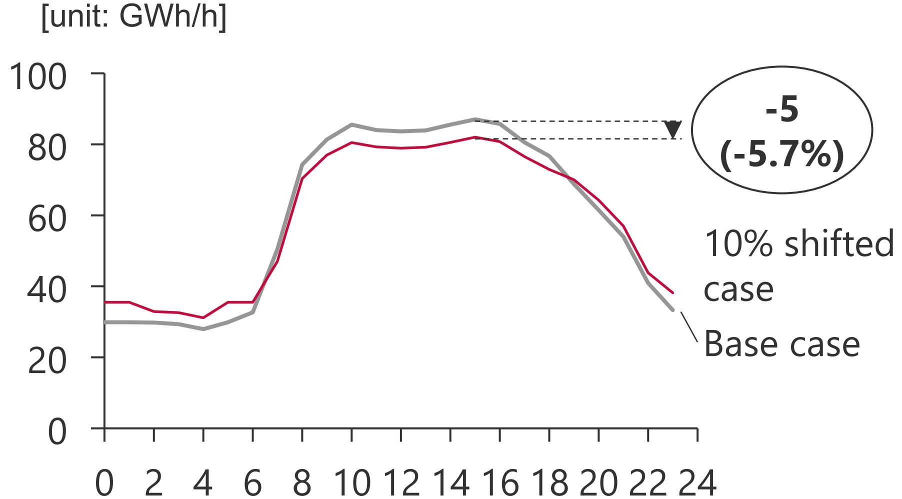
- The peak demand of electricity demand excluding heat applications decreased by 7.6% on a day with high electricity demand and low PV/wind generation (January 12).
- Regarding the electricity generated by the LNGCC on the same day, the peak decreased by 5.7% on the same day.

Temporal pattern on a day with high electricity demand and low PV/wind generation (January 12)

Industry electricity demand (excl: for Heat)



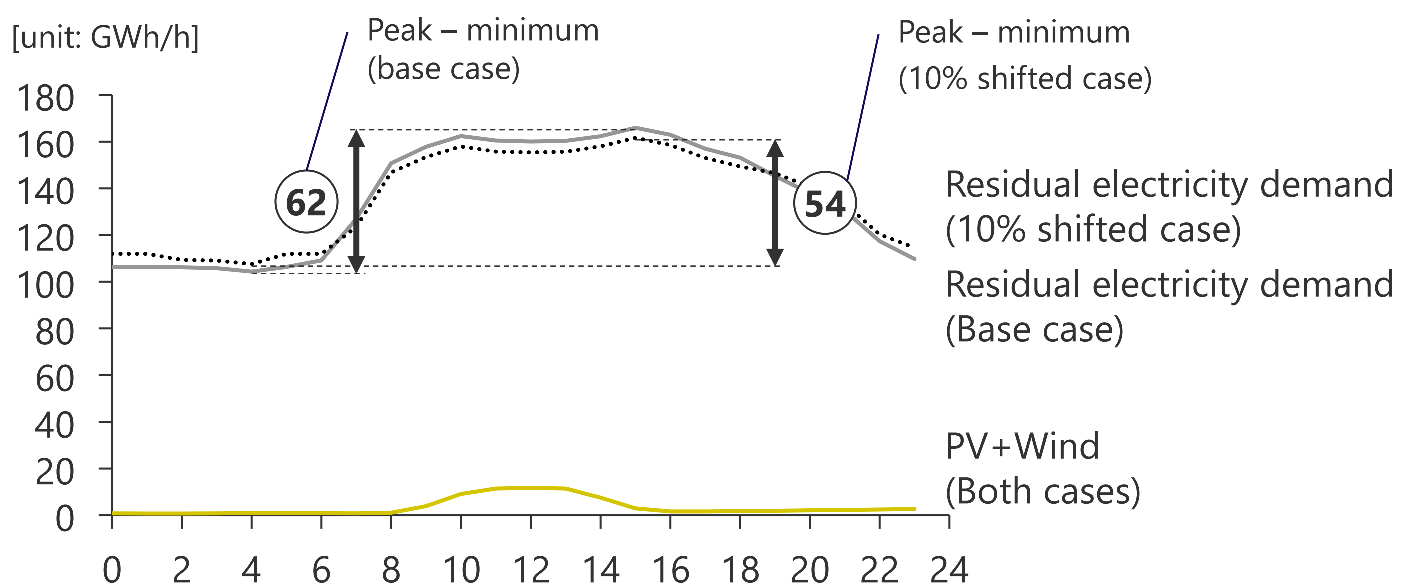
LNGCC generation



Result (3/6): On a day with heavy electricity demand; Residual electricity demand becomes flatter

- Duck curve is calculated as [actual electricity demand] – [PV generation] – [wind generation].

Residual electricity demand (actual demand - PV, wind) on a day with high electricity demand and low PV/wind generation (January 12)

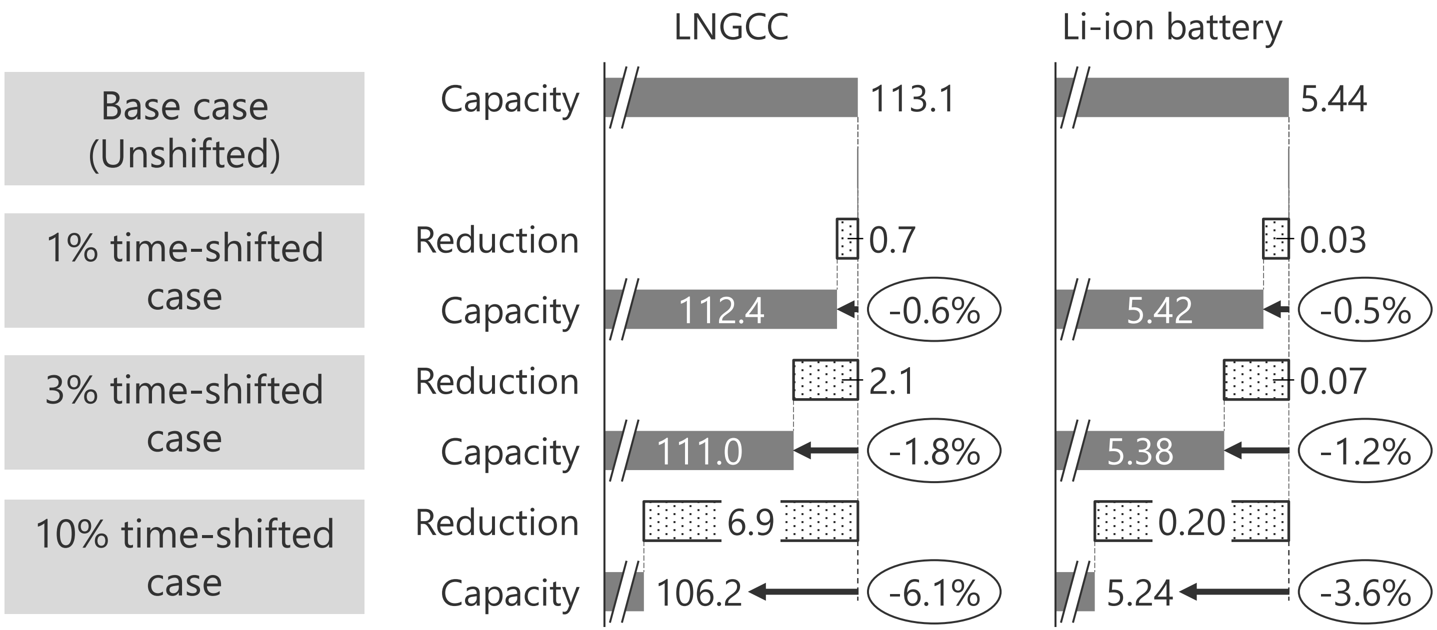


Result (4/6): Change in power supply capacity

- The capacities of LNG combined cycle (LNGCC) and lithium-ion (Li-ion) batteries in time-shifted cases are smaller compared to the base case.
- The capacities of other power sources (nuclear, hydro, coal, IGCC, LNG, petroleum, fixed pumping, variable pumping, NaS battery, wind, solar) are stable.

Generation capacity of LNGCC and Li-ion battery

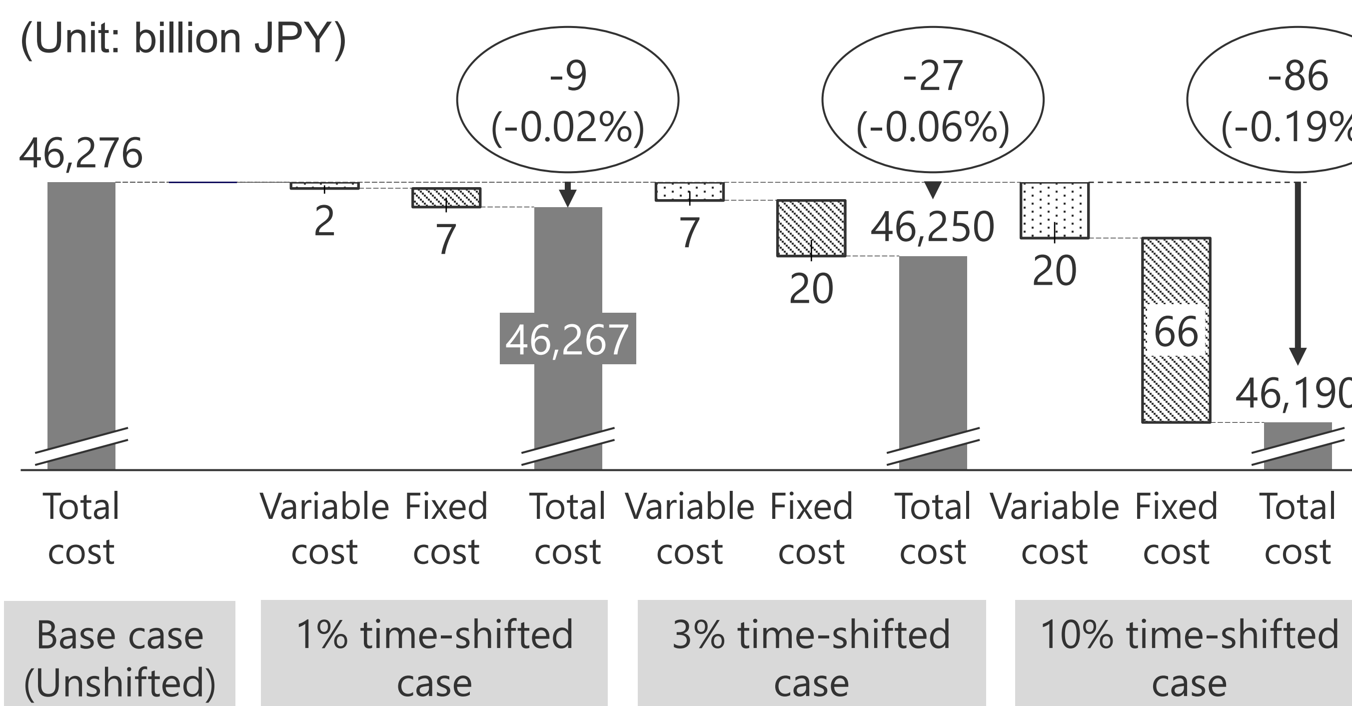
[unit: GW]



Result (5/6): Change in total system cost

- Below shows the calculated total cost of energy-chain in the base case and 1%, 3%, and 10% time-shifted cases. The total cost was reduced by 8.9 billion JPY in 1% time-shifted case compared with the base case. The total cost reduction increase gradually from 1% time-shifted case to 10% time-shifted case.

Total system cost change



Result (6/6): Effect per kWh of time-shifted demand

- Below table shows the conversion of total costs and CO2 emissions into per kWh of time-shifted industrial electricity demands. Total cost consists of fixed costs which includes equipment costs from power generation to final service demand, and variable costs such as fuel costs and operation and management costs.
- In each case, the fixed cost portion is larger than the variable cost portion in the total cost reduction. The reduction of the total cost and the CO2 emission per time-shifted demand are almost constant among the three cases.

Cost and CO2 emission change per time-shifted electricity demand

	Rate of time-shifted industrial electricity demand		
Cost	1% case	3% case	10% case
Total cost reduction (JPY/kWh)	5.68	5.63	5.51
Variable cost (JPY/kWh)	1.39	1.39	1.28
Fixed cost (JPY/kWh)	4.29	4.25	4.22
Reduction of CO2 emission from power generation sector (kg-CO_2/kWh)	0.020	0.019	0.018

Summary

- **Peak reduction of Industrial electricity use**
  - The peak of industry electricity demand (excl. for heat) decreased by 7.6% on a day with high electricity demand and low PV/wind generation (January 12).
  - It caused peak reduction of LNGCC generation on the same day by 5.7%.

- **Potential value of time-shifting of industrial electricity use**
  - The reduction of total system cost is 5.5-5.7 JPY per time-shifted kWh.
  - About 2/3 of it for fixed cost reduction (power supply and storage equipment costs) and 1/3 for variable cost reduction (fuel costs).

- **How to promote the time-shifting of industrial electricity use?**
  - Providing reasonable financial incentives to industrial consumers is one way of promoting demand time-shifting.
  - Total system cost reduction (5.5-5.7 JPY per time-shifted kWh) can be regarded as upper limit of incentive for demand time-shifting. In realty, we should take into account operation cost such as transmission cost, market dealing cost in balancing market and order & measurement cost etc.

Thank you!