USAEE/IAEE 36th North American Conference, Concurrent Session 28,
Hilton Crystal City , Washington DC USA, September 25, 2018

Modelling Analysis for Optimal Integration of Solar PV in National Power Grid of Japan

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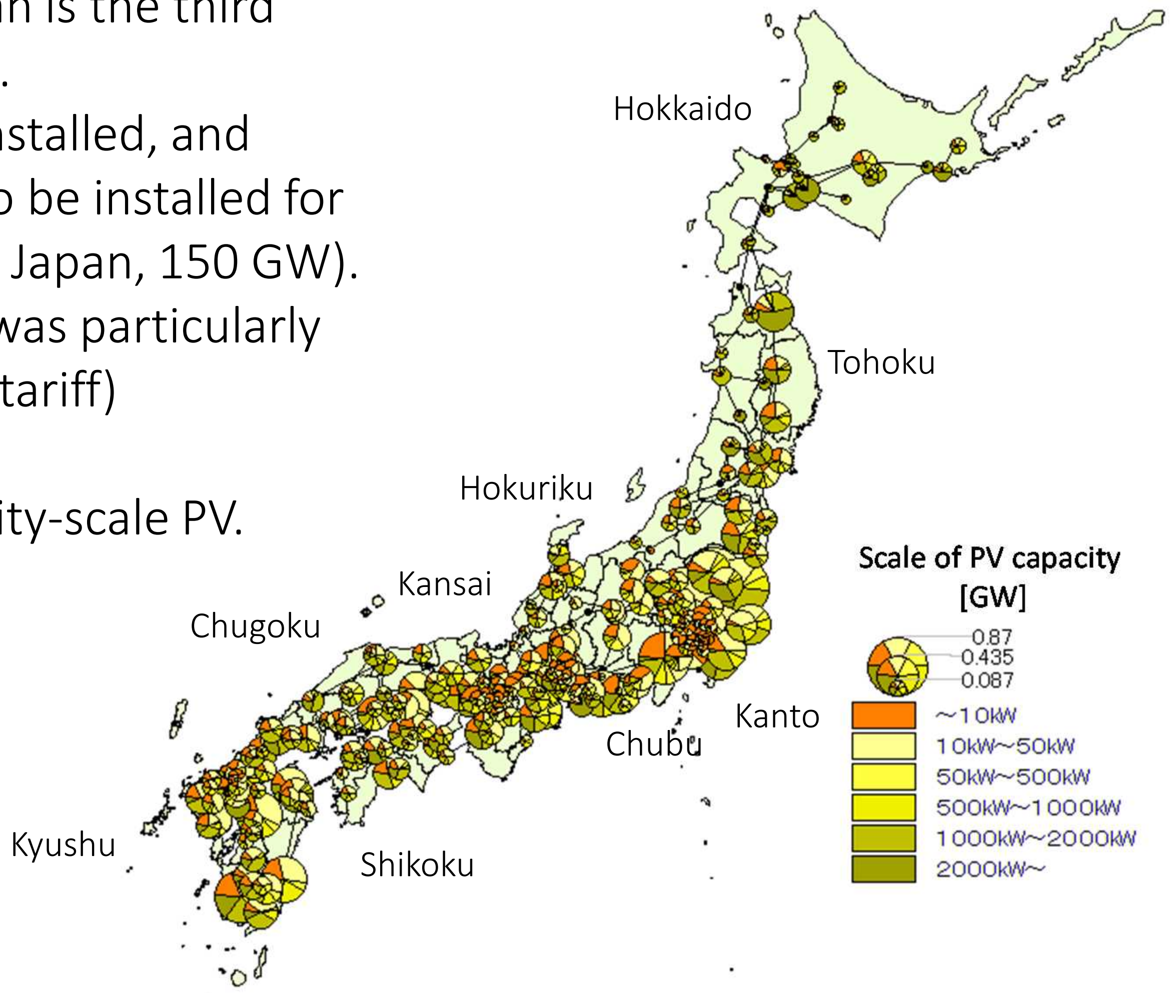
Outline

- Backgrounds: PV Status in Japan
- Methodology: Optimal Power Generation Mix Model
  - Single-year optimization (cost minimization)
  - 352 buses, 441 transmission lines with 8,760 time slices per year
- Scenario & Results: Optimal Integration of Solar PV
- Conclusions and Implications

Status of Solar PV in Japan

- Installed PV capacity in Japan is the third largest in the world at 2017.
- 40 GW or more is already installed, and another 40GW is planned to be installed for the future (peak demand in Japan, 150 GW).
- Penetration of PV capacity was particularly encouraged by FIT (feed-in-tariff) implemented in 2012
- Majority of the install is utility-scale PV.

Installed PV Capacity in Japan (2017)



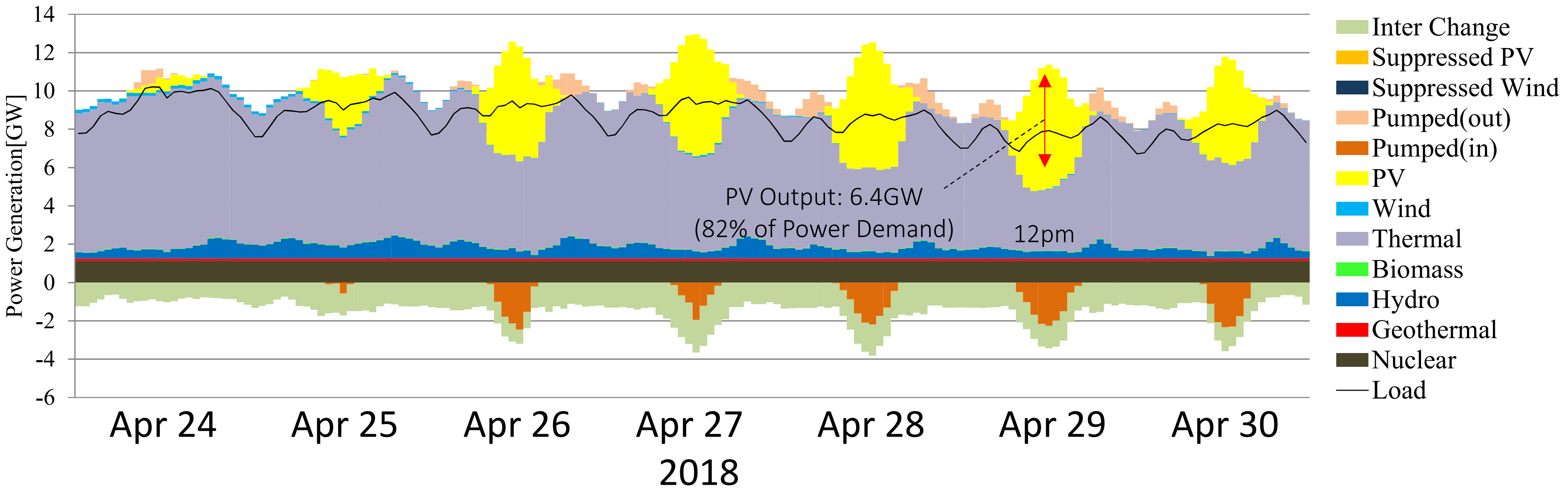
(Source) Compiled from the data of Ministry of Economy, Trade and Industry <http://www.enecho.meti.go.jp/category/saving_and_new/saiene/kaitori/>

Impact of Solar PV in Japan

- In Kyusyu area (15GW), PV output recorded 82% of power demand in April 29, 2018, while 80% is observed in May 5, 2018 in Shikoku area (10GW)
- The Japanese rule of renewable priority dispatch:

  Dispatchable thermal (online)→pumped-hydro→ Dispatchable thermal (not online) → interconnection→curtailing biomass→curtailing PV & Wind→contingency balancing order→curtailing inflexible resource (nuclear, geothermal, hydro).

Dispatch in Kyushu, Japan from April 24 to April 30 in 2018

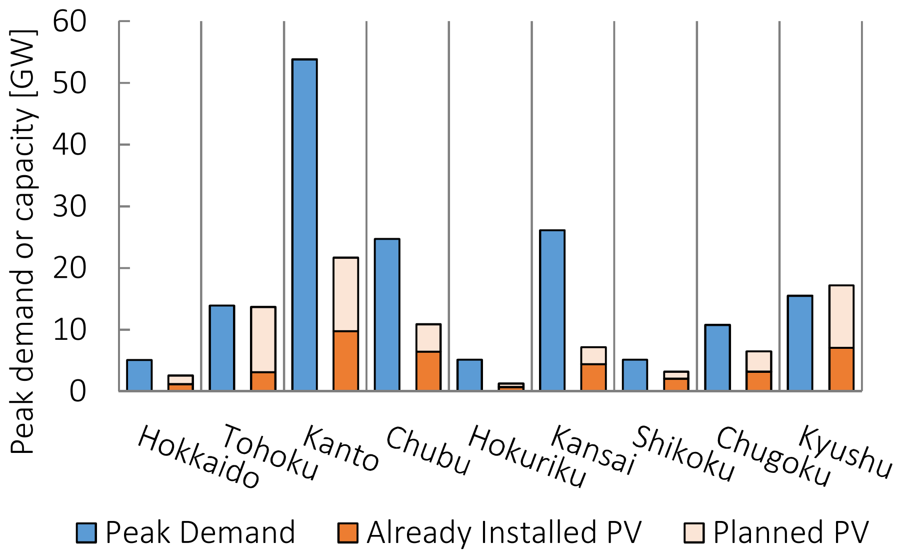


(Source) Compiled from the data of Kyushu Electric Power Company

Research Background

- ➢ **In specific service area, enough grid capacity will not be secured to manage PV output**
- ➢ Installed PV capacity is more than or comparable to that of power grid in specific area, while PV capacity is well less than the scale of power grid in some area.
- ➢ **Optimal deployment of solar PV is important for addressing regional imbalances between the scale of power grid and that of PV.**
- ➢ **This presentation attempts to optimize planned 40GW of PV deployment (light orange)**
  (Now in Japan, 40 GW is already installed, and another 40GW is planned to be installed)

<u>Installed and Planned PV capacity, with Grid Capacity (Peak Demand)</u>



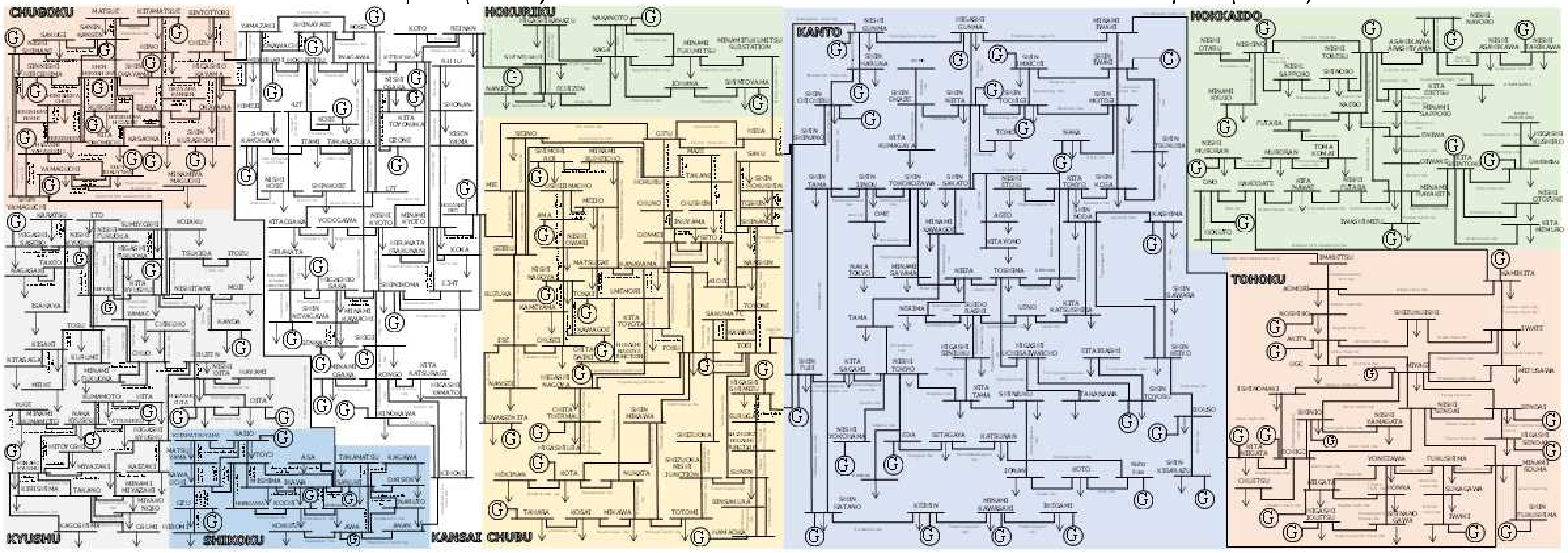
(Source) Compiled from the data of METI and OCCTO

Optimal Power Generation Mix Model in Japan

Geographical Resolution: 352 buses, 441 bulk power transmission lines (HVAC:435 lines, HVDC:6 lines)
Temporal Resolution: An hourly resolution for 1 year = 8,760 time slices / year
Method: LP model from scratch, Single-year cost min. (operating cost + battery install cost)
Scale of LP Model: Constraints: 62 millions, Endogenous variables: 44 millions

<u>Bus system diagram in Japan, 352 nodes and 441 bulk power transmission lines</u>

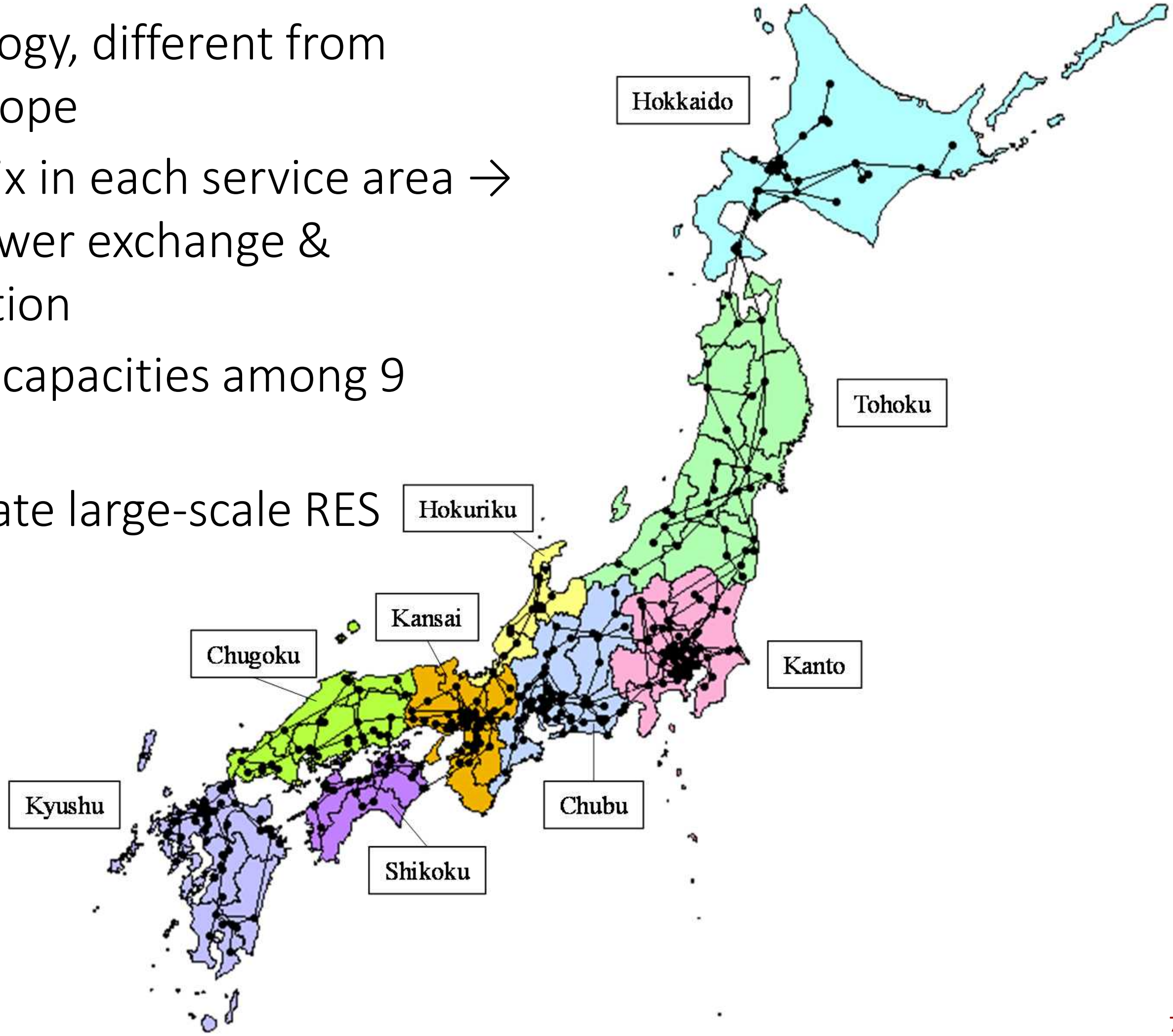
Western Japan (60Hz) *Eastern Japan (50Hz)*



(Related Works)
Komiyama R, Fujii Y, *Energy Policy* ;66:73-89 (2014)
Komiyama R, Fujii Y, *Energy* ;81:537–555 (2015)
Komiyama R, Fujii Y, *Energy Policy* ;101:594-611 (2017)
………

Grid Topology (352 nodes, 441 power transmission lines)

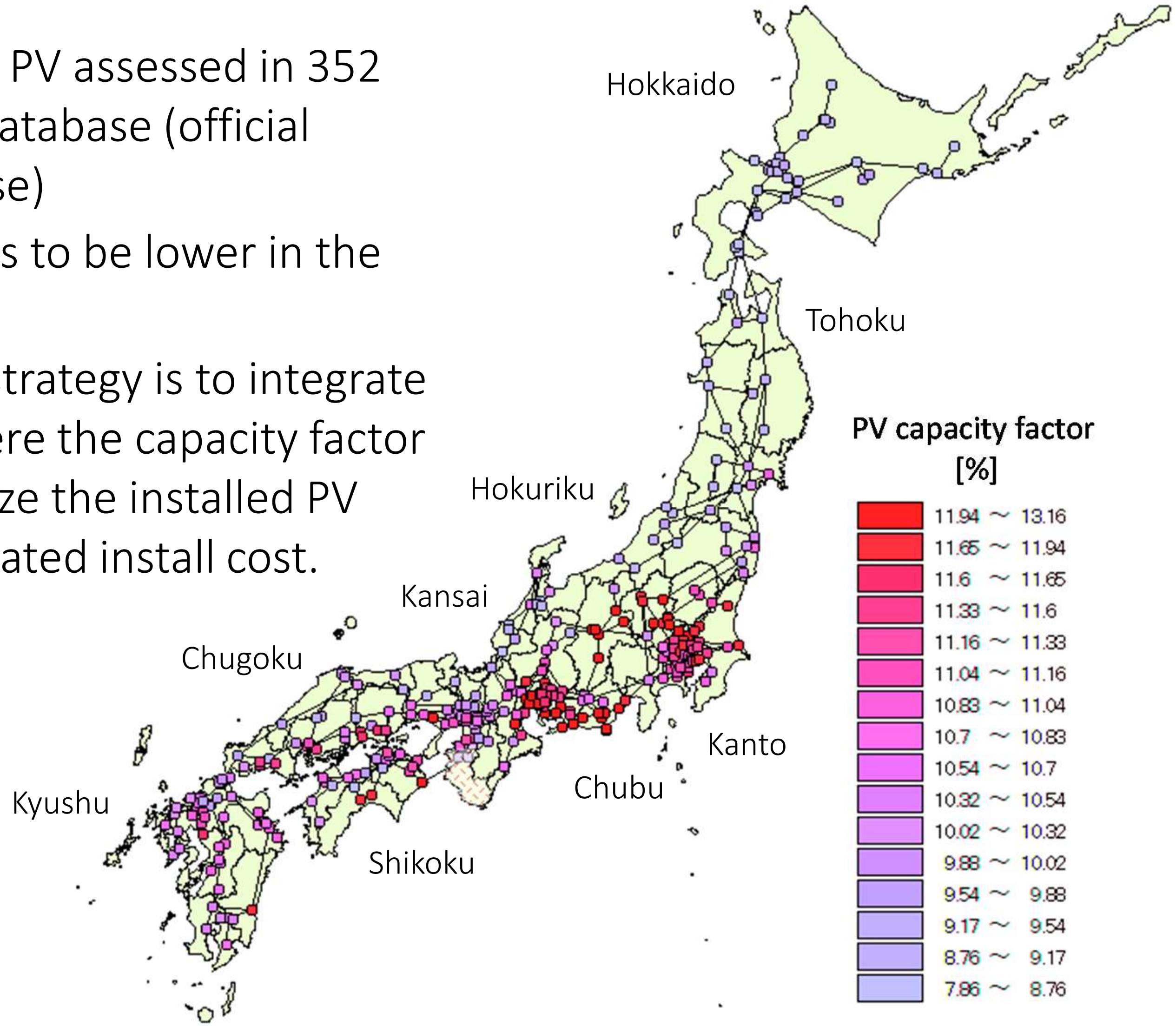
- **Consideration of grid topology is important in Japan**
- Longitudinal-type grid topology, different from mesh-type topology like Europe
- Similar power generation mix in each service area → few incentive to regional power exchange & national resource consolidation
- Insufficient interconnection capacities among 9 service areas
- Inherently difficult to integrate large-scale RES



PV Capacity Factor in 352 buses

Annual-average Capacity Factor of Solar PV

- Capacity factor of solar PV assessed in 352 buses, from AMeDAS database (official meteorological database)
- PV capacity factor tends to be lower in the northern part of Japan.
- As implied, the better strategy is to integrate solar PV in the bus where the capacity factor is higher and to minimize the installed PV capacity and the associated install cost.

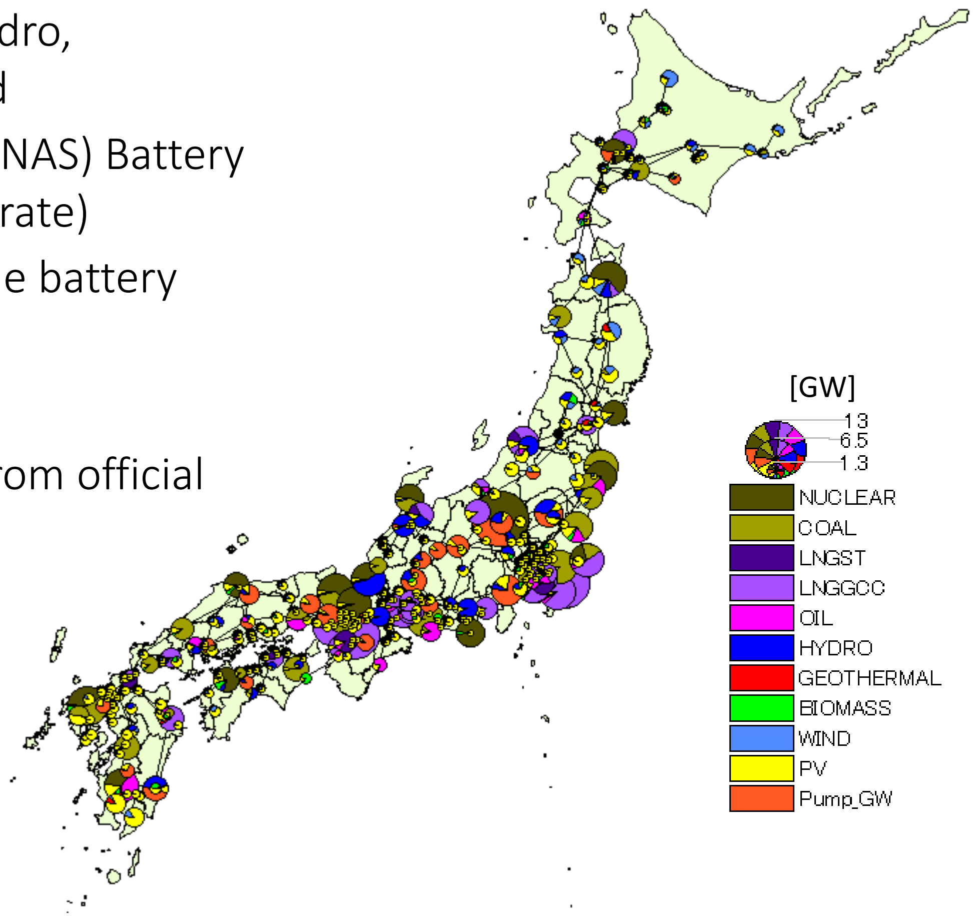


Power System Resources

- Power system resources are set by long-term power supply plan of government and utilities

Assumptions of Power System Resources

- Coal, LNG-GCC, LNG-ST, Oil, Nuclear, Hydro, Geothermal, Biomass, Marine, PV, Wind
- Pumped-hydro Storage, Sodium-sulfur (NAS) Battery (Lower C-rate), Li-ion Battery (Higher C-rate)
- Given capacities, except for rechargeable battery
- Fixed power transmission capacity
- Fixed load curve
- PV, wind outputs in 10-min estimated from official meteorological database in 352 nodes
- Nuclear, consistent with official target



Scenario of PV Integration (2 Scenarios)

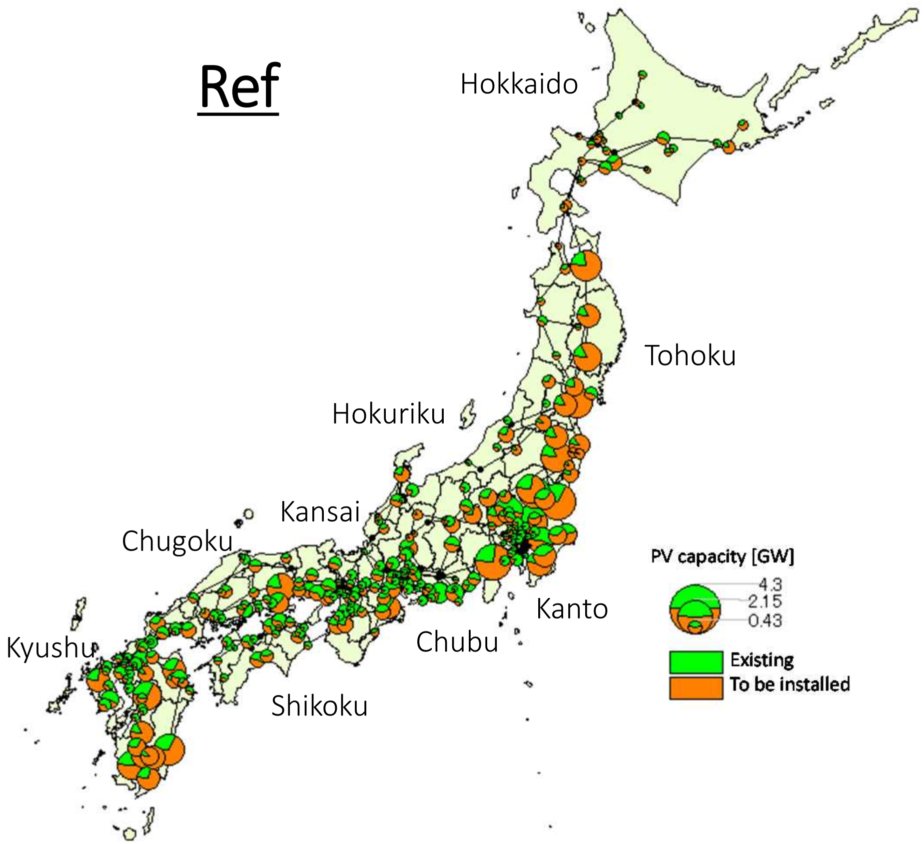
- Japanese power generation cost is currently the highest all over the world, and the economically efficient integration of solar PV is very important
- Planned 40 GW of PV will enormously affect the national power system
- **The motivation is to understand "Where is the best location of PV to be installed in the power grid ? "**

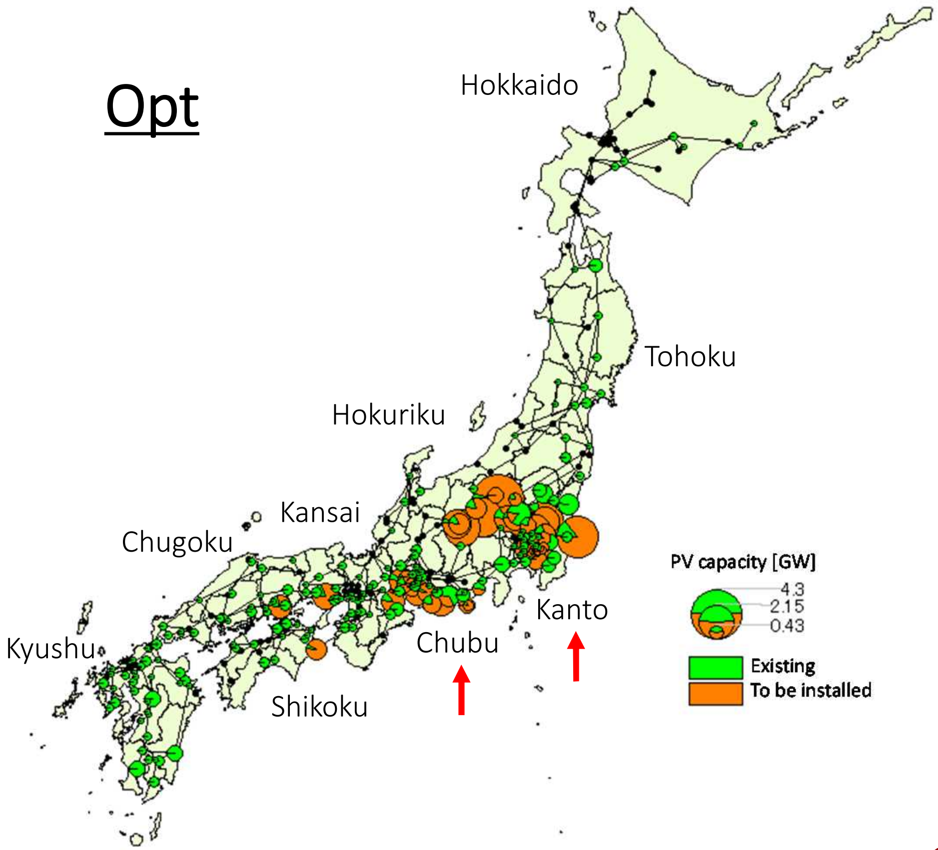
- **Reference Scenario (Ref)**
  - Most possible projection of PV deployment in Japan
  - PV, 40GW, is to be installed into the location as already announced.

- **Optimal Integration Scenario (Opt)**
  - Deployment of PV capacity to be installed, 40GW, into each node is optimized, so as to minimize the total power system cost

Optimal Integration of PV capacity

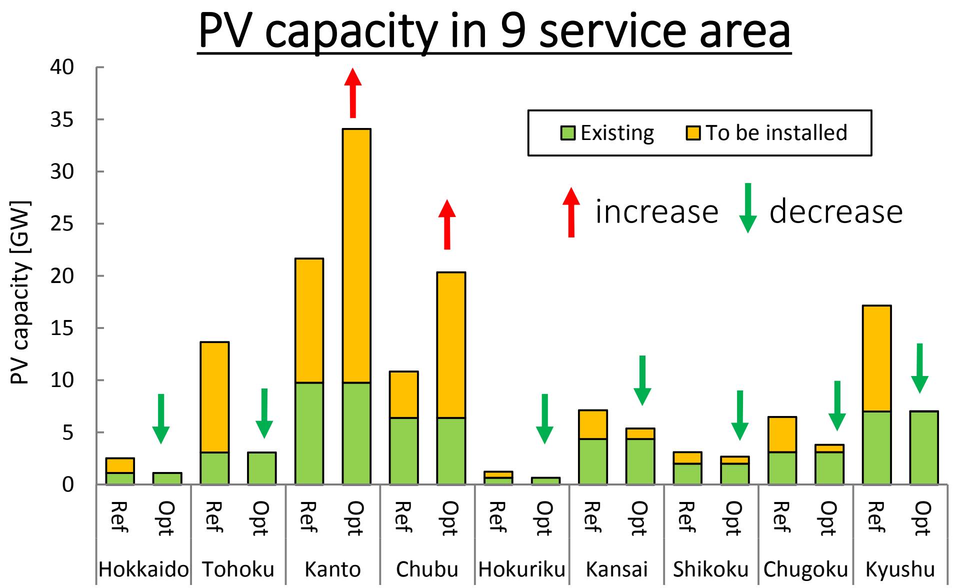
- In Opt scenario, nodal PV deployment shifts to the area with larger grid capacity and with higher capacity factor of solar PV, compared with Ref scenario.

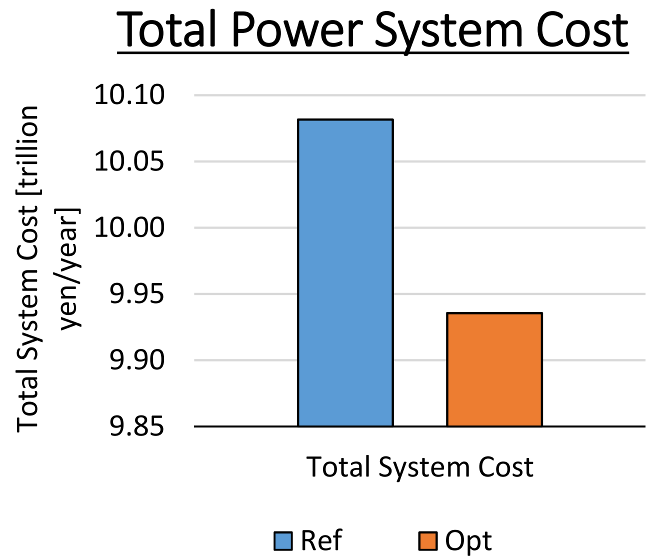




Effect of Optimal PV integration

- PV deployment in Opt shifts to the area with sufficient grid capacity, higher solar radiation and higher wholesale electricity price to further cost minimization.
- For example, PV install in higher solar insolation leads to reduce the required PV capacity for gaining the same amount of PV power and to save the PV investment cost.
- Difference of results between Ref and Opt
  - Total 6GW less PV capacity in Opt
  - Total 100 billion yen of PV investment can be saved in Opt
  - Total 80 billion yen of fossil fuel cost is conserved in Opt
  - Total 1.3TWh of electricity transmission loss can be reduced in Opt

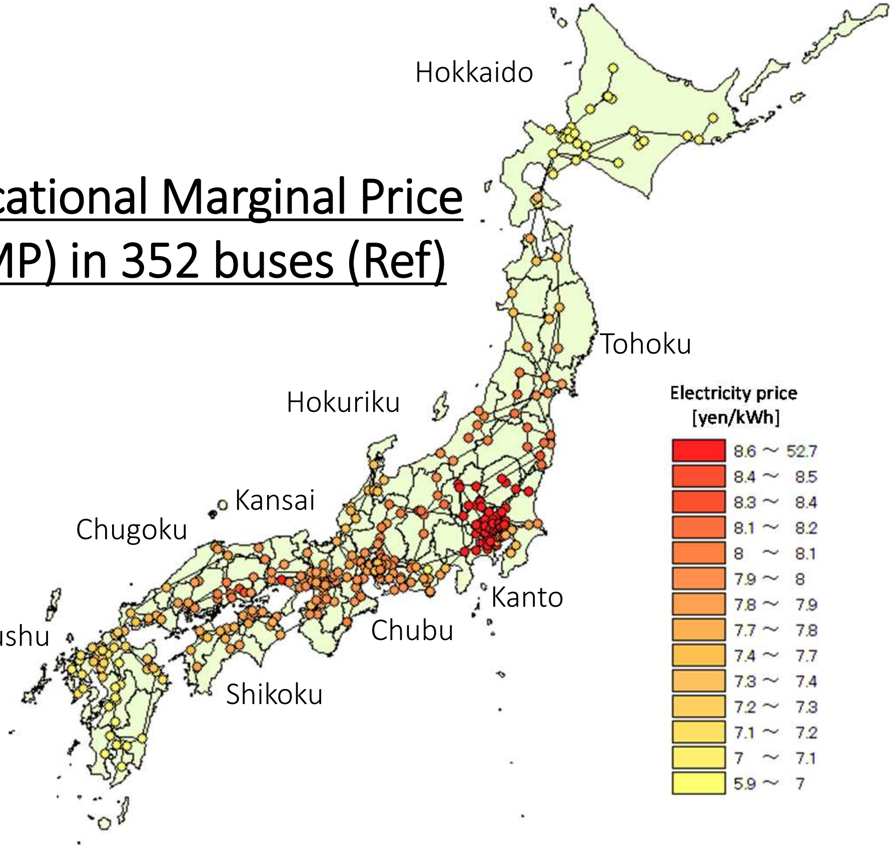




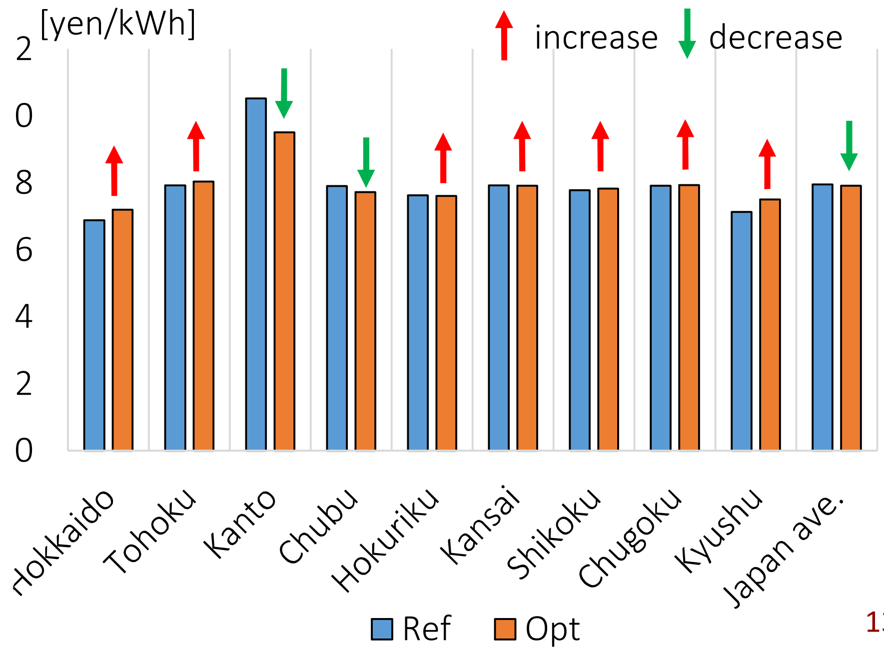
Locational Marginal Price (LMP)

- Optimal deployment of PV encourage PV install shifted to Kanto and Chubu area from the most of other regions
- Wholesale price decreases in the area where PV capacity is incremented, while the price increases in the area where the PV capacity is decremented
  → Regional gap of area price is reduced.

Locational Marginal Price (LMP) in 352 buses (Ref)

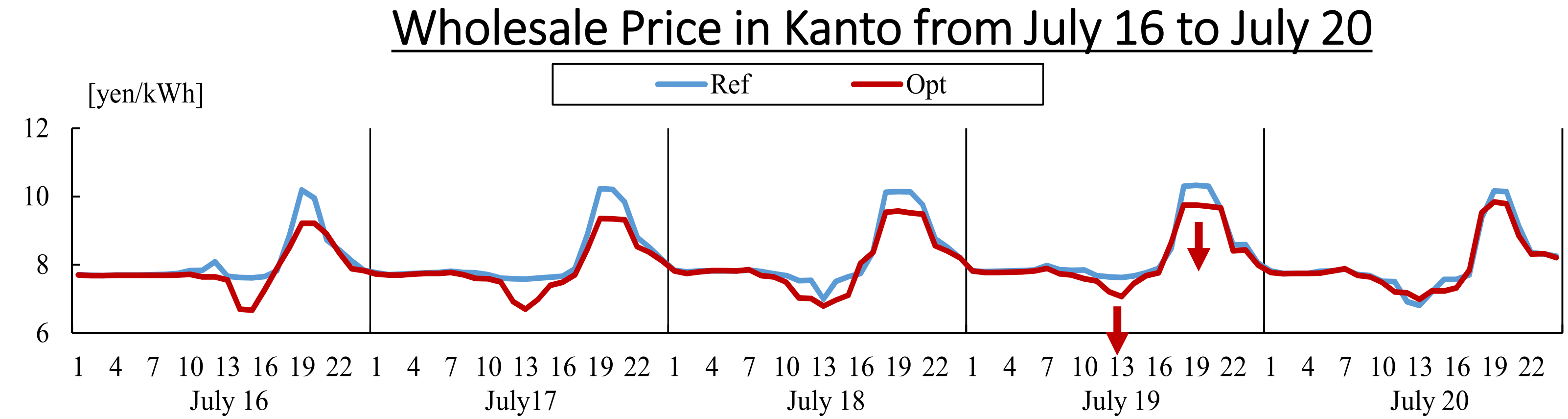


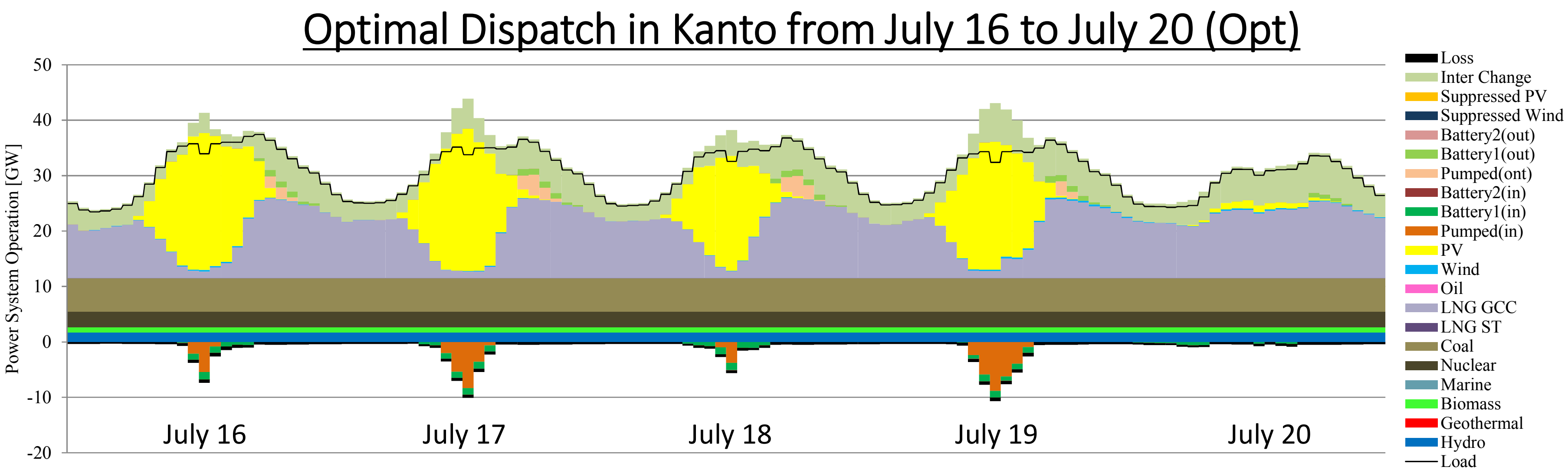
Annual-Average LMP (wholesale Price) in 9 service area (Ref, Opt)



Wholesale Electricity Price & Optimal Dispatch in Kanto

- Increased PV output reduces wholesale price in around noon and night.
- Wholesale price in night is reduced by electricity discharged from pumped-hydro charged by PV in daytime





Conclusions

- ■Optimal PV integration will serves as a supportive material to discuss a preferable energy policy to expand more massive solar PV in future power generation mix with minimizing power system cost.

- ■Recommendation for electricity market in Japan, so that PV power generator can recognize the best location for the integration.
  - Zoning information of the preferable location of PV integration
  - LMP-based electricity trade

Thanks for your kind attention.

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Acknowledgment
This work was supported by JSPS KAKENHI Grant Number JP17H03531, JP15H01785, and by the Environment Research and Technology Development Fund 2-1704 of the Environmental Restoration and Conservation Agency .

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