SIMPLIFIED ANALYSIS OF THE RELATIONSHIPS BETWEEN THE PRICES AND OPTIMAL CAPACITIES OF PV SYSTEMS AND BATTERIES

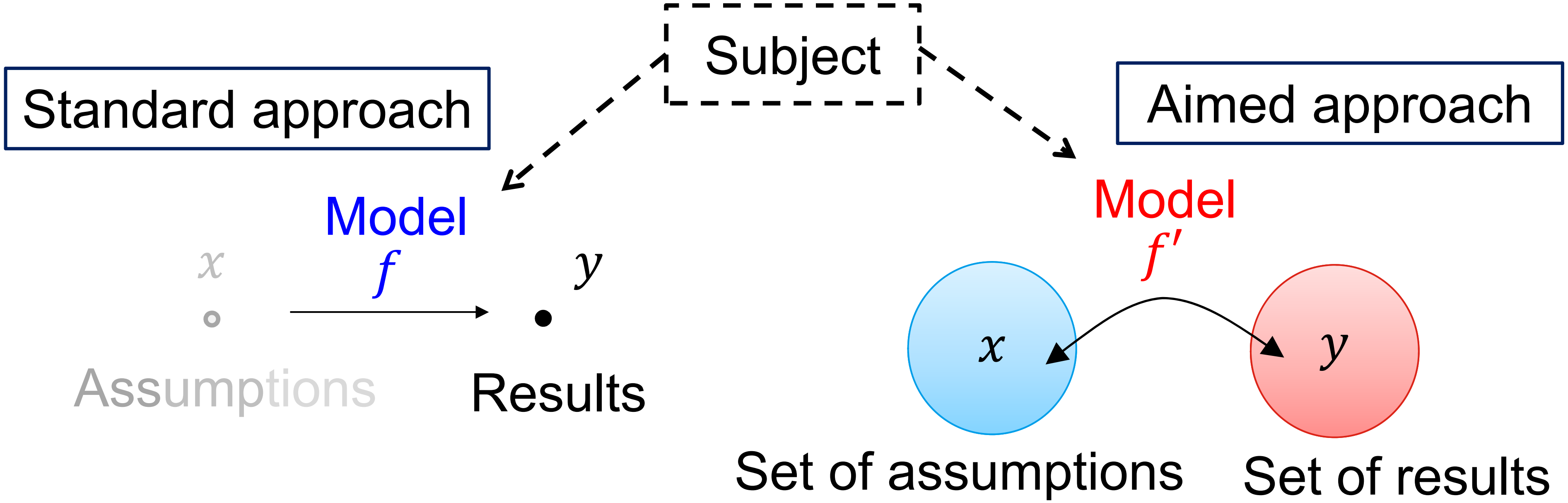
Takuya Hara
Toyota Central R&D Labs., Inc.

豊田中央研究所

The 42nd IAEE International Conference, Montreal, June 1, 2019

Fundamental motivation

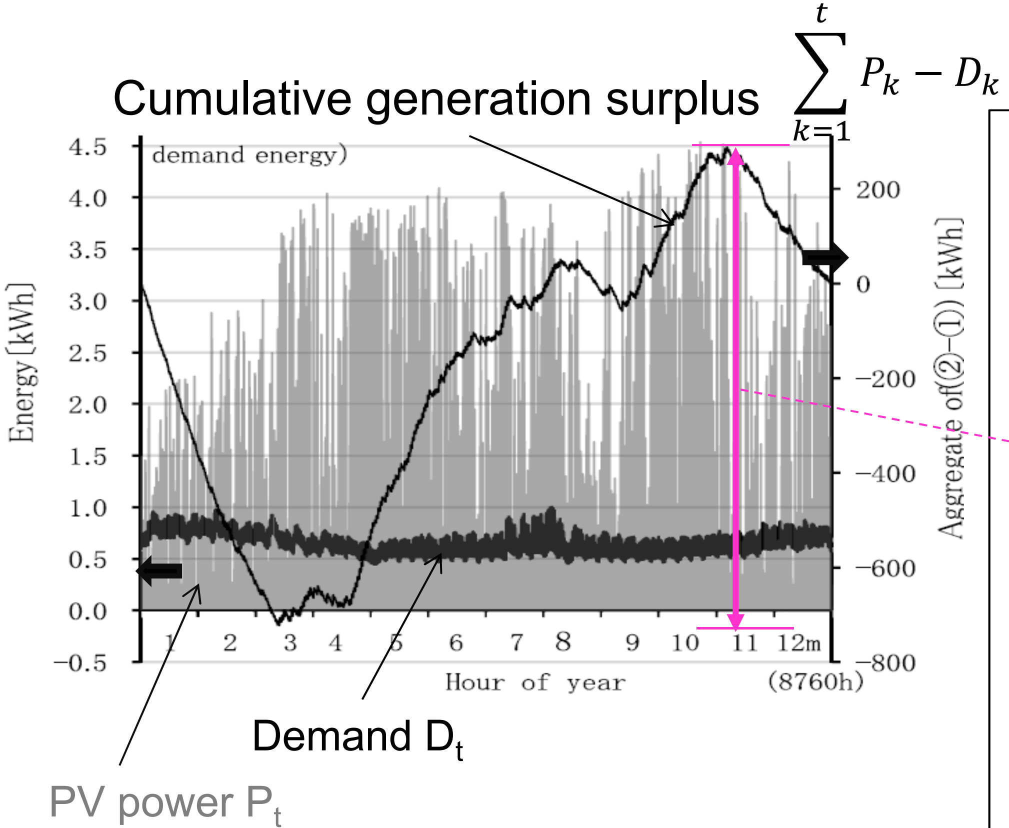
- **How to understand the corresponding relationships between assumptions and results of energy models?**



⇒Problem settings and models should be simplified

Best practice of simplified analysis (Aratame, 2018)

What is the required battery capacity to achieve 100% PV power?



PV capacity is set as 4.54 kW such that $\Sigma D_t = \Sigma P_t$

- **Real demand profiles are normalized as max 1 kW**
- **Using cumulative generation surplus, the required battery capacity is obtained as 1011 kWh*, ** by calculating the difference of Max and Min (you do not have to perform optimization calculation)**

  *** Charge/discharge efficiency is assumed to be 1**

  **** It is almost as large as 20% of the total annual demand**

(Aratame, IEEJ Trans. Power and Energy, 2018)

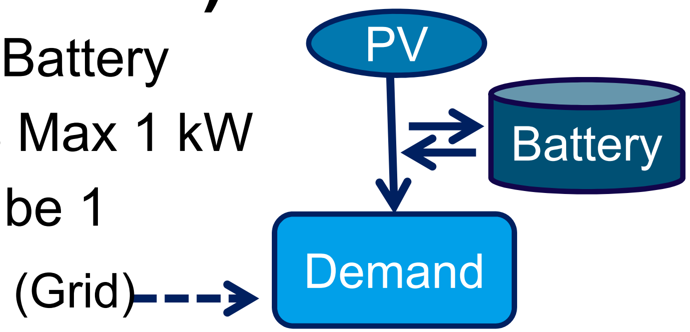
Purpose

Aratame only considers the single case s.t. $\Sigma D_t = \Sigma P_t$
→Wider possibility exists of considering the combination of the amounts of PV and battery availability

- **To analyze the relationships between**
  (1) prices of PV systems and batteries,
  (2) share of PV power in the total demand
  (3) cost of PV power based on the optimal installed capacities of the PV systems and batteries

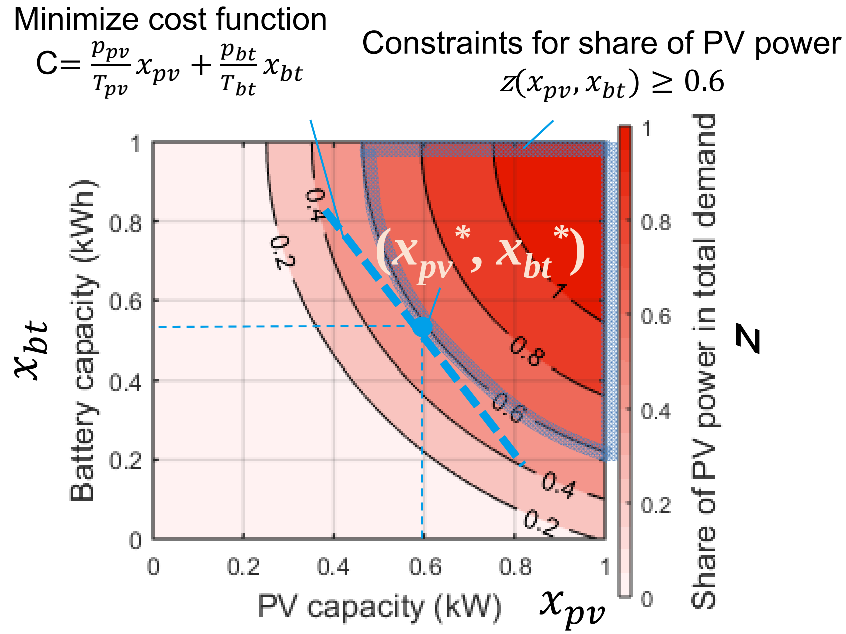
Approach (following Aratame's method)

- Simple model consisting Demand, PV, and Battery
- Demand and PV Profiles are normalized as Max 1 kW
- Charge/Discharge efficiency is assumed to be 1

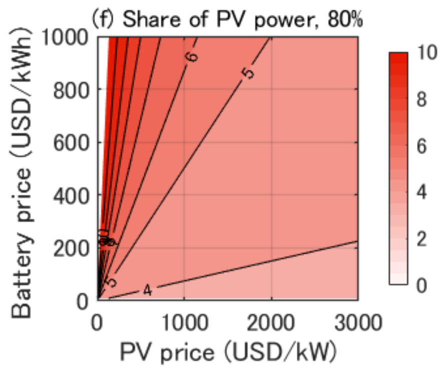


The essence of the framework

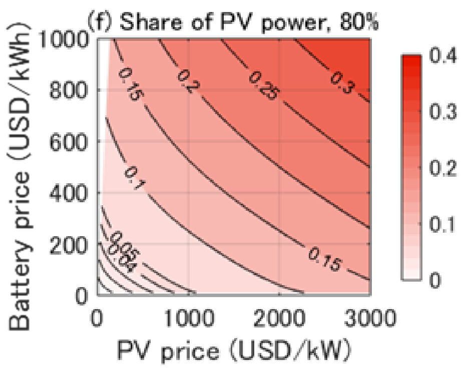
1. **Develop a map (contour diagram) representing the relationships between PV and Battery capacity, and share of PV power**
2. **Extract the information on the optimal capacities of PV and Battery, and the prices of PV and Battery**
3. **Develop maps representing the relationships between the prices of PV and Battery, and the optimal capacity and cost of PV power**



Optimal PV capacity (kW)

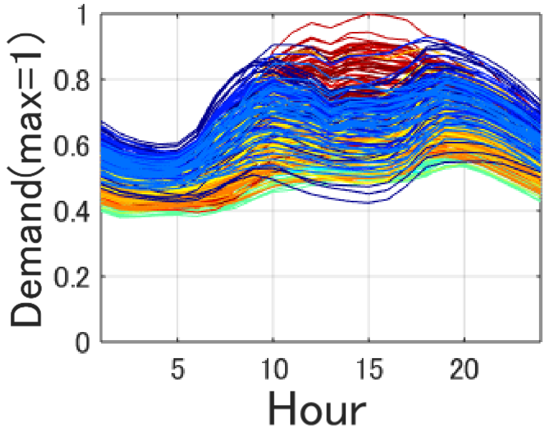


Cost of PV power (USD/kWh)

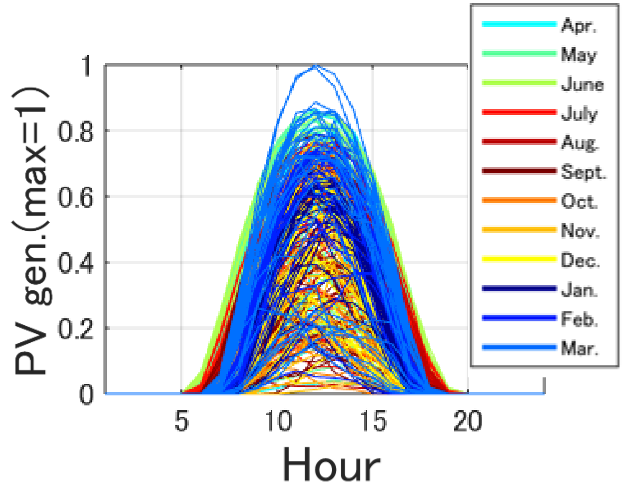


Tokyo Electric Power Company FY 2016 data
(in this presentation*)

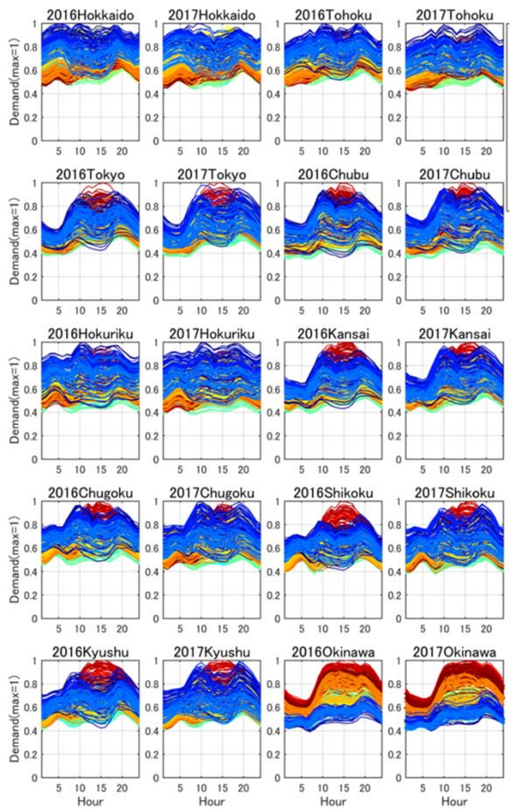
Demand

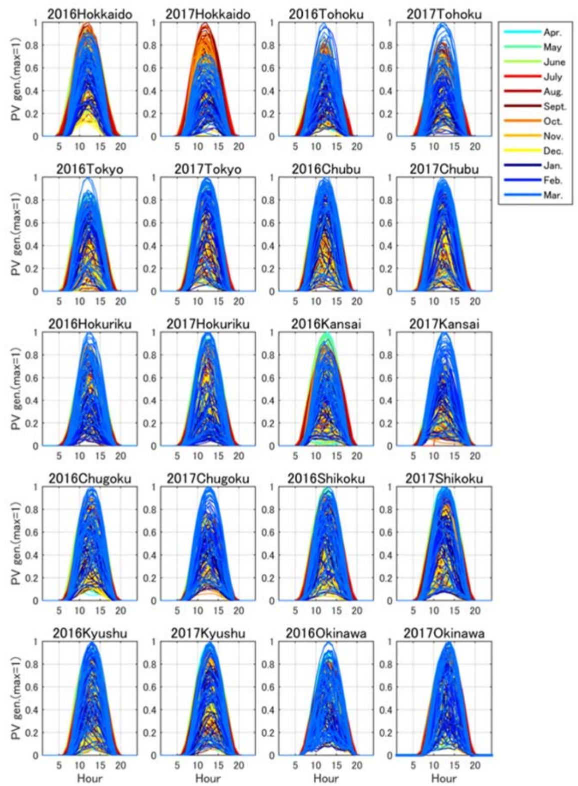


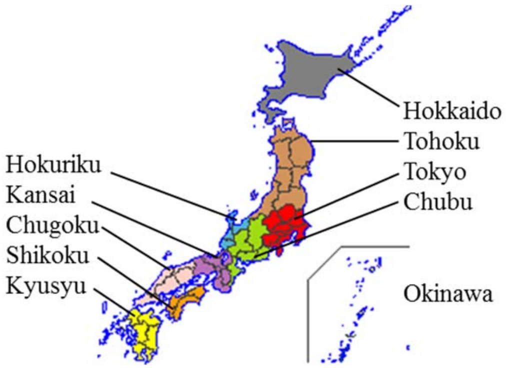
PV generation



*Hourly demand and PV power generation for 10 utility companies in Japan for FYs 2016 and 2017 were employed (20 datasets) (See the full paper)

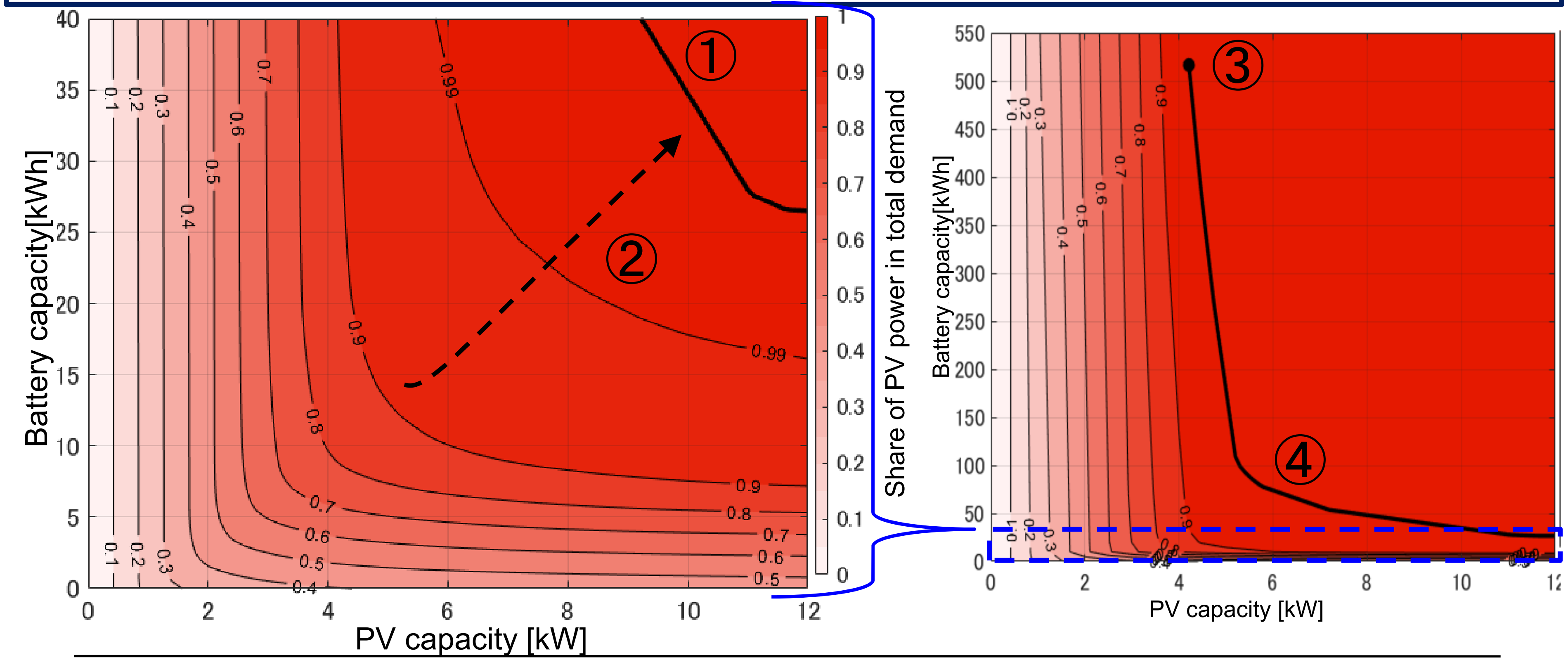






Result 1 (PV and Battery capacities, and the share of PV power)

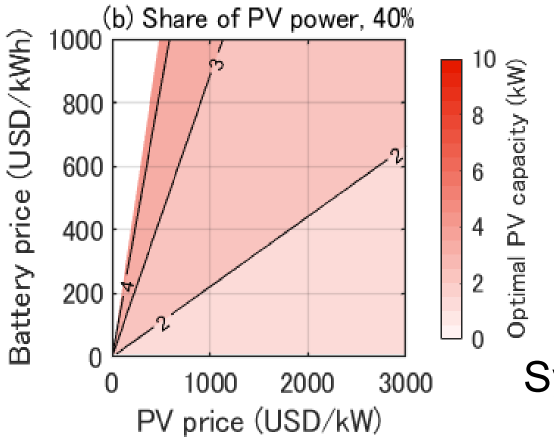
① The contour line of the share of PV power =1 is a piecewise linear function
② To achieve 100% PV power is very hard (great distance to the line①)
③ In the Aratame's case (i.e. ΣP=ΣD), the required battery capacity for the share of PV power = 1 is incomparably large
④ Small increase of PV capacity leads to drastic decrease of battery capacity

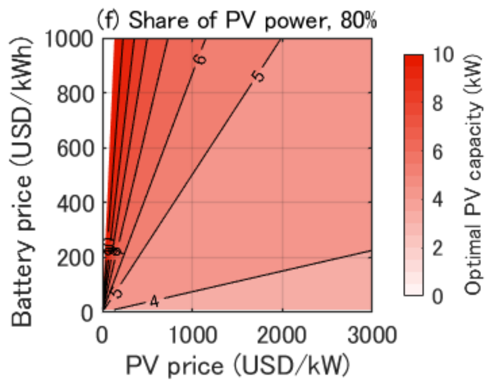


Result 2 (PV and Battery prices, and the optimal capacities)

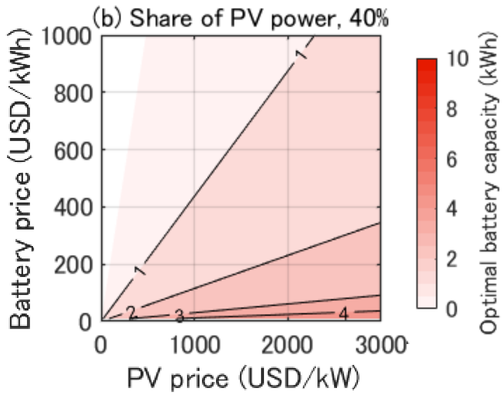
① Larger PV price leads to smaller optimal PV capacity
② Larger Battery price leads to larger optimal PV capacity
③ Larger share of PV power leads to larger optimal PV/Battery capacity under the same prices

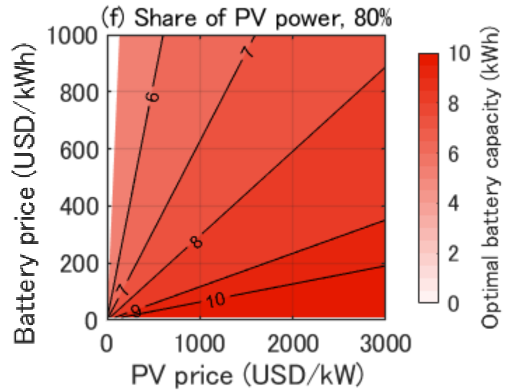
Optimal PV capacity





Symmetric maps imply complementary relationships





Optimal Battery capacity

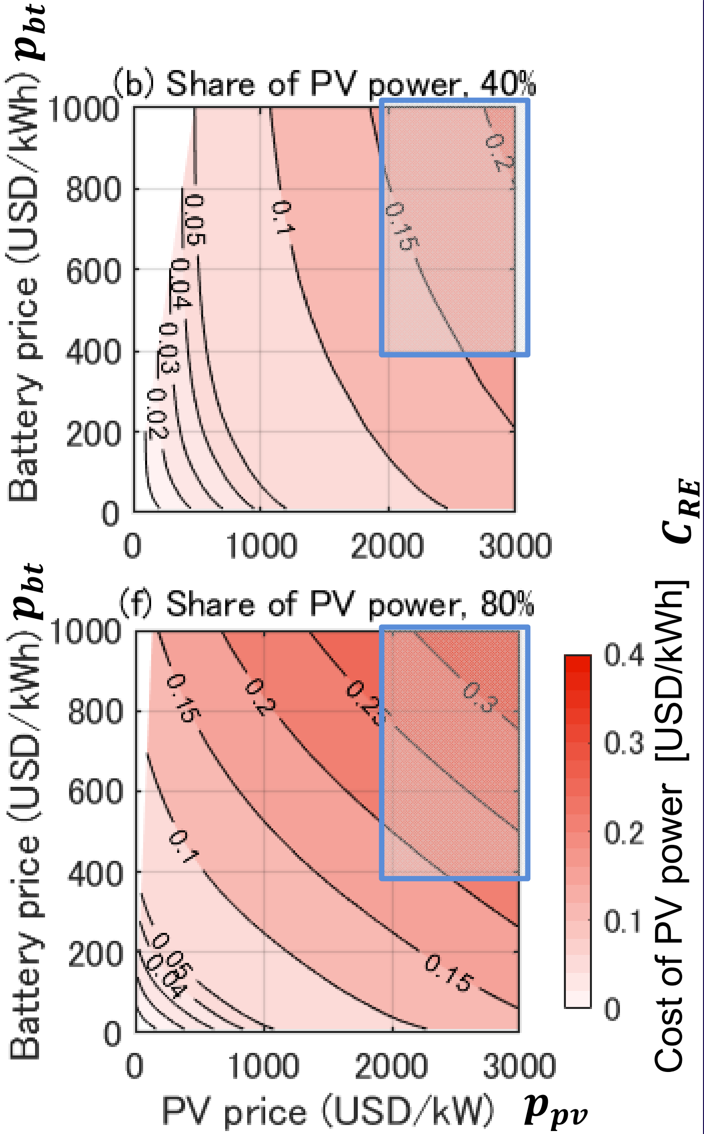
Result 3 (PV and Battery prices, and cost of PV power)

- The range of cost of PV power under current price level (PV 2000~3000 USD/kW, Battery 400~1000 USD/kWh)
  - 0.13~0.22 USD/kWh @ 40% share of PV
  - 0.18~0.38 USD/kWh @ 80% share of PV

※Note that it is a rough estimate

$$C_{RE}(p_{pv}, P_{bt}, T_{pv}, T_{bt}) = \frac{1}{y_0 \sum_t D_t}\left(\frac{p_{pv} x_{pv}^*}{T_{pv}} + \frac{p_{bt} x_{bt}^*}{T_{bt}}\right)$$

- C_{RE}: Cost of PV power (USD/kWh)
- y_0: Share of PV power
- D_t: Demand
- $y_0 \sum_t D_t$: Total PV power used (kWh/yr)
- $p_{pv} x_{pv}^*$, $p_{bt} x_{bt}^*$: Capital cost (USD)
- T_{pv}, T_{bt}: Lifetime(yr) PV 20 yrs, Battery 10 yrs assumed



Summary

- Summary

  This study developed a framework for analyzing the relationships between the prices and optimal installed capacities of PV and batteries, and derived PV power costs.

- Limitations

  →The accuracy of output values, owing to its simplified approach (battery efficiency as 1, no constraints on charge/discharge rate). However, these simplifications are easy to amend, depending on the required level of accuracy.

- Benefits: This framework can

  →evaluate the effects of technological development (e.g., price decreases of PV systems or batteries) on the total costs of electricity,

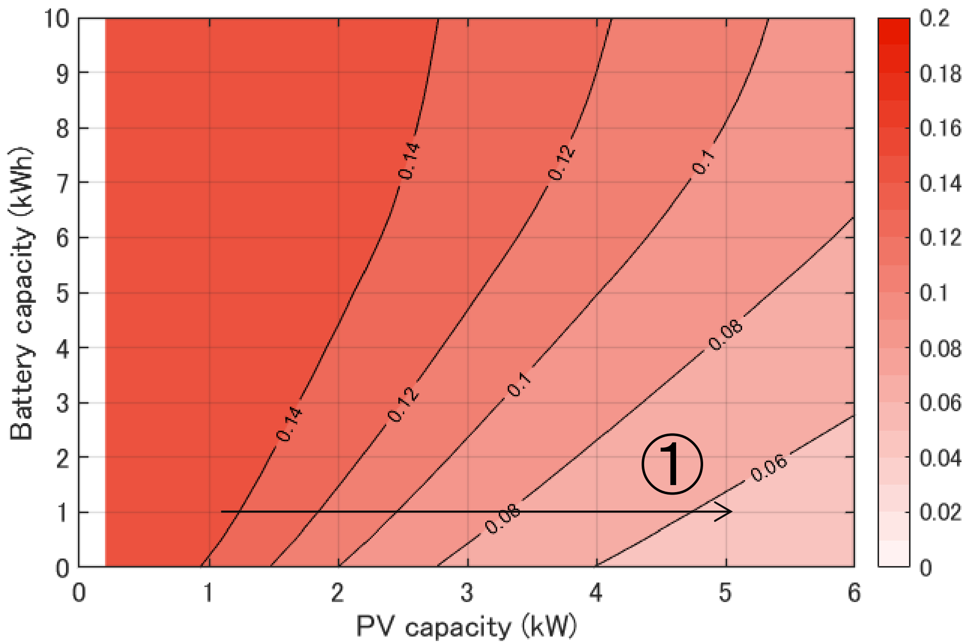
  →provide cost targets for PV and battery technologies to achieve certain costs and shares of PV power,

  →be applied to a wide variety of systems, such as households, buildings, regions, and countries if the profiles are obtained.

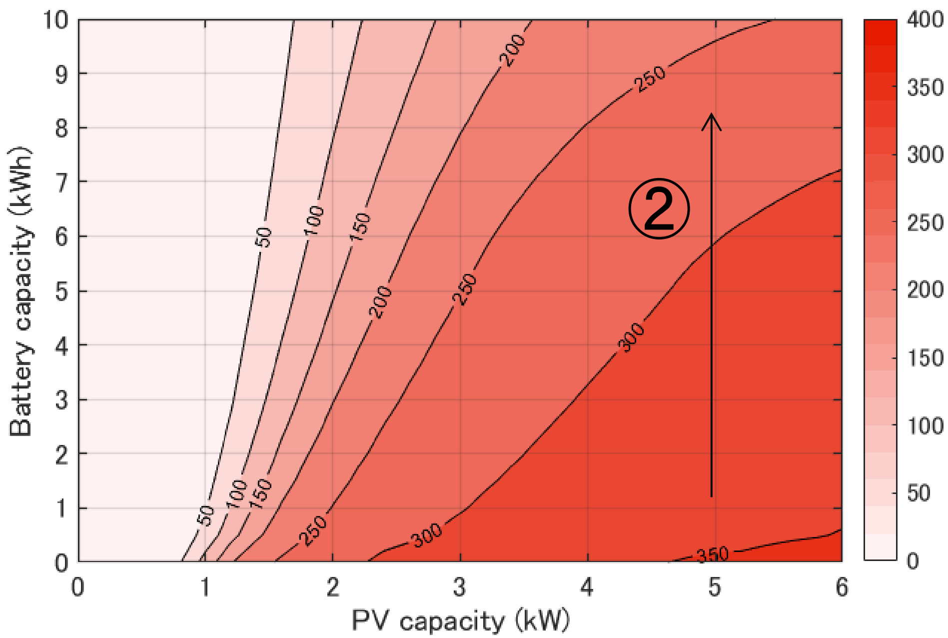
Result 1-2 (Maps for PV capacity factor and annual charge/discharge cycle of the battery)

① PV CF decreases as PV capacity increases
② Charge/discharge cycle decreases as battery capacity increases

PV capacity factor



Annual charge/discharge cycle of battery



Comparison of results from twenty datasets (10 utility companies for 2years)