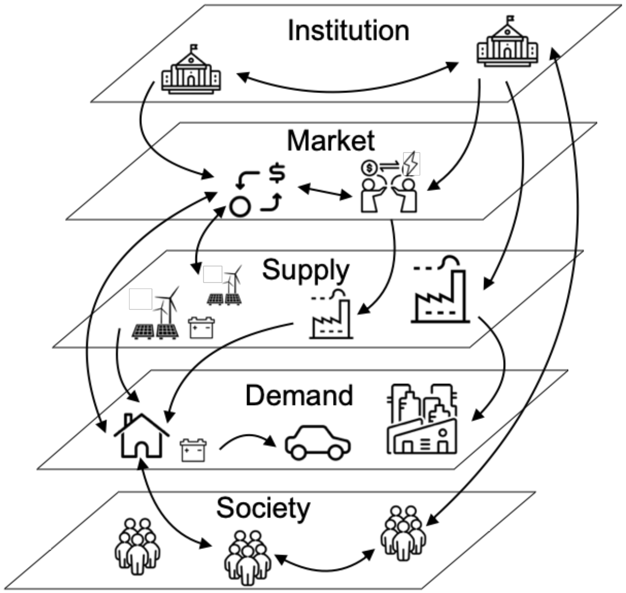
A Study on the Linkage Between Capacity Pricing and Carbon Pricing in Electricity Market

Graduate School of Energy Science
Kyoto University

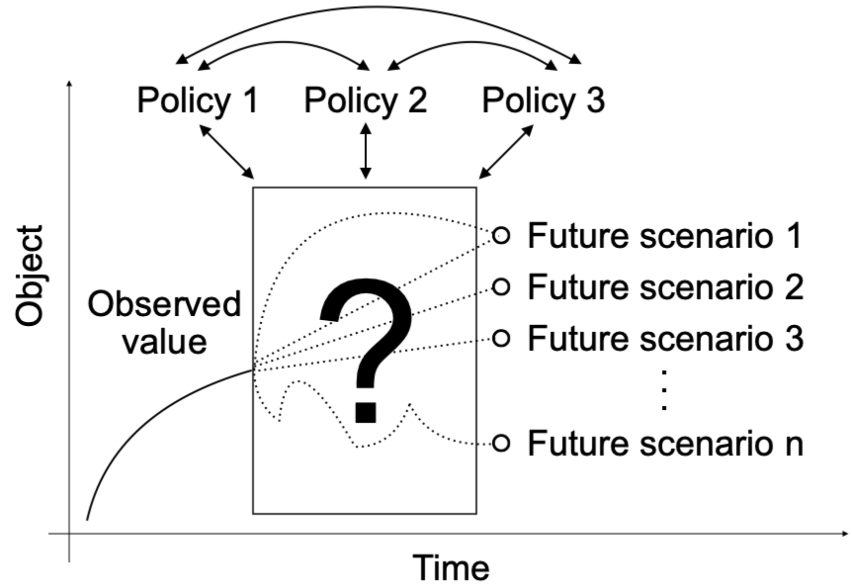
Yilun Luo, Benjamin C. McLellan, Seiichi Ogata, Tetsuo Tezuka

June 7th, 2021

Complex system transition



Inspired by K. C. Seto et al., 2016



Inspired by J. Blazquez et al., 2020

Electricity system is facing the transition problem as a complex system

Market-based policies in liberalized electricity market are designed to achieve desired goals

Single electricity price in liberalized electricity market is not enough to achieve all desired goals during the transition period of the complex system

Research aim

Previous studies:

- Qualitative: barrier and misalignment of integration among electricity market related mechanisms (Hu et al.,2018; Peng. et al.,2019; Parmar. et al., 2019).
- Quantitative: VRE incentive and carbon pricing (Pablo. et al.,2017; Gillich. et al., 2020), VRE and capacity pricing (Özdemir. et al., 2020).

Some studies noticed the unclear interaction between capacity pricing and carbon pricing (Edenhofer et al., 2013; Kraan et al., 2019; Joskow et al., 2019).

Aim: contribute a better understanding of framework design of pricing mechanisms in liberalized electricity market considering reliability and decarbonization during the transition period.

This study choose capacity mechanisms and emission trading mechanisms as the examples of market-based policies for study.

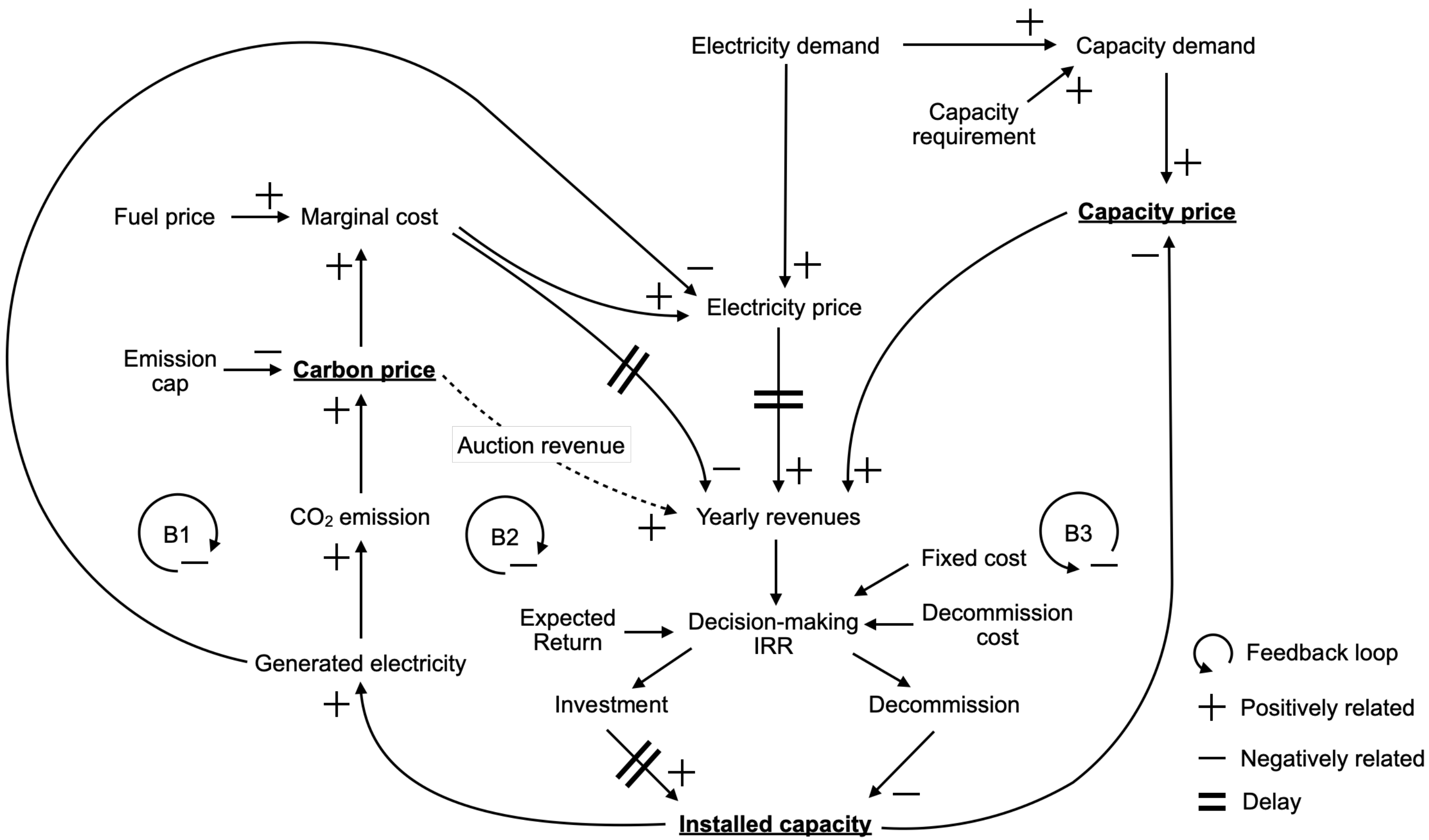
Questions addressed in this study

What is the interaction between capacity pricing and carbon pricing in a liberalized electricity market during the low-carbon transition period, and how this interaction ultimately affects the trajectory of power mix change?

The increasingly complex designs of liberalized electricity market may cause unexpected side effects through the interactions among policy instruments during the energy system transition period.

System structures

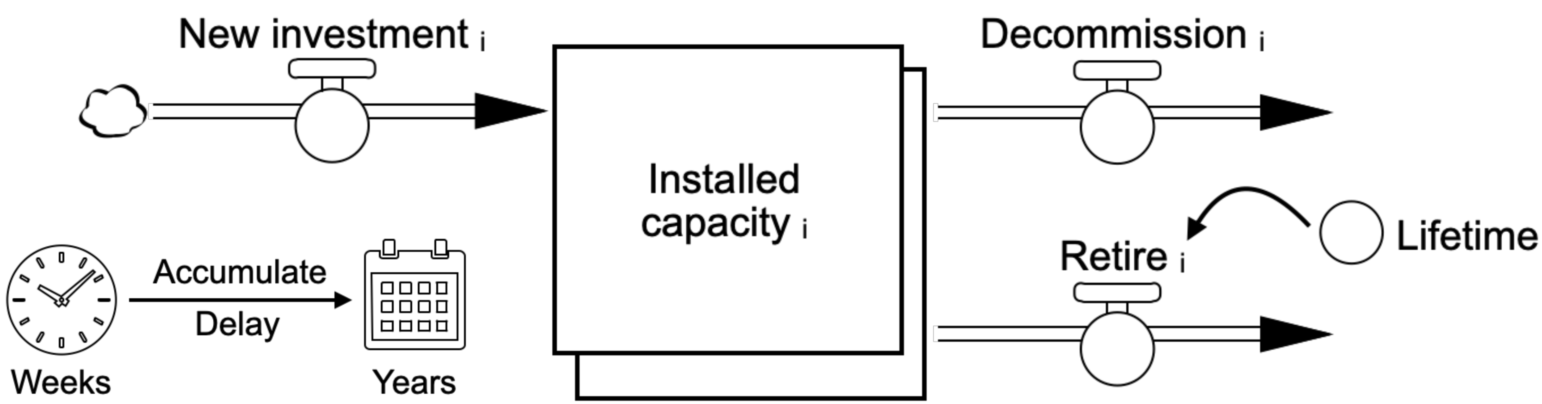
A semi-quantitative dynamic simulation model based on the System Dynamics method will be built to investigate the question.



Five Modules: capacity changing module, capacity price module, carbon price module, electricity price module, investment decision module.

Capacity changing model

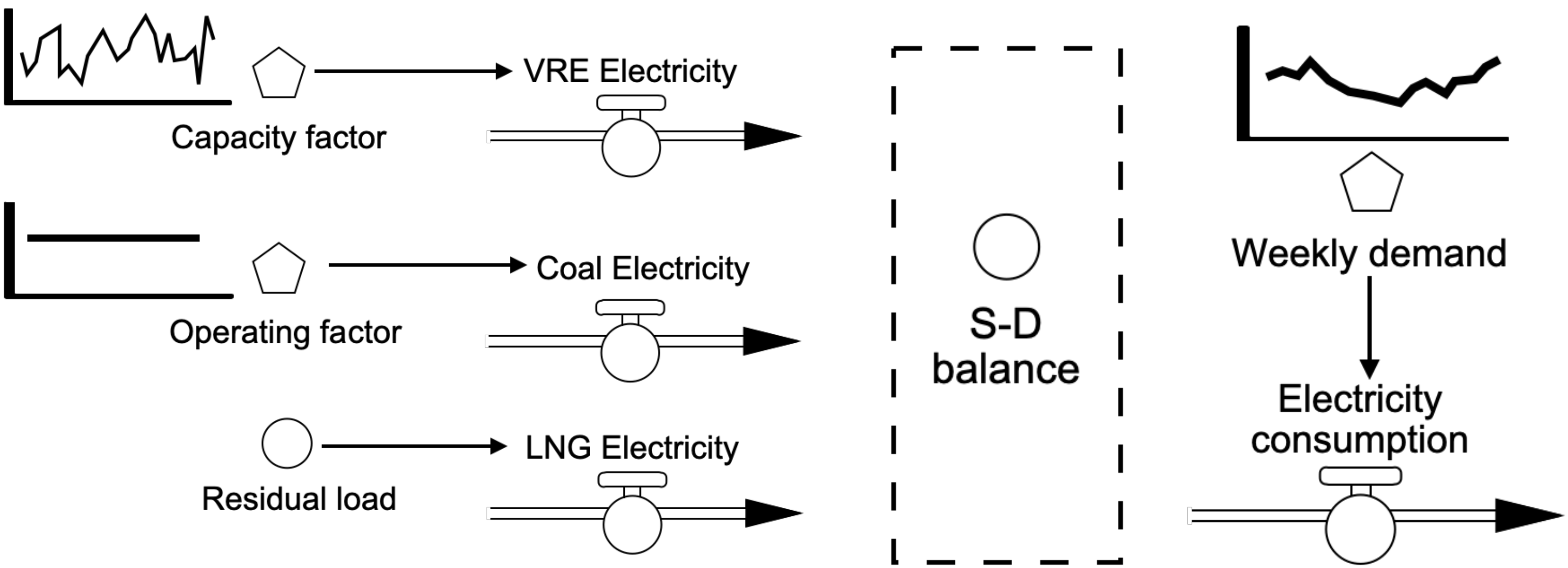
Technology i	Power output	CO_2 emission	Capacity value
VRE: Wind	Fluctuate	Zero emission	Low value
Fossil fuel: Coal	Stable	High emission	High value
Fossil fuel: LNG	Flexible	Medium emission	High value



$$CP_i(t) = CP_i(t_0) + \int_{t_0}^{t} NewIn_i(t) - Decom_i(t) - Retire_i(t) \cdot dt$$

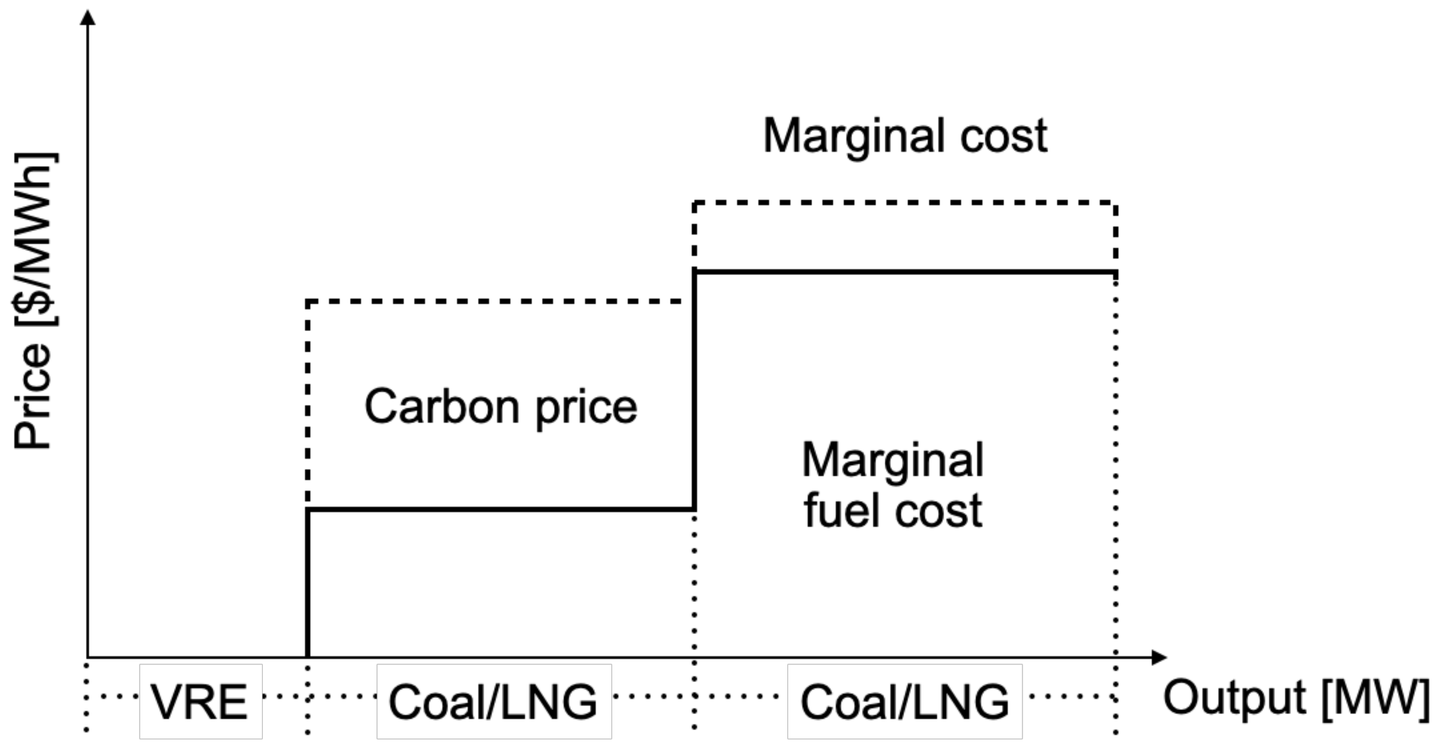
Supply-demand balance

$$SDbalan(t) = TotalSup(t) - Demand(t)$$



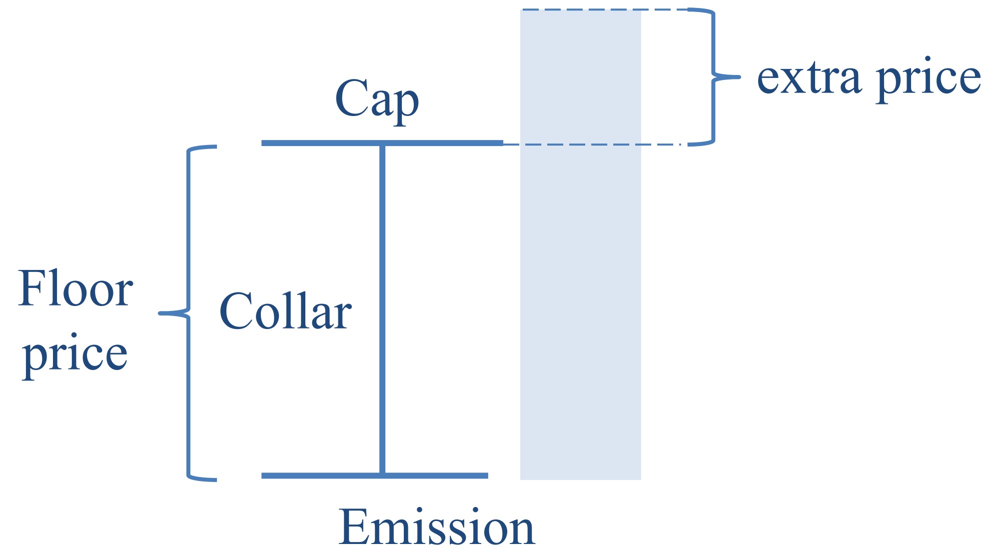
$$ResidualLoad(t) = Demand(t) - Genearate_{Wind}(t) - Genearate_{Coal}(t)$$

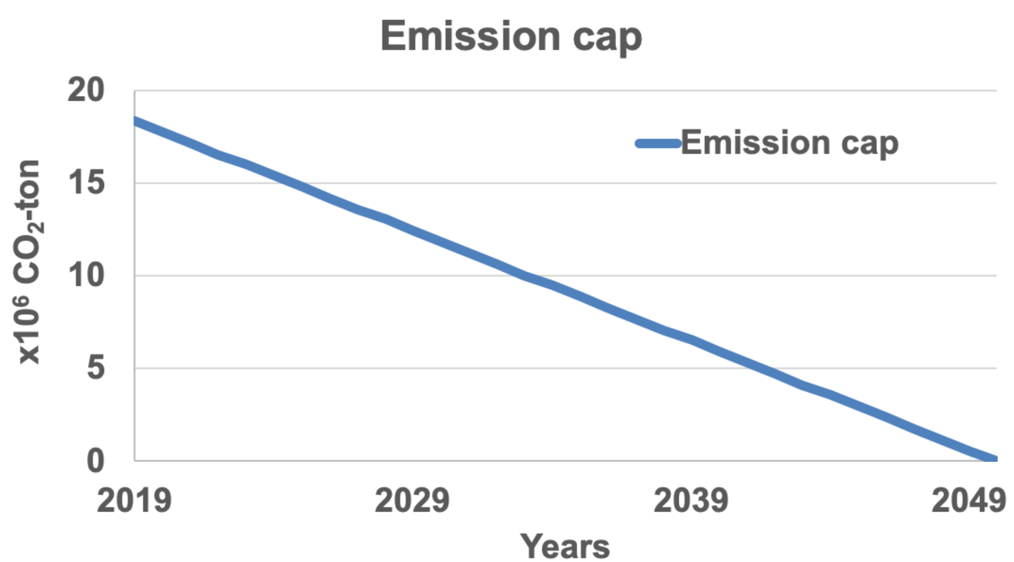
Electricity price



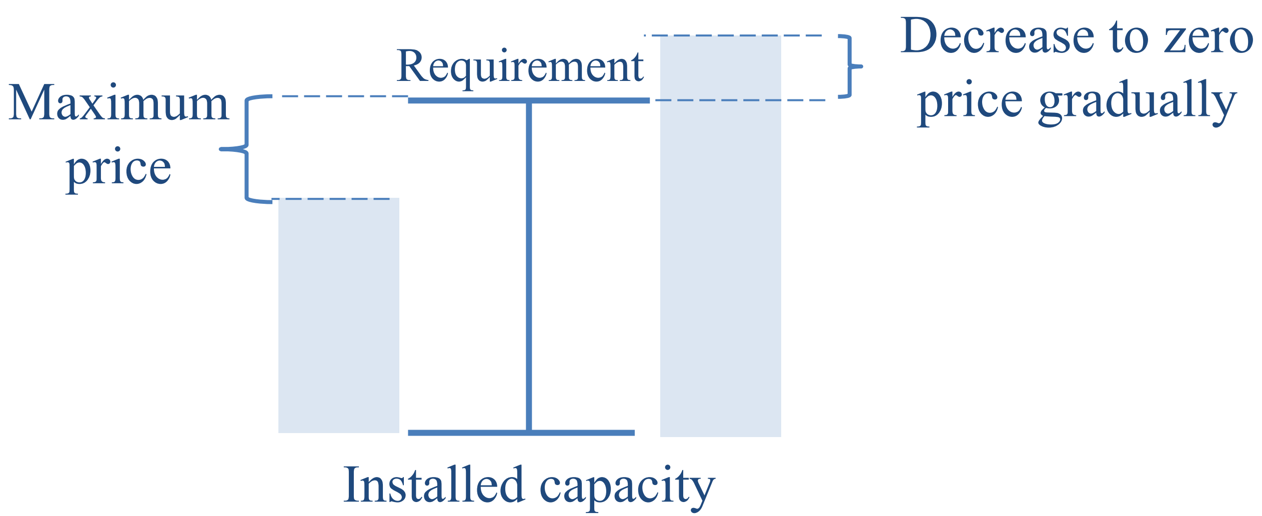
	S-D balance **loose**	S-D balance **tight**
Flexible plants work	Highest marginal cost	Price spike
Flexible plants not work	Weighted average of marginal cost	Price spike

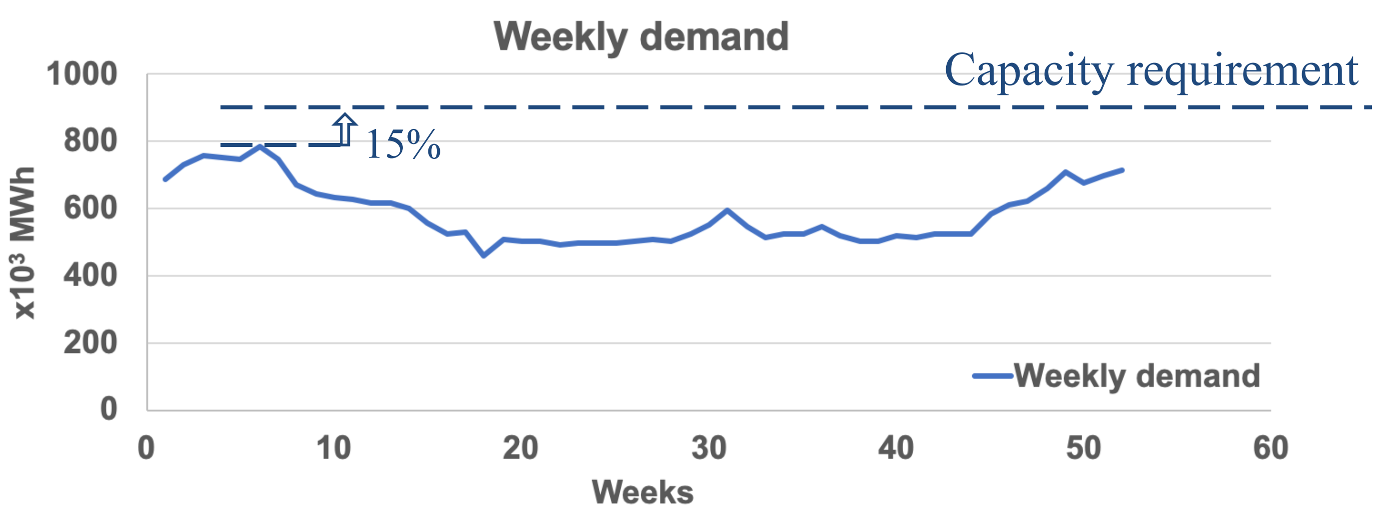
Carbon price





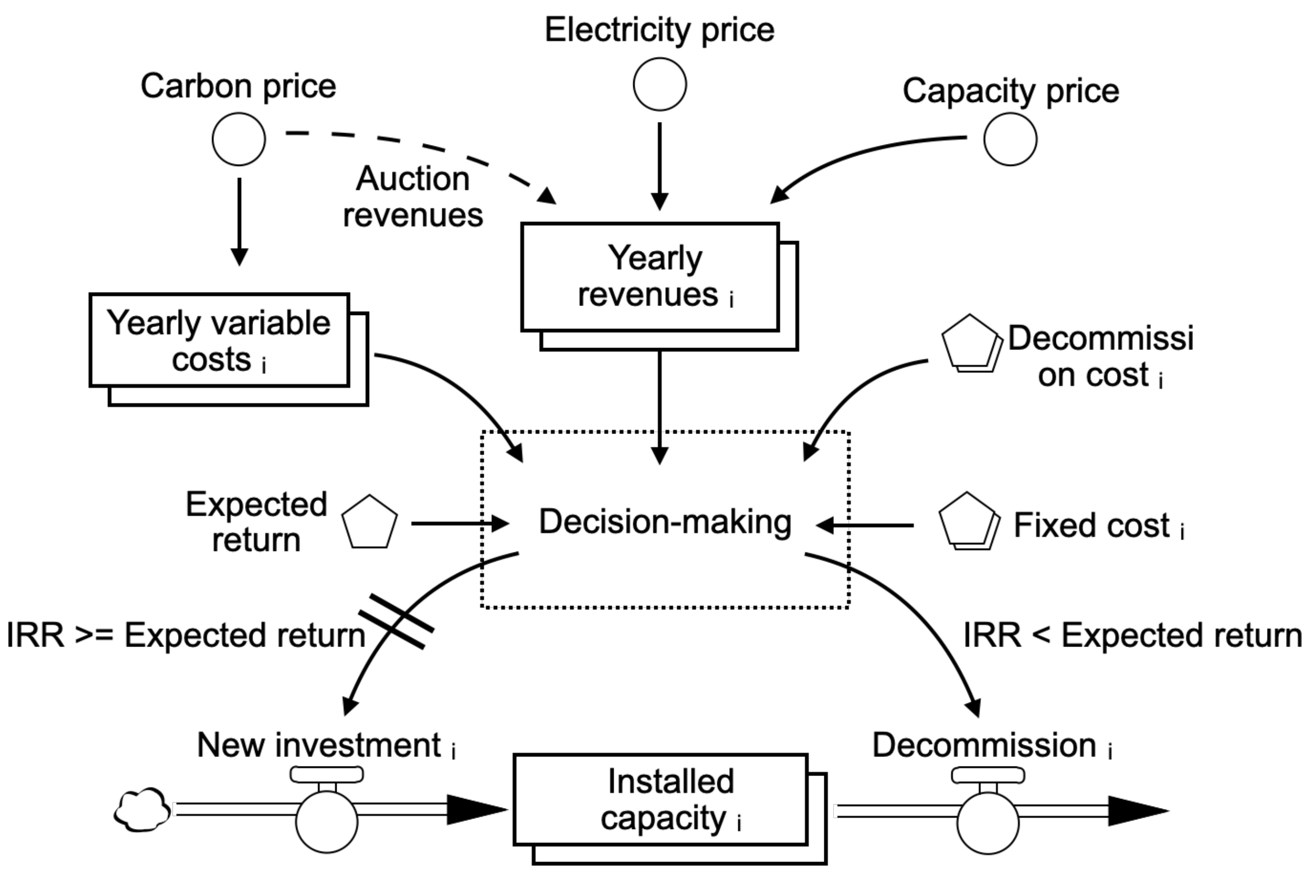
⬤Capacity price





Decision-making module

Technology i	kWh income	Subsidy income	Cost
Wind	FIT	emission allowance auction	Fixed cost
Coal	electricity price	capacity price	Fixed and variable cost
LNG	electricity price	capacity price	Fixed and variable cost



●Scenarios setting

Scenarios	Carbon pricing	Capacity pricing
① Base	–	–
② Carbon	30\$/ton CO_2 floor price	–
③ Capacity	–	All Fossil fuel power plants
④ Interaction	30\$/ton CO_2 floor price	All Fossil fuel power plants
⑤ Advance	60\$/ton CO_2 floor price	Flexible power plants

Worst scenario: ④ Interaction

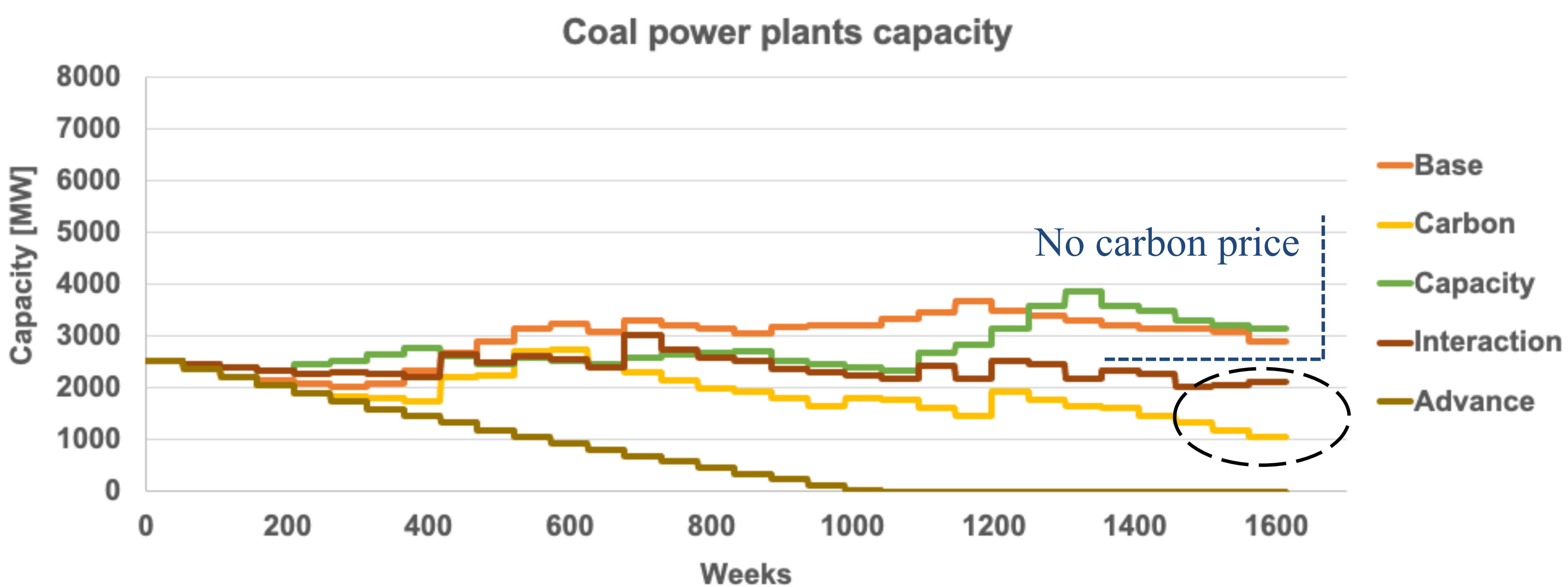
Proposed solution scenario: ⑤ Advance

Input data: Real demand, wind power output and CO_2 emission of Hokkaido Japan in 2019.

Technical and economical parameters are based on author's assumptions, official statistics, and research institute reports.

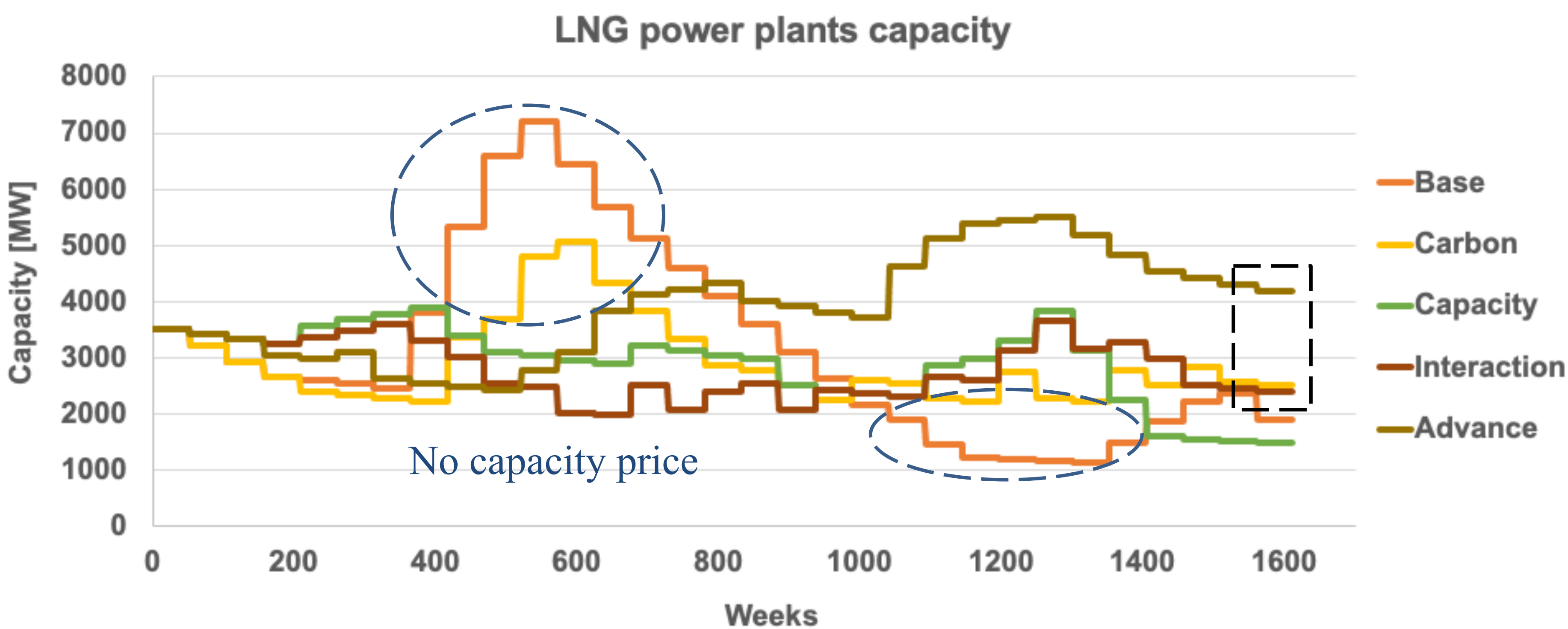
Results: Coal capacity during 2019-2050

- Capacity price maintain the highest coal capacity in all scenarios
- Carbon price promote decommissioning of coal power plants.
- The payments from capacity price slow down the coal decommissioning efforts of carbon price.



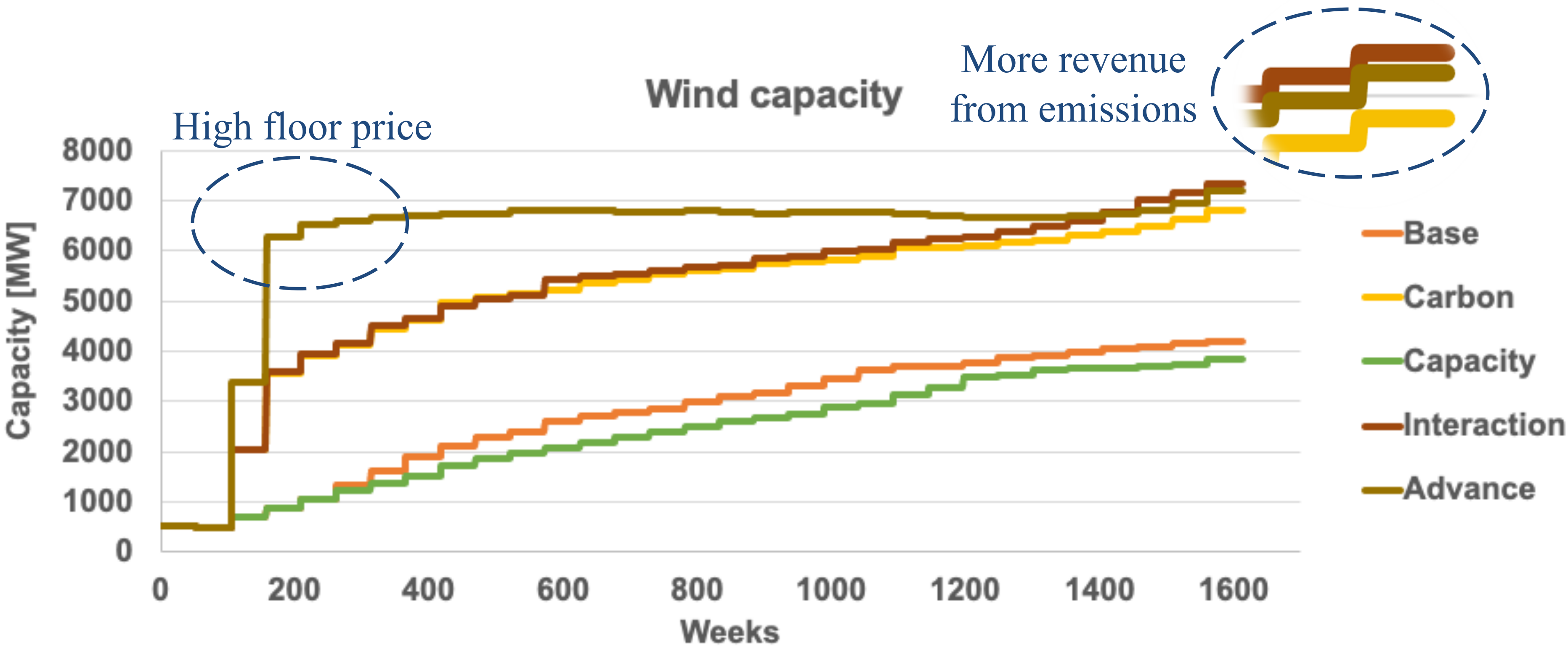
Results: LNG capacity during 2019-2050

- Capacity price curbs the investment fluctuations.
- LNG power benefit less from non-distinguish payments, as well as low floor carbon price is not enough to promote flexibility resources.



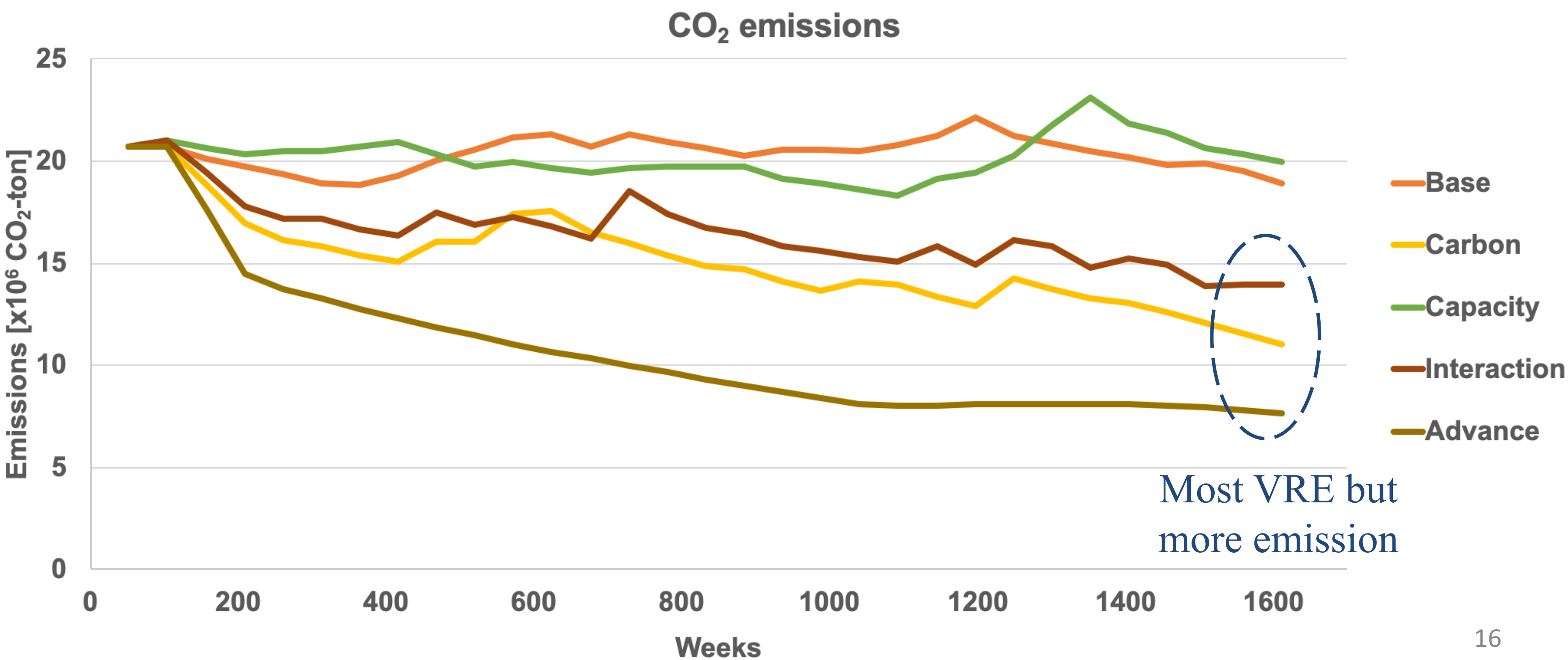
Results: Wind capacity during 2019-2050

- Wind power capacity can reach similar levels of fossil fuel through FIT
- Revenue from emission allowance auction will lead wind power to become the largest portion in the power mix



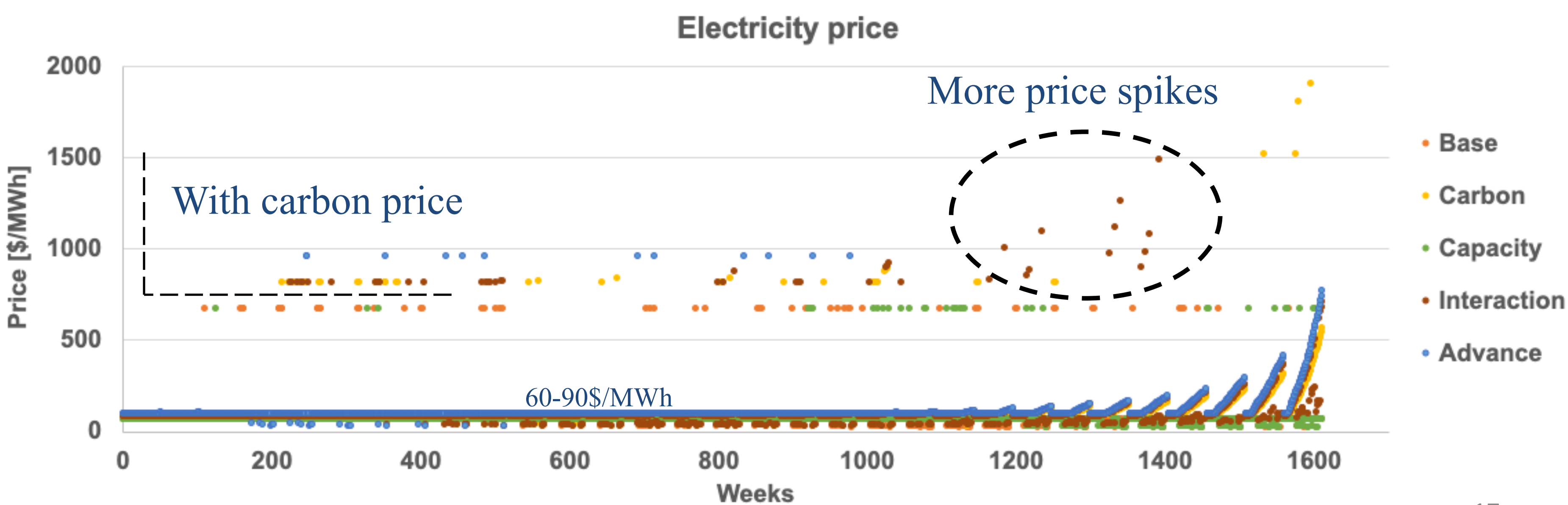
Results: CO_2 emissions during 2019-2050

- Capacity scenario results in the highest CO_2 emission
- Low floor carbon price with non-distinguish capacity price leads to the highest VRE but more emission
- High floor carbon price together with flexibility focus capacity price shows consistent incentives effects.



Results: Electricity price during 2019-2050

- Carbon price increase the electricity price, capacity price reduces the number of electricity prices spikes
- Low floor carbon price with non-distinguish capacity price leads to more price spikes.
- Even the carbon price is higher, the electricity price remain at a relatively stable level in Advance scenario.



Conclusions

This study investigated the interaction between carbon pricing and capacity pricing in liberalized electricity market, the simulation results shows:

- Although carbon pricing and capacity pricing functioning well individually, together the advantages of the two mechanisms will be offset by each other.

- Capacity price not only affects system reliability, but also CO_2 emissions. The non-distinguish capacity pricing will maintain the proportion of coal in the system, thereby weakening the emission reduction effect from carbon pricing

- Carbon price not only affects CO_2 emissions, but also affects system reliability. If the carbon price is not high enough to distinguish the emission gap between coal and LNG, it will indirectly squeeze flexible LNG plants out, thereby weakening the system security

- Design the two pricings considering the side effects from interactions will achieve consistent incentives to better reach goals of transition