A HYBRID SYSTEM DYNAMICS MODEL OF POWER ADEQUACY AND DECARBONIZATION IN AN ELECTRICITY MARKET

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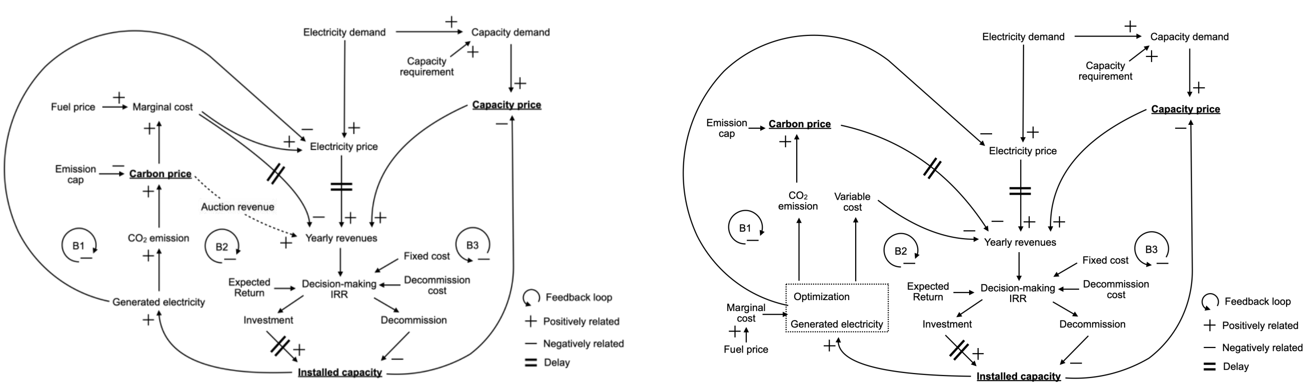
Overview

Capacity pricing has begun to be implemented in some markets to mitigate the potential defects of a liberalized electricity market and ensure power adequacy. Meanwhile, carbon pricing has been designed to internalize the environmental cost of CO_2 emissions from fossil fuels and support the achievement of climate mitigation targets. However, there is potential for these two pricing mechanisms to interact and potentially counteract each other, as fossil fuel power plants that exist in the system may pay for CO_2 emissions through carbon pricing while gaining subsidies from capacity pricing, thereby slowing down the transition to a low-carbon energy system. Previous studies [1] have focused on the qualitative interaction of the above-mentioned policies in the electricity market. The authors have discussed the linkage between capacity pricing and carbon pricing using the System Dynamics (SD) method [2]. Although SD is suitable to simulate decision-making in liberalized markets, it lacks efficiency and accuracy in modeling technical factors such as hourly grid supply-demand balance. This study proposes an optimization-embedded SD model and tests it using data from Hokkaido, Japan, as a case study. The results from both methods suggest that carbon pricing and capacity pricing may offset the advantages of each other. By comparing the results from the model based on the SD method and the hybrid model with optimization, hour-level technical details will lead to an increasing impact on investment decisions on annual time scales.

Methods

System dynamics modeling often uses proprietary software to conduct simulations, however, due to the limitations of these modeling platforms, most of the available functions are limited to using the stock-flow concept of SD to construct different functions, achieving the simulation of a specific idea. For example, the TREND function in most of the SD software is constructed through a feedback loop to predict data trends, but the accuracy of the predicted results of this function is hard to compare with the current leading time series analysis forecasting. As for optimization, this is typically limited to internal model calibration, parameter estimation, and sensitivity analysis of the SD model, rather than modeling and solving optimization problems as part of the SD model. In this study, we develop an optimization-embedded hybrid SD model in the Python environment to simulate power capacity change considering policy interaction in a liberalized electricity market. As shown in Figure.1, the SD model illustrates the interaction between two pricing mechanisms, in the context of the liberalized electricity market, the optimization model simulates the hourly grid supply-demand balancing by solving the self-dispatch problems to maximize the profits of power plants.

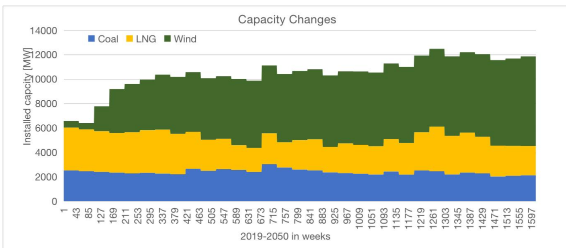


(a) (b)

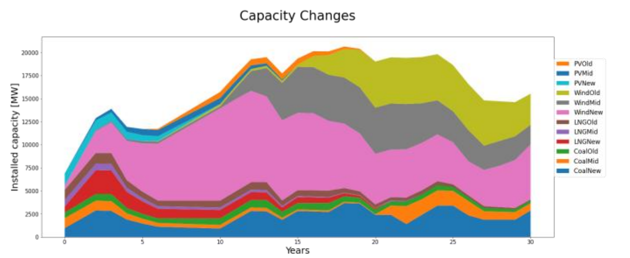
Figure 1. Comparison between two causal-loop diagrams, a) SD only model, b) hybrid model with optimization.

Results

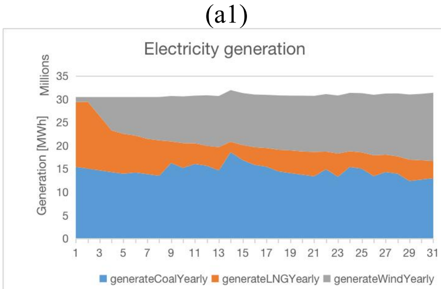
Figure 2 shows the results of SD with and without optimization. Both methods simulated the capacity changes from 2019 to 2050 in Hokkaido Japan without changing demand, considering the policy interaction between carbon and capacity pricing. The SD only method is in weekly based time steps as a compromise between electricity supply-demand balance and capacity investment decisions. The hybrid method is a 200 sample hours optimization with scaling factor (8760 hours of a year divided by 200h), combined with yearly based capacity investment simulation in SD. Both results show that regardless of the high carbon price and massive deployment of renewable energy, the emissions do not decrease to the targeted level, since a significant amount of thermal power still exist in the system, which indicates the potential side effects caused by policy interactions between carbon and capacity pricing. By comparing the results from the two methods, the trends of the simulation results are similar, but some the features are different. For specific numerical differences, partly because the hybrid model uses the sample hours multiplied by a scaling factor which changes the total amount of electricity. Nevertheless, it is more because hourly-level technical details lead to changes in investment decisions. For example, from the results of the SD only model, liquefied natural gas (LNG) power plants still exist and maintain the same level as in 2019, but in the results of the hybrid model, almost all LNG plants are retired.The results from the hybrid model which includes more technical details and using finer time-steps, indicate that generation from LNG, as the representative technology of flexible resources, is squeezed-out at the hourly level by uncontrollable VRE and baseload coal, ultimately leading to yearly capacity retirements.



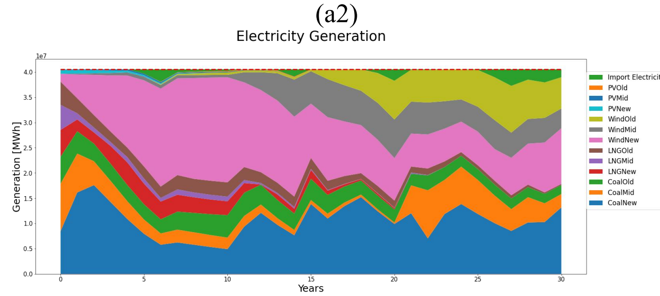
(a1)



(a2)



(b1)



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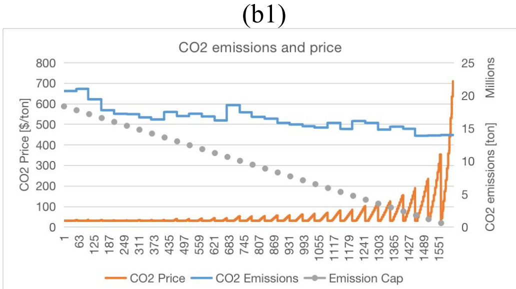
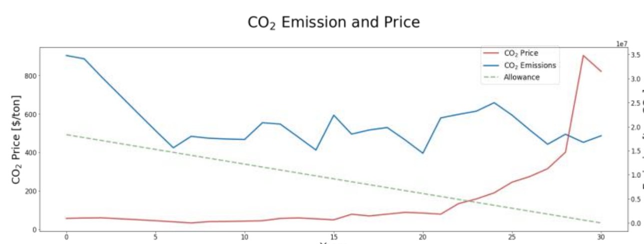


(c1)



(c2)

Figure 2. Comparison between the results from two method, 1 for SD-only, 2 for hybrid.
a) capacity changes, b) generation changes, c) CO_2 emission, allowance and price.

Conclusions

In this study, a hybrid modeling approach is proposed, which embedded an optimization model into the system dynamics model. It solves the hourly grid dispatch optimization problem within the framework of the yearly decision-making simulation of the SD model, thereby coordinating the different time scale simulations between hourly and yearly. We chose Hokkaido, Japan, as a case study to test and compared the results from the model based on the SD method and the hybrid model. The results indicate that carbon pricing and capacity pricing may offset the advantages of each other. By comparing the two methods, we found that with the increasing deployment of variable renewable energy, more precise hour-level technical details will lead to an increasing impact on investment decisions on annual time scales. Therefore, the accurate assessment of hourly generation volatility and grid flexibility has become a non-negligible part of long-term electricity market design.

References

[1] A. Bublitz et. al., A survey on electricity market design: Insights from theory and real-world implementations of capacity remuneration mechanisms, Energy Economics, Volume 80, 2019, Pages 1059-1078

[2] Y. Luo et. al., A Study On The Linkage Between Capacity Pricing And Carbon Pricing In Electricity Market, 1st IAEE Online Conference, June 7-9, 2021