THE ROLE OF SUBSIDIES FOR CARBON-NEUTRAL ENERGY SYSTEMS WITH SECTOR COUPLING - A CASE STUDY OF JAPAN

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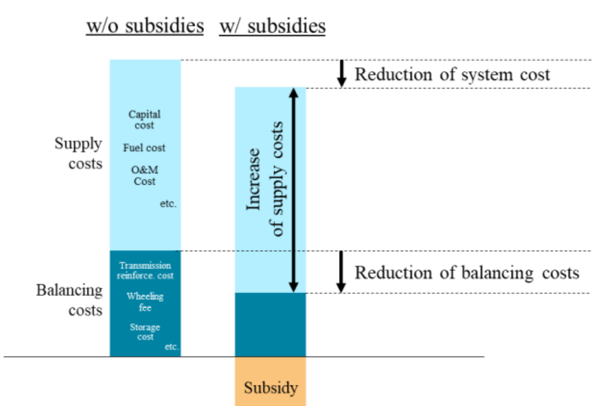
Overview

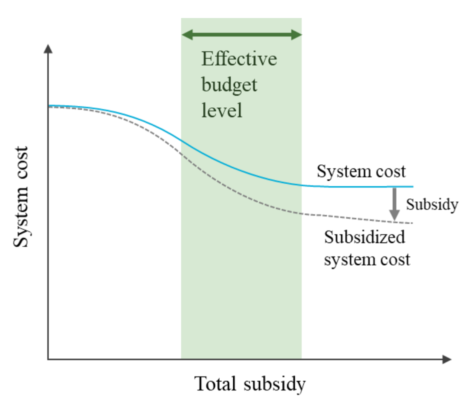
Among the several options to achieve a carbon-neutral society, including renewable energy resources and energy balancing technologies, it is important to identify economically efficient pathways for a rapid transition. In recent years, many studies have been conducted to reveal the cost-optimal energy system configuration and operation using energy system models [1,2,3]. Policymakers can lead energy systems to the optimal solution through public investment such as subsidies. Our hypothesis is that subsidies in the appropriate resources and technologies could reduce the system cost. This is because subsidies enable the introduction of flexible but expensive resources, and reduces the installation of energy balancing technologies. To verify this hypothesis, we develop an energy system model with endogenous subsidies to evaluate its role and impact on the configuration and costs of energy systems. In addition, sensitivity analysis of the budget parameter revealed the effective level and targets of subsidies.

Methods

We design energy systems with and without subsidies taking Japan as a case study, and compare the systems configuration and costs. A cost optimization model based on linear programming is developed to depict an integrated energy system that takes into account interregional electricity trading and sector-coupling of electricity, heat, transportation, and synthetic fuels including hydrogen and hydrocarbon. The model has high spatio-temporal resolution with hourly energy supply at prefectural level. The CO_2 to synthesize hydrocarbons is captured from the industrial sector, biomass generator, incinerators, or ambient air. The energy mix is assumed to consist of renewable resources in order to maximize the utilization of domestic resources. The objective function is expressed as the annualized systems cost which consists of fixed costs for generation, storage capacity and additional transmission capacity, variable costs for storage charging and discharging, and wheeling fee for traded electricity. Subsidies are provided for the fixed costs of each technology in each region. The total subsidies are capped by the annual budget and maximum subsidy rate for each technology. Other constraints are included such as the regulation of hourly balance of electricity, annual balance of fuels, charging and discharging of storage technologies including battery electric vehicle (BEV) battery, or the installation of renewable energy resources. Renewable energy fluctuations depending on weather conditions are estimated from weather forecast data [4]. The availability of BEV battery for V2G, which also fluctuates depending on transportation demand, is estimated using mobile location data.



(a) System cost reduction mechanism.



(b) Effective level of subsidies.

Fig. 1. Hypotheses on the relationship between subsidies and system cost.

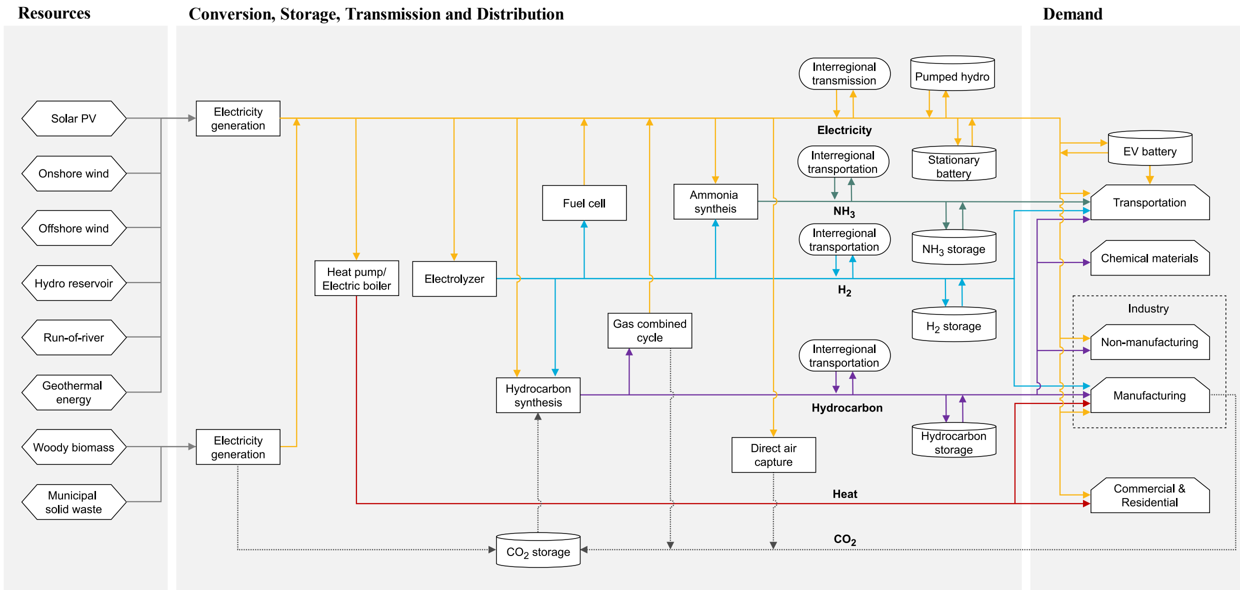


Fig. 2. Sector-coupled 100% renewable energy system diagram.

Results

Our energy system model shows spatial and temporal energy balancing with additional transmission capacity and battery storage, demand response of P2G/P2L, and V2G as previous studies [1,2]. It is clear that these balancing technologies pave the way towards a decarbonized energy system based on 100% domestic renewable energy resources in Japan. Furthermore, the results show that the system configuration is affected by subsidies. We found that the subsidies in offshore wind power in Kyushu, which has a relatively low capacity factor and high generation cost, mitigates the uneven distribution of energy supply, reduces grid reinforcement, and consequently reduces the system cost excluding subsidies. In other words, the offshore wind in Kyushu appears as a bottleneck of the system cost in Japan.

A sensitivity analysis of budget for subsidies verifies the relationship between total subsidy and cost reduction effects. The results show that the system cost is reduced as the subsidy level is increased to some extents. This indicates that subsidies should be within effective level.

Conclusions

Subsidies affects optimal configuration of carbon-neutral energy systems and has a role in reducing the system cost. Therefore, it should be considered endogenously in energy system models in order to suggest decision making by policy makers. Furthermore, subsidies should be executed to the effective extent because the cost reduction effect depends on the level of subsidies.

References

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