Future Electricity Market Designs for a Carbon-neutral Switzerland: Challenges and Solutions

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Overview

The electricity system will be the central pillar of our future decarbonized energy provision, particularly because decarbonization of several sectors, e.g., mobility and air conditioning, is at least partially envisioned through electrification. However, future electricity markets may widely differ from current markets with regard to available assets and active stakeholders. On the physical asset side, available CO2-neutral generation technologies have different operational characteristics than traditional ones. For instance, due to their intermittency and variability, PV and wind plants differ from traditional dispatchable technologies, increasing storage technologies' role in the electricity market. Therefore, operational behavior and cost structure of the generation side will differ from today. On the consumption side, electrification of heating and air conditioning generally increases total electricity consumption but increases the potential flexibility of the demand side.

On the other hand, on the stakeholder side, traditional actors' behavior will be affected by the changes in the available set of technologies and their differentiated features. For instance, producers' investment behavior may differ as the operational and investment costs of available technologies differ greatly from today's technologies. Moreover, new types of actors may enter the market or experience increased importance as new technologies or regulations allow new players to actively participate in the system. For instance, digitalization may allow more consumers to become directly or indirectly (e.g., via aggregators) involved in the market with their flexible consumption. Addressing the challenges of future electricity markets and taking advantage of the opportunities calls for better modeling and coordination of the involved actors and policies.

From a Swiss perspective, two more aspects play a crucial role: Firstly, its relatively small size compared to its neighbors (that are all parts of the European Union) limits its influence on key developments and policy decision space. Secondly, imports and exports are relatively more important in Switzerland particularly because it is highly relient on import in winter. These points lead to a central question: How can future electricity market designs help to ensure a secure, sustainable, and economical energy provision for Swiss citizens and industries?

Methods

We develop a parsimonious quantitative model that captures fundamental system dimensions and relevant actors, namely, producers, consumers (including the possibility of investing in PV and storage), aggregators, etc. This microeconomic model describes the decisions of the main actors (e.g., investment and deployment decisions of generators or investment and consumption decisions of prosumers), their interactions, and system-level consequences for several market and policy designs (e.g., tariff design, capacity payments, etc.).

Unlike large-scale models that rely on a centralized modeling approach, we use a hybrid agent-based model to allow different actors to be profit-maximizing entities so that the underlying economic incentive structure and behavior of actors are modeled in more detail. To gain some insights on which aspects are likely to be most relevant for Switzerland, the model will be parameterized to capture the main characteristics of the Swiss electricity system (existing generation capacities, potentials, cost structures, demand, and potential demand flexibility). However, it will not aim at a detailed quantitative assessment.

The simulation framework consists of several sections: input data, data simplification (e.g., time setp reduction), simulation core, and post process/analysis (Figure 1). **Input data** consists of necessary parameters and time series that eventually shape the operational and investments decisions. Asset parameters include investment costs and operational features of the different technologies (e.g., CO2 intensity, losses, the extent of flexibility), operational costs (fuel cost and CO2 price). A set of climate-related time series also shapes the electricity sector: renewable availability factors (for PV and wind), demand time series (divided to flexible and inflexible parts), and hydro inflows.

The **time step reduction** module reduces hourly time series climate data to four representative weeks. Each of the time series consists of 8760 hours for each weather year. Simulating the yearly electricity sector for so many time steps may become time-consuming. As a result, to reduce the computation time and simplify analyzing model interactions, we use the time step reduction module to reduce the hourly analysis to only a few representative weeks.

The **simulation core** consists of two main submodules: **hourly market** (operational) and **yearly (investment)**. In the hourly (operational) submodule, agents take their assets (and characteristics) as given and try to maximize their profit/utility. Agents include different types of consumers (consumers, prosumers, and prosumagers, all of them with several subsections), suppliers (conventional, RES, and mixed generating companies). The hourly market will be cleared, considering that many future generation technologies (e.g., storage) behave based on their opportunity cost rather than their nominal marginal cost. The investment submodule simulates multi-year decisions, asset capacities, and policy adjustments. To maximize utility/profit, consumers and suppliers act as agents and may invest in assets (to generate/store energy or provide flexibility of consumption) based on the profitability and utility of their assets in the operational module. Policymakers may adjust their policies depending on the outcomes of the operational submodule, e.g., by adjusting the CO2 price.

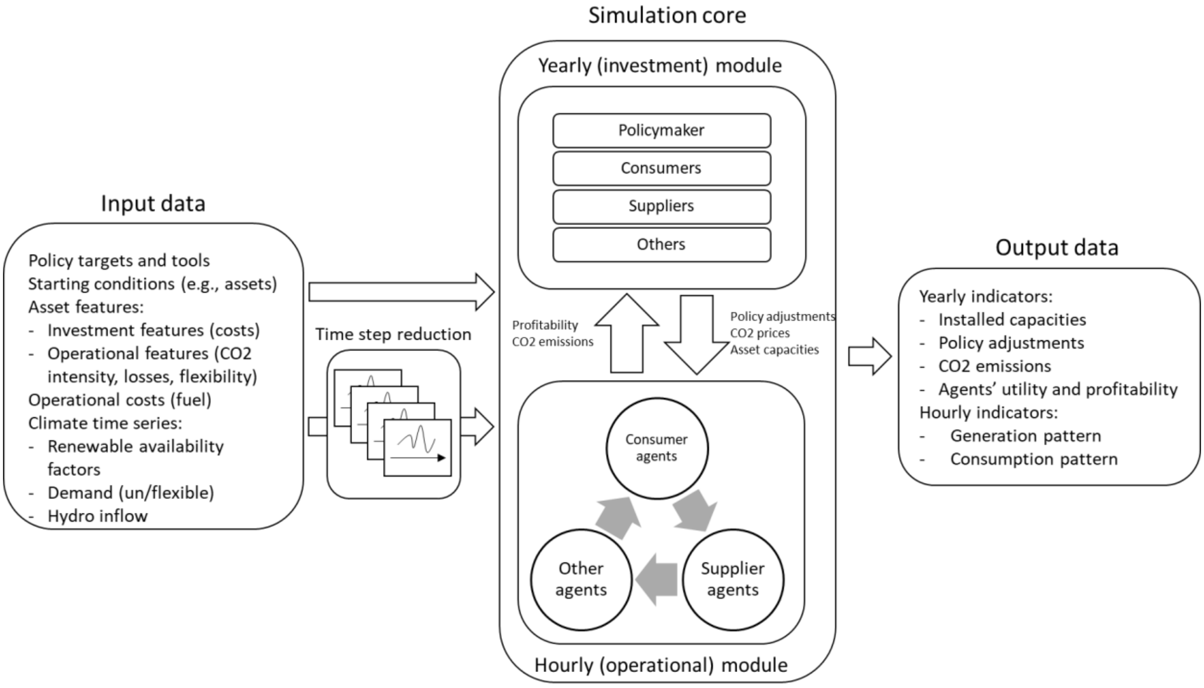

Figure 1 The model structure

Results

We will analyze the interaction between profit-maximizing actors and between policies for future decarbonized electricity markets with a focus on the Swiss actors and policy choice set. Particularly, we will compare the effectiveness of several policy mixes with regard to total system costs and security of supply.

Conclusions

This paper will analyze the effect of actor and policy diversity in achieving a functionning decarbonized electiricty markets in Europe with the main focus on Switzerland.