LONG-TERM ISSUES WITH THE ENERGY-ONLY MARKET DESIGN IN THE CONTEXT OF ELECTRICITY DECARBONISATION: INSIGHTS FROM A SYSTEM DYNAMICS SIMULATION MODEL

Alexis LEBEAU, EDF R&D and CentraleSupélec, alexis.lebeau@edf.fr
Marie PETITET, KAPSARC, marie.petitet@kapsarc.org
Marcelo SAGUAN, EDF R&D, marcelo.saguan@edf.fr
Simon QUEMIN, EDF R&D, simon.quemin@edf.fr
Rakotomisa Eli, EDF R&D, eli.rakotomisa@edf.fr

Overview

Decarbonisation of energy systems is a growing trend worldwide. In the EU and California for instance, long-term climate policy objectives are ambitious, aiming at net carbon neutrality by 2050 and 100% zero-carbon electricity by 2045 respectively. In the electricity sector, decarbonisation prospective analysis mostly resorts to generation expansion (GEP) models, which cost-optimize over time to determine the optimal electricity mix trajectories in order to achieve given policy objectives. There is a rich literature discussing underlying optimization techniques and technology assumptions (e.g. renewables integration, representation of short-term issues, long-term seasonal storage) behind such analyses. By contrast, there is a scant literature analyzing: (1) how an energy-only market (EOM) design, whose cornerstone is the short-term price signal, may yield mix trajectories that are compatible with policy objectives; (2) the role of underlying investor behaviour assumptions – a notable exception is Tao et al. (2021)).

In this paper, we develop an electricity market model to provide insights on two questions: (1) which assumptions about investor behavior and available information are needed to ensure that an EOM induces the target mix trajectory, i.e. that which achieves decarbonisation objectives at least cost?; (2) how robust is an EOM (as measured by deviations between realized vs. optimal mix trajectories) when different assumptions are considered?

Methods

Our simulation model utilizes system dynamics (SD), a programming tool which has already been used to study the electricity sector (e.g. de Vries & Heijnen, 2008; Petitet et al., 2017). Starting from the case of fully informed and rational investors, the model can accommodate various sorts of impairment in the extent of available information and sophistication in investors' decision-making, e.g. biased optimistic or pessimistic forecasts, limited foresight (ignoring future investments), risk aversion.

Our modelling framework is completed by a traditional carbon-constrained generation expansion planning model with a twofold purpose: (1) it provides optimal development trajectories used as a reference to assess simulation results and (2) the SD model can be fed with some of its outputs such as the CO2 shadow price associated with the decarbonisation trajectory.

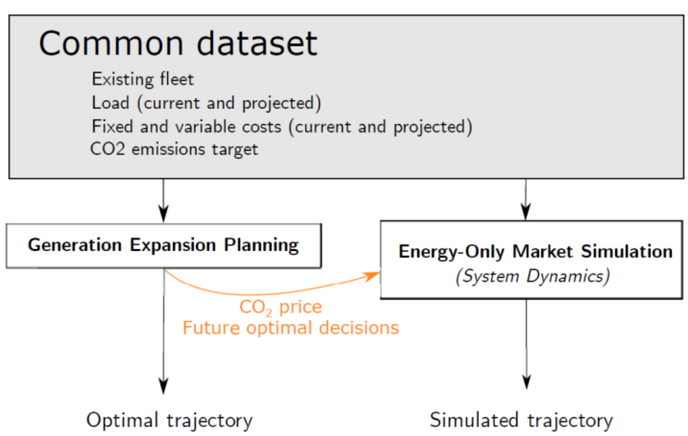

Figure 1 - Modelling framework

Results

First findings based on an illustrative case inspired by the Californian[1] power system:

1) Energy-only market (completed with a carbon price signal) is able to track and reproduce the optimal mix trajectory but required assumptions are demanding and do not fit with reality, i.e. perfect rationality, perfect information (about future investment and decommissioning decisions, demand, fuel & carbon prices, etc.), perfect coordination between decommissioning and investment decisions.
2) When relaxing some of these theoretical assumptions (to switch to more realistic ones) mix trajectory of the energy-only market can considerably deviate from the optimal trajectory. While an EOM looks appealing in theory, its desirable properties suffer from a lack of robustness with regard to practical investor behaviors.

Conclusions

Modelling contributions

System Dynamics methodology completes the economic toolbox to analyse electricity market designs and decarbonization. It is complementary to

- GEP models because it is possible to explicitly represent market design, information available and investors behaviour
- Equilibrium market models, given that it allows to analyze "out of equilibrium" situations which are the norm in power systems.

In this paper, we develop a System Dynamics model with endogenous investment and decommissioning decisions to study the properties of an energy-only market. We compare SD market results using different information assumptions with GEP optimal decarbonization trajectory.

Policy insights

We show that EOM is not robust: generation mix can considerably deviate from the optimal trajectory when relaxing some theoretical assumptions. Thus, it is necessary to define a more robust market design to ensure power system decarbonization at least cost, e.g. in the form of hybrid markets that rely on long-term arrangements alongside short-term markets as we know them today.

References

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[1] Our data are adapted from the Integrated Resource Planning exercise performed by the California Public Utilities Commission (CPUC) completed with historical hourly resolution data for load and Renewables Ninja database for wind and solar generation.