LARGE-SCALE ENERGY SYSTEM IMPACTS OF DIFFERENT SUBSIDY SCHEMES

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Overview

The pressing need to reduce carbon emissions entails to speed up the energy transition, which requires significant investments in low-carbon technologies. For that matter, effective market design and robust risk management strategies are essential. This paper examines the challenges of integrating renewable energy into electricity markets, focusing on market design and risk management.

Energy investors face various types of risks, that altogether impact project viability. The markets and financial underlying risks mainly comprise of weather variability, demand uncertainty, price volatility, market incompleteness, carbon market fluctuations, but also regulatory and policy risks. Different technologies can be unequally impacted due to a variable capital intensity, their fuel price exposure or their relative intermittency. All those risks can result in increased costs of capital, and some risk investment and production behaviours from the energy market actors.

In this setting, properly balancing risk allocation between governments and investors is crucial. It ensures that risks are borne by the parties best suited to manage them, creating incentives while reducing risk premiums, and therefore project costs. Those risk premiums have been implemented by the governments as early as in the 1970s-1980s in Europe and in the US, with the goal of promoting market efficiency, driving competitiveness, while providing the stability needed to encourage long-term investments in the energy transition. For that matter, the subsidies should be carefully designed, accounting for the energy system's technological structure, the market dynamics, the main uncertainties risks, and the actors' behavior. Previous works have looked at the electricity sector only (Dimanchev et al., 2023; Mays et al., 2019), studied only capacity-based premiums (Dimanchev et al., 2023; Mays et al., 2019), and were showing significant computational limitations (Abrell et al., 2019; Dimanchev et al., 2023; Mays et al., 2019). Instead, this paper develops a method able to deal with the presence of non-linearities brought by the subsidies variables, and compatible with large-scale modelling works.

Methods

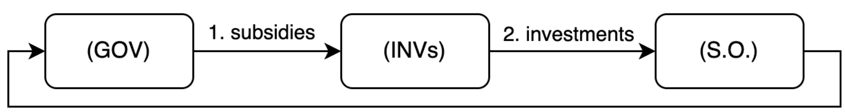

Figure 1 – graphical representation of the model

The method consists in having a government actor, setting some subsidy schemes under the constraints of some market actors' reactions. It aims to represent a three steps problem: first having the government (GOV) fixing some subsidies, then having some atomistic actors (INVs) in a competitive equilibrium deciding on their capacity investment and finally having the system operator (S.O.) solving the dispatch, with no market power. It departs from the classical social welfare maximization approach, traditionally used in energy system optimization models, which assumes deterministic perfect foresight of future costs and demand, perfect market coordination, and social welfare maximization. Instead, this paper introduces a scenario-based stochastic model to incorporate uncertainty in costs and demand, adopts a framework of competition among investors, and focuses on energy investors profit maximization.

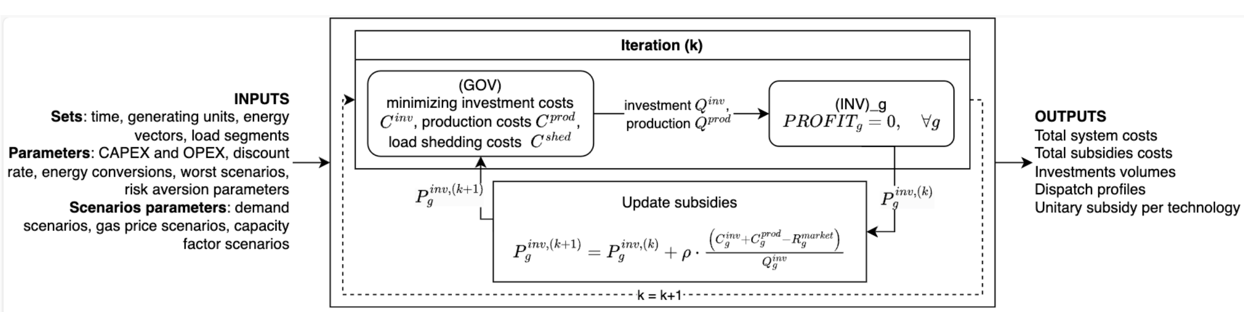

Figure 2 - graphical representation of the resolution method

The resolution method developed consists in an algorithmic approach of a generation capacity expansion problem, a type of problem solved by optimization techniques since more than 60 years (Ehrenmann and Smeers, 2011). The equilibrium problem consists of two types of agents: the government (GOV), acting as a risk-neutral social welfare maximizing entity, and the risk-averse atomistic energy investors (INV)_g, maximizing their profits, and each representing a specific technology. The two actor's models are iterated upon to converge on a volume of energy subsidies exchanged. In the details, and as illustrated in Figure 1 for the investment premium case, the government (GOV) first determines the welfare-optimal investments, dispatch and load shedding, assigning the same weight to all the scenarios (risk-neutrality). The investments and dispatch are then used in the atomistic market model to compute the risk-averse profit of the energy market actors (INV)_g. For instance, if the profit of a given energy producer is negative, it sends a positive signal to the government to increase the technology's subsidies, in accordance with the perfect competition theory.

The uncertainties covered in the model include the uncertainty on the capacity factor parameter, on the demand capacity, on the gas price, and on the renewable energy capital intensity. As mentioned above, they are integrated into the model in a scenario-based way: by sampling what are considered as representative scenarios. Hence, each of those parameters are represented with three representative scenarios: low, middle and high. The energy subsidies modelled and compared are of three types: a capacity remuneration scheme, a fixed feed-in premium and a sliding feed-in premium. This approach reduces computational complexity, while capturing key variations in uncertain parameters (Roald et al., 2023).

The investors' risk-aversion is inspired by the CVaR method (Rockafellar and Uryasev, 2002), insofar as the best scenarios are given a low weight, and the scenarios assumed to be the worst for each generator are weighted more, the worst they are for the investor. After solving the problem, the profit distributions are checked, and the model is run again if there is a deviation from the expected worst cases. The case study is the French context. Contrary to previous risk-assessing models (Abrell et al., 2019; Dimanchev et al., 2023; Mays et al., 2019), this model not only include the electricity sector, but also other energy vectors such as methane, heat and hydrogen.

Results

The expected results include the comparison of the effects of the optimal subsidy amount on the invested capital, on the production profiles and on the cost of the system, as well as the comparison of the impacts of different types of subsidies. The results will also allow to compare the level of support needed for each type of technology, and to investigate for each of them the leading type of risk. In addition, some sensitivity analysis on the risk-aversion parameters is expected to unveil the impact of the modelling choices

Conclusions

This approach offers several advantages compared to previously developed methods. It allows for the evaluation of both production-based and capacity-based subsidies. Additionally, it incorporates interactions between different energy markets and supports a wider range of technologies for public subsidies, moving beyond a focus on wind and solar generation technologies only. The resolution method is also computationally efficient and is compatible with existing large-scale energy system models that optimize social welfare. By applying this framework, we expect to draw robust conclusions, showing how the evaluated subsidies can help counteract distortions arising from investors' risk aversion and market incompleteness.

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