HOW POWER PRICES AND RENEWABLES' MARKET VALUES DIFFER BETWEEN NEAR-OPTIMAL FUTURE ENERGY SYSTEMS

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Overview

To realise the transition towards climate-neutral energy systems based on renewable sources, large investments in generation, transmission and storage infrastructure are needed. The expected revenues and profitability of these investments are key drivers for investors' decisions and hence for the feasibility of the energy transition. As future energy systems and the realisable revenues are unknown, energy system models have been used for decades to generate insights into possible transition pathways. Authors have, for instance, studied future system designs (Zappa et al., 2019), renewables' market values (Bernath et al., 2021; Bötter & Härtel, 2022) or investments' profitability in terms of internal rates of return (Finke et al., 2023). These models, however, come with structural and parametric uncertainties that significantly affect the outcomes. Modelling to Generate Alternatives (MGA) is a method to systematically address structural and parametric uncertainties by exploring the near-optimal solution space (DeCarolis, 2011). It has been used to generate diverse, almost cost-minimal energy system designs, e.g. by Price & Keppo (2017) and Lombardi et al. (2020). However, to our knowledge, MGA has never been used to systematically analyse the implications of structural and parametric uncertainties for modelling investors' future revenues, for example in the form of renewables' market values.

Methods

Building on openly available power system data from PyPSA-Eur (Hörsch et al., 2018), we model the Central Western European power system (Belgium, France, Germany, Luxembourg and the Netherlands) using the open-source energy system optimisation framework Backbone (Helistö et al., 2019). As shown in Figure 1, we use this model in three subsequent optimisations and an ex-post economic assessment. First, we carry out a cost-minimising expansion planning. Second, we iteratively generate near-cost-minimal alternative system designs using MGA. Here, we introduce a new objective function that is the weighted sum of investment variables x_i and reformulate the cost function f into a constraint, allowing for some slack ε in addition to the cost minimum. Iteratively altering the weights w_i^k, we generate diverse system designs by optimising

$$\min_{x \in F} \sum_{i \in I} w_i^k x_i \quad s.t. \quad f(x) \leq (1+\varepsilon) \cdot \min_{x \in F} f(x) \quad \text{for} \quad k = 0, 1, 2, \ldots$$

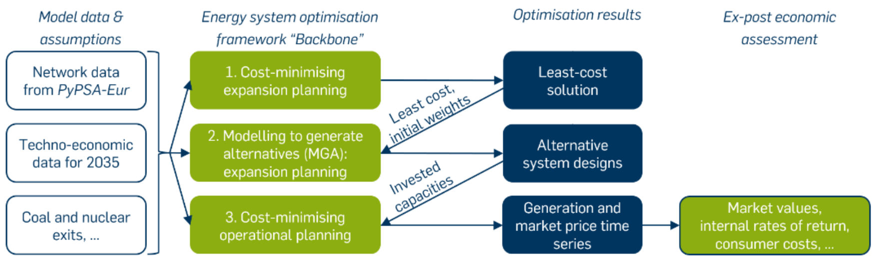

Figure 1: The methodology with three optimisation steps and a subsequent economic assessment.

over the feasible set F. Third, we fix the invested capacities from the alternative system designs obtained in steps 1 and 2 one by one and carry out a cost-minimising operational planning for each alternative. Finally, we use the results of the operational planning for an ex-post economic assessment. In particular, we use marginal values of the energy balance equation to proxy spot market prices in each country in order to determine generation-weighted market price time series, i.e. market values, for renewable generators.

Results

As first, preliminary results, we obtain six alternative system designs with costs deviating no more than 10% from the minimum. The spatial and technological distribution of renewables' and storage investments varies significantly between these alternatives (see Figure 2). In terms of renewables' investors' revenues, we find that the market values (per country and technology) and time-averaged market prices (per country) vary significantly between the alternatives as shown in Figure 3. These variations in market prices and values are not merely a re-distribution between countries or technologies: The market price time series, when aggregated for all countries and renewable technologies and weighted with either renewable generation (i.e. market values) or demand or averaged over time, vary significantly between the alternatives (see Figure 4).

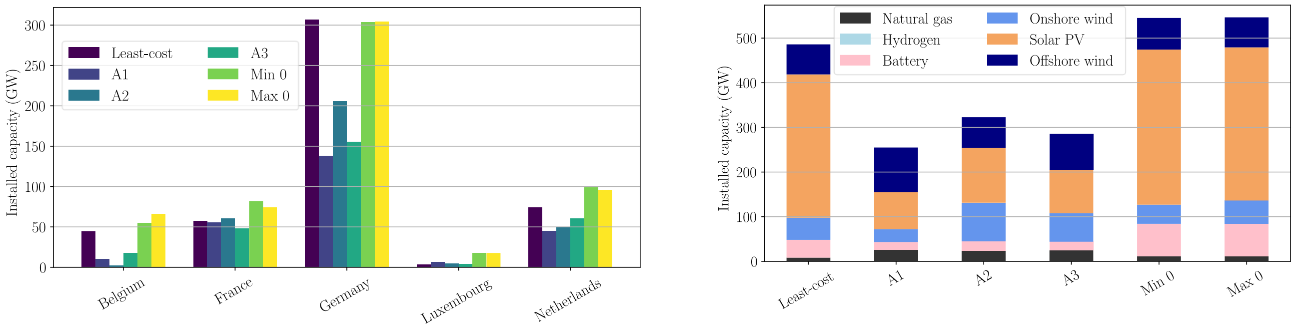

Figure 2: Spatial (left) and technological distribution (right) of renewable and storage investments for six alternative system designs.

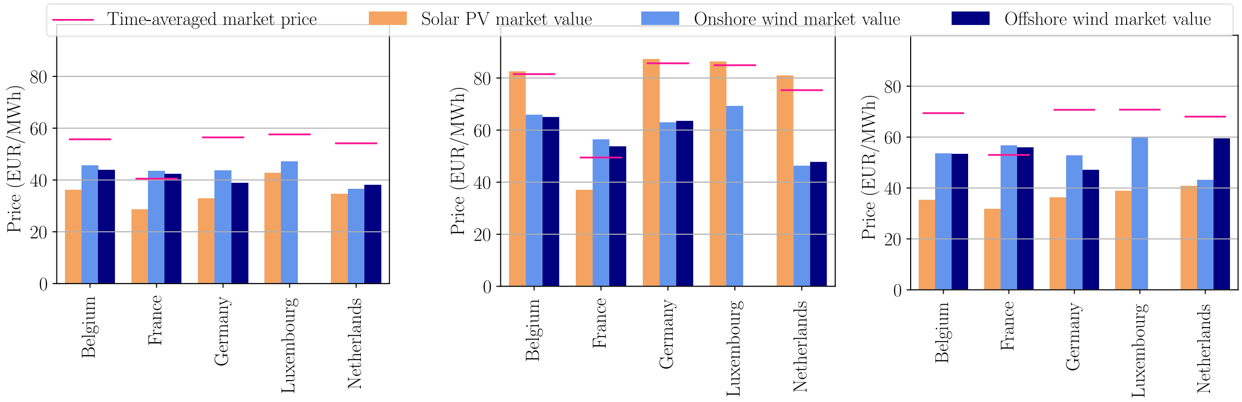

Figure 3: Renewables' market values and time-averaged market prices for three alternatives (from left to right: Min 0, A2 and Least-cost).

Conclusions

Our preliminary results show that market prices and market values vary significantly between alternatives that are within 10% of the cost minimum. Awareness of these price effects of structural and parametric model uncertainties are therefore important for interpreting results of energy system models in general. Furthermore, we can generate only slightly more expensive alternatives that might be more feasible and more attractive to certain stakeholders (particularly private-sector investors) due to significantly increased market values and thus higher expected returns on investments.

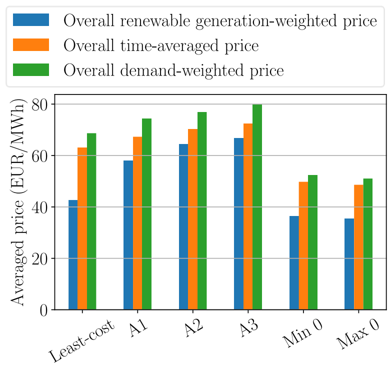

Figure 4: Market prices aggregated for the whole system and weighted with renewables' generation or demand or averaged over time.

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