TRADE-OFFS IN ELECTROLYSER REPRESENTATION FOR MEDIUM-TERM ELECTRICITY SECTOR MODELLING

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Overview

As decarbonization efforts advance, hydrogen produced with low-carbon emissions is expected to become a critical component of the energy mix, potentially supplying up to 24% of the final energy demand by 2050 [1]. Hydrogen also offers significant potential for enhancing the integration of variable renewable energy into the electricity system, as it is one of the few solutions for storing energy over extended periods, ranging from days to months [2]. Furthermore, since renewable energy is a key driver of green hydrogen production, there is a strong interconnection between the electricity and hydrogen sectors. In this context, incorporating electrolysers into electricity sector models is essential to understanding and leveraging these interconnections between the electricity and hydrogen sectors, which is highly valuable for policymakers and private stakeholders.

In the literature, electrolysers used to produce hydrogen from electricity are modelled with varying levels of detail [3]. However, to maintain computational tractability, many simplifying assumptions are made on the electrolysers when integrating them into broader energy system models, which are often complex and computationally demanding. Examples include disregarding start-up and shut-down dynamics or overlooking ramp constraints [4]. Therefore, finding efficient ways to integrate electrolysers with adequate detail, while minimising computational costs, has become a key challenge. This work aims to shed some light on the trade-offs between modelling detail and computational tractability.

In this paper, we use a detailed medium-term electricity sector model and investigate various simplified approaches to integrate electrolysers. These approaches can be classified into two categories: exogenous approaches, where electrolyser operations are precomputed, and endogenous approaches, where electrolyser operations are optimised within the model. To evaluate these approaches, we conduct case studies on six electricity systems, all of them inspired by the Iberian electricity system. Each case differs in system size and shares of thermal generation, variable renewables, and hydropower. For each electricity system, we compare a benchmark case, where electrolysers are modelled in high detail, with different simplifying modelling approaches to identify the most efficient modelling detail for these six distinct electricity systems.

Methods

In the benchmark case, the electricity model consists of a detailed hydrothermal Unit Commitment and Economic Dispatch problem, operating with an hourly resolution. It provides a detailed representation of generation units, including hydroelectric, thermal, and pumped storage units, grouped by type and operational constraints. This approach results in a Mixed Integer Quadratically Constrained Program (MIQCP). To this electricity model, we integrate electrolysers that satisfy energy production constraints (usually defined by means of a physical contract) and that are also subject to operational constraints, including start-up and shut-down costs, production efficiencies, ramp limits, minimum and maximum consumption limits, and minimum uptime limits. The detailed modelling of the electrolyser included in the benchmark introduces both binary variables and time coupling constraints that add complexity to an already demanding problem. We then compare this detailed approach against other simplified modelling approaches of integrating electrolysers into the electricity system. These approaches fall into the aforementioned two categories:

1. **Exogenous approaches:** Exogenous approaches determine the operation of electrolysers independently of the optimisation problem, relying instead on pre-calculated rules based on demand or price patterns. These data are subsequently introduced in the optimisation problem as an input parameter.
    - Net demand duration curve: In this approach, the electrolysers are set to run during hours with the lowest net demand, where net demand is defined as the electricity demand minus solar and wind generations.
    - Price duration curve: In this approach, we first run the model without electrolysers to obtain the marginal electricity prices. The electrolyser is then set to run during hours when the prices fall below a certain threshold.

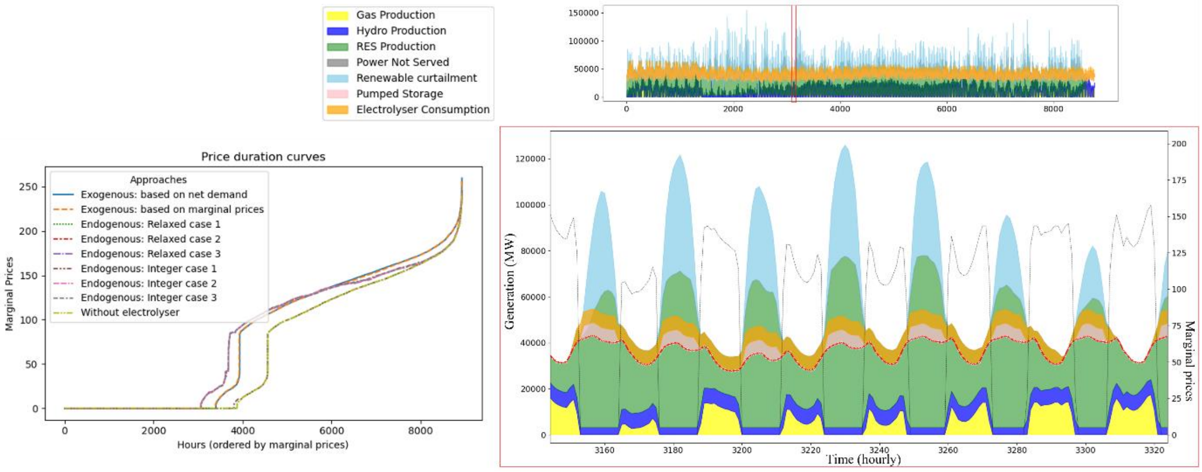
   In both approaches we choose the hours such that the minimum uptime constraint is satisfied.
2. **Endogenous approaches:** In these approaches, the operation of electrolysers is optimised within the model and not computed beforehand. We investigate three cases that differ in their level of detail in modelling the electrolysers.
    - Case 1: Electrolysers are subject to a minimum monthly energy consumption constraint and a maximum hourly consumption constraint.

- Case 2: Building on Case 1, startups, shutdowns, and a minimum electricity consumption capacity of the electrolysers are modelled.
- Case 3: Expanding upon Case 2, a minimum uptime constraint and ramp limits are added for the electrolysers.

To study the modelling trade-offs in the different systems, we define some key performance indicators (KPI) that quantify the alignment of the simplifications with the benchmark model. These KPIs revolve around the total system costs, the renewable curtailments, the electrolyser consumption profile, the total consumption cost of the electrolyser and the system's marginal electricity cost differences.

Results

In the paper, it is shown how across the tested systems, variations in the mix and the size influence the performance of each simplified modelling approach. The following figures illustrate some of the resulting dispatches and marginal costs obtained from the simulations, which are further analysed in the paper.



Conclusions

Finding efficient ways to integrate electrolysers with adequate modelling detail, while minimising computational costs, has become a key challenge. This work shows how the most efficient simplifications depend on the size and the composition of the mix of the system being considered. The paper also gives some guidelines regarding how to suitably balance the need for model accuracy against acceptable computational demand in each particular case.

References

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