

OPTIMISING TECHNICAL PARAMETERS OF EMERGING TECHNOLOGIES WITH INVERSE MULTI-OBJECTIVE ENERGY MODELLING

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Overview

The energy sector is undergoing a transformation towards a climate-neutral future based on renewable energy sources. Besides the increasing demand for decentralised, flexible, and environmentally friendly technologies, technology innovation will be imperative for this transition, offering unknown environmental, technological, and commercial potentials (Moriarty and Honnery, 2022). Energy system models are an important tool for this transition, using, among others, costs and efficiencies as input parameters for all energy technologies considered. However, technologies with low technology readiness levels (TRLs) require estimations for those parameters which are usually not possible or poorly verified at an early stage of development. Therefore, the inclusion of low TRL technologies in energy models is associated with enormous parametric uncertainty and brings great challenges to current research (Prina et al., 2020; Pfenninger et al., 2014). Against this background, this work aims at developing a novel inverted approach to turn typical model input parameter into model outputs, thereby reducing parametric uncertainties in input parameter estimation. Combining this approach with multi-objective optimisation to considering multiple perspectives / interests simultaneously, we implement the inverted multi-objective methodology in an open-source highly flexible energy system modelling framework. Results give insights into the worst technical parameters that would still lead to the market success of a low TRL technology.

Methods

We develop a novel inverted approach for energy system modelling to support the design of low TRL technologies from their basics. To achieve this, we turn model input parameters, such as technology cost or efficiencies, into decision variables and use them in the formulation of the optimisation problem – either in the objective function or as additional constraints. The results of this modelling approach include, from a market perspective, optimal values of technology-specific parameters, so that in addition to reducing initial parametric uncertainties in energy models, they offer valuable insights from a product developer's perspective. However, to still satisfy economic interests of decision-makers and therefore simultaneously consider multiple interests, multi-objective optimisation is needed. We therefore employ the augmented epsilon-constraint method (AUGMECON) to identify trade-off solutions between the objectives. Like this, the modelling objective becomes to find the system design with the lowest total system cost while, at the same time, achieving the worst technical parameters that would still lead to the deployment of the technology.

Putting this approach into practice, we build on openly available power system data from PyPSA-Eur (Hörsch et al., 2018) and model the capacity expansion planning of the Central Western European power system (Belgium, France, Germany, Luxembourg and the Netherlands) for 2050 using the open-source energy system optimisation framework Backbone (Helistö et al., 2019). We use capital expenditures (CAPEX) as a second objective to be maximised while total system costs are minimised and Carnot Batteries (CB) as a location-independent energy storage technology with low TRL.

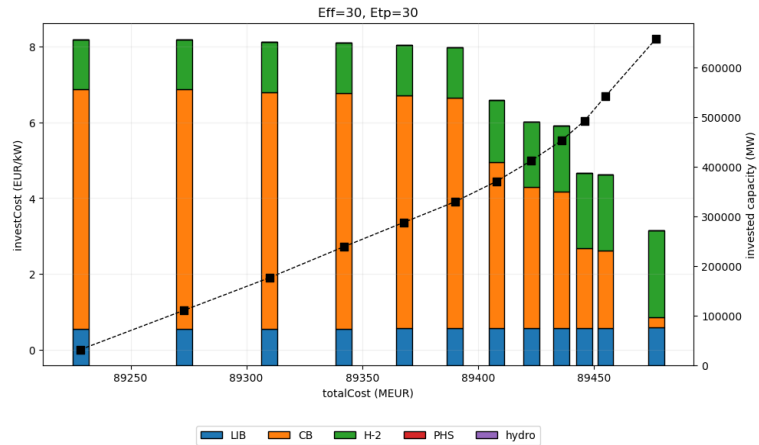


Figure 1: Trade-off curve, marked by black dots, between total system cost and capital expenditures for the scenario of 30% RTE and 30h EtP-ratio. Bars represent the invested capacity per storage technology.

Results

As preliminary results, we obtain ten trade-off solutions each for different scenarios of exogenously given roundtrip efficiency (RTE) and energy-to-power (EtP) ratio. As displayed explanatory for the scenario of 30% RTE and 30h EtP-ratio in Figure 1 the maximal CAPEX value of the CB for which a pre-defined level of total system cost can be satisfied, increases with increasing total system cost going from the lowest system cost on the left-hand side to the highest on the right. Simultaneously, the invested capacity into CBs decreases as they compete and get replaced with other available storage options. At some CAPEX value, CBs are no longer competitive in the energy market and further increases do not affect the total system cost. We find that this break-even point differs depending on the RTE and EtP ratio as shown in Figure 2 for the scenario of 50% RTE and 20h EtP-ratio. If compared to the scenario of 30% RTE and 30h EtP-ratio in Figure 1, higher CAPEX values are realised at this point, however, result in higher total system cost while invested capacities drop. Overall, the lower CAPEX values combined with higher invested capacities of the scenario presented in Figure 1 result in higher total unit investment costs and, depending on the margin per sold unit, possibly lead to higher revenues of CBs.

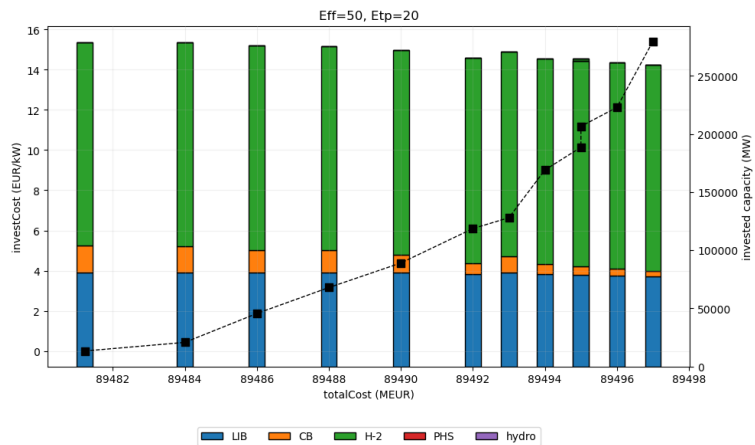


Figure 2: Trade-off curve, marked by black dots, between total system cost and capital expenditures for the scenario of 50% RTE and 20h EtP-ratio. Bars represent the invested capacity per storage technology.

Further expected results can be analysed in stacked trade-off curves for fixed values of either RTE or EtP-ratio while varying the other. They will provide additional insights into the CAPEX or total system cost necessary to make up for lower RTEs or EtP-ratios but still ensure market success. From this, the technological property with the highest influence on CAPEX can be derived. It is expected to see the boundaries of these curves shift towards the bottom right with decreasing technological properties, i.e. the least requirements for CBs compete in the market become more strict/ambitious with worsening properties. Therefore, a decrease in system cost can only be achieved by improving the CBs properties and knowledge about the relation between the improvement necessary and the possible decrease of system cost offers valuable insights for further development paths and system design. Furthermore, each calculated point of the trade-off curve is a full solution of the energy system model and can be analysed and utilised as such. For example, a whole ensemble of time series for CBs' operation in terms of load and state-of-charge is generated. This information can be particularly useful for product development.

Conclusions

We present preliminary results and an outlook on further expected results of a novel inverted optimisation approach for energy system modelling which we apply to the Central Western European power system at the example of CBs as a low TRL technology and CAPEX as an optimised technological property aside from total system cost. The results include, from a market perspective, optimal values of technology-specific parameters, so that in addition to reducing initial parametric uncertainties in energy models, they offer valuable insights from a product developer's perspective e.g. ranges of CAPEX that ensure market shares of CBs and the requirements and effects of technology property improvements. In addition, results such as operation time series, target markets, concurring technologies of CBs can be further utilised and offer valuable insights for an early stage product development.

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