Enabling Competing Energy Storage Technologies: Towards a Carbon-Neutral Power System

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Abstract

Assessment of energy storage technologies at a macro-scale for grid integration, has often focused on singular technologies and neglected competition between them, thus leaving out of the optimization the decision of which energy storage to prioritize. We present a systematic deployment analysis method that enables system-value evaluation in perfect competitive markets and demonstrate its application to 20 different energy storage technologies across 40 distinct scenarios for a representative future power system in Africa. Our results demonstrate the significant benefits of optimizing energy storage with competition compared to without (+10% cost savings) and highlight the relevance of several energy storage technologies in various scenarios. This work provides insights into the role of multi-technology energy storage in carbon-neutral power systems and informs future research and policy decisions.

Keywords

Energy modelling, Energy storage, Optimization, Technology evaluation, Variable renewable energy

1 Introduction

As the world decarbonizes its power systems to mitigate the impacts of climate change, it has become clear that Energy Storage Systems (ESS) will play a critical role in the transition to a carbon-neutral future, as they provide a solution by decoupling the generation and consumption of electricity. The system-value of ESS, defined as their market potential resulting from possible and probable least-cost scenarios in capacity expansion models, stems from the broader techno-economic benefits it provides to the grid, such as displacement of firm generation, deferral of network infrastructure expansion, better renewables utilization, and reduction of transmission and distribution losses [1].

Assessing the competitiveness of ESS in larger power systems with well-known Levelized Cost of Storage (LCoS) methods is often less suitable than system-value assessment methods [2]. However, most system-value studies explore isolated storage technologies that do not consider any competition with others. Adding more technology options to models often results in synergies, reducing the total system costs, and raising questions on the validity of previously found results with single ESS scenarios.

In this research we assess multiple ESS both individually and in combination, with a novel systematic deployment analysis, also addressing uncertainty.

2 Methodology

We use an (already validated) interconnected 10-node Nigerian power system model, using high temporal resolution (8760 hours), modelled in PyPSA-Earth, an open energy system modelling platform suitable for investment and operational co-optimization [3]. Within this model, we integrate for the first time 20 different ESS technologies and present their system-value with and without competition across 40 distinct scenarios, for a representative future power system in Africa (Fig. 1).

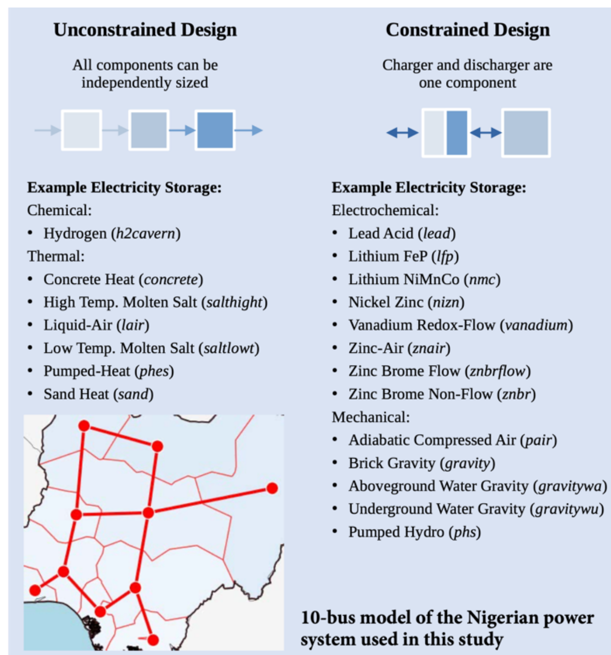

Fig. 1 The ESS technologies with abbreviations and the 10-bus model of the Nigerian power system used in this study.

We thus explore two previously unanswered questions: how significant the system benefit from optimizing energy storage is, both with competition and without, and which energy storage is optimization-relevant considering uncertainty. To answer these questions, we focus on two scenario trees, each including 20 optimization runs; the first, (single storage scenario), involves optimizing each of the energy storage solutions in isolation, assuming business-as-usual costs but excluding any competition between the different storage solutions. This allows investigation of the total system costs (€/MWh) and setup (GW for charger/discharger or GWh for store). In the second scenario tree all ESS solutions can be selected and optimized within each scenario. This enables competition and cost synergies between various technologies. To facilitate this, we introduce the 'lonely optimist' approach, where one storage option has optimistic capital costs while the others have pessimistic assumptions. This extreme parameterization allows distinction between the ESS solutions that provide system-value and those which can potentially be neglected - at least within the modelled power system conditions [2].

3 Results

Figure 2 shows that when storage competition (lonely optimist scenario) is enabled, ESS in the studied Nigerian power system will be significantly cheaper compared to the single storage scenario. The competitive scenarios are 29% cheaper compared to single storage optimization. While the competitive scenario tree has few cost increases for some technologies initially, the cost gradient becomes relatively low after the optimistic 'phes' scenario with changes of less than 0.1%. In contrast, in the single storage scenarios the cost increases continuously.

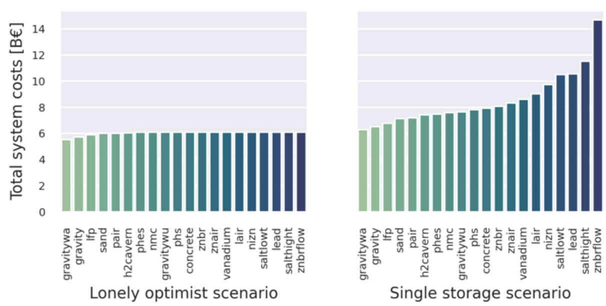

Fig. 2 Total system cost for energy storage scenario with (left) and without (right) competition. Scenarios sorted according to the total system cost.

Secondly, the grid benefits from ESS synergies even under the worst cost assumptions. The total system cost of the most expensive competitive scenario is 3% cheaper than the best non-competitive scenario (6.1 vs. 6.3 B€). Thirdly, when considering 'gravitywa' with business-as-usual assumptions in both scenario trees, one can observe 8% cost saving or 500 M€ in absolute terms. These results suggest that studies assessing the system-value with single optimized ESS [1,4] miss significant benefits from synergies caused by co-optimizing multiple technologies. It is also likely that power systems with 2 or 3 modelled ESS such as in [5,6] could benefit from system cost reduction when including more of the technologies that were found highly optimization-relevant; for instance, the gravity or sand based thermal ESS.

Fig. 3 illustrates the market potential of 20 lonely optimist scenario optimizations for the Nigerian grid in 2050. Each scenario given on the x-axis requires a single optimization run, with all technologies listed on the y-axis treated as variables. The color gradient, normalized to the maximum value across all runs, indicates the extent that the technologies are deployed in each optimization result. These results, presented in full detail in [7], suggest that 9 out of 20 storage technologies are optimization-relevant (rows with at least one non-clear colored square), providing system benefits due to synergies in storage design and operation.

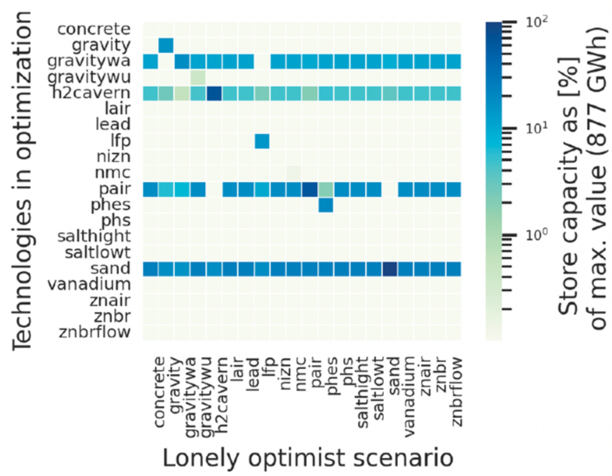

Fig. 3 Optimized storage capacity for the lonely optimist scenario in Nigeria.

Fig. 3 only presents the results for storage capacity, but in the full study the charger and the discharger stages are also optimized. These results indicate that system-value assessment with multiple ESS can be an advanced approach that could potentially find more application in research and industry compared to approaches that ignore competition by isolating technology considerations.

4 Concluding remarks

The standard practice of excluding the selection of ESS technology from the optimization and considering only one at a time is proven to yield suboptimal results in terms of the overall system cost. This brief paper presents a method that allows the concurrent assessment and optimization of multiple ESS technologies down to component level and illustrates the benefits of synergies in design and operation. The methodology, presented in full in [7] including detailed information on the case studies and a discussion of its applicability and limitations, can be used by decision-makers to define probable scenarios. What is likely most interesting for technology innovators, manufacturers, and regulators is the identification of the mixture and amount of a various ESS technologies required to be deployed to benefit the power system.

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