Efficient Storage Capacity in a System with High Photovoltaic Penetration

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Many countries aim to reduce carbon emissions and, consequently, implement policies to foster power generation from renewable energy sources (RES). Besides wind power, photovoltaic systems (PV) are the major technology used for that purpose, with large capacities being connected to the grid every year. Given its intermittent nature, RES cannot be controlled to follow the system load. Today, primarily conventional power plants are used to compensate these fluctuations in order to ensure availability of electricity when needed. Considering the foreseen path of massive expansion of renewable energy, this is no longer sufficient.

Storage systems can be used to store energy in time of high RES feed-in and to provide the needed energy just in time. With pumped-hydro storage (PHS) an efficient and proven technology is available. Most of the other storage technologies are characterized by high but declining investment costs, so that a widespread rollout could be expected within the next 20 years.

In future power systems, storages will be part of the efficient technology portfolio. Because of typical storage characteristics (volume limitations, charging and discharging cycles), storage capacity is not always available. The typical setup of PHS in lower mountain ranges allows several hours of full-load operation, which complements the day-night-pattern of PV systems. In comparison to that, battery systems (e. g. Li-Ion) are characterized by flexibility and high power supply during a short period of time.

In this analysis, we apply an extended capacity planning model for storages (cf. Böcker & Weber, 2014) to specifically investigate the efficient use of pumped-storage and battery systems to complement PV systems. In light of the political objectives to reduce carbon emissions and other major scenario assumptions, the efficient capacity of storages will be derived for several case studies.

Storages in a System Perspective (Model)

Various technologies may be used for power generation and their operation typically is determined by their position in the merit order. The efficient portfolio is obtained by considering the long-term capacity planning problem (also known as peak-load-pricing problem), which is an extension of the merit-order model taking into account both investment and operational costs and load restrictions. Storages can also be attributed a position in the merit order and thus can be a part of the efficient portfolio. If storage volume restrictions are neglected, they can be treated almost like conventional technologies (Steffen & Weber, 2013).

Yet, the storage volume is a major restriction implying two effects on the efficient portfolio. First, the amount of energy which can be shifted from high supply to high demand is limited. Second, the required capacity of technologies ranked to the right of the storage technology in the merit order may be increased in comparison to the case of unlimited storage volume (Böcker & Weber, 2014).

	Unit	**Lignite**	**Coal**	**CCGT**	**OCGT**	**Wind**	**Wind**	**PV**	**PHS**	**Li-Ion**
								Offs.	**Ons.**	
Capacity costs	k€/MW	1,500	1,200	700	400	1,600	1,200	800	840	100
Volume costs	k€/MWh	0	0	0	0	0	0	0	20	150
Technical lifetime	years	40	40	30	25	20	20	25	50	20
Efficiency	- - -	49%	51%	62%	41%	100%	100%	100%	80%	90%
Operational costs	EUR/MWh	8.2	23.9	50.5	76.3	0	0	0	0	0

Table 1: Main Input Parameter

Based on data by IEA (2013), ISE (2013), RWTH Aachen (2013/2014), own analyses

In the present analysis, the cost-optimal combination of storage volume and storage filling/withdrawal capacity is determined together with the optimal operation from a system perspective. In this context, an appropriate storage operation strategy will notably minimize the needed peak capacities. It is thereby also taken into account that most RES have marginal costs of nearly zero so that they are dispatched with priority given their natural availability.

Key technology characteristics used for the analysis are summarized in Table 1. These correspond to expected technology developments until 2040. For this year, current generation capacities only play a minor role. Therefore, a greenfield

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approach is applied. Load and RES feed-in profiles are based on German data for 2011. Moreover the following German policy objectives are included: 1) CO_2 emissions at 20 % of the 1990 level, 2) 65 % share of renewables in electricity generation.

Efficient Portfolio and Sensitivities

The optimal sizing of storages and capacities of generation plants in a long-term economic equilibrium is given for the reference case in Table 2. Investments in wind offshore are limited to the realistic sites along the German coast leading to a maximum installed capacity of 54 GW (IWES, 2013). The resulting CO_2 price is almost 75 €/tCO_2.

Efficient Portfolio	Capacity	Volume
Lignite	3 GW	---
Coal	0 GW	---
CCGT	46 GW	---
OCGT	14 GW	---
Wind Off.	54 GW	---
Wind On.	61 GW	---
PV	66 GW	---
PHS	15 GW	371 GWh
Li-Ion	4 GW	14 GWh

Table 2: Results reference case

Sensitivities of the efficient Li-Ion capacity and volume with respect to key input parameters (± 50% of the reference value) are given in Figure 1. The installed storage quantities turn out to be strongly dependent on the investment costs, notably the storage volume related costs. Also reduced investment costs for PV increase the amount of Li-Ion batteries, showing that these are complementary technologies. CO_2 emissions targets above the reference case do not influence the efficient storage capacity and volume, because the target share for renewables is then binding in the analyzed setting. This changes and the role of storages increases significantly, if the target is strengthened by 25 % or more. Then lignite plants are out of the efficient portfolio and further emission reductions are achieved through increased renewable penetration. In the extreme case (10 % of 1990 emissions), the efficient Li-Ion capacity declines again. More long term storage using PHS is required and PHS partly substitutes Li-Ion batteries. This is also true if the requirement on the RES share is tightened. In the most extreme cases no Li-Ion capacities are installed, instead RES fluctuations are solely flattened through the use of PHS. Efficient storage capacity and volume are less sensitive to operational costs (less than 5 % variation), their installation is mainly driven by RES fluctuations.

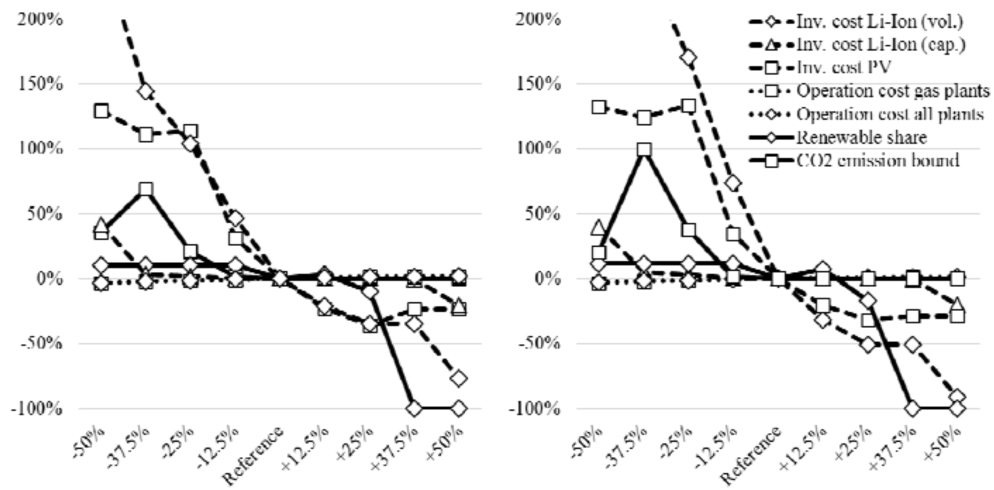

Figure 1: Sensitivities of efficient Capacity (left) and Volume (right) of Li-Ion Battery

The model provides insights into the optimality of storage expansion in power systems with large shares of renewables and especially PV feed-in. It therefore complements large-scale optimization models allowing a detailed assessment of specific scenarios by indicating the main driving forces and impediments for the implementation of storages in a competitive environment.

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