# *ON THE ECONOMICS OF ELECTRICAL STORAGE FOR VARIABLE RENEWABLE ENERGY SOURCES*

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## Overview

The use of renewable energy sources is a major strategy to mitigate climate change. Yet some researchers have questioned the viability of power markets largely based on fluctuating renewables. In a recent publication (which was presented in an earlier version as a keynote at the IAEE 2016 conference in Bergen), Sinn (2017) argues that electrical storage requirements may become excessive and could thus impede the further expansion of variable wind and solar power in Germany. Based on historic time series of electricity demand and variable renewable energy supply, he illustrates storage requirements to take up renewable surplus energy quickly rise to vast numbers. To avoid any "waste" of renewable energy, current German storage installations would not allow a share of wind and solar PV in electricity demand greater than 30%. And for a fully renewable electricity supply, storage requirements would be more than 400 times as high as the currently installed German pumped-hydro storage capacity, and also much higher than the entire European potential to build such plants.

We replicate his findings and put them in perspective by providing an open-source analysis which addresses shortcomings in Sinn's approach two of which are particualarly notable: first, we avoid corner solutions by allowing for combinations of storage and renewable curtailment; second, we employ an economically sound objective function. We further illustrate the effects of additional flexible demand related to energy sector coupling. We find that electrical storage requirements derived by Sinn (2017) are vastly exaggerated.

## Methods

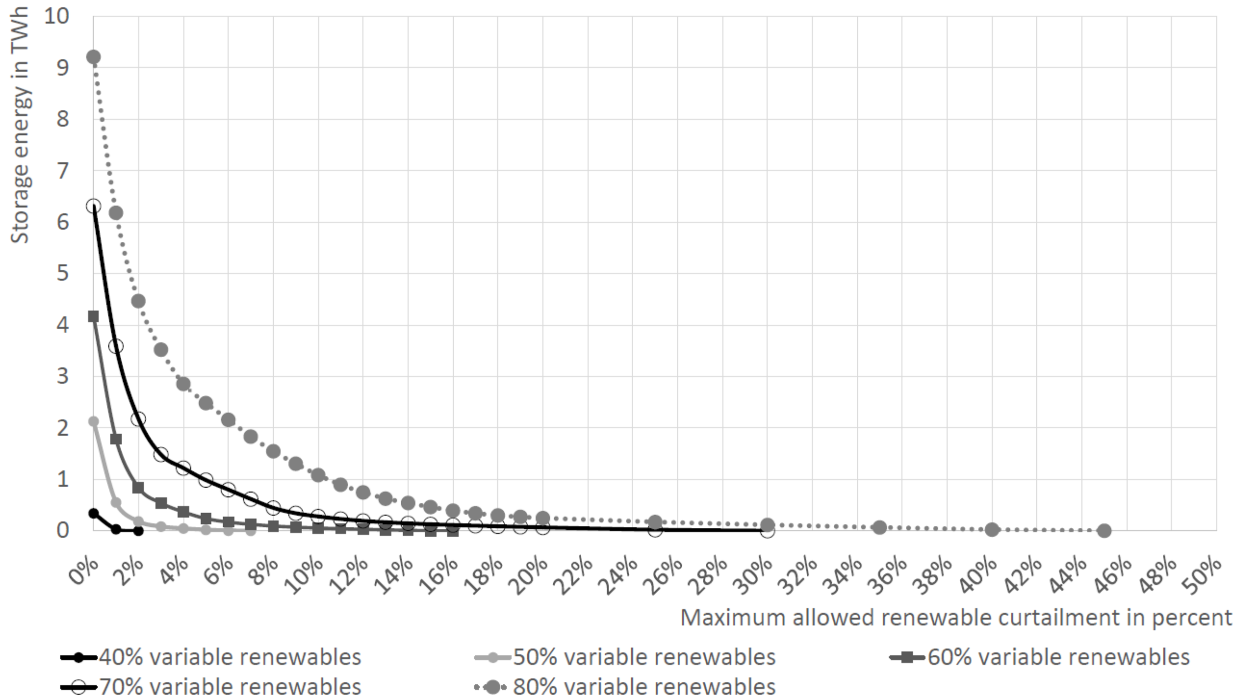
Sinn's considerations deserve merit as they illustrate important properties of variable renewable energy sources. Yet his findings are not backed up by the literature and his approach is based on strong implicit assumptions, two of which are particularly questionable. First, it only considers two extreme cases in which either all surplus energy is stored or none. In turn, either storage needs are excessive or an excessive share of the available renewable energy is not used. Yet any economically efficient solution is likely to be located in between, i.e., combines some amount of storage and some renewable curtailment. Second, Sinn uses an objective function – minimization of the required storage energy capacity – that is unlikely to lead to a first-best outcome. This objective neither captures the full costs of storage nor the costs of other required assets in the power market.

We put Sinn's finding into perspective by gradually extending and improving his approach, addressing the limitations mentioned above. We start with a replication of Sinn's analysis and also illustrate the effects of alternative base years, making use of open data and an Excel tool, which we provide under an open-source license. Using this tool, we then examine the effects of allowing for various levels of renewable curtailment on storage requirements. Next, we substitute the data-driven approach with a numerical cost-minimization model and show how storage requirements evolve in this setting, which may be considered to be more convincing from an economic perspective. To do so, we use a reduced form of the numerical model DIETER presented by Zerrahn and Schill (2017). We also provide this model under an open-source license. In the last part of the analysis, we illustrate the effects of additional sector coupling using an extended model version. Such sector coupling induces additional flexible electric loads, for example related to electric mobility, electric heating or power-to-gas.

## Results

When addressing, and altering, the strong implicit assumptions, both results and conclusions change substantially. We first demonstrate that we can replicate Sinn's results using open data and an open-source Excel tool. In doing so, we show that also the choice of base years has a substantial effect on storage requirements We further illustrate the findings with residual load duration curves in order to provide better intuition.

We then show that storage requirements substantially decrease if increasing levels of renewable curtailment are allowed, in a framework and model otherwise identical to Sinn (2017).




The Figure shows storage energy requirements (in TWh) for Germany for different shares of variable renewables (wind and solar PV) in final electricity demand. If no curtailment is allowed, Sinn's corner solution emerges on the vertical axis. Already allowing low rates of curtailment, storage needs drop substantially. For instance, assuming no curtailment, storage energy needs are at 2,100 GWh for 50% variable renewables in final demand. With 5% curtailment, they drop to 19 GWh.

The findings using a parsimonious optimization model are analogous. Finally, we show that storage requirements may further decrease if additional sector coupling (power-to-heat, power-to-mobility, power-to-x) is considered, under the assumption that such sector coupling is also linked to an additional expansion of variable renewable energy sources. Yet effects strongly depend on the assumed full load hours of the sector coupling technologies.

## Conclusions

Based on our open-source analysis, we conclude that storage requirements are exaggerated in Sinn's (2017) analysis. Already with moderate rates of renewable curtailment, they are lower by up to two orders of magnitude in a framework otherwise identical to Sinn. The economic rationale is the straightforward: if electricity demand is satisfied, electrical storage can be used to take up renewable surplus energy. Yet integrating increasing amounts of such surpluses requires disproportionately growing storage capacities which are not valuable at most times. Instead, an efficient solution seeks to balance investments into storage, renewables that get curtailed at times, and other capacities to minimize the total cost of providing electricity.

All things considered, we conclude that electrical storage requirements do not limit the further expansion of variable renewable energy sources.

## References

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Zerrahn, A. and Schill, W.-P. (2017): Long-run power storage requirements for high shares of renewables: review and a new model. Renewable and Sustainable Energy Reviews (79), 1518-1534.