AGGREGATION OF INTERMITTENT RENEWABLES IN ENERGY MARKET MODELS: CAPTURING CORRELATIONS AND EXTREME EVENTS

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Overview

With the transition to highly renewables energy systems, the increasing reliance on intermittent renewables for electricity, heat and hydrogen production will likely result in more price-peaks for consumers and more integration measures due to the increased variability of supply. In multi-regional interconnected energy markets as for example in Europe, the dynamics of intermittent supply is difficult to capture by bottom-up energy models because the time dimension must be usually aggregated into representative periods for numerical tractability. The representative periods should take into account the price-relevant correlations and extreme events to faithfully represent supply. In this work, after reviewing existing aggregation methods, we consider a new scenario generation method for representative days of wind and solar availability that considers the correlations and the extreme events as the first construction principle (and not ex-post as other methods). Using a cross-regional electricity market model of the Central Western European countries, we show how such improved scenario modeling of renewables can better represent expected prices in different hours and seasons of a year.

Method

To capture the correlations between availabilities of different renewables, the new method uses principal component analysis (PCA), which is based on correlations. PCA is applied to daily time series of hourly profiles of regional solar and wind power availability to yield low-dimensional scenarios, which can be used to represent the year with a limited set of representative days within a single region. Subsequently, the scenarios generated with PCA are used as building blocks for daily multi-regional scenarios under different assumption on dependence (i.e., whether or not we allow for extreme joint (tail) events of different supply options). The cross-regional tail-dependency is represented by so-called copulas (which are common in finance to represent probabilistic dependencies). As an application, the price variability by intermittent renewables with a – numerically tractable – low number of scenarios is investigated in the cross-border electricity market model BEM (Wan, 2022; Densing, 2022a); BEM uses conjectural variations for calibration to today's prices and comprises the market regions of Austria, Germany, France, Italy, and Switzerland. The documented software code of the statistical analysis is freely available (Densing, 2022b).

Results

First we consider the single-region results, which are based on the principal component analysis. We identify a sequence of patterns of intermittent supply of solar and wind in descending order of variance. The sequence is (surprisingly) qualitatively the same for all considered countries (Austria, Germany, France, Italy, and Switzerland). In terms of multi-regional results, we implement the extreme value (copula) scenario approach in the electricity market model. We show that the extreme events in the scenarios have a significant impact on price formations, and that high price regimes have a higher probability than lower ones because of the different joint tail-dependence. Strengths and limits of the approach are shown in terms of possible extensions (e.g. extending to demand variations) and by comparison with common hierarchical clustering techniques: The new approach captures a larger portion of correlations and extreme events (tough we point out also the border cases where approximating correlations is not specific enough). The scenarios of representative days are used in the cross-regional electricity market model BEM; the scenario generation with tail-dependence yields results more in line with historical price duration curves. The cross-regional results of BEM indicate that whereas a gaussian copula is outperformed in terms of price variability by a (simple) cross-regional hierarchical clustering, a t-copula can lead to price-peaks more in line with empirical data.

Conclusions

Market prices in renewable energy systems are increasingly influenced by intermittent electricity supply. Hence, the aggregation of intermittent supply patterns will become more important, while key properties of the variability should be preserved. With our new statistical method using principal component analysis and extreme value theory (copulas), we can ensure to capture the correlations within hours of a day in a single market region, and also cross-regional electricity market modeling accuracy in terms of price duration curves is at least on par (or surpasses) with current

methods. Nevertheless, the statistical effort becomes considerable such that we hint also to future research directions using simpler modeling.

References

Densing, M. and Wan, Y. (2022a) “Low-dimensional scenario generation method of solar and wind availability for representative days in energy modeling”, Applied Energy, 306, 118075.

Densing, M. and Wan, Y. (2022b). “representative days”, R-package, electronic open source code repository, PSI https://gitlab.psi.ch/energy-economics-group/representative-days

Wan, Y., Kober, T., Densing, M. (2022) “Nonlinear inverse demand curves in electricity market modeling”, Energy Economics, 107, 105809.