PyPSA-ZA: Investment and operation co-optimization of integrating wind and solar at high spatial and temporal detail

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Motivation

South Africa and Southern Africa are in the fortunate position of having access to high-quality wind and solar resources promising energy production costs well below the ones projected for future installations of thermal generation; yet the feasibility of a low carbon energy system is still under scrutiny.

Problem Statement

We demonstrate the feasibility and cost-effectiveness of integrating the available high capacity factor renewable resources into the South African electricity system. Therefore, one needs to show that a suitable generation, storage and transmission capacity configuration can be operated to supply the spatially and temporally distributed energy demand, under the condition of varying and geographically correlated renewable feed-in. Transparency and reproducibility of the modelling results must be guaranteed.

Methodology

From the high-voltage network topology a 64-bus network is determined using a k-means based clustering algorithm. On the basis of a Voronoi partition, we add to each bus the thermal and hydro generation capacities and its population-determined share of a historical South African 8760-hour demand time-series, corrected for demand growth. We estimate the wind and solar capacity potential from landuse data and use reanalysis weather data of the same historical year to generate renewable generation per-unit time-series, which are thus reproducing the actual spatial and temporal correlations. An iterated linear least-cost co-optimization of generation, long- and short-term storage and transmission capacities determines a capacity configuration for which the energy demand can be met within transmission limits. Finally, we study the influence of including further sectoral demands from electrifying water heating and transportation from cars and rails. The model is based on PyPSA and will be published under an open-source licence.

Results

Extrapolating our experience with the European system, the cost-effective solution of a low carbon energy system depends on four important factors:

1. The renewable energy resources are developed at high capacity factors.

2. Particularly wind energy profits from a wide geographical spread beyond the typical correlation length by smoothing the varying energy yield with a strong transmission grid.

3. Flexibility for the daily varying solar energy is provided by short-term battery storages, while wind energy with its synoptic time-scale needs longer-term hydrogen storages in the deep-decarbonization scenarios.

4. The remaining residual load is covered with flexible dispatchable hydro and gas power plants. For Europe a 95% renewable energy share is thus achievable with a moderate 20% increase in costs. The considerably higher capacity factors in South Africa promise to make a deep decarbonization even more economical.

Conclusions

A spatially and temporally highly resolved linear optimization of the investment and operational costs finds a distribution of generation, storage and transmission capacities to supply the South African electricity, transport and water heating demand with mainly renewable energy; giving proof of the feasibility and benefits of wind and solar integration.