Inter-annual climate variability and adequate planning of future energy systems

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Objective & Background

Mitigation of climate change requires a massive expansion of renewable but weather-dependent energy sources, like wind, solar, or hydro. Energy planning models are powerful tools to guide this expansion and shape the transformation toward a reliable and sustainable energy system. Currently, most models only consider a single year of climate data to represent weather conditions and assume perfect forecasting [1]. However, research shows that renewable supply varies substantially across years and significantly impacts system planning, especially at high renewable shares [2,3]. In addition, reasonable forecasts for renewable generation are only possible in the short term.

Against this background, we introduce a method to consider different climate years, or scenarios, in energy planning models and perform a benchmark against existing methods.

Method

Figure 1 compares the introduced method (3) with existing methods to consider inter-annual climate variability in energy planning optimization models. These models generally consist of an expansion stage that decides on capacities and an operational stage that determines the operation of capacities for all hours of the year. The operational stage accounts for long-term storage, like reservoirs or (in the future) hydrogen caverns, by cyclic constraints creating interdependence between all hours.

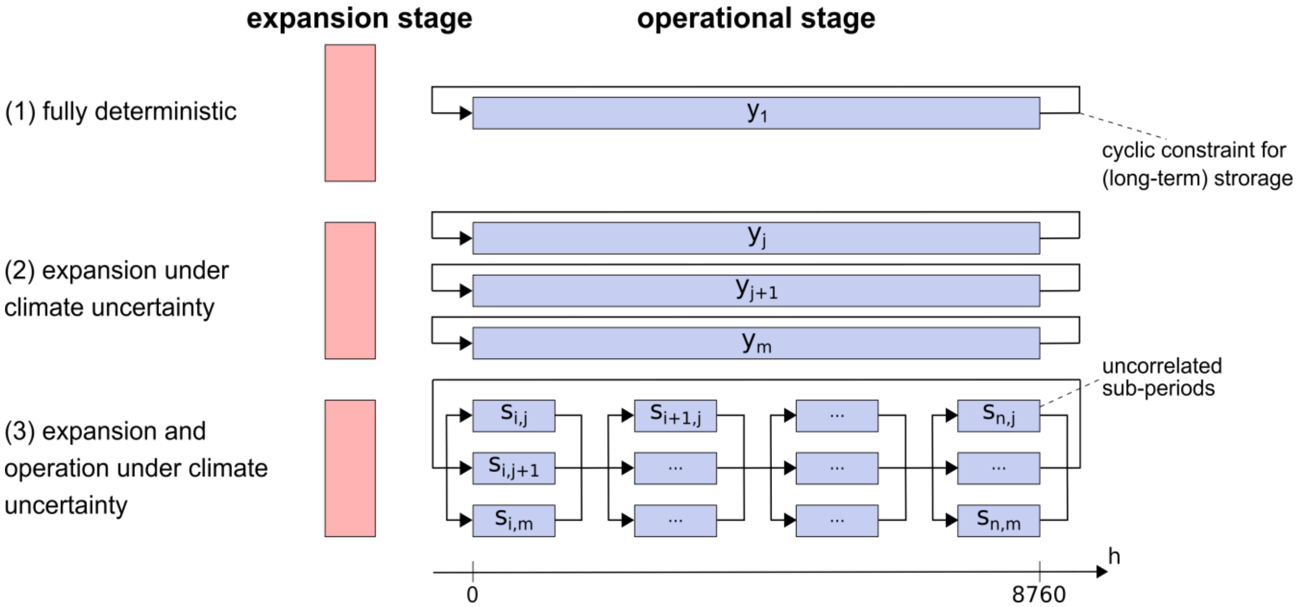

Figure 1: Proposed method (3) in comparison to benchmark methods (1) and (2) from the literature.

The proposed method (3) divides the year into shorter periods, for instance of 3 months, assuming perfect forecasts within each period and serial independence, i.e., no correlation, between periods. As a result, operation under uncertainty can be modeled without an extensive scenario tree but with uniform storage levels between periods instead. In contrast, method (1), the current state-of-the-art, solves a deterministic problem separately for each climate scenario and uses the solution of the most expensive year. The more advanced method (2) includes multiple climate scenarios, but still assumes perfect forecasts for operation within each year [4].

For a case study, we derive representative scenarios for years and periods using clustering on a sample of time-series data based on the MERRA2 reanalysis dataset [5]. With these scenarios, we run an hourly planning model of a renewable power system in a greenfield setting for each method. The solutions are assessed for the entire sample and out-of-sample data using a more detailed model of the operational stage.

Principal Findings

Preliminary results suggest that the proposed method (3) achieves the lowest unmet demand and the most cost-efficient energy system. Thanks to the uncorrelated periods, the method can consider a great range of climatic conditions at a small problem size. For instance, 3 representative periods for each of the 4 seasons result in 3^4, or 81, different climatic years considered for planning.

Discussion

The proposed method can account for various climatic conditions in energy planning. Therefore, the method is not only capable of capturing inter-annual variability under constant climatic conditions but in addition also different developments of the climate system itself.

Future research should investigate distributed solution methods based on decomposition to apply the method to large-scale models of integrated energy systems.

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