Simulating Annual Variation in Load, Wind, and Solar by Representative Hour Selection

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Executive summary

A key research question for energy system modeling is what role wind and solar could play in the transition to a low-carbon energy system. To explore this question effectively, a model must capture the strong effect of temporal and spatial variability on the fundamental economics of intermittent renewable energy. Ideally, a model would maintain full hourly resolution to represent this variability. In practice, computational constraints require more compact alternatives for use in large-scale energy system or integrated assessment models with national or global coverage and long (multidecadal) timeframes. This issue is common to any model seeking to understand the implications of electric sector investments, including utility-scale resource planning models, regional or national power sector models used for policy-making, and global integrated assessment models used to inform issues like climate change mitigation where the power sector plays an important role.

Prior to the emergence of wind and solar power as major potential resources of electricity supply, the variability of electricity demand was the only significant source of intra-annual variability that an energy system model needed to account for. The commonly employed “seasonal average” approach emerged as a compact alternative to full hourly resolution that captured key characteristics of load variability. This approach uses a limited number of segments to capture the load curve (peak, shoulder, and base in summer, winter, and fall/spring). While simple approaches of this type can be effective at reproducing a load duration curve, they poorly represent the distribution and co-variation with load of renewable resources, as well as the co-variation among regions needed to effectively model power transmission. The seasonal average approach assigns wind and solar coefficients to each segment based on average resource availability during the corresponding load period. This replicates average wind and solar capacity factors, but completely misses key intra-annual extremes, such as periods where load is high, but wind and solar are low. Despite emerging innovations in this active area of research, many prominent models nevertheless mimic variability in stylized ways using simple approaches, prioritizing increased resolution in other modeling dimensions over intra-annual temporal detail.

This study describes a “representative hours” method to bridge this gap between the recognized shortcomings of existing approaches to representing power system variability in capacity planning models and need for computationally tractable solutions. This approach consists of strategic selection of particular hours during a calibration year that satisfy simultaneously key distributional requirements for load, wind, and solar time series across multiple inter-connected model regions, including extreme hours that represent potential capacity shortfalls and surpluses in renewable energy generation. The relevant

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extremes include not only the peaks and minimums of the individual series, but crucially also the joint extremes for each region. This novel augmented clustering approach recognizes the importance of boundary events in system operations, price extremes, and consequently the profitability of new capacity investments. We describe the implementation of this procedure in EPRI's US-REGEN model and compare impacts on energy system decisions with more common approaches.

The results demonstrate how power sector modeling and capacity planning decisions are sensitive to the representation of intra-annual variation and how our proposed approach outperforms simple heuristic selection procedures. The representative hour approach preserves key properties of the joint underlying hourly distributions, whereas seasonal average approaches over-value wind and solar at higher penetration levels and under-value investment in dispatchable capacity by inaccurately capturing the corresponding residual load duration curves. These considerations are shown to be most important in investment environments where widespread deployment of variable renewable generation is possible. Figure ES-1 shows that the representative hours method reproduces far more closely the value of wind and solar as measured in the hourly model compared with the seasonal average approach.

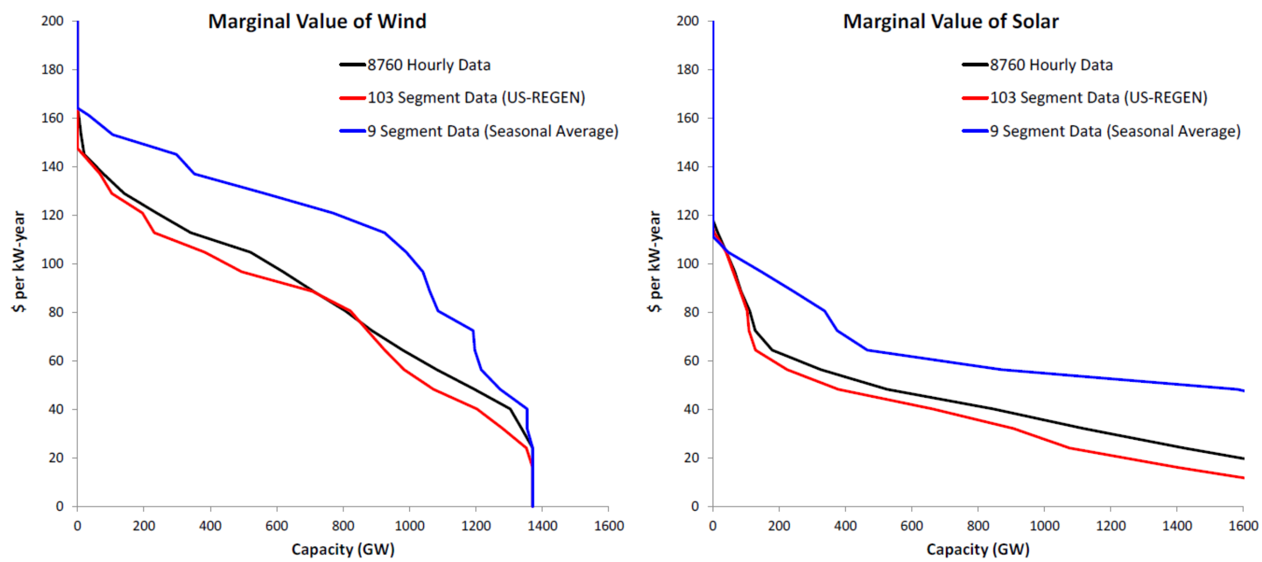

Figure ES-1. Marginal value curves for wind (left panel) and solar (right panel) using the full hourly data (black), representative hour approach (red), and seasonal average approach (blue).

We provide a range of diagnostic tests demonstrating the method's performance. Although the shortcomings of seasonal average approaches are well known, we provide new explanatory evidence comparing these simplified approaches to our proposed representative hours method and to the underlying hourly data. Differences arise not simply due to a small number of chosen intra-annual segments but due to the manner in which these segments are selected. We also demonstrate that a clustering-only approach to hour selection yields a significant improvement over the seasonal average approach but that some information about the capacity value of resources is lost.

Overall, these experiments illustrate how a representative hour approach can provide more reliable energy modeling insights and accurate asset valuation relative to simplified approaches that appear in commonly used frameworks for decision-making and policy-making.

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