More than one arrow in the quiver: Why "100% renewables" misses the mark

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Jacobson et al. (1) aim to demonstrate that an all-renewable energy system is technically feasible. Not only are the study's conclusions based on strong assumptions and key methodological oversights, but its framing also omits the essential notion of trade-offs. A far more relevant question is how renewable energy technologies relate to the broader set of options for meeting long-term societal goals like managing climate change. Even if the goal were to maximize the deployment of renewable energy (and not decarbonization more generally), Jacobson et al. still fail to provide a satisfactory analysis by glossing over fundamental implications of the technical and economic dimensions of intermittency. We briefly highlight two prominent examples, and then return to the question of framing.

First, the paper's "no load loss" assertion is predicated on the large-scale availability of energy storage, demand response, and unconstrained transmission to handle periods of supply surpluses and shortfalls. Its assumptions about the cost and reliability of intertemporal demand flexibility within and across sectors, as well as the electrification of end-use demand, are particularly aggressive. The potential scale and scope of these novel technologies remain highly uncertain and speculative, and the narrow confidence intervals presented in Jacobson et al. (1) do not reflect the full range of possible outcomes.

Second, the paper does not account for the regional provision of resource adequacy (i.e., market clearing with spatial heterogeneity) in its reliability results—indeed, the analysis is conducted at the national level. Although geographic smoothing can ameliorate some balancing challenges, seasonal and diurnal variability of wind and solar output cannot be managed through offsetting spatial variability alone. Moreover, these effects require data that reflect renewable output simultaneously with load in each hour of a given year, yet Jacobson et al. (1) use different, nonsynchronous datasets. Consequently, their analysis preserves neither joint temporal nor spatial variability between intermittent resources and demand, which are among the main drivers of decreasing returns to scale for renewable energy (2).

There is an emerging literature on integrated modeling of long-term capacity planning with high-temporal-resolution operational detail that effectively incorporates such economic drivers (e.g., ref. 3). By contrast, Jacobson et al. (1) use a "grid integration model" in which investment and energy system transformations are not subject to economic considerations. The resulting renewable-dominated capacity mix is inconsistent with the wide range of optimal deep decarbonization pathways projected in model intercomparison exercises (e.g., refs. 4 and 5) in which the contribution of renewable energy is traded off in economic terms against other low-carbon options.

Jacobson et al. (1) underscore how balancing and fleet flexibility will be important elements of power system design, and that electrification of other demand sectors is a promising option. However, the study underestimates many of the technical challenges associated with the world it envisions, and fails to establish an appropriate economic context. Every low-carbon energy technology presents unique technical, economic, and legal challenges. Evaluating these trade-offs within a consistent decision framework is essential. Such analyses consistently demonstrate that a broad research, development, and deployment portfolio across supply- and demand-side technologies is the best way to ensure a safe, reliable, affordable, and environmentally responsible future energy system.

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