PSE Healthy Energy
SCIENCE SUMMARY
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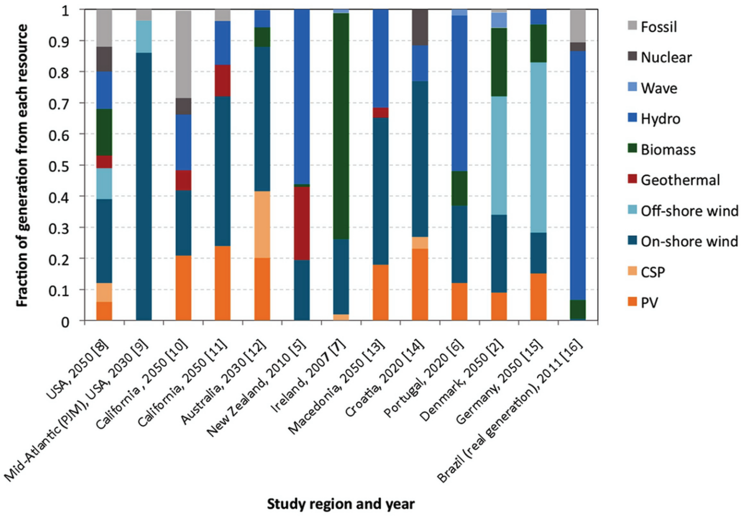
Running on Renewables: A review of 80% - 100% renewable electricity scenarios

The transition from a power sector based on fossil fuels to one run primarily on renewable energy is a central component of many climate change mitigation strategies [1]. This transition can also have environmental and public health benefits by reducing the total production and combustion of coal, oil and natural gas [2]. Many analyses in the literature have demonstrated that there are more than enough solar, wind and water resources to meet most or even all energy demand on a national or global scale [3,4]. However, the integration of a high proportion, or "penetration," of renewables into the electric grid requires rethinking its structure to accommodate the variability and intermittency of solar and wind generation. Here, we compare technical studies that use real resource and demand data to model how renewables might meet power needs in different regions across the globe, both now and in 2050. **While the energy generation mix varies greatly based on local resources, the results all demonstrate the technological feasibility of renewable energy resources meeting 80-100% of power demand**.

Studies

In **Figure 1** we compare the mix of energy resources used in 12 different studies to meet hourly power demand on the electric grid, either based on historic usage or predicted demand in in 2020 or 2050. All models are based on real demand and weather data and existing technologies; studies are either published in peer-reviewed journals or by national labs and government agencies. The last region shown is for real generation data from Brazil in 2011, where renewables make up more than 85% of the electricity mix [16]. Only some models include transportation, which can serve to increase electricity demand in scenarios based on electric vehicles. A diversity of generation mixes are found for different regions, reflecting differences in assumptions and local resources, and varying allowances in each model for energy storage or over-generation. Models for New Zealand [5] and Portugal [6] show both can meet about half of their demand with hydropower and another large percentage with wind, while a model for Ireland [7] relies on biomass for the bulk of energy. The National Renewable Energy Laboratory's model for the US reflects the wide diversity of resources across the country [8], although state-specific studies are dominated by the most available local resources [9-11].

Figure 1: Generation mix in high-penetration renewables scenarios, modeled to meet demand in the year given. Note: when wind not classified by type, it is plotted as "on-shore."



> **The results of these studies suggest that there are numerous ways to technically meet a majority if not all electricity demand with renewables, and the transition to a renewables-based grid is not constrained by the scalability or success of any one technology.**

Strategies

A few key strategies to help achieve a high penetration of renewables were common across many of these studies:

Efficiency measures for vehicles, households, and industry enable fewer renewables to meet total demand. The Danish model uses a 50% drop in household electricity consumption [2].

Energy storage is used sparingly in some models, but is critical in others. The New Zealand model employs enough pumped hydropower to match 14% of grid capacity [5].

Transmission infrastructure must be expanded to integrate new resources. NREL estimates over 100 million MW-miles needed to reach 80% renewables penetration in the US [8].

Transportation is diversely modeled as powered by biofuels, hydrogen, or electricity, with implications for total electricity and fuel demand; electric vehicles increase power demand but improve efficiency and provide built-in storage and demand response.

Spillage of excess renewables generation is assumed in many models. Over-generation is assumed to be negligible in New Zealand, with its large storage capacity [5], but nearly half of all renewables generation in the model for the Mid-Atlantic PJM grid is spilled [9].

Grid flexibility, such as flexible electric loads on the grid, quickly ramping power generation, and the integration of combined heat and power and other efficient technologies, plays a central role in most models.

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Ongoing Research Needs

Economics: the cost of future technologies is difficult to predict; renewables in Denmark are projected to cost the same as a business-as-usual model [2], whereas NREL estimates 80% renewables would cost an additional $25-50/Mwh [8]. Getting incrementally closer to 100% of generation from renewables is associated with increasing costs [8, 9, 17, 18]. Savings associated with improved health impacts and carbon mitigation are not addressed in most of these models.

Biomass: environmental impacts of biomass are highly uncertain, and while some models rely on it (e.g. 75% of supply in Ireland [7]), lifecycle inputs and emissions for large-scale use of biomass must be carefully assessed.

Resources: the availability of different materials is not considered in many of these studies, but must be addressed to determine the scalability of technologies reliant on rare earths or other uncommon materials.

Transportation challenges remain for powering airplanes and heavy duty trucks, which are not easily electrified [17].

Infrastructure upgrades: transmission, storage and the incorporation of smart grid technologies are widely seen as needed, but optimal design and therefore costs still have many uncertainties.