Future Wind and Solar Power Deployment by Congressional District

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This brief describes the process of estimating the amount of wind and solar power technology that might be deployed in each U.S. congressional district through the mid-2030's in a decarbonization scenario. The analysis is limited to onshore wind, utility-scale photovoltaic (PV), and rooftop/distributed PV technology. All of the key data inputs come from the National Renewable Energy Laboratory (NREL).

Modeling decarbonization of the U.S. power sector

NREL's Cambium data platform provides results from nationwide power sector simulation studies. These studies simulate changes to the U.S. power sector over time under different assumptions (scenarios) using NREL's state-of-the-art Regional Energy Deployment System (ReEDS). ReEDS captures detailed features of the power system, including matching of supply and demand across time and space; feasibility and cost of transmission, seasonal and diurnal uncertainty of wind and solar power (i.e. intermittency), and maintenance of grid reliability.

For a given scenario, ReEDS identifies the least-cost evolution of the power system that meets reliability and engineering constraints, given assumptions about technology and fuel costs, demand growth, resource availability, and other factors. ReEDS's spatial resolution consists of 134 individual "balancing areas" (BA's) within the continental U.S. The model optimization process ensures that sufficient transmission infrastructure is available to balance hourly electricity supply and demand within each BA.

Model outputs include the amount of installed capacity (MW) and generation (MWh) in each BA for each generating technology at two-year intervals through 2050. In short, given key assumptions regarding future technology costs and electricity demand, ReEDS provides a projection of how the power system could develop in a least-cost manner.

The most aggressive decarbonization scenario currently available in Cambium is the "Lower RE Costs, High Electrification" scenario developed for the Electrification Futures Study (EFS). It pairs lower-cost renewable energy technology with an increase in electricity demand (e.g. adoption of electric vehicles). The least-cost solution in this scenario includes large-scale build-out of wind and solar technology and results in power sector CO_2 emissions falling ~62% between 2020 and 2034. Although this scenario does not include explicit carbon pricing, by assuming lower renewable power costs (relative to fossil fuels) it likely reflects the key supply-side effects of aggressive carbon pricing.

Downscaling ReEDS model output to congressional districts

The BA-level ReEDS model output is too coarse to provide good estimates of district-specific development of wind and solar power over time.[1] However, NREL has developed high-resolution, wind and solar power "supply curves" that underpin ReEDS internal representation of renewable energy potential across space. The supply curve data consist of a list of feasible wind and solar power sites (latitude/longitude) with an estimate of each site's potential capacity (total MW), rank-ordered by the expected levelized cost of electricity ($ per MWh). These data generally take into account siting and feasibility criteria, proximity to transmission, and the quality of local wind and solar resources (e.g. wind speed).

The basic approach here is to use technology-specific supply curves to spatially downscale the BA-level model output. For each BA, technology, and year, the ReEDS model output provides the total installed capacity and generation in the least-cost solution. The high-resolution supply curve data for each technology is processed to derive a rank-ordering of feasible sites within each BA. The BA-level installed capacity is then assigned to individual sites (for each technology), starting with the sites with the lowest levelized cost of electricity. Once all installed capacity has been assigned to specific sites, it is possible to "sum up" installed capacity by technology and congressional district.

In effect, this process takes the ReEDS BA-level model output as given and then assumes that the "actual" spatial deployment *within* each BA strictly prioritizes the lowest-cost locales as identified by the supply curves.

Processing of technology-specific supply curves

Onshore wind

NREL has released high-resolution supply curve data for onshore wind power. The data incorporate ReEDS's default "Reference Access" exclusionary screens (land cover, proximity to population, protected areas, etc.) to identify potential locations along with site-specific available area, capacity potential, generation potential, generator capacity factor, and distance to transmission interconnect. These variables are used to make levelized cost estimates using assumptions from Rhodes et al. (2017) (data here). The final dataset contains ~57,000 potential wind power sites (lat/lon) rank-ordered by levelized cost.

Utility-scale PV

NREL staff provided the utility-scale PV supply curve data underpinning current ReEDS model runs. It includes site-specific available area, capacity potential, generation potential, and levelized cost. The final dataset contains ~203,000 potential utility-scale PV sites (lat/lon) rank-ordered by levelized cost.

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[1] NREL has released only state-level (not BA-level) results for the EFS scenarios. To estimate what the "Lower RE Costs, High Electrification" scenario might look like for each BA, the BA-level outputs for the Standard Scenarios 2020 "Low RE Cost, Low Battery Cost" scenario were scaled at the state level to match the technology-year totals for the selected EFS scenario.

Rooftop PV

A rooftop/distributed PV supply curve was constructed by combining data from five sources:

1. Estimates of rooftop PV technical potential and capacity factor for ~5,000 zip codes, derived from local LIDAR data (Gagnon et al. 2016; data here).
2. County-level estimates of rooftop PV technical potential from NREL's SLOPE Platform (provided by NREL staff).
3. The EPA Smart Location Database (SLD), which contains block group-level variables describing features of the local built environment.
4. Annual average global horizontal irradiance (GHI) raster data for the Americas (Sengupta et al. 2018; data here).
5. Zip code-level data on average residential electricity prices in 2018 (data here).

For zip codes lacking data in Gagnon et al. (2016), technical potential and capacity factor were imputed using SLD built environment variables and local GHI as predictors in a CART model trained on zip codes with complete data. The technical potential results were then scaled at the county level to match the SLOPE data. A levelized cost estimate was made for each zip code, using cost assumptions from Rhodes et al. (2017) (data here). On the advice of NREL staff, the final supply curve rank-ordering of ~33,000 zip codes is based on the difference between the observed average residential electricity price and the estimated levelized cost. That is, we expect rooftop PV to be preferentially installed in places where grid electricity is comparatively expensive and PV electricity (per-kWh) is relatively cheap.

Summary of results

Figure 1 summarizes results for 432 congressional districts (Hawaii, Alaska, and D.C. are excluded). Each dot is a congressional district, oriented left-to-right according to the district's 2016 Cook Partisan Voting Index – a measure of how strongly Democratic or Republican the district tends to vote. The vertical axes indicate how much of each wind and solar power technology (GW) is built in each district between 2020 and 2034, according to the ReEDS EFS "Lower RE Costs, High Electrification" scenario and spatial downscaling process described above.

Onshore wind and utility-scale PV account for about 92% of wind and solar capacity added between 2020 and 2034 in the selected scenario. Rooftop PV plays a comparatively limited role. Both onshore wind and utility-scale PV are preferentially deployed in Republican congressional districts. This is less true of rooftop PV, which is more likely to be located within urban population centers. Overall, nearly 80% of wind and solar power generating capacity added between 2020 and 2034 is built in Republican-held congressional districts.

Caveats and limitations

As with all scenario modeling, the ReEDS model output is not a projection or prediction of how the U.S. power system will develop in coming decades. Rather, it reflects the assumptions specific to the "Lower RE Costs, High Electrification" scenario under a least-cost evolution of the power system. The

U.S. *may* decarbonize in a way broadly consistent with the selected scenario, but there is certainly no guarantee that it will.

It is unlikely that renewable power technologies will be strictly sited according to the supply curve rank-orderings. On-the-ground realities will play a significant role in where technologies can be placed. Local siting constraints, regulations, and zoning could have a significant impact on the amount of technology ultimately deployed in different places (Lopez et al. 2021). The results here generally reflect prioritization of technologies and locales where available physical resources are most conducive to *financial* least-cost operation of the power system. There are many reasons that the American public might choose to deviate from this scenario.

Figure 1: Wind and solar power (GW) added between 2020 and 2034, by congressional district

ReEDS EFS “Lower RE Costs, High Electrification” scenario downscaled to districts via high-resolution supply curves