On the Road to 100% Renewables

States Can Lead An Equitable Energy Transition

Appendix: Methodology and Assumptions

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This appendix describes the methodology and assumptions used for developing the *On the Road to 100% Renewables* analysis, which assesses the effects of U.S. Climate Alliance (USCA) states meeting 100 percent of their electricity consumption with renewable energy by 2035.

Regional Energy Deployment System (ReEDS)

We used the Regional Energy Deployment System (ReEDS) 2.0 version from the National Renewable Energy Laboratory (NREL) for this analysis. ReEDS is a capacity-planning model for the deployment of electric power-generation technologies in the contiguous United States through 2050 (NREL 2016a). ReEDS is designed to analyze in particular the impact of state and federal energy policies, such as clean energy and renewable energy standards, for reducing carbon emissions. ReEDS provides a detailed representation of electricity generation and transmission systems. It specifically addresses issues, such as transmission, resource supply and quality, variability, and reliability, related to renewable energy technologies (NREL 2020).

Based on project-specific data and estimates from recent studies, we made a few adjustments to NREL's assumptions on renewable and conventional energy technologies as described below. Our assumptions for each of the scenarios are also described below.

We also drew from NREL's dGen (Distributed Generation Market Demand) model (NREL 2016b). ReEDS does not endogenously simulate the uptake of distributed solar photovoltaic (PV) systems (those installed onsite by residential or commercial customers). Instead, ReEDS users develop projections for uptake of these systems as an exogenous input to the model based on dGen projections. dGen simulates customer adoption of distributed energy resources for residential, commercial, and industrial entities in the United States through 2050. It uses net-metering data from 2019/2020.

Overall Model Assumptions

- **Coal.** We updated coal retirements included in the model (see below). For power plants with carbon capture and sequestration (CCS), we used the cost and performance assumptions used by both NREL and the Energy Information Administration (EIA), and included the tax credits for CCS under a provision known as 45Q.

- **Natural gas.** For plants with CCS, we used NREL and EIA assumptions and included the 45Q tax credits.

- **Nuclear.** We used EIA's assumed costs for 2020 and assumed that some existing plants (those identified in EIA's Annual Energy Outlook for 2020, or AEO2020) [EIA n.d.]) will receive second 20-year license extensions, allowing them to operate for up to 80 years.

- **Onshore and offshore wind.** We used NREL's cost and performance projections from its mid-cost case, as described in the 2020 Annual Technology Baseline (ATB). These projections are based on NREL's estimate of values from its review of literature. For Massachusetts, we also limited land-based wind builds to 50 megawatts (MW) per year.

- **Utility-scale PV.** We used NREL's 2020 ATB cost and performance projections from its mid-cost case.

- **Distributed PV.** We used NREL's 2020 ATB cost and performance projections from its low renewable cost case.

- **Geothermal, biomass, hydro, and landfill gas.** We used NREL's mid-cost assumptions.

- **Storage technologies.** We used NREL's utility-scale battery analysis based on a literature review (Fu, Remo, and Margolis 2018).

- **Discount rate.** We used the default discount rate in ReEDS, 5 percent, for that portion of the modeling, and expressed all findings related to our analysis in 2020 dollars.

Model-Specific Assumptions

NO NEW POLICY SCENARIO

- **Electricity demand.** For the electricity load projection, which is exogenously defined for ReEDS modeling, we used the AEO2020 reference case demand.

- **Costs**. For distributed solar, we use the low-cost assumptions for solar and high-cost assumptions for natural gas in dGen to incorporate the highest penetration of distributed solar possible.

- **Policies and practices**. We included all state renewable electricity standards (RES), and state policies regarding trading of electricity and renewable energy credits (RECs).

- **Retirements.**

    - General: We included all power plant retirements announced by July 2021.

    - Massachusetts: We assumed retirement of the Mystic Generating Station in 2024.

    - Michigan: We assumed the retirement years shown in Table 1 for Michigan coal-fired units.

Table 1. Michigan Coal-Fired Unit Retirement Years

Plant Unit	Retirement Year for Model
Eckert 4, 5, 6	2020
River Rouge 3	2021
St. Clair 2, 3, 6, 7	2022
Trenton Channel 9	2022
Karn 1, 2	2023
Erickson 1	2025
J.H. Campbell 1, 2, 3	2025
TES Filer City Station	2025
Belle River 1	2029
Belle River 2	2030
Monroe 1, 2, 3, 4	2040

- Minnesota: We assumed the retirement years shown in Table 2 for Minnesota coal-fired units.

Table 2. Minnesota Coal-Fired Unit Retirement Years

Plant Unit	Retirement Year for Model
Hoot Lake 2, 3	2021
Sherco 2	2023
Sherco 1	2026
Hibbing 3, 5, 6	2027
Allen S. King	2028
Clay Boswell 3	2030
Sherco 3	2030
Clay Boswell 4	2035

100% RES SCENARIO

Same assumptions as in the No New Policy scenario except:

- **Policy.** We assumed that 24 U.S. Climate Alliance states (those in the contiguous United States) increase their state RES to 100% renewable by 2035. Current state RES policies are kept as is for eligible technologies and carveouts (hydropower, wind, solar, geothermal, and biopower) with the exception of waste-to-energy technologies, which are not allowed to qualify for the RES.

- **Electricity demand.** We increased load to reflect the "high electrification" scenario from NREL's Electrification Futures Study (Mai et al. 2018), which also incorporates load flexibility.

- **Costs.** We used NREL's 2020 ATB low renewable cost projection for renewable energy cost and performance assumptions.

ELECTRIFICATION WITHOUT DECARBONIZATION SCENARIO

Same assumptions as in the No New Policy scenario except:

- **Policy.** We incorporated the high electrification included in the 100% RES scenario.

RESTRICTED FOSSIL FUEL SCENARIO

100% RES scenario assumptions plus:

- **Policy.** We prohibited new combined-cycle gas plants in Massachusetts, Michigan, and Minnesota starting in 2025.

- **Retirement.** We assumed retirement of the Monroe coal plant in Michigan in 2030.

CLEAN ELECTRICITY STANDARD SCENARIO

100% RES scenario assumptions plus:

- **Policy.** We assumed each of the USCA states adopts a CES of 80 percent by 2030 and 100 percent by 2035. This is in line with the Biden Administration goals. Nuclear, CCS with capture rates of 90 percent or more, and all renewable energy sources are eligible.

ReEDS Reliability Requirements

ReEDS calculates the least-cost way to build and operate an electric system to meet demand while maintaining system adequacy and operational reliability. The primary constraint in ReEDS is to meet load in each model balancing area for each model time-slice.

ReEDS includes planning reserve requirements to ensure that adequate resources are available at all times, within an acceptable risk probability of failure. In other words, the electricity system is required to have enough firm capacity to meet peak demand, plus a reserve margin. This constraint is enforced for each season to accommodate the potential for the peak net load to shift seasons as renewable penetration increases. The planning reserve margin fractions applied in ReEDS are based on reserve margin requirements for North American Electric Reliability Corporation (NERC) reliability subregions (NERC 2010).

In addition to ensuring adequate capacity to satisfy long-term planning reserve requirements, ReEDS requires operational reliability; that is, the ability to continue operating the bulk-power system in the event of a sudden disturbance (NERC 2016). In practice, ancillary reserve requirements ensure there is sufficient flexibility from supply-side and demand-side technologies to rebalance fluctuations in generation and demand. ReEDS represents three type of operating reserve products: spinning, regulation, and flexibility reserves (Cole et al. 2018).

The ability of technologies to contribute to reserves is limited by the ramping requirement for a given reserve product, the plant ramp rate, and online capacity. Online capacity is approximated in ReEDS as the maximum generation from all time-slices within a modeled day. Reserves can be provided by generation and storage technologies that are turned on but not fully dispatched in a time-slice. In addition, demand-side interruptible load can also contribute to reserve requirements, if enabled in a scenario. Nuclear, solar, and wind are not allowed to contribute toward the supply of reserves. The cost for providing regulation reserves is represented in ReEDS using data from Hummon et al. (2013).

Greenlink Analytics – Economic Development, Public Health, and Energy Burden Impacts

UCS and partners collaborated with Greenlink Analytics to analyze the socioeconomic impacts if the USCA states shift to 100 percent renewable energy. UCS provided Greenlink with data regarding annual energy generation, new capacity, wholesale electricity prices, and emissions. Greenlink then used the data to estimate economic development, public health, and energy burden impacts for the Climate Alliance states, with a focus on Massachusetts, Michigan, and Minnesota for some pieces.

EPIDEMIOLOGICAL AND MONETIZATION ANALYSIS

Reduced illness and improved health outcomes. This project's epidemiological benefit analysis refers to reduced illness and health-related outcomes resulting from fewer emissions in 100% RES scenario compared with the No New Policy scenario. Those health outcomes included differences in mortality from all causes (low and high estimates), incidents of asthma (coughing, shortness of breath, or wheezing), and workdays lost as a result of poor air quality.

The health outcomes portion of the analysis draws on ReEDS projections for carbon dioxide (CO2), sulfur dioxide (SO2), and nitrogen oxides (NOx). For other pollutants—ammonia (NH3), particulate matter (PM2.5 and PM10), and volatile organic compounds (VOCs)—the analysis uses annual fossil fuel generation provided by UCS and emission values from EPA's Co-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping tool, which assigns to power plants across the country localized public health impacts from emissions (EPA 2020). These localized impacts are applied to the difference in generation between two scenarios, in this case the No New Policy and 100% RES scenarios.

Power plants within COBRA were assigned to balancing areas provided by UCS according to their fuel and technology type. Using 2016 as a base year, emission tonnage (SO2, NOx, NH3, PM2.5, PM10, and VOCs) from each COBRA plant were applied proportionally to UCS generation values to gain an emission rate for each pollutant and balancing area. Emission rates specific to technologies and fuel types were then applied each year onward for the No New Policy and 100% RES scenarios. The result uses the difference in emissions between each scenario. Final values represent the aggregate change in the number of cases in each health outcome for the entire United States.

Public health benefits. Along with reduced health related damages, Greenlink analyzed monetary benefits resulting from reduced emissions and improved public health for Massachusetts, Michigan, and Minnesota. The second version of the Air Pollution Emission Experiments and Policy Analysis (AP2) model was applied to marginal emission damages between each scenario. AP2 uses a Gaussian plume pollution dispersion model to estimate the monetary damages from pollution emitted as certain heights from within a specific county (NRC 2010). CO2, SO2, and NOx were provided by UCS. Greenlink Analytics confirmed fossil fuel generation provided from UCS with EPA's 2017 reported totals. Once validated, NH3, PM2.5, and VOCs were then derived using the UCS fossil fuel generation and the EPA's 2017 National Emissions Inventory. Emission rates specific to fuel and technology were then applied to generation values for each year across both scenarios. This approach is likely conservative, as it assumes plant emission rates will not degrade over time. Annual net-benefits between the two scenarios for the three states were calculated as a present value in 2020 dollars, discounted at 3 percent.

Because ReEDS calculates and presents its results in two-year increments (shown for even years), both health analyses used an average of the prior- and subsequent-year values for emissions impacts to calculate values for the intervening (odd) years.

MACROECONOMIC ANALYSIS

Shifting toward a clean and renewable energy future may cause shifts in the economy. As investments in renewable technologies increase, electricity supplied from fossil fuels decreases, thereby shifting demand and potentially the employment situation in the fossil fuel industry.

This analysis measures shifts in employment, income, and GDP from the traditional fossil-fuel-dependent energy sector to an advanced clean energy industry using IMPLAN, a widely utilized regional economic impact model. Custom industrial aggregation multipliers were created through IMPLAN based on previous industry studies and reports (Brown, Soni, and Li 2020).

Capital cost data for each technology provided by EIA's Annual Technology Baseline were assigned to new capacity forecasted in the ReEDS modeling. A product of new capacity investments (discounted at 3 percent) and job multipliers from IMPLAN resulted in a net-analysis of employment, labor income, and GDP for each focus state.

Jobs are expressed as "job-years"—a full-time position held by one person for one year. Some research converts job-years to jobs by assuming that a job is maintained by an individual for an average of four years. This is based on average job tenure data from the US Bureau of Labor Statistics (BLS 2020).

ENERGY BURDEN ESTIMATES

Energy burden is the proportion of household income spent on electricity, natural gas, and/or water bills. While all households experience a unique utility burden, recent conventions have established that a household is typically considered "in burden" if its energy bills (gas and electric) exceed 6 percent, and in "energy poverty" if its energy bills exceed 10 percent of annual income (Drehobl and Ross 2016). Proximate causes of excessive utility burdens can be attributed to a number of issues such as poor insulation, outdated appliances, or excessive utility use (Brown et al., forthcoming). There are also structural and systemic causes that cause low-income and communities of color to face higher barriers to accessing opportunities to alleviate high utility burdens (Ross, Drehobl, and Stickles 2018; Jessel, Sawyer, and Hernández, 2019; Berry, Hronis, and Woodward 2018), including low wages, the wealth gap, and other financing barriers (Jargowsky 2015), historical governmental policies such as redlining (Rothstein 2017), housing quality, and even higher costs for energy efficient equipment from neighborhood retailers (Bednar, Reames, and Keoleian 2017).

Greenlink Analytics derived energy consumption and burden calculations from data drawn from the American Community Survey. These data points are processed to calculate the energy burdens at a census-tract level, and then aggregated to the county level for each state.

The electrification scenario analyzed by UCS considered the expected increase of electricity demand and the decrease of natural gas demand. Annual changes in electricity demand provided by UCS were applied first to 2020 energy consumption values and each subsequent year after. Changes in natural gas were drawn from NREL's Electrification Futures Study (Mai et al. 2018).

Energy burden calculations were disaggregated to determine electricity and natural gas consumption in kilowatt-hours and million British thermal units and were applied to energy costs calculated from forecasted wholesale generation costs across the three focus states from the ReEDS modeling. Wholesale costs were aggregated with region specific transmission and distribution ratios from EIA's National Energy Modeling System to generate a residential retail rate forecast. While the NREL electrification data used in the ReEDS modeling assumed electrification beginning in 2018, the energy burden calculations assume cost effects begin after 2020.

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