Accelerating toward a Clean Energy Economy

Capitalizing on the Clean Power Plan and Federal Renewable Energy Tax Credits

Technical Appendix: Methods and Assumptions

Union of Concerned Scientists

This document describes the methodology and assumptions that the Union of Concerned Scientists (UCS) used for its analysis, "Accelerating toward a Clean Energy Economy: Capitalizing on the Clean Power Plan and Federal Renewable Energy Tax Credits".

The UCS employed the National Renewable Energy Laboratory's (NREL's) Regional Energy Deployment System (ReEDS)—a capacity-planning model for the deployment of electric power–generation technologies in the contiguous United States through 2050—to analyze the technical and economic feasibility of the US Environmental Protection Agency's (EPA's) Clean Power Plan in six states and the country as a whole.

ReEDS is designed to analyze in particular the impacts 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 2015).

The UCS used the 2015.2 version of ReEDS for its analysis (see Cole et al. 2015 for NREL's description of this version). 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 in more detail in the section, "Overall Model Assumptions," just below. Our assumptions for the policies being tested in our analysis are described in a section, "Policy Assumptions for Scenarios," that appears later in this document.

Overall Model Assumptions

Cost and performance. The cost and performance assumptions for electricity-generating technologies that the UCS made in using ReEDS are shown in Tables A-3 through A-6 below. We compare our key assumptions to the Energy Information Administration's (EIA's) Annual Energy Outlook (AEO) 2015 assumptions (EIA 2015), given that the AEO assumptions are widely used for energy policy analysis and provide a well-recognized industry benchmark.

We made several changes to NREL's capital-cost assumptions. NREL uses the EIA's AEO 2015 cost assumptions for conventional plants; our revisions are based on project-specific data for recently installed and proposed projects and on mid-range estimates from recent studies. We did not make any changes to the assumptions for operating and maintenance (O&M) costs and heat rates.

NREL provides a set of projections, which users can easily select, regarding cost and performance assumptions on renewable energy technologies. Our choices of these projections were consistent with the corresponding assumptions underlying the DOE Wind Vision report (DOE 2015) and the SunShot Vision report (DOE 2012).

The main changes we made were in the following areas:

- **Learning**. Unlike NREL, we do not use the EIA's "learning" assumptions pertaining to the lowered capital costs of different technologies over time as the US penetration of these technologies increases (EIA 2015). The EIA's approach does not adequately capture growth in international markets, and potential technology improvements from research and development, which are important drivers of cost reductions. Instead, we assume that costs for mature technologies stay fixed over time and that costs for emerging technologies decline over time. We assume that costs for emerging technologies decline on a trajectory that is independent of technology penetration.

- **Coal**. For new integrated gasification and combined cycle (IGCC) and supercritical pulverized-coal plants, we use NREL's assumptions, which are based on the EIA's higher costs for a single-unit plant (600–650 MW), as opposed to dual-unit plants (1200–1300 MW). For plants with carbon capture and sequestration (CCS), we use the same assumptions as NREL and the EIA do.

- **Natural Gas**. For new plants, we use NREL's assumptions, which are based on the average of the EIA's assumptions for conventional and advanced plants in 2015. We do not include the EIA's projected cost reductions due to learning because we assume that these are mature technologies. For plants with CCS, we assume: a) higher initial capital costs than the EIA, based on mid-range estimates from recent studies (EIA 2015; Lazard 2013; Black & Veatch 2012; NREL 2012); b) no cost reductions through 2020, as very few plants will be operating by then; and c) the EIA's projected cost reductions by 2040 will be achieved by 2050 (on a percentage basis).

- **Nuclear**. We use the EIA's assumed costs for 2015, but we did not include its projected capital cost reductions, given the historical and recent experiences of cost increases in the United States. We also assume that existing plants will receive a 20-year license extension, allowing them to operate for 60 years, and that they will then be retired because of safety and economic issues. To date, no existing plant has received or applied for an operating license extension beyond 60 years.

- **Onshore and Offshore Wind**. Current cost and performance assumptions are benchmarked to data from actual onshore US wind projects, the global offshore wind industry, and recent developmental activity off the Atlantic Coast of the United States. (Wiser and Bolinger 2015; Tegen et al. 2012). We use NREL's cost and performance projections from its median cost-reduction case, as described in the DOE Wind Vision document (DOE 2015). These cost and performance projections are based on NREL's estimate of median values from their review of recent literature.

- **Utility-scale solar photovoltaics (PV)**. Current costs are based on data from actual projects (Bolinger and Seel 2015; SEIA/GTM 2015). We use NREL's cost and performance projections from the ReEDS case with 62.5 percent cost reductions (from 2010 levels) by 2020 and 75 percent cost reductions by 2030, based on scenarios developed for the DOE Sunshot Vision Study. (DOE 2012).

- **Distributed solar photovoltaics (PV).** ReEDS does not endogenously simulate the uptake of distributed PV systems (those typically installed on site by residential or commercial customers). Instead, users must select the appropriate projections for uptake of these systems as an exogenous input to the model based on projections from NREL's Solar DS model (Denholm, Margolis, and Drury 2009). For our reference case, we use NREL projections based on the DOE Sunshot Vision Study's 62.5 percent cost reduction (from 2010 levels) by 2020 case with no further cost decrease after 2020. For policy cases that support more distributed solar, we use NREL projections from the Sunshot 62.5 percent cost reduction by 2020 case, with costs declining to reach the Sunshot 75 percent cost reduction case by 2040 (DOE 2012).

- **Solar CSP**. We assume that concentrating solar plants (CSP) will include six hours of storage and exhibit the capital and O&M cost projections of the DOE Sunshot Study's "62.5 percent by 2020 and 75 percent by 2030" cost-reduction scenarios (DOE 2012).

- **Biomass**. We use the EIA's initial capital costs for new fluidized-bed combustion plants and for biomass cofiring with coal, but we do not include the EIA's projected cost reductions due to learning because we assume these are mature technologies. We also use a slightly different biomass supply curve from those of the EIA and NREL; based on a UCS analysis of data from the DOE's Updated Billion Ton study, which included additional sustainability criteria, we project a potential biomass supply of 680 million tons per year by 2030 (UCS 2012; ORNL 2011). Further, we limit the coal capacity that can be retrofitted for cofiring biomass to 10 percent of a plant's capacity—not the 15 percent maximum used in NREL assumptions.

- **Geothermal, landfill gas, and storage technologies**. We didn't make any changes to NREL's assumptions for these technologies.

- **Hydro.** In order to reflect the long lead times for planning, permitting, and building large hydro dams, we restricted the construction of such facilities until after 2019. NREL's assumptions in ReEDS were based on a 2006 report, and more recent research indicates that future costs will likely be higher than those earlier projected. Based on the *2014 Hydropower Market Report* (Cohen 2015; ORNL 2015), we increased the costs of non-powered dams to be twice those assumed by NREL. We didn't make any other changes to NREL's assumptions for the hydro supply curves, which are site-specific.

Electricity sales and energy-efficiency projections. ReEDS does not endogenously model electricity sales or efficiency; instead, users provide assumptions of future use. As a default, electricity sales are taken from the EIA's AEO 2015 projections. ReEDS starts with the 2010 electricity sales for each state, then projects future electricity sales using the growth rate for the appropriate census region from the AEO 2015 reference case. The UCS adjusts these projections to account for reductions in load growth resulting from currently viable state energy efficiency resource standards (EERS) that are not included in the AEO 2015. Our adjustments follow the approach used by the US Environmental Protection Agency in *National Impacts of State Energy Efficiency and Renewable Energy Policies* (EPA 2015a). We assume full compliance with EERS policies that had been established as of end of October 2015.

Accounting for recent or planned changes to generating resource or transmission availability. We reviewed ReEDS assumptions for expected changes in power plant capacity and transmission lines in the near term and compared those assumptions with our own, which we based on SNL Energy (2015) data and industry reports/projections with respect to real-world conditions. As a result, our updates to ReEDS included:

- Accounting for prescribed builds of newly constructed or under-construction generating resources (including natural gas, nuclear, coal, wind, and utility-scale solar facilities) using a combination of SNL and industry association data published as of May 7, 2015, and including plants expected to be on line by 2018
- Accounting for recent or recently announced coal-plant retirements, based on data published as of July 2015
- Revising assumptions for transmission projects, based on data published as of August 2015
- Adding California's storage mandate.

Calculation of energy-efficiency costs and savings. In an analysis separate from our work with ReEDS, we estimate the costs and electricity savings resulting from the implementation of state EERSs (see the Policy Assumptions for Scenarios section below). We calculate the electricity savings by adjusting the EIA's electricity-sales projection to account for the EERS. We also estimate the investment and program costs of achieving these savings, based on recent studies by the American Council for Energy Efficiency Economy (Hayes et al. 2014; Molina 2014). We assume average first-year costs of $0.62 per kWh (based on Hayes et al. 2014). We split these costs between utilities (55 percent) and consumers (45 percent), with 20 percent of the utility costs allocated to administering the programs and 80 percent allocated to investment in more efficient technologies and measures. We also assume that 20 percent of utility and consumer investment costs and 100 percent of utility administration costs are financed over an average measure lifetime of 11 years. We then add the total annual costs of efficiency investments to the electricity-sector compliance costs. The utility energy-efficiency costs are also included in the consumer electricity bills specified in the policy briefs.

Calculation of the monetary value of carbon dioxide (CO_2) reduction benefits. To determine the monetary value of CO_2 reductions, we use the US government's estimates of the "social cost of carbon (SCC)"—an estimate of the damages, expressed in dollars, resulting from the addition of a metric ton of CO_2 to the atmosphere in a given year. We multiply the tons of CO_2 reduced in our scenarios by the SCC to derive the CO_2 reduction benefits, or avoided damages.

We use the updated SCC values reported in the EPA's *Regulatory Impact Assessment for the CPP Final Rule* (EPA 2015b), shown here in Table A-1.

TABLE A-1. **Social Costs of Carbon Values**

Year	Social Cost of Carbon (2015$ per ton of CO_2)[1]
2015	37
2020	43
2025	47
2030	51

[1] Assuming a 3 percent discount rate.

SOURCE: EPA 2015, TABLE 4-2.

Calculation of the monetary value of sulfur dioxide (SO_2) and nitrogen oxides (NOx) reduction benefits. To value SO_2 and NO_x emissions reductions, we again use estimates from the EPA *Regulatory Impact Assessment for the CPP Final Rule* of the dollar value of the health benefits per ton of SO_2 and NO_x reduced by different industrial sectors, including the electricity sector (EPA 2015b).

In particular, for the 2020 emissions reductions generated in our models, we use the values in the EPA's Table 4-7. These values are expressed in 2011$ using a 7 percent discount rate, so we convert them to 2015$ so as to be consistent with other dollar values in our analysis. For 2025 and 2030, we use the values in Tables 4-8 and 4-9, again converted to 2015$.

Policy Assumptions for Scenarios

For this analysis, we compared a number of cases: the Reference Case, the Clean Energy Transition Case, and the Clean Power Plan Only Case. For each case we ran the ReEDS model for the contiguous United States, with a consistent set of assumptions across all states.

The Reference Case includes:

- The electricity demand, natural gas prices, and coal prices from the reference case of the AEO 2015
- State and federal policies in place at the end of 2014 with the following additions
    - State energy-efficiency standards through October 2015, as calculated by the UCS (based on data from state utilities and from the Database of State Incentives for Renewables & Efficiency) using a methodology developed by the EPA for state analyses
    - State renewable energy standards, as established through October 2015 based on information calculated by Lawrence Berkeley National Laboratory (LBNL) or NREL as part of ReEDs assumptions
- The model revisions described in the previous section.

The Reference Case assumptions do not require state compliance with the Clean Power Plan (CPP).

The Clean Energy Transition Case includes:

- Compliance with the CPP mass-based approach, including the new source complement, which takes both new and existing fossil-fired power plants into account. The carbon caps used in this run are from the EPA's Clean Power Plan "Final Goals for States and Tribes" spreadsheet (EPA 2015c). The CPP offers a number of options for each state to develop an implementation plan best suited to its own electricity mix, resource availability, and policy objectives. For this case, we apply one set of compliance options for all states.

- All states having the option to meet their CPP targets by trading carbon allowances with any other state.
- The assumption that all states, as part of their compliance strategy, invest in energy efficiency at a level that achieves a reduction in electricity sales of at least 1 percent per year from 2022 to 2030. This energy-efficiency assumption serves as a proxy for state or utility action; it is needed because the ReEDS model does not include choices on energy efficiency. States with stronger mandatory EERS policies are assumed to continue meeting their respective targets.
- The CPP includes a Clean Energy Incentive Program (CEIP), which offers states incentives for early development of renewable energy and energy efficiency. A portion of the generation that meets a state's renewable energy and energy efficiency requirements may qualify for the CEIP, but our analysis does not attempt to estimate this portion.
- Extensions of the federal production tax credit (PTC) and investment tax credit (ITC) that were part of the *Consolidated Appropriations Act of 2016*, announced in December 2015. The act extended the PTC to December 31, 2019 for wind facilities and to December 31, 2016 for other facilities such as geothermal, landfill gas and hydro. For the PTC extension for wind, the tax credit value ramps down for facilities starting construction in 2017 and later (DSIRE 2015a). The act extended the timeframe of the ITC's full tax credit (30 percent of development costs) for utility-scale and commercial solar from 2016 to 2019; the credit value then decline to 10 percent of development costs in 2022 and subsequent years (DSIRE 2015b). Facilities qualify for the PTC and ITC if they "commenced construction" prior to the expiration date of the tax credit for wind, utility-scale solar, commercial solar plants, geothermal, biomass and qualifying hydro-power. Residential solar photovoltaics projects must be placed-in-service prior to the expiration date. Since ReEDs does not explicitly capture the time-period for construction, we simulated the commenced construction provision by applying a 2-year lag for the PTC for wind projects and a 1-year lag for solar projects.

The Clean Power Plan Only case includes

- The same assumptions as the Clean Energy Transition case except it excludes the extensions to the PTC and ITC. Instead it assumes the PTC and ITC that were in place as of November 2015.

Calculation of the monetary value of sulfur dioxide (SO_2) and nitrogen oxides (NOx) reduction benefits. To value SO_2 and NO_x emissions reductions, we also use estimates from the EPA Regulatory Impact Assessment for the CPP Final Rule of the dollar value of the health benefits per ton of SO_2 and NO_x reduced by different sectors, including the electricity sector (EPA 2015).

In particular, for the 2020 emissions reductions generated in our models, we use the values in Table 4-7: \$30,000 per ton of SO2 and \$2,800 per ton of NO_x. These values are in 2011\$ using a 7-percent discount rate for the East region. We convert them to 2015\$ to be consistent with other dollar values in our analysis. For 2025 and 2030, we use the values in Tables 4-8 and 4-9: \$33,000 per ton of SO_2 and \$3,000 per ton of NO_x in 2025 and \$36,000 per ton of SO_2 and \$3,200 per ton of NO_x in 2030. These values are also in 2011\$ using a 7-percent discount rate. Again, we convert them to 2015\$ for consistency.

TABLE A-2. **Comparison of Assumed Overnight Capital Costs for Electric Generation Technologies (2015$/kW)**

	UCS 2015					EIA AEO 2015			
Technology	**2010**	**2020**	**2030**	**2040**	**2050**	**2010**	**2020**	**2030**	**2040**
Natural Gas CC	1,015	988	988	988	988	1,015	970	935	903
Natural Gas-CC-CCS	N/A	3,087	2,798	2,582	2,472	N/A	2,002	1,863	1,733
Natural Gas CT	862	841	841	841	841	862	821	788	759
Coal-Supercritical PC	3,069	2,995	2,995	2,995	2,995	3,069	2,965	2,899	2,833
Coal-IGCC	3,958	3,816	3,816	3,816	3,816	3,958	3,708	3,539	3,382
Coal-PC-CCS	6,615	6,322	5,941	5,573	5,573	6,615	6,322	5,941	5,573
Nuclear	5,003	5,420	5,420	5,420	5,420	5,003	4,935	4,575	4,283
Hydro*									
Biomass, dedicated	4,302	3,743	3,743	3,743	3,743	4,302	3,656	3,515	3,380
Biomass, cofired with coal**	447	447	447	447	447	294	294	294	294
Solar PV-Utility	4,464	1,647	1,098	1,098	1,098	5,012	3,119	2,826	2,586
Solar PV-Residential	6,697	2,471	2,471	2,471	2,471	10,316	4,880	3,990	3,762
Solar PV-Commercial	5,581	2,059	2,059	2,059	2,059	7,358	4,148	3,268	3,078
Solar CSP-With 6 hour Storage	6,965	4,183	3,164	3,164	3,164	AEO 2015 does not include CSP with storage			
Wind-Onshore***	1,720	1,615	1,560	1,554	1,554	2,410	2,238	2,100	1,940
Wind-Shallow Offshore	5,453	4,652	3,957	3,850	3,729	AEO 2015 does not include shallow offshore wind			
Wind-Deep Offshore	6,021	5,135	4,366	4,248	4,113	6,321	6,119	5,781	5,444
Landfill gas	8,945	8,408	8,220	8,034	8,034	8,945	8,408	8,220	8,034

Abbreviations are as follows: combined-cycle (CC), combustion turbine (CT), carbon capture and storage (CCS), pulverized coal (PC), integrated gasification and combined-cycle (IGCC), photovoltaic (PV), and concentrating solar plants (CSP)

* Hydro capital costs are too detailed to show in this table; ReEDS uses supply curves with capital cost variation by potential resource capacity.

** The cost for biomass cofiring is per kW of plant capacity, including coal capacity.

*** ReEDS uses "techno-resource groups" instead of wind power classes to represent wind cost and performance parameters. This is an approximate comparison of wind capital costs technologies for Class 6 (onshore) and Cass 7 (offshore—deep) resources.

TABLE A-3. **Operation and Maintenance (O&M) and Heat Rate Assumptions**

Technology	Fixed O&M (2015$/ kW-yr)	Variable O&M (2015$/MWh)	Heat Rate (Btu/kWh)	
			2010	2030
Natural Gas-CC	14.6	3.5	6,624	6,567
Natural Gas-CC-CCS	32.6	7.0	7,504	7,493
Natural Gas CT	7.4	13.3	9,756	9,500
Coal-Supercritical PC	32.5	1.7	8,760	8,740
Coal-IGCC	52.8	7.4	7,867	7,450
Coal-PC-CCS	7.5	8.7	9,105	8,307
Nuclear	95.8	2.2	10,479	10,479
Biomass	108.4	5.4	13,500	13,500
Solar PV-utility	22.3	0.0	n/a	n/a
Wind-Onshore	50.75	0	n/a	n/a
Wind-Shallow Offshore	132	0	n/a	n/a

Abbreviations are as follows: combined-cycle (CC), combustion turbine (CT), carbon capture and storage (CCS), pulverized coal (PC), integrated gasification and combined-cycle (IGCC) and photovoltaic (PV).

TABLE A-4. **Comparison of Solar Capacity Factors**

Technology	UCS2015
Solar PV-utility	17-28%
Solar CSP-With 6-hour Storage	28-38%

Table A-5. **Comparison of Wind Capacity Factors**

	UCS 2015					EIA AEO 2015			
Technology	**2014**	**2020**	**2030**	**2040**	**2050**	**2014**	**2020**	**2030**	**2040**
Wind-Onshore Class 3	32%	35%	37%	38%	40%	28%	29%	31%	31%
Wind-Onshore Class 4	38%	41%	44%	45.1%	47%	32%	33%	34%	34%
Wind-Onshore Class 5	44%	47%	49%	51%	53%	36%	37%	38%	38%
Wind-Onshore Class 6	47%	49%	52%	53%	55%	40%	41%	30%	42%
Wind-Onshore Class 7	51%	54%	56%	58%	60%	n/a	n/a	n/a	n/a
Wind-Offshore Class 4	43%	44%	47%	48%	48%	32%	33%	35%	35%
Wind-Offshore Class 5	47%	48%	51%	52%	52%	36%	37%	39%	39%
Wind-Offshore Class 6	49%	50%	54%	54%	55%	40%	41%	43%	43%
Wind-Offshore Class 7	42%	43%	46%	46%	47%	44%	44%	45%	45%

* ReEDS uses "techno-resource groups" instead of wind power classes to represent wind cost and performance parameters. This table provides an approximate comparison.

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