METHODOLOGY

Levelized Cost of Electricity

NRDC has designed the Levelized Cost tool to illustrate the changing underlying economics of the power sector, and specifically the economics of building new power projects. .

This user-friendly web-based tool compares the cost of building and operating a new power plant for five different technologies: coal, nuclear, natural gas (combined cycle), wind, and solar (utility-scale). A user can select a state to compare these technologies and explore the impacts of different assumptions on the competitiveness of each technology.

What Is the Levelized Cost of Electricity?

In order to illustrate costs in a way that allows comparisons among different technologies, the tool calculates what is known as the levelized cost of electricity (LCOE), which represents the total costs of financing, building, and operating a power plant, divided by the total amount of electricity generated by the plant over its economic lifetime, expressed as dollars per megawatt-hour ($/MWh).

$$LCOE\left(\frac{\$}{MWh}\right) = \frac{\sum Annualized\ Capital\ Costs + Operating\ Costs + Fuel\ Costs}{Total\ Generation}$$

The LCOE does not account for the different operating characteristics of power plants. This measure also does not include additional costs such as transmission, permitting, or environmental control costs, nor does it take into account the nonenergy value streams that power plants might provide (e.g., capacity, ancillary services, environmental benefits, etc.).[1]

Each data point in the LCOE chart represents the levelized cost of a project built in a certain year, over the course of its 20-year lifetime.[2] Therefore, a policy implemented during the project's lifetime will impact the project economics; e.g., a carbon price implemented in 2022 will raise the LCOE of a natural gas project built in 2018.

The NRDC LCOE tool calculates the cost of new electricity generation technologies using a methodology similar to those in other levelized cost analyses, such as the ones developed by Lazard, the National Renewable Energy Laboratory (NREL), and Black & Veatch.[3,4,5] The tool calculates the costs of new projects for five power generation technologies: coal (supercritical), natural gas combined cycle (NGCC), nuclear, onshore wind, and solar PV (with single-axis tracking). The user can select key assumptions for each technology, detailed below, in the state under consideration.

The tool relies primarily on fuel price projections from the Energy Information Administration's (EIA's) *Annual Energy Outlook 2019* (AEO 2019) and capital cost projections from the NREL's *Annual Technology Baseline for 2018* (ATB 2018).[6,7] NRDC plans to update the tool regularly with the latest available projections.

User Inputs

The calculator is structured such that a user can explore the impacts of several key technological, economic, and policy factors on the relative competitiveness of each generation technology. Specifically, the user can adjust the capital cost projections for renewable technologies, fuel price projections for natural gas power plants, the expected capacity factors for all technologies, and the impacts of federal tax credits and carbon policies.

The input selections that are in place upon opening the tool are referred to in the following sections as the "default" inputs.

FOSSIL FUEL PRICES

The tool relies on fuel price projections for coal and natural gas from EIA's AEO 2019. The user can select among five sets of natural gas price projections from AEO 2019:

- **AEO REFERENCE CASE**
- **AEO HIGH OIL PRICE CASE:** Assumes the high price of oil increases demand for alternative liquid fuels, such as those produced from natural gas. The assumed economic growth ultimately leads to higher demand and slightly higher gas prices.
- **AEO LOW OIL PRICE CASE:** Assumes the low price of oil is caused by slow economic growth. The associated decrease in demand results in slightly lower gas prices.
- **AEO HIGH OIL AND GAS RESOURCE AND TECHNOLOGY CASE:** Assumes higher resource availability and lower technology/drilling costs; results in significantly lower natural gas prices.
- **AEO LOW OIL AND GAS RESOURCE AND TECHNOLOGY CASE:** Assumes lower resource availability and higher technology/drilling costs; results in significantly higher natural gas prices.

EIA provides delivered natural gas price projections in each census region for each scenario.[8] The tool applies the delivered natural gas price projections from the associated census region to each state. EIA does not provide delivered coal price projections on a regional or state basis, so the tool relies on EIA's projections for the national average delivered price to the power sector.

Delivered Natural Gas Prices in AEO 2019 *(national average)*

	2020	2025	2030
Reference Case	3.20	3.78	3.96
High Oil Price	3.24	3.57	4.10
Low Oil Price	3.17	3.72	3.87
High Oil and Gas Resource and Technology	2.93	3.19	3.27
Low Oil and Gas Resource and Technology	3.71	4.78	5.60

All prices are in $2015/MMBtu, on a delivered basis.

RENEWABLES COSTS

The tool relies on capital cost projections for each technology from NREL's ATB 2018 report. The user can select among three sets of capital cost projections for wind and solar technologies from ATB 2018:

- **MID-CASE:** Technology costs fall and performance improves through continued advancements and innovation; progress characterized as "likely"; no major breakthrough needed.
- **LOW:** Technology costs fall and performance improves consistent with R&D breakthrough.
- **HIGH:** Technology costs and performance remain constant at current (2017) levels.

For each state, the capital costs projections are scaled by regional cost multipliers derived from historical installation data from the Lawrence Berkeley National Laboratory.[9,10] For example, LBNL found that utility-scale solar PV installation costs in the Northwest were 16 percent higher than the national average installation cost in 2016; that scaling factor is applied to NREL's national cost projections to arrive at a regional cost projection.

Renewables Cost Assumptions

(national average)

	2020	2025	2030
Onshore Wind ($/kW)			
Mid-case	1,455	1,389	1,337
Low	1,340	1,038	734
High	1,578	1,578	1,578
Solar PV ($/kWdc)			
Mid-case	942	852	802
Low	832	707	594
High	1,124	1,144	1,144

All values are in $2015.

CAPACITY FACTORS

The user can adjust each technology's average capacity factor (averaged over the course of its lifetime).

For coal, NGCC, and nuclear projects, the default capacity factor is 75 percent, 60 percent, and 85 percent, respectively, based on the historical operations of each technology.[11] The user can also input their own estimated capacity factor.

For solar and wind projects, the default capacity factor is the average capacity factor of projects that have been installed in the state since 2012, if there have been installations in the state corrected for single-axis tracking technologies.[12] Capacity factor data for these projects are taken from reported values for year-end 2017 in EPA Form 923.[13] For projects that entered service after Q1 2017, the Form 923 dataset reported a limited amount of monthly operating data, making it difficult both to account for the impacts of seasonality on actual 2017 performance and to accurately estimate annu-al performance. Where this was the case, projected unit-specific future annual capacity factors from S&P's PowerForecast model were used. The determination of average and maximum solar and wind capacity factors for each state included wind projects above 5 MW and solar projects above 2.5 MW.

The user also has the option to choose the highest capacity factor of any installed project to date. If there have not been any projects built in the state yet, then the default is the average mid-case capacity factor used in NREL's *Annual Technology Baseline,* or the user can input their own estimated capacity factor. Displayed CFs for solar refer to AC/AC capacity factors, consistent with other technologies. The calculations divide this value by 1.3, the inverter load ratio, in order to obtain the AC/DC CF.

POLICY INPUTS

The user can explore the impacts of different policies on project economics. The default selection includes the Production Tax Credit for eligible wind projects (built before 2020) and the Investment Tax Credit for eligible solar projects (built before 2023).[14] The user can examine the costs of wind and solar projects without the tax credits, or explore the cost trajectories if the tax credits were to be extended indefinitely. The tax credits also have an impact on the financing costs, as detailed below.

The user can also examine the impacts that a carbon policy would have on the costs of coal and natural gas projects.[15] The user can set the starting year of the policy, the expected price level in the start year, and the rate of escalation. The user-selected carbon price level is inclusive of the carbon price in states where a carbon market is currently active.

Renewable Energy Tax Credits

	2016	2017	2018	2019	2020	2021	2022+
Production Tax Credit ($/MWh)	24	19.2	14.4	9.6	0	0	0
Investment Tax Credit (%)	30%	30%	30%	30%	26%	22%	10%

Other Assumptions

CAPITAL COSTS

All capital costs projections are derived from NREL's ATB 2018 report. For coal, natural gas combined cycle, and nuclear projects, the calculator relies on NREL's mid-case projections.[16] For wind and solar projects, the user has the ability to choose among the mid-case, high, and low projections, as discussed above.

For coal, natural gas, and nuclear projects, regional scaling factors from AEO 2016 are applied to NREL's capital cost projections in order to develop regional cost projections.[17]

OPERATING AND MAINTENANCE COSTS

All operating and maintenance (O&M) cost projections for all technologies rely on the mid-case scenario in NREL's ATB 2018 report. O&M costs for all technologies are projected to escalate at a rate of 2.25 percent annually.

FINANCIAL ASSUMPTIONS

The financial assumptions used in the calculator are consistent with the assumptions used by Lazard in its annual *Levelized Cost of Energy Analysis*. Specifically, the calculator relies on the following inputs, which are held constant for each technology except where otherwise noted.

Financial Assumptions

Economic life	20 years
Tax rate (combined)	40%
Debt financing	60%
Cost of debt	8%
Equity financing	40%
Cost of equity	12%
Depreciation	
• Wind and Solar	5-year MACRS
• Coal, NGCC, Nuclear	20-year MACRS

The financing structure will often vary if wind or solar projects are taking advantage of the federal tax credits, in which case developers may need to rely on tax equity. To account for these differences, this tool adopts Lazard's assumptions that solar projects will rely on 30 percent debt at an 8 percent interest rate, 50 percent tax equity at a 10 percent cost, and 20 percent common equity at a 12 percent cost. Wind projects are expected to rely on 15 percent debt at an 8 percent interest rate, 70 percent tax equity at a 10 percent cost, and 15 percent common equity at a 12 percent cost.

Calculation Methodology

The Levelized Cost of Energy is determined by calculating the lowest average annual price a project would need to receive to earn an internal rate of return (IRR) equal to its cost of equity. This is solved through the following equations:

$$Capex = OCC * Capacity * RegionalMltp\ [* (1 - ITC)]$$

$$NetGeneration_t = Capacity * CapFactor_t * 8760$$

$$Revenues_t = PowerPrice_t * NetGeneration_t$$

$$Costs_0 = EquityRatio * Capex$$

$$Costs_t = Fuel_t + O\&M_t\ [+Carbon_t]$$

$$Tax_t = TaxRate * (Revenues_t - Costs_t - Depreciation_t - InterestPmt_t)\ [-PTC * NetGeneration * t]$$

$$CashFlow_0 = Costs_0$$

$$CashFlow_t = Revenues_t - Costs_t - InterestPmt_t - PrinciplePmt_t - Tax_t$$

$$NPV(cash\ flow) = \sum_{(t=0)}^{(economic\ life)} CashFlow_t * \left(\frac{1}{R_{equity}}\right)^t$$

THE INTEREST AND PRINCIPAL PAYMENTS IN THE ABOVE FORMULATION ARE SOLVED FOR USING THE STANDARD ANNUITY CONSTRUCT:

$$MonthlyPmt_t = \frac{Debt * i}{(1 - (1 + i)^{-n}}$$

$$InterestPmt_t = i * OutstandingDebt_t$$

$$PrinciplePmt_t = MonthlyPmt_t - InterestPmt_t$$

WHERE:

$$i = cost\ of\ debt$$

$$n = EconLife + 1 = Debt\ term$$

$$Debt = Capex * DebtShare$$

$$OutstandingDebt_{t=1} = Debt$$

$$OutstandingDebt_t = OutstandingDebt_{t-1} - PrincipalPmt_{t-1}$$

[1] For a more detailed discussion of what the LCOE does (and does not) include, see: Energy Information Administration, Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2018, March 2018, https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf.

[2] Based on IRS's "Commence Construction Guidance" issued in June 2018, tax credits corresponding to a given year can be applied if the construction begins by the end of that calendar year. For a more detailed discussion, see: https://www.seia.org/initiatives/commence-construction-guidance

[3] Lazard, Levelized Cost of Energy Analysis, version 11.0, November 2017, https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf.

[4] Black and Veatch, Black and Veatch's (RETI's) Cost of Generation Calculator, May 2011, www.energy.ca.gov/reti/documents/2011-04-11_RETI_COG_Updated.xls

[5] National Renewable Energy Laboratory, LCOE Calculator, https://www.nrel.gov/analysis/tech-lcoe.html

[6] Energy Information Administration, Annual Energy Outlook 2019, January 2019, https://www.eia.gov/outlooks/aeo/.

[7] National Renewable Energy Laboratory, Annual Technology Baseline, July 2018, https://atb.nrel.gov/electricity/2018/approach-methodology.html.

[8] For a mapping of U.S. census regions, see: Energy Information Administration, Annual Energy Outlook 2016, Appendix F, "Regional Maps," Figure F1, https://www.eia.gov/outlooks/aeo/pdf/f1.pdf.

[9] Ryan Wiser et al., 2017 Wind Technologies Market Report, Lawrence Berkeley National Laboratory, August 2018, https://emp.lbl.gov/wind-technologies-market-report

[10] Mark Bolinger et al., Utility-Scale Solar 2018, Lawrence Berkeley National Laboratory, September 2018, https://emp.lbl.gov/sites/default/files/lbnl_utility_scale_solar_2018_edition_report.pdf.

[11] The operating characteristics of fossil plants have changed substantially over the past several years, driven by the same market and regulatory dynamics that have bolstered clean energy technologies. Since 2014, the average capacity factor of utility-scale coal plants has declined to 53.5 percent from 61.1 percent. In the same period, the average capacity factor of natural gas combined-cycle plants has increased from 48.3 percent to 54.8 percent (peaking at 55.9 percent in 2015). See Energy Information Administration, Electric Power Monthly, https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_a.

[12] This includes all facilities operating or under construction in a state as of July 2018. Projects were derived from S&P Global Market Intelligence, including estimated capacity factors and performance. For projects installed before April 2017, capacity factors were taken from EIA Form 923 data and mainly reflect preliminary reporting for 2017. In a few cases, where a plant's preliminary reporting for 2017 changed radically from prior years and resulted in a unrealistically high or low capacity factor for 2017, the reported CF from the finalized 2016 Form 923 data set was used instead.

[13] See U.S. Energy Information Administration, Form EIA-923 Detailed data, Early Release 2017 data, posted June 15, 2018, https://www.eia.gov/electricity/data/eia923/

[14] Congress extended the renewable energy tax credits as part of the Consolidated Appropriations Act of 2016. The Production Tax Credit (PTC) for onshore wind projects was extended at its full value of 2.4 cents/kWh for projects that began construction before the end of 2016; it will phase down to 80% of full value in 2017, 60% in 2018, and 40% in 2019. The Investment Tax Credit (ITC) for solar projects was extended at its full value of 30% of project investment costs through the end of 2019; it will drop to 26% in 2020 and 22% in 2021. Without additional legislation, the PTC will expire after 2019, and after 2021 the ITC will drop to 10% of investment costs for utility-scale projects.

[15] One user option is to apply the social cost of carbon, which represents an estimate of the expected marginal climate damages that result from the release of 1 ton of additional carbon dioxide; see White House Office of Management and Budget, Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis, July 2015, https://obamawhitehouse.archives.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf.

[16] The capital cost projections for new coal-fired power plants rely on NREL's estimate for an advanced supercritical plant with SO_2 and NO_x controls.

[17] See Energy Information Administration, Capital Cost Estimates for Utility Scale Electricity Generating Plants, AEO 2016, November 2016, https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capcost_assumption.pdf.