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# Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes:

## Results from a Survey of U.S. Solar Industry Professionals

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This paper draws on a survey of solar industry professionals and other sources to clarify trends in the expected useful life and operational expenditure (OpEx) of utility-scale photovoltaic (PV) plants in the United States.

Solar project developers, sponsors, long-term owners, and consultants have increased project-life assumptions over time, from an average of ~21.5 years in 2007 to ~32.5 years in 2019. Current assumptions range from 25 years to more than 35 years depending on the organization; 17 out of 19 organizations surveyed or reviewed use 30 years or more.

Levelized, lifetime OpEx estimates have declined from an average of ~\$35/kW$_{DC}$-yr for projects built in 2007 to an average of ~\$17/kW$_{DC}$-yr in 2019. Across 13 sources, the range in average lifetime OpEx for projects built in 2019 is broad, from \$13 to \$25/kW$_{DC}$-yr. Operations and maintenance (O&M) costs—one component of OpEx—have declined precipitously in recent years, to \$5-8/kW$_{DC}$-yr in many cases. Property taxes and land lease costs are highly variable across sites, but on average are—together—of similar magnitude. Other OpEx line items include security, insurance, and asset management.

Given 2007-2009 values for not only project life and OpEx but also other drivers of the levelized cost of energy (LCOE, excluding the investment tax credit), the LCOE for utility-scale PV projects built from 2007 through 2009 averaged \$305/MWh. Using 2019 values for all parameters yields an average LCOE of \$51/MWh. The decline in LCOE from \$305/MWh to \$51/MWh was predominantly caused by reductions in up-front expenditures (and, to a much lesser extent, by changes in capacity factors, financing costs, and tax rates), but 9% (\$22/MWh) of the overall decline is due to improvements in project life and OpEx. Project life extensions and OpEx reductions have had similarly sized impacts on LCOE over this period, at \$11/MWh each. Had project life and OpEx not improved over the last decade, LCOE in 2019 would have instead been \$73/MWh—43% higher.

Given the limited quantity and comparability of previously available data on these cost drivers, the data and trends presented here may inform assumptions used by electric system planners, modelers, and analysts. The results may also provide useful benchmarks to the solar industry, helping developers and assets owners compare their expectations for project life and OpEx with those of their peers.

## Methods

The findings in this paper draw in part from a brief survey of U.S. solar project developers, sponsors, financiers, and consultants. We distributed the survey in December 2019. Responses were received from seven organizations. Additionally, we conducted a review of the annual financial reports from some of the large, publicly traded solar project developers and owners, yielding a number of additional sets of project-life assumptions.[1] Ultimately, we assembled 19 different time-series estimates of useful project life.[2] For OpEx estimates, in addition to seven survey responses, we synthesized data from seven literature sources, leading to 14 different time-series estimates.[3]

With respect to project life, our interest was in better understanding how expectations for useful life have changed over time, as the industry has grown and matured. We focus on 'useful' life, defined here to mean the period of time in which the expected costs and revenues of a project are assessed to determine its economic viability. Typically, an asset with a useful life of, for example, 30 years is expected to earn ongoing operating profits during those 30 years (ongoing revenue > ongoing costs). At the end of year 30, however, either decommissioning or full project repowering would be expected. A longer assumed project life may enhance the expected long-term profitability of a project, assuming any resulting increase in O&M is kept within reasonable bounds. Moreover, longer depreciation terms reduce annual book depreciation from an accounting perspective, thereby boosting net income in the near term. From a planning and modeling perspective, longer lifetimes may enable lower LCOE by recovering up-front capital costs (and, potentially, any component replacement or refurbishment costs) over additional years of electricity production. We specifically sought insights into assumptions most-commonly used by developers and sponsors for project life when considering the lifetime profitability of a project, pitching projects to financiers, and establishing power purchase agreements during the development and financing process. We asked about current assumptions, and how those assumptions have changed over time.

With respect to OpEx, our interest was in total all-in operational expenditures and how expectations for OpEx have changed over time. We define OpEx to include scheduled and unscheduled maintenance, operations personnel, land lease costs, property taxes, and any other ongoing operations costs; some studies focus solely on O&M, but our interest was total OpEx. We sought levelized estimates considering the full expected lifetime of utility-scale PV plants. We asked respondents to report data in $/kW_{DC}$-yr, and requested elaboration on any variations that might exist depending on whether a project is fixed-tilt vs. tracking, whether a project is located in a region with heavy soiling (requiring frequent washing) or vegetation growth (requiring vegetation management), or other project characteristics. We supplement the survey results with estimates from other literature. Much of the available literature does not report all-in OpEx (instead reporting only O&M, or ignoring certain costs); in many cases, coverage and even units are unclear. We therefore adjust literature estimates (and some survey responses) as necessary to ensure greater comparability based on total OpEx, but admit that judgement was required in this process.

For both project life and OpEx, we focused on expectations from project developers, sponsors, and long-term owners because these are the entities most likely to be thinking about the full lifecycle of a project. We also included major consultancies, including those that provide due diligence services to the solar industry. The organizations from which we sourced data have likely been engaged in more than half of all utility-scale PV projects built in the United States since 2007.

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[1] In some cases, project-life assumptions that derive from financial reports reflect depreciation- or accounting-based lives, which may in theory differ from useful-life assumptions used by developers and sponsors. However, a review of our results indicates no such bias in the estimates reported later in this paper, as the distribution of responses is generally similar for both sources of data.

[2] These estimates come from staff and annual reports from: NextEra, EDPR, RES, FirstSolar, EDF, Enel, Pattern, 8point3, Southern Power, PSE&G, BNEF, Lazard, Cypress Creek, Recurrent, Macquarie Capital, Norton Rose Fulbright, MAP, DNV GL, NRG.

[3] These estimates come from staff and literature from: RES, BNEF, NREL, FirstSolar, EDF, MAP, NRG, sPower, Lazard, DNV GL, GTM, Wood Mackenzie, IHS Markit.

## Estimated Project Lifetimes

Project developers, sponsors, long-term owners, and consultancies now most-commonly assume 30-year or greater useful project lives, as depicted in Figure 1. Current assumptions range from 25 years to more than 35 years depending on the organization; 17 out of 19 organizations use 30 years or more. Modules are now typically warranted for 25- or even 30-years, and are generally expected to have some useful life after warranties expire. Project life expectations from developers, sponsors and owners often exceed, by 5 to 10 years, these module warranty durations.

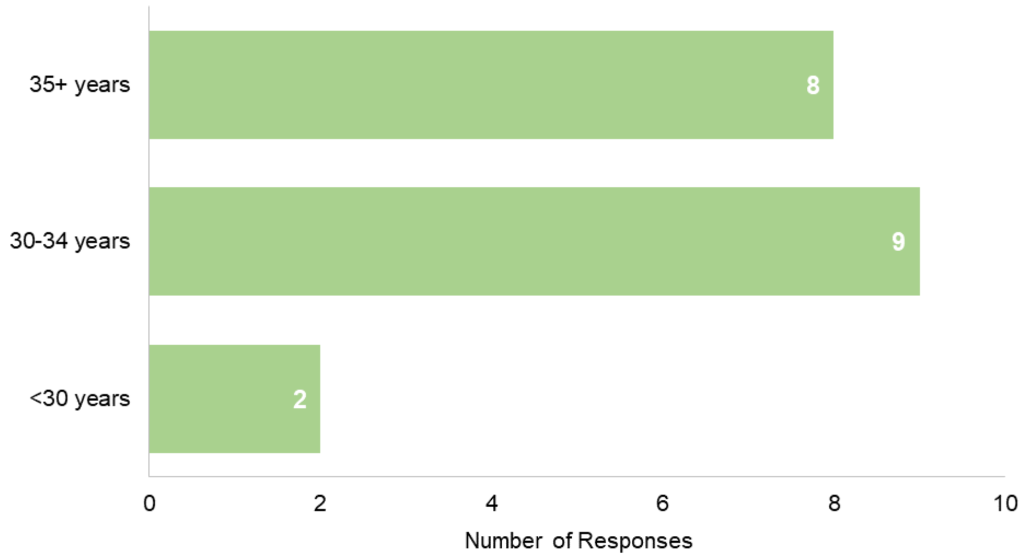


**Figure 1. Current Project Life Expectations for Utility-Scale PV**

Expectations for the useful life of utility-scale PV projects vary by respondent, but have consistently increased over time—from an average value of ~21.5 years in 2007 to ~32.5 years in 2019 (Figure 2). Directionally, this tracks the increase over time of the typical duration of module warranties.

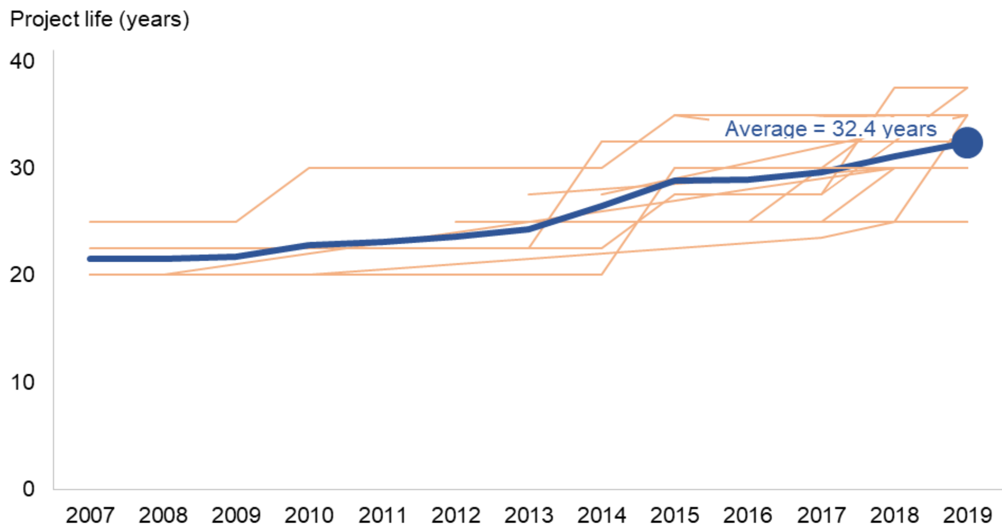


**Figure 2. Project Life Expectations for Utility-Scale PV, over Time**

One respondent noted a link between project life expectations and the cost of finance. Specifically, the cost of capital is, at present, very low, leading to lower discounting of possible profits in the long term. Previously, with a higher cost of capital, discounting meant that project life beyond 25 years was largely unimportant. The same respondent also noted that as project life expectations have increased, so too has the length of the "merchant tail"—the remaining operational period expected after a fixed-price sales agreement has ended. Expectations for a profitable merchant tail (which may or may not ultimately be fulfilled) helps enable aggressive pricing for initial power sales agreements.

## Anticipated Operational Expenditures

Levelized, lifetime OpEx estimates have declined with time, though various sources report different numerical values. Across all sources, lifetime OpEx estimates averaged ~\$35/kW$_{DC}$-yr for projects built in 2007, declining to ~\$17/kW$_{DC}$-yr for projects built in 2019 (Figure 3).[4] The results derived from the industry survey are comparable to the broader literature, as shown by the blue and grey lines in Figure 3. They also generally align with the trend of declining annual solar operations costs reported by regulated utilities, which decreased from an average of \$30/kW$_{DC}$-yr in 2011 to \$15/kW$_{DC}$-yr in 2018.[5]

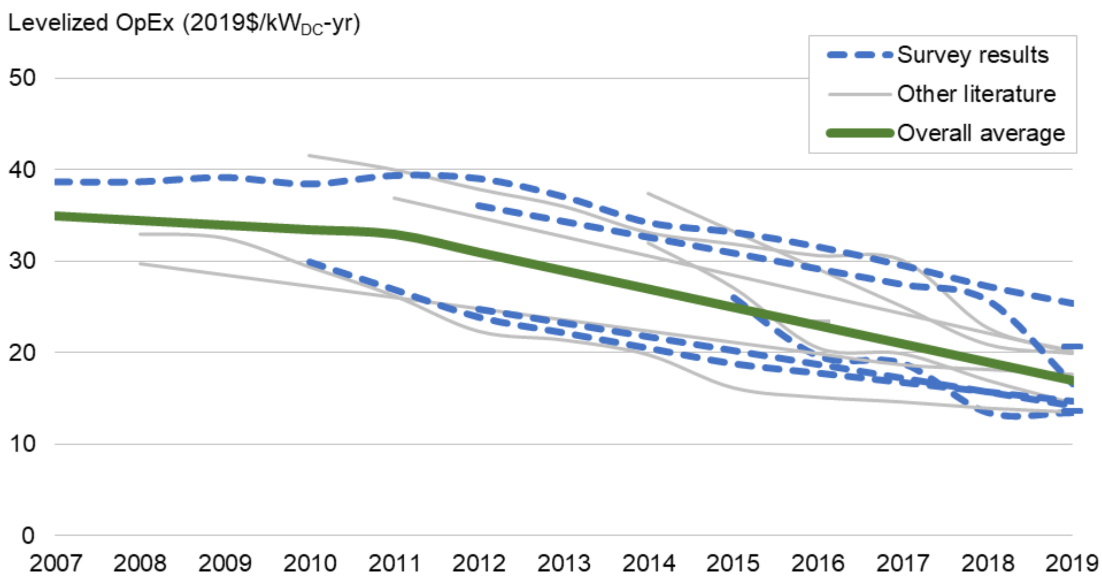


**Figure 3. Lifetime OpEx Expectations for Utility-Scale PV, over Time**

Variations in estimated lifetime OpEx for the most recent projects are depicted in Figure 4, and span a range of \$13 to \$25/kW$_{DC}$-yr. Survey-based responses are again broadly comparable to other literature-based estimates. Note that because respondents provided data on average costs, often for large project

[4] OpEx costs for tracking PV projects are slightly higher than for fixed tilt, by ~\$1/kW$_{DC}$-yr. The costs reported in this section are for average projects that reflect a mix of tracking and fixed tilt.

[5] See data summarized in Bolinger, M., J. Seel and D. Robson. 2019. *Utility-Scale Solar: Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States.* Lawrence Berkeley National Laboratory. The underlying FERC Form 1 OpEx data includes operational costs of supervision and engineering, maintenance, rents, and training (and therefore excludes payments for property taxes, insurance, land royalties, performance bonds, various administrative and other fees, and overhead). Focusing only on 2018 operating expenses, utilities report a range from \$6/kW$_{DC}$-yr to \$32/kW$_{DC}$-yr.

fleets, the costs reported here are a range across fleets; the range across individual projects is larger still, with one respondent noting that costs as high or higher than $30/kW$_{DC}$-yr are possible in some regions.

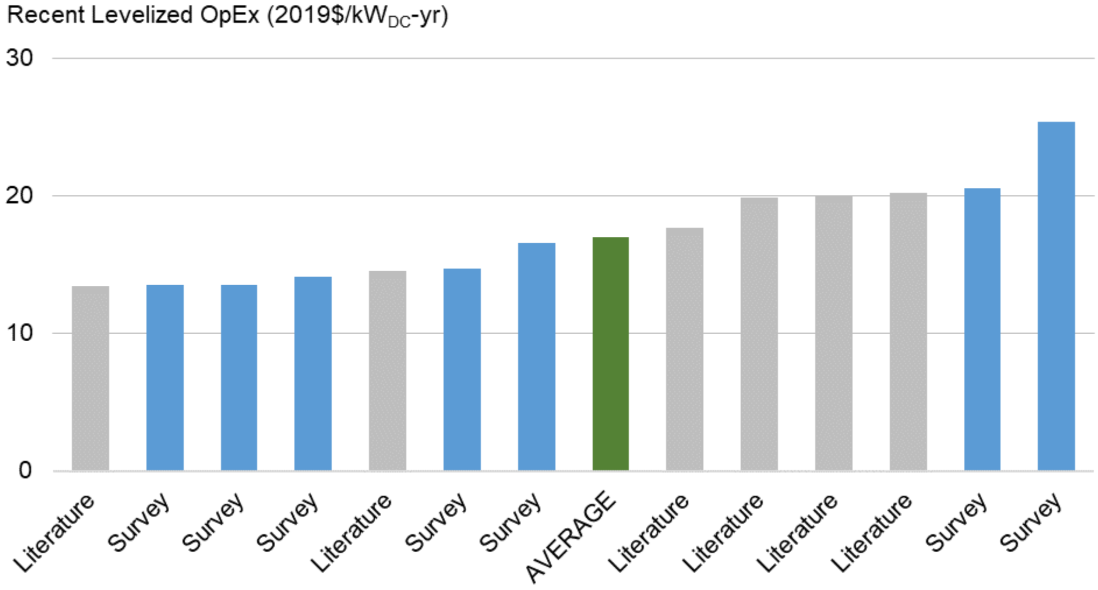


**Figure 4. Recent Lifetime OpEx Expectations for Utility-Scale PV**

While we primarily focused on all-in OpEx, some respondents broke out OpEx into its constituent parts, albeit using different categories of costs (Figure 5).

Operations and maintenance (O&M) costs—inclusive of scheduled and unscheduled maintenance—represent the single largest component of overall PV plant OpEx, as well as a primary source of OpEx reductions over the last decade. Current levelized O&M cost expectations range from $5-8/kW$_{DC}$-yr in many cases. One respondent focused on trends in the cost of initial 5-year O&M contracts (excluding module cleaning and vegetation management, which might add ~$1/kW$_{DC}$-yr), siting a decline in cost from ~$15/kW$_{DC}$-yr in 2010 to $4.5/kW$_{DC}$-yr in 2019. This same respondent indicated that actual OpEx costs for older PV projects may be lower than expectations that existed at the time of initial commercial operation, as these older projects have been able to avail themselves of lower-priced O&M contracts as their original contracts have expired and been renewed.

Property taxes and land lease costs are highly variable across sites. One respondent cited a range in property taxes of $2 to $4/kW$_{DC}$-yr depending on location. That same respondent cited lease costs of $1 to $8/kW$_{DC}$-yr, impacted by the cost of land in a region and site layout—sites in complex terrain often result in more land needing to be leased for a project of a fixed size.[6] Module cleaning and vegetation management were also cited as being variable depending on site needs. Other notable OpEx line-items include security, insurance, and asset management. Fleet size was mentioned as impacting OpEx, with owners benefitting when able to share fixed costs across nearby projects.

[6] Utility-scale PV projects do not generally own the land on which they are placed. Instead, the project owner leases the land from the original landowner or a third party that purchases the land. In the latter case, a third party purchases the land from the original owner, and then leases the land to the project owner. Which lease arrangement is used (from landowner or an intermediary) depends on site and region. Either way, the project owner incurs land costs in the form of an annual lease. For analysts, it is important to take care not to double count costs by including them both as up-front (presuming ownership) and ongoing (presuming ongoing lease) expenditures.

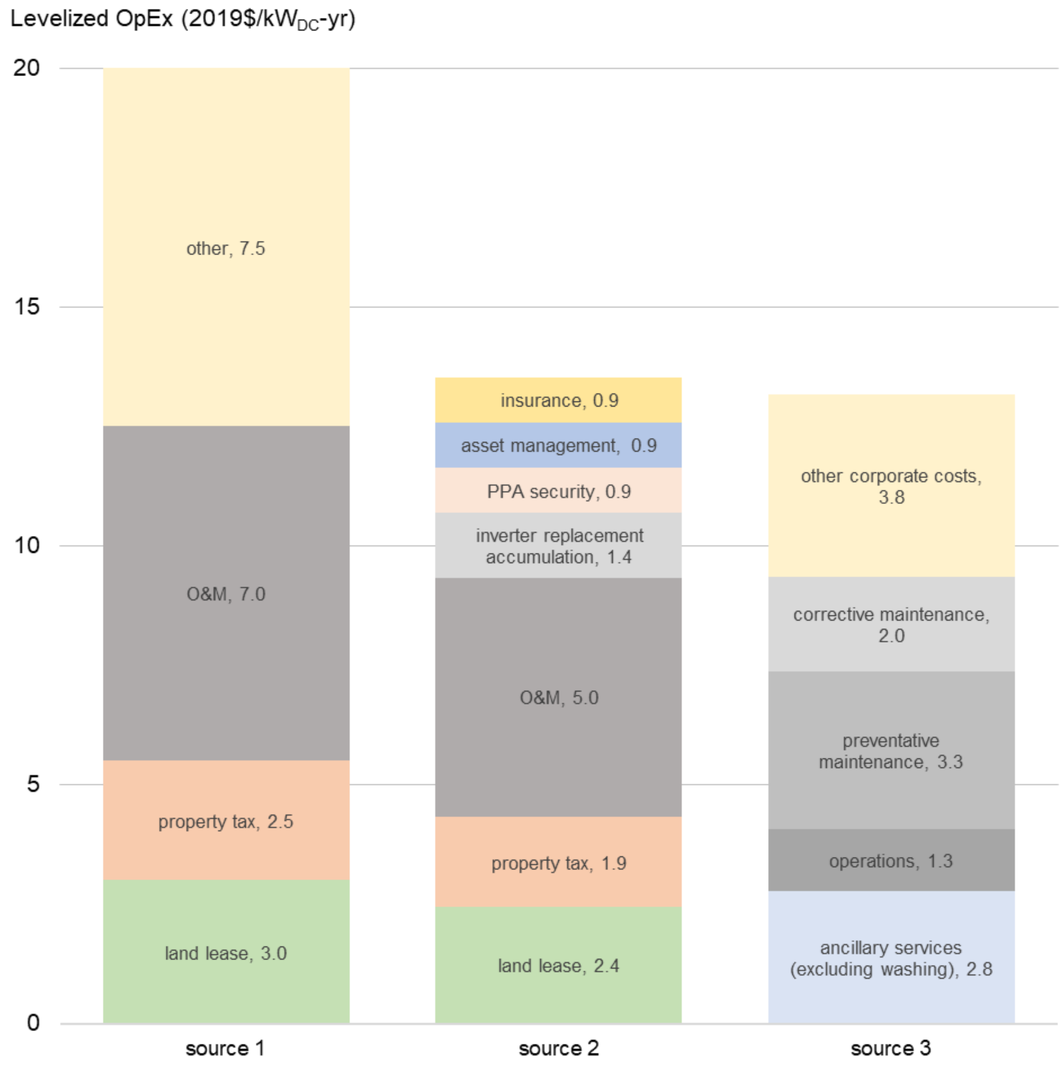


**Figure 5. Recent Lifetime OpEx Expectations by Component**

Reductions in OpEx over time have, in part, been motivated by the low power sales prices now common in the sector, requiring focused attention on lowering OpEx. Related, owners are asking for fewer services than in the past. As a result, overall costs are declining partly due to per-service cost reductions (as one example, via automated panel washing) and partly due to a smaller number of services being procured (as one example, owners realizing that field-level inspections of electrical wiring and equipment are not required every year).

However, one respondent noted that they anticipated that all-in OpEx could rise in the future, as developers may be underestimating certain costs in new markets. O&M is now offered at rock-bottom prices, with relatively few opportunities for further reductions. Land costs, meanwhile, may increase as landowners become increasingly savvy and competition for sites intensifies. Counties may offer fewer property tax abatements as the industry matures. Finally, as projects move closer to population centers, full-time onsite security staff may be required—something not needed for remotely located projects. A consultant echoed some of these themes, postulating that some developers and owners may be underestimating long-term costs.

## Impacts on Levelized Cost of Energy[7]

The levelized cost of energy (LCOE) of solar plants is driven by five primary parameters: upfront capital expenditures, project performance, financing and tax assumptions, OpEx, and project life. Project life extensions and OpEx reductions therefore represent two potential levers for LCOE improvement.

Applying 2007-2009 values for not only project life and OpEx but also other drivers of LCOE, the LCOE for utility-scale PV projects built from 2007 through 2009 averaged $305/MWh, excluding the federal investment tax credit (ITC). Using 2019 values for all parameters yields an average LCOE of $51/MWh in 2019, again excluding the ITC (Figure 6). The decline in LCOE from $305/MWh to $51/MWh was predominantly caused by reductions in up-front capital expenditures (and, to a much lesser extent, by changes in capacity factors, financing costs, and tax rates), but 9% ($22/MWh) of the overall decline is due to improvements in project life and OpEx. Project life extensions and OpEx reductions had similarly sized impacts on LCOE over this period, at $11/MWh each. Had project life and OpEx not improved over the last decade, LCOE in 2019 would have instead been $73/MWh—43% higher.

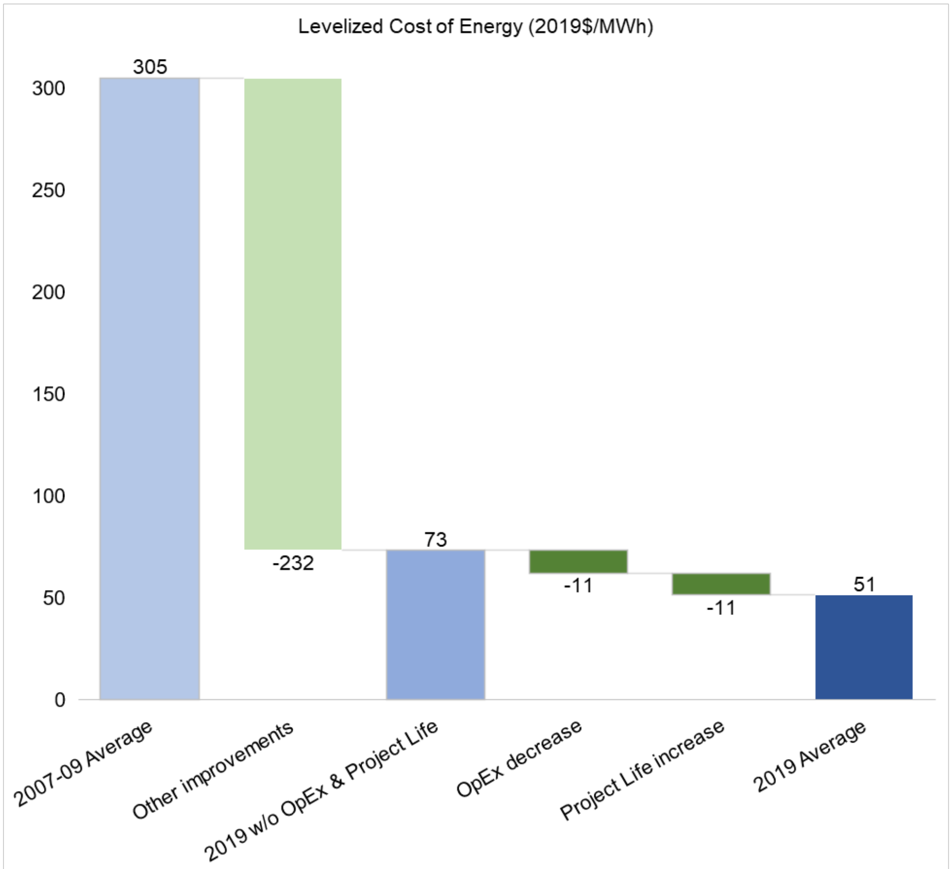


**Figure 6. Impact of Project Life and OpEx Improvements on LCOE**

Clearly, OpEx and project life can be important drivers for LCOE trends over time.

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[7] Assumptions derive in part from Bolinger, M., J. Seel and D. Robson. 2019. *Utility-Scale Solar: Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States.* Lawrence Berkeley National Laboratory.
For projects built from 2007-2009, assumptions include: $5.5/W$_{DC}$ installed cost, 17.6% DC capacity factor, 6.36% weighted average cost of capital, 40% combined tax rate, $34.5/kW$_{DC}$-yr OpEx, and 21.6 year project life. For projects built in 2019, assumptions include: $1.1/W$_{DC}$ installed cost, 17.9% DC capacity factor, 5.94% weighted average cost of capital, 27% combined tax rate, $17/kW$_{DC}$-yr OpEx, and 32.4-year project life.

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