# UTILITY-SCALE FIXED-TILT PV VS. SINGLE-AXIS TRACKER PV: NEMS PROJECTIONS TO 2050

by
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**Executive Summary**

The main purpose of this National Energy Modeling System (NEMS) project was to investigate the cost and performance tradeoffs of utility-scale solar PV through modeling variations in fixed-tilt and single-axis tracker technologies. This objective was accomplished by using capital costs and capacity factors as inputs into NEMS to produce outputs for utility-scale crystalline silicon (c-Si) fixed-tilt solar PV. Yearly capital costs, cumulative unplanned capacity additions, and levelized cost of electricity (LCOE) were the projected outputs at the regional and national level from the year 2019 to 2050. These outputs were also produced in the same manner for utility-scale c-Si single-axis tracker solar PV.

Expected modeling results for the three NEMS outputs were determined prior to running the models. Due to the technology learning curve, fixed-tilt and single-axis tracker capital costs will continue to decline from 2019 to 2050. The LCOE for single-axis tracker PV in many cases will be lower than that for fixed-tilt PV, depending on resource quality and financial assumptions. Furthermore, the national LCOE for single-axis tracker projects will decrease at a larger percentage than the national LCOE for fixed-tilt projects. If the cost gap between single-axis tracker and fixed-tilt widens, growth rates and total yearly capacity additions for fixed-tilt PV will become greater than those for single-axis tracker PV at the national level. A similar result will be observed, in some instances, if the capacity factors for fixed-tilt improve.

The results of this modeling project matched closely with the predicted outcomes. Capital costs for both fixed-tilt and single-axis tracker did in fact decline as expected, but the capital costs decreased by approximately 33% between 2019 and 2050 for both technologies. This result indicates that the learning rate for fixed-tilt PV is equivalent to that of single-axis tracker PV. As was predicted, the single-axis tracker LCOE for the baseline run decreased at a

greater percentage than the fixed-tilt LCOE for the baseline run – 18% compared to 14%. Single-axis tracker LCOE was in fact lower than fixed-tilt LCOE in many regions and at the national level, and only at 25% and 50% input capital cost decreases was fixed-tilt LCOE competitive with single-axis tracker LCOE at the national level.

Based on the output results for the cumulative unplanned capacity additions, new project development in the utility-scale solar PV market will be dominated by single-axis tracker projects over fixed-tilt projects. At the baseline input price of $2.53/W-AC for single-axis tracker projects and $2.36/W-AC for fixed-tilt projects, single-axis tracker capacity growth vastly outnumbered capacity growth for fixed-tilt projects with 143.29 GW built by 2050, whereas capacity growth for fixed-tilt projects only reached 0.04 GW built by 2050. In conclusion, even though the capital costs for fixed-tilt PV and single-axis tracker PV declined at the same percentage, the capacity addition growth rates and totals from single-axis tracker were greater than those for fixed-tilt in the baseline capital cost scenarios, due in large part to the lower single-axis tracker LCOE compared to fixed-tilt.

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## Introduction

Energy modeling software is commonly used to compare the price and energy production projections of different energy technologies. Therefore, modeling allows an energy decision-maker to see a potential energy landscape far into the future. The main purpose of this project was to investigate the cost and performance tradeoffs of utility-scale solar PV through modeling variations in fixed-tilt and single-axis tracker technologies. This objective was accomplished by using capital costs and capacity factors as inputs into NEMS to produce outputs for utility-scale crystalline silicon (c-Si) fixed-tilt solar PV. Yearly capital costs, cumulative unplanned capacity additions, and levelized cost of electricity (LCOE)[1] were the projected outputs at the regional and national level from the year 2019 to 2050. These outputs were also produced in the same manner for utility-scale c-Si single-axis tracker solar PV. The outputs for fixed-tilt and single-axis tracker PV were then compared and analyzed.

The National Energy Modeling System (NEMS) is an Energy Information Administration (EIA) energy-economy modeling software which outputs projections in the U.S. energy system through 2050. Projected energy outputs include production, imports, conversion, consumption, and prices. Critical energy and electricity market assumptions are utilized in NEMS to structure inputs and calculate outputs. These assumptions include: macroeconomic factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, and cost and performance attributes of various energy technologies. When taken into consideration, these assumptions allow NEMS, through the use of an electricity market sub-module, to produce electricity market projections from load and demand to pricing. Electricity market outputs are

[1] LCOE is the lifetime cost of an electricity generator per unit of electricity produced by the generator.

produced for the 22 North American Electricity Reliability Corporation (NERC) regions[2]. This allows for useful and detailed projections that are refined at a regional scale, including load, capacity, and generation by region through time to 2050. Furthermore, NEMS produces financial projections in both the forms of capital costs and levelized cost of electricity (LCOE) through time and by region. Technologies, such as solar, will decrease in price from now until 2050; however the price relationships among solar technologies are more uncertain. For instance, will a high-cost/high-performing solar PV application produce a lower LCOE than a low-cost/low-performing solar PV application?

The expected modeling results for this study were as follows:

*Due to the technology learning curve, fixed-tilt and single-axis tracker capital costs will continue to decline from 2019 to 2050. Although capital costs for fixed-tilt PV are lower than those of single-axis tracker PV for all utility-scale solar PV projects, so is the overall performance of fixed-tilt PV. As a result, the LCOE for single-axis tracker PV in many cases will be lower than that for fixed-tilt PV, depending on resource quality and financial assumptions. Furthermore, the national LCOE for single-axis tracker projects will decrease at a larger percentage than the national LCOE for fixed-tilt projects. If the cost gap between single-axis tracker and fixed-tilt widens, growth rates and total yearly capacity additions for fixed-tilt PV will become greater than those for single-axis tracker PV at the national level. A similar result will be observed, in some instances, if the capacity factors for fixed-tilt improve.*

A comparison between the basic characteristics of single-axis tracker and fixed-tilt PV systems deserves attention in order to understand the context of this modeling project. Fixed-tilt

[2] NERC is a non-profit international regulatory authority that ensures the reliability and security of the grid. NERC's jurisdiction includes the continental United States, Canada, and the northern portion of Baja California, Mexico.

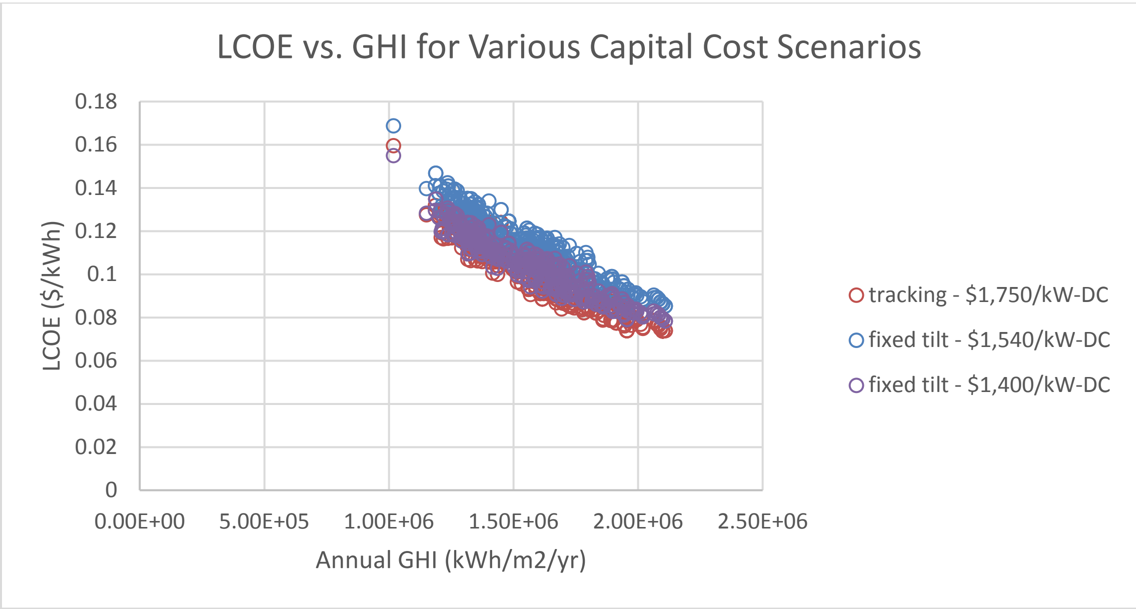
systems are simpler than single-axis tracker systems, in that there are less moving parts. The trackers themselves cost money, making a single-axis tracker solar PV project more expensive. Furthermore, trackers make the land requirements for a solar project more demanding. Therefore, fixed-tilt projects are easier to plan and execute at a cheaper cost. However, despite these cost and land barriers, single-axis trackers allow for greater energy production at a given site, since the solar panels track the sun from east to west at its peak intensity. These projects tend to be deployed in regions with a high amount of global horizontal irradiance (GHI)[3], such as in the southwest United States.

Single-axis tracker and fixed-tilt performance have been compared in several research articles. Basha (2016) concludes that for 8 locations in the southern states of India, single-axis tracker solar plants produce more energy when compared to fixed-tilt solar plants throughout the year. Annually, on average single-axis tracker plants generate a minimum of 17% more energy than fixed-tilt plants (Basha, 2016). Fixed-tilt panel orientation has also been a topic of research. Chang (2009) compares fixed-tilt panels facing west to panels facing south and concludes that "the amount of yearly energy in due west (or east) is less than its maximum in due south by about 11%, 10% and 5% for the extraterrestrial, predicted and observed radiation respectively." Another study, by Li and Lam (2007), substantiates the advantage in total energy production from southward facing panels compared to westward facing panels. Li and Lam (2007) conclude that in Hong Kong "the optimum tilt angle was found to be around 20° due south, which would receive the annual solar yield over 1598 kWh/m$^2$."

The graph below, showing LCOE vs. GHI, forms the basis for the idea that trackers take advantage of higher GHI to produce more energy and consequently lower LCOE. The LCOE for

[3] GHI is the total amount of radiation received from the sun by a surface horizontal to the ground. This value is equal to Direct Normal Irradiance (DNI) plus Diffuse Horizontal Irradiance (DIF).

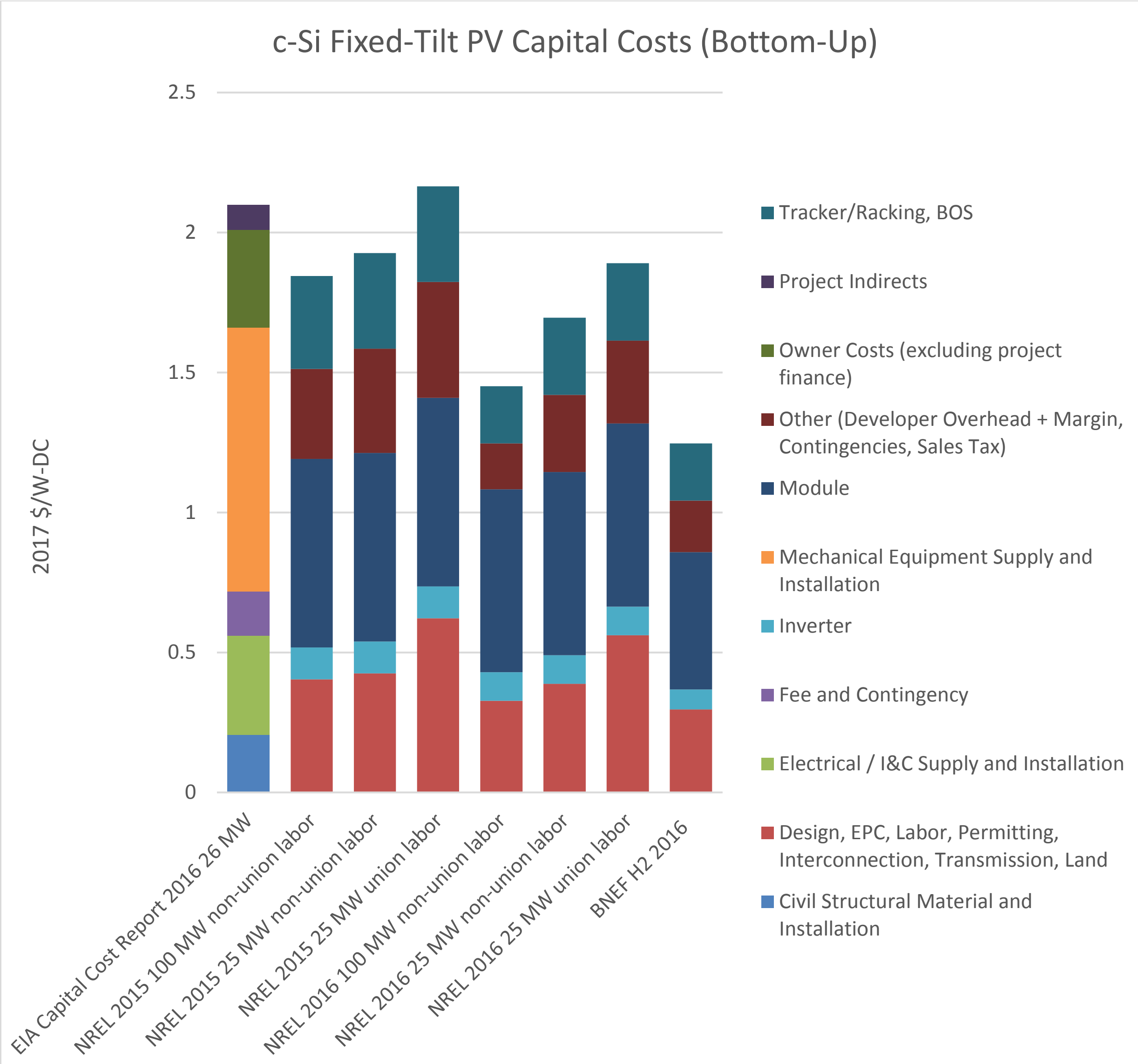
fixed-tilt and single-axis tracker becomes almost identical when fixed-tilt capital costs drop from the LBNL 2016 value of $1540/kW-DC (shown in blue) to $1400/kW-DC (purple) and when the LBNL 2016 single-axis tracker capital costs remain fixed at $1750/kW-DC (red). Although fixed-tilt PV capital costs are expected to decrease in the coming years, the single-axis tracker PV capital costs will not remain fixed at $1750/kW, but will also decline and perhaps at a greater rate. This prediction indicates that LCOE for single-axis tracker systems should remain lower than the LCOE for fixed-tilt systems in the future.




A literature review was conducted to find articles and data sources that revealed current, past, and projected crystalline silicon (c-Si) fixed-tilt and single-axis tracker solar PV installed project prices. Both bottom-up and top-down capital cost reports were researched in the literature review. Bottom-up cost models aggregate the various costs that make up the final capital cost, such as owner costs, construction costs, PV component costs, etc. Alternatively, top-down models use reported final installed project prices from a variety of sources. Furthermore, while solar PV module prices for c-Si were not analyzed using NEMS, background research was conducted to examine price movement patterns. Thin film modules, while still having a significant U.S. utility-scale solar PV market presence, are more rarely used for new utility-scale solar PV projects compared to crystalline silicon modules because of the longer lifetimes and rapidly decreasing module prices for c-Si. This market observation, in addition to the lack of data published for both current and projected thin film solar PV project prices, forms the rationale for leaving thin film technologies out of this NEMS analysis project.

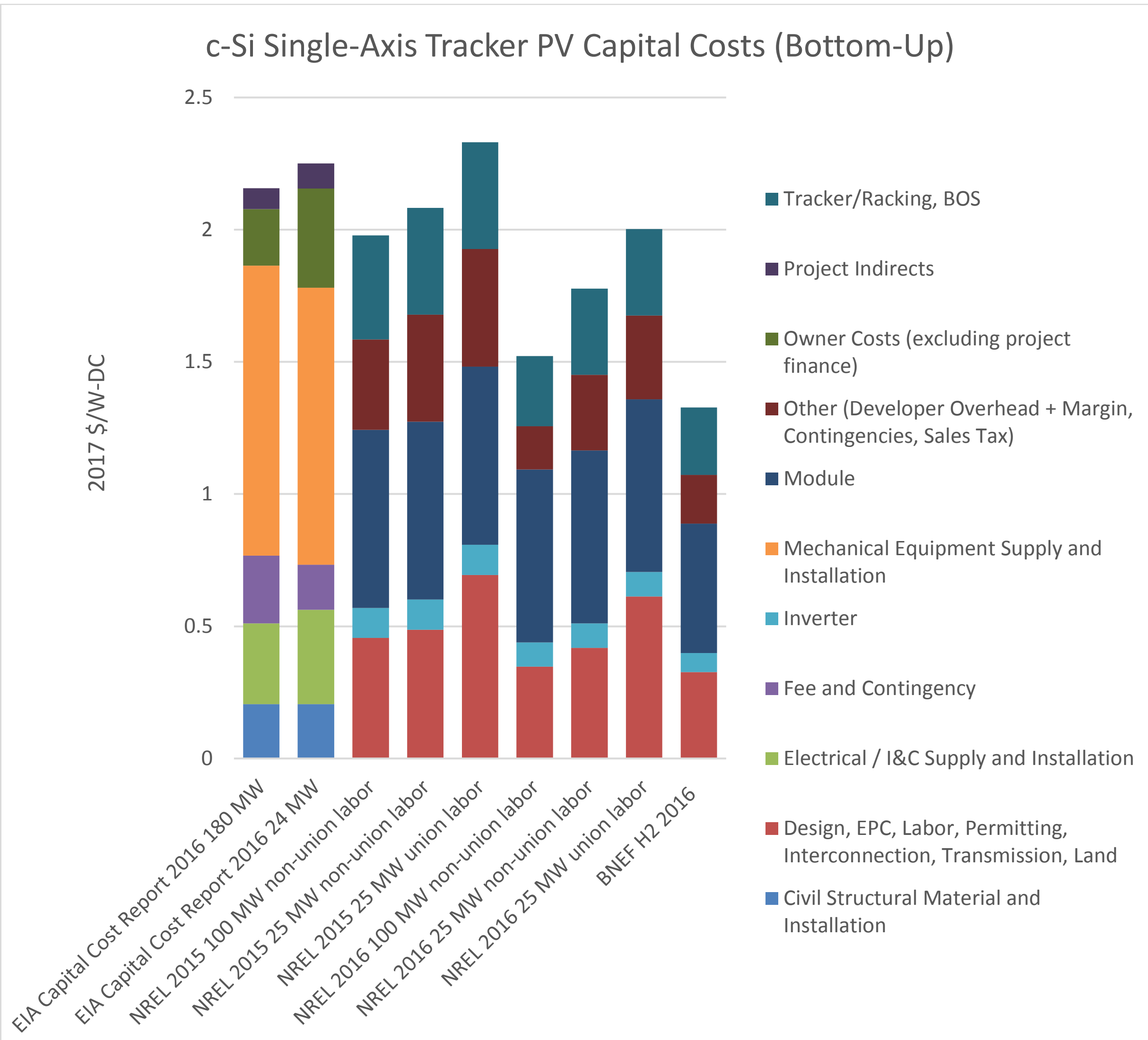
Both Bloomberg New Energy Finance (BNEF) and the National Renewable Energy Laboratory (NREL) provide detailed data for module prices for solar PV, which is the largest component cost out of the total system costs. In BNEF's *H2 2016 US PV Market Outlook*, Serota and Bromley (2016) describe c-Si modules "readily accessible at around $0.40 per watt (W) plus import duties" for the second half of 2016. Forward pricing for the first half of 2017 has been placed at $0.35/W (Serota & Bromley, 2016). In NREL's *U.S. Photovoltaic Prices and Cost Breakdowns report for Q1 2015*, Chung et al. (2015) list an ex -factory gate price on delivery duty paid for c-Si modules at $0.65-$0.70 per watt. The NREL *Q1/Q2 2017 Solar Industry Update* by Feldman and Margolis (2017) shows a similar trend, placing c-Si module prices at $0.49 for small buyers and $0.33 for large buyers.

Installed project prices, or capital costs, for utility-scale c-Si fixed-tilt and single-axis tracker PV projects are decreasing every year, and the data from benchmark sources reflects this. The graph below shows capital costs from NREL 2015, NREL 2016, EIA *Capital Cost Report* 2016, and BNEF H2 2016 for fixed-tilt projects using a bottom-up cost approach, where all the cost components of a project are added to get a resulting total capital cost. Prices are in 2017 $/W-DC, and were converted from $/W-AC when necessary using a conversion factor of 1.3 W-AC/W-DC; these prices were also adjusted for inflation when necessary.




BNEF H2 2016 has the lowest bottom-up cost estimate at $1.26 per W-DC, while the lowest NREL 2016 price estimate is $1.45 per W-DC, which represents a 100 MW system that is constructed with non-union labor. The bottom-up cost estimates from NREL and BNEF tend to provide prices at the time when construction contracts were finalized and when construction began (Bolinger et al., 2017). On the other hand, EIA provides prices at the time when solar PV projects achieve commercial operation. For this reason, EIA's 2016 costs for a 26 MW fixed-tilt system at $2.10/W-DC fall between the union and non-union labor systems from NREL's 2015 reported capital costs.

The next graph uses the same sources and parameters for bottom-up cost modeling; only this time it shows these costs for c-Si single-axis tracker PV systems and uses a W-AC/W-DC conversion factor of 1.2. The BNEF H2 2016 cost for utility-scale single-axis tracker projects is $1.33 per W-DC, and the lowest NREL 2016 estimate is also for the 100 MW system built with non-union labor at $1.52 per W-DC. The extra cost of single-axis trackers is quite low, especially when a project with greater nameplate capacity is built.



In the graphs above, the "EIA Capital Cost Report 2016" includes bottom-up capital costs for a 26 MW fixed-tilt system ($2.10/W-DC), a 24 MW single-axis tracker system ($2.25/W-DC), and a 180 MW single-axis tracker system ($2.16/W-DC). The 180 MW single-axis tracker system price is used as the capital cost input in NEMS for single-axis tracker systems. Due to economies of scale and the large size of the 180 MW single-axis tracker system compared to the smaller size of the fixed-tilt system in this EIA *Capital Cost Report*, fixed-tilt capital costs appear to be virtually identical to single-axis tracker capital costs. EIA's *Capital Cost Report* did not include a large-scale fixed-tilt solar PV project. The following excerpt is EIA's methodology for formulating capital costs:

> "The estimates were developed through costing exercises, using a common methodology across technologies. Comparing cost estimates developed on a similar basis using the same methodology is of particular importance to ensure modeling consistency.
> Each technology is represented by a generic facility of a specific size and configuration, in a location that does not have unusual constraints or infrastructure requirements. Where possible, costs estimates were based on information on system design, configuration, and construction derived from actual or planned projects known to the consultant, using generic assumptions for labor and materials rates. When this information was not available, the project costs were estimated using a more generic technology representation and costing models that account for the current labor and materials rates necessary to complete the construction of a generic facility as well as consistent assumptions for the contractual relationship between the project owner and the construction contractor." (EIA, 2016)

The Lawrence Berkeley National Laboratory (LBNL) *Utility-Scale Solar 2016* report provides top-down estimates for capital costs from sources (e.g., corporate financial filings, FERC filings, the Treasury's Section 1603 grant database, EIA) (Bolinger et al., 2017). Due to their empirical nature, sources such as LBNL are regarded as an accurate reflection of current markets. Like EIA, LBNL provides prices at the time when solar PV projects achieve commercial operation (Bolinger et al., 2017). Furthermore, as stated in the report, "LBNL's top-down empirical estimates reflect a mix of union and non-union labor and span a wide range of project sizes and prices" (Bolinger et al., 2017).

Data publications also provide projections for utility-scale solar PV capital costs, capacity, and electricity generation. These sources include NREL's *Annual Technology Baseline* (ATB), the EIA *Annual Energy Outlook* (AEO), and the BNEF *H2 2016 US PV Market Outlook*. In addition, technology trends and financial aspects of single-axis tracker and fixed-tilt utility-scale systems are important to identify and to understand. A notable article for explaining the state of tracker PV systems is BNEF's *Tracking the Sun Has a Bright Future* by Xiaoting Wang (2017). In this article, Wang (2017) explains that single-axis trackers can lower LCOE by 5-12%, while adding 5-9 cents to system capital costs.

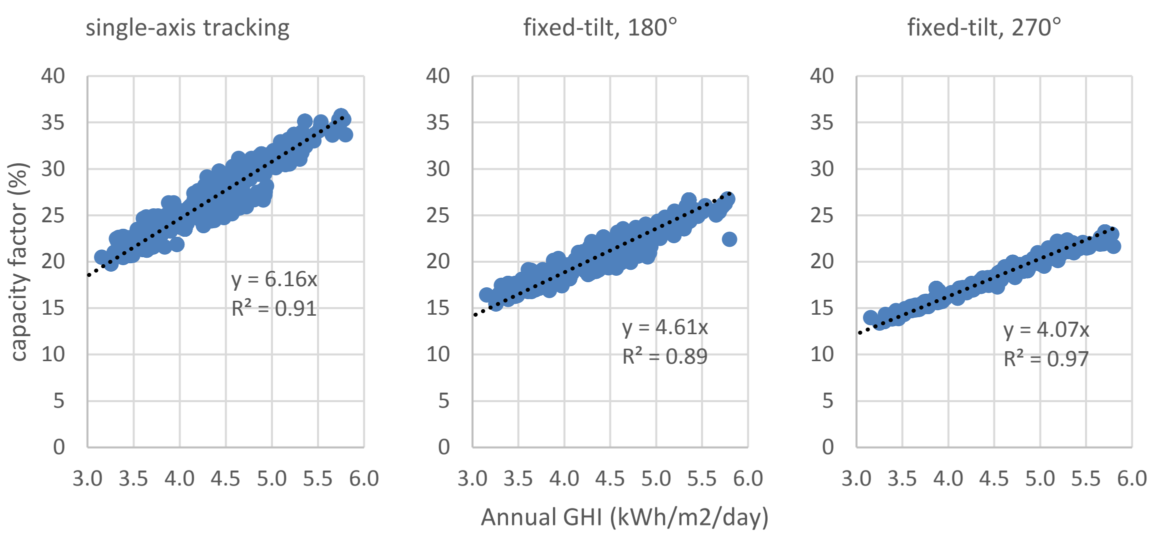
**Methods**

The $2.06/W-AC and $2.21/W-AC values for fixed-tilt and single-axis tracking systems from LBNL's *Utility-Scale Solar 2016* report (Bolinger et al., 2017) were used as variables in this NEMS project. The rationale for using the LBNL figures is validated in the **Introduction** and further expanded upon in the text of the LBNL report. It should be noted that in NEMS the capital cost for both fixed-tilt and single-axis tracker PV is in the form of $/W-AC and not $/W-DC. Although much of the literature reviewed in this project uses $/W-DC, a simple conversion can be used to convert $/W-AC to $/W-DC, and vice versa: fixed-tilt W-DC = W-AC/1.3 and single-axis tracker W-DC = W-AC/1.2.

The current NEMS capital cost input of $2.53/W-AC for utility-scale single-axis tracker PV, taken from the EIA *Capital Cost Report*, was the single-axis tracker capital cost input for all NEMS runs. Since EIA's *Capital Cost Report* did not have an equivalent sized system for fixed-tilt, the LBNL 2016 report values were used. Instead of plugging in LBNL's 2016 values directly into NEMS, the ratio of the LBNL single-axis tracker to fixed-tilt prices was applied to the existing EIA value in NEMS for single-axis tracker PV, in order to derive a fixed-tilt capital cost value to input into NEMS. Using the LBNL 2016 figures, this ratio of single-axis tracker to fixed-tilt pricing is 1.073 ($2.21/$2.06). Dividing the NEMS value for single-axis tracking of $2.53/W-AC by 1.073, a value of $2.36/W-AC is calculated, which was used as the baseline in NEMS for the fixed-tilt capital cost input. Three other fixed-tilt capital cost inputs were used: $1.18/W-AC, $1.77/W-AC, and $2.12/W-AC. These three values correspond to 50%, 75%, and 90% of the baseline price of $2.36/W-AC. Using only one value for the single-axis tracker price, while concurrently using a range of values for the fixed-tilt price, allows for a simpler comparison of the NEMS outputs of cumulative unplanned capacity additions and LCOE between these two technologies.

For each of these four fixed-tilt input prices, runs were conducted for fixed-tilt panels orientated towards the south (baseline) and for panels orientated towards the west. Westward facing panels, which are rotated 270 degrees from due north, shift the electricity generation curve towards later in the day. This can be ideal for matching fluctuating electricity demand in certain regions, but less total daily energy is produced compared to standard, southward facing PV panels. The fixed-tilt angle for all NEMS runs was fixed at the latitude of the test region, which produces the optimal annual radiation.  Naturally, the single-axis trackers in NEMS track the sun from east to west.

The second input, as mentioned earlier in this proposal, was capacity factor.  The capacity factors for standard fixed-tilt (southward facing), westward facing fixed-tilt, and single-axis tracker PV were derived from data analysis in NREL's System Advisor Model (SAM) software (see graphs below).  The graph labelled "fixed-tilt, 180°" (center) corresponds to southward (baseline) facing fixed-tilt PV panels, while the graph labelled "fixed-tilt, 270°" (right) corresponds to westward facing fixed-tilt PV panels.




NEMS models the solar resource by dividing it into six bins defined by the global horizontal irradiance (GHI). The GHI ranges are shown in the table below (left), from low resources (bin 1) to high resources (bin 6).  The corresponding ranges for capacity factors by technology are shown in the adjacent panels.  The table below displays the six bins that were formulated from the relationship between capacity factor and annual GHI in SAM. The capacity factors for each technology for each bin were determined using the trend lines shown in the figure above.  These bins were used as the baseline inputs in NEMS for capacity factor.

| | GHI | | | CF single-axis | | | CF fixed-tilt | | | CF fixed-tilt 270 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bin* | *Bin Min* | *Bin Max* | | *Bin Min* | *Bin Max* | | *Bin Min* | *Bin Max* | | *Bin Min* | *Bin Max* |
| 1 | 3.0 | 3.5 | | 18 | 22 | | 14 | 16 | | 12 | 14 |
| 2 | 3.5 | 4.0 | | 22 | 25 | | 16 | 18 | | 14 | 16 |
| 3 | 4.0 | 4.5 | | 25 | 28 | | 18 | 21 | | 16 | 18 |
| 4 | 4.5 | 5.0 | | 28 | 31 | | 21 | 23 | | 18 | 20 |
| 5 | 5.0 | 5.5 | | 31 | 34 | | 23 | 25 | | 20 | 22 |
| 6 | 5.5 | 6.0 | | 34 | 37 | | 25 | 28 | | 22 | 24 |

As the capital cost input is varied for fixed-tilt PV, a range of values above and below the capacity factor range listed for each bin for fixed-tilt was also used in NEMS. Additional runs were produced for an increase of 3% to the capacity factors represented in each bin range and again for a decrease of 3%. Similar to the capital cost input, the capacity factor input for single-axis tracker PV remained fixed at the values for each bin in the corresponding table above. Bins are correlated with the 22 NERC regions in order to define regional outputs in NEMS. Using capital cost and capacity factor as inputs as described above, projections to 2050 for cumulative unplanned capacity additions, LCOE, and capital costs for the 22 NERC regions were produced for comparison between single-axis tracker and fixed-tilt PV. A table showing all of the NEMS runs used for this modeling analysis is shown below.

| file | capital cost (shares) | capital cost ($/W-AC) | capacity factor | panel orientation |
|---|---|---|---|---|
| test601r | 50% | 1.18 | baseline | south |
| test601wr | 50% | 1.18 | baseline | west |
| test601_3r | 50% | 1.18 | +3 | south |
| test601w_3r | 50% | 1.18 | +3 | west |
| test601_m3r | 50% | 1.18 | -3 | south |
| test601w_m3r | 50% | 1.18 | -3 | west |
| test901r | 75% | 1.77 | baseline | south |
| test901wr | 75% | 1.77 | baseline | west |
| test901_3r | 75% | 1.77 | +3 | south |
| test901w_3r | 75% | 1.77 | +3 | west |
| test901_m3r | 75% | 1.77 | -3 | south |
| test901w_m3r | 75% | 1.77 | -3 | west |
| test1081r | 90% | 2.12 | baseline | south |
| test1081wr | 90% | 2.12 | baseline | west |
| test1081_3r | 90% | 2.12 | +3 | south |
| test1081w_3r | 90% | 2.12 | +3 | west |
| test1081_m3r | 90% | 2.12 | -3 | south |
| test1081w_m3r | 90% | 2.12 | -3 | west |
| test1201r | baseline | 2.36 | baseline | south |
| test1201wr | baseline | 2.36 | baseline | west |
| test1201_3r | baseline | 2.36 | +3 | south |
| test1201w_3r | baseline | 2.36 | +3 | west |
| test1201_m3r | baseline | 2.36 | -3 | south |
| test1201w_m3r | baseline | 2.36 | -3 | west |

**Results**

Fixed-tilt capital cost projection data for NEMS runs with baseline capacity factors and baseline panel orientation is shown in Table 1 below. Because the single-axis tracker capital cost input was held at $2.53/W-AC for all NEMS runs, single-axis tracker capital cost outputs were virtually identical for all NEMS runs. Therefore, single-axis tracker capital costs for 2019 and 2050 are only displayed for the baseline NEMS run, where the fixed-tilt capital cost was held at $2.36/W-AC. The data in Table 1 includes national values only, but data for all 22 NERC regions can be found in Table A1 in the **Appendix**. A map which displays the 22 NERC regions can be found in the **Appendix** as well.

**Table 1: Capital Costs for 2019 and 2050 (2017 $/kW)**

| | National | |
|---|---:|---:|
| **NEMS run (price)*** | **2019** | **2050** |
| 50% fixed-tilt | 982.8 | 658.4 |
| 75% fixed-tilt | 1473.3 | 986.8 |
| 90% fixed-tilt | 1767.7 | 1183.9 |
| baseline fixed-tilt | 1963.9 | 1315.3 |
| baseline single-axis tracker | 2107.8 | 1411.6 |

Regional differences in total system costs are based on regional cost multipliers, which attempt to account for regional variation in labor wages, productivity differences, and materials costs. For every run listed in Table 1, the minimum capital cost for both 2019 and 2050 was found in Region 15. This region corresponds to the SERC Reliability Corporation/Central (SRCE). The SRCE mainly consists of Tennessee and Kentucky. The maximum capital cost for all runs listed in Table 1 occurred in Region 6, which corresponds to the Northeast Power Coordinating Council/NYC-Westchester (NYCW). This region obviously is representative of the New York City area, but not including Long Island, which is part of a different NERC region.

The percentage decrease in the national value of fixed-tilt and single-axis tracker capital costs from 2019 to 2050 was approximately 33% in all cases. As was observed, the capital cost minimums and maximums occurred at the same region for all fixed-tilt and single-axis tracker capital cost inputs with baseline capacity factors and baseline panel orientation (south). Furthermore, the national value for capital costs decreased at the same percentage from 2019 to 2050 regardless of the fixed-tilt input capital cost.

Table 2 shows the 2019 and 2050 national values for fixed-tilt LCOE (in 2017 $/MWh) for all NEMS runs, as well as the single-axis tracker LCOE for the baseline fixed-tilt input capital cost, since single-axis tracker LCOE does not vary from run to run. Single-axis tracker

LCOE does not vary from run to run for three reasons: the single-axis tracker input capital cost is held constant at $2.53/W-AC, panel orientation variation (south vs. west) only applies to fixed-tilt PV projects, and the capacity factor bins are only adjusted +3% and -3% for the fixed-tilt PV projects.

**Table 2: LCOE (2017 $/MWh)**

| | National | |
|---|---|---|
| **NEMS run (price)*** | **2019** | **2050** |
| 50% fixed-tilt | 44.1 | 39.8 |
| 50% fixed-tilt, +3% CF | 38.5 | 34.9 |
| 50% fixed-tilt, -3% CF | 51.5 | 46.5 |
| 50% westward fixed-tilt | 50.5 | 45.6 |
| 50% westward fixed-tilt, +3% CF | 43.5 | 39.2 |
| 50% westward fixed-tilt, -3% CF | 60.6 | 54.6 |
| 75% fixed-tilt | 58.0 | 51.1 |
| 75% fixed-tilt, +3% CF | 50.7 | 44.9 |
| 75% fixed-tilt, -3% CF | 67.9 | 59.2 |
| 75% westward fixed-tilt | 66.5 | 58.5 |
| 75% westward fixed-tilt, +3% CF | 57.2 | 50.5 |
| 75% westward fixed-tilt, -3% CF | 79.7 | 69.7 |
| 90% fixed-tilt | 66.4 | 57.5 |
| 90% fixed-tilt, +3% CF | 58.0 | 50.6 |
| 90% fixed-tilt, -3% CF | 77.6 | 67.3 |
| 90% westward fixed-tilt | 76.1 | 66.0 |
| 90% westward fixed-tilt, +3% CF | 65.6 | 57.1 |
| 90% westward fixed-tilt, -3% CF | 91.2 | 79.1 |
| baseline fixed-tilt | 71.9 | 62.1 |
| baseline fixed-tilt, +3% CF | 62.9 | 54.3 |
| baseline fixed-tilt, -3% CF | 84.2 | 72.7 |
| baseline westward fixed-tilt | 82.5 | 71.2 |
| baseline westward fixed-tilt, +3% CF | 71.1 | 61.3 |
| baseline westward fixed-tilt, -3% CF | 98.9 | 85.4 |
| baseline single-axis tracker | 60.1 | 49.3 |

For all runs in both 2019 and 2050, the minimum LCOE occurred in region 21, the Western Electricity Coordinating Council/Northwest Power Pool Area (NWPP). This region is comprised of the Pacific Northwest and the mountain west. The maximum LCOE for all runs in

2019 and 2050 occurred in region 10, the Reliability First Corporation/Michigan (RFCM), which consists of most of Michigan. The percentage decrease in LCOE from 2019 to 2050 was very similar for all runs within a given input price. For the fixed-tilt LCOE outputs, all the 50% cost runs had a percentage decrease around 10%, the 75% cost runs were around 12%, the 90% cost runs were around 13%, and the baseline cost runs were around 14%. The percentage decrease in single-axis tracker LCOE for the baseline cost run rounds off at exactly 18%.

The run which produced the lowest 2019 national LCOE of $38.50/MWh was the 50% cost fixed-tilt, +3% capacity factor run. This observation could have easily been predicted, given that LCOE is smallest when capital costs are lowest and energy produced is highest. The run which produced the highest 2019 national LCOE of $98.90/MWh was the baseline cost westward fixed-tilt, -3% capacity factor run. The 2019 baseline single-axis tracker national LCOE of $60.10/MWh most closely matched the 50% cost westward fixed-tilt, -3% capacity factor run, where LCOE was $60.60/MWh. The minimum and maximum national LCOE occurred at the same runs for 2050 as for 2019, with the minimum being $34.90/MWh and the maximum being $85.40/MWh. The 2050 baseline single-axis tracker LCOE of $49.30/MWh most closely matched the 75% cost westward fixed-tilt, +3% capacity factor run LCOE of $50.50/MWh. When comparing the baseline orientation and baseline capacity factor fixed-tilt runs from all input costs to the baseline single-axis tracker run in 2019, it can be noted that single-axis tracker LCOE was lower than fixed-tilt LCOE at the 90% and baseline input costs, but not at the 50% and 75% input costs. However, in 2050, the baseline single-axis tracker LCOE became lower than the fixed-tilt LCOE for even the 75% input cost. In addition, the standard, southward fixed-tilt PV projects had a lower LCOE than projects which utilize westward facing fixed-tilt PV panels.

Table 3 displays the unplanned, cumulative capacity additions in 2050 for all runs and for both fixed-tilt and single-axis tracker projects for each run.

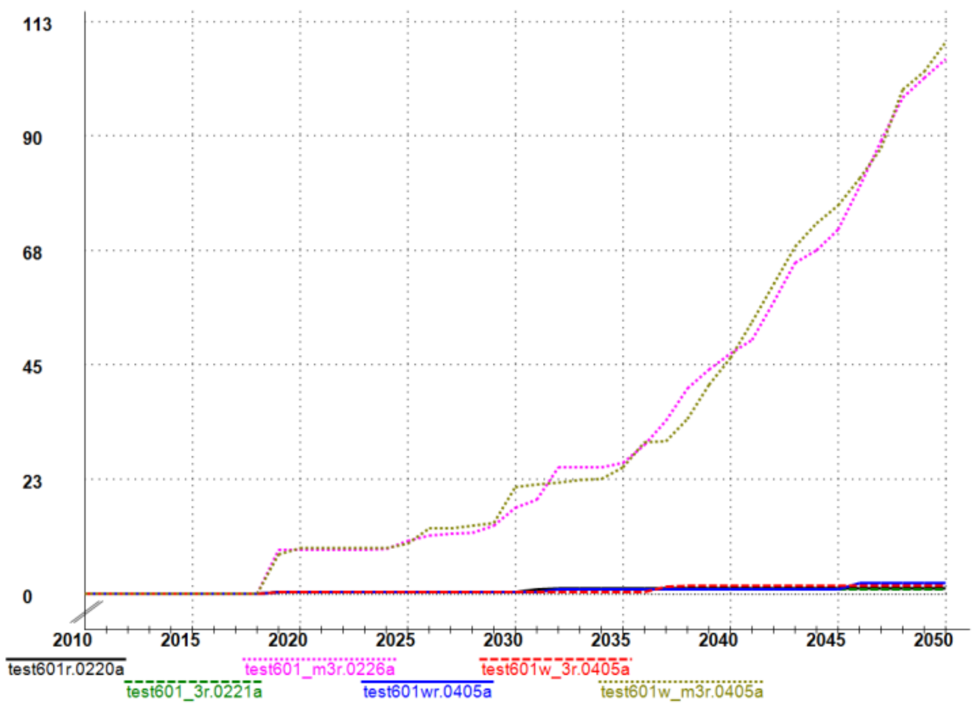
**Table 3: Cumulative PV Capacity Additions (GW) 2050**

| | U.S. Total | |
|---|---|---|
| **NEMS run* (price)** | **Fixed-Tilt** | **Single-Axis Tracker** |
| 50% fixed-tilt | 187.41 | 0.97 |
| 50% fixed-tilt, +3% CF | 198.36 | 0.87 |
| 50% fixed-tilt, -3% CF | 49.42 | 105.55 |
| 50% westward fixed-tilt | 187.99 | 2.04 |
| 50% westward fixed-tilt, +3% CF | 242.08 | 1.58 |
| 50% westward fixed-tilt, -3% CF | 69.27 | 108.85 |
| 75% fixed-tilt | 1.24 | 135.04 |
| 75% fixed-tilt, +3% CF | 144.55 | 19.28 |
| 75% fixed-tilt, -3% CF | 0 | 147.11 |
| 75% westward fixed-tilt | 10.67 | 129.00 |
| 75% westward fixed-tilt, +3% CF | 184.70 | 19.31 |
| 75% westward fixed-tilt, -3% CF | 0.04 | 146.16 |
| 90% fixed-tilt | 0.04 | 142.35 |
| 90% fixed-tilt, +3% CF | 1.96 | 131.95 |
| 90% fixed-tilt, -3% CF | 0 | 151.86 |
| 90% westward fixed-tilt | 0.23 | 145.21 |
| 90% westward fixed-tilt, +3% CF | 17.43 | 127.32 |
| 90% westward fixed-tilt, -3% CF | 0 | 142.75 |
| baseline fixed-tilt | 0.04 | 143.29 |
| baseline fixed-tilt, +3% CF | 0.05 | 143.13 |
| baseline fixed-tilt, -3% CF | 0 | 148.42 |
| baseline westward fixed-tilt | 0 | 151.25 |
| baseline westward fixed-tilt, +3% CF | 1.26 | 130.77 |
| baseline westward fixed-tilt, -3% CF | 0 | 154.01 |

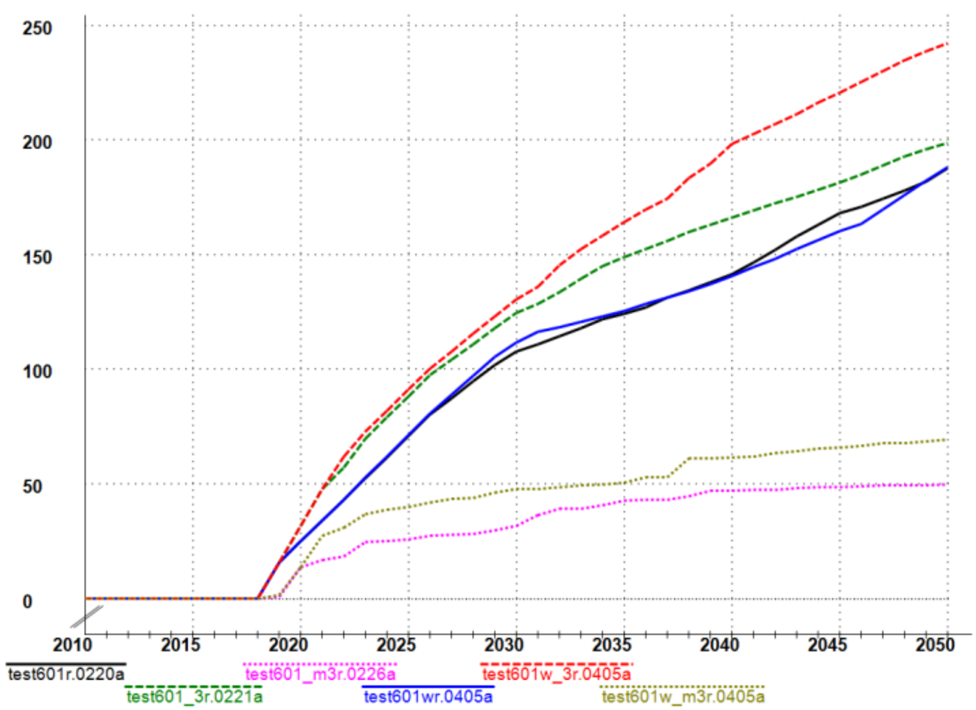
In 2050, no fixed-tilt capacity was built in the 75% cost, 90% cost, and baseline cost southward -3% capacity factor runs, the 90% cost and baseline cost westward -3% capacity factor runs, and the baseline cost westward run. Consequently, these are the runs where the single-axis tracker capacity built was the highest. There was growth from 2019 to 2050 in single-axis tracker capacity additions for all runs, whereas fixed-tilt capacity additions did not grow in certain runs. In the baseline run, fixed-tilt capacity additions only grew to 0.04 GW in 2050, while the single-axis tracker capacity additions grew to 143.29 GW in 2050. In the lowest cost fixed-tilt case (50%), fixed-tilt capacity additions reached 187.41 GW in 2050, while single-axis tracker capacity additions only reached 0.97 GW. Furthermore, in the lowest cost fixed-tilt case with +3% capacity factors, fixed-tilt capacity additions were 198.36 GW in 2050, while single-axis tracker capacity additions were only 0.87 GW in 2050.

Graphs 1-8 show fixed-tilt and single-axis tracker cumulative unplanned capacity additions for all runs for each of the four input capital costs (50%, 75%, 90%, and baseline) using their 1987 $/kW-AC NEMS input value – 601 (50%), 901 (75%), 1081 (90%), and 1201 (baseline). Graphs showing fixed-tilt capital costs for each of these input capital costs can be found in the **Appendix**. Corresponding capital cost graphs for single-axis tracker PV are not included in this report, since single-axis tracker capital costs do not vary from run to run.

**Graph 1: Cumulative Unplanned Additions (GW): Single-Axis Tracker PV, 50% Price**



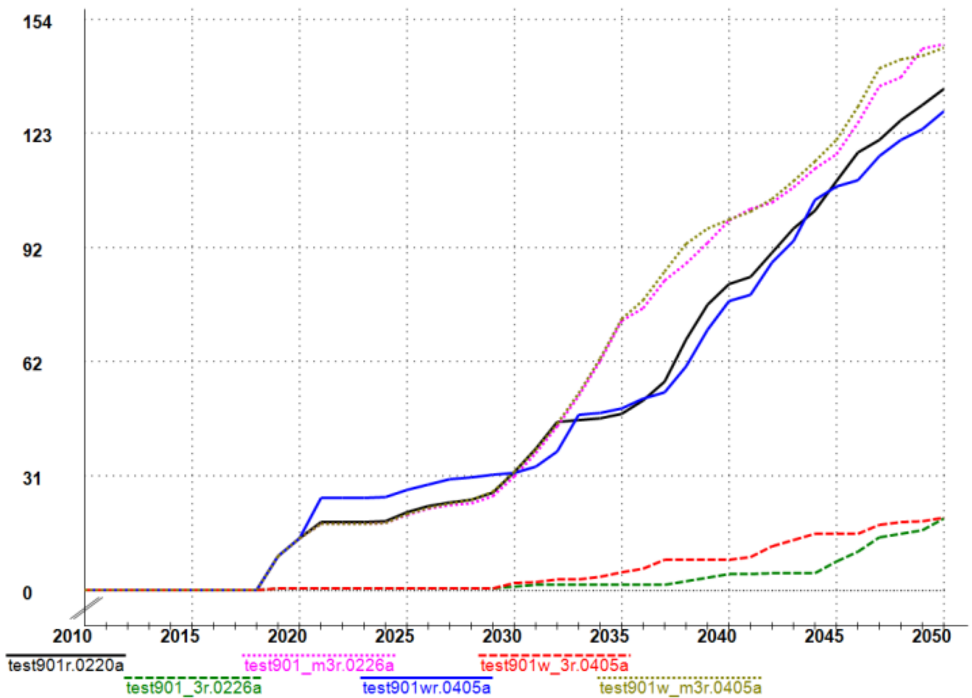

**Graph 2: Cumulative Unplanned Additions (GW): Fixed-Tilt PV, 50% Price**



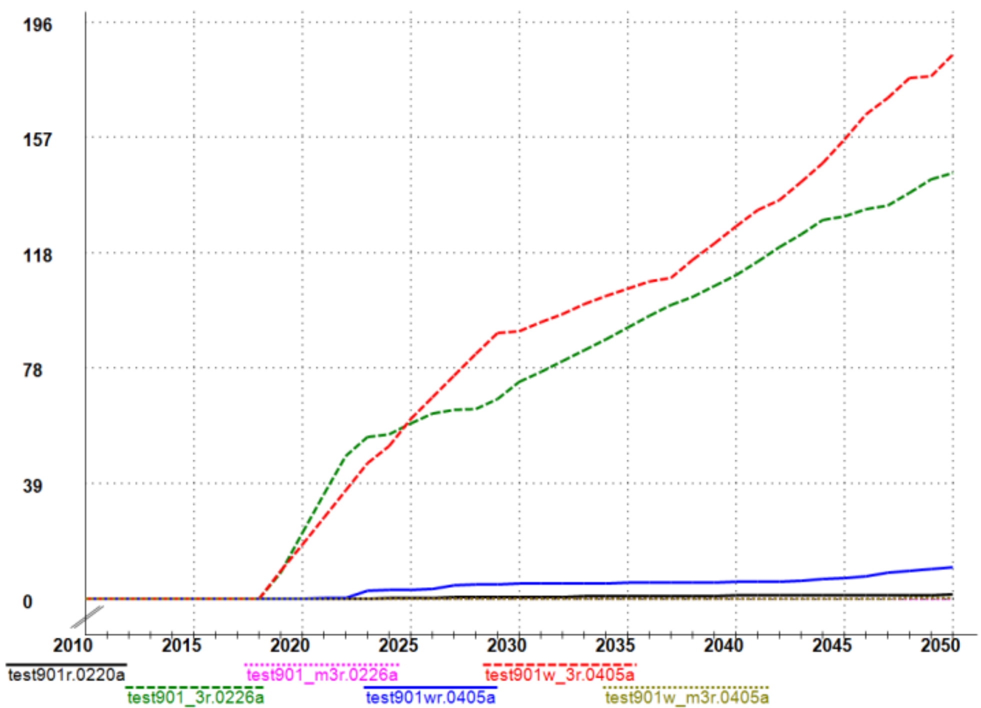
Graph 1 and Graph 2 show that at the 601 input capital cost for both westward and southward facing panels, single-axis tracker capacity additions only have large growth to 2050 when the fixed-tilt capacity factor range is adjusted by -3%. Fixed-tilt capacity additions grow substantially in all other 601 runs. Furthermore, fixed-tilt capacity addition growth is higher with westward orientation, with the exception of the baseline capacity factor runs, where there does not seem to be a noticeable difference in westward versus southward facing orientation.

Graph 3 and Graph 4 show that at the 901 input capital cost, fixed-tilt capacity additions experience large growth only at two runs: both westward and southward orientation where capacity factors are adjusted by +3%. Correspondingly, single-axis tracker capacity additions experience large growth for all runs except these two runs. Fixed-tilt capacity addition growth is higher with westward orientation versus southward orientation in the +3% capacity factor case and the baseline capacity factor case, but there appears to be no discernable difference for the -3% capacity factor case.

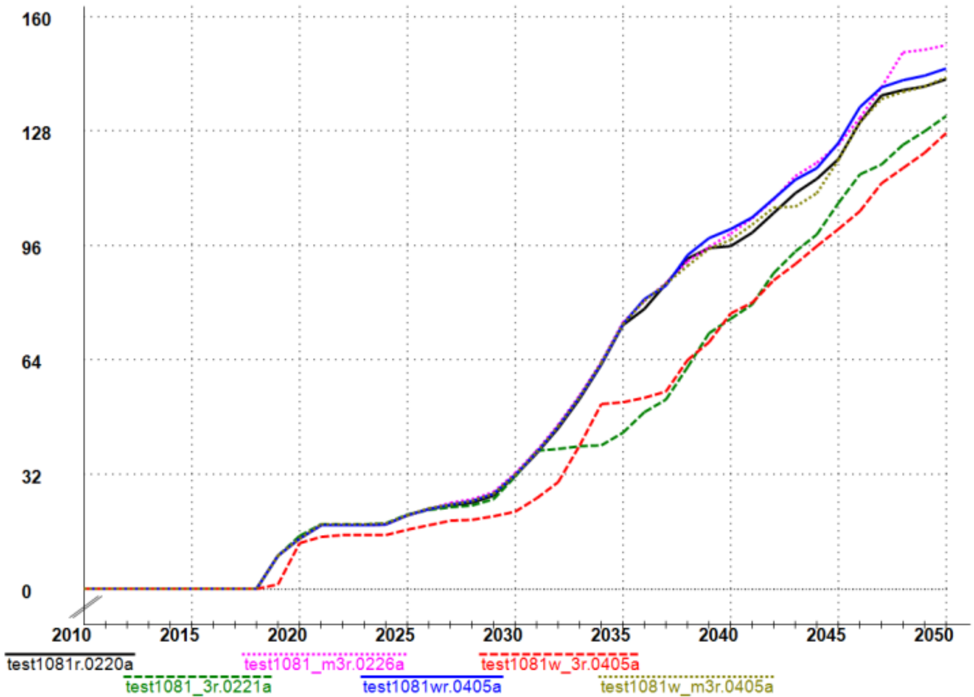
**Graph 3: Cumulative Unplanned Additions (GW): Single-Axis Tracker PV, 75% Price**



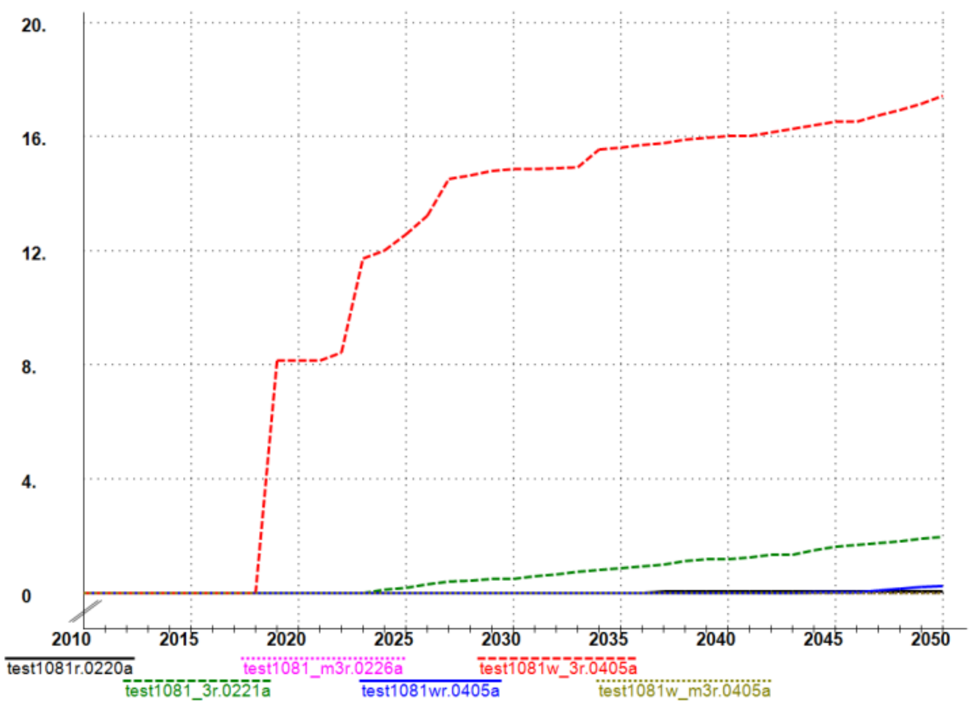

**Graph 4: Cumulative Unplanned Additions (GW): Fixed-Tilt PV, 75% Price**



**Graph 5: Cumulative Unplanned Additions (GW): Single-Axis Tracker PV, 90% Price**



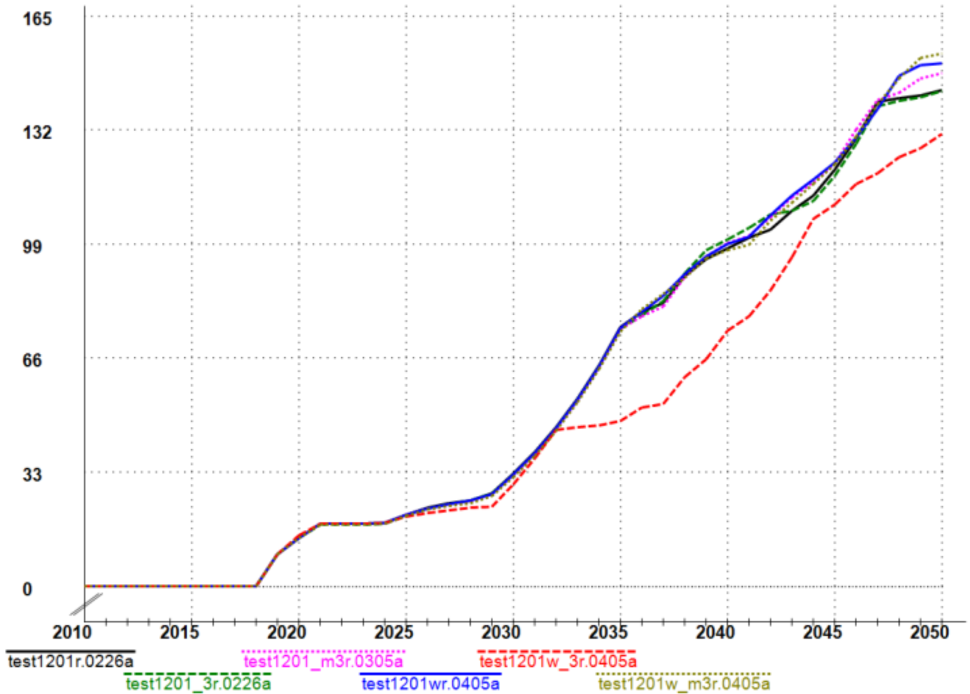

**Graph 6: Cumulative Unplanned Additions (GW): Fixed-Tilt PV, 90% Price**



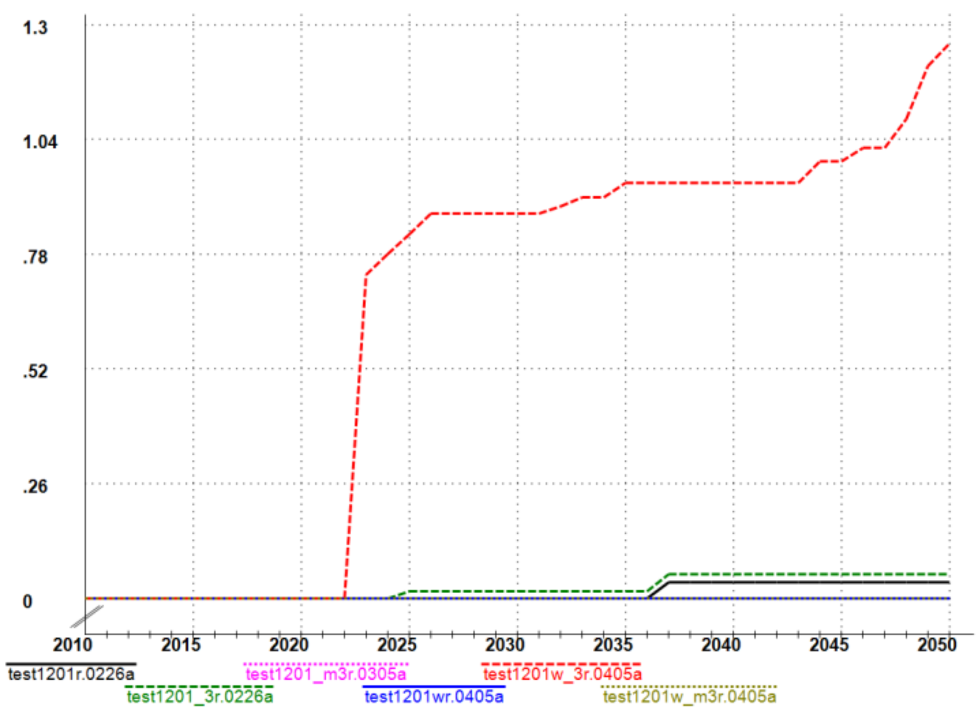
In Graph 5 and Graph 6, there is large fixed-tilt capacity addition growth with the 1081 westward orientation +3% capacity factor range, small growth at the southward orientation +3% capacity factor range, and virtually no growth in all other 1081 runs.  Conversely, single-axis tracker capacity additions grow significantly in all 1081 runs.

In Graph 7 and Graph 8, displaying the 1201 baseline runs, fixed-tilt capacity addition growth only significantly occurs at the westward orientation +3% capacity factor range. Conversely, single-axis tracker capacity additions grow at large rates in all 1201 runs.

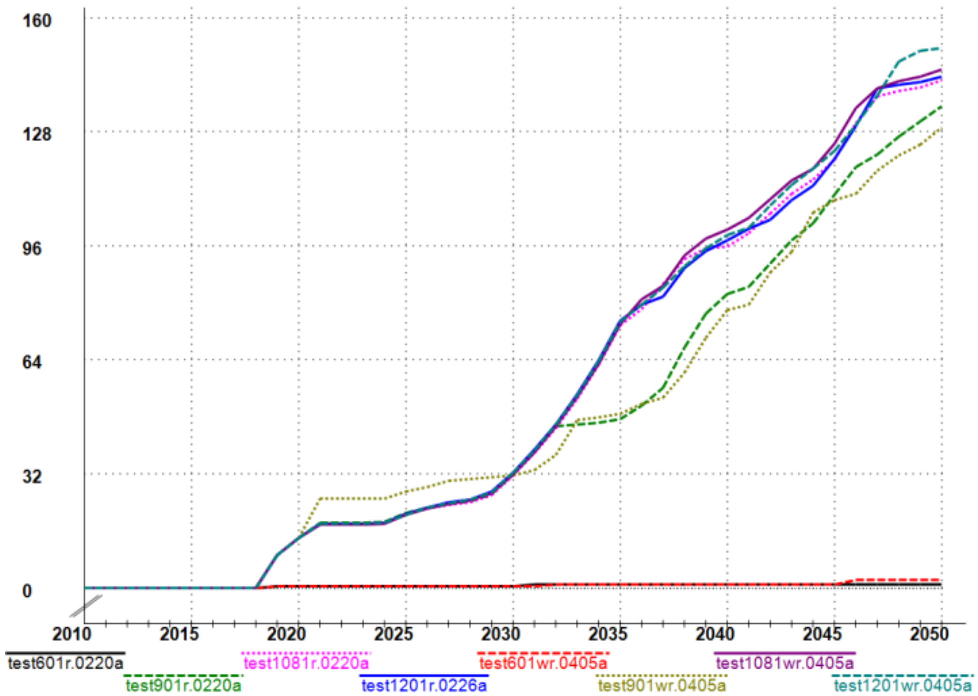
**Graph 7: Cumulative Unplanned Additions (GW): Single-Axis Tracker PV, Baseline Price**



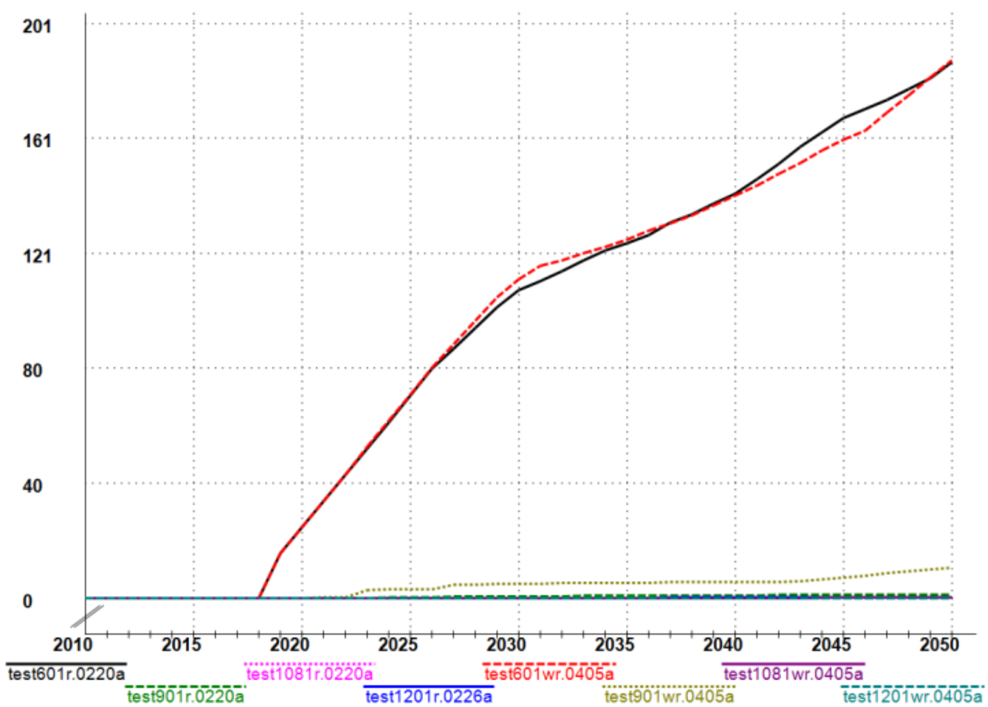

**Graph 8: Cumulative Unplanned Additions (GW): Fixed-Tilt PV, Baseline Price**



**Graph 9: Cumulative Unplanned Additions (GW): Single-Axis Tracker PV, All Prices, Baseline CF**




**Graph 10: Cumulative Unplanned Additions (GW): Fixed-Tilt PV, All Prices, Baseline CF**



Graph 9 and Graph 10 show cumulative unplanned capacity additions for fixed-tilt and single-axis tracker for all input capital costs in the baseline capacity factor range. In Graph 9 and Graph 10, significant fixed-tilt capacity addition growth only occurs at both PV panel orientations at the 601 capital cost. Consequently, large single-axis tracker capacity addition growth occurs at every run in these graphs except the 601 runs.

Capital cost graphs for the runs shown in Graph 9 and Graph 10 can be found in the **Appendix**, as can graphs for the cumulative unplanned capacity additions and capital costs for southward orientation baseline capacity factors versus southward orientation +3% capacity factors for fixed-tilt and single-axis tracker technologies.

**Discussion**

The results of this modeling project closely match the predicted outcomes. Capital costs for both fixed-tilt and single-axis tracker did in fact decline as expected, but the capital costs decreased by 33% between 2019 and 2050 for both technologies. This result indicates that the learning rate for fixed-tilt PV is equivalent to that of single-axis tracker PV, which is how NEMS is programmed for the capital cost learning rate.

As was predicted, the single-axis tracker LCOE for the baseline run decreased at a greater percentage than the fixed-tilt LCOE for the baseline run – 18% compared to 14%. Single-axis tracker LCOE was also lower than fixed-tilt LCOE in many regions and at the national level, and only at the 75% and 50% input capital costs was fixed-tilt LCOE competitive with single-axis tracker LCOE at the national level. It seems evident that despite higher capital costs, in many regions of the U.S., it would be worthwhile for a project developer to build single-axis tracker PV versus fixed-tilt PV because of the increased energy payoff.

Based on the output results for the cumulative unplanned capacity additions, new project development in the utility-scale solar PV market will be dominated by single-axis tracker projects over fixed-tilt projects. At the baseline input capital cost of $2.53/W-AC for single-axis tracker projects and $2.36/W-AC for fixed-tilt projects, single-axis tracker capacity growth vastly outnumbered capacity growth for fixed-tilt projects with a cumulative total of 143.29 GW in 2050, whereas the cumulative total for fixed-tilt projects was a mere 0.04 GW in 2050. So, even though the capital costs for fixed-tilt PV and single-axis tracker PV declined at the same percentage, the capacity addition growth rates and totals from single-axis tracker were greater than those for fixed-tilt, due in large part to the lower single-axis tracker LCOE compared to fixed-tilt. Once again, a drastic decrease in capital costs is needed for fixed-tilt capacity additions to be competitive with single-axis tracker capacity additions.

Also of note, in several of the single-axis tracker cumulative capacity additions graphs, around 2032 certain runs branch off and take a path of lower capacity addition growth than the majority of the runs. The exact reason why NEMS programming produces this deviation in 2032 is unclear, but it may be related to regional developments or constraints in the electricity market.

In the low-cost runs, westward fixed-tilt PV had greater capacity additions than southward fixed-tilt PV despite having higher LCOEs. The PV panel orientation is mainly significant for matching the solar electricity produced with peak electricity load for the purposes of maximizing revenue generation for the solar project owner. Westward fixed-tilt produces a higher LCOE than the traditional southward fixed-tilt, since total energy production on a daily basis is less for westward than southward facing panels. Furthermore, as was seen with the NEMS modeling outputs, just a small increase or decrease (3%) in capacity factors can have large ramifications for the cost and viability of solar projects.

All results considered, this modeling project helped to quantify major techno-economic tradeoffs in the solar energy industry. Data is not the only factor in deciding whether a certain type of solar project is worth the risk, but modeling data can greatly benefit those in the solar industry. New technological trends will always emerge, and other technologies, such as dual-axis trackers, can be considered in future modeling studies.

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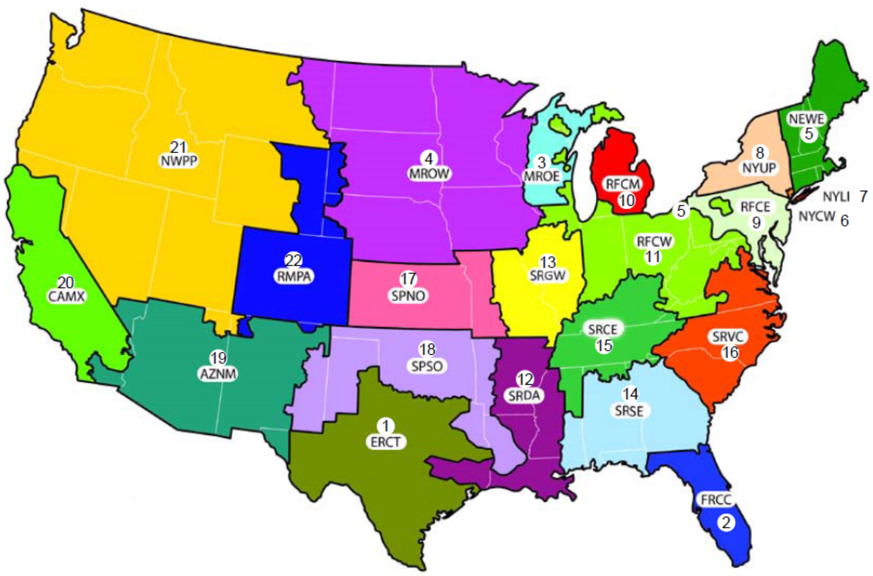
## Appendix

### NERC Regions

Electricity Market Module Regions




1 – Texas Reliability Entity (ERCT)
2 – Florida Reliability Coordinating Council (FRCC)
3 – Midwest Reliability Organization – East (MROE)
4 – Midwest Reliability Organization – West (MROW)
5 – Northeast Power Coordinating Council / New England (NEWE)
6 – Northeast Power Coordinating Council / NYC – Westchester (NYCW)
7 – Northeast Power Coordinating Council / Long Island (NYLI)
8 – Northeast Power Coordinating Council / Upstate New York (NYUP)
9 – Reliability First Corporation/ East (RFCE)
10 – Reliability First Corporation/Michigan (RFCM )
11 – Reliability First Corporation/West (RFCW)
12 – SERC Reliability Corporation / Delta (SRDA)
13 – SERC Reliability Corporation / Gateway (SRGW)
14 – SERC Reliability Corporation / Southeastern (SRSE)
15 – SERC Reliability Corporation / Central (SRCE)
16 – SERC Reliability Corporation / Virginia-Carolina (SRVC)
17 – Southwest Power Pool Regional Entity / North (SPNO)
18 – Southwest Power Pool Regional Entity / South (SPSO)
19 – Western Electricity Coordinating Council / Southwest (AZNM)
20 – Western Electricity Coordinating Council / California (CAMX)
21 – Western Electricity Coordinating Council / Northwest Power Pool Area (NWPP)
22 – Western Electricity Coordinating Council / Rockies (RMPA)

**Table A1: Capital Costs for 2019 and 2050 (2017 $/kW)**

| | Region | | | | |
|---|---|---|---|---|---|
| **NEMS run (price)*** | **National** | **1** | **2** | **3** | **4** |
| 50% fixed-tilt 2019 | 982.8 | 988.7 | 800.5 | 941.5 | 853.7 |
| 50% fixed-tilt 2050 | 658.4 | 662.3 | 536.3 | 630.7 | 571.9 |
| 75% fixed-tilt 2019 | 1473.3 | 1482.2 | 1200.0 | 1411.4 | 1279.8 |
| 75% fixed-tilt 2050 | 986.8 | 992.7 | 803.7 | 945.4 | 857.2 |
| 90% fixed-tilt 2019 | 1767.7 | 1778.3 | 1439.7 | 1693.4 | 1535.4 |
| 90% fixed-tilt 2050 | 1183.9 | 1191.0 | 964.3 | 1134.2 | 1028.3 |
| baseline fixed-tilt 2019 | 1963.9 | 1975.7 | 1599.6 | 1881.4 | 1705.9 |
| baseline fixed-tilt 2050 | 1315.3 | 1323.1 | 1071.3 | 1260.0 | 1142.5 |
| baseline single-axis tracker 2019 | 2107.8 | 2120.4 | 1716.8 | 2019.3 | 1830.9 |
| baseline single-axis tracker 2050 | 1411.6 | 1420.1 | 1149.8 | 1352.3 | 1226.2 |

| NEMS run (price)* | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|
| 50% fixed-tilt 2019 | 1100.4 | 1461.4 | 936.2 | 885.3 | 1038.6 |
| 50% fixed-tilt 2050 | 737.2 | 979.0 | 627.2 | 593.1 | 695.8 |
| 75% fixed-tilt 2019 | 1649.6 | 2190.8 | 1403.5 | 1327.1 | 1557.0 |
| 75% fixed-tilt 2050 | 1104.9 | 1467.4 | 940.0 | 888.9 | 1042.8 |
| 90% fixed-tilt 2019 | 1979.2 | 2628.5 | 1683.8 | 1592.3 | 1868.1 |
| 90% fixed-tilt 2050 | 1325.5 | 1760.4 | 1127.7 | 1066.4 | 1251.1 |
| baseline fixed-tilt 2019 | 2198.9 | 2920.3 | 1870.8 | 1769.0 | 2075.4 |
| baseline fixed-tilt 2050 | 1472.6 | 1955.8 | 1252.9 | 1184.8 | 1390.0 |
| baseline single-axis tracker 2019 | 2360.0 | 3134.3 | 2007.8 | 1898.7 | 2227.5 |
| baseline single-axis tracker 2050 | 1580.5 | 2099.1 | 1344.7 | 1271.6 | 1491.8 |

| NEMS run (price)* | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|
| 50% fixed-tilt 2019 | 1358.3 | 899.4 | 853.8 | 744.9 | 749.8 |
| 50% fixed-tilt 2050 | 909.9 | 602.6 | 572.0 | 499.0 | 502.3 |
| 75% fixed-tilt 2019 | 2036.2 | 1348.4 | 1279.9 | 1116.7 | 1124.1 |
| 75% fixed-tilt 2050 | 1363.8 | 903.1 | 857.3 | 747.9 | 752.9 |
| 90% fixed-tilt 2019 | 2443.0 | 1617.8 | 1535.7 | 1339.8 | 1348.7 |
| 90% fixed-tilt 2050 | 1636.2 | 1083.5 | 1028.5 | 897.3 | 903.3 |
| baseline fixed-tilt 2019 | 2714.2 | 1797.3 | 1706.1 | 1488.5 | 1498.4 |
| baseline fixed-tilt 2050 | 1817.8 | 1203.7 | 1142.6 | 996.9 | 1003.5 |
| baseline single-axis tracker 2019 | 2913.1 | 1929.0 | 1831.1 | 1597.6 | 1608.2 |
| baseline single-axis tracker 2050 | 1951.0 | 1291.9 | 1226.4 | 1069.9 | 1077.0 |

| NEMS run (price)* | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|
| 50% fixed-tilt 2019 | 633.5 | 784.4 | 656.0 | 847.9 | 1009.0 |

| | | | | | |
|---|---|---|---|---|---|
| 50% fixed-tilt 2050 | 424.4 | 525.5 | 439.4 | 568.0 | 675.9 |
| 75% fixed-tilt 2019 | 949.7 | 1175.9 | 983.4 | 1271.1 | 1512.6 |
| 75% fixed-tilt 2050 | 636.1 | 787.6 | 658.6 | 851.4 | 1013.1 |
| 90% fixed-tilt 2019 | 1139.4 | 1410.8 | 1179.8 | 1525.0 | 1814.8 |
| 90% fixed-tilt 2050 | 763.1 | 944.9 | 790.2 | 1021.4 | 1215.4 |
| baseline fixed-tilt 2019 | 1265.9 | 1567.5 | 1310.8 | 1694.3 | 2016.2 |
| baseline fixed-tilt 2050 | 847.8 | 1049.8 | 877.9 | 1134.7 | 1350.3 |
| baseline single-axis tracker 2019 | 1358.6 | 1682.3 | 1406.9 | 1818.5 | 2164.0 |
| baseline single-axis tracker 2050 | 909.9 | 1126.7 | 942.2 | 1217.9 | 1449.2 |

| **NEMS run (price)*** | **20** | **21** | **22** |
|---|---|---|---|
| 50% fixed-tilt 2019 | 1060.9 | 664.8 | 871.3 |
| 50% fixed-tilt 2050 | 710.7 | 445.4 | 583.7 |
| 75% fixed-tilt 2019 | 1590.5 | 996.6 | 1306.2 |
| 75% fixed-tilt 2050 | 1065.3 | 667.5 | 874.9 |
| 90% fixed-tilt 2019 | 1908.2 | 1195.7 | 1567.2 |
| 90% fixed-tilt 2050 | 1278.0 | 800.8 | 1049.6 |
| baseline fixed-tilt 2019 | 2120.1 | 1328.4 | 1741.2 |
| baseline fixed-tilt 2050 | 1419.9 | 889.7 | 1166.1 |
| baseline single-axis tracker 2019 | 2275.4 | 1425.8 | 1868.7 |
| baseline single-axis tracker 2050 | 1523.9 | 954.9 | 1251.5 |

**Table A2: LCOE 2019 (2017 $/MWh)**

| | **Region** | | | | |
|---|---|---|---|---|---|
| **NEMS run (price)*** | **National** | **1** | **2** | **3** | **4** |
| 50% fixed-tilt | 44.1 | 38.6 | 36.7 | 52.0 | 41.8 |
| 50% fixed-tilt, +3% CF | 38.5 | 34.5 | 32.5 | 44.5 | 36.6 |
| 50% fixed-tilt, -3% CF | 51.5 | 43.9 | 42.2 | 62.4 | 48.8 |
| 50% westward fixed-tilt | 50.5 | 43.9 | 42.2 | 58.4 | 48.8 |
| 50% westward fixed-tilt, +3% CF | 43.5 | 38.7 | 36.8 | 49.2 | 42.0 |
| 50% westward fixed-tilt, -3% CF | 60.6 | 50.8 | 49.7 | 71.9 | 58.6 |
| 75% fixed-tilt | 58.0 | 51.3 | 47.9 | 68.8 | 54.9 |
| 75% fixed-tilt, +3% CF | 50.7 | 45.8 | 42.4 | 58.9 | 48.0 |
| 75% fixed-tilt, -3% CF | 67.9 | 58.3 | 55.1 | 82.5 | 64.1 |
| 75% westward fixed-tilt | 66.5 | 58.3 | 55.1 | 77.3 | 64.0 |
| 75% westward fixed-tilt, +3% CF | 57.2 | 51.4 | 47.9 | 65.1 | 55.1 |
| 75% westward fixed-tilt, -3% CF | 79.7 | 67.5 | 64.8 | 95.2 | 76.9 |
| 90% fixed-tilt | 66.4 | 58.9 | 54.6 | 78.8 | 62.7 |
| 90% fixed-tilt, +3% CF | 58.0 | 52.6 | 48.3 | 67.6 | 54.9 |
| 90% fixed-tilt, -3% CF | 77.6 | 67.0 | 62.8 | 94.6 | 73.2 |
| 90% westward fixed-tilt | 76.1 | 67.0 | 62.8 | 88.7 | 73.2 |

| | | | | | |
|---|---|---|---|---|---|
| 90% westward fixed-tilt, +3% CF | 65.6 | 59.1 | 54.7 | 74.8 | 63.0 |
| 90% westward fixed-tilt, -3% CF | 91.2 | 77.5 | 73.9 | 109.1 | 87.8 |
| baseline fixed-tilt | 71.9 | 64.0 | 59.1 | 85.5 | 67.9 |
| baseline fixed-tilt, +3% CF | 62.9 | 57.1 | 52.2 | 73.3 | 59.4 |
| baseline fixed-tilt, -3% CF | 84.2 | 72.7 | 67.9 | 102.6 | 79.3 |
| baseline westward fixed-tilt | 82.5 | 72.7 | 67.9 | 96.2 | 79.3 |
| baseline westward fixed-tilt, +3% CF | 71.1 | 64.2 | 59.2 | 81.1 | 68.3 |
| baseline westward fixed-tilt, -3% CF | 98.9 | 84.2 | 79.9 | 118.4 | 95.1 |
| baseline single-axis tracker | 60.1 | 53.5 | 49.6 | 70.0 | 57.7 |

| **NEMS run (price)*** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|
| 50% fixed-tilt | 59.8 | 62.3 | 46.2 | 52.1 | 47.5 |
| 50% fixed-tilt, +3% CF | 51.3 | 54.5 | 40.5 | 44.7 | 41.6 |
| 50% fixed-tilt, -3% CF | 71.8 | 72.7 | 54.0 | 62.6 | 55.4 |
| 50% westward fixed-tilt | 67.3 | 72.7 | 53.9 | 58.6 | 55.4 |
| 50% westward fixed-tilt, +3% CF | 56.6 | 62.9 | 46.3 | 49.4 | 47.7 |
| 50% westward fixed-tilt, -3% CF | 82.8 | 87.3 | 64.8 | 72.2 | 66.5 |
| 75% fixed-tilt | 79.5 | 84.7 | 60.6 | 67.9 | 63.4 |
| 75% fixed-tilt, +3% CF | 68.1 | 74.1 | 53.0 | 58.2 | 55.5 |
| 75% fixed-tilt, -3% CF | 95.4 | 98.8 | 70.7 | 81.5 | 74.0 |
| 75% westward fixed-tilt | 89.4 | 98.8 | 70.7 | 76.4 | 73.9 |
| 75% westward fixed-tilt, +3% CF | 75.2 | 85.4 | 60.6 | 64.3 | 63.6 |
| 75% westward fixed-tilt, -3% CF | 110.0 | 118.5 | 84.8 | 94.1 | 88.7 |
| 90% fixed-tilt | 91.2 | 98.1 | 69.1 | 77.4 | 72.9 |
| 90% fixed-tilt, +3% CF | 78.2 | 85.8 | 60.5 | 66.4 | 63.8 |
| 90% fixed-tilt, -3% CF | 109.5 | 114.4 | 80.7 | 92.9 | 85.0 |
| 90% westward fixed-tilt | 102.6 | 114.4 | 80.7 | 87.1 | 85.0 |
| 90% westward fixed-tilt, +3% CF | 86.4 | 99.0 | 69.3 | 73.3 | 73.2 |
| 90% westward fixed-tilt, -3% CF | 126.3 | 137.3 | 96.8 | 107.2 | 102.1 |
| baseline fixed-tilt | 99.1 | 107.0 | 74.9 | 83.7 | 79.2 |
| baseline fixed-tilt, +3% CF | 84.9 | 93.6 | 65.5 | 71.8 | 69.3 |
| baseline fixed-tilt, -3% CF | 118.9 | 124.8 | 87.3 | 100.5 | 92.5 |
| baseline westward fixed-tilt | 111.4 | 124.9 | 87.3 | 94.2 | 92.5 |
| baseline westward fixed-tilt, +3% CF | 93.9 | 108.0 | 75.1 | 79.3 | 79.6 |
| baseline westward fixed-tilt, -3% CF | 137.2 | 149.8 | 104.8 | 115.9 | 110.9 |
| baseline single-axis tracker | 81.1 | 91.9 | 63.6 | 68.2 | 67.7 |

| **NEMS run (price)*** | **10** | **11** | **12** | **13** | **14** |
|---|---|---|---|---|---|
| 50% fixed-tilt | 75.2 | 50.5 | 38.2 | 38.5 | 35.3 |
| 50% fixed-tilt, +3% CF | 63.3 | 43.2 | 33.8 | 33.7 | 31.2 |
| 50% fixed-tilt, -3% CF | 92.6 | 60.6 | 44.0 | 45.0 | 40.6 |

| | | | | | |
|---|---|---|---|---|---|
| 50% westward fixed-tilt | 85.9 | 56.7 | 43.9 | 44.9 | 40.6 |
| 50% westward fixed-tilt, +3% CF | 70.7 | 47.8 | 38.3 | 38.7 | 35.3 |
| 50% westward fixed-tilt, -3% CF | 109.4 | 69.9 | 51.7 | 53.9 | 47.8 |
| 75% fixed-tilt | 102.5 | 66.5 | 50.1 | 49.9 | 45.8 |
| 75% fixed-tilt, +3% CF | 86.2 | 57.0 | 44.3 | 43.7 | 40.5 |
| 75% fixed-tilt, -3% CF | 126.1 | 79.8 | 57.7 | 58.2 | 52.6 |
| 75% westward fixed-tilt | 117.1 | 74.8 | 57.6 | 58.2 | 52.6 |
| 75% westward fixed-tilt, +3% CF | 96.3 | 62.9 | 50.2 | 50.1 | 45.8 |
| 75% westward fixed-tilt, -3% CF | 149.0 | 92.1 | 67.8 | 69.9 | 61.9 |
| 90% fixed-tilt | 118.8 | 76.1 | 57.3 | 56.7 | 52.0 |
| 90% fixed-tilt, +3% CF | 100.0 | 65.3 | 50.7 | 49.7 | 46.1 |
| 90% fixed-tilt, -3% CF | 146.2 | 91.3 | 65.9 | 66.2 | 59.9 |
| 90% westward fixed-tilt | 135.7 | 85.6 | 65.9 | 66.2 | 59.9 |
| 90% westward fixed-tilt, +3% CF | 111.8 | 72.1 | 57.4 | 57.0 | 52.1 |
| 90% westward fixed-tilt, -3% CF | 172.8 | 105.4 | 77.5 | 79.4 | 70.4 |
| baseline fixed-tilt | 129.7 | 82.5 | 62.0 | 61.3 | 56.2 |
| baseline fixed-tilt, +3% CF | 109.2 | 70.7 | 54.9 | 53.6 | 49.7 |
| baseline fixed-tilt, -3% CF | 159.6 | 99.0 | 71.3 | 71.5 | 64.7 |
| baseline westward fixed-tilt | 148.2 | 92.8 | 71.3 | 71.5 | 64.7 |
| baseline westward fixed-tilt, +3% CF | 122.1 | 78.2 | 62.2 | 61.6 | 56.3 |
| baseline westward fixed-tilt, -3% CF | 188.6 | 114.3 | 83.9 | 85.8 | 76.1 |
| baseline single-axis tracker | 108.0 | 67.4 | 52.2 | 51.9 | 47.1 |

| **NEMS run (price)*** | **15** | **16** | **17** | **18** | **19** |
|---|---|---|---|---|---|
| 50% fixed-tilt | 35.1 | 39.7 | 32.7 | 35.0 | 40.7 |
| 50% fixed-tilt, +3% CF | 30.7 | 34.8 | 28.9 | 31.3 | 36.4 |
| 50% fixed-tilt, -3% CF | 41.0 | 46.4 | 37.6 | 39.8 | 46.3 |
| 50% westward fixed-tilt | 41.0 | 46.3 | 37.6 | 39.8 | 46.3 |
| 50% westward fixed-tilt, +3% CF | 35.1 | 39.7 | 32.7 | 35.1 | 40.9 |
| 50% westward fixed-tilt, -3% CF | 49.2 | 55.6 | 44.2 | 46.1 | 53.6 |
| 75% fixed-tilt | 44.8 | 51.7 | 41.8 | 45.9 | 53.7 |
| 75% fixed-tilt, +3% CF | 39.2 | 45.2 | 37.0 | 41.0 | 47.9 |
| 75% fixed-tilt, -3% CF | 52.3 | 60.3 | 48.1 | 52.2 | 61.0 |
| 75% westward fixed-tilt | 52.3 | 60.3 | 48.1 | 52.1 | 61.0 |
| 75% westward fixed-tilt, +3% CF | 44.8 | 51.7 | 41.9 | 46.0 | 53.9 |
| 75% westward fixed-tilt, -3% CF | 62.7 | 72.4 | 56.6 | 60.4 | 70.6 |
| 90% fixed-tilt | 50.6 | 58.9 | 47.3 | 52.4 | 61.4 |
| 90% fixed-tilt, +3% CF | 44.3 | 51.6 | 41.9 | 46.8 | 54.9 |
| 90% fixed-tilt, -3% CF | 59.0 | 68.7 | 54.4 | 59.6 | 69.8 |
| 90% westward fixed-tilt | 59.0 | 68.7 | 54.4 | 59.6 | 69.8 |
| 90% westward fixed-tilt, +3% CF | 50.6 | 58.9 | 47.4 | 52.6 | 61.8 |
| 90% westward fixed-tilt, -3% CF | 70.8 | 82.5 | 64.0 | 69.0 | 80.9 |

| | | | | | |
|---|---|---|---|---|---|
| baseline fixed-tilt | 54.5 | 63.7 | 51.0 | 56.8 | 66.6 |
| baseline fixed-tilt, +3% CF | 47.7 | 55.7 | 45.1 | 50.7 | 59.5 |
| baseline fixed-tilt, -3% CF | 63.6 | 74.3 | 58.6 | 64.5 | 75.7 |
| baseline westward fixed-tilt | 63.6 | 74.3 | 58.6 | 64.5 | 75.7 |
| baseline westward fixed-tilt, +3% CF | 54.5 | 63.7 | 51.1 | 57.0 | 67.0 |
| baseline westward fixed-tilt, -3% CF | 76.3 | 89.2 | 69.0 | 74.7 | 87.7 |
| baseline single-axis tracker | 45.9 | 54.0 | 42.5 | 47.3 | 55.6 |

| NEMS run (price)* | 20 | 21 | 22 |
|---|---|---|---|
| 50% fixed-tilt | 42.1 | 31.9 | 37.2 |
| 50% fixed-tilt, +3% CF | 37.6 | 28.5 | 33.2 |
| 50% fixed-tilt, -3% CF | 47.8 | 36.2 | 42.3 |
| 50% westward fixed-tilt | 48.0 | 36.4 | 42.3 |
| 50% westward fixed-tilt, +3% CF | 42.8 | 32.7 | 37.5 |
| 50% westward fixed-tilt, -3% CF | 55.3 | 42.0 | 48.9 |
| 75% fixed-tilt | 55.7 | 40.4 | 48.4 |
| 75% fixed-tilt, +3% CF | 49.7 | 36.2 | 43.2 |
| 75% fixed-tilt, -3% CF | 63.3 | 45.9 | 55.0 |
| 75% westward fixed-tilt | 63.6 | 46.1 | 55.0 |
| 75% westward fixed-tilt, +3% CF | 56.7 | 41.4 | 48.8 |
| 75% westward fixed-tilt, -3% CF | 73.3 | 53.2 | 63.7 |
| 90% fixed-tilt | 63.9 | 45.5 | 55.1 |
| 90% fixed-tilt, +3% CF | 57.1 | 40.8 | 49.2 |
| 90% fixed-tilt, -3% CF | 72.6 | 51.7 | 62.6 |
| 90% westward fixed-tilt | 72.9 | 51.9 | 62.6 |
| 90% westward fixed-tilt, +3% CF | 65.1 | 46.7 | 55.6 |
| 90% westward fixed-tilt, -3% CF | 84.0 | 59.9 | 72.5 |
| baseline fixed-tilt | 69.3 | 48.9 | 59.6 |
| baseline fixed-tilt, +3% CF | 61.9 | 43.8 | 53.2 |
| baseline fixed-tilt, -3% CF | 78.7 | 55.6 | 67.7 |
| baseline westward fixed-tilt | 79.1 | 55.8 | 67.7 |
| baseline westward fixed-tilt, +3% CF | 70.6 | 50.2 | 60.1 |
| baseline westward fixed-tilt, -3% CF | 91.2 | 64.4 | 78.4 |
| baseline single-axis tracker | 57.9 | 40.4 | 49.5 |

**Table A3: LCOE 2050 (2017 $/MWh)**

| | Region | | | | |
|---|---|---|---|---|---|
| **NEMS run (price)*** | **National** | **1** | **2** | **3** | **4** |
| 50% fixed-tilt | 39.8 | 34.1 | 32.7 | 46.0 | 37.2 |
| 50% fixed-tilt, +3% CF | 34.9 | 30.4 | 29.0 | 43.5 | 32.6 |
| 50% fixed-tilt, -3% CF | 46.5 | 38.7 | 37.7 | 55.1 | 43.4 |

| | | | | | |
|---|---|---|---|---|---|
| 50% westward fixed-tilt | 45.6 | 38.7 | 37.6 | 51.7 | 43.4 |
| 50% westward fixed-tilt, +3% CF | 39.2 | 34.2 | 32.8 | 43.6 | 37.4 |
| 50% westward fixed-tilt, -3% CF | 54.6 | 44.8 | 44.3 | 63.6 | 52.1 |
| 75% fixed-tilt | 51.1 | 44.5 | 41.9 | 59.7 | 47.9 |
| 75% fixed-tilt, +3% CF | 44.9 | 39.7 | 37.1 | 51.2 | 41.9 |
| 75% fixed-tilt, -3% CF | 59.2 | 50.5 | 48.1 | 71.6 | 55.8 |
| 75% westward fixed-tilt | 58.5 | 50.5 | 48.2 | 67.2 | 55.8 |
| 75% westward fixed-tilt, +3% CF | 50.5 | 44.6 | 41.9 | 56.6 | 48.1 |
| 75% westward fixed-tilt, -3% CF | 69.7 | 58.5 | 56.7 | 82.6 | 67.0 |
| 90% fixed-tilt | 57.5 | 50.7 | 47.4 | 67.9 | 54.3 |
| 90% fixed-tilt, +3% CF | 50.6 | 45.2 | 41.9 | 58.2 | 47.5 |
| 90% fixed-tilt, -3% CF | 67.3 | 57.6 | 54.5 | 81.5 | 63.3 |
| 90% westward fixed-tilt | 66.0 | 57.6 | 54.5 | 76.4 | 63.3 |
| 90% westward fixed-tilt, +3% CF | 57.1 | 50.9 | 47.5 | 64.4 | 54.5 |
| 90% westward fixed-tilt, -3% CF | 79.1 | 66.7 | 64.1 | 94.0 | 76.0 |
| baseline fixed-tilt | 62.1 | 54.8 | 51.0 | 73.4 | 58.5 |
| baseline fixed-tilt, +3% CF | 54.3 | 49.0 | 45.1 | 62.9 | 51.2 |
| baseline fixed-tilt, -3% CF | 72.7 | 62.3 | 58.7 | 88.1 | 68.3 |
| baseline westward fixed-tilt | 71.2 | 62.3 | 58.7 | 82.6 | 68.3 |
| baseline westward fixed-tilt, +3% CF | 61.3 | 55.0 | 51.1 | 69.6 | 58.8 |
| baseline westward fixed-tilt, -3% CF | 85.4 | 72.2 | 69.0 | 101.7 | 81.9 |
| baseline single-axis tracker | 49.3 | 43.5 | 40.7 | 57.0 | 47.3 |

| **NEMS run (price)*** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|
| 50% fixed-tilt | 52.9 | 54.3 | 41.2 | 46.6 | 48.8 |
| 50% fixed-tilt, +3% CF | 45.3 | 47.6 | 36.0 | 39.9 | 41.8 |
| 50% fixed-tilt, -3% CF | 63.4 | 63.4 | 48.1 | 55.9 | 58.6 |
| 50% westward fixed-tilt | 59.4 | 63.4 | 48.0 | 52.4 | 54.9 |
| 50% westward fixed-tilt, +3% CF | 50.1 | 54.9 | 41.3 | 44.1 | 46.2 |
| 50% westward fixed-tilt, -3% CF | 73.2 | 76.1 | 57.7 | 64.5 | 67.6 |
| 75% fixed-tilt | 68.9 | 72.6 | 52.9 | 59.5 | 64.0 |
| 75% fixed-tilt, +3% CF | 59.1 | 63.5 | 46.3 | 51.0 | 54.8 |
| 75% fixed-tilt, -3% CF | 82.6 | 84.6 | 61.7 | 71.3 | 63.9 |
| 75% westward fixed-tilt | 77.5 | 84.7 | 61.7 | 66.9 | 71.9 |
| 75% westward fixed-tilt, +3% CF | 65.3 | 73.3 | 53.0 | 56.3 | 60.6 |
| 75% westward fixed-tilt, -3% CF | 95.4 | 101.6 | 74.0 | 82.4 | 76.7 |
| 90% fixed-tilt | 78.5 | 83.6 | 59.9 | 67.2 | 62.6 |
| 90% fixed-tilt, +3% CF | 67.3 | 73.1 | 52.4 | 57.6 | 62.6 |
| 90% fixed-tilt, -3% CF | 94.2 | 97.5 | 69.9 | 80.7 | 73.0 |
| 90% westward fixed-tilt | 88.3 | 97.5 | 69.9 | 75.6 | 73.0 |
| 90% westward fixed-tilt, +3% CF | 74.4 | 84.4 | 60.1 | 63.7 | 69.2 |
| 90% westward fixed-tilt, -3% CF | 108.7 | 117.0 | 83.9 | 93.1 | 87.6 |

| | | | | | |
|---|---|---|---|---|---|
| baseline fixed-tilt | 84.9 | 90.9 | 64.6 | 72.4 | 67.8 |
| baseline fixed-tilt, +3% CF | 72.8 | 79.5 | 56.5 | 62.0 | 59.3 |
| baseline fixed-tilt, -3% CF | 101.9 | 106.0 | 75.3 | 86.9 | 79.1 |
| baseline westward fixed-tilt | 95.6 | 106.1 | 75.4 | 81.4 | 79.1 |
| baseline westward fixed-tilt, +3% CF | 80.5 | 91.7 | 64.7 | 68.6 | 68.1 |
| baseline westward fixed-tilt, -3% CF | 117.6 | 127.2 | 90.4 | 100.2 | 94.9 |
| baseline single-axis tracker | 66.0 | 73.9 | 52.1 | 56.0 | 54.9 |

| **NEMS run (price)*** | **10** | **11** | **12** | **13** | **14** |
|---|---|---|---|---|---|
| 50% fixed-tilt | 65.4 | 44.7 | 37.2 | 34.5 | 34.6 |
| 50% fixed-tilt, +3% CF | 55.1 | 38.3 | 32.6 | 30.2 | 30.3 |
| 50% fixed-tilt, -3% CF | 80.5 | 53.7 | 43.4 | 40.2 | 36.3 |
| 50% westward fixed-tilt | 74.7 | 50.3 | 43.4 | 40.2 | 40.4 |
| 50% westward fixed-tilt, +3% CF | 61.6 | 42.4 | 37.2 | 34.7 | 34.6 |
| 50% westward fixed-tilt, -3% CF | 95.1 | 61.9 | 52.1 | 48.3 | 42.7 |
| 75% fixed-tilt | 87.7 | 57.9 | 43.7 | 43.8 | 40.2 |
| 75% fixed-tilt, +3% CF | 73.8 | 49.6 | 41.9 | 38.3 | 38.5 |
| 75% fixed-tilt, -3% CF | 107.8 | 69.4 | 50.2 | 51.0 | 46.1 |
| 75% westward fixed-tilt | 100.2 | 65.1 | 50.3 | 51.1 | 46.2 |
| 75% westward fixed-tilt, +3% CF | 82.5 | 54.8 | 47.9 | 44.0 | 40.2 |
| 75% westward fixed-tilt, -3% CF | 127.5 | 80.1 | 59.1 | 61.3 | 54.3 |
| 90% fixed-tilt | 101.0 | 65.7 | 49.5 | 49.4 | 45.3 |
| 90% fixed-tilt, +3% CF | 85.1 | 56.3 | 43.8 | 43.2 | 40.0 |
| 90% fixed-tilt, -3% CF | 124.4 | 78.9 | 57.0 | 57.6 | 52.1 |
| 90% westward fixed-tilt | 115.5 | 73.9 | 57.0 | 57.6 | 52.1 |
| 90% westward fixed-tilt, +3% CF | 95.1 | 62.3 | 49.7 | 49.6 | 45.3 |
| 90% westward fixed-tilt, -3% CF | 147.0 | 91.0 | 67.0 | 69.1 | 61.3 |
| baseline fixed-tilt | 109.9 | 71.0 | 53.4 | 53.1 | 48.7 |
| baseline fixed-tilt, +3% CF | 92.6 | 60.8 | 47.3 | 46.5 | 43.1 |
| baseline fixed-tilt, -3% CF | 135.3 | 85.1 | 61.5 | 61.9 | 56.0 |
| baseline westward fixed-tilt | 125.7 | 79.8 | 61.5 | 61.9 | 56.0 |
| baseline westward fixed-tilt, +3% CF | 103.5 | 67.2 | 53.5 | 53.4 | 48.7 |
| baseline westward fixed-tilt, -3% CF | 159.9 | 98.3 | 72.3 | 74.3 | 65.9 |
| baseline single-axis tracker | 86.8 | 55.1 | 42.7 | 42.7 | 38.8 |

| **NEMS run (price)*** | **15** | **16** | **17** | **18** | **19** |
|---|---|---|---|---|---|
| 50% fixed-tilt | 31.7 | 35.5 | 29.4 | 31.1 | 36.1 |
| 50% fixed-tilt, +3% CF | 27.7 | 31.0 | 26.0 | 27.8 | 32.3 |
| 50% fixed-tilt, -3% CF | 37.0 | 41.4 | 33.9 | 35.4 | 41.1 |
| 50% westward fixed-tilt | 37.0 | 41.4 | 33.9 | 35.4 | 41.0 |
| 50% westward fixed-tilt, +3% CF | 31.7 | 35.5 | 29.5 | 31.2 | 36.3 |

| | | | | | |
|---|---|---|---|---|---|
| 50% westward fixed-tilt, -3% CF | 44.4 | 49.6 | 39.8 | 40.9 | 47.5 |
| 75% fixed-tilt | 39.6 | 45.3 | 36.9 | 40.0 | 46.7 |
| 75% fixed-tilt, +3% CF | 34.7 | 39.6 | 32.7 | 35.7 | 41.7 |
| 75% fixed-tilt, -3% CF | 46.2 | 52.8 | 42.4 | 45.5 | 53.1 |
| 75% westward fixed-tilt | 46.2 | 52.8 | 42.5 | 45.5 | 53.1 |
| 75% westward fixed-tilt, +3% CF | 39.6 | 45.3 | 37.0 | 40.1 | 47.0 |
| 75% westward fixed-tilt, -3% CF | 55.4 | 63.4 | 50.0 | 52.7 | 61.5 |
| 90% fixed-tilt | 44.3 | 51.1 | 41.4 | 45.4 | 53.1 |
| 90% fixed-tilt, +3% CF | 38.8 | 44.7 | 36.6 | 40.5 | 47.4 |
| 90% fixed-tilt, -3% CF | 51.7 | 59.7 | 47.6 | 51.5 | 60.3 |
| 90% westward fixed-tilt | 51.7 | 59.7 | 47.6 | 51.6 | 60.3 |
| 90% westward fixed-tilt, +3% CF | 44.4 | 51.2 | 41.5 | 45.5 | 53.4 |
| 90% westward fixed-tilt, -3% CF | 62.1 | 71.6 | 56.0 | 59.7 | 69.8 |
| baseline fixed-tilt | 47.5 | 55.1 | 44.4 | 48.9 | 57.3 |
| baseline fixed-tilt, +3% CF | 41.6 | 48.2 | 39.3 | 43.7 | 51.2 |
| baseline fixed-tilt, -3% CF | 55.4 | 64.2 | 51.1 | 55.6 | 65.1 |
| baseline westward fixed-tilt | 55.4 | 64.2 | 51.1 | 55.6 | 65.1 |
| baseline westward fixed-tilt, +3% CF | 47.5 | 55.1 | 44.5 | 49.1 | 57.6 |
| baseline westward fixed-tilt, -3% CF | 66.5 | 77.1 | 60.1 | 64.4 | 75.4 |
| baseline single-axis tracker | 38.1 | 44.4 | 35.3 | 38.7 | 45.4 |

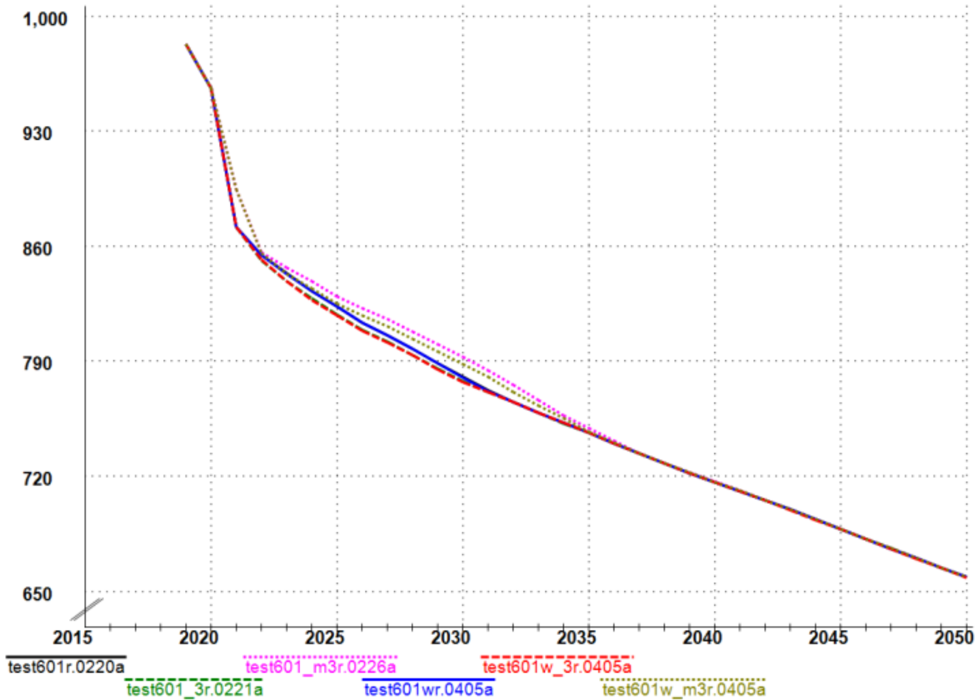
| **NEMS run (price)*** | **20** | **21** | **22** |
|---|---|---|---|
| 50% fixed-tilt | 37.2 | 28.9 | 36.1 |
| 50% fixed-tilt, +3% CF | 33.3 | 25.9 | 32.0 |
| 50% fixed-tilt, -3% CF | 42.3 | 32.8 | 41.5 |
| 50% westward fixed-tilt | 42.5 | 33.0 | 41.5 |
| 50% westward fixed-tilt, +3% CF | 37.9 | 29.6 | 36.2 |
| 50% westward fixed-tilt, -3% CF | 49.0 | 38.0 | 48.9 |
| 75% fixed-tilt | 48.4 | 35.9 | 46.1 |
| 75% fixed-tilt, +3% CF | 43.2 | 32.1 | 40.8 |
| 75% fixed-tilt, -3% CF | 54.9 | 40.7 | 52.9 |
| 75% westward fixed-tilt | 55.2 | 40.9 | 53.0 |
| 75% westward fixed-tilt, +3% CF | 49.3 | 36.8 | 46.1 |
| 75% westward fixed-tilt, -3% CF | 63.6 | 47.2 | 62.3 |
| 90% fixed-tilt | 55.0 | 40.1 | 52.0 |
| 90% fixed-tilt, +3% CF | 49.2 | 35.9 | 46.0 |
| 90% fixed-tilt, -3% CF | 62.5 | 45.5 | 59.8 |
| 90% westward fixed-tilt | 62.8 | 45.7 | 59.8 |
| 90% westward fixed-tilt, +3% CF | 56.1 | 41.1 | 52.1 |
| 90% westward fixed-tilt, -3% CF | 72.4 | 52.7 | 70.4 |
| baseline fixed-tilt | 59.5 | 42.8 | 56.0 |
| baseline fixed-tilt, +3% CF | 53.1 | 38.4 | 49.5 |

| | | | |
|---|---|---|---|
| baseline fixed-tilt, -3% CF | 67.6 | 48.7 | 64.4 |
| baseline westward fixed-tilt | 67.9 | 48.9 | 64.4 |
| baseline westward fixed-tilt, +3% CF | 60.6 | 43.9 | 56.1 |
| baseline westward fixed-tilt, -3% CF | 78.3 | 56.4 | 75.8 |
| baseline single-axis tracker | 47.2 | 33.7 | 44.6 |

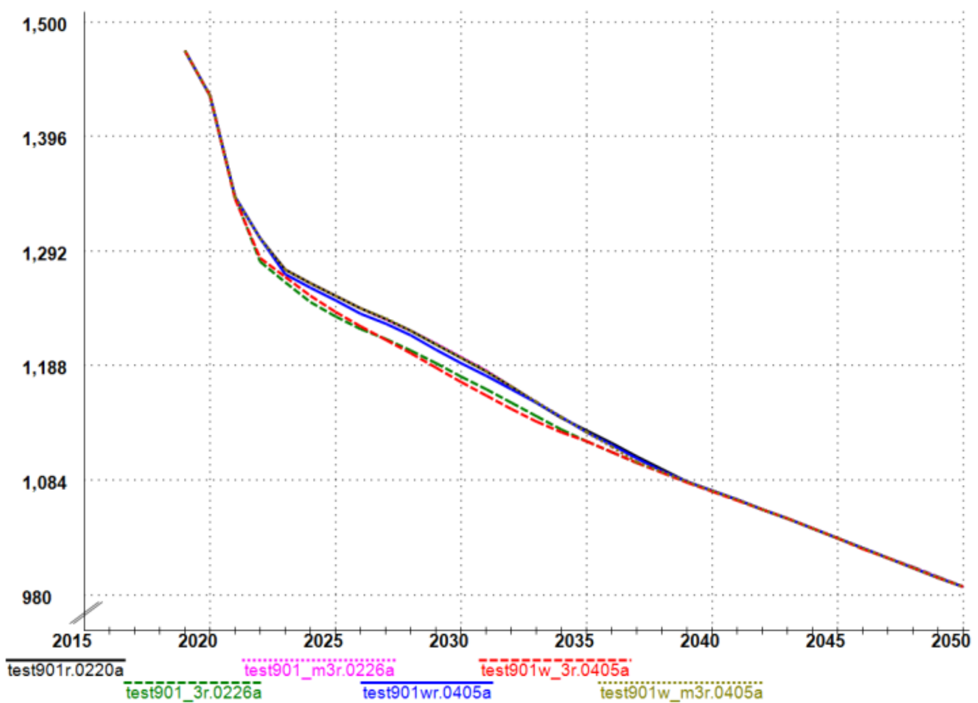
**Table A4: Cumulative PV Capacity Additions (GW) 2019**

| | **U.S. Total** | |
|---|---|---|
| **NEMS run* (price)** | **Fixed-Tilt** | **Single-Axis Tracker** |
| 50% fixed-tilt | 15.65 | 0.25 |
| 50% fixed-tilt, +3% CF | 15.66 | 0.24 |
| 50% fixed-tilt, -3% CF | 0.51 | 8.64 |
| 50% westward fixed-tilt | 15.65 | 0.25 |
| 50% westward fixed-tilt, +3% CF | 15.66 | 0.24 |
| 50% westward fixed-tilt, -3% CF | 1.38 | 7.77 |
| 75% fixed-tilt | 0 | 9.14 |
| 75% fixed-tilt, +3% CF | 8.89 | 0.25 |
| 75% fixed-tilt, -3% CF | 0 | 9.14 |
| 75% westward fixed-tilt | 0 | 9.14 |
| 75% westward fixed-tilt, +3% CF | 9.28 | 0.24 |
| 75% westward fixed-tilt, -3% CF | 0 | 9.14 |
| 90% fixed-tilt | 0 | 9.14 |
| 90% fixed-tilt, +3% CF | 0 | 9.14 |
| 90% fixed-tilt, -3% CF | 0 | 9.14 |
| 90% westward fixed-tilt | 0 | 9.14 |
| 90% westward fixed-tilt, +3% CF | 8.12 | 1.02 |
| 90% westward fixed-tilt, -3% CF | 0 | 9.14 |
| baseline fixed-tilt | 0 | 9.14 |
| baseline fixed-tilt, +3% CF | 0 | 9.14 |
| baseline fixed-tilt, -3% CF | 0 | 9.14 |
| baseline westward fixed-tilt | 0 | 9.14 |
| baseline westward fixed-tilt, +3% CF | 0 | 9.14 |
| baseline westward fixed-tilt, -3% CF | 0 | 9.14 |

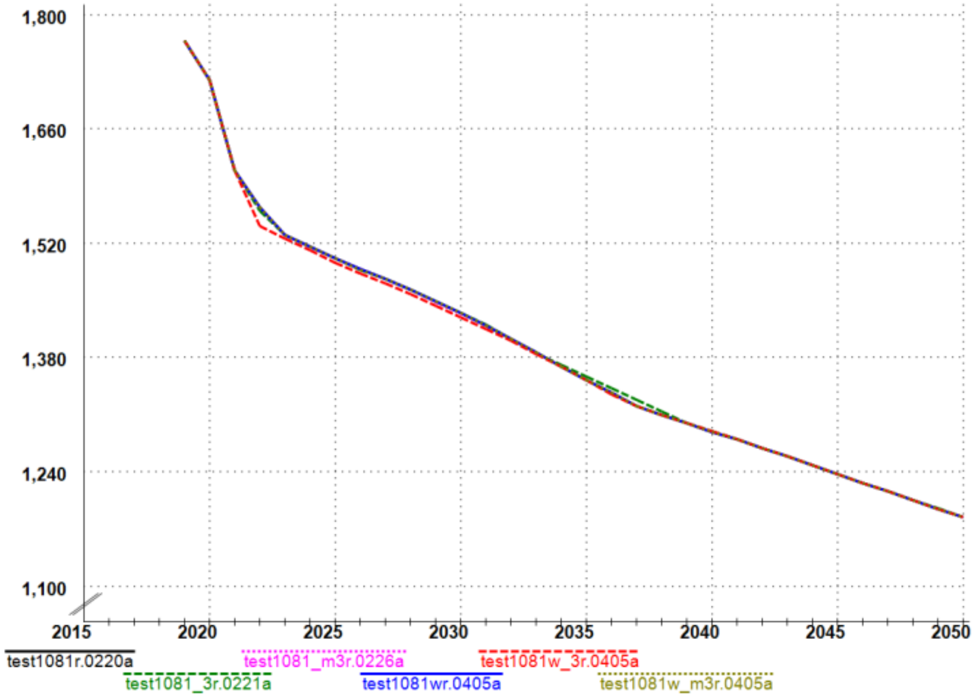
**Graph A1: Capital Costs (2017 $/kW): Fixed-Tilt PV, 50% Price**



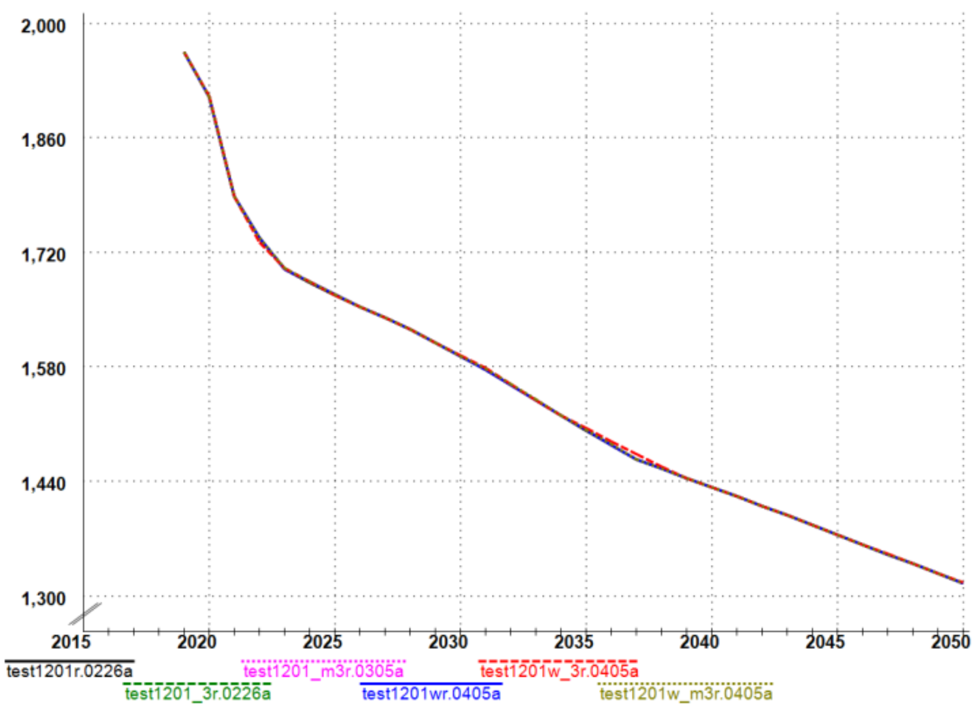

**Graph A2: Capital Costs (2017 $/kW): Fixed-Tilt PV, 75% Price**



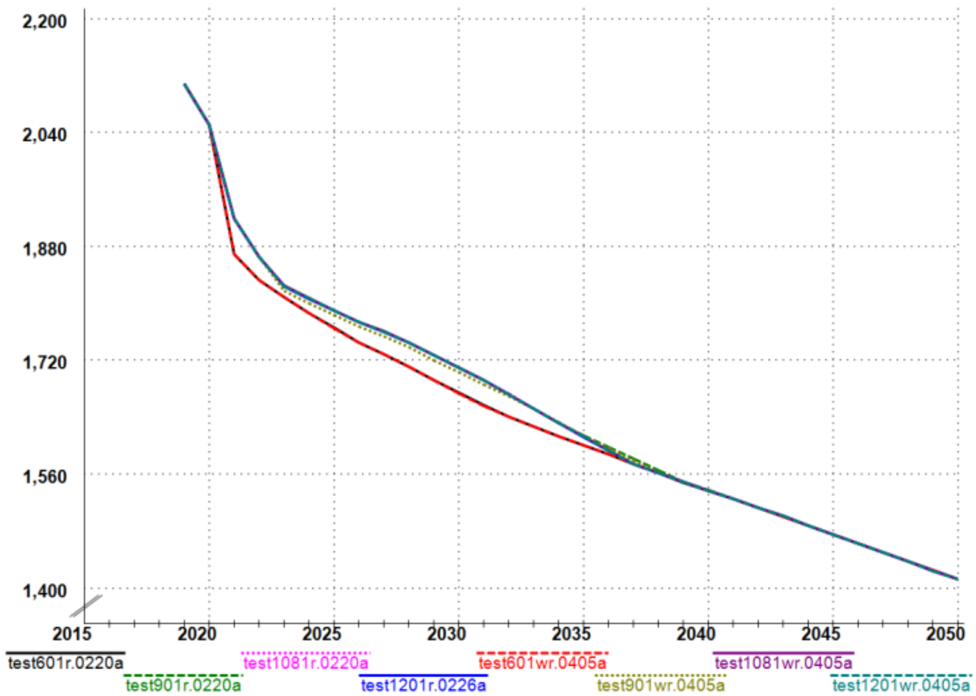
**Graph A3: Capital Costs (2017 $/kW): Fixed-Tilt PV, 90% Price**



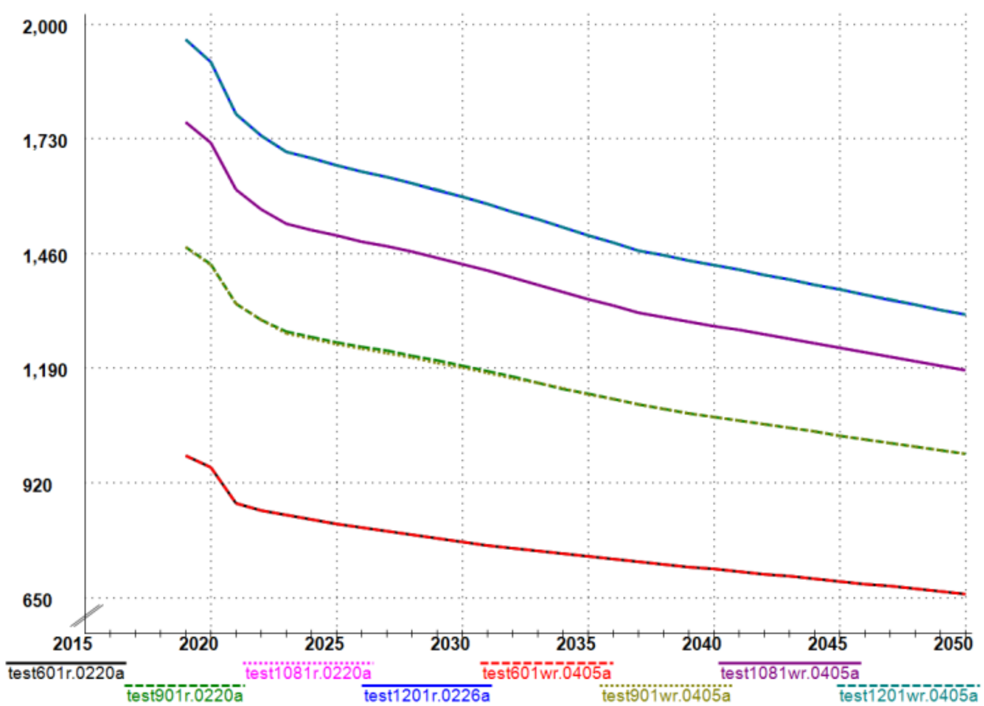

**Graph A4: Capital Costs (2017 $/kW): Fixed-Tilt PV, Baseline Price**



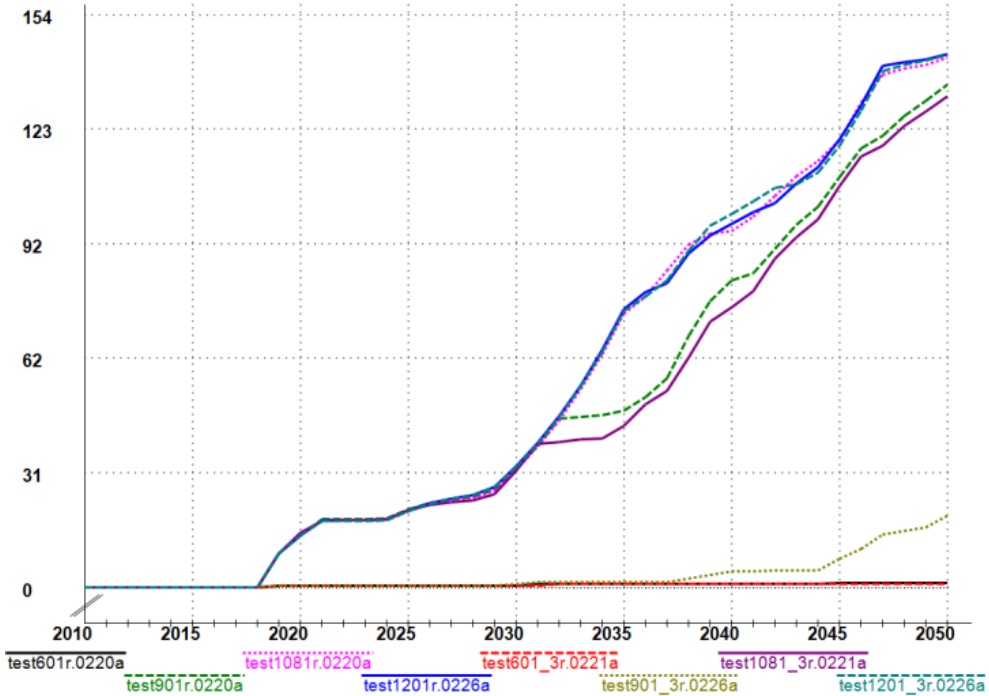
**Graph A5: Capital Costs (2017 $/kW): Single-Axis Tracker PV, All Prices, Baseline CF**



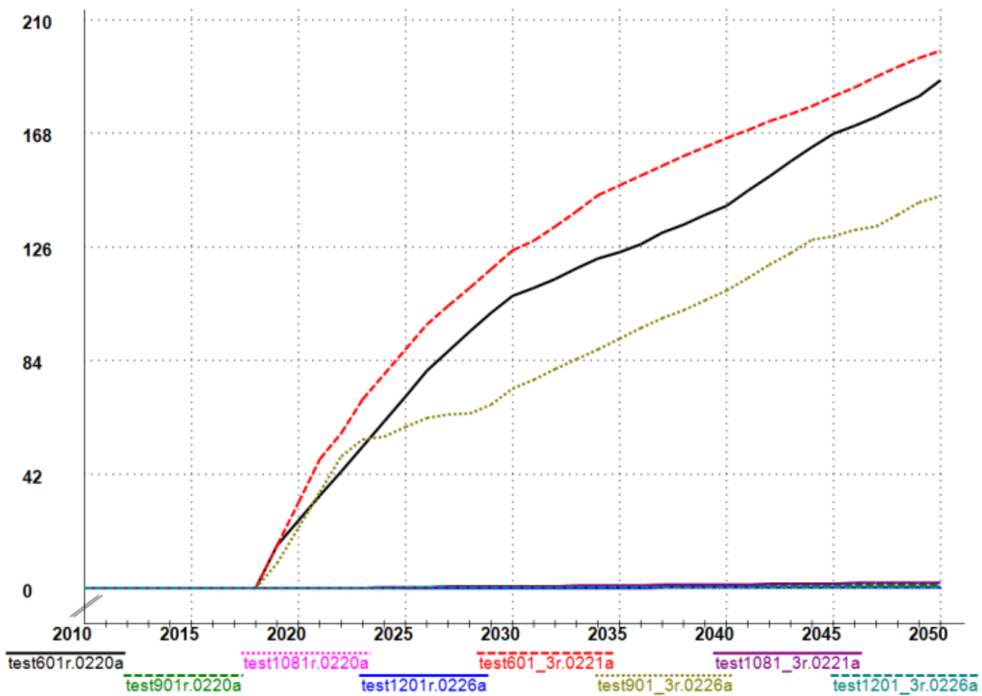

**Graph A6: Capital Costs (2017 $/kW): Fixed-Tilt PV, All Prices, Baseline CF**



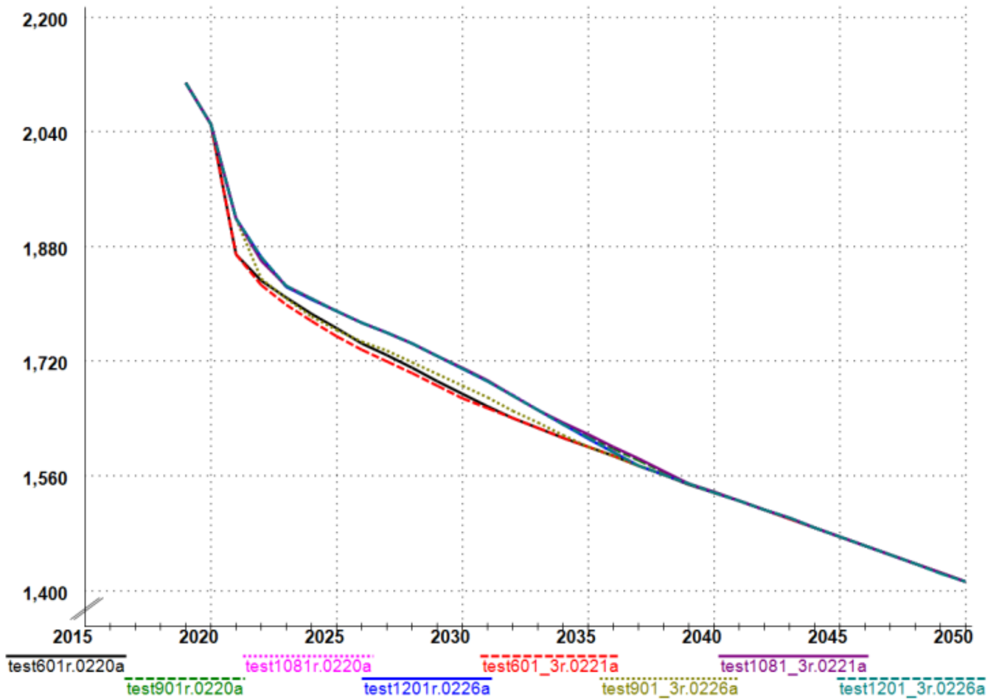
**Graph A7: Cumulative Unplanned Additions (GW): Single-Axis Tracker PV, All Prices, Baseline/+3% CF**



**Graph A8: Cumulative Unplanned Additions (GW): Fixed-Tilt PV, All Prices, Baseline/+3% CF**



**Graph A9: Capital Costs (2017 $/kW): Single-Axis Tracker PV, All Prices, Baseline/+3% CF**




**Graph A10: Capital Costs (2017 $/kW): Fixed-Tilt PV, All Prices, Baseline/+3% CF**