# SPECs Early-Stage Decision Model

## User's Manual

Version 4 • September 2022

NC CLEAN ENERGY TECHNOLOGY CENTER

SPECs Solar-Plus for Electric Co-ops

Cliburn and Associates, LLC

## Acknowledgments

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Version 4 of this Manual documents 2022 updates to the SPECs Early-Stage Decision model that were completed under contract to North Carolina State University (NC Clean Energy Technology Center) as part of the Center's 2022 American Rescue Plan grant. We acknowledge the NCCETC team, Electricities of North Carolina and their member utilities for contributions to this update. It incorporates customizations, including a new use case and financing options that appropriate for use of incentives under the Inflation Reduction Act (IRA) of 2022. References to IRA incentives are based on currently available information, pending full implementation of the Act.

The SPECs ESD Model is an open-access software tool, suited to user customization. The authors welcome user feedback. Further information and the downloadable model are posted on [the Community Solar Value Project website;] information on current applications, as well as limited technical support, is also available from [NC Clean Energy Technology Center].

## Disclaimer

This manual is co-authored by Christian Casillas, Cliburn and Associates, LLC, Simon Sandler, NCCETC, and Jill K. Cliburn (jkcliburn@cliburnenergy.com), Principal Investigator for SPECs and President, Cliburn and Associates, LLC, under Subcontract No. AGR-2020-10205, as part of the Solar Energy Innovation Network, a collaborative research effort administered by the National Renewable Energy Laboratory under Contract No. DE-AC36-08GO28308 funded by the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. Additional support for this update was provided by Emily Wichart, NCCETC. The views expressed herein do not necessarily represent the views of Alliance for Sustainable Energy, LLC, the DOE, or the U.S. Government.

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# 1 INTRODUCTION

Solar-Plus for Electric Co-ops (SPECs) is a project of Cliburn and Associates, LLC, with the North Carolina Clean Energy Technology Center (NCCETC) and co-funded by the Solar Energy Innovation Network. Led by the National Renewable Energy Laboratory (NREL) and supported by the U.S. DOE Solar Energy Technologies Office, the Innovation Network was created to support project teams across the United States that are pursuing novel applications of solar and other distributed energy resources by providing critical technical expertise and facilitated stakeholder engagement. This approach helps to ensure all perspectives are heard, key barriers are identified, and the resulting solutions are robust and ready for replication. The 2022 update (Version 4 of this manual) was co-funded by the North Carolina Clean Energy Technology Center, with support from an American Recovery Plan grant. This update includes small refinements for applications in the public power sector, as well as addition of a new use case and a direct-purchase option, which has become attractive to many non-taxable utilities since passage of the Inflation Reduction Act (IRA) of 2022.

SPECs aims to increase the pace and impact of front-of-the-meter (FTM), solar-plus-storage procurements for electric cooperative utilities (co-ops). Electric distribution co-ops are a primary target audience, but local public power utilities, wholesale power suppliers, and other entities sponsoring, or co-sponsoring solar-plus-storage projects are also likely beneficiaries. Working in partnership with numerous co-ops and industry stakeholders, SPECs identified a combination of factors, including utility staff limitations, the fast-changing and specialized nature of the storage industry, and the needs of utility decision-making boards, which could be addressed in part by a streamlined early-stage decision-support tool.

The SPECs Early-Stage Decision (ESD) model is an Excel-based spreadsheet model, which provides information about the economic and strategic value of a proposed battery-storage project or solar-plus-storage (solar-plus) project. The assumed battery chemistry is lithium-ion (Li-Ion), though the model is for the most part agnostic to specific technologies. The model can be used to explore combinations of storage-related project value streams in order to define a project, while educating utility decision-makers about project benefits and costs. A sensitivity analysis function speeds the development of "what-if" scenarios. A gap analysis function solves for top-priority metrics and supports the inclusion of hard-to-monetize values, such as the value of storage to defer system upgrades if the project can be sited strategically on the local grid. Model outputs include the utility data, assumptions, and use-case scenarios that are recommended content for the requests for proposals (RFPs).

The model may also provide an initial "sanity check" for RFP responses, supporting further discussions and more refined modeling. *The ESD is not a "finance-grade" modeling tool, and users are cautioned to be mindful of its limitations,* but the model has been reviewed by users, who recommend it as a way to drive faster, better informed project planning.

The model focuses on the exploration of likely battery energy storage system value streams. In particular, the model helps characterize savings and costs from local demand charge reduction, wholesale coincident peak reduction, energy arbitrage, ancillary services sales, distribution upgrade deferral, and increased resiliency. As noted above, the original model (2021) assumes procurement using a solar power purchase agreement (PPA) and an energy storage service agreement (ESA), but 2022 ESD update also includes a direct-purchase option. Further, the ESD model is designed around a process that readily incorporates data and some value outputs from NREL's System Advisor Model (SAM), which is accessible at https://sam.nrel.gov/. SAM is a free software model that facilitates technical and economic decision-making for people in the renewable energy industry. The ESD model process flow, shown in Figure 1, includes scenario definition, data collection and running SAM, additional data entry, and the analysis of results.

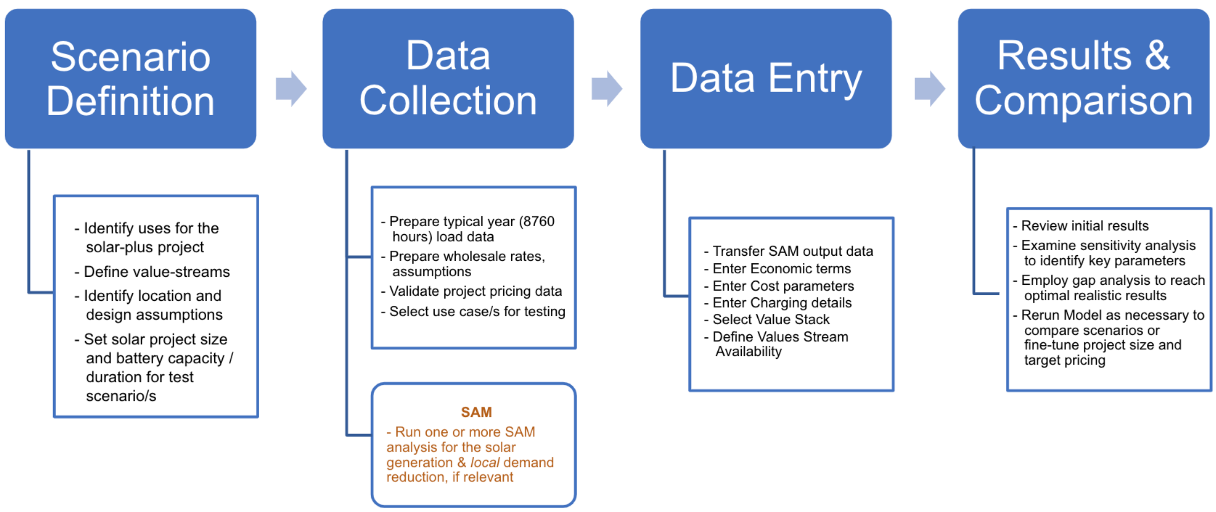


**Figure 1: SPECs Early-Stage Decision Model Process Flow.**

## 2 NREL'S SYSTEM ADVISOR MODEL (SAM)

Excel-based models are not ideal for running computationally intensive calculations. In order to keep the Excel-based ESD model user-friendly, it dovetails with specific functions of a more complex and detailed model. SAM is a robust technical and financial simulation tool from NREL that allows users to model location-specific solar photovoltaic (PV) system performance and aspects of solar-plus-storage system performance; however, it does not currently allow for the exploration of multiple value streams from solar-plus-storage systems, nor is it customized for local utility use. The ESD model taps SAM to simulate annual hourly values for a solar PV system and to simulate the hourly charging and discharging of the battery to reduce local system peak demand. This hourly time series data will then be imported into the ESD model to explore the costs and benefits of adding (or "stacking") additional values for the solar-plus-storage system. Details for downloading free SAM software, setting appropriate parameters, and importing the simulation outputs in the ESD model are detailed in an Appendix of this manual, Section 6.3, Using SAM to Prepare the ESD model. Figure 2, below, is also included in that Appendix.

## Parameters and Defaults to Run SAM and the ESD Model

| SAM Parameters | Default Value |
|---|---|
| Battery Size (kWh-AC) | ** |
| Battery Power (kW-AC) | ** |
| Min Battery State of Charge | 0.15 |
| Max Battery State of Charge | 0.95 |
| PV Array Size (kW-DC) | ** |
| PV Degradation Rate | 0.5 %/year |
| System Load Data (hourly data, typical year) | |

| ESD Model Parameters | Default Value |
|---|---|
| PV PPA Price ($/kWh) | ** |
| Battery ESA price ($/kWh) | ** |
| Contract Price Escalator | 0 |
| PV System Unit Cost ($/W DC) | ** |
| Battery Energy Unit Cost ($/kWh AC) | ** |
| IRA Direct-Payment (or ITC) Incentive | 30% |
| Utility Tax Rate (for MACRS) | 35% |
| Loan Term | |
| Battery Calendar-Life Degradation Rate | 1.0 %/year |
| Battery End of Life | 80% |
| Battery Turnovers to Reach 90% of Capacity | 1300 |
| Wholesale Energy Cost 1 ($/kWh) | |
| Wholesale Energy Cost 2 ($/kWh) | 0 $/kWh |
| Electricity Cost Escalation rate/year | 0 |
| Utility Local Demand Charge ($/kW) | |

| | |
|---|---|
| Utility Demand Escalation (rate/year) | 0 |
| Utility Coincident Peak Demand Charge ($/kW) | |
| Freq Regulation Capacity Payment | 0.011 $/kW-hr |
| Freq Regulation Nominal Price Decline | 5 %/yr |
| Freq Regulation hrs/day Available | 24 hrs |
| Inflation Rate | 0.025 /yr |
| Utility Nominal Discount Rate | 0.07 /yr |
| REC Price | 0.002 $/kWh |
| Infrastructure Deferral Capital Cost ($)* | |
| Infrastructure Deferral Years* | |
| Microgrid Controller/Additional Infrastructure Unit Cost* | 300,000 $/MW |
| Anticipated Outage Duration (hrs)* | |
| Peak of Lost Load (kW)* | |
| Ave Lost Load (kW)* | |

**Figure 2: Parameters and Defaults to Run SAM and the ESD Model. Data marked with an asterisk (*) represent optional parameters and are not required for basic use of the model. Data marked with two asterisks (**) represent key system-design parameters that may be estimated and then refined through further modeling, as discussed in this manual and its references. All defaults may be adjusted.**

# 3 DETERMINING INITIAL BATTERY/PV SIZES

Setting initial battery and PV system sizes is prerequisite to using the ESD model. Users may have various constraints, guiding them to PV size and battery capacity. For example, they may already have a PV system and wish to add battery storage, or they may be constrained by policy, physical space, financing, or technical limits related to the point of interconnection. Such considerations can inform the project design. Many users are unsure of where to begin, and specification of an unusual battery size or system match may constrain vendor responses to the RFP. Background information on battery operations and degradation is included in the Appendix. Test runs for different technical configurations using the ESD model may further inform the user, so they can create increasingly viable solutions.

For many utilities, local peak-shaving is a top value stream that can drive the storage acquisition. Here, the duration of a typical peak, which is related to customer load characteristics and existing load-management efforts, may impact project battery requirements. The broader the peak, the more battery energy (duration) will be required to reduce the peak by a given amount as shown in Figure 3 below.

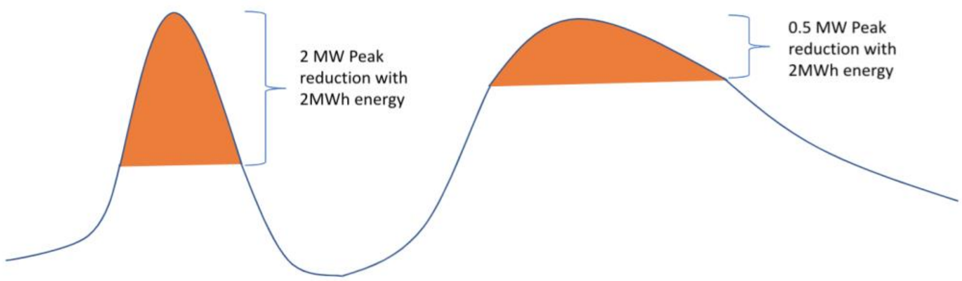


Figure 3: Illustrative Example of Peak Shaving Opportunities that can be achieved with a 2-MW battery at 1- to 4-hour durations (providing 2 MWh of energy) for different load shapes.

Depending on scale, the addition of local solar generation without battery energy storage would typically reduce a mid-day peak and narrow its duration on the load curve, but effectively shift the peak to the evening, without creating desired local demand savings.

Because the impact of a given battery storage capacity on peak-shaving depends upon the nature of the peaks, the project modeler might use SAM to run a series of different battery and solar sizes and observe the output variable "Demand peak with system (kW)," as shown in Figure 4. If several runs are being made with the same battery energy capacity, and increasing the capacity shows little additional impact on the demand peak, then one could ascertain that the peak is relatively wide and additional battery energy capacity would be required to improve peak demand reduction. Note that battery energy capacity is the primary cost driver for a battery system, so aiming for the lowest effective capacity is advised.

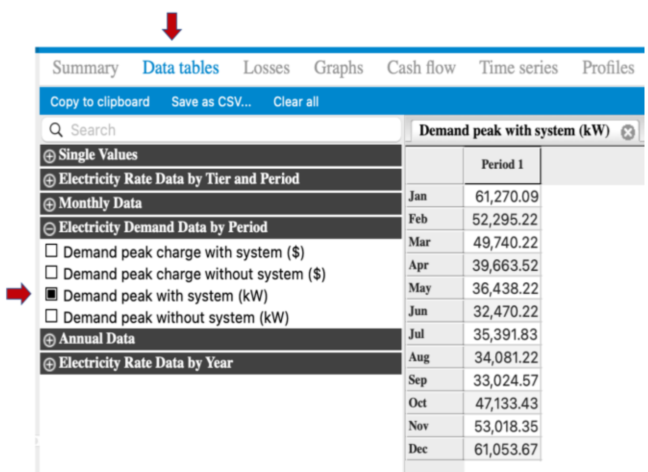


Figure 4: Data Table Outputs from SAM.

In practical terms, system planners may first ask whether lower cost load management strategies and technologies have been optimized, before they increase the scale of a costly battery system. For example, an adjustment to solar orientation or use of single-axis tracking (SAT) may facilitate more modest and cost-effective use of battery storage. In addition, customer load management (e.g., automated equipment cycling or variable price signals) may help reduce or even shape the system peak. Such strategies can lead to optimized results and significant savings on battery storage capacity. SAM has a useful capability, referred to as parametric runs, which allows the user to quickly make many changes to chosen variables, such as battery power and duration, and to quickly test impacts on a chosen output, e.g., peak reduction. This capability is useful in determining a good range of choices for battery energy capacity, when peak-shaving is a targeted value stream. [Here is a video]() posted on YouTube, that demonstrates the use of parametric runs. See also the Appendix for background information on battery system sizing and operations.

Figure 5, below, was produced in Excel using parametric runs in SAM to output annual peak-demand reduction cost savings for 2-MW battery power with 2-, 4-, 6-, and 8-MWh capacity, matched with 2-, 4-, and 6-MW PV system sizes. The annual peak demand reduction impacts for the battery were calculated after subtracting out the PV peak-reduction impacts. The resulting financial benefit for this scenario was estimated assuming a 15 $/kW demand charge and a 10-year battery life. (This level of demand charge is typical in some–though not all–regions of the U.S.) The y-axis is $ saved per MWh of battery installed, so the higher the value the better. As shown in the graph, the benefits rise steeply at first, from increasing battery energy capacity from 2 MWh to 4 MWh. The impact of further incremental increases appears to level off, suggesting that the peak has been significantly reduced and increasing battery capacity is now having less per-unit impact. Based on preliminary analysis for this scenario, the user might select a base case with a 2- or 4-MW PV system and a 2-MW battery of 2-hour duration (4 MWh). Note that the dispatching entity's forecasting and dispatch capabilities may be an important factor in this decision.

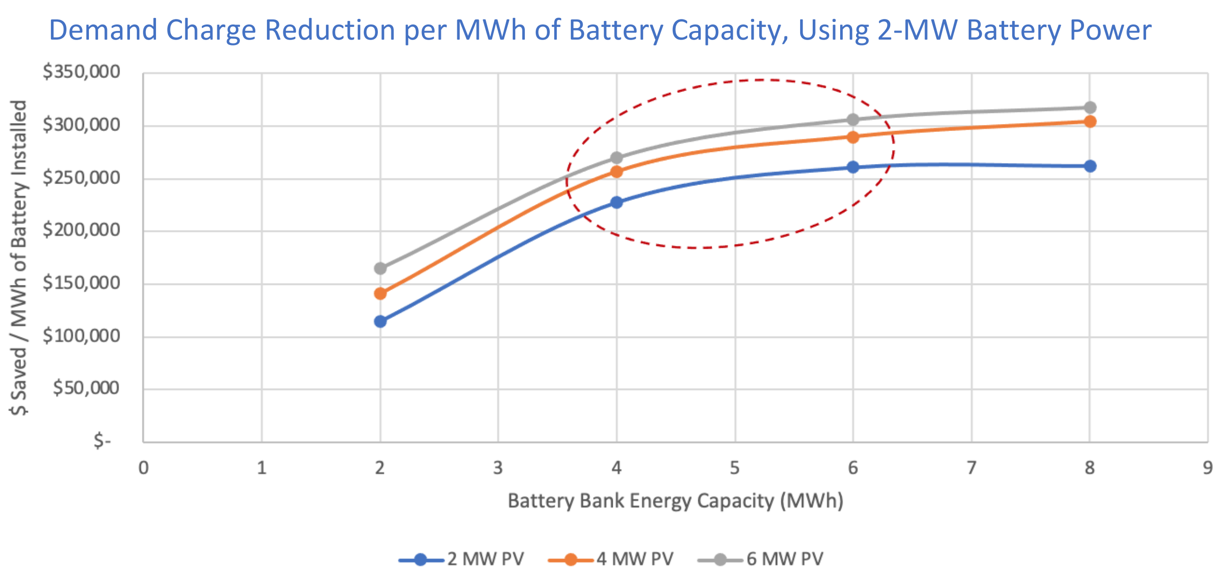


**Figure 5: Example Illustrating the Economic Impact of Choosing an Optimal Range for Battery Capacity (MWh) in a solar-plus-storage system aimed to reduce the system peak, while using 2-MW PV and a 2-MW storage battery.**

In order to integrate the economic impacts of additional value streams, such as energy arbitrage, one alternative to SAM parametric runs with peak-shaving would be to use an iterative approach, making several runs in SAM with different PV and battery design configurations, and then exploring each run in the SPECs ESD model. That is, one might simply keep increasing the battery and PV parameters until the economic gains begin to plateau.

# 4 SPECs EXCEL-BASED ESD MODEL

## 4.1 ESD General Inputs Tab

As summarized above, use of the NREL SAM tool is a prerequisite for running the ESD model. Section 6.3, Running SAM and Importing Simulation Outputs in the Appendix of this manual provides support for that first step. After importing data from SAM into the **SAM Inputs** tab of the ESD Excel Workbook, the user can focus on the **ESD General Inputs** tab and prepare to model storage and solar-plus project scenarios. The Inputs tab is divided into five sections:

- Value Stack Scenario
- General Inputs
- Results
- Gap Analysis Tool
- Sensitivity Analysis

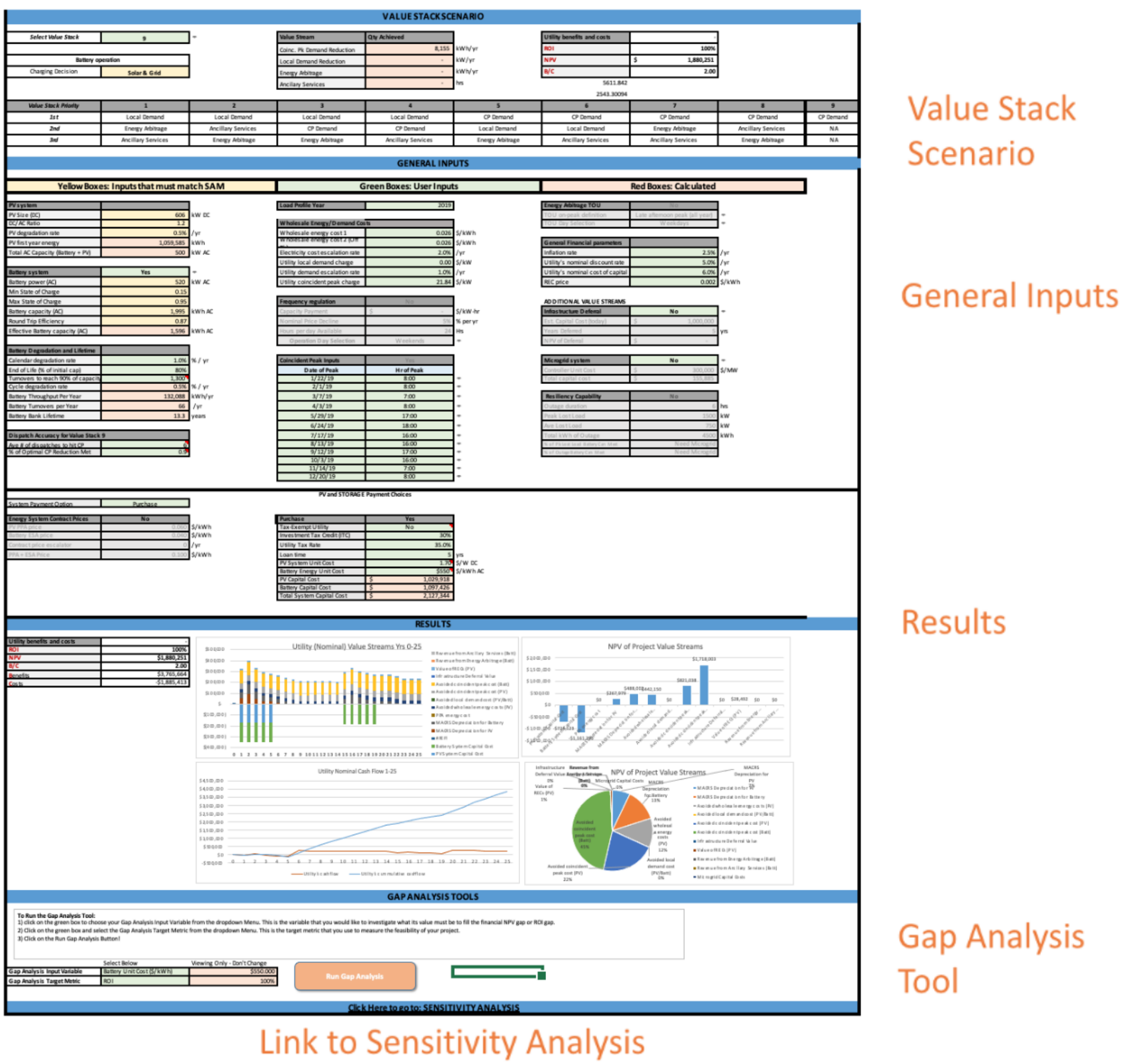


**Figure 6: Overview of the ESD Model Spreadsheet, Inputs Tab.**

## 4.2 Value Streams and Use-Case Parameters

Batteries can be dispatched in ways that allow them to capture revenue from different value streams. However, there are opportunity costs for pursuing different value streams; for example, if a battery has been discharged to reduce a load peak, it may not be used for another value stream until it has been charged again. Note that the ESD is not a complex optimization model that can determine a battery dispatch schedule to optimize revenue across multiple value streams. Instead, the user is presented with prioritized combinations of four solar-plus-storage value streams, sometimes called value stacks, that are accessible to many distribution utilities now or later, within the project lifetime. The four values streams are:

- Reducing the monthly peak demand on the local distribution system (i.e., local demand).
- Reducing coincident peak demand on the wholesale provider or the regional transmission system. This is typically a charge passed through by the local utility's wholesale power supplier.
- Shifting energy from a time of low value to a time of higher value (i.e., energy arbitrage). This applies if the local utility has a wholesale time-of-use or seasonal rate.
- Using the battery to address ancillary service value, currently limited in this model to the value of frequency regulation.

These value streams relate primarily to avoided costs at the wholesale or regional-services level. The user may wish to explore other value streams, such as the ability to shift solar generation in order to increase solar-hosting capacity on the local distribution grid. Such value streams may be highly desirable; however, they are addressed separately in the Gap Analysis Section 5.1, which may be used after the ESD scenario analysis completed

The user is asked to choose one of 9 likely scenarios, as shown in Figure 7, that estimate revenue from prioritized combinations of value streams. For scenario 1 through 8, each scenario represents a prioritized list of three value streams. Prioritization results in the battery first being dispatched to the top priority, then to the second priority, and finally the third. For Scenario 9, the model assumes that only one value, coincident peak (CP) demand reduction; it is treated as the first and only priority.

| ***Value Stack Priority*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| ***1st*** | Local Demand | Local Demand | Local Demand | Local Demand | CP Demand | CP Demand | CP Demand | CP Demand | CP Demand |
| ***2nd*** | Energy Arbitrage | Ancillary Services | CP Demand | CP Demand | Local Demand | Local Demand | Energy Arbitrage | Ancillary Services | NA |
| ***3rd*** | Ancillary Services | Energy Arbitrage | Energy Arbitrage | Ancillary Services | Energy Arbitrage | Ancillary Services | Ancillary Services | Energy Arbitrage | NA |

Figure 7: Tab 1 of the ESD Allows Selection Among Eight Combinations of Solar-Plus-Storage Value Streams.

In summary, the methodology for assessing multiple value streams is based on a fair approximation of how batteries function in a solar-plus-storage, value-stacked application. The assumption that the battery system would be discharged for one purpose per day is generally conservative and is realistic for the purpose of this model.

Note that under new IRA guidelines, incentives are available for grid-charged batteries as well as for charging from renewable energy projects. Generally, design for grid-charging provides more flexibility and project value. Renewable (i.e., solar-only) charging may be modeled as an additional reference point when designing a grid-connected project with resilience (islanding) capabilities. Whether it is solar-only or grid and solar charged, the project's resilience value may be estimated after the initial analysis, using the Gap Analysis tool, discussed in Section 5.1.

The ESD is relatively easy to use because it uses simplified operating assumptions. This model assumes the project is operated first to maximize the primary value stream. For example, in many cases, this would be local peak-demand reduction. The battery requirements for this vary, but assuming operation to maximize the primary value stream, the model would then apply remaining energy in the battery and available days to fulfill requirements for the secondary value stream. If energy and days remain to address a tertiary value stream, then the battery would fill those requirements last. Subsequently, any remaining energy that is not used by the battery would go to the grid, and for remaining days, the battery would be left unused. In practice, if the battery is properly sized and the selection of value streams is relevant, the battery is likely to be fully utilized. Definitions for **value-stream options** include:

**Demand Reduction**

- **Local Demand.** Distribution utilities typically hold wholesale supply contracts from an electric generating and transmission cooperative (G&T) or another wholesale provider. Many distribution utilities have a demand charge that is based upon local peak demand each month, often ranging between 10 and 20 $/kW[1]. Assuming a favorable wholesale contract or policy, a battery system may be discharged in order to reduce the monthly peak and the monthly demand charge. A battery would typically need to be discharged across multiple days achieve monthly peak demand savings. For some utilities, the single largest peak in a month is only marginally higher than the next highest peak, meaning that multiple peaks on multiple days must be reduced in order to reduce the peak demand bill. Forecasting experience, co-optimization with load management, and increasingly, machine-learning software, can be useful for successfully addressing the peak day and time.

**Coincident Peak (CP) Demand.** The coincident peak demand charge is based on the power (kW) usage that is coincident with the demand peak of the energy supplier or applicable transmission system. There are variations in CP rates and billing. If the coincident peak were forecasted accurately and provided by the supplier, then the battery could readily offset CP demand, ideally with only 12 dispatches per year. In practice, perfect dispatch seldom the case, but a battery used for CP Demand reduction is typically capable of addressing one or more other value streams, as well. Note that the Coincident Peak (CP-Only) scenario offers a new option, introduced in the 2022 update to the model. It assumes that no other value streams are available to this utility. This option is more accurate than simply "zeroing out" the secondary and tertiary value streams in a value stack. It is useful for utilities that wish to test a CP-Only scenario before testing additional values that may not materialize in the near future, due to policy constraints. Specific assumptions and methodologies to customize CP dispatch are discussed Section 4.3.3, below, as well as in the Appendix Model Logic Section, 6.

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[1] Clamp, A. (2017). When It Comes to Battery Storage Systems, Co-ops Should Focus on a Primary Application (Tech Surveillance). National Rural Electric Cooperative Association.

## Benefits of a Streamlined Model for Early-Stage Decision-Making

As noted above, the ESD model is not intended to be a finance-grade planning model. At the outset of this project, the SPECs team confirmed that, while there are numerous proprietary and industry-provided project planning models (some referenced on the Solar Value Project website), many of them are not practical for smaller local utilities. This is especially true when projects face early-stage "go/no-go" decisions. Thus, the SPECs team designed the ESD model as a flexible project screening and educational tool. It provides a baseline for comparing different storage use cases in an acceptably accurate and conservative manner. It screens out use cases that are not economic, and it spotlights use cases that are economic or nearly so. It also offers an add-on gap analysis to assess how real but less commonly considered values could help a nearly economic project design to meet its economic goals.

Specifically, by using the ESD model's Gap Analysis tool, the user can define the value gap between initial economic results and the desired outcome (e.g., break-even or better results). The ESD model then supports development of practical strategies to fill the value gap by adjusting assumptions or calculating value from previously unconsidered value streams, such as the value of a grid-upgrade deferral or of resilience enhancements.

There are limitations to using a streamlined, spreadsheet-based model like the ESD. Yet this model fulfills an important need for early-stage planning. A key objective of the ESD model is to help local utility planners and non-technical decision-makers to understand solar-plus-storage and storage-only opportunities, and to help them organize data and performance objectives for subsequent RFP development, review, and negotiations.

**Energy Arbitrage.** If the wholesale supplier offers time of use (TOU) or time of day rates, then the local utility would charge the battery during periods of cheaper energy and discharge it during times of more expensive energy, thus reducing the wholesale energy bill. In some regions, wholesale TOU rates may be imposed instead of demand charges. They also may complement demand charge reduction, since demand peaks often occur during times when high TOU rates are imposed. In some cases, users may wish to test a proposed TOU rate, in order to assess the risk of future rate changes upon the solar-plus-storage acquisition. Note that the term "energy arbitrage" is sometimes also applied to the value of managing solar generation and dispatch locally–an operation that is also called "solar shifting." While that value may be significant (as discussed in Section 5.1, Gap Analysis, of this user's manual), the choice of Energy Arbitrage on the Inputs page of this model pertains *only* to wholesale cost savings.

**Ancillary Services.** These comprise services that support reliable operation of the transmission and distribution grid. Typical ancillary services include frequency regulation, reactive power and voltage control, spinning and non-spinning reserves, and blackstart capabilities. Assuming that there is a functioning regional Independent System Operator (ISO) or Regional Transmission

Operator (RTO) market or a balancing authority that is willing to offer ancillary services compensation, a local utility may monetize ancillary services value from a solar-plus-storage project. In some cases, the local utility could work through its wholesale power supplier or another aggregator to value and market these services. Users also may test "what-if" scenarios, as they plan projects in regions where such markets are emerging. The ESD Ancillary Services option is currently designed to account only for the market value of frequency regulation.

An overview of **battery-charging options** is summarized below. The selection of battery-charging parameters is a decision that the user initially needs to make before running SAM; however, it should be checked again as the user prepares to run the ESD model. This input should automatically set when data is imported from SAM to the ESD model.

Note that under new federal Inflation Reduction Act (IRA) guidelines, incentives are available for grid-charged batteries as well as for charging by renewables, i.e., solar-only. Generally, grid-charged project design provides more flexibility and greater project value. Solar-only charging may be modeled as an additional reference point, especially when designing a solar-plus battery project with resilience (islanding) capabilities. Some users may wish to test a battery-only use case, but neither SAM nor the ESD were expressly designed for that use case.

- **Solar-Only Charging.** The battery may be set to charge only from solar generation. Users of the ESD model will find that if the battery is restricted to charge only from solar, this will limit the battery's availability for all value streams, especially second and third priority value streams, since the battery will need to wait for solar availability to recharge. Especially in locations with limited solar resources, this could require waiting at least until the following day before discharging the battery again. If the user chooses to run SAM with parameters set to allow charging from *solar and the grid*, they are likely to see greater revenue streams for the value stacks in the ESD model. Projects built using the new IRA incentive structures are no longer restricted to this option.
- **Solar or Grid Charging.** Projects designed for grid charging are now eligible for federal incentives under the IRA, offering flexibility that usually improves project economics. Utilities are encouraged to research evolving IRA guidelines and state incentive guidelines as well, prior to finalizing design decisions[2].

**Financing options.** Earlier versions of the ESD model focused on the power purchase agreement (PPA) method of financing, because non-taxable utilities could not use tax credits directly. But with implementation of the IRA in 2023, electric co-ops, public power utilities, and other non-profits will be able to receive direct federal incentive payments. Thus, the ESD model now offers two financing options.

- **PPA with an accompanying battery Energy Storage Agreement (ESA).** By using a PPA and ESA, the utility minimizes its up-front cost, accesses accelerated depreciation (MACRS) benefits, and lowers project risk. Technology risk for PV systems is generally

[2] Federal Tax Incentive Guidance Current to September 2022.

no longer a concern; yet storage technology risks may affect some acquisitions (e.g., if long-term system maintenance and performance or dispatch capabilities are at issue). The PPA/ESA approach often includes a service bundle. Further, optimal IRA benefits hinge on meeting additional project requirements, such as U.S. equipment sourcing and workforce development measures, which may be easier to meet with a PPA/ESA development partner. The drawback is that PPA/ESA transaction costs may add 10 to 20% or more to the total project cost. Utilities choosing this option should carefully review such costs in their RFP responses.

- **System purchase option.** Now that non-taxable utilities can receive direct payments for incentives that were previously only available as tax credits, the purchase option is increasingly desirable. The model assumes a 30% IRA project incentive, but this number may be adjusted up or down, based on achieving specific criteria in the IRA guidance cited below.[3] The user is also advised the monitor other, potentially more current sources. Further, user-defined inputs, such as the expected interest rate, may affect the economics of the purchase option.

## 4.3 General Inputs

The section titled General Inputs allows the users to adjust a range of parameters that impact financial outputs for the modelled battery and PV system. Color-coding refers to:

- green (to be modified by the user)
- yellow (updated automatically with input/import from SAM)
- **red** (calculations - no user interaction).

### 4.3.1 Values That Must Match SAM

The values that are used to define the PV system capacity and battery system power rating and duration are automatically updated when new SAM data is pasted into the SAM Inputs tab. Because the ESD model calculations are based upon the time series that comes from SAM (e.g., solar generation and battery charging and discharging quantities), these values should not be changed by the user, unless the changes are made in SAM and the SAM simulation is subsequently re-run.

| PV system | | |
|---|---|---|
| PV Size (DC) | 2,000 | kW DC |
| DC/AC Ratio | 1.2 | |
| PV degradation rate | 0.5% | /yr |
| PV first year energy | 2,686,681 | kWh |
| PV size (AC) Nameplate | 1,667 | kW AC |
| **Battery system** | Yes | |
| Battery power (AC) | 2000 | kW AC |
| Min State of Charge | 0.15 | |
| Max State of Charge | 0.95 | |
| Battery capacity (AC) | 8000 | kWh AC |
| Round Trip Efficiency | 0.9 | |
| Effective Battery capacity (AC) | 6400 | kWh AC |

**Figure 8: Values Imported from SAM.**

### 4.3.2 Energy System Pricing Options

This 2022 update of the ESD model allows the user to choose either a PPA/ESA option, signifying procurement through energy and energy services contracts, or to choose a project-purchase model, including a purchase of both the solar PV system and the battery system.

[3] See Solar Energy Industries Association, [Inflation Reduction Act: Solar Energy and Energy Storage Provisions Summary](). Accessed September 21, 2022. Additional resources for non-taxable utilities are forthcoming.

Both the PPA/ESA option and the Asset Purchase Option assume a project life of 25 years for the financial analysis. The model assumes that the solar project life is readily 25 years or more, whereas the battery system, if it is not progressively upgraded, will last 15 to 20 years, requiring a replacement during the system life. Under the PPA/ESA option, the model assumes that the ESA provider will progressively upgrade or replace the battery during the 25-year life of the contract. The ESD conservatively assures that battery energy system costs are included for the life of the project, excluding any salvage value that would increase the value of the project.

For the **PPA/ESA pricing option,** neither the battery nor the PV system would be purchased and owned by the utility; rather, their energy and energy services would be acquired through a PPA for the solar PV system, accompanied by a battery energy services agreement (ESA). The user must set these prices and other terms as inputs to the model, as shown in Figure 9. The model assumes that the PV system is the primary cost, and the battery agreement price is set as an "adder." Note that the most common sources for utility solar and battery "adder" data refer to utility projects that are on the scale of 5 MW or above and sell into power markets, rather than primarily meeting distribution-scale needs. Therefore, such cost data may need to be adjusted for local utility use. A full explanation of utility solar PPA pricing with a storage ESA adder, along with a range of current market pricing data, is available from Berkeley Lab[4] or from Pacific Northwest National Lab (PNNL).[5]

| System Payment Option | PPA/ESA | |
|---|---|---|
| **Energy System Contract Prices** | **Yes** | |
| PV PPA price | 0.060 | $/kWh |
| Battery ESA price | 0.040 | $/kWh |
| Contract price escalator | 0 | /yr |
| PPA + ESA Price | 0.100 | $/kWh |

**Figure 9: Energy System Contract Prices. Selected prices provided for illustration only.**

For the purpose of understanding PPA/ESA pricing, it is useful to see that the storage adder is affected by the ratio of battery capacity to PV capacity, rather than solely as a function of battery energy capacity. This makes sense, since the PPA price is paid for every unit of energy produced by the PV system. If the battery system can only store a small percentage of the PV energy, one would not expect that user to pay a large battery storage adder for the PV PPA price (i.e., the battery is only being utilized for a fraction of the solar production). If, however, the battery system can store a larger percentage of the solar PV production, one would expect the adder to increase, as the battery storage will likely be utilized with each unit of energy produced by the PV system. Figure 10 illustrates the impact of the capacity ratio on storage-adder pricing, as reported in a 2022 Utility-Scale Solar market review from LBL[6].

Note that when assessing local utility projects that are designed for demand-charge reduction, the number of battery discharges per year, as well as the depth of discharge, have a major

[4] For current reports on recent solar PPA pricing, see https://emp.lbl.gov/utility-scale-solar

[5] PNNL Energy Cost and Performance Database, retrieved September 2022.

[6] Bolinger, M., Seel, J., Warner, C., & Robson, D. (2022). Utility-scale solar: 2022 Edition.

impact battery life and therefore on levelized-cost based ESA pricing. Such projects may have a high battery to PV capacity ratio by design but may utilize that capacity for relatively few hours per year, practically supporting a somewhat lower-cost adder.

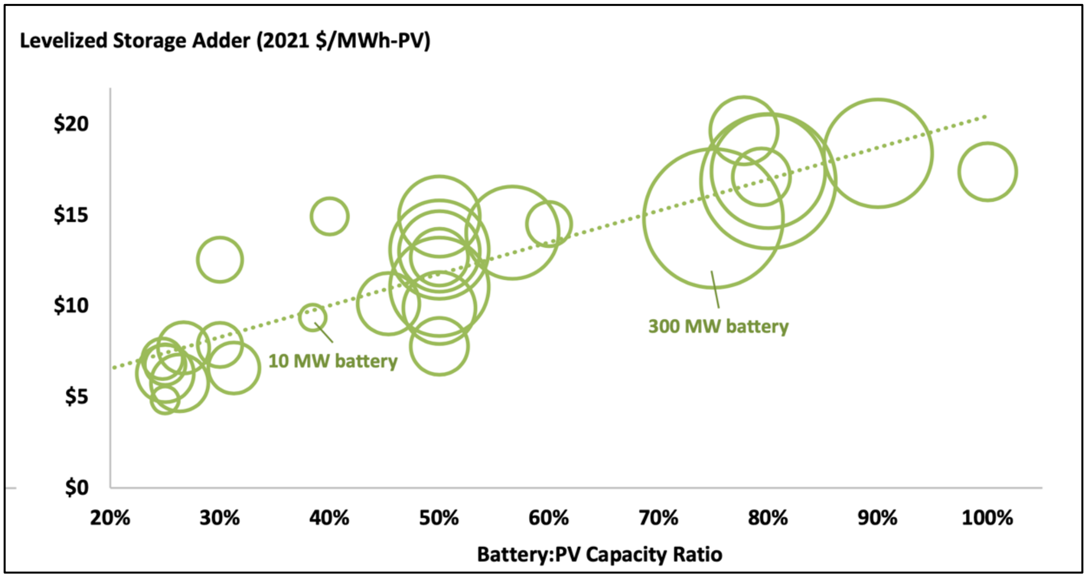


**Figure 10: Levelized Storage Adder for Hybrid Solar-Plus-Storage Projects is shown as a function of battery to PV capacity. Note that batteries designed for market applications are often fully utilized as designed. (Source: Bolinger et al, 2022)**

Pricing for PPAs and ESA adders vary considerably from region to region, and may be relatively volatile, due largely to supply-chain uncertainty. Users of the ESD model may consider initially setting pricing levels from 30 to 45 $/MWh for the solar PPA (the national average cost in 2021 was 33 $/MWh), with battery adder of 15 to 30 $/MWh. Users may then work with the ESD sensitivity analysis tool to establish an acceptable price range to test via an RFI or more regionally specific cost research.

Utility projects under 1 MW may be priced closer to large-commercial scale. Refer to sources cited in the asset-purchase section below. Users that have limited access to market-specific pricing data and a primary interest in peak reduction may initially test a PPA price in the range of 0.045 - 0.055 $/kWh for the PV, with an ESA adder price of 0.035 - 0.045 $/kWh for typical systems (assuming 2- to 4-hour durations). Users may set ESA pricing on the higher end of this scale for battery systems that will store a larger fraction of energy produced by the PV system.

The impact of PPA or ESA contract transaction costs is also relatively greater on smaller projects, leading some utilities to prefer the asset-purchase option (see below), so long as they tap IRA incentives. Whatever path the utility choses for its acquisition, note that pricing is currently volatile. ESD modeling can help utilities to optimize their project plans, but current, region-specific pricing is best discovered through the procurement process itself. Information gleaned from running different acquisition scenarios, as well as an early-stage Request for Information (RFI) and informal talks with vendors are all highly useful. A graphic summarizing the overall procurement process for utility solar-plus-storage is included in the Appendix.

The **Asset Purchase Pricing Option** assumes that the utility will finance and purchase the solar PV system and battery storage system outright. This is a new option for the updated 2022 ESD model. It was added in anticipation of federal IRA incentives, which will be available to non-taxable electric utilities in 2023. To use the asset purchase option, the utility must input specific pricing assumptions into the model, including an installed cost in $/W DC for the solar PV system and a battery energy unit cost in $/kWh ac, plus an inverter cost in $/W. For co-located PV and battery systems, a single inverter may be used.

Obtaining accurate data for running any solar-plus-storage economic model requires a mix of research and strategy. Regarding PV costs, LBL's Utility-Scale Solar report cites median project costs in 2021 for utility-scale PV at $1.35/W DC; however, it cites much higher costs for PV in a solar-plus-storage configuration. This is due partly to costs associated with increasing battery to PV capacity ratios (discussed above) and to current supply chain issues. While this manual is not intended as a primary source for pricing data, it may be reasonable to test single-axis tracking solar prices in the range of $0.90 to $1.70 per Wdc (adjusted for regional cost trends and the expected battery:PV capacity ratio).

On the battery side, price volatility is even more of a challenge. Current sources suggest 2022-23 pricing between $400 and $500 per kWh. This is so, even though the Bloomberg New Energy Finance Annual Battery Price Survey confirmed record-breaking price reductions for batteries in 2021, falling to a median cost of $132/kWh before market disruptions took hold.[7] Prices are not expected to decline again to that level or below for some time. Meanwhile, many projects are cost-effective at higher prices and may benefit from taking a market-leader advantage. SPECs advises reviewing cost-projections from NREL and adjusting the price ranges cited above through an RFI processes or vendor communications to refine your pricing expectations.[8] The results of different modeling runs that are internally consistent can help define the utility's optimal project design, which can then be presented to bidders through a formal RFP.

Note that for large-commercial scale projects (under 5 MW), the U.S. Solar Market Insight Q3 2022 report from SEIA and Wood-MacKenzie, reports installed project costs for PV averaging $1.70/W DC.[9] To pair with storage, useful references may include the PNNL storage cost database, NREL solar and battery storage market reports, and regional solar and storage industry associations. The sensitivity analysis tool in the ESD model may also be used to better understand specific market conditions and the utility's break-even pricing requirements.

[7] Bloomberg NEF Annual Battery Price Survey 2021

[8] Cole, W., Frazier, A.W., Augustine, C., Cost Projections for Utility-Scale Battery Storage 2021.

[9] Solar Energy Industies Association and Wood-MacKenzie, U.S. Solar Market Insight Q3 2022.

| Purchase | Yes | |
|---|---|---|
| Tax-Exempt Utility | No | |
| Investment Tax Credit (ITC) | 30% | |
| Utility Tax Rate | 35.0% | |
| Loan time | 5 | yrs |
| PV System Unit Cost | 1.70 | $/W DC |
| Battery Energy Unit Cost | $550 | $/kWh AC |
| PV Capital Cost | $ 1,029,918 | |
| Battery Capital Cost | $ 1,097,426 | |
| Total System Capital Cost | $ 2,127,344 | |

Figure 11. Model Inputs for Direct Purchase. Updated parameters provided for illustration only.

### *4.3.3 Wholesale Energy and Demand Charges*

In the General Inputs section of the ESD Model, the user should specify wholesale energy costs, escalation rates, and demand charges, as applicable. Most utilities that purchase wholesale energy at a fixed rate from a supplier (as opposed to buying on a market) have a single rate. If this is the case, the user would simply enter zero for "Wholesale energy cost 2 (Off Pk)." If the utility has or anticipates having a tiered or TOU rate, then the lower of those rates should be entered as the wholesale energy cost 2 (Off Pk). This supports the choice of a use case that includes energy arbitrage.

Further, the user should enter a value for the "Electricity cost escalation rate," meaning the average annual increase that the utility anticipates, including rate increases for any reason, over the project lifetime (25 years). Recently, general cost inflation and utility modernization goals have raised the expectation that wholesale costs may increase at a greater rate than in recent years. Demand cost escalation may be affected by that trend to a greater or lesser degree.

| Wholesale Energy/Demand Costs | | |
|---|---|---|
| Wholesale energy cost 1 | 0.050 | $/kWh |
| Wholesale energy cost 2 (Off Pk) | 0.030 | $/kWh |
| Electricity cost escalation rate | 0.020 | /yr |
| Utility local demand charge | 5.00 | $/kW |
| Utility coincident peak charge | 7.00 | $/kW |
| Electricity demand escalation rate | 0.014 | /yr |

Figure 12: Inputs for Demand-Cost Reduction and Energy Arbitrage

The coincident peak (CP) demand charge is based on the peak power (kW) usage that is coincident with the monthly peak demand or transmission peak of the energy supplier. The user can enter the date and hour of the expected coincident peak in a table in the General Inputs section. Users are encouraged to adapt these inputs to address their situations; for example, some utilities that have unconventional wholesale rates or multiple supply contracts can create a blended rate that reflects the impact of more complex wholesale agreements.

If applicable, also enter the local demand charge that is based upon the utility's local peak demand each month. That cost often ranges from between 10 to 20 $/kW and is a driver for many solar plus storage projects[10].

### *4.3.4 Coincident Peak Reduction Only Use Case*

The Coincident Peak (Only) Scenario offers a customized option, introduced in the 2022 update to the ESD model. It assumes a wholesale demand or transmission-capacity charge is imposed, and that no other value streams are available to this utility. This option produces more accurate modeling than simply "zeroing out" the secondary and tertiary value streams in a value stack. If using the CP-Only use case (Scenario 9), the user must also input two additional parameters: the average number of dispatches required to hit the coincident peak each month and the percent of coincident peak hours that are actually reduced across a year by the battery.

| **Dispatch Accuracy for Value Stack 9** | |
|---|---|
| Ave # of dispatches to hit CP | 6 |
| % of Optimal CP Reduction Met | 0.75 |

**Figure 13: CP-Only Reduction Scenario. The user may adjust performance expectations.**

Functionally the least number of times a battery may be dispatched each month to and still hit the CP is 1, however utility experience suggests that to achieve CP Demand reduction consistently using typical forecasting strategies, the battery may be discharged between 5 and 10 times per month. It is likely that on occasion, due to forecasting error or lack of battery energy availability (driven by battery state of charge or battery duration), the local utility may miss a peak, leading to a less than 100% CP savings. Therefore, by applying a % of optimal CP reduction met, the user can reduce the CP savings and thus model a more realistic CP savings, based on their confidence level in the battery operation and forecasting services. In practice, a well-designed system may deliver optimal return on investment, while assuming that some percentage of coincident peaks will be missed. For more on the logic of these two variables see Model Logic for Scenario 9, in Section 6 of this manual.

Note that several combinations of value streams (value stacks) that include a CP demand reduction as the primary, secondary, or tertiary option are available in the ESD model. They approximate the value of more complex use cases that may apply now, or that may be tested as part of a forward-looking project design, as wholesale rates change or markets for ancillary services evolve. These use cases do not automatically factor in the challenge of consistently forecasting and hitting monthly coincident peaks. They provide a benchmark for best-case performance, which can be manually adjusted to reflect realistic utility expectations.

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[10] Clamp, A. (2017). When It Comes to Battery Storage Systems, Co-ops Should Focus on a Primary Application (Tech Surveillance). National Rural Electric Cooperative Association.

### 4.3.5 General Financial Parameters

These parameters are required for project financial calculations. The default value for inflation is a long-term average in the U.S. over the last 30 years, historically 2.5%. The average nominal cost of capital for rural electric utilities, between 2008 and 2017, was estimated to be 6%[11], and that is the current default value within the model. The default for the utility's nominal discount rate is 7%[12]. Users may adjust all these inputs as needed. The Renewable Energy Credit (REC) price pertains to utilities that can monetize REC values in compliance with regulatory mandates. If REC prices are not applicable, enter zero. All financial assumptions, including REC prices, should be reviewed based on current and anticipated wholesale agreements and cost trends.

### 4.3.6 Energy Arbitrage

Energy arbitrage, at its most basic level, entails buying energy at one price and selling it at a higher price. The ESD model assumes that arbitrage is supported by wholesale time-of-use (TOU) rates or access to a wholesale power market, where prices change based upon supply and demand. Under any of these conditions, shifting solar-generated energy from one time of day to another could have monetary or strategic value. The ESD model compares the economics of battery-enabled shifting upon wholesale or market-imposed costs.

Some utilities that currently do not have TOU rates may wish to use the ESD model to test arbitrage value, in order to understand the impacts of a possible future rate change or of an emerging regional electricity market, where prices fluctuate with wholesale demand. If the user is investigating a use case that applies wholesale TOU rates, they must enter these as "Wholesale energy cost 1" and "Wholesale energy cost 2 (Off Pk)." Note that the second (Off Pk) value must be the cheaper rate.

| Wholesale Energy/Demand Costs | | |
|---|---|---|
| Wholesale energy cost 1 | 0.049 | $/kWh |
| Wholesale energy cost 2 (Off Pk) | 0.030 | $/kWh |

Figure 14: Wholesale Demand Cost Inputs required for the arbitrage case.

Next, the user may choose from among several options that define how and when the TOU rates apply. Under "Energy Arbitrage TOU," the user can set the analysis to reflect how different rates are applied on a daily or seasonal basis. Figure 15 shows one pre-loaded option.

| Energy Arbitrage TOU | Yes |
|---|---|
| TOU on-peak definition | Late afternoon peak (all year) |
| TOU Day Selection | Weekdays |

Figure 15: Example Input Settings, regarding how TOU rates are applied.

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11 Royer, Jeffrey S. "Measuring the cost of capital in cooperative businesses." *Agribusiness* 35.2 (2019): 249-264.

12 See, for example, this document for the Sixth Northwest Conservation and Electric Power Plan.

In all, there are three pre-loaded options for defining TOU on peak rate periods, plus a manual input option:

- Early afternoon peak (all year) - on peak (2:00 - 5:59 pm)
- Late afternoon peak (all year) - on peak (4:00 - 8:59 pm)
- Seasonal (summer early afternoon peak & winter morning/evening peaks) - on peak (November to April: 6:00 - 9:59 am & 6:00 - 9:59 pm, and May to October: 2:00 - 5:59 pm)
- Manual input

To use the Manual Input option, the user must first open the Values tab of the ESD model, located to the far right of the Inputs tab. There, the user can create hour-by-hour and month-by-month rate-table parameters. Enter 1 for times when the off-peak wholesale energy rate applies (identified as "Off Pk" under "Wholesale Energy/Demand Costs" on the Inputs page), and 0 for times when the more costly "Wholesale Energy Cost 1" applies.

In addition, the user must make a TOU day selection to indicate when the rate schedule would apply, either choosing "none," or options for weekdays or weekends. For all other times, the rate indicated in "Wholesale energy cost 1" would apply. By incorporating these settings, the ESD model can approximate the benefits of battery-based energy arbitrage, as a secondary or tertiary value stream.

Note that the option to set energy arbitrage as a secondary or tertiary value stream in this model pertains only to achieving wholesale cost savings. A different interpretation of energy arbitrage is sometimes called "solar shifting." This involves charging and discharging of a strategically sited battery to improve the match between local resource availability (e.g., local solar generation) and the local load curve.

### *4.3.7 Ancillary Services*

As briefly defined above, ancillary services refers to a range of services that generators or energy storage systems provide in order to maintain grid stability and reliability in the face of imbalances between supply and demand, integration of intermittent resources, and power outages. Typical ancillary services include

- Frequency regulation
- Reactive power and voltage control
- Spinning reserves
- Non-spinning reserves, and
- Blackstart capabilities.

In some regions, these services are provided by vertically integrated utilities that manage portions of the grid or by RTOs or ISOs. In areas with partially or fully deregulated markets, these services are traded on regional wholesale markets.

The figure below, from Balducci et al[13], shows compensation ranges for various ancillary services. While some values may be outdated since publication, frequency regulation is still a leading ancillary service that can be marketed by distribution utilities where there are monetary mechanisms (either through an ISO/RTO or wholesale market) for compensation. Frequency regulation is the default focus for the ESD model's analysis of ancillary services value.

Several FERC orders, such as FERC Order 755, have helped ensure that energy storage systems receive fair compensation for frequency regulation. FERC Order 755 requires energy storage systems to be compensated based upon performance. Most entities will compensate frequency regulation based on a capacity payment, which rewards the provider of the service for the opportunity cost of making a given capacity available, and a mileage payment based upon the sum of the up and down deviations of the frequency signal being regulated. Some markets also compensate based on the accuracy of the regulation. Capacity payments for ancillary services represent the larger part of total available revenue[14].

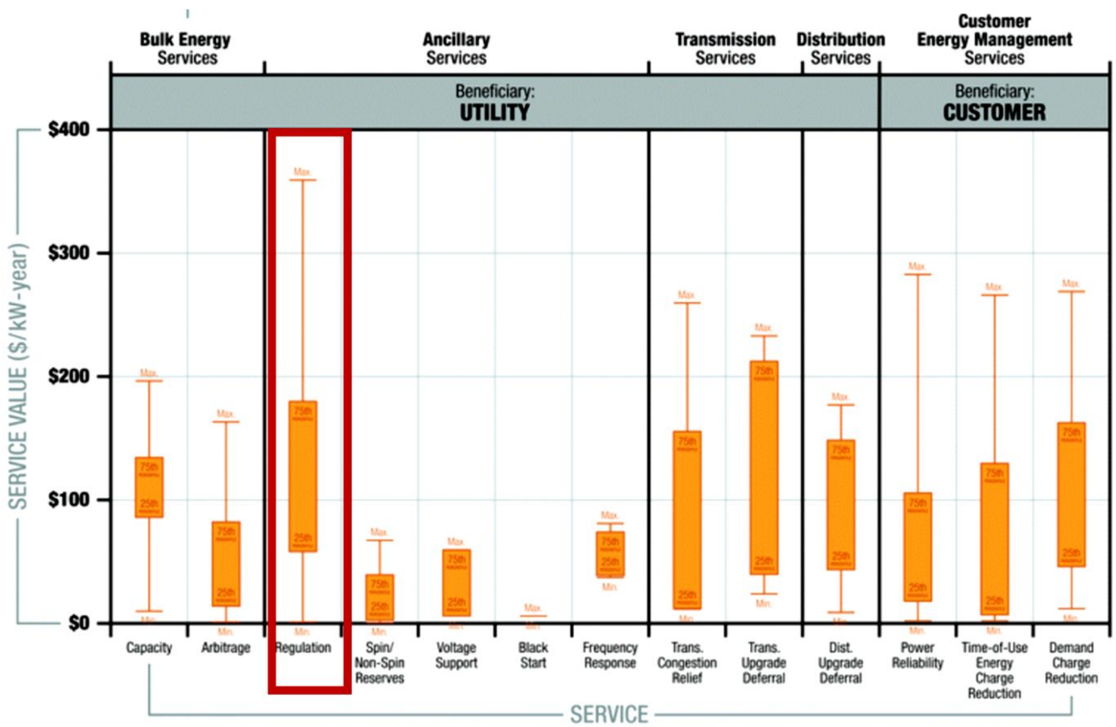


**Figure 16: Ranges of Value for Various Services that Battery Storage Can Provide. Image from Balducci, P, Alam, M., Hardi, T., and Wu, D. (2018) in Energy and Environmental Science, 11 (8).**

[13] Balducci, P., Alam, M., Hardi, T., & Wu, D. (2018). Assigning value to energy storage systems at multiple points in an electrical grid. Energy & Environmental Science, 11(8).

[14] Liu, K., Chen, Q., Kang, C., Su, W., & Zhong, G. (2018). Optimal operation strategy for distributed battery aggregator providing energy and ancillary services. *Journal of Modern Power Systems and Clean Energy*, 6(4), 722-732.

Figure 17, also taken from Balducci et al, shows compensation structures in various regions and markets, current as of 2018. Though representative, this payment schedule would change with supply and demand for frequency regulation services.

| | RTO/ISO | | | | | |
|---|---|---|---|---|---|---|
| Service | PJM | MISO | CAISO | NY ISO | ISO-NE | ERCOT |
| Capacity payment | Yes | Yes | Yes | Yes | Yes | No |
| Mileage payment | Yes | Yes | Yes | Yes | Yes | Yes |
| Accuracy payment | No | No | Yes | Yes | No | No |
| Basis of mileage payments | DA and real time | Real time | DA and real time | | | |

**Figure 17: Assigning Value to Energy Storage Systems at multiple points in an electrical grid. Table from Balducci, P, Alam, M., Hardi, T., and Wu, D. (2018) in Energy and Environmental Science, 11 (8).**

The ESD model provides a very simple estimation of revenue that might be earned from providing frequency regulation services in a market, as described below.

$$Revenue\ (\$) = Market\ Price \left(\frac{\$}{MW\ per\ hr}\right) \times Capacity\ (MW) \times Availability\ (hr)$$

The market price for capacity payments is often expressed in $ per MW per hour of participation in the market. Capacity is the power rating for the battery system and is based upon a battery being able to provide the capacity commitment for the duration of the hour bid. For example, a 2-MW bid for one hour would require the battery to have at least 2 MWh of storage capacity. It would need this capacity to modulate the frequency with 2 MW, whether that is up or down, requiring the absorption or dispatch of energy. The default value for frequency regulation payments in the model is 11 $/MW-hr, based upon the average value of numerous markets from 2017.[15] Users should consult current regional data.

Availability refers to the time that the battery can be used to meet bid requirements for capacity. For example, if the battery would not be delivering any other services on weekends, then the daily participation on weekends could be 24 hours. The user also must select the pattern of days that the battery would be available to participate in the market. The ESD model provides options simply defined as weekends or weekdays, assuming the user's choice would be set so it would not conflict with other selected value streams, e.g., energy arbitrage. This feature of the model is streamlined compared to actual market participation, but it approximates a conservative value of frequency regulation, where markets exist.

| Frequency regulation | Yes | |
|---|---|---|
| Capacity Payment | $ 0.011 | $/kW-hr |
| Nominal Price Decline | 5% | % per yr |
| Hours per day Available | 24 | Hrs |
| **Operation Day Selection** | Weekends | |

**Figure 18: Input Table for Frequency Regulation.**

15 Denholm, Paul, Yinong Sun, and Trieu Mai. 2019. An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind. Golden, CO: NREL/TP-6A20-72578.

Here, energy throughput (which will affect degradation for the battery) when delivering frequency regulation is estimated as 20%, similar to values used in other analytic models[16]. This means that if a 2-MW battery is bid into a frequency regulation market for one hour, it would only be utilizing about 20% of its full capabilities and only absorb or dispatch 0.4 MWh of energy to meet the market need. The default value of 20% can be changed in the Values tab of the model, if the user has unique or new data to apply to the utility's specific scenario.

Users should be cautioned against basing long-term revenue estimates upon a high return from ancillary services, such as frequency regulation. As more energy storage systems come online, the market may become saturated, leading to steep declines in value for a number of ancillary services[17]. Under such conditions, they may fall to near-market or sub-market levels. As a safeguard, the ESD model includes a variable for an exponential rate of decline in the market price for the 25 years of the project, with a default of 5%. This means that each year, the revenue obtained from frequency regulation will be reduced by 5% of the previous year's value. If the user would like to negate such annual revenue degradation, the value may be set to 0%.

The ESD model is focused on ways to monetize frequency regulation as a relevant ancillary services value today. However, other values are emerging, and the model may be updated to include additional ancillary services. In addition, targeted local storage applications may become highly valued in in the future. Battery storage may help solve local grid reliability problems or resolve transmission-level issues, such as potential back-feeding on a high-renewables grid. The ESD model does not directly address these value streams, but they are reflected in infrastructure deferral savings discussion below.

### *4.3.8 Infrastructure Deferral*

Increasingly, situations arise, where local energy storage or solar-plus-storage can increase effective grid capacity. Infrastructure upgrade deferral represents a subset of such benefits that may be monetized as a strong local-project driver. A value stream from infrastructure deferral may support one or more of the ESD use cases, so this value is treated separately in the model.

The model provides a simple, proxy valuation for the deferral of a distribution-grid investment, as the difference between the value of the capital investment at the time of the solar-plus-storage project and the net present value (NPV) of the project, if it were deferred several years into the future. The resulting value underestimates the true, total value of an infrastructure deferral; that value could be more fully explored through non-wires alternative (NWA) studies and more complex models. The ESD offers a streamlined approach, to simply introduce a more inclusive decision-making process.

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[16] Concepcion, R. J., Wilches-Bernal, F., & Byrne, R. H. (2019, August). Revenue opportunities for electric storage resources in the Southwest Power Pool Integrated Marketplace. In 2019 IEEE Power & Energy Society General Meeting (PESGM) (pp. 1-5). IEEE.

[17] Mandel, J., Morris, J., & Touati, H. (2015). The economics of battery energy storage. Rocky Mountain Institute. Technical Appendix A

In the ESD model, the primary deferral value arises due to the deferral of borrowing, as reflected in electric utility's cost of capital. The present value of the deferred investment can be represented as

$PresentValue = \frac{C_0}{(1+k_r)^T}$ , where $C_0$ is the cost of a capital investment at a given time and $T$ is the number of years into the future that the capital cost would be deferred. The term $1 + k_r = \frac{1+k_n}{1+i}$ represents the real cost of capital for the electric utility, with $k_n$ being the nominal cost of capital and $i$ the inflation rate.

As an example, imagine that a capital investment of $1,000,000 for feeder-line reconductoring is planned, but the development of a solar-plus-storage project could cause the reconductoring to be delayed by 5 years.

The average nominal cost of capital for rural electric utilities has been estimated at 6%[18]. The average annual inflation rate in the U.S. over the last 30 years was 2.5%. (Adjustment based on the outlook for current inflationary conditions is optional.) Using these values, the real cost of capital is:

$$1 + k_r = \frac{1 + 0.06}{1 + 0.025} = 1.034$$

Thus, the present value of the deferred investment would be: $PresentValue = \frac{\$1,000,000}{(1.034)^5} = \$154,546$.

The value to the project would then be the difference between the capital cost and the present value of the deferred investment, or $154,546. This value does not represent all related savings, which in reality would require much more detailed input data, but it offers a reference point for a broader discussion of strategic project value. SPECs has created a structure for that discussion, called a Gap Analysis process. That process, detailed in Section 5.1 below, asks the user to define the gap between the initially calculated project economics (expressed as NPV, IRR, etc.) and acceptable minimum metrics. It then seeks to apply "just enough" additional value (in this case from the proxy distribution deferral value stream and possibly other strategic value streams), in order to achieve threshold cost-effectiveness. In short, the Gap Analysis is a decision-making tool to get promising projects beyond the initial go/no-go decision point.

### *4.3.9 Resilience and Reliability*

A battery storage system may increase both resilience and reliability by reducing the frequency and impact of electricity outages on portions of the distribution grid. Reliability refers to the grid's ability to minimize common outages. It can be characterized by the System Average Interruption Duration Index (SAIDI), which represents the average interruption duration for each customer served on a distribution grid. Resilience refers to the grid's ability to respond to and recover from power outages that are greater in both geographic coverage and time.

[18] Royer, Jeffrey S. "Measuring the cost of capital in cooperative businesses." *Agribusiness* 35.2 (2019): 249-264.

Several methods may be used to quantify the value of avoiding power interruptions, such as contingent valuation, damage cost, input-output modeling, and defensive behavior[19]. The primary cost of an outage is typically calculated as the productivity losses or damage costs to local customers. Damage cost and defensive behavior methodologies look at the revealed preferences of customers, related to what they pay to avoid an outage, such as the purchase of a back-up generator system or insurance-cost impacts upon either the local utility or the utility plus all affected customers.

The ESD model provides another streamlined proxy method, using data provided in the General Inputs section of the model, for utilities to begin to explore costs and benefits of resiliency, which could be incorporated into a solar-plus-storage solution. As another approximated value, ESD model assumes that resiliency capability will be considered as a strategic local project value, subject to the gap analysis process. The model asks users to specify the characteristics of the outages that they are looking to avoid, such as peak and average loads, outage duration, and outage frequency. The model can then estimate the additional costs that would be required for the solar-plus project to meet their resilience criteria.

To run the ESD model to ensure grid resiliency, the user must include additional costs for microgrid infrastructure, such as switchgear and a microgrid controller, and to update the battery specifications, so they meet the user's resilience needs (i.e., the anticipated load requirement and duration for an outage). The model includes a default value of $300,000 per MW for a microgrid controller and additional infrastructure[20]. The user must provide

- Outage duration they are seeking to cover
- Peak of lost load (kW)
- Average of lost load (kW)

| **Microgrid system** | | Yes | |
|---|---|---|---|
| Controller Unit Cost | $ | 300,000 | $/MW |
| Total capital cost | $ | 600,000 | |

| **Resiliency Capability** | No | |
|---|---|---|
| Outage duration | 6 | hrs |
| Peak Lost Load | 1500 | kW |
| Ave Lost Load | 750 | kW |
| Total kWh of Outage | 4500 | kWh |
| % of Pk Lost Load Battery Can Meet | 133% | |
| % of Outage Battery Can Meet | 142% | |

**Figure 19: Microgrid Inputs and Resiliency Calculations.**

Using these inputs, the ESD model calculates the total kWh of the outage based upon duration and average lost load, and it provides the user a percent of peak lost load and overall outage that the solar-plus system could meet when it is fully charged. The user should be aware that if the grid outage occurs after the battery has been discharged for another purpose, the battery's availability will be limited until it is fully or partially charged again by the solar resource. The user may decide to adjust the battery size and run the prerequisite SAM model again in order to meet their desired reliability/resilience requirements.

[19] Rickerson, W., Gillis, J., & Bulkeley, M. (2019). The value of resilience for distributed energy resources: An overview of current analytical practices. National Association of Regulatory Utility Commissioners.

[20] Giraldez Miner, J. I., Flores-Espino, F., MacAlpine, S., & Asmus, P. (2018). Phase I Microgrid Cost Study: Data Collection and Analysis of Microgrid Costs in the United States. National Renewable Energy Lab.(NREL), Golden, CO.

The principles of the ESD Gap Analysis (see Section 5.1) are useful for applying the results of a resilience analysis. Decision-makers would be asked to consider whether the additional cost (gap) created by adding resilience microgrid features could be offset by adjusting other project economic expectations or by considering non-monetary strategic values. Decision-makers might consider both the calculated resilience value and other strategic values, such as achieving emergency-service goals or meeting utility insurance requirements. SPECs recommends that the ESD user provide both the analysis of solar-plus-storage *without and with* microgrid capabilities, in order to inform decision-makers fully. SPECs also notes that adding a resiliency function–especially in the context of a PPA/ESA acquisition–will affect the battery operating agreement or storage warranty. Anticipate a negotiation with prospective developers around resiliency requirements, and review additional resources, such as publicly funded products of the Clean Energy Group.[21]

# 5 ESD MODEL RESULTS AND ANALYSIS

The ESD model provides a series of outputs under the Results section on the Inputs tab. The primary metrics that are calculated include the project NPV, Return on Investment (ROI), and Benefit/Cost Ratio. Briefly defined, the NPV is the net present value of the summation of future costs and benefits (i.e., income) over the project lifetime. A positive NPV indicates the benefits exceed the costs. The ROI is simply the ratio of benefits to costs, expressed as a percentage.

| Project Metrics | - |
|---|---|
| ROI | 81% |
| NPV | $1,490,392 |
| B/C | 1.81 |
| Benefits | $3,339,065 |
| Costs | -$1,848,673 |

**Figure 20: Metrics for Project Evaluation. Specific results will vary.**

The Results section also provides several graphics that enable the user to quickly review primary cost and benefit drivers. Figure 21, below, shows on the left a bar chart of annual costs and benefits over the project lifetime. The pie chart on the right shows the NPVs for each value stream, as a percentage of the project's total economic benefits.

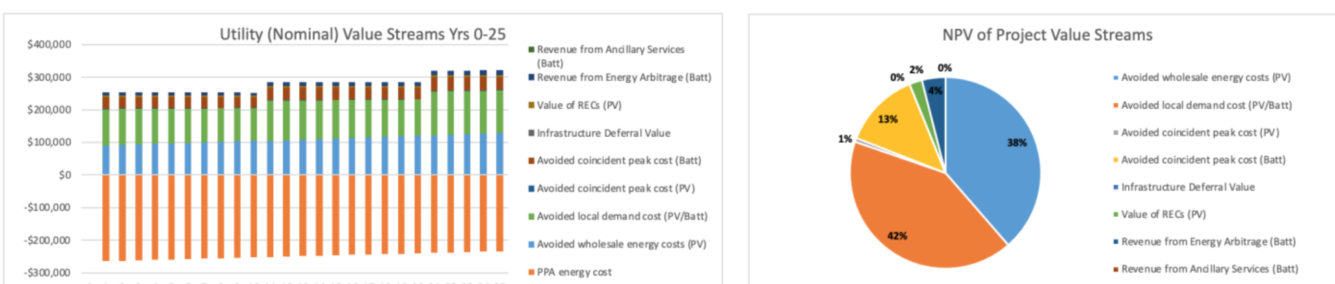



**Figure 21: Graphic Illustrating Annual Value Streams Over the Project Life and Overall Proportional Value Streams, for one sample project, as shown in the ESD Results section.**

In Figure 21, below, the graph on the left side portrays results as nominal cash flow for the project life, showing utility's annual cash flow in red, and cumulative cash flow in blue. On the

[21] See the Resilient Project Archive of the Clean Energy Group, accessed September 2022.

right, the NPV of Project Revenue Streams provides more detail on the magnitude of specific value streams. Multiple ESD runs, creating different metrics and graphic results, may be very useful in presentations to early-stage decisionmakers.

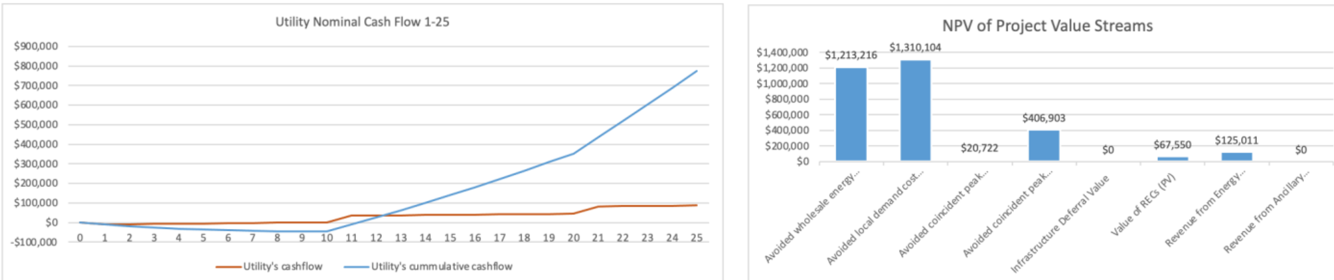



**Figure 22: Graphic Illustrating Nominal Cash Flow and the NPV of Each Value Stream, as shown in the ESD Results section for one sample project. Each utility's modeling results for each use case tested will vary significantly.**

## 5.1 Gap Analysis

In business management, the term "gap analysis" describes a comparison of actual performance with a desired, optimal level of performance. Gap analysis may be used to support an argument for a process change or investment that impacts future strategic performance, including values that are not primarily economic. For users of this model, the SPECs ESD Gap Analysis applies both to an economic gap, using standard performance metrics to reach break-even or a specific goal, and to the fine-tuning of the strategic argument, assigning value to real, but less conventional utility and community benefits. For example, this analysis process can help decision-makers to incorporate costs and benefits associated with risk-management, resiliency goals, infrastructure deferral, or local sustainability and renewable energy policies.

In short, the ESD Gap Analysis allows the user to explore the value gap that needs to be filled by one or more harder-to-quantify or negotiable value streams. In some cases, a policy-related or strategic value stream could be a key driver for a solar-plus project.

There may be cases where a user is exploring a project that falls short of one or more standard economic metrics, such as a desired internal rate of return (IRR) or net present value (NPV). It may be that the economics appear unfavorable because there is uncertainty in how to quantify some of the value streams, or because some of the value streams may be negotiable, such as project pricing or, in some cases, wholesale rate parameters.

The Gap Analysis section of the model provides the user with the option to run a simple numerical solver that will determine what a targeted input variable must be (e.g., PPA price or demand charge) in order to reach a desired NPV or IRR. The utility can then conservatively assign value to strategic benefits or seek bidders that can lower specific costs, seeking "just enough" value to meet minimum project requirements.

To run the Gap Analysis tool, the user should **first save the existing spreadsheet**, in order to reference the original analytic run and to be able to restore certain values after the gap analysis, if desired. Then the user must choose an *input metric* from the dropdown menu, as shown in Figure 23. This selected variable should be the one that the utility might specify in the RFP or negotiate with the parties involved, in order to fill the project's economic gap. For example, they might ask, "What if we could negotiate a slightly better battery system ESA price?" or "What if we could defer an infrastructure upgrade for five years, thanks to the strategic value of this project?"

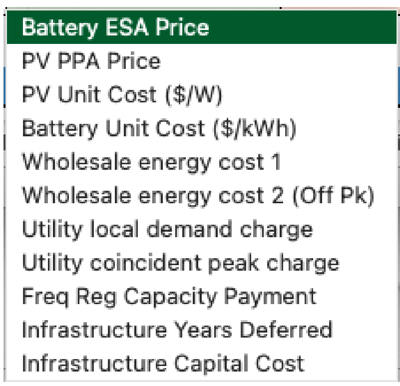



**Figure 23: Input Metrics for Gap Analysis. Note inputs support analysis with the preferred acquisition option.**

The user then selects a *target metric*, such as NPV or IRR, from a second dropdown menu. This is the metric that will be used to measure the feasibility of the project. Once these two values are chosen, the user clicks on "Run Gap Analysis." This will bring up a window, asking for the target metric value–in this example, "Enter desired Net Present Value." **When this function is run, it will change the actual input variable's value in the General Inputs section of the model.** That is why the first step in the Gap Analysis is to save previous work.

If the calculation returns a value that seems unrealistic, then the user should reduce the value for the input metric to a minimum acceptable value and then run the analysis again to see if the new input metric could drive a successful economic outcome. For example, if the initial run shows a Battery ESA price of 0.01 $/kWh to achieve an IRR of 8%, then the user should reenter the lowest *reasonable* Battery ESA price that they think they can achieve, and then test to see if a minimum acceptable target metric can be achieved. If a project is close to cost-effective, project planners generally can find financial-improvement measures or broaden their view of valid project benefits to "close the economic gap" without too many iterations.

Utility decision-makers are often motivated by strategic values that are left out of conventional economic analyses. Project planners know that such values are seldom "equal to zero." The ESD Gap Analysis allows users to incorporate minimum, supportable proxy values, in order to close an economic gap and achieve the project's target metrics. This strategic planning approach was first documented by Bourg, Cliburn, and Powers for application in utility solar development, where local decision-makers were responsive to it.[22] The approach may be applied to the strategic value of regulatory or contract compliance, local grid reliability, reduced risk of transmission back-feeding, fire or storm risk management, achievement of job development, equity and sustainability goals, and even customer retention values, when a project can meet competitive energy-service needs. One key to successfully applying this Gap Analysis tool is to seek minimum acceptable values, rather than to engage in a thorough, time-consuming value-

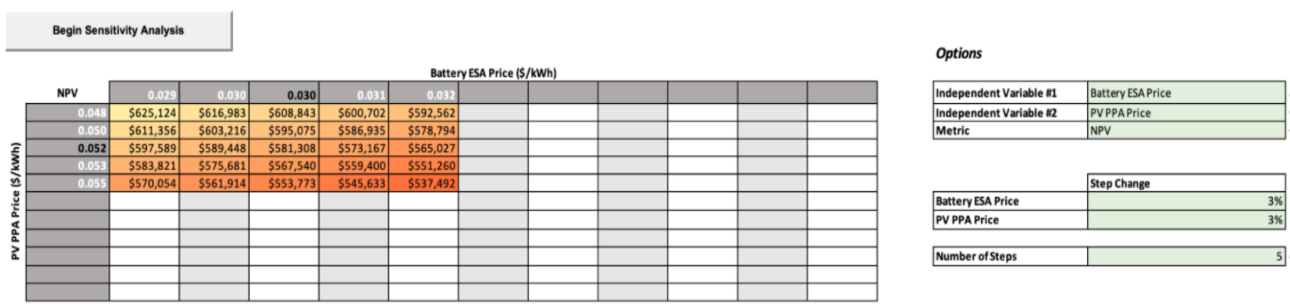
[22] Bourg, J., Cliburn, J., and Powers, J. (2017) The GAP process: A streamlined economic analysis for the procurement and pricing of community solar. Community Solar Value Project for the U.S. Department of Energy, Solar Market Pathways. Accessed September 2022.

of-solar analysis. The ESD Gap Analysis is a practical alternative, especially for co-ops and public power utilities that have leeway for local decision-making to serve the needs of their communities.

## 5.2 Sensitivity Analysis

Sensitivity analysis provides a tool for the user to look at how a desired target metric, such as project NPV or ROI, changes in response to a range of input variables. Sensitivity analysis is valuable for project development, because it may be inadvisable or impossible to define exactly what some input variables, such as PPA price, should be. In modeling without access to a sensitivity analysis, the user would have to run the model over and over, changing the PPA price or other variable and comparing runs side by side. Using the sensitivity analysis function, the user could see how sensitive the target metric is in relation to a range of PPA prices, all at once. The sensitivity analysis both saves time and supports easy comparisons.

The tool is opened by clicking a link on the General Inputs page of the model. Once the sensitivity analysis is run, outputs are visualized in a two-dimensional grid that allows users to gauge NPV or ROI sensitivity to two independent input variables concurrently. For example, the figure below shows a heat map of the NPV changes with respect to solar PPA price (vertical axis) and battery ESA price (horizontal axis). The lighter the color, the higher the value of NPV.


Begin Sensitivity Analysis

Battery ESA Price ($/kWh) / PV PPA Price ($/kWh)

| NPV | 0.029 | 0.030 | 0.030 | 0.031 | 0.032 |
|---|---|---|---|---|---|
| 0.048 | $625,124 | $616,983 | $608,843 | $600,702 | $592,562 |
| 0.050 | $611,356 | $603,216 | $595,075 | $586,935 | $578,794 |
| 0.052 | $597,589 | $589,448 | $581,308 | $573,167 | $565,027 |
| 0.053 | $583,821 | $575,681 | $567,540 | $559,400 | $551,260 |
| 0.055 | $570,054 | $561,914 | $553,773 | $545,633 | $537,492 |

*Options*

| | |
|---|---|
| Independent Variable #1 | Battery ESA Price |
| Independent Variable #2 | PV PPA Price |
| Metric | NPV |

| | Step Change |
|---|---|
| Battery ESA Price | 3% |
| PV PPA Price | 3% |

| | |
|---|---|
| Number of Steps | 5 |

**Figure 24: ESD Sensitivity Analysis Function shows the sensitivity of the project NPV to aspects of project pricing, using a 3% variation in each input variable with each step. The Sensitivity Analysis effectively compresses the analytic process.**

The user can determine the scale over which the sensitivity analysis will vary by setting the percent by which the values will vary with each step-change. The user may also set the number of steps applied. The model is preloaded for a 3% step-change, this this metric be customized.

In addition, the sensitivity analysis provides line graphs to visualize the same data in two dimensions, as shown in Figure 25. The graph on the left shows NPV as a function of battery ESA price for the five different values of PPA price. This is the equivalent of plotting each row of the heat map. The graph on the right shows NPV as a function of PV PPA price for the five different values of battery ESA price. This is the equivalent of plotting each column of the heat map.

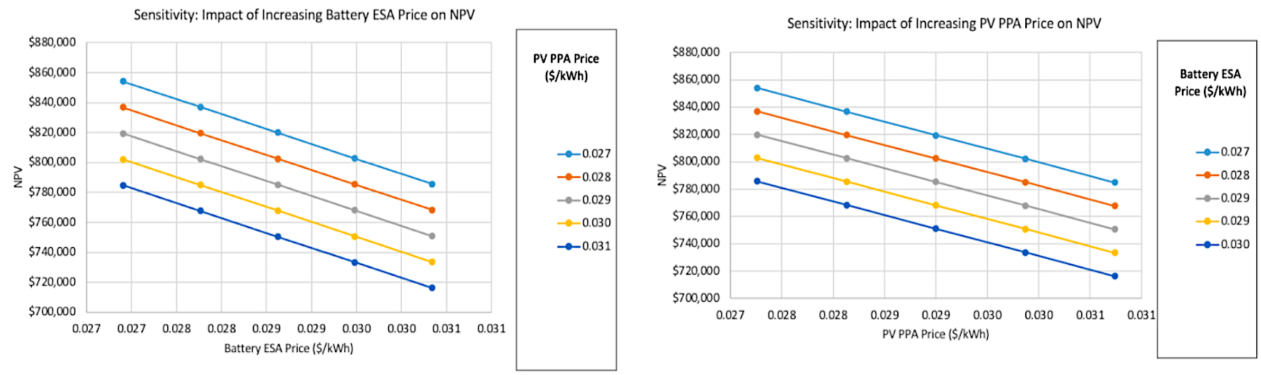



**Figure 25: Graphic Results from the Sensitivity Analysis, showing the sensitivity of NPV to battery ESA (left), where each line is equivalent to a row of the heat map, and (right) showing NPV sensitivity to the solar PPA price.**

# 6 Appendices

## 6.1 ESD Model Checklist

The worksheet below is also provided under the RFP Outputs tab of the ESD model. A utility that is using the ESD model to define project goals and broad specifications is encouraged to use this as a checklist and share their assumptions, to varying degrees, with bidders. For the RFI or a first-round RFP, the utility might wish to provide only a summary of project goals and key assumptions. However, in later-round discussions with bidders, the completed ESD model spreadsheet could be shared, as way to see how each potential vendor would approach a more detailed analysis of the early-stage project concept and fine-tune the analytic results. The sensitivity analysis tool in the ESD could help support the utility in updating assumptions for a near-final run of the model, suggesting an economically viable target range for pricing products or services sought.

### Parameters and Defaults to Run SAM and the ESD Model

| SAM Parameters | Default Value |
|---|---|
| Battery Size (kWh-AC) | ** |
| Battery Power (kW-AC) | ** |
| Min Battery State of Charge | 0.15 |
| Max Battery State of Charge | 0.95 |
| PV Array Size (kW-DC) | ** |

| | |
|---|---|
| PV Degradation Rate | 0.5 %/year |
| System Load Data (hourly data, typical year) | |

| ESD Model Parameters | Default Value |
|---|---|
| PV PPA Price ($/kWh) | ** |
| Battery ESA price ($/kWh) | ** |
| Contract Price Escalator | 0 |
| PV System Unit Cost ($/W DC) | ** |
| Battery Energy Unit Cost ($/kWh AC) | ** |
| IRA Direct-Payment (or ITC) Incentive | 30% |
| Utility Tax Rate (for MACRS) | 35% |
| Loan Term | |
| Battery Calendar-Life Degradation Rate | 1.0 %/year |
| Battery End of Life | 80% |
| Battery Turnovers to Reach 90% of Capacity | 1300 |
| Wholesale Energy Cost 1 ($/kWh) | |
| Wholesale Energy Cost 2 ($/kWh) | 0 $/kWh |
| Electricity Cost Escalation rate/year | 0 |
| Utility Local Demand Charge ($/kW) | |
| Utility Demand Escalation (rate/year) | 0 |

| | |
|---|---|
| **Utility Coincident Peak Demand Charge ($/kW)** | |
| **Freq Regulation Capacity Payment** | **0.011 $/kW-hr** |
| **Freq Regulation Nominal Price Decline** | **5 %/yr** |
| **Freq Regulation hrs/day Available** | **24 hrs** |
| **Inflation Rate** | **0.025 /yr** |
| **Utility Nominal Discount Rate** | **0.07 /yr** |
| **REC Price** | **0.002 $/kWh** |
| **Infrastructure Deferral Capital Cost ($)*** | |
| **Infrastructure Deferral Years*** | |
| **Microgrid Controller/Additional Infrastructure Unit Cost*** | **300,000 $/MW** |
| **Anticipated Outage Duration (hrs)*** | |
| **Peak of Lost Load (kW)*** | |
| **Ave Lost Load (kW)*** | |

**Figure 26. ESD Model Parameters and Defaults. Data marked with an asterisk (*) represent optional parameters and are not required for basic use of the model. Data marked with two asterisks (**) represent key system-design parameters that may be estimated and then refined through further modeling, as discussed in this manual and its references. All defaults may be adjusted.**

## 6.2 Battery Degradation

There are a wide variety of mechanisms that lead to capacity degradation in Li-ion batteries, which are dominant in the market today and the assumed technology for modeling by the ESD. Most popular solar-plus storage models also focus on Li-ion chemistries. In fact, SAM, which is prerequisite to the ESD, is capable of modeling Li-ion battery degradation for its limited storage case, but since the ESD provides full treatment of multiple storage use cases, it is best for users to ignore inputs for battery degradation in SAM. Key aspects of degradation, described in this section of the ESD manual, are handled internally to the ESD model, so any degradation counted in SAM would lead to an overestimation of project battery decay and a shorter battery life. This advice is repeated in the Section 6.3, below, on Running SAM.

According to battery research specialists at DNV GL, variables that impact battery capacity degradation include depth of discharge (DOD), state of charge (SOC) of the battery while resting, rate of charge/discharge, battery temperature, age, and energy throughput.[23] Battery research leader, DNV-GL, cites data that Li-ion battery life today is 10 to 20 years, depending upon the application and specific product technology. The ESD model takes a streamlined approach, accounting for battery degradation simply as a function of battery age, cycling, and throughput. Degradation that is increased at high temperatures can be partly mitigated by conditioning the containers; however, the energy cost to do so must be included in an economic analysis. It is important to monitor market-wide improvements in battery operations and performance and to examine performance for a particular product and site when finalizing the battery storage warranty or ESA. Sources include the annual DNV GL Battery Performance Scorecards cited above. This introduction to battery degradation principles, combined with the information developed in running the ESD model, can help project decisionmakers in fine-tuning and procurement.

Notably, some battery ESAs are written so that the subscriber is guaranteed the full battery nameplate capacity for a given timeframe. When using the ESD model, the user may set the degradation to zero if they expect to seek out an ESA with guaranteed battery capacity. However, an ESA with a guaranteed capacity may prove more costly over time than one that assumes degradation and eventual replacement.

### *6.2.1 Calendar-Life Degradation*

The ESD model assumes that calendar-life and cycle-life degradation are independent mechanisms within the battery, and thus their degradation rates can be summed to produce a net annual capacity degradation. Battery calendar-life degradation provides a simple empirical estimate of how the battery degrades over time. This battery degradation is caused by chemical reactions within the battery, and it is typically accelerated at higher states of charge and at high temperatures. While the calendar-life degradation rate for a resting battery is non-linear (faster initially and then slowing down), it may be approximated as linear. Figure 27 shows three lines from a model of calendar-life degradation[24], for different resting SOC. The red dotted line shows the default calendar-life degradation rate used in the SPECs Early-Stage Decision Model (ESD), which is 1.0 % capacity loss per year. This approximation is a straight-line approximation for the calendar-life modeled degradation for a SOC of 0.9. Notably, DNV GL recently observed calendar-life degradation in the range of 0.2 - 1% per year under test conditions.[25]

[23] See DNV GL's 2022 Battery Performance Scorecards: https://www.dnv.com/Publications/2022-battery-scorecard-228565

[24] Smith et al (2017). Life Prediction Model for Grid Connected Li-ion Battery Energy Storage System. NREL. Pg 3.

[25] DNV GL (2020). 2020 Battery Performance Scorecard. Page 29.

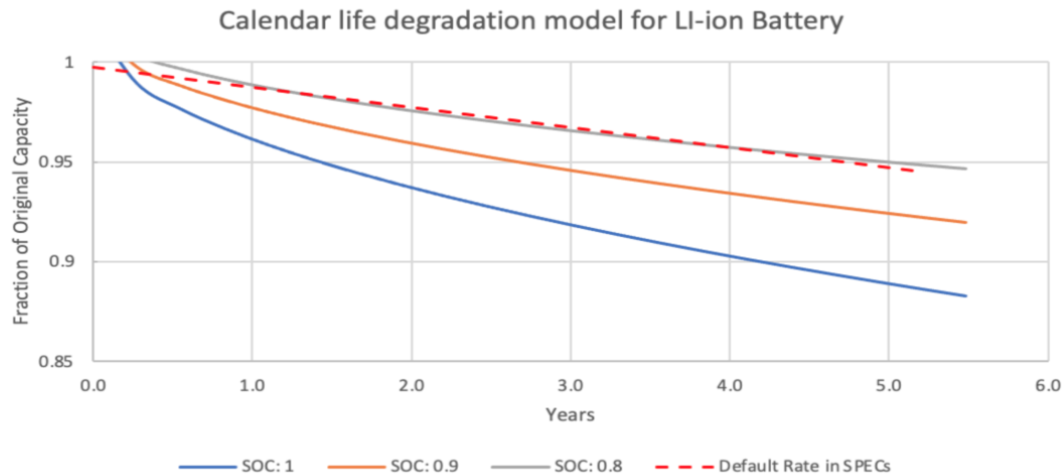



**Figure 27: Default Calendar Life Capacity Degradation Rate in SPECs ESD (1%) compared to analytic models of calendar life degradation for batteries kept at various states of charge (SOC). The analytic model is from Smith et al (2017). *Life prediction model for grid connected Li-ion battery energy storage system.***

## *6.2.2 Cycle-life Degradation*

Cycle-life degradation occurs with all battery chemistries and results each time the battery is charged or discharged. Cycle-life degradation accelerates with high or low battery temperature, lower depth of discharge, and higher charge/discharge rates. Battery end-of-life (EOL) is usually defined as occurring when the battery degrades to 80% of its initial capacity.

The figure below, from DNV GL's *Battery Performance Scorecard*, shows energy throughput to 90% remaining capacity for various Li-ion battery systems, identified by chemistry, with 50% of the systems being NMC (Nickel Manganese Cobalt Oxide). Throughput is seen as a more dependable metric for looking at battery decay, as opposed to cycles, which can vary over depth of discharge and resting state of charge. Total number of turnovers is defined as the total cumulative discharged energy, divided by the battery's nameplate capacity. Turnovers would align closely with the number of cycles for a new battery but would be less than total cycles as capacity degrades.

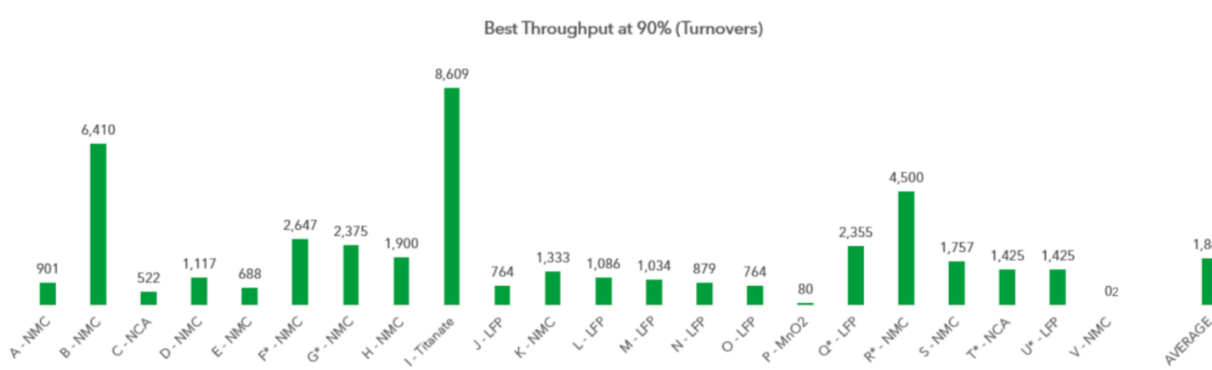



**Figure 28: Throughput of Different Tested Batteries. Source: DNV GL (2020).**

While the average throughput for all batteries was 1,868 turnovers, this is skewed by several outliers. Removing the high and low values in the example above (6410, 8609, 80, 4500), leaves an average of 1,325 turnovers to 90% throughput.

Cycle-life degradation in the ESD model is determined by users entering in a value on the model spreadsheet for "Turnovers to reach 90% of capacity," which should be based upon current and future results from DNV GL's Battery Performance Scorecards. The current default is 1,325, but it could be customized, if the user knows what battery chemistry they would be using, based on an average value from current data reported by DNV GL, as shown in the previous figure.

| Battery Degradation and Lifetime | | |
|---|---|---|
| Calendar degradation rate | 1.0% | % / yr |
| End of Life (% of initial cap) | 80% | |
| Turnovers to reach 90% of capacity | 1300 | |
| Cycle degradation rate | 2.5% | % / yr |
| Battery Throughput Per Year | 2,585,556 | kWh/yr |
| Battery Turnovers per Year | 323 | /yr |
| Battery Bank Lifetime | 5.7 | years |

**Figure 29: Battery Degradation Parameters and Calculations.**

The impact of operational factors upon battery degradation is illustrated in a recent study from co-authors at PNNL and the North Carolina utility joint action agency, Electricities.[26] The study modeled battery applications for demand reduction for North Carolina public power utilities. It showed that dispatch of a 2- and 4-hour battery could capture approximately the same number of peaks per year, but that the difference between a daily dispatch scenario and one requiring only 38 dispatches per year would correspond to the difference between a 4-year battery life and a 20-year battery life. While the study focused on one utility case, it underscored the importance of both the technology and its operation in determining project success.

The reason that the ESD model sums the values for cycle-life degradation and calendar-life degradation is because the cycle-life degradation rate results from batteries that are tested in a laboratory, with a high rate of cycling over a shortened time period. That alters the true mechanisms of calendar-life degradation. If the user were to have access to battery degradation field data, where capacity fade would include calendar-life and cycle-life degradation, the user could enter zero for calendar degradation rate and only use a value for "Turnovers to reach 90% of capacity." For current use of the ESD model, the user may simply use the defaults provided.

## 6.3 Running SAM and Importing Simulation Outputs

The SPECs ESD model relies upon some inputs derived from running the U.S. DOE National Renewable Energy Laboratory (NREL) System Advisor Model (SAM). SAM is a widely trusted and user-friendly tool for the economic analysis of power systems, including functions to assess solar-plus-storage demand-reduction values. The SPECs ESD model dovetails with SAM, adding new features, so it can provide solar project assessment and review of demand-reduction values, integrated with an assessment of *multi-value* solar-plus-storage use cases, viewed from

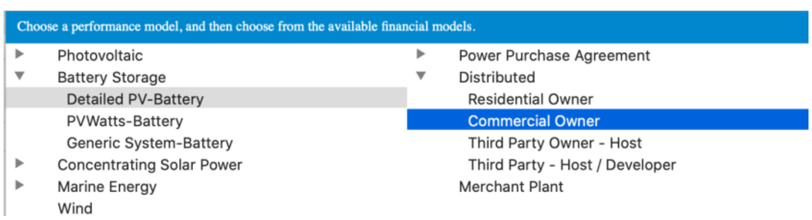
[26] Wu, D. et al, Design of a Battery Energy Management System for Capacity Charge Reduction, IEEE Open Access Journal of Power and Energy, 10.1109/OAJPE.2022.3196690. Accessed September 21, 2022.

a utility project perspective. The integration of SAM with the SPECs ESD model offers a practical solution for utilities' early-stage solar-plus-storage project decision-making.

The SAM model can be downloaded at no cost and installed from https://sam.nrel.gov. The ESD model was first developed with SAM Version 2020.11.29.[27] The SAM model will be updated to reflect the 2022 IRA, but as of this publication that has not been completed. (By contrast, key aspects of IRA incentives are included in this update of the ESD.) After SAM is downloaded and installed, the user may follow the steps below to set it up, run it, and transfer the outputs to the ESD model. When downloading the ESD Excel-based model from the Solar Value Project or NCCETC websites, users are directed to a SAM project file called *SAM-generic-user-file.sam.*

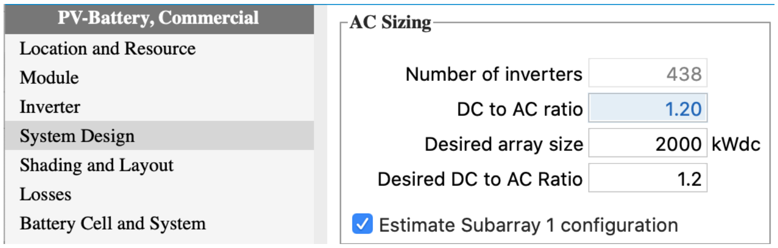
Users are advised to refer to SAM support materials to run the overall model for solar-plus-storage system assessment. Online technical support for SAM includes several user-friendly videos and resources that can help project designers dive deeper into strategic solar design. The instructions below pertain specifically to the integration of SAM with the ESD model.

1. **In order to assess savings on demand charges, SAM must be run as if it were assessing a behind-the-meter (BTM), commercial system.** This is analogous to the situation of a distribution utility that pays wholesale demand charges. In SAM, the user will need to choose: Create new project > Choose Battery Storage > Detailed PV-Battery > Distributed > Commercial Owner, as shown in the image below:
2. 

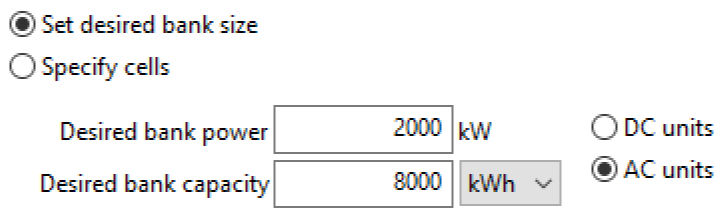



3. **Choose an appropriate location and solar resource file** under "location and resources". Follow SAM instructions to choose or download a solar resource file to the model. The user may want to download a weather file for a specific year if load data is from a specific year, rather than the default typical meteorological year (TMY) file. On the Location and Resource page, type a location name or address and change the file option from the Default TMY File option to the Choose Year option. Then click Download and Add to Library and follow the prompts to choose a year. The National Solar Radiation Database (NSRDB) has historical data from 1998 to 2020. The most recent year is updated periodically.
4. **Check the System Design (for PV) setting** under "System Design." Select "Estimate Subarray 1 Config." Specify the array size in kW DC and the DC to AC ratio (1.2 to 1.3 is typical). See illustration below.

[27] System Advisor Model Version 2020.11.29 (SAM 2020.11.29). National Renewable Energy Laboratory. Golden, CO. Accessed September 21, 2022. The newest version of SAM is SAM 2021.12.02 Revision 2, SSC 274, which is generally compatible with ESD and includes some improvements outlined on the landing page.

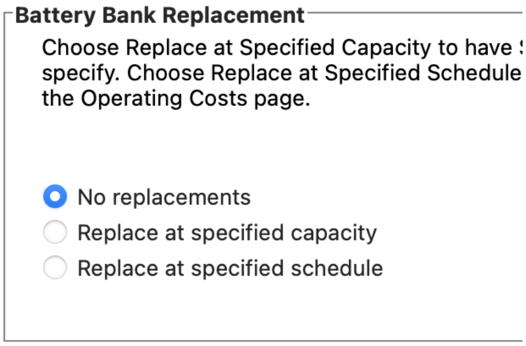



5. **Set battery storage parameters** under "Battery cell and system".
   - Battery Bank Sizing. For example: 8,000 kWh, 2,000 kW, as illustrated below. Make sure that this setting is AC in order to be consistent with assumption in the ESD Excel model.

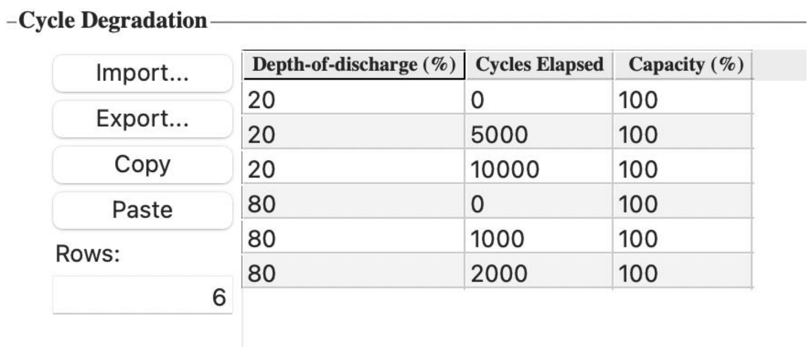



   - Scroll down to **Power Converters**
     - The power converters can be set to either AC or DC, however it is recommended that AC is used unless there are known design parameters that would make a DC connected system better. The AC connected system allows for a more flexible system that is reflective of most PV and BESS systems installed today.
     - The converter efficiency for AC to DC and DC to AC can be set to 100% to ensure that the battery storage parameters are matched realistically for maximum and minimum discharge as these values will be greater otherwise. See the SAM manual for a further explanation behind these parameters.
     - Previous versions of the model required that the system be Set to DC for a case where the batteries would be charged by "Solar Only" in the ESD model. In this case, the user must **make sure the inverter power ratings are greater than the battery power**. Check "inverter clipping" in output variables to see if there is an issue. This was done in order to ensure that BESS would charge in the model when the load was much greater than the solar output. Previous versions of SAM would not charge the battery if the load was greater than the solar output since the model is behind the meter.

6. **Set the battery bank replacement to** "No Replacements".
   - Under "Battery Bank Replacement" the replacement should be set to no replacements regardless as the battery replacement will be modeled in ESD.




7. **Set the battery degradation to zero** under "Battery Lifetime".
    - Under "Cycle Degradation" the battery capacity should be set to 100% regardless of the depth of discharge or the number of cycles so that the battery does not degrade.

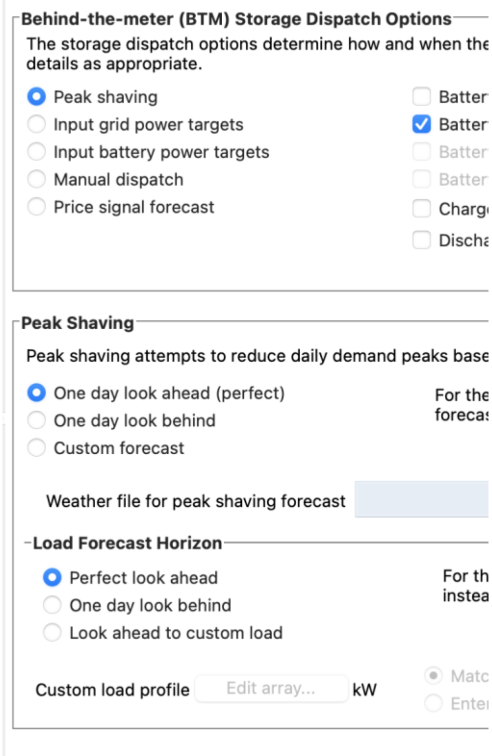



| Depth-of-discharge (%) | Cycles Elapsed | Capacity (%) |
|---|---|---|
| 20 | 0 | 100 |
| 20 | 5000 | 100 |
| 20 | 10000 | 100 |
| 80 | 0 | 100 |
| 80 | 1000 | 100 |
| 80 | 2000 | 100 |

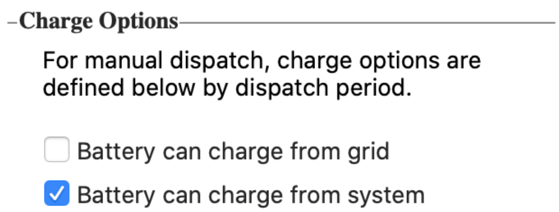
    - Under "Calendar Degradation" the circle with "none" should be selected.


    - Note: The battery degradation is all handled internal to the ESD model, so any degradation counted in SAM will lead to an overestimation of battery decay and a shorter battery life.

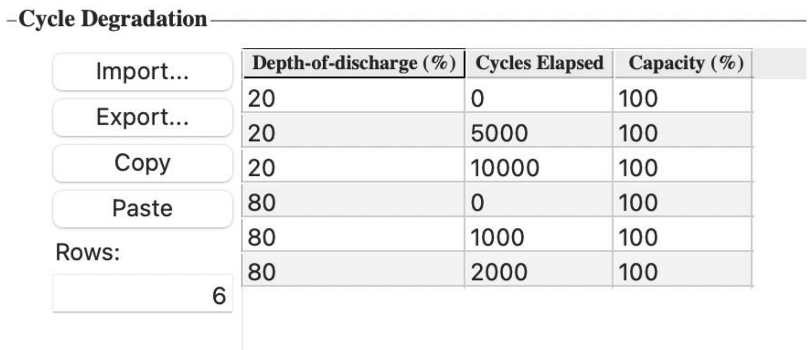
8. **Select Storage Dispatch Controller options** > Behind-the-meter (BTM) Storage Dispatch Options > Peak Shaving, > Peak Shaving > One-day look ahead (perfect), > Load Forecast Horizon > Perfect look ahead




9. **Charge Options**. Select “Battery can charge from system,” if the user plans to run the “Solar Only” battery charging option in the ESD model. Make sure that the PV system is adequately sized to charge the battery, and that the inverter selected is large enough, so that it will not limit solar or battery operations. Select both “Battery can charge from system” and “Battery can charge from grid,” in order to assess both options. (Under the new IRA incentives, non-taxable utilities can access direct-pay incentives, previously only available as the Investment Tax Credit).




10. **Set the battery degradation to zero** under “Battery Lifetime”.
    - Under “Cycle Degradation” the battery capacity should be set to 100% regardless of the depth of discharge or the number of cycles so that the battery does not degrade.



Cycle Degradation

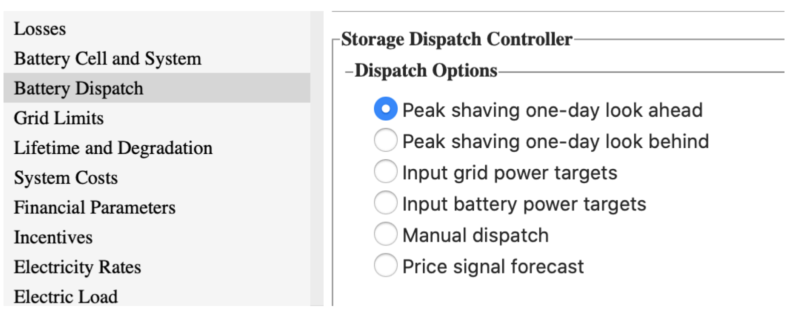
| Depth-of-discharge (%) | Cycles Elapsed | Capacity (%) |
|---|---|---|
| 20 | 0 | 100 |
| 20 | 5000 | 100 |
| 20 | 10000 | 100 |
| 80 | 0 | 100 |
| 80 | 1000 | 100 |
| 80 | 2000 | 100 |



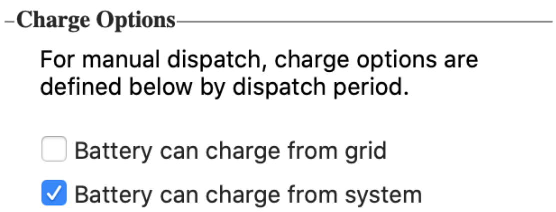
- Under "Calendar Degradation" the circle with "none" should be selected.


- Note: The battery degradation is all handled internal to the ESD model, so any degradation counted in SAM will lead to an overestimation of battery decay and a shorter battery life.

11. **Select a Storage Dispatch Controller option** > Dispatch Options > Peak Shaving One-day Look Ahead

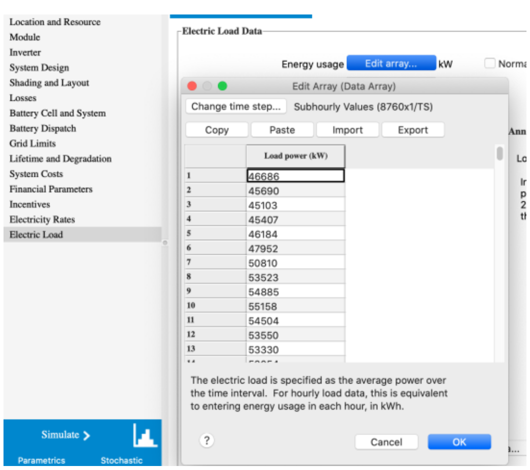



12. **Charge Options**. Select "Battery can charge from system," if the user plans to run the "Solar Only" battery charging option in the ESD model. Make sure that the PV system is adequately sized to charge the battery, and that the inverter selected is large enough, so that it will not limit solar or battery operations. Select both "Battery can charge from system" and "Battery can charge from grid," in order to assess both options. (Under the new IRA incentives, non-taxable utilities can access direct-pay incentives, previously only available as the Investment Tax Credit).




13. **IRA 2022 Updates.** The version of SAM available in fall 2022 is not yet updated to reflect changes imposed by the IRA of 2022. Users should monitor the NREL SAM website, as an update is expected. Until those updates are provided, some language in SAM support documents will pertain to design and financing protocols prior to the IRA. Conversely, the SPECs ESD model reflects key IRA updates current to fall 2022.

14. **Electric Load.** Click on "Edit Array" to import the utility's hourly load profile for one year (8760 values) in units of kW. If the load data is for a particular year, download a weather file for that year as described in Step 2 above. This will help ensure that any correlation between the load and weather is represented in the analysis assumptions. If the data represents the average load over a historical period, then use a typical meteorological year (TMY) weather file. Many analysts would recommend reviewing results from multiple years of utility hourly data, due to the possibility of a one-year anomaly. For use with the ESD model, which aims to provide quick, estimated results, the utility may quickly review annual load data from several years, in order to choose the most representative data, or it may use another method to aggregate the data sets. As a supplement to the requirements of this model, the utility may be asked to provide multiple (typically 3 or more) years of hourly load data to share with short-listed bidders in the later stages of a project procurement.

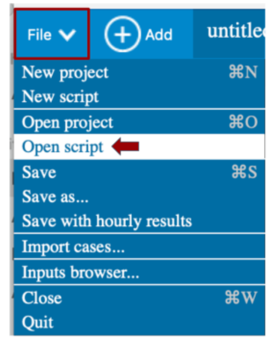



15. **Run the simulation.** Press "Simulate" to run the SAM simulation function.

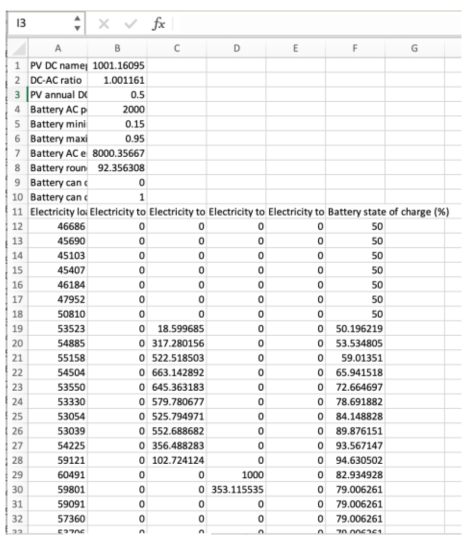
16. **Importing SAM output into SPECs ESD model**
    - In order to facilitate importing SAM simulation outputs into SPECs, the SAM model comes with a script, named **sam-to-specs.lk**, which will run the model and create a

CSV (spreadsheet) file, with all of the relevant SAM parameters and time series needed to run the ESD model.

  - To run the script, the user clicks on: File > Open script > sam-to-specs.lk
  - This will open a new window with the script. In the script window choose "run", which will result in the creation of a file called **sam-inputs-for-specs.csv**




- The CSV file contains the following parameters, as illustrated in the figure below.
  - PV DC Nameplate capacity
  - DC-AC ratio
  - PV annual DC degradation rate
  - Battery AC power (kW)
  - Battery minimum state of charge
  - Battery maximum state of charge
  - Battery AC energy capacity (kWh)
  - Battery round trip efficiency (%)
  - Battery can charge from grid
  - Battery can charge from system



| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | PV DC namep | 1001.16095 | | | | |
| 2 | DC-AC ratio | 1.001161 | | | | |
| 3 | PV annual DC | 0.5 | | | | |
| 4 | Battery AC p | 2000 | | | | |
| 5 | Battery mini | 0.15 | | | | |
| 6 | Battery maxi | 0.95 | | | | |
| 7 | Battery AC e | 8000.35667 | | | | |
| 8 | Battery roun | 92.356308 | | | | |
| 9 | Battery can c | 0 | | | | |
| 10 | Battery can c | 1 | | | | |
| 11 | Electricity lo | Electricity to | Electricity to | Electricity to | Electricity to | Battery state of charge (%) |
| 12 | 46686 | 0 | 0 | 0 | 0 | 50 |
| 13 | 45690 | 0 | 0 | 0 | 0 | 50 |
| 14 | 45103 | 0 | 0 | 0 | 0 | 50 |
| 15 | 45407 | 0 | 0 | 0 | 0 | 50 |
| 16 | 46184 | 0 | 0 | 0 | 0 | 50 |
| 17 | 47952 | 0 | 0 | 0 | 0 | 50 |
| 18 | 50810 | 0 | 0 | 0 | 0 | 50 |
| 19 | 53523 | 0 | 18.599685 | 0 | 0 | 50.196219 |
| 20 | 54885 | 0 | 317.280156 | 0 | 0 | 53.534805 |
| 21 | 55158 | 0 | 522.518503 | 0 | 0 | 59.01351 |
| 22 | 54504 | 0 | 663.142892 | 0 | 0 | 65.941518 |
| 23 | 53550 | 0 | 645.363183 | 0 | 0 | 72.664697 |
| 24 | 53330 | 0 | 579.780677 | 0 | 0 | 78.691882 |
| 25 | 53054 | 0 | 525.794971 | 0 | 0 | 84.148828 |
| 26 | 53039 | 0 | 552.688682 | 0 | 0 | 89.876151 |
| 27 | 54225 | 0 | 356.488283 | 0 | 0 | 93.567147 |
| 28 | 59121 | 0 | 102.724124 | 0 | 0 | 94.630502 |
| 29 | 60491 | 0 | 0 | 1000 | 0 | 82.934928 |
| 30 | 59801 | 0 | 0 | 353.115535 | 0 | 79.006261 |
| 31 | 59091 | 0 | 0 | 0 | 0 | 79.006261 |
| 32 | 57360 | 0 | 0 | 0 | 0 | 79.006261 |

**<u>And time series:</u>**

  - Electricity load (kW)
  - Electricity to battery from grid (kW)
  - Electricity to battery from system (kW)
  - Electricity to load from battery (kW)
  - Electricity to load from system (kW)
  - Battery state of charge (%)

- The final step requires the user to select the first 7 columns (A-H) in the CSV file, copy them, and then paste them in the same first 7 columns in the SPECs ESD Excel Model's tab called SAM Inputs. The data will then automatically update throughout the ESD model.

## 6.4 Model Assumptions and Model Logic

This section illuminates logic behind the battery operation and solar dispatch for each ESD scenario. Numerous assumptions are made regarding battery availability and operation in order to simplify the model and make it user-friendly, while maintaining technical integrity. Most of the logic is discussed in the guidance for using the ESD model, but this section provides a deeper look and supports more customization. The logic may be changed by modifying the embedded calculations, as needed for a particular utility application. However, this comes with the warning: The authors cannot assure the accuracy of the model's performance, once modifications are made, because many calculations and cells are interconnected and inform multiple further calculations.

### *6.4.1 Logic Basics*

Scenarios for the use cases that may be tested with the ESD model are introduced in Section 4.2, Value Stack Selection. Scenarios 1 through 4 all utilize local demand reduction as the primary value stream. Scenarios 5 through 8 use CP demand reduction as the primary value, along with secondary and tertiary values. Scenario 9 represents a unique case where CP reduction is the only tested value stream. Scenarios 5 and 6 both prioritize local demand reduction as the secondary value stream.

For Scenarios 1 through 4, the primary value stream is calculated using SAM's output while scenarios 5 and 6 use a modified set of SAM outputs adjusted to account for the primary CP demand value stream. CP demand, energy arbitrage, and frequency regulation (ancillary services) are all calculated internally to the ESD model and use SAM model results primarily to assess the solar-array generation.

| *Value Stack Priority* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| *1st* | Local Demand | Local Demand | Local Demand | Local Demand | CP Demand | CP Demand | CP Demand | CP Demand | CP Demand |
| *2nd* | Energy Arbitrage | Ancillary Services | CP Demand | CP Demand | Local Demand | Local Demand | Energy Arbitrage | Ancillary Services | NA |
| *3rd* | Ancillary Services | Energy Arbitrage | Energy Arbitrage | Ancillary Services | Energy Arbitrage | Ancillary Services | Ancillary Services | Energy Arbitrage | NA |

**Figure 30. Illustration of Use-Case Scenarios for the ESD Model.**

As stated previously, the streamlined ESD model assumes that the battery can only be used once a day to serve one of the three selected value streams. The solar energy is used by the battery as applicable each day, and the remaining energy is sent to the grid in order to offset otherwise purchased wholesale electricity.

The model also delineates two different logics between the different battery charging options, solar and/or grid and solar-only. If the battery may only be charged by solar, the battery's modeling is more complicated. It must check the availability of solar energy to charge the battery, which limits its ability to be readily available for dispatch. Under solar or grid charging, the battery may be charged at any point by solar or the grid. Under ideal and real-world circumstances, the battery would be charged from the cheapest energy source. In the dual charging scenarios, the model makes assumptions about the charging energy source, as described below.

The four major use case value streams considered include local demand reduction, coincident peak demand reduction, energy arbitrage, and ancillary services in the form of frequency response. Local demand reduction logic is largely handled by SAM with some modifications for specific scenarios. Coincident peak (CP) demand reduction is calculated based upon the actual CP Day and hour from historical data that the user has put in. In general, it assumes that the storage will be dispatched only once to meet the need. This provides a "best case scenario" outcome; if the project fails cost-effectiveness under this assumption, then it can be assumed to be unworkable. The perfect-dispatch assumption for CP demand reduction may be adjusted by a proxy method discussed below. (If the utility has no low confidence in its ability to dispatch effectively, it may seek an ESA with forecasting and dispatch services included, or it may acquire such services directly—or it may not be appropriate to target this value stream.)

An exception to these assumptions for CP demand reduction is the CP-Only case defined in Scenario 9. Here, the battery is assumed to reduce the coincident peak by full battery capacity on each CP Day. But overall yearly CP reduction is reduced by a percentage based on the users input on the "General Inputs" tab under "% of Optimal CP Reduction Met" cell. Future updates to the ESD may incorporate this automated proxy for real-world system performance, but currently it is limited to Scenario 9.

The general logic for other value streams also merits a quick overview. Arbitrage value is calculated by determining the amount of energy available during off peak hours that can charge the battery and then be sold in the on peak hours. Frequency regulation (ancillary services) is calculated by determining the number of hours that storage is expected to bid into the market and multiplying the number of hours by the storage nameplate capacity (MW). For ancillary services, the amount of energy in the battery is not considered, as the system would have to charge and discharge to and from the grid in order to supply ancillary services. The user may run ancillary services with solar-only; however, the need to interact bidirectionally with the grid could prove incompatible with solar-only charging. (Besides, Solar-Only operation is no longer required for a project to qualify for federal incentives.)

### *6.4.2 Grid-Charging (Solar and Grid Charging) Logic*

For all coincident peak and energy arbitrage battery charging, the battery will be charged by the grid almost exclusively, unless the solar resource costs less than the off-peak grid rate on a \$/kWh basis. If the PPA or purchased solar asset \$/kWh is cheaper than the wholesale supply, then the battery will be charged by solar in proportion to the amount of solar energy available and the amount of energy needed. The assumption in this case, that the project will be solar-charged is based on a related assumption, that the hybrid solar PV and battery components will be co-located, giving the local grid practical first-access to the solar PV generation. The ESD does not truly track the source of electricity on the grid, as electricity kilowatt-hours (kWh) are indistinguishable. Since federal IRA incentives no longer require tracking the percentage of solar versus grid-charging for the battery, it is preferable to simply refer to this case as Grid-Charging.

**Scenario 1 [Local Demand, Energy Arbitrage, Ancillary Services]**

1. The solar and battery operations are imported from SAM in order to determine local demand reduction, solar generation to the grid, and battery throughput.
2. Since the battery is not limited to solar charging only, it is assumed that the battery shifts its full energy capacity from off peak to on peak on all days that energy arbitrage is dictated, and that the battery is not already being used for local demand reduction.
3. For all the remaining days that the battery has not been used for the two previous value streams, and for which ancillary services are dictated to be marketable, the battery nameplate capacity is multiplied by the number of hours the battery can bid into the ancillary services market.

**Scenario 2 [Local Demand, Ancillary Services, Energy Arbitrage]**

1. The solar and battery operations are imported from SAM in order to determine local demand reduction, solar generation to the grid, and battery throughput.
2. On each day where ancillary services are dictated to be available for compensation and the battery has not been used for local demand reduction already, the battery nameplate capacity is multiplied by the number of hours the battery can bid into the ancillary services market.
3. For all the remaining days that the battery has not been used for the two above value streams, the full battery energy capacity is shifted from off peak to on peak.

**Scenario 3 [Local Demand, Coincident Peak, Energy Arbitrage]**

1. The solar and battery operations are imported from SAM in order to determine local demand reduction, solar generation to the grid, and battery throughput.
2. Since the battery is not limited from solar charging only, the battery reduces the coincident peak by full battery capacity on each day that the battery is not being used for local demand reduction. On days set for local demand reduction battery operation, the battery output during the CP hour is used, the same as in the solar only charging scenarios. See further notes above on the wholesale-level forecasting and real-time information that may be needed to pursue fully access the CP value stream.
3. For all the remaining days that the battery has not been used for the two above value streams, the full battery energy capacity is shifted from off peak to on peak.

**Scenario 4 [Local Demand, Coincident Peak, Ancillary Services]**

1. The solar and battery operations are imported from SAM in order to determine local demand reduction, solar generation to the grid, and battery throughput.
2. Since battery is not limited from solar charging only, the battery reduces the coincident peak by full battery capacity on each day that the battery is not being used for local demand reduction. On days set for local demand reduction battery operation, the

battery output during the CP hour is used, the same as in the solar only charging scenarios. See further notes above on the wholesale-level forecasting and real-time information that may be needed to pursue fully access the CP value stream.

3. For all the remaining days that the battery has not been used for the two previous value streams, and for which ancillary services are dictated to be marketable, the battery nameplate capacity is multiplied by the number of hours the battery can bid into the ancillary services market.

**<u>Scenario 5</u> [Coincident Peak, Local Demand, Energy Arbitrage]**

1. The battery is assumed to reduce the coincident peak by full battery capacity on each CP day. See further notes above on the wholesale-level forecasting and real-time information that may be needed to fully access the CP value stream. If the utility has a lower level of confidence in CP forecasting or access to real-time information, but it still wishes to apply the battery to reduce CP demand in any "value stack" Scenario, then the CP demand rate may be adjusted manually to approximate the percentage of total annual value (determined by the expected percentage of peaks hit). Remember that many projects achieve cost-effectiveness by finding the right balance between the need to successfully reduce peaks and the cost of increasing the battery capabilities.
2. The local demand reduction battery operation is completed as SAM dictates it with the exception of the days when the battery is being utilized for the CP reduction. This is similar to the solar-only scenarios except day before and after considerations are not important since the battery can be recharged at any point from the grid.
3. For all the remaining days that the battery has not been used for the two above value streams, the full battery energy capacity is shifted from off peak to on peak to achieve energy arbitrage.

**<u>Scenario 6</u> [Coincident Peak, Local Demand, Ancillary Services]**

1. The battery is assumed to reduce the coincident peak by full battery capacity on each CP day. See further notes above on the wholesale-level forecasting and real-time information that may be needed to fully access the CP value stream. If the utility has a lower level of confidence in CP forecasting or access to real-time information, but it still wishes to apply the battery to reduce CP demand in any "value stack" Scenario, then the CP demand rate may be adjusted manually to approximate the percentage of total annual value (determined by the expected percentage of peaks hit). Remember that many projects achieve cost-effectiveness by finding the right balance between the need to successfully reduce peaks and the cost of increasing the battery capabilities.
2. The local demand reduction battery operation is completed as SAM dictates it with the exception of the days when the battery is being utilized for the CP reduction. This is similar to the solar-only scenarios except day before and after considerations are not important since the battery can be recharged at any point from the grid.
3. For all the remaining days that the battery has not been used for the two previous value streams, and for which ancillary services are dictated to be marketable, the battery nameplate capacity is multiplied by the number of hours the battery can bid into the ancillary services market.

**<u>Scenario 7</u> [Coincident Peak, Energy Arbitrage, Ancillary Services]**

1. The battery is assumed to reduce the coincident peak by full battery capacity on each CP day. See further notes above on the wholesale-level forecasting and real-time information that may be needed to fully access the CP value stream. If the utility has a lower level of confidence in CP forecasting or access to real-time information, but it still wishes to apply the battery to reduce CP demand in any “value stack” Scenario, then the CP demand rate may be adjusted manually to approximate the percentage of total annual value (determined by the expected percentage of peaks hit). Remember that many projects achieve cost-effectiveness by finding the right balance between the need to successfully reduce peaks and the cost of increasing the battery capabilities.
2. Since the battery is not limited from solar charging only, it is assumed that the battery shifts its full energy capacity on all days that energy arbitrage is dictated, and that the battery is not already being used for coincident demand reduction.
3. For all the remaining days that the battery has not been used for the two previous value streams, and for which ancillary services are dictated to be marketable, the battery nameplate capacity is multiplied by the number of hours the battery can bid into the ancillary services market.

**<u>Scenario 8</u> [Coincident Peak, Ancillary Services, Energy Arbitrage]**

1. The battery is assumed to reduce the coincident peak by full battery capacity on each CP day. See further notes above on the wholesale-level forecasting and real-time information that may be needed to fully access the CP value stream. If the utility has a lower level of confidence in CP forecasting or access to real-time information, but it still wishes to apply the battery to reduce CP demand in any “value stack” Scenario, then the CP demand rate may be adjusted manually to approximate the percentage of total annual value (determined by the expected percentage of peaks hit). Remember that many projects achieve cost-effectiveness by finding the right balance between the need to successfully reduce peaks and the cost of increasing the battery capabilities.
2. On each day where ancillary services are dictated to be available for compensation and the battery has not been used for CP Reduction already, the battery nameplate capacity is multiplied by the number of hours the battery can bid into the ancillary services market.
3. For all the remaining days that the battery has not been used for the two previous value streams, and for which ancillary services are dictated to be marketable, the battery nameplate capacity is multiplied by the number of hours the battery can bid into the ancillary services market.

**<u>Scenario 9</u> [Coincident Peak Reduction Only – CP-Only]**

1. The battery is assumed to reduce the coincident peak by full battery capacity on each CP day. The overall yearly CP reduction will be reduced by a percentage based on the users input on the “General Inputs” tab under “% of Optimal CP Reduction Met” cell. Thus, input must be a percentage between 0% and 100% If the user inputs a 100% accuracy the CP reduction will match the full battery capacity each month. 90% accuracy will reduce the battery capacity by 10%, there in receiving 90% of the total battery capacity during CP hours. Furthermore, the user will input the “Ave # of dispatches to hit CP”, which must be a number 1 or greater and 31 or less. This number is used to model a

more realistic battery degradation by reflecting more realistically reflecting the number of cycles the battery will make each month for CP only operations. The higher the number the more likely the battery will hit the CP thus increasing the user's confidence in a higher "% of Optimal CP Reduction Met" parameter, while penalizing the battery cost by requiring a battery replacement sooner via increased degradation. This logic only applies to scenario 9 and not to scenarios 1-8, due to the complexity of modeling such logic while also enabling accurate modeling for the other two value streams. See above for a manual approach to incorporating the utility's realistic expectations for CP Demand Reduction in a use case that incorporates secondary and tertiary value streams.
2. This is the only value stream assessed for the CP-Only Scenario.

### *6.4.3 Solar-Only Charging Logic*

Since the introduction of IRA incentives in fall 2022, this option will be used for a limited set of applications. The flexibility of grid-charging is almost always preferable to a solar-only charging scenario. However, there are use cases, such as a grid-support or resilience case, when the user will benefit from testing Solar-Only Charging results. For all the scenarios where the storage is limited to solar only charging, the battery's availability and its operation are determined by the amount of energy generated and available to the battery prior to its operational need. Because Solar-Only cases will be rarely applied in 2023 and beyond, this Section uses "shorthand references" to operational functions in the first few scenarios, rather than repeating the text for a given operation, unless the Scenario discussed requires unique considerations.

**Scenario 1 [Local Demand, Energy Arbitrage, Ancillary Services]**

1. The solar and battery operations are imported from SAM in order to determine demand reduction, solar generation to the grid, and battery throughput
2. On each day where energy arbitrage is dictated to be available for compensation, the amount of solar energy below the battery energy capacity that is off peak is summed. On days where the battery is available (not already in use for local demand) the energy summed is "shifted" to on peak.
3. For all the remaining days that the battery has not been used for the two above value streams and that ancillary services are dictated to be available for compensation, the battery nameplate capacity is multiplied by the number of hours the battery can bid into the ancillary services market.

**Scenario 2 [Local Demand, Ancillary Services, Energy Arbitrage]**

1. Same as Scenario 1
2. On each day where ancillary services are dictated to be available for compensation and the battery has not been used for local demand reduction already, the battery nameplate capacity is multiplied by the number of hours the battery can bid into the ancillary services market.
3. For all the remaining days that the battery has not been used for the two above value streams, the amount of solar energy below the battery energy capacity that is off peak is summed and assumed to be "shifted" to on peak hours.

**Scenario 3 [Local Demand, Coincident Peak, Energy Arbitrage]**

1. Same as Scenario 1
2. On coincident peak days where the battery is being used for local demand reduction, the battery output during the CP hour is used for CP calculations. On days where the battery is available, the amount of energy available to charge the battery for two hours prior to the CP hour is summed. The energy summed is then used to calculate a fraction of the total battery energy capacity. This fraction is then multiplied by the battery's energy capacity to determine the fraction of the total energy capacity that the coincident peak hour demand reduction achieved is expected. If the utility has a lower level of confidence in CP forecasting or access to real-time information, but it still wishes to apply the battery to reduce CP demand, then the CP demand value (rate) may be adjusted to roughly approximate the percentage of total annual value, determined by the percentage of peaks hit, that is likely to be captured.
3. Same as scenario 2

**<u>Scenario 4</u> [Local Demand, Coincident Peak, Ancillary Services]**

1. Same as Scenario 1
2. Same as Scenario 3
3. Same as Scenario 1

**<u>Scenario 5</u> [Coincident Peak, Local Demand, Energy Arbitrage]**

1. As the primary value stream, the battery is assumed to be fully charged and therefore the battery reduces the coincident peak by the full battery capacity.
2. The local demand reduction is calculated with the SAM model, similar to scenarios 1-4, with two modifications. To ensure the battery is charged and able to produce the full CP reduction, the battery's state of charge at midnight prior to the CP day as dictated by SAM is observed. If the state of charge is below 80% full at midnight, then the SAM-dictated battery operation for local demand reduction from the day before is set to zero to ensure the battery is 100% full for CP reduction, and the battery state of charge is not modified (assumed to be 100%). By doing so, this ensures the CP reduction is met. This reflects the assumption that when CP reduction is the primary use case, preparing the battery for CP reduction is more important than achieving local demand reduction today. Similarly, if the total amount of energy after the CP hour for that day is less than 80% of the battery state of charge that SAM shows at midnight at the end of the day, then the day-after local demand battery operation is also voided. See further notes above on the wholesale-level forecasting and real-time information that may be needed to pursue fully access the CP value stream.
3. Same as Scenario 2

**<u>Scenario 6</u> [Coincident Peak, Local Demand, Ancillary Services]**

1. Same as Scenario 5
2. Same as Scenario 5
3. Same as Scenario 1

**<u>Scenario 7</u> [Coincident Peak, Energy Arbitrage, Ancillary Services]**

1. Same as Scenario 5
2. Since there is no local demand reduction the SAM battery operation is ignored. Rather, the total amount of PV solar generation is calculated for non-coincident peak days and

all of the off peak energy below the battery's energy capacity is summed and shifted to off peak.

3. Same as Scenario 1

__Scenario 8__ **[Coincident Peak, Ancillary Services, Energy Arbitrage]**

1. Same as Scenario 5
2. On each day where ancillary services are dictated to be available for compensation and the battery has not been used for coincident peak reduction already, the battery nameplate capacity is multiplied by the number of hours the battery can bid into the ancillary services market.
3. Same as Scenario 2 with the note that the amount of solar energy available is from the total PV solar generation (as opposed to the solar generation left after the battery is used for local demand reduction as dictated by SAM).

**Scenario 9 [Coincident Peak Reduction Only – CP-Only]**

As the primary value stream, the battery is assumed to be fully charged and therefore the battery reduces the coincident peak by the full battery capacity. The battery is assumed to reduce the coincident peak by full battery capacity on each CP day. The overall yearly CP reduction will be reduced by a percentage based on the users input on the "General Inputs" tab under "% of Optimal CP Reduction Met" cell. Thus, the input must be a percentage between 0% and 100%. If the user inputs a 100% accuracy the CP reduction will match the full battery capacity each month. 90% accuracy will reduce the battery capacity by 10%, there in receiving 90% of the total battery capacity during CP hours. Furthermore, the user will input the "Ave # of dispatches to hit CP", which must be a number 1 or greater and 31 or less. This number is used to model a more realistic battery degradation by reflecting more realistically reflecting the number of cycles the battery will make each month for CP only operations. The higher the number the more likely the battery will hit the CP thus increasing the user's confidence in a higher "% of Optimal CP Reduction Met" parameter, while penalizing the battery cost by requiring a battery replacement sooner via increased degradation. This logic only applies to scenario 9 and not to scenarios 1-8 due to the complexity of modeling such logic while also enabling accurate modeling for the other two value streams)

# 7 Overview of SPECs Procurement Framework

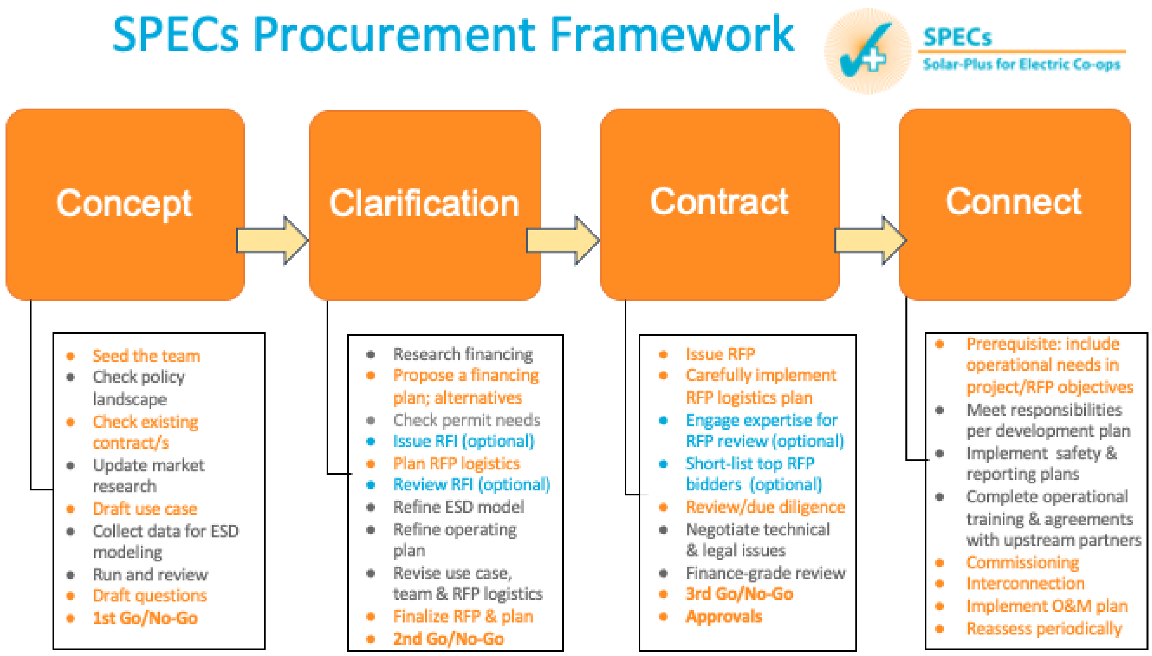



Figure 31: SPECS Procurement Process for Solar-Plus-Storage, establishing a framework for utility planning.

The graphic above summarizes the procurement process for a local utility solar-plus-storage project. The bullets shown in Orange are key milestones. The bullets shown in Blue related directly to the optional Request for Information from vendors (RFI) and the Request for Proposals (RFP). The bullets in black are important research elements for the project team. A full explanation and other support materials are available from the Solar Value Project website, at https://www.communitysolarvalueproject.com, under the Solar-Plus tab.

# 8 Comparative Matrix: Solar-Plus-Storage Modeling Tools

| Valuation Tool | Developer | Access | Comments |
|---|---|---|---|
| StorageVET | EPRI | Public/Free | Relatively complex, python-based. Analyzes storage for pre-dispatch and market optimization values |
| DER-VET | EPRI | Public/Free | Relatively complex, python-based. Analyzes portfolios of DER strategies; residential to C&I |
| QuESt | Sandia Labs | Public/Free | Python-based, focused on benefits of storage, market value and BTM value |
| Energytoolbase | Payson Systems (parent co.) | Commercial | A range of products for economic modeling, storage operation/control, and asset monitoring |
| SAM and RE-Opt Lite | NREL | Public/Free | Focused originally on solar, now all renewables and storage. SAM is strong on storage for demand reduction; RE-opt Lite for buildings, campuses, microgrids. |
| MASCORE | PNNL | Public/Free | Models DERs (inc. PV, ESS, and generators) considering underlying economic and technical aspects and resiliency goals. |
| SPECs Early-Stage Decision Model | Cliburn/NCCETC | Public/Free | Excel-based. Screens and fine-tunes distribution utility storage use-case options; works w SAM |

Figure 32: Alternative Modeling Tools for Utility Solar-Plus-Storage. (Source: Cliburn, 2021; Sandia National Labs, 2020)

The Figure above offers a comparative summary of recently available modeling tools for utility solar-plus-storage projects. It is not intended as an exhaustive list, but it illustrates the range of models currently available, suited to specific utility needs. As indicated, the SPECS ESD model builds on the open-source SAM model from NREL, in order to provide a highly accessible alternative, suited to local utility use, and especially for electric co-ops and public power systems.