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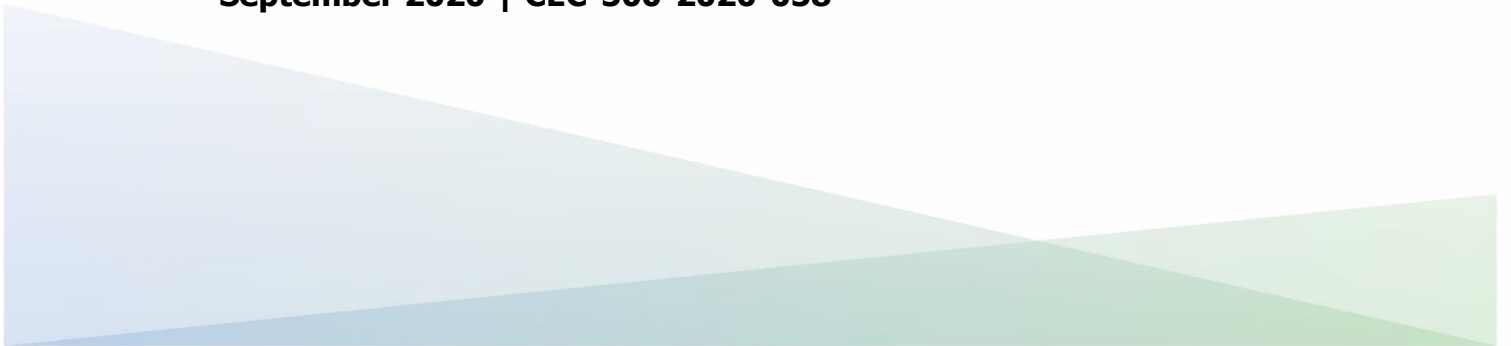


Energy Research and Development Division

## **FINAL PROJECT REPORT**

# **Enhanced Modeling Tools to Maximize Solar + Storage Benefits**

**Gavin Newsom, Governor**  
**September 2020 | CEC-500-2020-058**



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## PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

*Enhanced Modeling Tools to Maximize Solar + Storage Benefits* is the final report for the Enhanced Modeling Tools to Maximize Solar + Storage Benefits project (EPC-17-004) conducted by Energy and Environmental Economics, Inc. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the [CEC's research website](http://www.energy.ca.gov/research/) (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

## ABSTRACT

The project team worked with industry stakeholders and leveraged work throughout the United States to develop the publicly available Solar + Storage Tool. The tool, available for download on the California Energy Commission's website, provides a comprehensive framework for cost-effectiveness analysis of solar photovoltaic, energy storage, and other distributed energy resources. It coordinates the dispatch of controllable distributed energy resources under various value scenarios such as customer bill management, utility grid support, utility transmission and distribution deferrals, and energy resilience. Distributed energy resource technologies modeled by the tool include: integrated solar and storage systems, smart thermostats, smart water heaters, electric-vehicle chargers, and fuel cell generators either in isolation or as a portfolio to leverage synergies among distributed energy resource options. For distributed energy resource technologies that are not used purely for generating or shifting electricity, such as smart water heaters, the uncertainty of customers' usage is taken into consideration. The tool also offers flexibility in modeling current or future hypothetical utility rates, resource adequacy programs, and utility demand-response programs, allowing users to test future rates and market designs. The tool has a pro forma financing module that calculates the financing costs and taxes associated with a project.

The tool has been used to conduct a cost-effectiveness analysis for a Solar Photovoltaic + Storage pilot at a gas station in Blue Lake Rancheria, California. The system is cost-effective from the participant's perspective, and offers considerable value as an emergency center during grid-outage events.

**Keywords:** energy storage, solar PV, distributed energy resource, DER, electric vehicle, smart thermostats, smart water heater, fuel cell generator, cost test, cost-benefit analysis, distribution deferral, optimization, modeling tool

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# EXECUTIVE SUMMARY

## Introduction

California is transforming its electricity system into a national model that is not only cleaner but also more resilient and affordable. Senate Bill 100 (De Leon, Chapter 312, Statutes of 2018) mandates that 100 percent of California's retail electricity sales be met with renewable or other zero-carbon resources by 2045. Energy storage will play an increasingly important role in this unprecedented transformation. As renewable power sources like wind and solar provide ever-greater percentages of California's electricity mix, storage can smooth and time-shift electric grid accommodation of renewable generation, and in the process minimize curtailment of carbon-free renewable energy generation.

Energy storage is often called the "Swiss Army knife" of the electricity system in recognition of its many services. This flexibility will become essential as the state's electric system becomes more decarbonized, decentralized, and complex. The Solar + Storage Tool crosses multiple complementary and competing programs to identify and implement operational strategies that deliver the greatest benefits at the lowest cost.

While energy storage will be foundational to California's fast-evolving clean-energy future, electrification and other distributed energy resources, such as rooftop solar photovoltaic and energy efficiency, will also be major players. As smart devices become more pervasive throughout the state and play an ever-larger role in managing and monitoring electricity use, understanding the interactions among distributed energy resources, electric vehicles, and smart appliances has become a critical component of utility-distribution planning. Utilities can now assess how distributed energy resources affect their transmission and distribution peak-demand periods and under what circumstances distributed energy resource portfolios may defer expensive system upgrades.

The Solar + Storage Tool developed by Energy and Environmental Economics, Inc. for this project can answer these and other questions. The tool can be downloaded and run on most personal computers. It estimates benefits provided by distributed energy resources and captures synergies among them by simulating the most efficient and economical dispatches of multiple distributed energy resource technologies, either in isolation or as a portfolio. These technologies include integrated solar photovoltaic and storage systems, smart thermostats, smart water heaters, electric-vehicle chargers, and fuel-cell generators. The tool's flexibility to function among multiple distributed energy resources allows utilities, developers, and microgrid owners and operators to simulate operation of their portfolios and gain greater understanding of the values and synergies that those portfolios can provide. The tool is a "one-stop shop" for analyzing the cost effectiveness of distributed energy resources, in front of and behind the meter. It simplifies the evaluation process to better inform California's energy policymakers as the state continues its ambitious journey toward carbon neutrality.

## Project Purpose

This project developed a free, publicly available tool that performs a comprehensive cost-effectiveness analysis for energy storage and other distributed energy resources.

The Solar + Storage Tool developed for this project identifies the most effective and economical approach of integrated solar photovoltaic and storage systems and estimates the value delivered to the customers based on their expected operations, location on the grid, electricity market prices, and other factors. The Solar + Storage Tool is equipped with the California Public Utilities Commission's avoided costs for distributed energy resources, as well as market-price forecasts and utility rates, to develop cost-benefit analyses from a variety of perspectives. Consequently, the tool can evaluate distributed solar photovoltaics with storage and other controllable distributed energy resource technologies and determine optimal dispatch under a wide range of customer programs and incentive designs. The tool also quantifies project-specific distribution deferral values using the Locational Net Benefit Analysis framework established by the California Public Utilities Commission, which incorporates load shape, load growth, and upgrade costs.

The tool is designed for maximum flexibility so that different users can answer different questions. For example, it allows utilities and policymakers to conduct non-wires alternative analyses, such as the distribution deferral opportunity reports published by California's investor-owned utilities, and identify opportunities for distributed energy resource portfolios to displace more expensive traditional infrastructure and deliver savings for utility customers. It also conducts rate- and program-design analyses so that utilities and policymakers can understand the impacts of distributed energy resource programs to transmission and distribution electric systems, participants, and others. The tool can also help utilities design distributed energy resource programs and rates that benefit participants and the system, which could further drive down utility customer costs. Finally, developers, aggregators, and investors can gain valuable insights from the tool's calculations of distributed energy resource costs and benefits.

## **Project Approach**

The project team was led by Energy and Environmental Economics, Inc. with support from the investor-owned utility Southern California Edison and Starboard Energy Advisors, LLC, a consultant for energy-storage developers. Energy and Environmental Economics, Inc. led the tool development with support and feedback from the project's technical advisory committee, which includes members from Pacific Gas and Electric Company, Southern California Edison, three members from the California Public Utilities Commission, and the storage developers Advanced Microgrid and Starboard Energy. After the tool was developed, Energy and Environmental Economics, Inc. focused on technology and knowledge transfer to promote and support the tool's widespread use. Southern California Edison and Starboard Energy Advisors monitored the tool's performance throughout the process and provided valuable feedback on its design and functionality. Staff from the investor-owned utility Pacific Gas and Electric Company and the California Public Utilities Commission also provided feedback on the functionalities related to the Distributed Resource Planning proceeding during several one-on-one meetings with E3.

The Solar + Storage Tool is built on the Locational Net Benefit Analysis tool, a Microsoft Excel-based tool that California's three investor-owned utilities use to evaluate the distribution deferral values of distributed energy resources. By reducing load during peak hours, distributed energy resources can alleviate distribution system constraints and defer or avoid

distribution upgrades. The distribution deferral value is the savings from deferring or avoiding an upgrade. The Solar + Storage Tool preserved the Locational Net Benefit Analysis tool's distribution deferral evaluation method but expanded it to include a broader range of distributed energy resources. Instead of using Excel, Energy and Environmental Economics, Inc. moved the Solar + Storage Tool to Python, a general-purpose computer programming language, and took an advantage of Python's computing power to provide additional tool functionalities, including optimization of dispatchable resources. The Solar + Storage Tool employs several Excel spreadsheets as a user interface to the Python code so the user can work in a familiar environment.

The project's technical advisory committee provided feedback on the project approach and tool functionalities. Their feedback was then integrated into each successive version of the tool.

In addition to tool development, the project team supported other research teams funded by the state's Electric Program Investment Charge (EPIC) program by using the Solar + Storage Tool to evaluate how distributed energy resource technologies can increase both utility and customer benefits on their projects.

## **Project Results**

The project achieved its goals; the tool has been successfully developed and its results vetted and benchmarked to historical revenues and other storage-evaluation tools.

The project team has shared the tool with the general public through several public workshops. In addition, Energy and Environmental Economics, Inc. worked with Humboldt State University's Sponsored Programs Foundation, an EPIC funding recipient, to conduct a case study where the tool was used to evaluate a solar + storage pilot project. To further demonstrate the tool, the project team also developed example studies for representative use cases and presented those results in public workshops along with six other case studies. Case studies presented in the public workshops also include results from other Energy and Environmental Economics, Inc. projects that used the tool. For example, the California Storage Program Evaluation project Energy and Environmental Economics, Inc. conducted in partnership with Itron for the California Public Utilities Commission<sup>1</sup>, a project to determine the grid benefits of distribution-aware vehicle-to-grid services performed by a fleet of electric vehicles at the University of California, San Diego campus<sup>2</sup>, as well as a project to evaluate the costs and benefits of a potential microgrid in Santa Monica, CA.<sup>3</sup>

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<sup>1</sup> See "2018 SGIP Advanced Energy Storage Impact Evaluation" and 2019 SGIP Energy Storage Market Assessment and Cost-effectiveness Report". available at: <https://www.cpuc.ca.gov/General.aspx?id=7890>

<sup>2</sup> See "Distribution System Constrained Vehicle-to -Grid Services for Improved Grid Stability and Reliability" CEC-500-2019-027. Available at: <https://ww2.energy.ca.gov/2019publications/CEC-500-2019-027/CEC-500-2019-027.pdf>

<sup>3</sup> See "Santa Monica City Yards Advanced Energy District" CEC-500-2019-032. available at: <https://ww2.energy.ca.gov/2019publications/CEC-500-2019-032/CEC-500-2019-032.pdf>

Pacific Gas and Electric and Los Angeles Department of Water and Power have each expressed interest in using this tool for rate design, distribution deferrals, and microgrid analyses.

To provide even more user-friendly and robust distributed energy resource evaluation tools for California, the research team recommends adding the following features in future studies:

- Including energy storage operation simulations according to detailed California Independent System Operator market rules.
- Addressing revenue uncertainty from imperfect foresight.
- Further developing the tool's electrification functionality.
- Including an adoption feature to assess the overall impact of distributed energy resources on bulk and distribution systems.
- Further developing the tool's microgrid functionality.
- Exploring the potential for new-user interface platforms that enable linkages with both external databases, such as the National Renewable Energy Lab's PVWatts, and users to make customized changes.

## **Technology Transfer, Knowledge Transfer, and Market Adoption**

Technology and knowledge transfer activities conducted in this project included three public workshops hosted in June, August, and December 2019. The first workshop briefly introduced the final release of the Solar + Storage Tool and then focused on use cases for the tool and example results for the three most common use cases. The second workshop shared results for the solar + storage pilot project case study conducted with Humboldt State University Sponsored Program Foundation. The third workshop focused on providing additional use examples, addressing stakeholder feedback, and making recommendations for future studies. The three public workshops attracted widespread interest, with 50 to 170 representatives attending each workshop from utilities, universities, regulators, developers, national labs, and environmental groups.

The project team also reached out to a broad group of EPIC project recipients through the California Energy Commission to seek collaboration, share the tool, and discuss pilot projects. The project team also conducted a case study in coordination with Humboldt State University Sponsored Program Foundation to evaluate the cost effectiveness of its solar + storage pilot project in Blue Lake Rancheria, in Northern California.

Before the model is published, to better design the tool for utilities' use, Energy and Environmental Economics, Inc. reached out to Pacific Gas and Electric Company and Southern California Edison individually to learn how the utilities will use the tool and get their feedback on existing functionalities. In addition, Energy and Environmental Economics, Inc. also discussed ideas for potential future functionalities with each utility.

After the model is published, Energy and Environmental Economics, Inc. was approached by Pacific Gas and Electric Company, Los Angeles Department of Water and Power, and Marin Clean Energy who all expressed interested in further using the tool for distributed energy resources program analysis, distributed energy resources planning, and bid evaluation. Energy and Environmental Economics, Inc. scheduled initial meetings with each of the utility to understand their use cases and answered their questions about the tool.

In addition to the technology and knowledge transfer activities performed in this project, Energy and Environmental Economics, Inc. has used this tool for many clients, including solar photovoltaic and storage developers for asset evaluation; state agencies for policy analyses, including for the Self-generation Incentive Program; and utilities for distributed energy resources program designs. Energy and Environmental Economics, Inc. will continue to promote the tool, including exploration of commercialization opportunities.

## **Benefits to California**

The tool developed in this project can be used by different entities to assess distributed energy resource benefits, especially the benefits provided by dispatchable distributed energy resource technologies. The ability to understand how customers use their distributed energy resource technologies has become increasingly important as the adoption of new distributed energy resource technologies increased rapidly in the past five years. Unlike the traditional distributed energy resources (e.g. energy efficiency with fixed load shapes or predictable performance), newer, flexible and dispatchable distributed energy resource technologies are much more versatile and at the same time more difficult to forecast.

Under the current rate structure, customers discharge batteries to reduce their own (non-coincident) peak load with the goal of minimizing demand charges. Since the customers' peak is not coincident with the system peak most of the time, dispatching batteries to reduce customers' peak doesn't benefit the system and might even increase system costs if customers decide to charge during system peak hours. To achieve California's goals for decarbonization and at the same time keep customers' rates low, utilities need to guide customers in using DERs to provide benefits to the overall system by sending supporting price signals.

Utilities can use this tool to identify cost-saving new technologies in their distributed-resource planning processes. The tool can also help utilities design rates or programs that benefit both participants and other ratepayers. In addition, the tool can be used to estimate the impact of electric vehicle adoption and the potential benefits provided by vehicle-to-grid programs. Furthermore, storage and PV developers can use this tool to compute future value estimations. The simplified evaluation process reduces soft costs and can facilitate investment and deployment of new technologies. Government and state agencies can also benefit from this tool by using it to evaluate state-wide programs (e.g. California's Self-Generation Incentive Program) or to set future policies.

The benefits of this project are summarized below:

- Identifying locations on the grid where solar photovoltaic + storage and other forms of distributed energy resources can cost effectively defer grid investments and offer other grid services.
- Identifying the portfolio interactions of multiple distributed energy resource technologies towards providing grid services.
- Providing rate-making stakeholders with a tool to evaluate different tariff and program designs to better align customer-sited distributed energy resource operations with the needs of the grid.
- Allowing users to understand customer's behaviors in using smart appliances, which is critical for achieving California's steep decarbonization goals.

- Reducing utility costs and emissions by designing sophisticated rates and DER programs.
- Allowing easy access to cost-effectiveness analyses and reducing soft costs in both energy storage and photovoltaic investment.
- Facilitating investment and deployment of new technologies and microgrids.
- Facilitating a standard practice within California to reduce communication barriers among entities by establishing a cost-benefit evaluation process for distribution energy resources.
- Developing a process to keep costs and benefits of solar photovoltaic + storage and distributed energy resources current, making sure that resource evaluations reflect the true value.
- Support other distributed energy resources or bulk grid decarbonization studies as the tool can be adapted easily for new analyses.
- Evaluate strategies for increasing allowable DER penetration. The tool can be used to evaluate strategies for preventing backflow from PV. By using distributed energy resources to reduce peak loads and limit backflows, the likelihood of associated outages on the distribution system can also be reduced.



# CHAPTER 1:

## Introduction

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In September 2018, California Governor Jerry Brown signed Senate Bill (SB) 100 (SB100, 2018), which accelerated and extended the environmental targets set forth in SB 350 (Leno, 2015). SB 100's mandates include a 50 percent renewable portfolio standard by 2026, 60 percent by 2030, and a final 2045 target of 100 percent renewable and zero-carbon renewable energy sources. Further, Executive Order (EO) B-55-18 established a new statewide goal to achieve carbon neutrality as soon as possible, and no later than 2045, in addition to existing statewide greenhouse gas (GHG) reduction targets.

Several analyses—including the Energy and Environmental Economic, Inc. (E3) California PATHWAYS study, which was sponsored by the California Public Utilities Commission (CPUC), the California Air Resources Board (ARB), the California Energy Commission (CEC), and the California Independent System Operator (California ISO)—have shown that meeting California's statewide 2045 GHG reduction goal will require nearly complete decarbonization of electric generation by 2045. (Amber Mahone, 2018) (Long, 2015) (Williams, 2012)

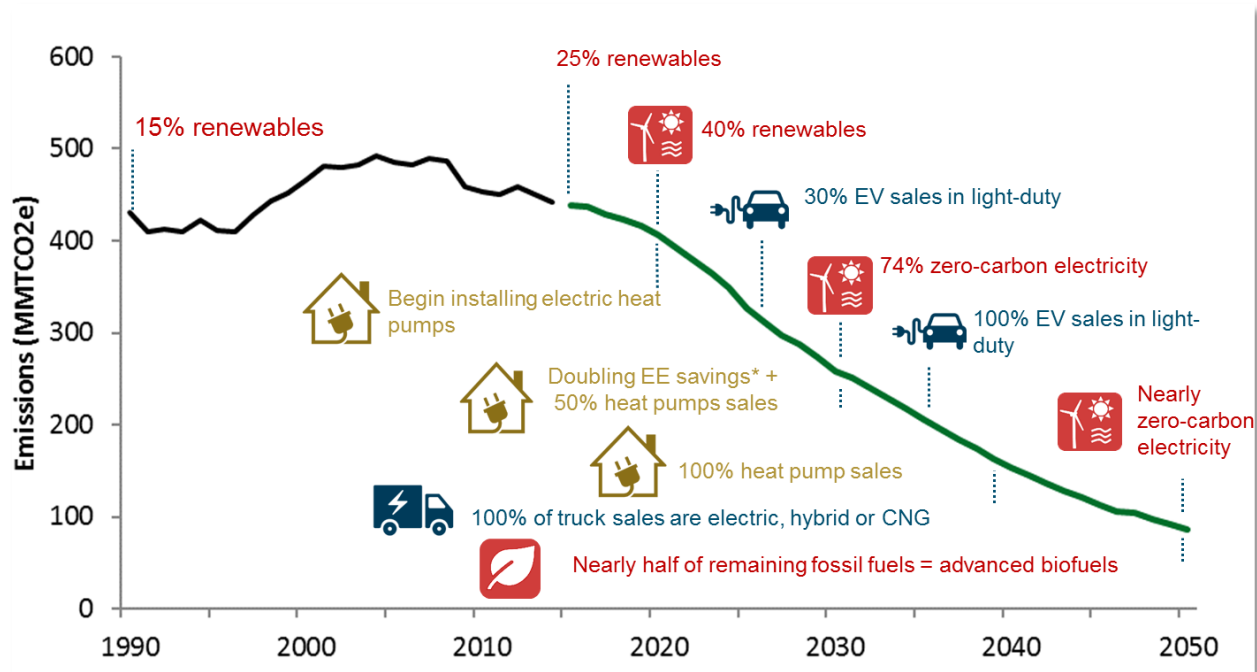
Although nuclear power, and carbon capture and storage are potentially viable pathways for decarbonizing electricity generation, California has not taken steps to develop these resources, and state law prohibits licensing new nuclear plants until the federal government adopts a permanent program for nuclear waste disposal. (National Conference of State Legislatures, 2017) Meanwhile, California continues to aggressively promote renewable energy, distributed energy resources (DERs), and storage technologies. Figure 1 shows details of one pathway, developed by E3, through which California can achieve its 2050 clean-energy goals.

Energy storage technologies will play an increasingly important role in the state's clean-energy transformation. As renewable power sources like wind and solar provide a larger percentage of California's electricity needs, storage can be used to smooth and time-shift renewable generation and minimize curtailment of wind and solar resources on the state's electric grid. Beneficial electrification of transportation and heating will be key to achieving the state's climate goals but will also place additional demands on the grid, further necessitating flexible solutions, including storage.

Challenges involved with integrating large amounts of intermittent renewable generation into the grid are nothing new. Figures such as the California ISO's "duck curve" (which graphically illustrates the imbalance between electricity supply and demand throughout the day) show how renewable generation is changing the grid's need for, and delivery of, electricity. Less recognized, however, are the challenges that utilities face at the distribution level as the electrification of buildings and vehicles increases demand for businesses and residences. Moving down the electricity delivery system from the bulk transmission grid to local transmission and then to distribution, the number of utility customers served by this infrastructure decreases. This reduces the diversity of loads and increases the need for additional transmission and distribution capacity that is driven by, and therefore more dependent upon, individual utility customer usage. Spikes from individual customers even out when looking at the transmission system as a whole; but could drive distribution investment

needs at distribution level because of individual spikes resulting from reduced load diversity. The Solar + Storage Tool accommodates highly focused evaluations at the distribution circuit or at even finer levels to capture location-specific capacity needs and characteristics.

**Figure 1: California Greenhouse Gas Emissions and Milestones in a High Electrification Scenario**



This graph shows 80 percent greenhouse gas reduction below 1990 levels by 2050

\*Per the CEC California Energy Demand 2017 IEPR Revised Forecast, “High Plus” Scenario 6 including SB 240.

Source: E3

Energy storage performs many energy-related services. Some of these services are mutually exclusive, while others can be “stacked” and performed either simultaneously or with the same resource. This flexibility is important as the electric system evolves to become more decarbonized, decentralized, and complex. Generally, storage technologies cannot perform all the services they are capable of simultaneously, which creates the need for clear performance, dispatch, and control signals. The Solar + Storage Tool operates efficiently across multiple complementary and competing value streams to best maximize operation strategies.

The CPUC has adopted three distinct types of multi-use applications for energy storage, shown in Figure 2.<sup>4</sup> A storage project’s future value will be determined by how many revenue streams it can both theoretically and practically access, and at what level.

<sup>4</sup> Decision on Multiple-Use Application Issues. Available at: <http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M206/K462/206462341.pdf>.

**Figure 2: Types of Multi-Use Applications for Storage**



Source: Decision on Multiple-Use Application Issues. Available at: <http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M206/K462/206462341.pdf>

While energy storage will be an important resource for achieving California’s clean energy future, electrification and other DERs will also be major participants. California leads the nation in electric vehicle adoption and behind-the-meter (BTM) solar photovoltaic (PV) and energy storage installations. In addition, growing interest in smart thermostats and smart water heaters is building quickly as these intelligent controls increasingly shape electricity usage, inexpensively and flexibly.

Customers adopt these technologies for various reasons and may use them differently. For example, customers who adopt energy storage for backup power are likely to behave differently than customers who use energy storage to reduce their electricity bills. Understanding customer behavior and guiding it to greater smart technology use is essential for meeting California’s mandated clean energy goals. Three options for the state to require or encourage these behaviors include effective rate designs, demand response programs, and direct system control.

To capture the value from these smart technologies, the research team first needed to understand how these technologies work together before integrating them into the planning and operations of the electricity grid. For example, energy storage; solar PV; energy efficiency; and smart heating, ventilation, and air conditioning (HVAC) systems can work together and be aggregated to defer expensive distribution upgrades. The ability to simulate these interactions to capture the synergies between technologies is critical for both utilities and developers when deciding program designs and bidding for energy projects.

DER performance is driven by several factors including the types of programs available for the resource, tariff designs for DER customers, the DER portfolio that a customer owns, the capabilities and limitations of any utility control systems in place for DER participation in grid services, and the available DER markets. These factors, in tandem with DER ownership and business models, will be incorporated into the new tool to create a truly integrated DER evaluation model that utilities can use to effectively evaluate tariffs and programs for grid services. Storage can vary considerably in value to the grid, depending on how its use is promoted through program and tariff designs. This tool can assess the impacts and test promising new program and tariff designs for storage, and when paired with solar, can

mitigate the risk of grandfathering in programs that do not meet grid requirements. Otherwise, the potential benefits that customer-installed storage could provide the grid and to ratepayers could go unrealized.

By value-stacking distribution deferral values with other available benefit streams, this tool allows the user to evaluate a full spectrum of values that energy storage could provide. Coordination between multiple DERs also allows utilities, developers, and micro-grid owners to simulate the most effective operation of their DER portfolios. This further increase understanding of the values and synergy provided by DER portfolios. Utilities can test future rates and utility programs using the flexible rate and program-design feature. The tool is a one-stop-shop for DERs and energy storage cost-effectiveness analyses. It simplifies the evaluation process and can therefore better inform California in making decisions toward decarbonization.

# CHAPTER 2:

## Project Approach

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### Purpose

The goal of this project was to develop a publicly available analysis tool that can evaluate the dispatch and operation of distributed solar-plus-battery storage, controllable-load systems, and other distributed energy resources (DERs). The project’s three main objectives were to:

- Develop an optimal dispatch algorithm for solar-plus storage and advanced control systems that maximize the value of these systems for a range of potential use cases, for example, wholesale market participation and BTM customer bill savings.
- Support the state’s Electric Program Investment Program (EPIC) research programs through assessment of a range of research and technologies that are investigating different aspects of solar-plus-battery storage technology development and implementation.
- Integrate distributed solar-plus-battery-storage systems into the distribution planning process of California’s IOUs so that these systems can become valuable resources in the state’s energy mix.

As summarized in Table 1, utilities and policymakers can use the tool for distribution bottleneck screening, non-wires alternative analyses, program design, and bid evaluation. From the developers' and aggregator's perspective, the tool can help assess the costs and benefits of DERs and provide valuable information for investors.

**Table 1: Potential Tool Users**

User	Questions to Answer
Utility/ Policymaker	Distribution bottleneck screening: Where are my distribution “hot spots”? How much value do I see in each area?
	Local Net Benefits Analysis of DER portfolios: How much value can the DER portfolio provide to my system (distribution deferral and system avoided costs)?
	DER Program Design: How would I design my programs to maximize value? Do I have ‘missing money’ that would make it hard to attract participants?
	Bid Evaluation: Which DER bids/portfolios are most cost-effective in competitive solicitations (aka non-wires alternatives)?
Developer/ Aggregator	Cost-benefit evaluation of individual technologies and DER portfolios from stakeholder perspectives. What is my expected return on investment, customer payback, and value to the utility?

Source: E3

### Approach

The project team was led by E3, an energy consulting firm based in San Francisco, California, with support from Southern California Edison (SCE) and Starboard Energy Advisors, LLC. The

project's technical advisory committee (TAC) included representatives from: Pacific Gas and Electric Company (PG&E), SCE, three members from the CPUC, and the storage developers Advanced Microgrid and Starboard Energy.

E3, as the primary recipient, developed the Solar + Storage Tool and led technology and knowledge transfer activities to promote the tool, including hosting public workshops and collaborating with other EPIC recipients. Throughout the project, E3 worked closely with partners SCE and Starboard Energy Advisors, LLC. The two partners participated in the TAC meetings regularly, reviewed the tool extensively, and provided valuable feedback in design and functionality.

E3 hosted several meetings with the TAC members during the tool development process, including an initial meeting in February 2018 where E3 presented the first version of the tool, which only provided a cost-effectiveness analysis for solar PV and storage. A subsequent meeting in June 2018 demonstrated the second version of the tool, which included the ability to calculate the distribution deferral values and model other DER technologies. The final meeting in February 2019 showcased the final version of the model, which incorporated two additional user interfaces (UIs), one for first-time users and the other for utility-distribution engineers interested in potential distribution-deferral opportunities. E3 collected TAC members' feedback after each meeting and adjusted the tool accordingly. For example, in response to TAC members' feedback, E3 developed a simplified interface to provide an easy portal for first-time users focused on solar-plus-storage evaluation. TAC members came from a wide range of backgrounds; their feedback was therefore particularly valuable in allowing the project team to consider opinions from various perspectives.

TAC members' feedback was grouped into several categories:

- Feedback and suggestions for UI improvement
- Suggestions for new features and the inclusion of a default database
- Clarification on input descriptions
- Identifying bugs in initial versions of the model

In addition to tool development, E3 collaborated with other research teams (also funded by EPIC in GFO-16-309) and used the Solar + Storage Tool to evaluate the cost-effectiveness of their real-life pilot projects. During this collaboration, the E3 team gained valuable insights into battery operation and financing.

The tool is designed as a successor to the Excel-based Local Net Benefits Analysis (LNBA) tool. The LNBA tool has been used by three IOUs extensively in the Distribution Deferral Opportunity Report (DDOR) process to evaluate DER benefits, including avoided cost and distribution deferral values. To expand the functionalities of the LNBA tool to provide cost-benefit analyses for more DER technologies, the E3 team built the Python-based Solar + Storage Tool based on the original LNBA tool. Compared with the LNBA tool, this new tool can evaluate a broader range of DER including solar PV, energy storage, electric vehicles, fuel cell generators, and other smart appliances. Dispatchable DERs can be either fully or partially dispatched by the model to maximize customer bill savings or utility avoided costs. This allows the cost-effective analysis to be conducted in consideration of customer behaviors. The tool also added a pro forma module to calculate the financing costs for DER projects. The tool is built with Microsoft Excel spreadsheet interfaces that enable users to enter inputs, review

results, and run the model. Calculations and dispatch optimization are performed in Python. This allows a user to work in a familiar spreadsheet environment while allowing the use of compiled Python code for efficiency.

The project encountered three major challenges.

1. Getting utility involvement given increased demands on utility resources:

The increased regulatory demands on utility resources posed major barriers to utility involvement in this project. The CPUC Integrated Resource Planning's new focus on distribution planning required the attention of the utilities and many TAC members. In addition, the DDOR is a new filing requirement with a tight timeline. Utilities are focusing on developing their approaches to meet these regulatory requirements.

To overcome this difficulty, the project team reached out to utilities independently and held one-on-one conversations to receive their feedback on tool functionalities and ideal-use cases. The project team conducted an example analysis for each IOU using each utility's rate and customer-load shapes to provide additional use-case examples. The project team also actively engaged with the CPUC staff working on Distributed Resource Planning (DRP) proceeding through hosting one-on-one meetings and participating in the DRP public workshops. The CPUC DRP staff also participated in this project's public workshops.

2. Technology and knowledge transfer to entities other than utilities:

The project team encountered this challenge in the development cycle of the project. While utilities were closely engaged in the entire process, it is difficult to engage the general public with a complex tool. To address this, the project team reached out to storage companies, and at least one company became an active TAC participant. Since then, the storage company has been closely engaged and provided valuable feedback in using the tool, from a developer's perspective.

3. Steep learning curve for first-time users:

TAC members emphasized the tool's steep learning curve in their feedback of the initial version of the tool. Although the tool is flexible and powerful, it can also be overwhelming for first-time users. The initial version of the tool had one single UI for running all use cases. Even though it allowed users the ability to select which revenue streams were available to their resource, it required considerable understanding of utility rates, utility programs, and California ISO market participation rules. To improve usability for first-time users, the project team developed two additional simplified interfaces with specific use cases. One of them focused on assessing front-of-the-meter and BTM energy storage and solar PV systems, while the other interface provided quick screenings for utility users in identifying distribution "hot spots" and suitable DER technologies for addressing distribution constraints.

# CHAPTER 3:

## Project Results

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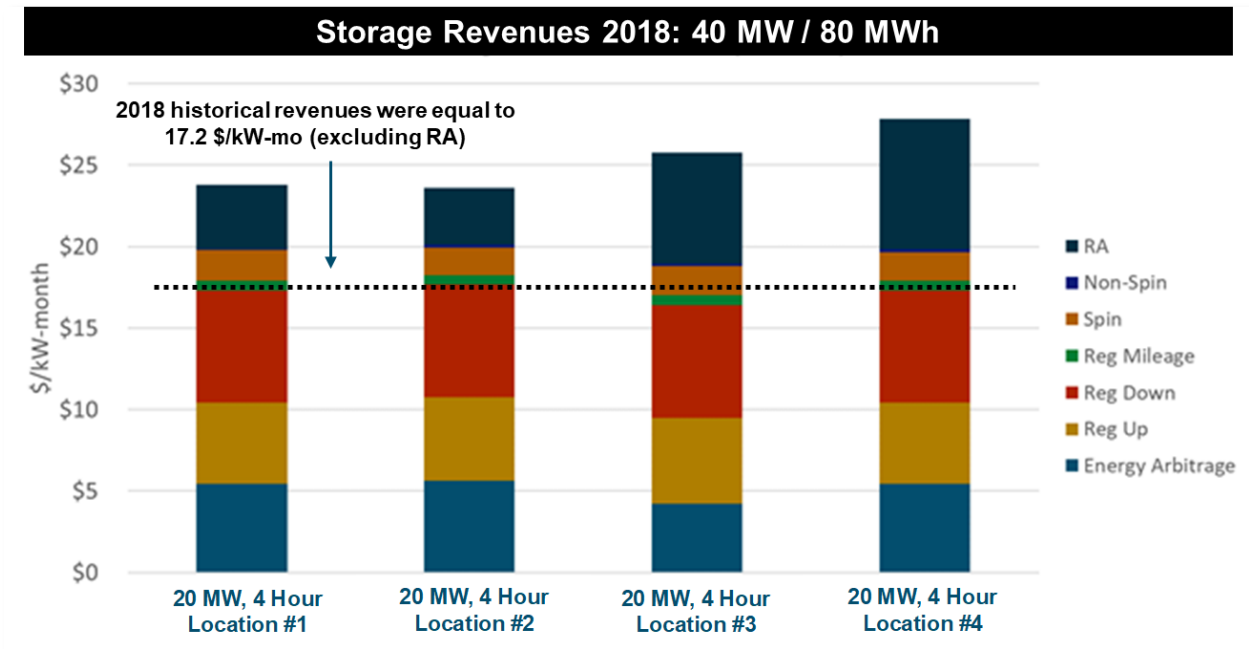
The project successfully developed the Solar + Storage Tool. As a successor to the LNBA tool, this tool can perform the same analysis, but with a higher degree of accuracy and additional functionalities. In addition to the DER benefits evaluation provided by the LNBA tool, the Solar + Storage Tool can evaluate a suite of DER technologies and perform pro forma analyses to calculate total project costs. The LNBA tool is currently used by utilities in the DDOR proceeding to evaluate distribution-deferral values provided by DER, though utilities can now use the Solar + Storage Tool. The Solar + Storage tool is more powerful in evaluating energy storage (stand-alone and paired with solar) with its optimal-dispatch logic. Modeling energy storage accurately has become more important as batteries become increasingly popular, as non-wires alternatives. To facilitate the use of this tool in the DDOR proceeding, the project team developed a separate UI for distribution engineers to screen for distribution hot spots and develop alternative DER solutions. This vetted public tool is also available for evaluating DER with local distribution benefits in the CPUC's Integrated Distributed Energy Resources and DRP proceedings.

The study results for the Solar + Storage tool, especially the results for solar PV and energy storage, have been thoroughly examined and vetted against current market revenues and other public and commercial tools.

The energy-storage wholesale market revenues estimated by this tool have been benchmarked to realized revenues reported in the Federal Energy Regulatory Commission's Electric Quarterly reports. The project team used the 20-Megawatt (MW) 4-hour AltaGas Pomona Battery in Southern California as an example to simulate optimal energy-storage dispatch with 2018 historical California ISO prices. The calculated optimal revenues were then compared with the realized revenues reported for the Pomona Battery in 2018. The realized revenues were around 90 percent of the calculated optimal revenues. This shows that predicted optimal revenues are in line with historical observations. The comparison is shown in Figure 3.



**Figure 3: Storage Revenues 2018**



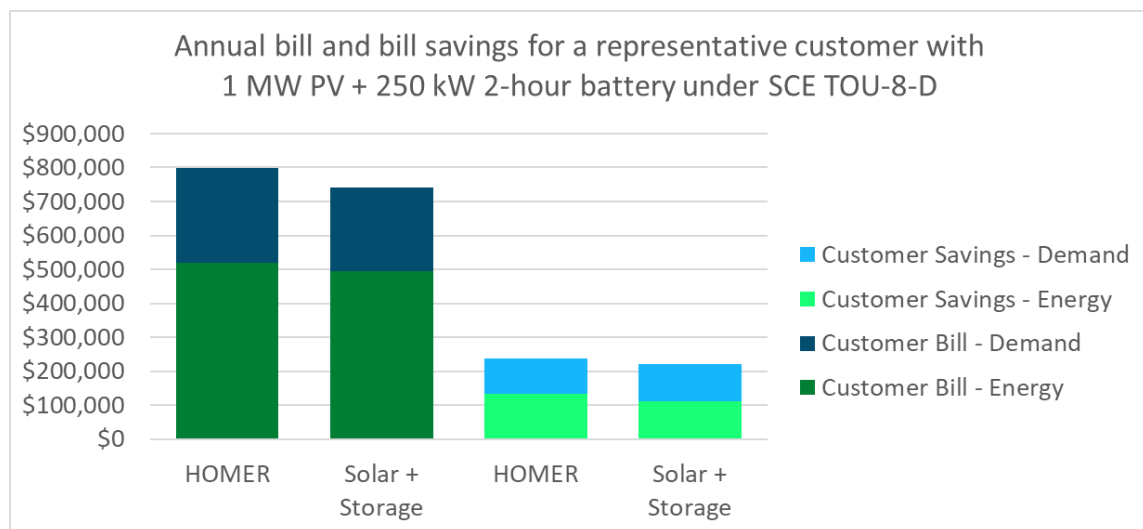
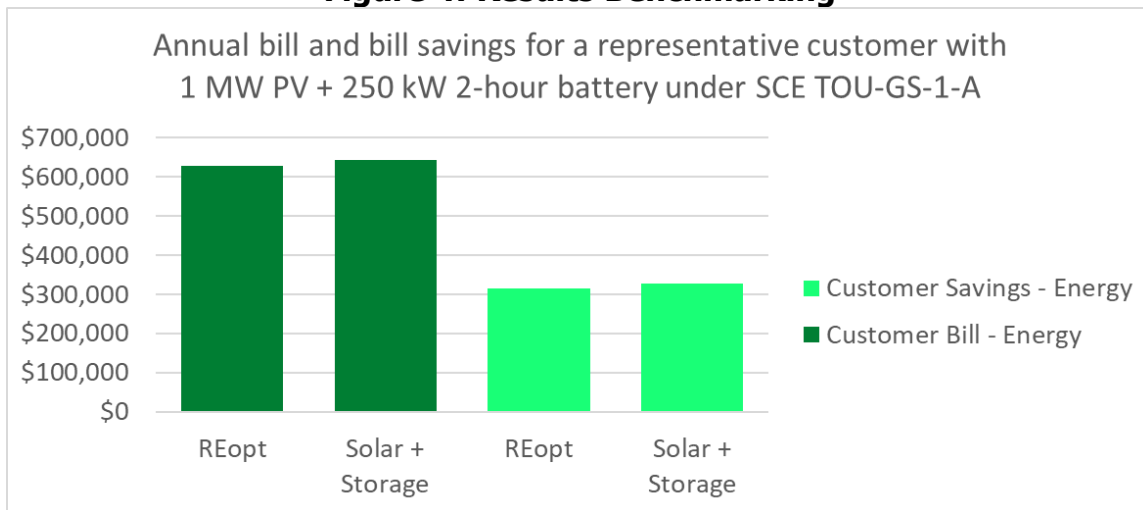
Source: E3

In addition to wholesale participation, the project team also benchmarked BTM bill savings results to other available public or commercial software: REopt Lite and HOMER Grid.<sup>56</sup> The comparison was conducted for a representative customer under a large commercial customer rate: SCE Time-of-Use (TOU)-8-D and a rate for small-sized businesses: SCE TOU-GS-1-A. As shown in Figure 4, resulting differences were within 5 percent for REopt and within 10 percent for HOMER.

<sup>5</sup> REopt Lite is developed by NREL for evaluating the economic viability of grid-connected solar PV, wind, and battery storage at a site: <https://reopt.nrel.gov/tool>.

<sup>6</sup> HOMER is a commercial software that is specialized in optimizing behind-the-meter distributed energy resources for minimizing customer bill savings: <https://www.homerenergy.com/products/index.html>.

**Figure 4: Results Benchmarking**



Source: E3

The project team also successfully conducted technology and knowledge transfer activities and gained substantial interest from utilities, storage developers, and policymakers.

The project team has shared the tool with the general public through three public workshops, starting with an introduction of the tool in the first workshop and then expanding into case studies and example-use cases in later workshops. The project team also provided high-level training in one of the workshops, along with a detailed user guide.

The project team reached out to a broad group of the state’s EPIC project recipients through the CEC to seek collaboration opportunities and information sharing, and discussed pilot projects with three of them. As previously mentioned, the project team also conducted a case study in coordination with the Humboldt State University Sponsored Program Foundation (HSUSPF) to evaluate the cost-effectiveness of its solar + storage pilot project in Blue Lake Rancheria, in Northern California.

In addition, utilities and energy-storage developers have reached out and inquired about the tool. PG&E and the Los Angeles Department of Water and Power have expressed interest in using this tool for rate design, distribution deferral, and microgrid analyses.

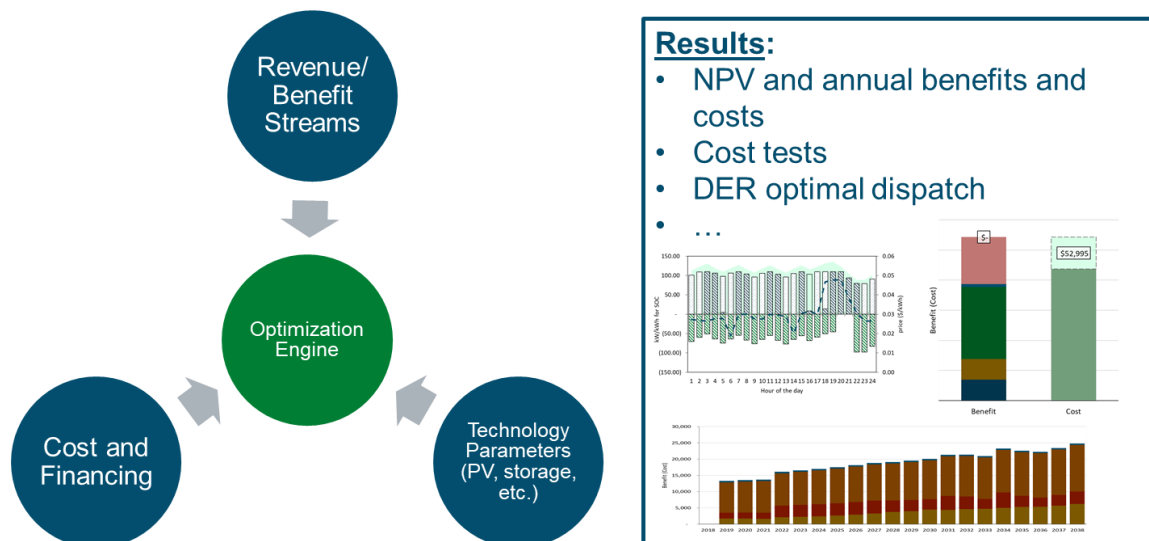
# CHAPTER 4:

## Modeling Tool Review

### Overview

This tool, in a nutshell, is a DER valuation tool with a dispatch engine. It estimates the value proposition of DER systems, in isolation or in a portfolio, based on expected operations, location on the electric grid, market prices, and other characteristics. As shown in Figure 5, the tool compiles inputs including technology operating parameters, available annual, hourly, or sub-hourly benefit streams, and cost and financing assumptions. This information is fed into the optimization engine, which then computes the energy-storage that maximizes overall net benefits. The tool is capable of simulating multiple types of energy storage including lithium-ion battery, flow battery, and compressed-air energy storage.

**Figure 5: Model Overview**



Source: E3

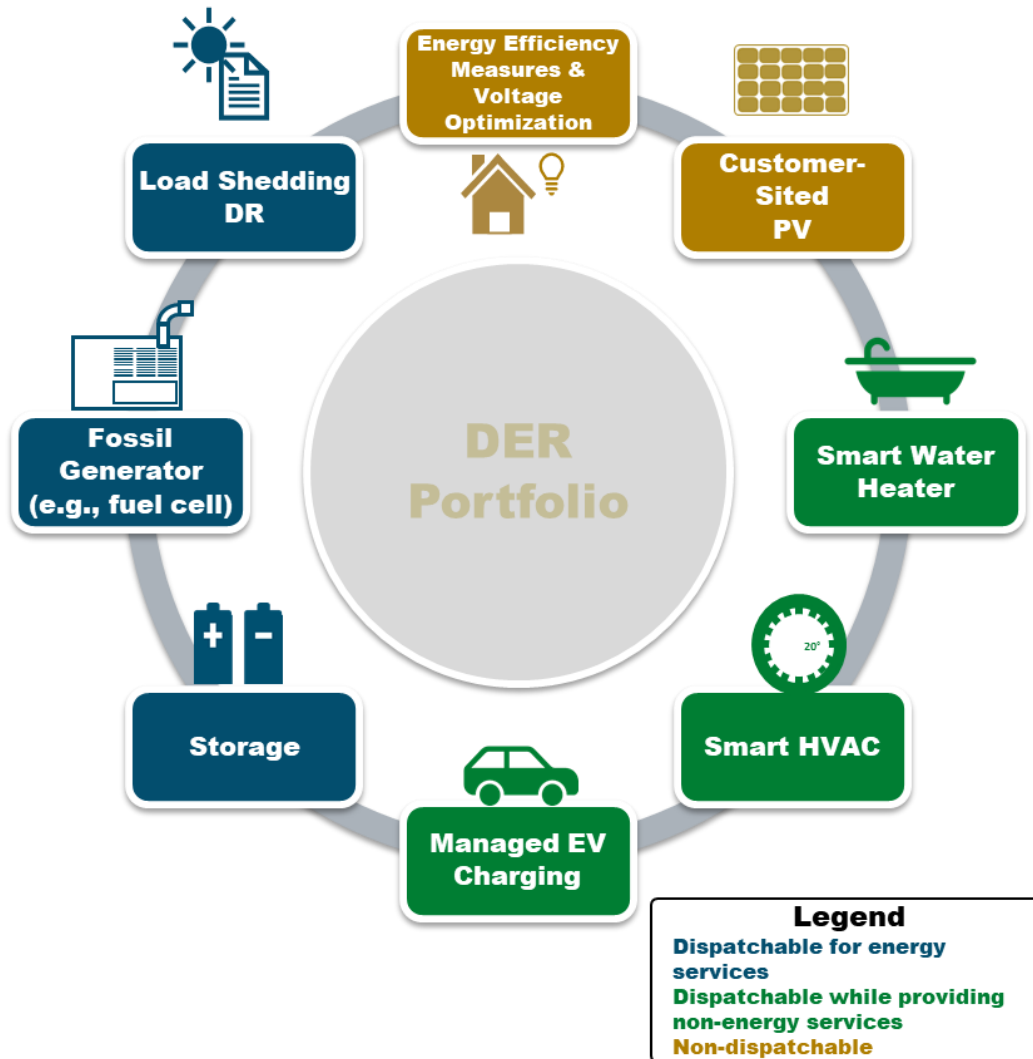
The optimization algorithm assumes perfect foresight, meaning that the hypothetical battery operator has perfect information about system wholesale prices, customer load, solar PV generation, and other parameters that could be uncertain in real-life operations. The user can specify optimization windows, which represent the duration of the period for which a hypothetical battery operator has information. For example, if the optimization window is 24 hours, the model can only make optimal dispatch decisions based on the information within that 24-hour window. The operator won't prepare the battery for demand response events the next day. In addition, the DER system is assumed to be a price-taker, meaning that the dispatch schedule of the DER system does not have an impact on system prices.

Results produced by this tool include life-time benefits and costs in net-present values (NPVs), an assessment of cost-effectiveness using the CPUC-defined Standard Practice Manual cost-effectiveness tests, as well as an hourly or sub-hourly technology-dispatch schedule.

## Distributed-Energy Resource Technologies

The tool also evaluates operations of distributed solar-plus-storage in combination with other dispatchable, partially dispatchable, and non-dispatchable DER technologies including smart thermostats, electric-vehicle chargers, and similar devices. The full suite of technologies that the tool is capable of modeling is shown in Figure 6.

**Figure 6: Distributed Energy Resource Technologies Evaluated in the Tool**



Source: E3

Dispatchable technologies include energy storage, fossil generator (including fuel cell, diesel-backup generation, or gas-combustion turbine), and utility-dispatch load-shedding demand response.

- For this group of technologies, the tool requires an engine to simulate an optimal dispatch to minimize net cost. The optimization is subject to technology, market, and incentive (for example, investment tax credits).
- Parameters considered for energy storage include maximum charge and discharge rate, maximum state of charge, round-trip efficiency, parasitic losses, fixed and variable

operation and maintenance costs, mileage costs, and annual maximum cycles, if available.

- Parameters considered for fossil generators include maximum output, minimum generation, maximum-ramp rate, heat rate, whether the unit is a must-run, and minimum up and down times.
- The dispatch for demand response is based on the maximum number of calls per year and per month, maximum call duration, and corresponding utility needs. The demand response can be dispatched to reduce system peak, distribution peak, or overall system marginal costs.

Partially dispatchable technologies include electric vehicles, smart water heaters, and smart thermostats. This group of technologies is purchased by customers for other uses: for example, driving, heating water, and maintaining comfortable temperatures at home. Customers' primary requirements must first be met before applying these technologies to lower electricity costs.

- The model also simulates charging and dispatch of partially dispatchable technologies through an optimization algorithm. Compared with dispatchable technologies, some constraints and parameters are added to reflect the uniqueness of this technology group.
- First, customers' day-to-day energy needs are the highest priority. For example, Bob drives 20 miles to work leaving home at 9 am and returning at 5 pm. He stops at a grocery store on the way back. This day-to-day driving schedule is fed into the optimization model so that his electric vehicle meets his needs before it moves the charging time.
- In addition to pre-scheduled driving needs, the optimization model makes charging decisions with consideration of additional unexpected uses. The amount of energy reserved for unexpected trips is based on a customer's risk preference. This optimization treatment of day-to-day needs and expected usages are also applied to smart water heaters and thermostats.

Non-dispatchable DER technologies include solar PV and energy-efficiency measures. Users can input their own generation or conservation shapes in hourly or sub-hourly time segments. The tool also provides default shapes for California if no specific shapes are available.

All the DER technologies are dispatched co-optimally and simultaneously if they belong to the same portfolio. This means that the operator considers synergies among multiple technologies and makes operation decisions that maximize each technology's strengths and minimize its weaknesses.

## **Benefit Streams**

The tool can also model and co-optimize the dispatch of DERs against a wide range of benefit streams. This allows the "value-stacking" of energy storage with consideration of technologies' operating constraints and market rules. The tool allows users to choose revenue streams that are eligible for their projects. Commonly used benefit combinations for each use case are summarized in Table 2. In addition to existing programs and revenue streams, the tool

provides great flexibility in evaluating future rates, demand responses, and resource-adequacy program designs including: multi-tiered TOU demand charges, daily demand charges, real-time rates, asymmetric energy charges, and volumetric payment for demand responses.

**Table 2: Benefit Streams by Use Cases**

Use Cases	Benefit Streams
Customer-sided	<ul style="list-style-type: none"> <li>• Demand charge management</li> <li>• TOU energy charge management</li> <li>• Utility program revenue (for example, demand response program)</li> <li>• Back-up power</li> </ul>
Distribution System	<ul style="list-style-type: none"> <li>• Project-specific transmission and distribution deferral</li> <li>• Interconnection costs reduction</li> <li>• Reliability</li> <li>• System avoided costs or bulk system revenues</li> </ul>
Bulk System	<ul style="list-style-type: none"> <li>• Resource adequacy program</li> <li>• Wholesale energy market</li> <li>• Ancillary services revenue</li> <li>• Project-specific transmission deferral</li> <li>• Renewable firming services</li> </ul>

Source: E3

**Pro Forma**

The tool also includes a detailed financial pro forma module to calculate all-in costs for DER systems. All-in costs include capital costs, operating and maintenances costs, financing costs, incentives from Self-Generation Incentive Program (SGIP) and investment tax credits, and taxes. The pro forma module allows users to calculate financing costs from both self-financing and third-party leasing options. Users can also overwrite project cost calculations with their own cost estimates.

**Tool Structure**

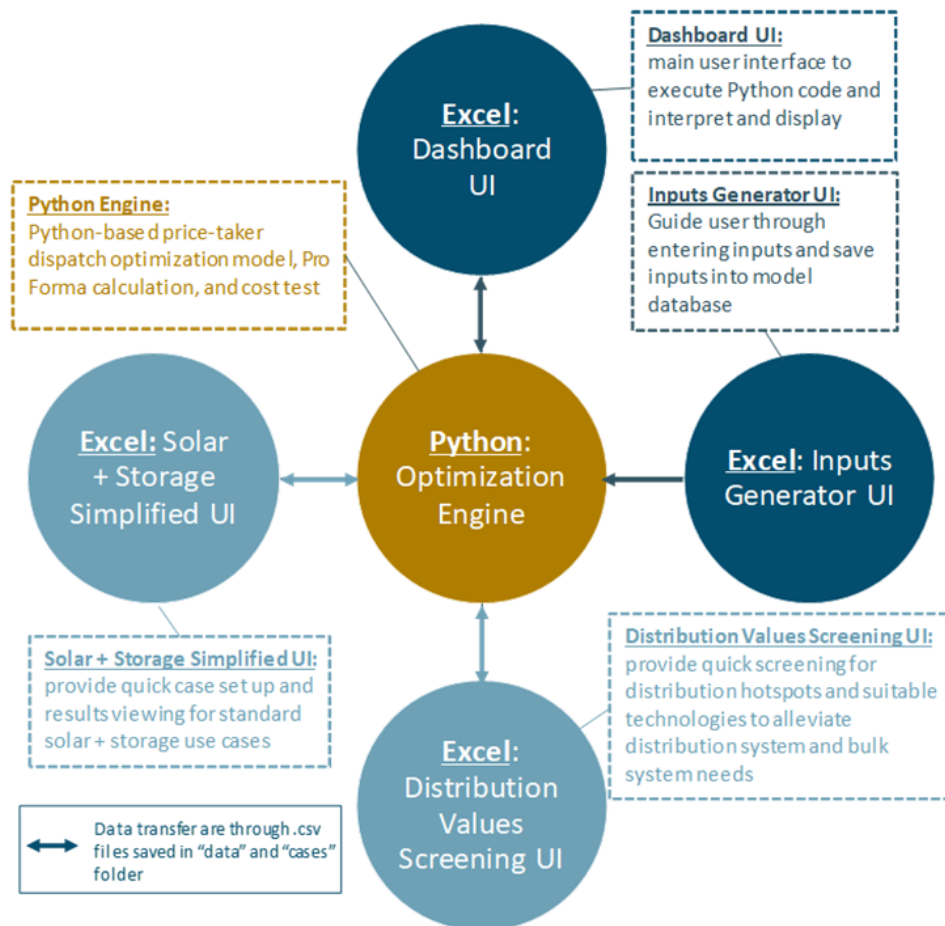
As shown in Figure 7, the core optimization and calculation engine was built in Python, an open-source and increasingly popular programming language. Python inputs and outputs are in .csv formats and are saved in the “cases” and “data” folders. Four UIs interact with the .csv files by saving them in the “cases” and “data” folders or by reading in .csv files. The Inputs Generator and Dashboard provide UI access to the full set of features; while the Solar + Storage Simplified UI and the Distribution Values Screening UI provide simplified set-ups with targeted use cases and limited features. The four UIs are summarized here:

- Inputs Generator UI:
  - This input interface saves all model-required inputs into data folders in .csv format.

- **Dashboard UI:**  
The main UI to set up cases, execute Python code, and interpret and display results
- **Solar + Storage Simplified UI:**  
This interface provides quick case set-up and results viewing for standard solar + storage use cases.
- **Distribution Values Screening UI:**  
This interface provides quick screening for distribution hotspots and suitable technologies to alleviate distribution system and bulk-system needs.

**Figure 7: Model Structure Overview**

Overall Tool Structure

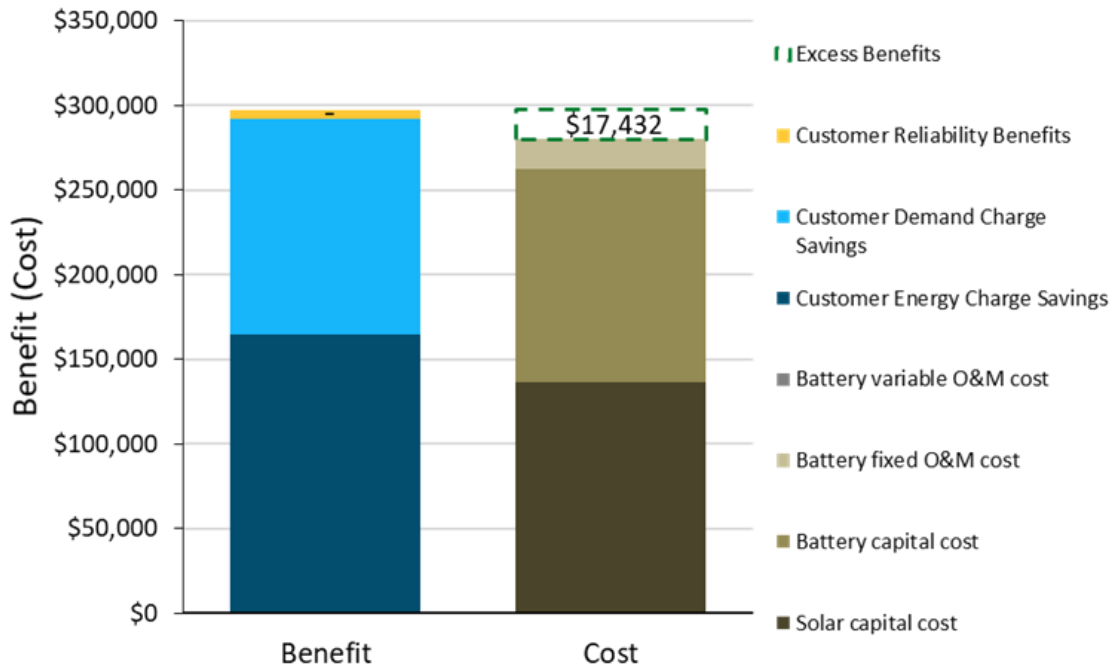


Source: E3

## Example Results

Figure 8 shows one of the charts in the UI. It plots the costs and benefits in NPV. The costs and benefits can be plotted for either an aggregated DER portfolio or an individual technology. The costs and benefits can also be displayed from different cost-test perspectives, including total resource cost test, participants' cost test, rate impact measure, societal cost test, and program administrative cost test. In addition, the benefits and costs can be shown as annual value streams for users to examine variations among modeling years.

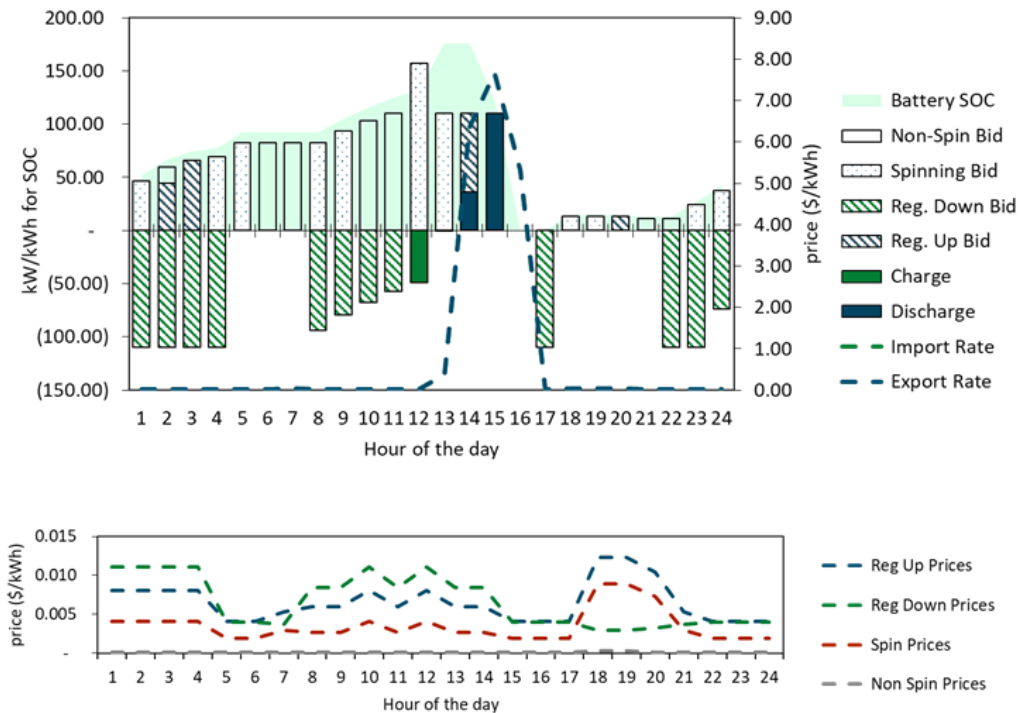
**Figure 8: Example Total Resource-Cost Test Results**



Source: E3

The model also outputs the hourly dispatch schedule for each DER technology modeled, which can be viewed separately in the UI. Figure 9 shows an example dispatch for an energy storage system.

**Figure 9: Example Energy Storage Dispatch Chart**  
Storage Dispatch for energy arbitrage (9/29/2019)



Source: E3



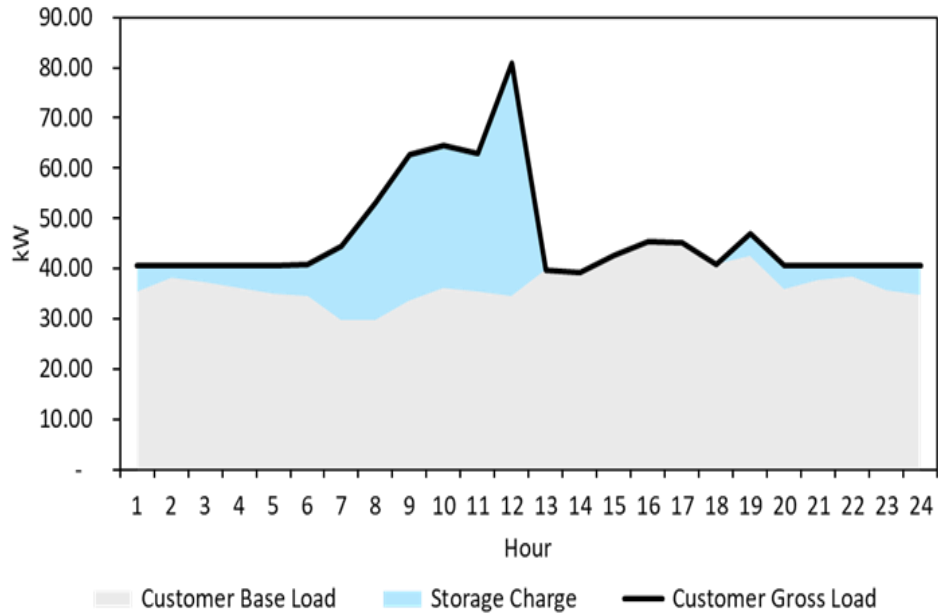
Energy charge, discharge, regulation, spin, and non-spinning provision for a single day are plotted together with prices to help users better understand dispatch behavior. In the example below, the battery sees a high-price spike between 2 pm to 3 pm. To prepare for the price spike, the battery starts charging earlier in the day through a combination of regulation-up services and charging directly from the grid.

In addition to dispatch charts for individual technologies, the tool also provides visualization for DER portfolios. Figure 10 shows energy consumption and an energy supply chart for a customer-sited solar PV + storage system. The energy consumption chart shows DER technology behaviors (like storage and electric vehicle charging) that increase energy consumption. The energy supply chart shows how household energy consumption is met with a combination of grid imports, storage discharge, and solar PV generation.

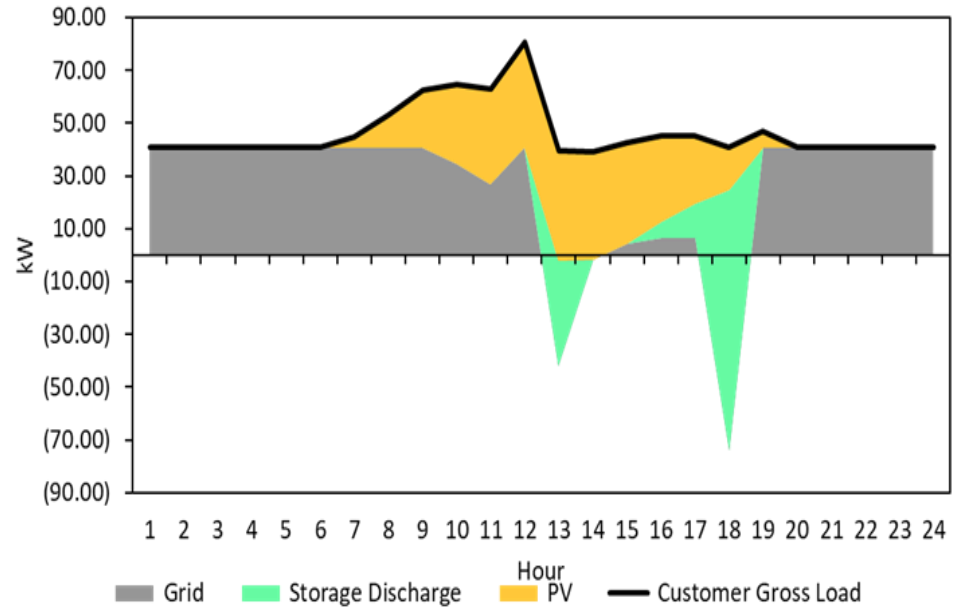
The project team also developed a detailed user guide as a separate document that includes step-by-step case set-up instructions and descriptions on the four UIs in the model. The user guide also documents the underlying methodology for the tool, including relevant formulas.

**Figure 10: Example Energy Consumption and Supply Chart**

**Pilot Site Energy Consumption on August 1, 2018**



**Pilot Site Energy Supply on August 1, 2018**



Source: E3

# CHAPTER 5:

## Case Studies

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### Case Study – Solar + Storage Pilot in Blue Lake, California

#### Pilot Site Overview

The project was led by HSUSPF, and addressed key market barriers to deploying solar + storage technologies in small-to-medium-sized commercial buildings. The project established a pilot site at the Blue Lake Rancheria gas station and convenience store in Blue Lake, California. The pilot was used for testing and developing an integrated design and operations strategy for solar + storage that improves on the status quo and leads to rapid market scaling in the small-to-medium-sized commercial building sector.

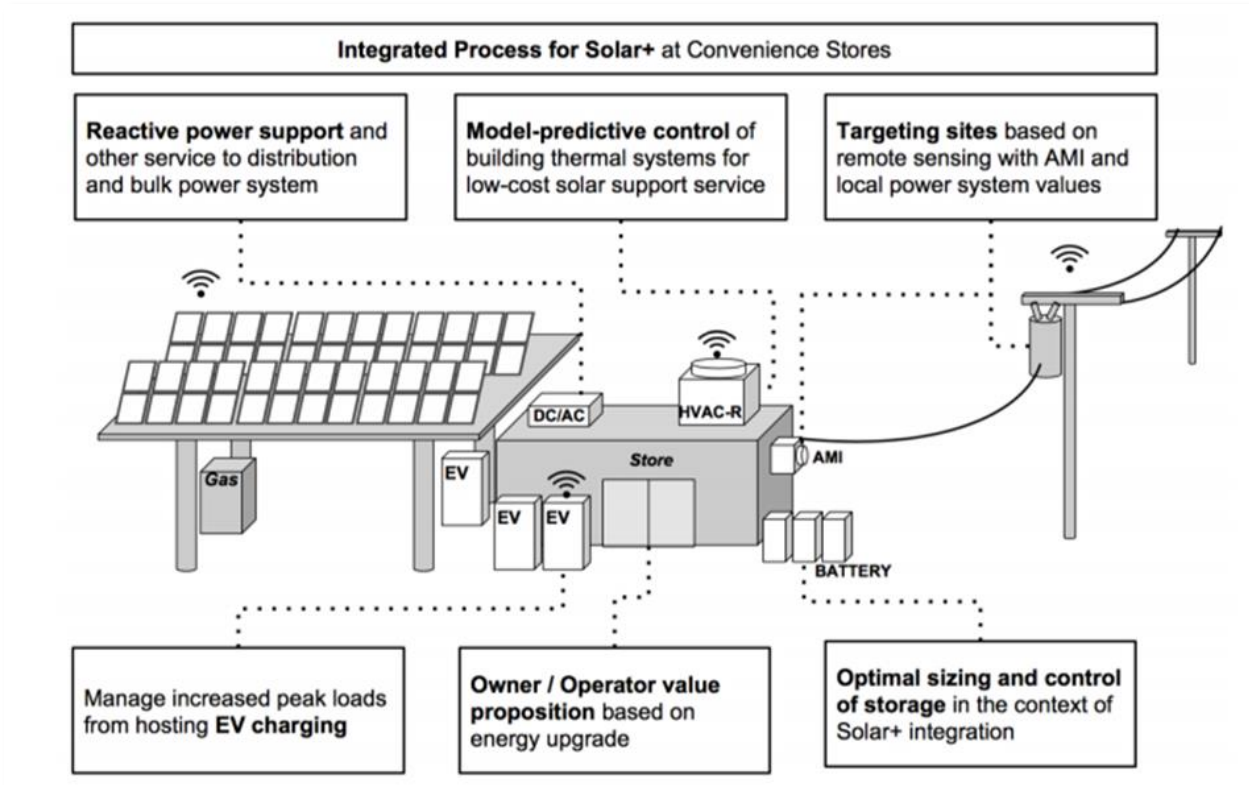
Because of its relative geographic isolation and distance from transmission corridors, Northern California's Humboldt County experiences unreliable electricity supply and is therefore at greater risk of rolling blackouts, including from wildfires. The owner of the Blue Lake Rancheria, a Native American tribe, has expressed a desire to use zero-emission generation for backup power due to environmental concerns. The gas station is on the PG&E E19 rate, a large commercial customer rate. This rate has expensive overall demand charges and multiple TOU demand charges for peak, partial-peak, and off-peak hours. Using energy storage to reduce demand charges can significantly reduce overall electricity bills.

A gas station was chosen as an appropriate site for several reasons:

- The project could provide high value for reliability or emergency services (as both a potential emergency meeting point and supplier of emergency gas).
- The site has a built-in canopy upon which to mount solar PV.
- The station has flexible refrigeration loads that provide demand-response value.
- A successful pilot model could be scaled to other gas stations.
- The station could include future electric vehicle charging stations.

The solar + systems include solar PV at 60-kilowatt (kW) DC, energy storage sized at 109 kW / 174 kilowatt-hours (kWh), and advance controls for communicating with thermostats and refrigeration. Figure 11 illustrates the site layout and research objectives.

**Figure 11: Solar + Storage at Convenience Stores**



Source: <https://schatzcenter.org/docs/solarplus-factsheet-dec2017.pdf>

### Analysis Summary

In collaboration with HSUSPF, E3 conducted a cost-effectiveness analysis using the Solar + Storage Tool to investigate potential benefits for both participants and society at large under PG&E’s large industrial customer E-19 rate. E3 entered the input data including electricity rates, the site load profile, and the technical characteristics for solar PV, and batteries through the “Inputs Generator UI”. After the inputs were set up, E3 used the “Dashboard UI” to run the cost-effectiveness analysis.

In addition, E3 developed two more scenarios to investigate the solar + storage system’s revenues under proposed near-term TOU and potential future rates and policy frameworks. The three different scenarios used to derive the revenues are shown in Table 3.

**Table 3: Rate Scenarios**

Scenario Name	Revenue Streams	Description
Business As Usual	Existing rates	PG&E E19S with current TOU periods
Near-Term	Proposed TOU rates	PG&E E20 with projected future TOU periods (later peak)
Future	Full-value tariff + ancillary services revenue	E3 “Current Policy” (mid-level) price forecast and E3 “High Electrification” (more aggressive) price forecast

Source: E3

All model runs incorporated benefits from reliability. For each of the scenarios, a system average interruption duration index of 172.5, a system average interruption frequency index of 1.5, and a value of lost load (VoLL) equal to \$1/kWh were assumed. This corresponded to the cost of operating an available diesel generator for backup at the site. Environmental concerns made the reliability of renewable resources more valuable than the diesel generator’s fuel-cost savings for the site hosts. Because this added “green” value is difficult to quantify, the study used a conservative \$1/kWh assumption for the base cases.

For the sensitivity analysis the study also tested a case with high VoLL and examined how it impacted overall revenue and storage dispatch. In this case, the site host valued the lost load at \$400/kWh and preferred to stay at least 50 percent full power to provide electricity during an outage.

Storage is a versatile energy resource. In addition to the utility-bill savings and ancillary services value just described, solar PV, together with storage can also participate in demand-response programs that defer distribution upgrades. To explore other potential revenue streams for solar PV and storage, the project team conducted sensitivity tests that evaluated the impact of additional revenue streams in addition to bill savings and ancillary services values. Sensitivities conducted for high-reliability value and additional revenue streams are summarized in Table 4.

**Table 4: Sensitivities Summary**

<b>Sensitivity/Additional Revenue Source</b>	<b>Description</b>
High Reliability	Change default \$1/kWh VoLL to \$400/kWh VoLL, constrain storage to 50 percent minimum state of charge
Demand Response Participation	Allow participation in the demand response auction mechanism program, modeled at eight 1-hour calls per year and \$55/kW-yr contract value. The call signal is based on either system or distribution peak
Distribution Deferral – Non-wires Alternative	Applies illustrative feeder upgrade cost and feeder load shape to simulate the impact of high distribution locational value for storage

Source: E3

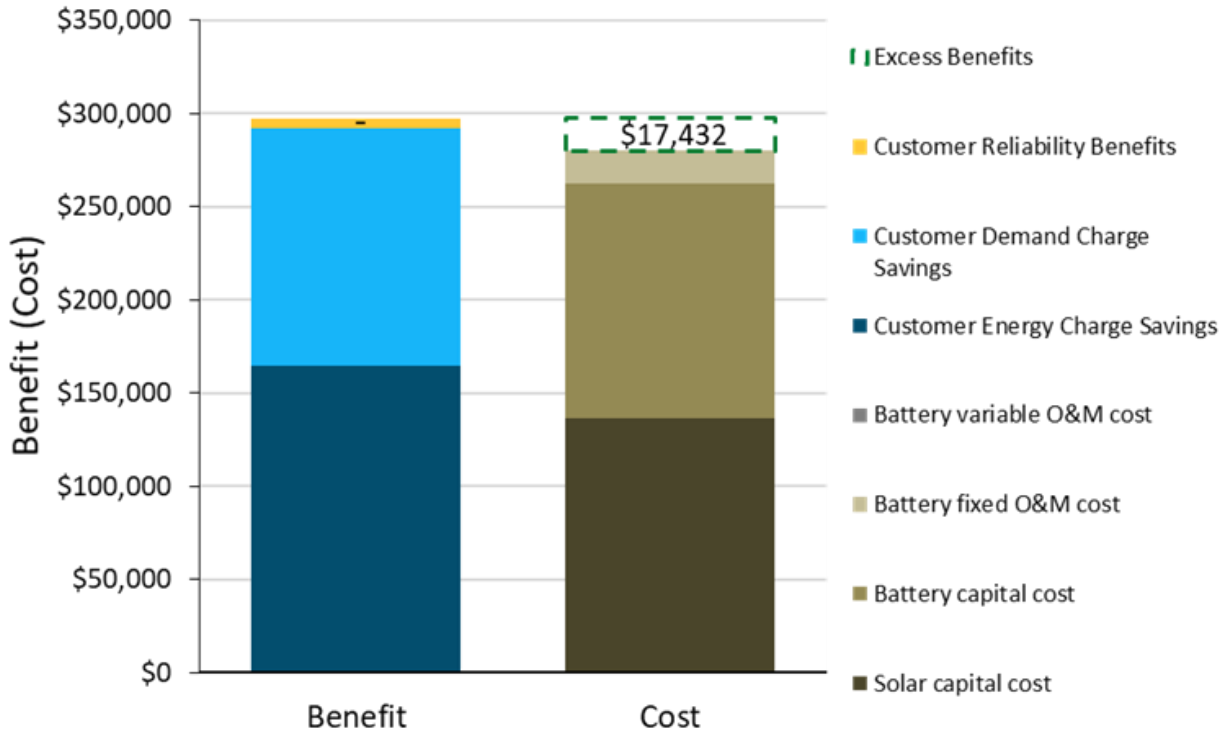
## **Results**

The analysis was conducted using the Solar + Storage Tool which generated all of the results shown in Figure 12. Many of the charts are copied directly from the Dashboard UI: for example, the benefits-and-costs comparison charts. Other charts are modified based on charts in the Dashboard UI that emphasize a comparison among sensitivities.

Across the various rate scenarios, the current E19 TOU rate was shown to be the most favorable from a participant’s perspective. The system is slightly cost-effective for participants with current TOU rates. However, from the total resource-cost and ratepayer-impact-measure perspectives, the system did not deliver positive net benefits, and there was a cost-shift to other ratepayers. The cost-shift is due to the misalignment between a customer’s retail-rate

signal and system needs. Energy storage was discharged during the customer’s peak hours for demand charge reductions, but because the customer’s peak was not aligned with system peak in most scenarios, this use of energy storage did not reduce system operating costs, and may have even increased system operating costs in certain cases.

**Figure 12: \$ Net Present Value Benefits and Costs for the Business As Usual Bill Savings Case**



Source: E3

As shown in Figure 13, under a future proposed TOU rate structure (prospective E20) where the TOU period is shifted from 12–6 pm to 4–9 pm, bill savings alone were not enough to provide net benefits. This is largely due to the solar PV contribution; placing peaks later in the day meant that solar PV generation was less coincident with on-peak TOU and therefore earned far less revenue. The other reason is that the solar + storage system was oversized given the on-site load. This particular pilot project oversized the battery that provided emergency services during a grid outage. For other solar + storage systems where the main-use case does not provide backup power, it is important to appropriately size the storage system’s cost effectiveness.

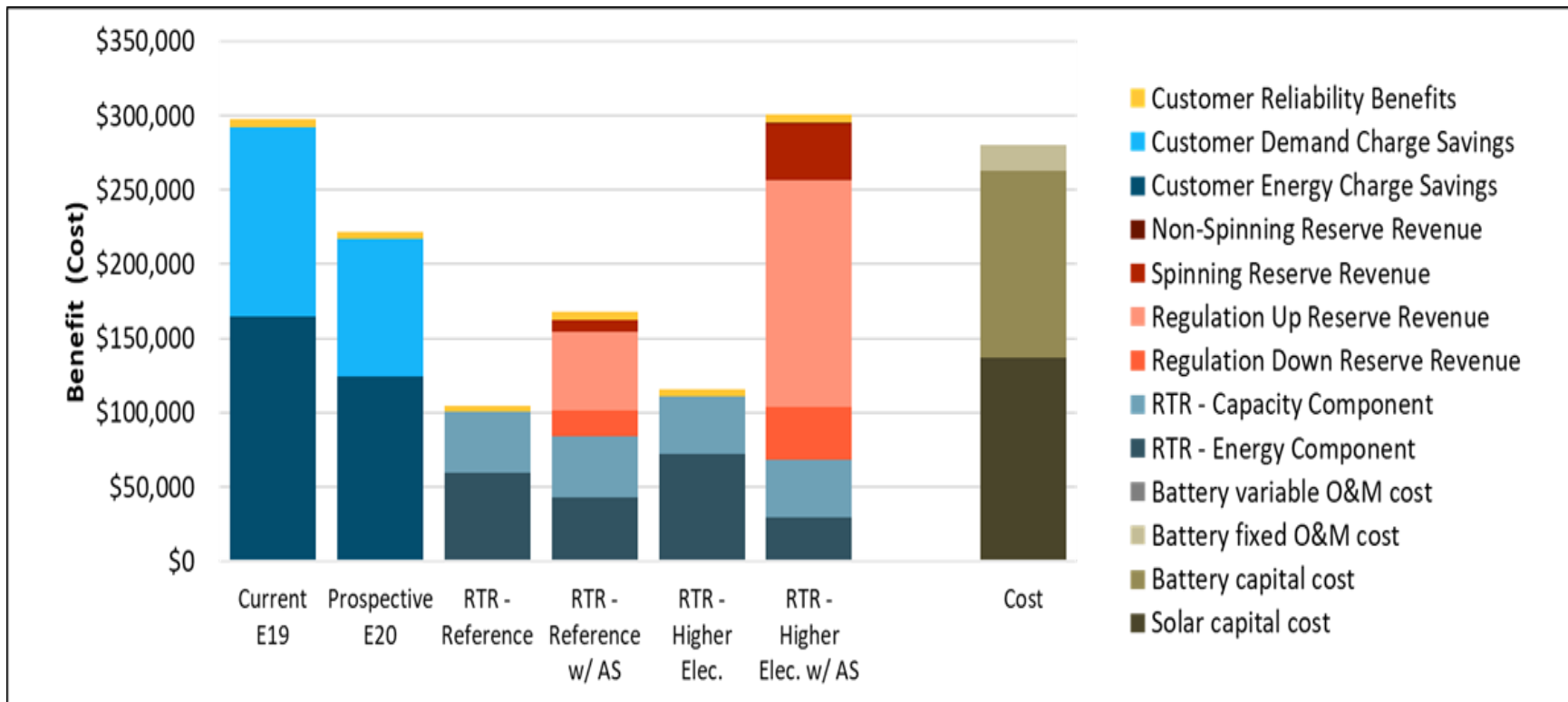
This full-value tariff, shown as a real-time-rate reference with higher electrification in Figure 13, assumed that the solar + storage system received the hourly real-time rate that reflected system marginal costs. This assumed future tariff doesn’t include the demand charge component. Instead, the capacity costs are reflected through high hourly prices during system peak hours. In addition to the real-time rate, energy storage in the system was assumed to be able to provide ancillary services in the wholesale energy market. In considering various future price scenarios, the project team chose to model a Medium/Current Policy scenario representing current policies and a High/High Electrification scenario representing a high electrification future. The future wholesale system price is simulated from AURORA, a commercial-production

simulation model. The Current Policy forecast incorporates all current legislation and goals in California, including those mandated in SB100. The Higher Electrification scenario represents a more aggressive forecast, with higher electrification in California and greater renewable buildout across the 14 western states included in the Western Electricity Coordinating Council.

When evaluated the cost effectiveness of the DER system under real-time-pricing rates depended largely on revenues from providing ancillary services, as shown in Figure 13.

A key goal of this pilot was to explore the project's potential reliability. When the solar + storage system is designed to provide backup power during grid emergency events like wildfires and storms, the site host does not have to fully charge the battery's energy during so-called blue-sky days. This is because grid emergency events can usually be predicted the day ahead, which allows enough time for the site host to charge batteries ahead of the event. The project team assumed normal operation for energy storage during blue-sky days in previous cases. To further estimate the benefits and costs of providing back-up power during unexpected grid outages, the project team modeled a sensitivity where the site host highly valued reliability services provided by the DER. A VoLL of \$400/kWh was assumed for this sensitivity, and the research team constrained the storage device to a 50-percent minimum charge to provide power during grid outages. E3 observed reliability benefits on the order of millions of dollars. However, when reliability is compromised by fallen trees or a damaged distribution system, they are difficult if not impossible to predict, so projects are often unable to access this value if a battery system has insufficient energy. But if the pilot project were actually able to capture even a fraction of this reliability, the net benefits would far outweigh the costs, as shown in Figure 14.

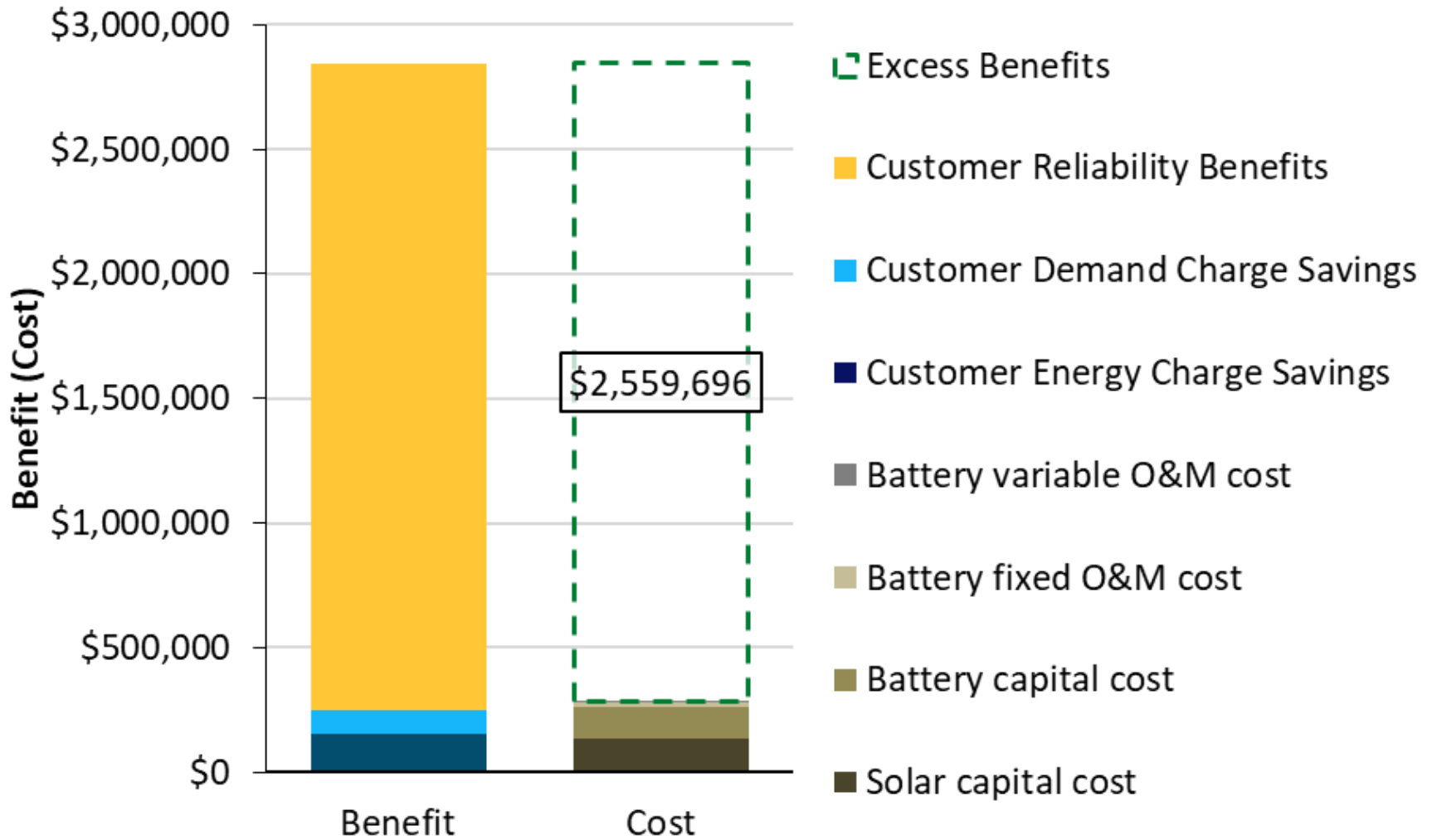
**Figure 13: Participant Benefits by Rates**



Source: E3



**Figure 14: Effect of High-Reliability Values on Project Benefits**



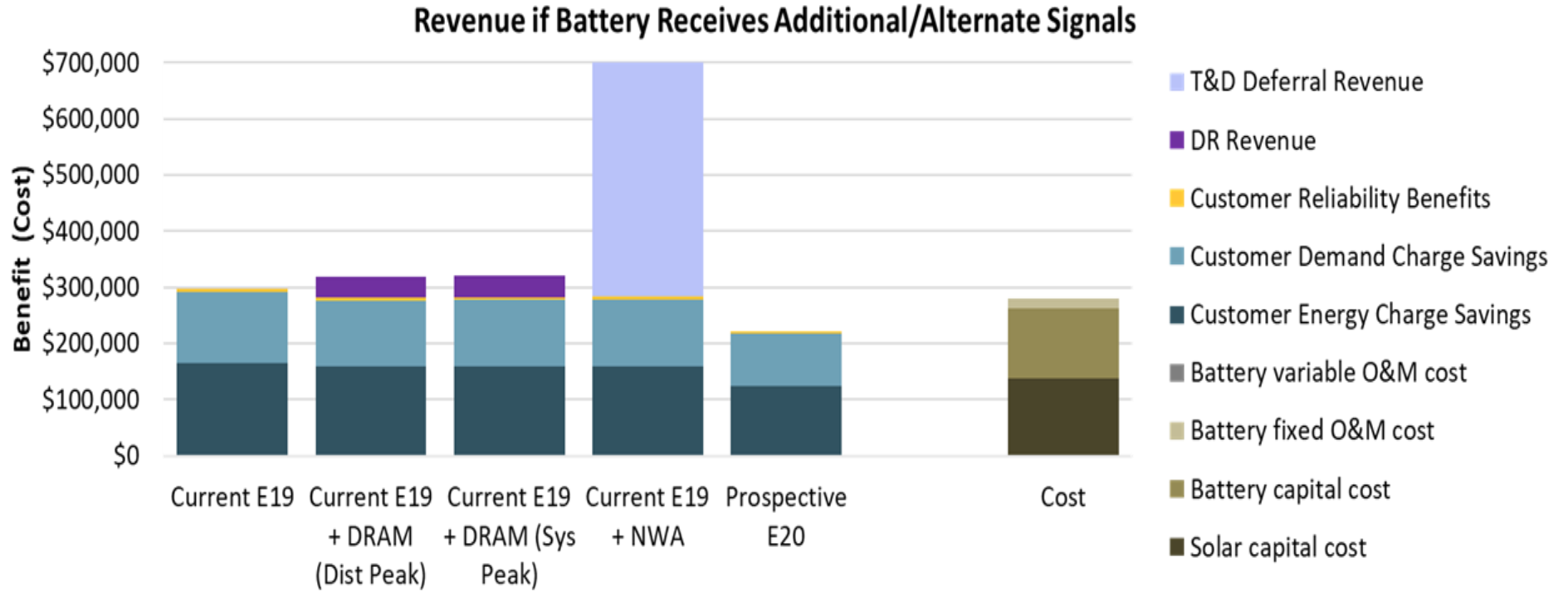
Source: E3

To explore more revenue opportunities for energy storage, the project team conducted analyses on the potential revenues for participating in demand response using the Solar + Storage Tool. For purposes of investigating this sensitivity, the project was allowed to participate in the demand response auction mechanism (DRAM) program. The demand response (DR) program was modeled at eight 1-hour calls per year and ~\$55/kW-year contract value. Two types of call signals were tested: one based on system peak, the other on distribution peak. Model results showed that participation in the DR program provided incremental benefits for all scenarios and had no major negative impacts on other revenue streams. The project team also found that event-dispatch signals based on system peaks as opposed to distribution peaks did not substantially affect results since the storage system was able to meet its full capacity obligations in both cases. The benefits and costs under this sensitivity appear in Figure 15.

One of the most promising use cases for storage is its ability to provide distribution deferral value, or a non-wires alternative (NWA). If a distribution feeder faces costly upgrades due to excessive load, storage can offset those load peaks, thereby deferring the need for a near-term capital investment. This sensitivity explored the value of deferring a hypothetical \$1 million distribution upgrade. The NWA solution needs to be able to reduce the system peak load by 12 kW and 142 kW in the first two years to successfully defer the hypothetical upgrade projects for 2 years. The model estimates that the DER system can successfully reduce system peak by 129kW, resulting in two years of capital deferral and \$406,000 in savings. The Humboldt pilot project could capture large amounts of distribution-deferral revenue, enough for the project to break even, if able to supply this reduction.

A summary of the impact of different sensitivities is shown in Figure 15.

**Figure 15: Participant Benefits with Additional Benefit Streams**



Source: E3

# Case Studies for Investor-Owned Utilities

## Overview

In addition to the case study with HSUSPF, the project team also conducted an example analysis for hypothetical solar + storage systems located in three IOU service territories. For each IOU, the project team investigated a use case that could potentially benefit it in both the near term and in the future.

In today's solar + storage landscape, customer-bill management and DR program participation are the most popular applications for BTM customers. The study analyzed this use case for a commercial customer in SDG&E's service territory.

The second case uses a proposed PG&E rate to estimate the near-term cost-effectiveness of solar PV and storage for customer-bill management. The proposed rate pushes peak hours to later in the evening and shortens the summer season from 6 months to 4 months. The cost-effectiveness impact of the rate structure change is examined from both system and customer perspectives.

The third case examined a high-value distribution deferral-use case focused on reducing the distribution system peak to defer potential upgrades. Although there is currently no well-defined utility program for this use case, distribution deferral can be highly valuable for both utilities and their customers in the future. The study uses one of the upgrade projects identified in SCE's 2018 DDOR and Grid Need Assessment (GNA) report as an example. In addition to deferring upgrades through distribution peak-load reductions, the study also allowed DERs to provide grid services during off-peak hours to access additional value.

## Results

### Current Rates: A San Diego Gas & Electric Example

This example examined the cost effectiveness of owning a solar + storage system for a commercial customer in San Diego Gas & Electric's (SDG&E's) Southern California territory. Published SDG&E commercial-customer load profiles were used for the load shape.<sup>7</sup> The annual average load is 33 kW, with a peak of 60.4 kW.

Based on the customer's load level, a 20 kW solar PV system and a 10 kW / 4-hour lithium-ion battery were chosen. The inputs are summarized in Table 5.

Figure 16 summarizes the NPV of both the benefits and costs of the whole solar PV + storage system, over 25 years. The solar + storage system provided electricity bill savings from both energy and demand components, as well as from revenues for participating in the DRAM program.

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<sup>7</sup> SDG&E Dynamic Load Profiles: <http://webarchive.sdge.com/customer-choice/customer-load-profiles/customer-load-profiles>.

**Table 5: Inputs for San Diego Gas and Electric Company Example**

<b>Item</b>	<b>Value</b>	<b>Sources &amp; Notes</b>
Customer Load Shape	SDG&E example commercial customer	SDG&E Dynamic Load Profiles
Rates	SDG&E AL-TOU rates <sup>8</sup>	SDG&E AL-TOU that is effective Jan, 2019
Solar PV Size	20 kW	22.5 percent capacity factor
Solar PV Cost	\$2750/kW	Based on mid-level estimates from NREL
Storage Size	10 kW, 4-hour	85 percent round-trip efficiency
Storage Cost	\$498/kWh	Based on Lazard Levelized cost of storage v4.0 E3 internal Pro Forma analysis
DRAM Program	\$55/kW-yr; 6 calls per year, maximum duration: 1-hour	DR payment is an E3 estimation; the frequency of the calls is based on the historic data collected in the 2017 SGIP Storage Impact Evaluation Report <b>Error! Bookmark not defined.</b>
Avoided Costs	SDG&E 2018 CPUC Avoided Costs	2018 CPUC Avoided Cost Calculator

Source: E3

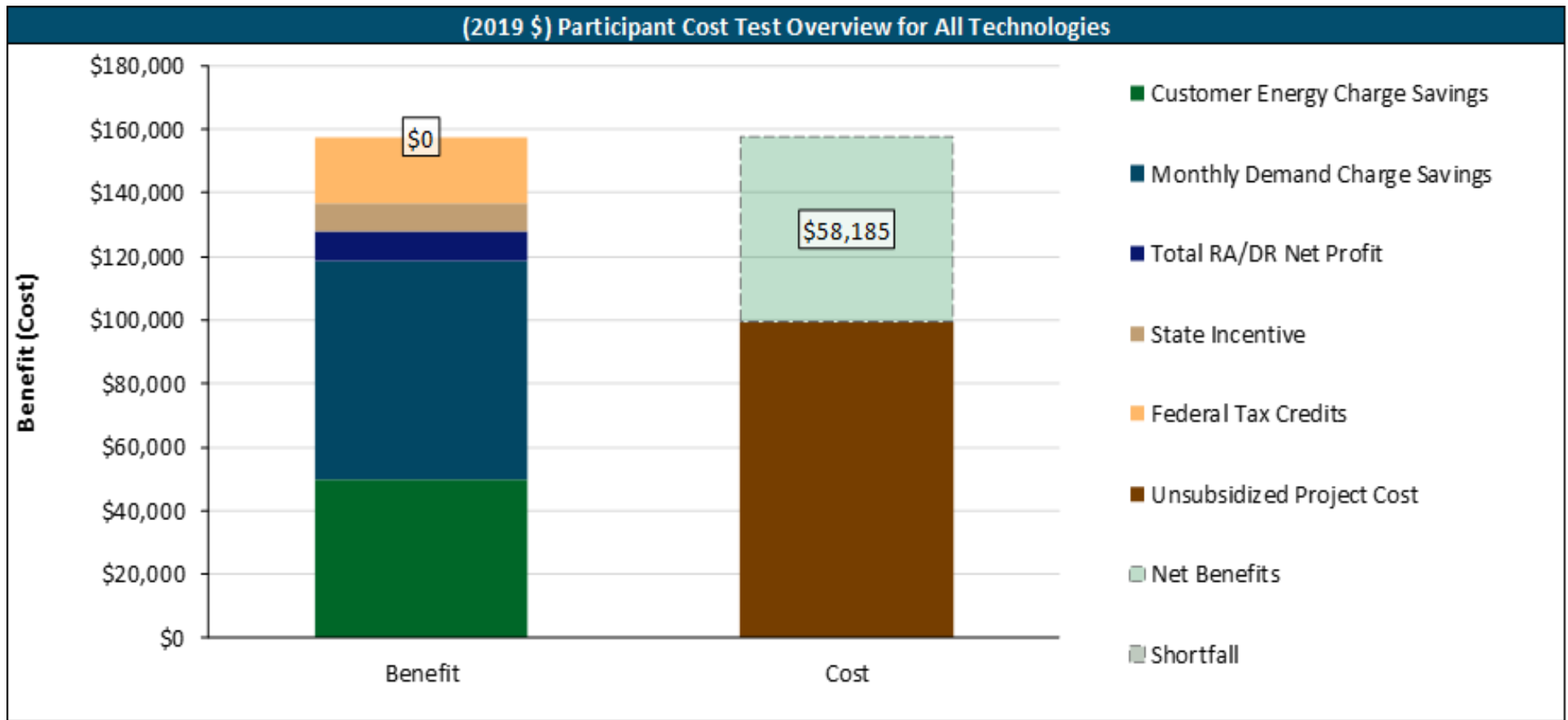
The combined system provided \$62,126 in total net benefits over the system lifetime from a customer’s perspective participant cost test (PCT). Most of the benefits are from monthly demand-charge savings and customer energy-charge savings. Even without state or federal incentives, it was cost effective for this customer to buy a solar PV and storage system for bill management. Revenues from the DRAM program were a good addition but not substantial when compared with utility bill savings.

The total resource cost test assesses monetized costs and benefits to the State of California. The costs were the purchase of the solar + storage system, while the benefits were the avoided costs of supplying energy and the investment tax credits. As shown in Figure 17, the benefits provided by the solar + storage system accounted for only 50 percent of the costs, a marked difference from the PCT. In addition, 20 percent of the total benefits come from the federal tax incentive, indicating that installation of the solar + storage system only constituted a small reduction in system operating costs. Due to the misalignment of electric rates and system avoided costs, the solar + storage system is a good investment for the customer, but it does not pencil out from a system perspective. Customers may discharge their battery for demand charge reductions during peak hours, but these peak hours will likely not align with the system peak. Either proper alignment of customer rates and system costs or a more dynamic rate and incentive design is necessary to allow energy storage to reap its full potential of system benefits.

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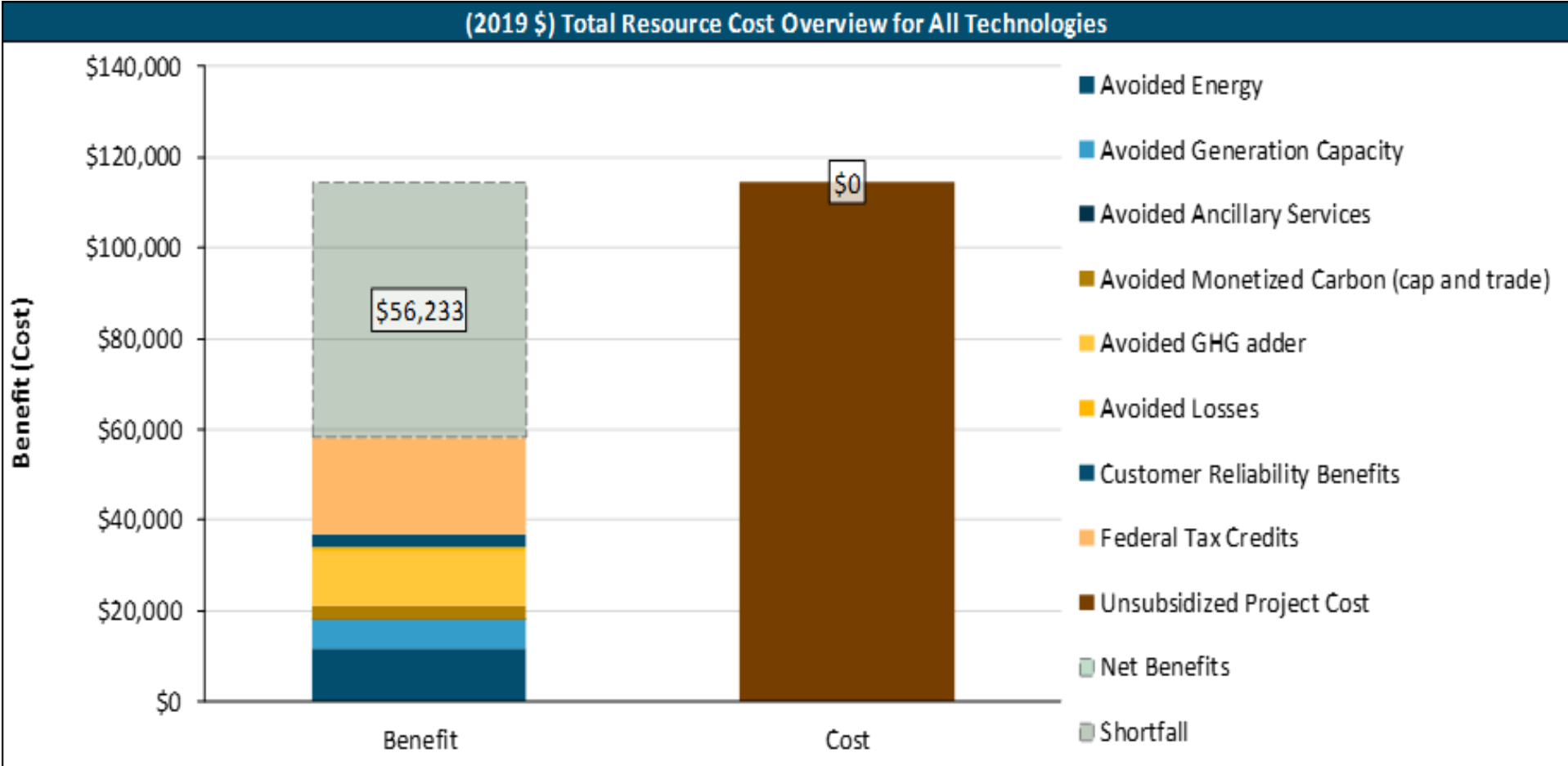
<sup>8</sup> AL-TOU rate is an electric rate for small business customers in SDG&E: [https://www.sdge.com/sites/default/files/elec\\_elec-scheds\\_al-tou.pdf](https://www.sdge.com/sites/default/files/elec_elec-scheds_al-tou.pdf).

**Figure 16: Participant Cost Test for San Diego Gas and Electric Company Example**



Source: E3

**Figure 17: Total Resource Cost – San Diego Gas and Electric Company**



Source: E3

## Near-Term Rates: Pacific Gas and Electric Company Example

This case examines the cost effectiveness of owning a solar + storage system for an industrial customer in PG&E’s service territory. This customer was modeled using a projected “near-future” PG&E E20 rate adjusted from the current PG&E E20 retail rate. As greater renewable generation shifts system peak demand into the evening, there is an increasing need to modify current TOU structures to better match the timing of a utility’s highest net demand. Since no official rate has been published for PG&E, E3 built a prospective E20 rate structure using guidelines for these new TOU periods to explore potential cost-effectiveness changes under the new TOU periods. Published PG&E industrial customer load profiles were used for the example’s load shape<sup>9</sup>. The annual average load was 664 kW, with a peak of 1094 kW.

A projected near-future rate structure based on the PG&E E20 retail rate was constructed to represent new TOU periods that would provide better alignment with system peaks that shift to later in the day because of increasing solar PV generation. SCE and SDG&E both offer options for commercial customers to enroll in rates with an evening TOU peak. In PG&E’s General Rate Case Phase II, the utility indicated it will also move in this direction. Since no official rate has been published, E3 constructed a prospective E20 rate structure using the guidelines set out for these new TOU periods. The main structural differences between current E20 and E3’s near-future rates are placing the TOU peak later in the evening (moving from 12–6 pm to 4–9 pm), making the on-peak period applicable during both weekends and weekdays, and shortening the definition of summer from May–October to June–September. A super off-peak period during March and April (when net renewables are highest) was also added, with a \$/kWh value equivalent to half the off-peak period’s charge. These changes reflect E3’s best attempt to reflect new default residential and commercial TOU rates with later TOU periods that have since been implemented in 2019 and 2020 for PG&E, SCE and SDG&E.

Based on the customer’s load level, a 300 kW solar PV system and a 200 kW, 2-hour lithium-ion battery were chosen. The inputs are summarized in Table 6.

**Table 6: Inputs for Pacific Gas and Electric Example**

Item	Value	Sources & Notes
Customer Load Shape	PG&E example industrial customer	PG&E Dynamic Load Profiles*
Rates	Modified PG&E E-20 Rate	PG&E E-20 Rate and General Rate Case Phase II
Solar PV Size	300 kW	E3 selection; 22.5 percent capacity factor
Solar PV Cost	\$2750/kW	Based on mid-level estimates from NREL
Storage Size	200 kW, 2-hour	E3 selection; 85 percent round-trip efficiency
Storage Cost	\$498/kWh	Based on Lazard levelized cost of storage v4.0 E3 internal Pro Forma analysis
Avoided Costs	PG&E 2018 CPUC Avoided Costs	2018 CPUC Avoided Cost Calculator

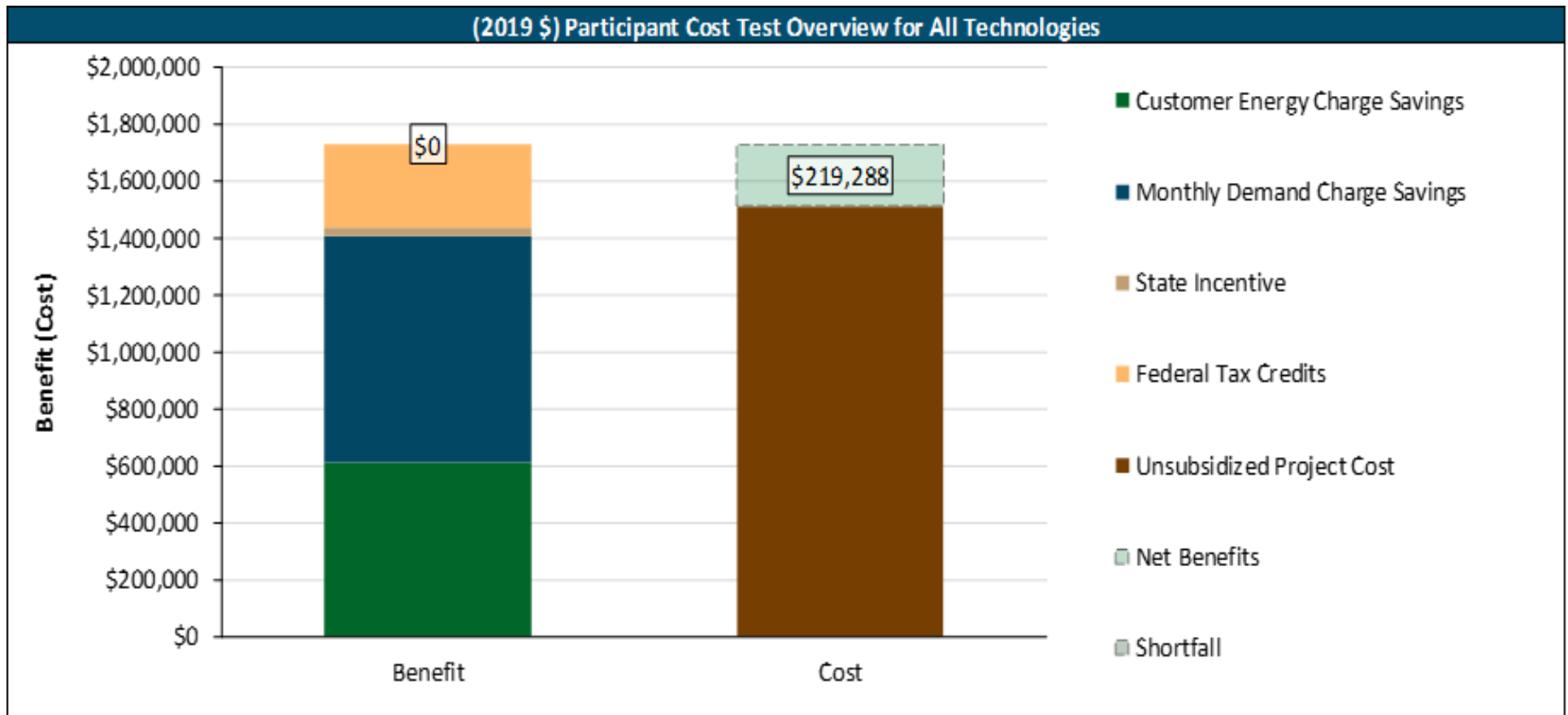
Source: E3

<sup>9</sup> PG&E Static Load Profiles: [https://www.pge.com/notes/rates/006f1c4\\_class\\_load\\_prof.shtml](https://www.pge.com/notes/rates/006f1c4_class_load_prof.shtml)



The following charts show PCT results for a combined solar PV + storage system. All the PCT results showed the solar PV + storage system to be cost effective. Even though it is not a direct comparison, the benefit-and-cost ratios are lower than in the previous SDG&E example for major reasons. First, the peak TOU period is shifted later in the day, meaning that solar PV generation has fewer hours available to access on-peak bill savings. Second, the summer period is shortened in the new rate structure, limiting the battery's revenues from clipping expensive summer on-peak demand charges. The cost-effectiveness results are similar to the SDG&E example from the system perspective, as shown in Figure 18, indicating that system benefits from solar + storage outweighed overall costs.

**Figure 18: Participant Cost Test for Pacific Gas and Electric Example Case**



Source: E3

### Distribution Deferral: an SCE Example

DERs can serve as non-wires alternatives for local capacity projects if they can reliably reduce local peak constraints. This use case examines potential distribution deferral values provided by DERs. An upgrade project identified by SCE in its 2018 DDOR and GNA reports was used for the project upgrade example. Due to limited information in the DDOR, additional assumptions were made, including distribution load shape, revenue requirement multipliers, and operation and maintenance costs. This example provides an illustration for how to use the tool to identify distribution-deferral values.

Table 7 summarizes information for the project upgrade.

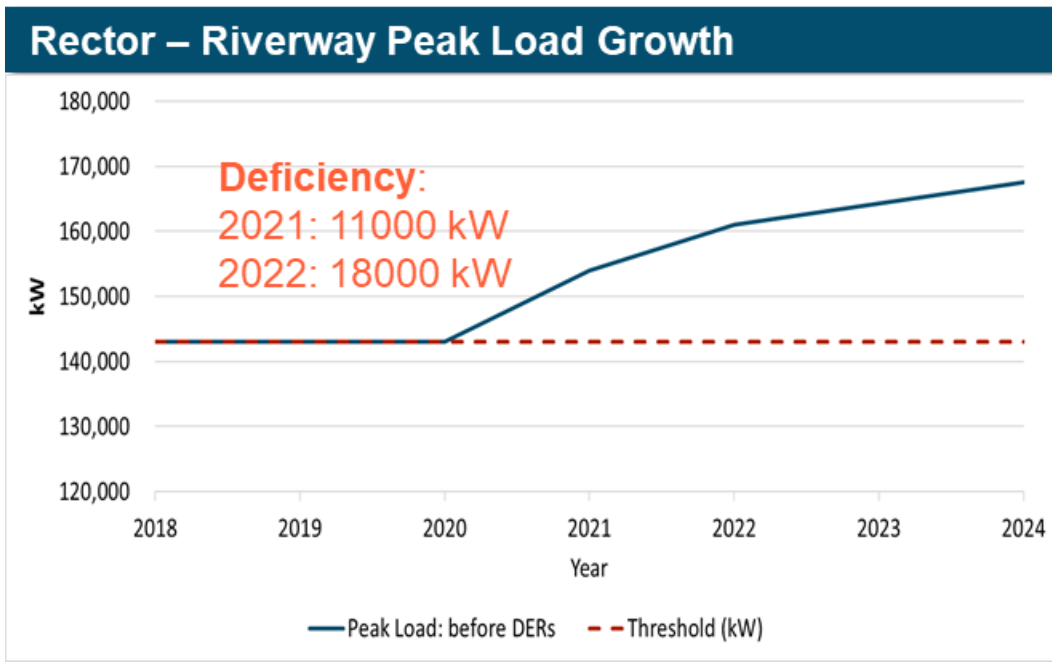
**Table 7: Upgrade Project Information**

<b>Input</b>	<b>Value</b>	<b>Source</b>
Upgrade project name	Rector – Riverway No.2 66 kV	SCE 2018 DDOR & GNA
Upgrade equipment type	Substation	SCE 2018 DDOR & GNA
Upgrade capital cost (\$)	\$27,410,000	SCE 2018 DDOR & GNA
Project commission year	2021	SCE 2018 DDOR & GNA
Deficiency	11 MW in 2021, 18 MW in 2022	SCE 2018 DDOR & GNA
Deficiency timing and shape	Late summer afternoon	Scaled based on the default load shape in the LNBA tool
Revenue Requirement (RR) multiplier	1.6	E3 Assumption
Operation and Maintenance	2 percent of the capital cost/year	E3 Assumption
Inflation rate	2 percent	E3 Assumption
Book life	30 years	E3 Assumption

Source: E3

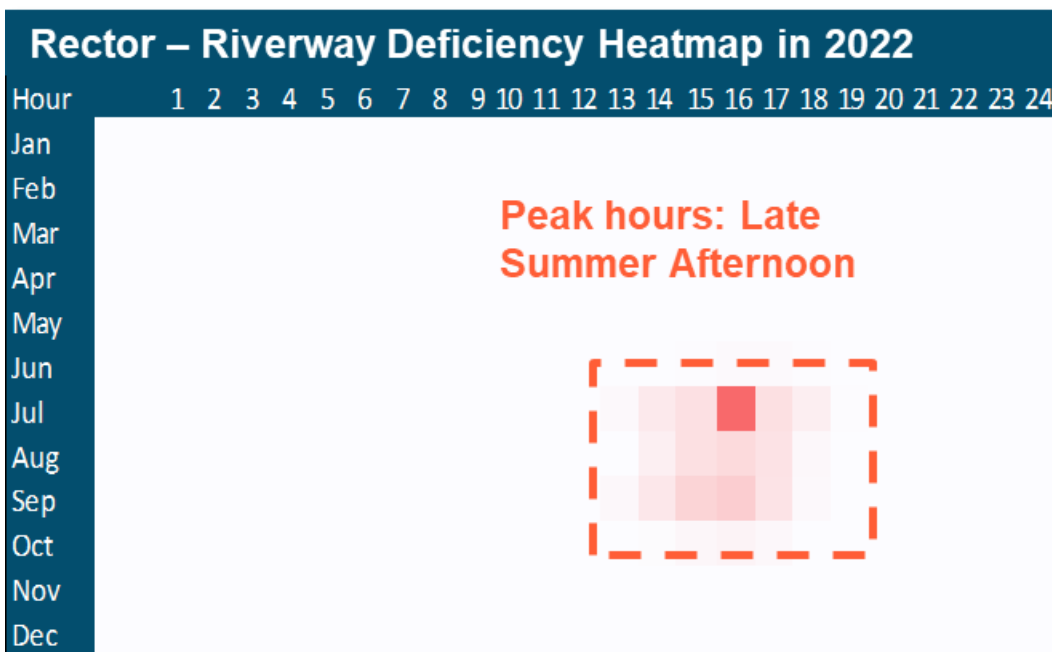
Figure 19 and Figure 20 show both the substation’s deficiency forecast and its deficiency timing for 2022. The distribution location requires 11 MW and 18 MW peak-load reductions in 2021 and 2022, respectively, to defer the upgrade. Distribution peak loads in both years occur on summer afternoon days.

**Figure 19: Substation Deficiency Forecast**



Source: E3

**Figure 20: Substation Deficiency Heatmap**



Source: E3

The study team chose the following DER portfolio to defer the upgrade, as shown in Table 8. The study assumed that the DER portfolio was installed in 2020 to allow a one-year lead time to make deferral decisions.

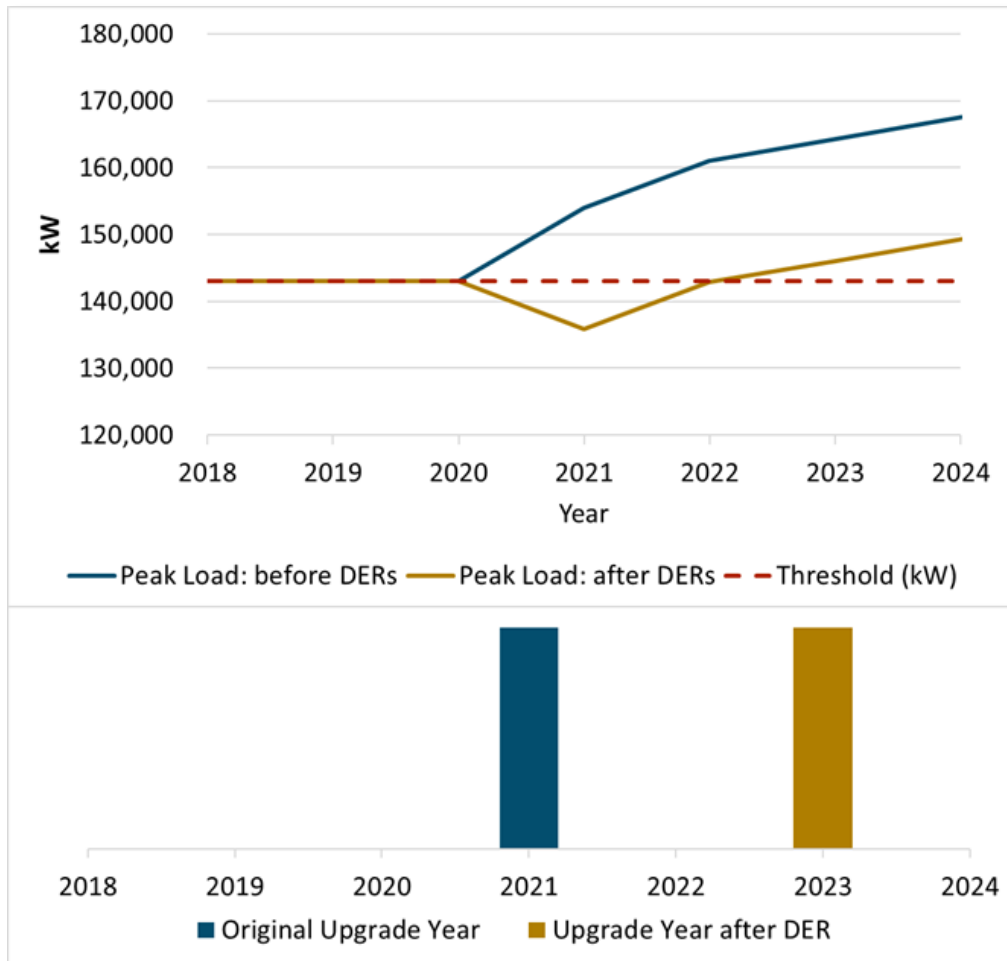
**Table 8: Distributed Energy Resource Portfolio Information**

DER Technology	Size	Notes
Solar PV	10 MW	22.5 percent capacity factor
Storage	10 MW 2-hour	85 percent round-trip efficiency
Energy Efficiency	Annual Average 400 kW	HVAC energy efficiency
Demand Response	2000 kW	Load shedding distribution peak targeted program: maximum 10 calls per year with a maximum 4 hours per call

Source: E3

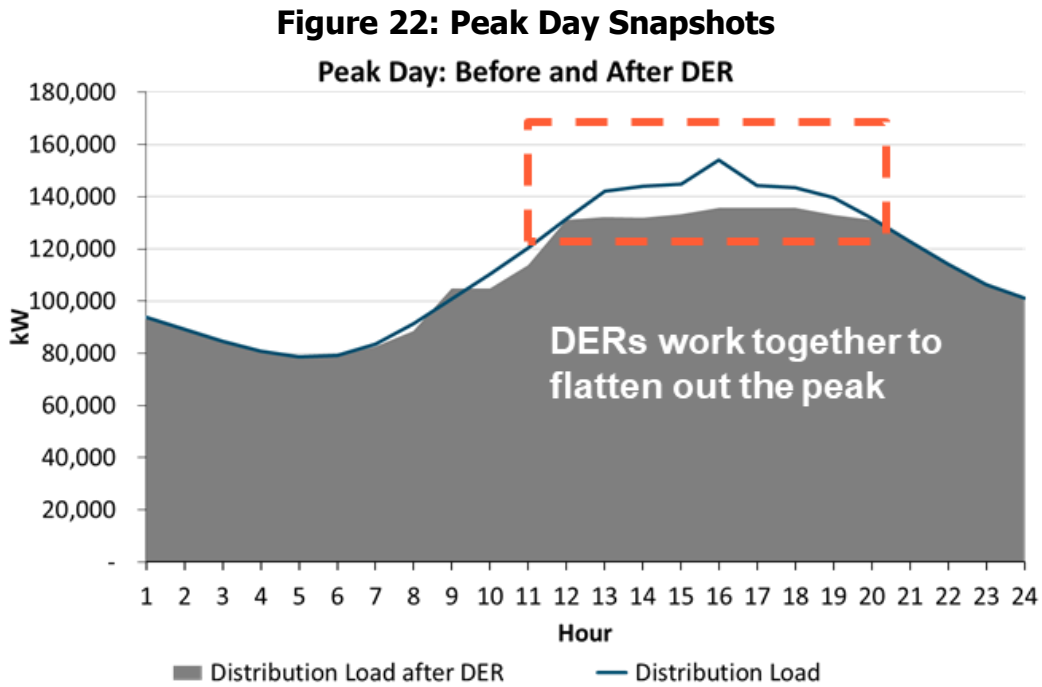
The tool collectively dispatched the DER portfolio based on an optimization algorithm that maximized distribution peak load reductions and benefits from other grid services. The model runs indicate that the DER portfolio provided 18 MW in peak-load reductions and deferred the upgrade by two years from 2021 to 2023, resulting in \$6.7 million in distribution deferral savings, as shown in Figure 21.

**Figure 21: Rector-Riverway Peak Load and Upgrade Before and After Distributed Energy Resources**



Source: E3

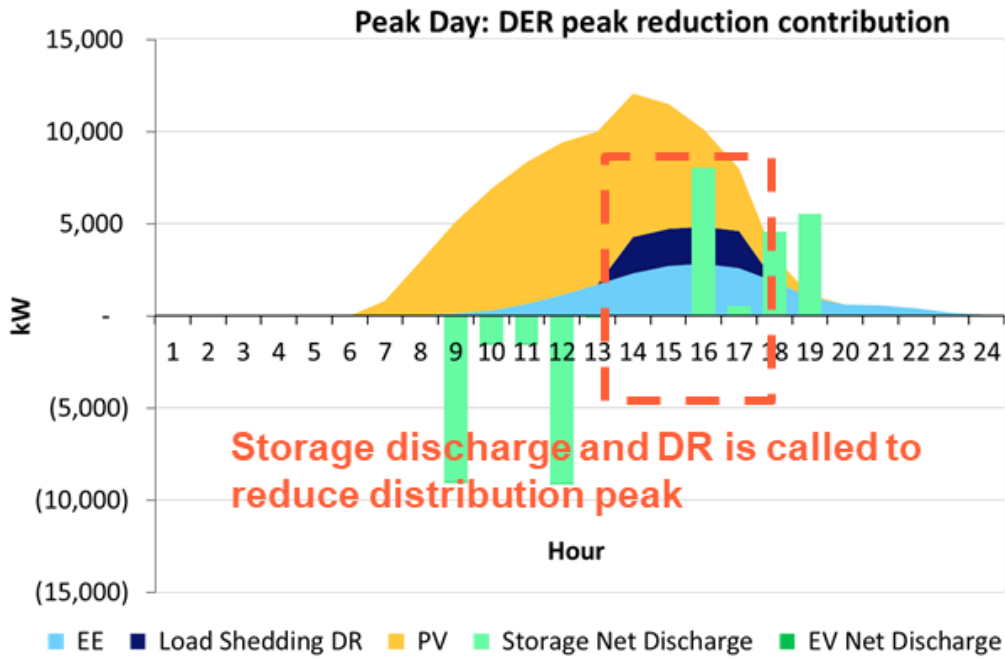
Figure 22 shows distribution load and DER load reduction contributions on a peak-demand day. The distribution load is flattened by DERs, and peak load was reduced by 18 MW.



Source: E3

Figure 23 shows the DER load reduction components, broken out by technology; solar PV, distribution-peak-focused load shedding DR, HVAC energy efficiency, and storage all contributed to the peak load reduction. Instead of undergoing full discharge during the original distribution peak (hour 16), the battery amassed peak-reductions from other DERs and saved energy to discharge during later shoulder hours. This was only possible because of a cooptimized dispatch schedule.

**Figure 23: Peak Day Distributed Energy Resource Dispatch**

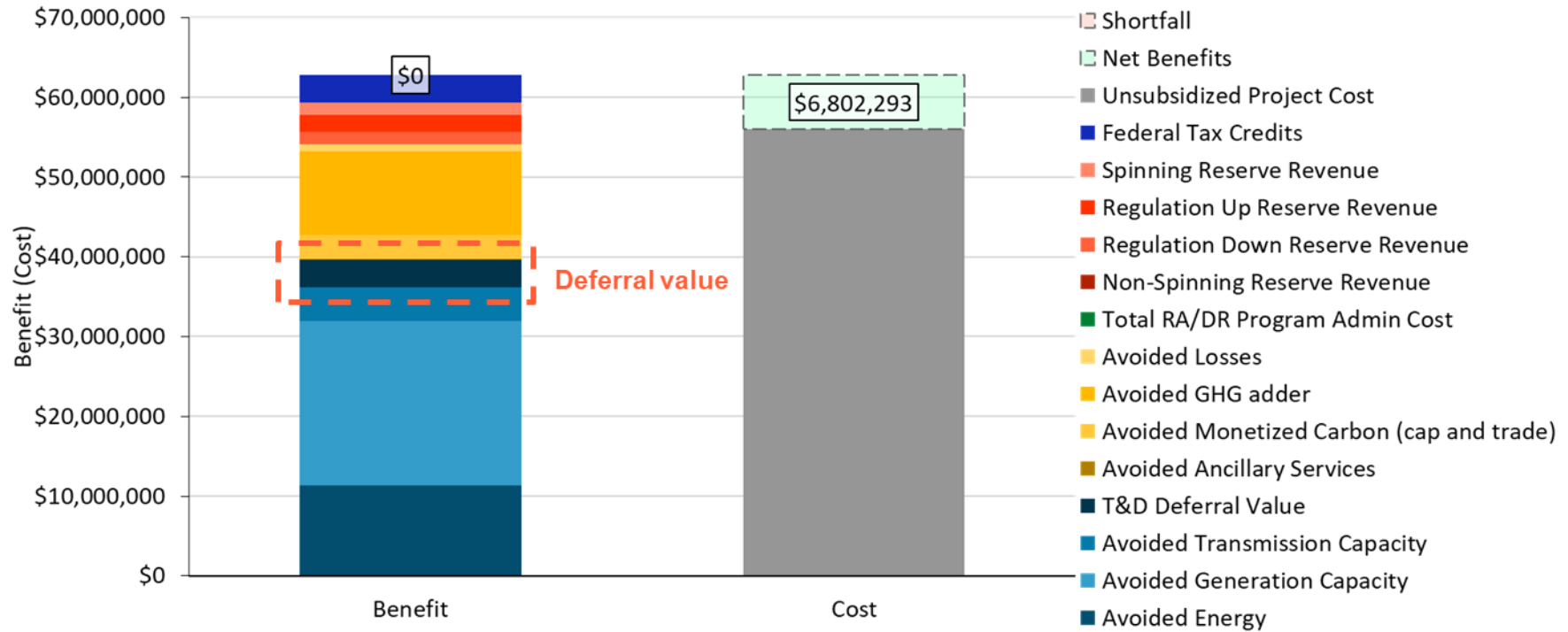


Source: E3

In addition to distribution deferral, the DER portfolio can also provide many other benefits including avoided energy and capacity during off-peak hours. Figure 24 shows benefits and costs based on the total-resource cost test for the whole DER portfolio. The overall DER portfolio has \$6.8 million in net benefits.

**Figure 24: Total Resource Cost Test for the Distributed Energy Resource Portfolio**

**Total system benefits provided by the DER portfolio**



Source: E3



# CHAPTER 6:

## Technology/Knowledge/Market Transfer Activities

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Technology and knowledge transfer activities are among the most important goals of this project. The project team engaged with the TAC, utilities, energy-storage developers, and regulators, beginning in the early tool-development phase. The tool had three draft releases before its final release. Multiple draft versions allowed enough time for TAC members to provide feedback and watch the tool's evolution over time. Since the tool's final release, the project team has found multiple opportunities to introduce the tool and its many benefits to the general public and provide support for users interested in further exploring its capabilities. The technology/knowledge transfer activities can be grouped into three major categories outlined below.

- TAC meetings
  - A Technical Advisory Committee (TAC) was formed at the beginning of this project. TAC members came from a wide range of backgrounds, including staff from IOUs, the CPUC, and storage companies; their feedback was therefore valuable in allowing the project team to consider opinions from various perspectives. E3 hosted several meetings with the TAC members during the tool development process to collect TAC members' feedback on model functionalities and model design, including
  - An initial meeting in February 2018 during which E3 presented the first version of the tool, which only provided a cost-effectiveness analysis for solar PV and storage.
  - A subsequent meeting in June 2018 demonstrated the second version of the tool, which included the ability to calculate the distribution deferral values and model other DER technologies.
  - The final meeting in February 2019 showcased the final version of the model, which incorporated two additional user interfaces (UIs), one for first-time users and the other for utility-distribution engineers interested in potential distribution-deferral opportunities.
  - Each meeting had about 6-10 TAC members participating. E3 collected their feedback after each meeting and adjusted the tool accordingly. After the model development period, E3 still kept TAC members in the loop by inviting TAC members to public workshops and by informing TAC members about the collaboration with other EPIC recipients.

- Workshops

The project team hosted three public workshops in June, August, and December of 2019. The first workshop started with a brief introduction of the release of the Solar + Storage Tool; after this introduction, the workshop focused on tool-use cases and discussed the three most common cases and their results. The second workshop shared

results for a solar + storage pilot project conducted in collaboration with HSUSPF. The third workshop focused on additional use-case examples, provided stakeholder feedback, and made recommendations for future studies. Each of the workshops attracted 60 to 170 participants from utilities, universities, regulators, developers, national labs, and environmental groups.

- Collaboration with other EPIC recipients

Through the Energy Commission, the project team reached out to a broad group of other EPIC project recipients to explore future opportunities for collaboration. Three project recipients expressed interest in learning more and potentially adopting the tool. They are the Electric Power Research Institute (EPRI), the Clean Coalition, and HSUSPF. All three projects have solar + storage pilot projects and are exploring different aspects of the business model. E3 hosted an introductory webinar that provided an overview of tool functionality for the three recipients, followed by three individual webinars to further discuss project details and potential collaboration opportunities. All three recipients expressed interest in further cooperation through either cost-effectiveness studies for their projects, or simply reviewing the tool and providing feedback. Two of the recipients later stopped or deferred their collaboration discussions because of resource and budget constraints. The project team conducted a case study in coordination with the third recipient, HSUSPF, to evaluate the cost effectiveness of their solar + storage pilot project in Blue Lake Rancheria, California.

- Using the tool for other projects

In addition to the technology and knowledge transfer activities through this project, the tool has been used to support analysis in many other projects. Those projects primarily focus on the benefit and costs analysis for storage and solar systems, but the tool has also been used for projects that investigated the cost-effectiveness of building electrification and vehicle-to-grid integration of electric vehicles. Please see CHAPTER 8: Benefits to Ratepayers for details on projects that benefit from the tool.

- Others

E3's attendance and presentation at the Avoided Transmission and Distribution Capacity Avoided Cost Workshop hosted by the CPUC Energy Division further spread awareness and knowledge of the tool, as did posting LinkedIn articles and reaching out to E3's contacts to let them know about the public workshops.

As a successor to the LNBA tool, this tool can replace the LNBA tool and be used directly in the DDOR proceeding. To smooth out the transition and remove potential integration barriers, the project team also reached out to utilities and CPUC staff to solicit their feedback on tool functionalities, especially use of the tool for the DRP process. This feedback was particularly important to the project team while developing functions for distribution deferral and distribution-hotspot screening. Based on these conversations, E3 developed a separate UI for distribution engineers in the DDOR proceeding. Unfortunately, by the time the UI was developed, each IOU had already developed its own process for fulfilling the DDOR requirements and did not have time to learn about this tool and how it works.

This tool was very valuable in the DRP proceeding to help utilities and developers evaluate the potential cost effectiveness of DER programs and the implications of their adoption on future load growth. The tool can also be used by both developers and utilities in their bidding and bid-evaluation processes. Even though the current DRP proceeding doesn't require use of the tool, as a publicly-vetted tool it can still provide highly valuable analyses, especially for smaller companies that don't have much analytical bandwidth. In addition, E3 is actively engaged with the CPUC on both the DRP and Integrated Resource Planning work streams and will continue to identify other beneficial use cases.

Lastly, after the tool went public, E3 was approached by PG&E, LADWP, and Marin Clean Energy. All three utilities have expressed interests in using the tool either for DER planning, DER program analysis, or bid evaluation. E3 set up one-on-one conversations with each utility to further discuss their needs and provided support for several hours to answer their questions on tool functionalities.

# CHAPTER 7:

## Conclusions and Recommendations

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### Conclusions

The project successfully developed the Solar + Storage Tool, a powerful and flexible DER benefit-cost analysis tool focusing on distribution deferral values. As a successor to the LNBA tool, this tool can be used directly in the DDOR proceeding to help utilities quantify distribution deferral values provided by non-wires alternatives. Its advanced dispatch logic for energy storage and other dispatchable DERs provides a highly accurate estimate of a storage owner's behavior. It is an increasingly valuable feature as energy storage becomes an increasingly popular DER technology in non-wires alternatives. This tool also has many other use cases: for example, helping developers and investors in utility-scale solar PV and storage investments and assisting utilities in implementing DER programs and rate design.

This tool went through several debugging and vetting iterations. Optimal wholesale revenues calculated by this tool were compared against historical earnings calculated by the California Independent System Operator (California ISO). This comparison showed that historical earnings were about 80 percent of the theoretical revenues calculated by the tool. Utility-bill savings for BTM use cases were also compared with those produced by other public or commercial tools, the differences of which were within 5 percent.

The project team also conducted a series of technology and knowledge transfer activities to promote use of the tool, including hosting three public workshops, collaborating with other EPIC fund recipients in case study analyses, and participating in the CPUC DDOR and DRP meetings. Many utilities and developers have either started or expressed an interest in using the tool.

### Recommendations

To provide a more user-friendly and robust DER evaluation tool for California, the research team recommends adding the following features in future studies.

#### Features

1. California ISO Market Rules

Modeling the detailed California ISO rules can be helpful for developers in their daily operation and project acquisition processes. For example, the model can pre-set participation schemes (such as, regulation energy management) to include certain revenues based on California ISO rules.

2. Imperfect Foresight

The tool's dispatch simulation is based on perfect foresight. Dispatch simulation with imperfect foresight can provide a revenue estimate that considers forecast error and risk management. Examples of possible additions are rule-based chronological dispatch and dispatch that considers the error bars of future price forecasts. For example, rule-based chronological dispatch logic simulates actions by an energy trader: the model

calculates decisions at each time-step according to certain rules and adjusts its estimates based on the current battery state-of-charge and future generation and market price forecasts. The other approach is to consider forecast errors and a dispatcher's risk tolerance.

### 3. Electrification

Electrification is one of the most important pillars in California's ambitious, mandated decarbonization efforts. The research team believes it is critical to consider both electrification and DERs when evaluating future distribution systems. Tool features can be used to analyze the value of flexibly moving some smart appliance loads to off-peak hours. The energy efficiency feature can also be used to evaluate a customer's electricity bill impact and avoided-cost changes. Features can also be added that further analyze the cost-effectiveness of electrification. For example, natural-gas bill calculations and building-stock rollover can consider appliance lifetimes and the timing of appliance replacements in a given building.

### 4. Adoption

Simulating customer adoption of DERs and electrification are critical for planners in the distribution planning process. A feature that simulates customer behavior based on the cost-effectiveness of these measures is recommended for future studies.

### 5. Microgrid

As wildfire risk increases in California, interest is growing in microgrids as emergency power providers. The tool is able to simulate microgrids that incorporate energy storage, solar PV, fossil-fuel generation, electric vehicles, and smart appliances. More features can be added to further perfect a microgrid's cost-effectiveness and decision-making processes. An example of this would be optimal sizing for microgrids based on both critical load and the number of operational hours during outage events.

### 6. Platforms

The tool's core calculation and optimization logic are built in Python, an open-source programming language. In addition, the tool includes interfaces in Microsoft Excel that allow users unfamiliar with the programming language to change inputs and view results. The research team has received positive feedback from stakeholders on the Excel interface platform because it is familiar to them and they feel comfortable inputting changes to it. Even though the Excel platform has received positive feedback, it has calculation limitations that make it difficult to handle large datasets or link to external databases. External datasets like utility rates and renewable profiles can reduce user time when configuring cases. It could be beneficial in future studies to explore new platforms that provide users with both familiarity and the capability of handling large or external datasets.

# CHAPTER 8:

## Benefits to Ratepayers

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There has been a rapid increase in the adoption of new DER technologies in the past five years, especially the adoption of PV, battery, and electric vehicles. Unlike the traditional DER (for example, energy efficiency), which has predictable performance, the new DER technologies are much more versatile and more complicated to forecast. As California aims to achieve its decarbonization goals, electrification and DER adoption will play an important role in transforming the grid to be cleaner and more sustainable.

This project developed a versatile DER evaluation tool that can be used by different entities to assess benefits of DER, especially the benefits provided by dispatchable DER technologies. Utilities can use this tool to identify new cost-saving technologies in their distributed-resource planning processes. The tool can also help utilities design rates or programs that benefit both participants and other non-participating ratepayers. In addition, the tool can be used to estimate the impact of electric vehicle adoption and the potential benefits provided by vehicle-to-grid programs. On the other hand, storage and PV developers can use this tool to compute future value estimations. The simplified evaluation process reduces soft costs and can facilitate investment and deployment of new technologies. Government and state agencies can also benefit from this tool by using it to evaluate state-wide programs (e.g. California's SGIP program) or to set future policies.

The benefits of this project can be summarized in the following categories:

- Reduce utility costs to California ratepayers by identifying cost-savings in DER planning processes through new technologies.
- Reduce utility costs and emissions through DER program and rate design.
- Facilitate investment and deployment of new technologies and microgrids.
- Facilitate a standard practice within California to both reduce communication barriers among entities and develop a process to keep the costs and benefits of solar + storage and DER updated.
- Support other studies as the tool can be adapted easily for new analyses.

### **Cost Savings in DER Planning Process**

One of the primary benefits identified at the beginning of the project is to reduce utility costs to California ratepayers by identifying cost-savings in distributed energy resource planning processes. The inclusion of this tool could significantly reduce California's IOU ratepayers' utility bills. More specifically, the tool enables utilities to direct DER deployment to distribution hotspots with the most expensive deferrable upgrades. After identifying these hotspots, the model also provides quick screening for suitable technologies in reducing distribution peaks. The screening is based on technology generation profiles and distribution system load shapes. These functionalities allow utilities to efficiently consider non-wire alternatives. If the expensive upgrade is deferred or avoided by cheaper non-wires alternatives, ratepayers' utilities will have lower overall system costs, leading to lower electricity bills.

IOUs used their own tools to evaluate DER potentials in distribution deferral in previous DDOR filings. Each IOU followed the same overall methodology but had slight differences in analytical details. If the CPUC can require each IOU to use the same public tool, the tool can help avoid inconsistencies between utilities and provide valuable transparency to third parties. Even without enforcement of a standard public tool for utilities, CEC's Energy Assessments Division and other third-party can still use this tool to validate distribution deferral results calculated by utilities.

The benefits of using DER to defer distribution upgrades affect all of California's IOU electricity customers. A conservative estimate of the total cost savings is \$6 million per year and \$25 million over five years. A secondary qualitative benefit is improved reliability, to the extent that the targeted deployment of DER can reduce peak loads and their associated distribution outages. This tool can also be used to evaluate and support a range of technologies designed and produced by California companies as many new DER technologies are owned or manufactured by California companies.

Recent General Rate Case filings for PG&E, SCE, and SDG&E show a total of \$6.3 billion in capital distribution system expenditures for the calendar year 2019. Based on the major work categories provided by the utilities that define different types of distribution investments, the project team estimated that \$314 million (or 5 percent) of those distribution capital expenditures are driven by peak-load growth and potentially deferrable by the targeted adoption of DER. The sizes and durations of distribution deferrals enabled by projects will be very location-specific. For estimation purposes, the research team assumed that the Solar + Storage Tool would facilitate targeted deployment of DERs that would defer 5 percent of those costs (\$16.7 million) for three years. Assuming a utility weighted-average cost of capital of 7.61 percent (based on the CPUC authorized rate of return for 2018), the cost reduction for utility ratepayers would be \$3.1 million for one year. The present value of those savings for a similar deferral value in each of the subsequent five years would total \$12.5 million.

## **Cost Savings from Rate and Program Design**

The Solar + Storage Tool can be used by utilities to evaluate different tariffs and program designs that better align customer-sited DER operations with grid requirements. A substantial amount of current BTM solar PV and storage systems cause cost shifts for other ratepayers. This could be improved by better aligning customer rate signals with overall system benefits. These include demand response programs with more frequent, granular signals; full-value tariffs that capture system hourly variations; and adding an hourly carbon emission signal to guide energy storage. A recent SGIP report (Itron and E3, 2019) shows that the storage devices installed with SGIP incentives actually increased grid GHG emissions under the current utility rates. Adding a carbon price signal to guide the dispatch can significantly reduce the GHG emissions and have minimal impact on customers' overall bill savings.

Similarly, the current distribution system might not be able to integrate the rapid adoption of electric vehicles if their charging behaviors are not guided by appropriate price signals. Shifting the charging to off-peak hours can help to avoid distribution system upgrade that would originally be triggered by EV adoption.

This tool also allows utilities and policymakers to understand customer behaviors in using smart appliances and better analyze interactions among smart electric appliances and solar PV and battery operations. Understanding customer use of smart appliances can help design programs that fully utilize these appliances' inexpensive but valuable energy-shifting capabilities.

## **Facilitate Investment and Deployment of New Technologies**

Renewable resource and energy storage developers can leverage this tool to compute future value estimations and use those results to support financing. The simplified evaluation process reduces soft costs and can facilitate investment and deployment of new technologies.

The optimal dispatch model provides a theoretical maximum value for future technologies while following fundamental market rules. For example, a battery's state of charge must have enough headroom and footroom to support the services it committed to, including capacity, energy, and ancillary services. We believe that the market rules will involve over time to allow DERs to provide maximum values to the system thus the model focuses on computing theoretical maximum values subject to fundamental technical constraints. When preparing for project financing, developers usually apply haircuts to the maximum values to account for the uncertainties in price forecast and market transformation. In addition, the tool provides both a signal and an incentive for policymakers working on market transformation with the goal of accessing as much of this theoretical maximum value as possible. The realization of the full value of energy storage would then lead to more efficient and lower-cost systems, which would ultimately mean cost savings for utility customers.

The tool has been used to support the evaluation and financing of multiple new stand-alone storage, hybrid PV and storage, and microgrid projects.

## **Projects that Benefit from the Tool**

During model development, the tool (or some parts of it) directly supported analyses in California, which created benefits for California utility ratepayers even before the project was completed. Those projects appear here.

- California Storage Program Evaluation (2018–2019): E3 conducted and published California's SGIP Advanced Energy Storage Impact Evaluation reports in partnership with Itron, for program years 2013 through 2018.<sup>10</sup> In this project, the tool simulated customer energy storage dispatch. Emissions, utility bill savings, and utility avoided costs were compared with historical dispatches to understand the maximum potential impacts from SGIP customers. E3 modeled the dispatch of 716 BTM storage systems totaling 49 MW using customer load, retail rate, and storage dispatch data from 223 systems; this was the largest database of metered storage data at that time. Larger

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<sup>10</sup> 2019 SGIP Energy Storage Market Assessment and Cost-Effectiveness Report: <https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442463457>; 2017 SGIP Advanced Energy Storage Impact Evaluation: [https://www.cpuc.ca.gov/uploadedFiles/CPUC\\_Public\\_Website/Content/Utilities\\_and\\_Industries/Energy/Energy\\_Programs/Demand\\_Side\\_Management/Customer\\_Gen\\_and\\_Storage/2017\\_SGIP\\_AES\\_Impact\\_Evaluation.pdf](https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy/Energy_Programs/Demand_Side_Management/Customer_Gen_and_Storage/2017_SGIP_AES_Impact_Evaluation.pdf)



systems (greater than 30 kW), representing 83 percent of installed capacity, performed well, reducing customer bills and peak loads with round-trip efficiencies averaging 74 percent. Smaller systems, however, actually increased peak loads and realized round-trip efficiencies of an average of only 44 percent. Both groups actually increased grid GHG emissions. Using the Solar + Storage Tool, the research team improved dispatch to minimize electricity bills, system-level costs, and GHG emissions. The research team found that with TOU retail rates, the customer incentive to dispatch storage to minimize bills is not well-aligned with the goals of minimizing utility costs or GHG emissions. The research team also modeled the value of energy storage for long-term resource planning to meet renewable-resource generation and GHG emission goals, and identified 49 MW of energy storage potential to reduce capital investment and variable operating costs by \$19 million (if it provides reserves in California ISO markets). Our 2017 program year report modeled 828 BTM storage systems totaling 67 MW and reached similar findings, suggesting again that more dynamic retail rates and participation in wholesale markets for BTM storage are essential for reducing costs and GHG emissions.

- Santa Monica City Yards Advanced Energy District (2018): E3 conducted a cost-effective analysis as part of the microgrid feasibility study funded by the EPIC program (Contract Number: EPC-16-008).<sup>11</sup> The project evaluated options for a renewable and self-sustaining microgrid for the City Yards redevelopment, which serves most of Santa Monica’s public works operations. The tool is used to simulate the operation of the microgrid system and perform cost-benefit analyses from three perspectives: the City of Santa Monica (Participant Cost Test), other ratepayers (Ratepayer Impact Measure) and the State of California (Total Resource Cost Test). The results found that more dynamic rates and incentives are required to bridge the gap between project costs and system benefits. When the system was dispatched against a real-time rate that reflected system marginal costs, the microgrid system provided \$4.6 million net benefits in a 25-year period. Construction and development of the project are still pending.
- EPRI and Nuvve, Value of Vehicle-to-Grid (V2G) in California (2016-2018):<sup>12</sup> E3 used this tool to determine the grid benefits of distribution-aware vehicle-to-grid (V2G) services performed by a fleet of electric vehicles at the University of California, San Diego campus. Nuvve, EPRI, and other partners implemented a demonstration of plug-in electric vehicles providing V2G services using established communication standards and interconnection rules. Combining energy storage and electric vehicle models, E3 modeled the incremental benefits of V2G services over managed one-way charging for the electric grid. E3 demonstrated higher-than-expected incremental benefits for V2G relative to managed one-way charging. In high value, capacity-constrained locations, V2G could provide additional benefits of up to \$1,100 per vehicle if full battery cycling is permitted. E3 found a more typical annual value of \$400 per vehicle, with limited

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<sup>11</sup> Final Project Report: <https://ww2.energy.ca.gov/2019publications/CEC-500-2019-032/CEC-500-2019-032.pdf>

<sup>12</sup> Final Project Report: <https://ww2.energy.ca.gov/2019publications/CEC-500-2019-027/CEC-500-2019-027.pdf>

cycling to preserve battery life. E3 demonstrated that the additional flexibility of V2G provided considerable additional value compared with simply reducing on-peak loads with smart charging. With managed one-way charging, the electric vehicles must be charging to provide benefits and they cannot provide services once the battery is full. With V2G, not only does the ability to discharge the battery double the capacity for grid services, but the dispatch can be more precisely timed to coincide with peak loads. The battery can also be used for grid services the entire time the vehicle is plugged in, even after the battery is full.

- Cost and Emissions Impacts of Residential Building Electrification in California, Three-Utility Study (2019): E3 was retained by three large California utilities — SCE, Sacramento Municipal Utility District, and the Los Angeles Department of Water and Power—to explore the consumer cost and emissions reduction potential of the electrification of California homes.<sup>13</sup> The study examined costs, savings, and emissions for electric and gas appliances in six different home types in geographical areas covering over half the state’s population. Unlike prior studies, it closely evaluated the consumer cost perspective on building electrification and quantified GHG emissions savings. E3 found that building electrification would deliver lifecycle cost savings for most home types in the study area. For homes with air conditioning—about 80 percent of the total—the economics are particularly strong. All newly constructed homes and the vast majority (84 percent) of existing single-family homes with air conditioning would save by going all-electric. E3 also found that electrification would substantially and immediately reduce greenhouse gas emissions from homes. For example, a Sacramento home built in the 1990s would immediately cut its GHG emissions nearly in half by switching to all-electric appliances; by 2050, with a substantially cleaner electric grid, the GHG savings would grow to over 80 percent, and more, if California achieves carbon neutrality. The rates and bill calculation modules of the tool have been used in this project to understand customer bill impacts after switching to electric appliances.

In conclusion, this versatile tool supports utilities in DER planning and program design and facilitates DER deployment. As a public tool, it provides transparency to stakeholders regarding the process of evaluating distribution deferral opportunities. The tool can be used by various entities to support the DER adoption and the overarching goal of deep decarbonization in California.

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<sup>13</sup> Study Report: [https://www.ethree.com/wp-content/uploads/2019/04/E3\\_Residential\\_Building\\_Electrification\\_in\\_California\\_April\\_2019.pdf](https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf)

## GLOSSARY AND LIST OF ACRONYMS

Term	Definition
BTM	Behind-the-Meter: Technology that serves a customer’s load at the site of the customer’s load and therefore does not pass through the customer’s electric meter
California ISO	California Independent System Operator: An organization that oversees California’s electric bulk grid and wholesale energy market to ensure reliability.
CEC	California Energy Commission: The agency that drives energy policy and planning in California.
CPUC	California Public Utilities Commission: Regulates California’s utility sectors, including electricity and natural gas.
DDOR	Distribution Deferral Opportunity Report: In February 2018 the Commission issued D.18-02-004 on Track 3 Policy Issues, Subtrack 1 (Growth Scenarios) and sub-track 3 (Distribution Investment and Deferral Process). This decision directed the IOUs to file a Grid Needs Assessment by June 1 of each year, and a DDOR by September 1 of each year. The Commission ordered that the investor-owned utilities, in their annual DDOR filing, shall report planned investments and candidate deferral opportunities reported in the DDOR and candidate deferral prioritization.
DER	Distributed Energy Resources: Technologies that produce or store energy that are deployed at the distribution-level and are not centrally located on the grid; these technologies provide energy services to the site at which they are located or can provide services to the grid.
DR	Demand Response: A program which calls on end-use customers to reduce energy consumption during certain periods of higher energy prices and stress on the grid.
DRAM	Demand Response Auction Mechanism: Beginning in 2016, the CPUC required investor-owned utilities (IOUs) in California to implement pilot programs to allow sellers to bid demand response capacity into the CAISO day-ahead market. D.19-07-009 has extended the DRAM pilot for the CA IOUs through 2022.
DRP	Distribution Resource Planning: Planning focused on identifying the optimal location for the deployment of distributed energy resources (DERs).
E3	Energy and Environmental Economics, Inc.
EPIC	Electric Program Investment Charge: A program run by the California Energy Commission that invests in research that focuses on the development of clean energy technologies to support CA climate goals.

<b>Term</b>	<b>Definition</b>
EPRI	Electric Power Research Institute: An independent, non-profit organization that conducts research and demonstration projects in the electricity sector.
GHG	Greenhouse Gas: Gases that trap heat in Earth's atmosphere, therefore contributing to a warming of the Earth's surface. GHGs include carbon dioxide (CO <sub>2</sub> ), methane (CH <sub>4</sub> ), nitrous oxide (N <sub>2</sub> O), and fluorinated gases such as hydrofluorocarbons.
GNA	Grid Need Assessment: An evaluation of upgrades required for the reliable operation of the electric grid. Beginning in 2018, the CPUC requires California IOUs to annually submit a GNA (D. 18-02-004)/
HSUSPF	Humboldt State University Sponsored Programs Foundation: A non-profit that connects research from the Humboldt State University community with external grants and contracts.
HVAC	Heating, Ventilation, And Air Conditioning: Technology that improves indoor climate and comfort.
IOUs	Investor-Owned Utilities: Electric distribution companies that issue stock owned by shareholders and are regulated as utilities.
LNBA	Locational Net Benefit Analysis
NPV	Net Present Value
PCT	Participant Cost Test is designed to assess if a demand side program is cost effective from the perspective of the end consumer who chooses to participate in a program or install a DER or energy efficiency measure.
PG&E	Pacific Gas and Electric Company: An investor-owned utility that serves northern California.
PV	Photovoltaic: Technology that uses solar cells to convert solar energy into electricity.
SB	Senate Bill: The mechanism by which lawmakers in the Senate introduce new laws and legislation.
SCE	Southern California Edison An investor-owned utility that serves southern California.
SDG&E	San Diego Gas & Electric: An investor-owned utility that serves San Diego and southern Orange counties.
SGIP	Self-Generation Incentive Program: The program provides incentives such as rebates for the purchase and installation of DERs.
TOU	Time of use: An energy pricing structure in which prices vary by the time of consumption.

Term	Definition
TAC	Technical Advisory Committee: A committee formed at the beginning of the project consisting of members from a wide range of backgrounds, including staff from IOUs, CPUC, and storage developers. TAC members provided feedback throughout the project regarding the project's model functionalities and design.
UI	User interface: The component of a model that a user interacts with and can select inputs and preferences as well as view results.
V2G	Vehicle-to-Grid: A system in which battery-powered vehicles can both accept electricity from the grid and provide electricity back to the grid depending on the needs of the car and grid.
VoLL	The Value of Lost Load is the estimated amount that customers receiving electricity with firm contracts would be willing to pay to avoid a disruption in their electricity service

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