CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Validated, Transparent, and Accessible Microgrid Valuation and Optimization Tool: EPRI DER-VET™

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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 and 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.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

The Distributed Energy Resource Value Estimation Tool (DER-VET™) provides a free, publicly accessible, open-source platform for calculating, understanding, and optimizing the value of microgrids and distributed energy resources based on their technical merits and constraints. An extension of The Electric Power Research Institute's 2016 Storage Value Estimation Tool (StorageVET®), DER-VET™ supports site-specific assessments of energy storage and additional DER technologies—including solar, wind, demand response, electric vehicle charging, internal combustion engines, and combined heat and power—in different configurations, such as microgrids. It uses load and other data to determine optimal size, duration, and other characteristics for maximizing benefits based on site conditions and the value that can be extracted from targeted use cases. Customers, developers, utilities, and regulators across the industry can apply this tool to inform project-level decisions based on a sound technical understanding and unbiased cost-performance data.

Keywords: California Energy Commission (CEC), California Public Utilities Commission (CPUC), microgrid, DER-VET™, distributed energy resources, energy storage, DER technologies, StorageVET®.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Background

The electric power system is changing to include more distributed energy resources, microgrids, and aggregations operating under increasingly complex rules, regulations, tariffs, and business models. Compounding this new complexity is the technical nature of the DERs, which includes energy storage. Planning for energy storage necessitates detailed time-series modeling that acknowledges degradation and interactions with other energy resources and meaningfully considers the potential of energy-limited resources to stack services. Distributed Energy Resource Value Estimation Tool (DER-VET™) provides a free, publicly accessible, open-source platform for calculating, understanding, and optimizing the value of DERs in this complex, rapidly evolving setting.

Recent extreme weather events, natural disasters, and ongoing electrification have demonstrated the United States' dependence on reliable and resilient electricity. Customer resilience requirements are increasing rapidly, especially in states that repeatedly experience natural disasters, such as hurricanes and wildfire-related power shutoff events. Microgrids are increasingly being deployed to improve resilience for remote communities with limited grid access or large institutions with a campus-style energy system infrastructure. They have the potential to enhance the electric power system's reliability and resilience in the face of new challenges, including an increasingly carbon-free generation mix and more frequent extreme weather events.

Microgrids can be expensive, and many cannot recover their costs through monetary value streams alone, so they rely on the value of the resilience they provide to end customers for justification. The value of resilience, however, cannot often be monetized easily and would require extensive insight into customer interruption costs to model meaningfully. However, with prudent grid siting, design, and operation, there are opportunities to stack financial benefits from the distributed energy resources in a microgrid to offset some or all the costs of such installations with potential trade-offs around the level of resilience the microgrid can provide. Planning for microgrids requires modeling and analysis tools that simultaneously consider resilience objectives, interconnection, and market-related constraints, costs, and benefits to help users navigate a complex and challenging multi-objective decision-making process. Additionally, microgrid development involves many stakeholders, including customers within the microgrid isolation boundary, ratepayers outside the microgrid, the electric utility supplying the microgrid when not islanded, funding organizations, regulators, etc.

All stakeholders for financial or resilience-driven projects need a common framework to understand, communicate, and trust decisions made around distributed energy resources. The DER-VET™ fills this role by providing the public with a trusted, validated, open-source tool. In addition to evaluating the techno-economic feasibility of a microgrid design, DER-VET™ is also built with additional capability to evaluate the value of distributed energy resources in general for various use cases across transmission, distribution, and customer domains from the perspective of different stakeholders.

As a follow-on to the California Energy Commission (CEC) funded, Storage Value Estimation Tool (StorageVET®), DER-VET™ initially focused on standalone energy storage applications. DER-VET™ functionality has expanded to comprise more complex installations such as microgrids, but its applicability to standalone storage (for example, grid-tied systems or commercial batteries used to reduce demand charges) remains and has been enhanced to include imperfect load and price forecasts and other features suggested by users. DER-VET™ has been developed throughout this project and can be downloaded from https://www.der-vet.com/.

Project Purpose and Approach

The goal of this project was to develop DER-VET™, a publicly available, open-source distributed energy resources and microgrid design and valuation tool that optimizes designs based on several critical objectives. DER-VET™ combines a robust technical analysis with economic optimization to aid in designing microgrid and distributed energy resources deployments with maximum benefit from the perspective of multiple stakeholders. This software has been shaped, reviewed, validated, and continuously enhanced by many technical users and stakeholders.

Before DER-VET™, there were no comprehensive analysis tools and distributed energy resources valuation that covered the following key features in an integrated manner: (1) stacked benefit analysis and optimization of grid-tied DER, (2) a reliability- and resilience-based analytical approach, (3) an interface with external analysis tools that enable an integrated value analysis, (4) a simple and intuitive user-interface that enables a multi-scenario analysis to be conducted in a streamlined manner, and (5) a valuation that encompasses multiple stakeholder perspectives.

DER-VET™ is a user-friendly, customizable, open-source modeling tool described as follows:

- The first substantial integration of robust technical analysis and economic optimization to design microgrid and DER deployments with a publicly available, open-source software platform that was made possible through funding from the CEC.
- A multi-purpose model that accommodates three main target user groups: (1) independent planners building their microgrid (including local government planners), (2) utility planners/operators, e.g., Utilities, California Independent System Operator (California ISO), and (3) California Public Utilities Commission and CEC program specialists.
- The first to perform stacked benefit analysis uniquely. DER-VET™ provides an avenue to valuate wholesale market services, transmission and distribution-related services, and customer services.
- Transparently and credibly models the technical attributes of distributed energy resources, including energy storage, solar photovoltaic systems, electric vehicles, demand response technologies, and energy efficiency.

- Calculates the costs and benefits of deploying distributed energy resources and microgrids to different stakeholders.
- Models a range of services that distributed energy resources may provide to the electric grid and to end-use customers.
- Works within a consistent, transparent microgrid analysis framework to compare various technical and economic options and to inform customers, developers, utilities, and regulators.

DER-VET™ addresses technical gaps in the suite of tools grid planners and technology developers use to design and analyze distributed energy resources in utility and micro-grids. Although these tools continue to be powerful aids for designing and engineering grid systems, they were not designed to address the unique strengths and limitations of the wide range of distributed energy resources and the increasing need for resilience and flexibility in the power system. DER-VET™ is based on the project team's extensive experience developing several of these existing tools, as well as the use of such tools in microgrid projects across North America. The DER-VET™ development process leveraged the lessons learned from the StorageVET® project, previously funded by the CEC, especially the feedback from its active users. The tool has been validated with reference distribution feeders and customer loads case studies.

Key Results

Project results and key findings for the development of DER-VET™ are represented as follows:

- Microgrid and distributed energy resource technical modeling framework development
- Microgrid and distributed energy resource projects financial and economic modeling framework development
- DER-VET™ user community acceptance and use
- Use cases used for validating the tool's functionality.

DER Modeling Framework Development

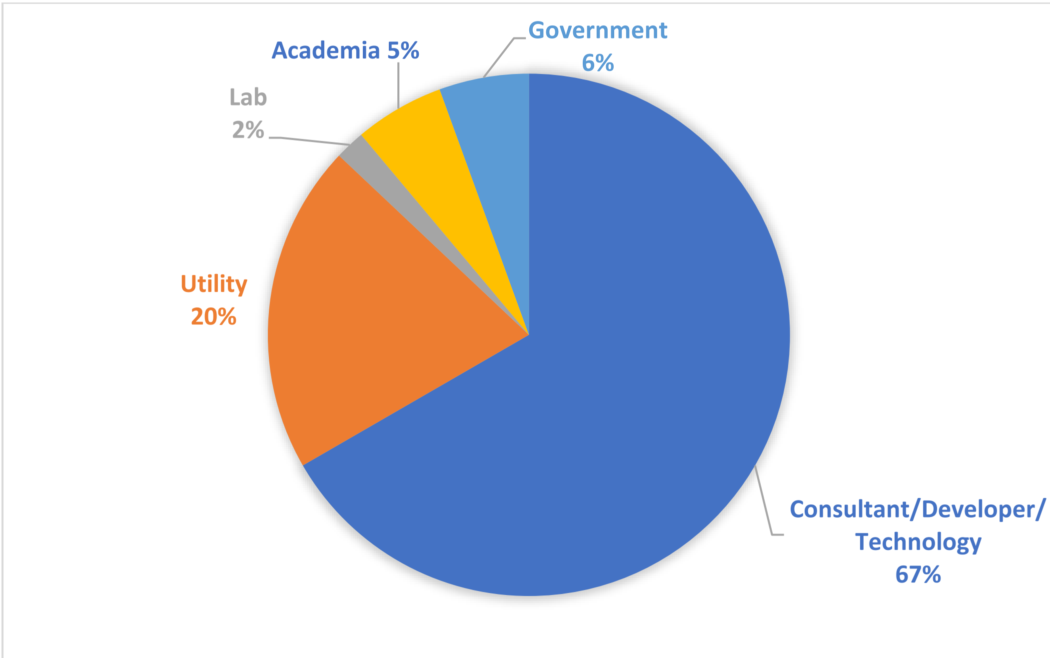
DER-VET™ includes a suite of advanced open-source Python modeling algorithms. A series of individual modules encapsulate the model architecture to enable ease of accessibility, transparency, and validation. DER-VET™ was created to be a microgrid system design and planning tool. It supports the analysis and associated mathematical models of many distributed energy resource technologies to investigate high renewable penetration scenarios. DER-VET™ includes a comprehensive microgrid analysis framework that integrates informal decision-making support and scenario analysis for optimal microgrid design, stacked service valuation, and a multi-perspective cost-benefit analysis.

DER-VET™ User Community Acceptance and Utilization

DER-VET™ was developed to be a publicly accessible, open-source tool for all stakeholders, including customers, technology providers, developers, utilities, and regulators. By

December 2023, DER-VET™ had roughly 1,000 unique users who had downloaded the software. These users span a multitude of organizations. Figure 1 categorizes DER-VET™ user downloads by organization type. Stakeholders visiting the DER-VET™ website are located worldwide and represent 150 countries. The latest version (1.2.3) of DER-VET™ was released in February 2023 and has been downloaded by over 200 unique users.

Figure 1: DER-VET™ User Downloads by Organization Type



Source: EPRI

For over five years, the Electric Power Research Institute (EPRI) has leveraged its public platform, Energy Storage Integration Council, to facilitate over 60 monthly task force meetings to collect stakeholder input for requirements and functionality, beta testing, validation with actual distributed energy resources and microgrid projects, training, ongoing bug fixes, and continuous feature and functionality improvements for DER-VET™. Recent DER-VET™ Energy Storage Integration Council Task Force meeting recordings and presentations can be found on the DER-VET™ website at: www.der-vet.com/esictf. EPRI's developer team has also presented at numerous public workshops and conferences to disseminate learnings to key stakeholders.

Use Cases for Tool Validation

Project results for developing DER-VET™ are illustrated in three primary use cases used for validating the tool's functionality. The first two use cases are customer-sited and owned microgrids designed for customer utility bill reduction and customer resilience objectives, respectively. The third use case is focused on utility-scale microgrids designed primarily for community resilience.

These use cases were selected after a careful review, and they represent practical cases to inform customers, developers, utilities, and regulators. These use cases accommodate the following three target user types:

- Independent customers and third-party microgrid developers
- Utility system planners
- State commissions and regulators

Knowledge Transfer and Next Steps

An important avenue of learning about the tool is through publicly available and easily accessible documentation tailored to different user groups.

Public Website

- Through the website, https://www.der-vet.com/, EPRI displays the most up-to-date information and tool release notes, and it can serve as the centralized location for all the documentation listed below.
- The website can be configured to allow users to collaborate and inform the website's content, including through the DER-VET™ User Forum (https://www.der-vet.com/forum). The website layout allows for intuitive navigation through extensive documentation.
- The website is also the repository of all DER-VET™ public webinar and workshop presentation materials and recordings from the activities listed below.

Documentation

- The DER-VET™ User Guide (https://storagewiki.epri.com/index.php/DER_VET_User_Guide) is provided as a wiki-style document on EPRI's StorageWiki. It is updated continuously with accurate information as newer versions of the software tool are released.
- For end-users, the User Guide contains detailed instructions on installing, using, and troubleshooting DER-VET™. This guide includes installation instructions, the DER-VET™ User Manual, definitions of the terms used in tools, and other topics.
- For researchers and stakeholders interested in the tool's methodology, formulations describing the details of the assumptions and formulations of DER-VET™ are included in the User Guide.
- For user-developers, a Google-style auto-documentation platform captures function or class-level documentation for users who want to develop the code. The codebase benefits from ample technical code comments and a general structure that aims to facilitate future developments of new features.
- For all stakeholders, a Use Case Development effort informs and structures most other technology transfer efforts. A collection of Energy Storage Analysis Case Studies is presented on EPRI's StorageWiki, at: https://storagewiki.epri.com/index.php/Energy_Storage_Analysis_Case_Studies.

Benefits to California

Prior to the development of DER-VET™, many microgrid projects were being deployed based on an ad hoc analysis across disparate approaches and tools, most of which were proprietary. The analysis framework and DER-VET™ give decision makers the tool set necessary to make informed and streamlined deployment decisions based on standardized guidelines. Rather than one-off analyses, DER-VET™ enables the informed deployment of microgrids throughout California and creates the potential for realizing various benefits, both to the grid and to the customers.

The applicants for the CEC Grant Funding Opportunity 17-302, titled "Demonstrate Business Case for Advanced Microgrids in Support of California's Energy and GHG Policies," included economic results like project net present value and break even cost of capital from DER-VET™ as part of their application submitted to the CEC for the task that involved evaluating ratepayer benefits. The objective of the grant funding opportunity was to demonstrate and promote the commercial viability of microgrids across California. The applicants who responded to this grant funding opportunity primarily included a combination of consultants, academia, and independent researchers based in California.

From the utility perspective, the Los Angeles Department for Water and Power (LADWP) performed an in-depth study [1] using DER-VET™ to determine the cost-effectiveness of a 100-megawatt (MW), 400-megawatt-hour (MWh) utility scale distributed energy resource solution paired with a 200 MW PV system in response to Senate Bill 801's requirement that the LADWP de-emphasize gas-fired power generation and increase reliance on renewables.

EPRI also used DER-VET™ to conduct a microgrid study [2] for improving military installations' energy security using lithium-ion battery technology. The objective of this study was to investigate whether distributed energy resource systems can provide the same reliability for a critical load as diesel generators do in the baseline scenario. The reliability performance targets and stacked grid services were investigated at five sites, two of which are in California — The Naval Base Ventura County, and March Air Force Base. The analyses constrained distributed energy resource operations to ensure that the primary reliability service met or exceeded the baseline reliability target at each site. After meeting the reliability target, the modeling goals were set to maximize stacked benefits provided by distributed energy resources at each site to reduce the net cost of serving peak critical load. This microgrid study served as a proof of concept for investigating whether reliance on diesel generators can be reduced by replacing some with distributed energy resource systems.

The direct benefits of well-planned and operated microgrids include reduced electricity costs, lower carbon dioxide (CO_2) emissions, greater reliability through better integration of renewable sources and reduced or avoided outage times, and the potential for additional revenue from customer and grid services such as demand response or ancillary service participation. California ratepayers also benefit from greater reliability and lower costs. DER-VET™ evaluates how microgrid systems could be used as potentially flexible resources, which utilities, through appropriate programs and incentives, can use to support their objectives. In this way, it directly supports California's clean energy and climate goals to achieve net-zero or carbon neutrality by 2045.

As of December 2023, approximately 200 DER-VET™ users have downloaded the tool from various locations within California. The breakdown by organization type is similar to that shown in Figure 1.

Next Steps: Support and Maintenance Strategy

EPRI has developed a support plan for DER-VET™ so that it is fully functional and supported for at least two years from the end date of this CEC project. The ongoing support and maintenance plan extends through at least 2025, and EPRI will continue with regularly scheduled Energy Storage Integration Council DER-VET™ Task Force meetings to allow users to participate in ongoing tool engagements. EPRI aims to develop and maintain DER-VET™ for the foreseeable future. Software issues will be resolved in a timely manner as shortcomings are identified and resolved. New features will be developed from a prioritized list, following recommendations from members, and dictated by funding opportunities and projects.

CHAPTER 1: Introduction

Project Need

A publicly available and transparent tool that supports valuation from different stakeholders' perspectives can enhance the understanding of microgrid value among stakeholders. A better understanding of the value can accelerate the development of microgrid projects with high cost-effectiveness, which aligns with the goals of the California Public Utilities Commission's (CPUC) Electric Program Investment Charge (EPIC) program. A valuation tool with the capabilities outlined by the California Energy Commission (CEC) is a complex piece of software whose development requires considerable human resources and previous experience in performing the types of analyses the tool is meant to perform. Developing the Distributed Energy Resource Value Estimation Tool (DER-VET™) required a team with various backgrounds, such as finance, software engineering, power engineering, optimization, and operations research. The microgrid industry is still nascent, and this EPIC funding fills the void of a valuation tool that enables streamlined and informed decision making to deploy microgrids in competitive or regulated markets through the completed framework for identification and optimization of customer and grid service benefits.

As part of the use case and scenario development, the Electric Power Research Institute (EPRI) team brings together the diverse tools available commercially and, at the same time, provides a platform for ongoing innovation. It cuts across multiple stakeholders and is virtually impossible for individual investor-owned utilities (IOUs) to implement effectively on their own. The completed open-source platform solution directly supports California's state energy goals and provides a foundation for individual customers, communities, and facilities to achieve the maximum value from investments in distributed energy resource (DER) and solar systems.

This completed project significantly reduces the time and costs associated with accurate techno-economic assessments of DER and microgrid applications, which directly supports the CPUC in executing its regulatory role of assessing the solar and DER procurement process and supporting California electricity ratepayers. Public benefit projects in this domain have historically been funded in California through public benefit agencies, such as the CEC, CPUC, and the U.S. Department of Energy. Public funding for a comprehensive microgrid valuation package will create a positive feedback loop, help the CEC promote microgrids, and ultimately make them a widespread solution.

Historical Microgrid Analysis Tool Gaps

Feature and Performance Gaps of Current Tools

Several tools are currently used for microgrid design and analysis, each with advantages and disadvantages. Used together, they can address many of the key concerns related to microgrids. However, there continue to be major gaps in the toolset:

- **Reliability and resilience analysis:** Existing tools focus on the design and operation of microgrids and do not allow systematic analysis and measurement of reliability and resilience in microgrid scenarios. None of the tools provided estimates of the improvement in end-user reliability gained by installing a microgrid at a specific location. The absence of this feature limits the ability to add in potential reliability and resilience benefits from the customer's perspective and the reliability improvements that can be relaxed from the perspective of infrastructure needs.
- **Stacked benefit analysis:** Existing tools do not support stacked benefit analysis that includes distribution system benefits and wholesale market benefits, in addition to end-customer benefits. This shortcoming is crucial since several cost-effective microgrid business cases rely on stacked benefits to be economically feasible.
- **Access to external databases:** Existing tools cannot retrieve data from an external database, such as site weather information, reference load profiles, and wholesale market prices. As a result, the tools require labor-intensive manual input of data.
- **User experience:** Existing tools are often challenging to use for any but the most experienced users. While such tools can, in principle, simulate complex scenarios with many types of DER and configurable options, in practice, the user interface makes this a very time-consuming and unrewarding process. Moreover, most existing tools also do not provide streamlined and easy ways of entering or importing data into the tool, necessitating a significant investment of time and energy in feeding the necessary input data and parameters.
- **Model complexities and approaches used:** There is little consistency in the methods and approaches used within existing tools to determine microgrid sizing and dispatch. The complicated model formulations do not easily lend themselves to review, examination, or further user customization. Furthermore, models are built on different platforms, making them challenging to reconcile.
- **Tool validation:** No tool has been extensively validated, and in some instances, modeled results appear inconsistent given similar input parameters.

Lack of Consistent Microgrid Analysis Framework

Microgrid modeling tools provide a means to conduct technical and economic analysis. However, a tool itself is not enough to conduct a comprehensive analysis. An analyst must also clearly formulate the model so that the results offer an answer to the question being asked — an answer that can be used to support decision making. A *microgrid analysis framework* is akin to a step-by-step guide that includes how to frame the study (defining objectives, scenarios), how to conduct the study (for example, what assumptions need to be made, what data are appropriate to use), how to interpret the results, and how to conduct a proper cost-benefit assessment. Although there have been partial efforts to establish a microgrid analysis framework, no widely approved comprehensive framework exists today. In particular, the past efforts on frameworks have not considered the perspectives of different microgrid stakeholders.

Lack of Locational Selection and Screening

Current tools do not include geospatial screening and analysis for potential microgrid site identification and prioritization. As a result, they cannot identify and assess the potential value of microgrids by geographic location and use case (critical facility, high penetration renewables, others) and consider whether these locations are within constrained areas of the grid or in disadvantaged communities and whether the benefits would apply to the community.

EPRI's Novel Approach to Microgrid Analysis Tools

The objectives of this project are focused on the development of: (1) a powerful and user-friendly microgrid assessment tool, (2) a comprehensive microgrid analysis framework, and (3) a novel approach to microgrid location screening/selection to help streamline deployment across the state of California. When applied together, they can be used to maximize potential benefits to end-customers (including disadvantaged communities), the distribution grid, and the bulk system. At the same time, they will reduce the soft costs of microgrid project development and enhance engineering capabilities by simplifying the techno-economic analysis of prospective microgrid projects. The microgrid assessment tool is further broken down into innovations surrounding the modeling platform and the software platform.

Integrated Analysis Framework

The completed DER-VET™ tool is accompanied by a comprehensive microgrid analysis framework that is adapted from EPRI's existing Integrated Grid Cost-Benefit Analysis (CBA) [3] and the lessons learned from EPRI's role as the chief architect and lead developer of StorageVET® (www.storagevet.com). The *integrated analysis framework* acts as a blueprint that will integrate informed decision-making support and scenario analysis for optimal microgrid design, stacked service valuation, operational strategies, locational screening, and a multi-perspective CBA.

Microgrids pose challenges for standardized economic assessment because of their variety of completed arrangements. As such, the completed microgrid analysis framework will outline the contextual complexities and questions surrounding microgrid valuation and highlight how the completed objective(s) of individual microgrid projects inform their CBA.

A CBA framework establishes a list of impacts or effects that will be included in an analysis. It also specifies the perspective that an analysis will assume. Both elements are inputs to the completed microgrid modeling tool. The cost and benefit items are often expressed as specific impacts, or physical changes caused by a microgrid project, whether directly or indirectly. The framework seeks to outline a sequence of steps or modules intended to quantify these economic factors to assist in decision making regarding a microgrid project.

The analysis framework will also address the key issues identified based on EPRI's experience conducting microgrid techno-economic assessments. If high reliability and resilience are not the primary objectives of a microgrid, advanced energy communities or other coordinated, complementary DER deployments may be more cost-effective. A common analysis framework and toolset can consistently support understanding multiple objectives and portfolios.

Model Architecture and Algorithms

The completed open-source microgrid valuation and optimization software tool DER-VET™ includes a suite of advanced modeling algorithms that are open source and a model architecture that enables accessibility, transparency, and validation. The model architecture outlines the relationship between these algorithms encompassed within individual modules: (1) Scenario Manager, (2) DER Sizing, (3) Optimizer and Scheduler, (4) Locational Screening, (5) Resilience and Reliability Improvement, (6) Stacked Benefits, and (7) Cost-Benefit Assessment. DER-VET™ enhances usability and supports practical and timely applications of completed microgrid use cases. DER-VET™ was designed to be:

- A multi-purpose model that accommodates three main target user groups: (1) independent planners building their microgrid (including local government planners), (2) utility planners/operators, for example, Utilities and the California Independent System Operator (California ISO), and (3) CPUC and CEC program specialists.
- A commercial microgrid system design and planning tool that supports the analysis and the associated mathematical models of DER — including distribution-connected distributed generation resources, energy efficiency, energy storage (ES), electric vehicles, and demand response technologies — that provide solutions of non-wire alternatives and high renewables penetration scenarios within microgrid applications.

The tool is validated (described as part of the Technical Approach) with case studies of reference customer loads. These case studies and scenarios will form the basis for developing application guidelines for microgrids in California that focus on the areas with maximum value for customers and society. Locational selection and screening demonstrate a novel approach to microgrid screening and siting to maximize locational value that is optimized based on feeder hosting capacity, local grid reliability, energy usage intensity, critical facility, high penetration renewables, and CalEnviroScreen for environmental impact and benefits to disadvantaged communities.

Software Platform

The completed tool delivers a software platform with a streamlined approach to estimate the benefits and costs of microgrids in diverse user-configured cases. Users can develop cases using a simplified Graphical User Interface (GUI) or work within a Python-based Command-line Interface (CLI) environment with more advanced features. Some of the features of DER-VET™'s software platform are:

- DER-VET™ achieves modularity, interoperability, transparency, and public availability. Regarding software innovation, this integrated platform is implemented as an interoperable, open-source tool to facilitate widespread use by the entire technical community.

- DER-VET™ enables: (1) users to access complex and locational specific retail tariff structures directly with an application programming interface connection to the Open Energy Information Database and (2) connectivity with external specialized tools such as PVsyst, OpenDSS, GridLab-D, CYME, System Advisor Model (SAM) via their application programming interface that can enhance and provide a greater level of accuracy/detail of certain modeled components, and (3) automating the analysis processes (for example, batch process) opening up possibilities to integrate with other tools (for example, a power flow solver).
- DER-VET™ contains an intuitive graphical user interface that enhances usability, reducing the tool's learning curve and analysis time.
- DER-VET™ is available in CLI Python environment and as a GUI desktop application. New versions are available as downloadable applications to address different and conflicting user requirements for accessibility and security.
- Finally, DER-VET™ leverages the lessons learned from the StorageVET® project, previously funded by the CEC. In particular, it considers all the thoughtful feedback received from active users of the StorageVET® tool.

CHAPTER 2: Project Approach

Key Policy, Planning, and Market Information Relevant to DER-VET™ Development

The project team has amassed key policy, planning, and market information relevant to DER-VET™'s development and leveraged it as a guide to build up DER-VET™'s specifications, architecture, software implementation, and reference cases for validation. This content is accessible on EPRI's StorageWiki and is a publicly available website (https://storagewiki.epri.com/index.php/Energy_Storage_Analysis_Case_Studies). This wiki page builds on earlier documentation, providing policy and market background, and technical details on a range of California DER and ES applications that are transmission-connected, distribution-connected, or customer-sited.

Overview of DER-VET™ Capabilities

DER-VET™ provides a highly detailed representation of many DER technologies, grid, market, customer services, and project-specific CBAs for communicating multi-perspective financial and economic results. Some of the key capabilities of DER-VET™ are listed below, and described in detail in Appendix B:

- Dispatch Optimization
- Service Stacking
- Energy Reservation Stacking
- Size Optimization
- Customizable for Location, Sizing, and Use Cases
- Data Options
- Compatibility with Other Tools
- Co-optimized DER Portfolio Sizing to Address Microgrid Reliability and Customer Resilience
- Degradation
- DER Project-Specific CBA

Comparison of DER-VET™ with StorageVET®

DER-VET™ is the next generation of EPRI's ES and DER valuation tool. It builds and expands on the functionality, accessibility, transparency, and success of the previous two iterations of EPRI's storage valuation tools, the Energy Storage Valuation Tool and the Storage Value Estimation Tool (StorageVET® 1.0 & 2.0). The following is a comparison of various DER-VET™ functionalities with its StorageVET® predecessor, and a comparison summary is shown in Table 1.

- **Multiple-technology optimization**: DER-VET™ allows multiple DER technologies to be modeled within a facility and community microgrid. Whereas previous EPRI tools allowed for a single storage system potentially paired with solar or other energy resources, DER-VET™ allows for a flexible combination of DER.

- **Reliability and resilience**: DER-VET™ is built with microgrids and islanding in mind. A key benefit of many microgrids is their ability to supply power to loads during grid outages. DER-VET™ adopts reliability approaches designed by EPRI researchers for military microgrids, where critical load coverage is paramount, and a high degree of reliability is required. The approach considers the likelihood of any piece of microgrid equipment to fail and the ability of the remaining pieces of equipment to cover critical load. This approach considers many potential grid outages with different start times and durations to ensure that the microgrid design is robust under a potential outage.
- **Size optimization**: A final key distinction of DER-VET™ from previous EPRI tools is its ability to automatically determine the best size for many DERs by including their size variables directly in its optimization or by performing analyses on different combinations of DER sizes and testing the reliability and economic results. Size optimization relies on a few things that dispatch optimization is not. These include:
    - Value that increases with size (both power and energy capacity) and incorporates diminishing returns. If the value of a DER increases linearly (or faster) with size and does not incorporate diminishing returns, then a size optimization may not be able to find the optimal size because it could be unrealistically at infinity. An example of this case is ancillary service market participation with a price-taker model. In this arrangement, the value of a DER providing a market service will be proportional to its size. If a small DER would be profitable, so would an indefinitely large one, so the optimum size would seem to be infinite. So, there needs to be some limiting factor or diminishing returns on the size of the DER that results in a realistic size below infinity.
    - A high-fidelity linear cost calculation that increases with all sizing variables. The cost function needs to fit in the mixed integer linear program, so there are limits on how it can be implemented. Additionally, specifying a complicated cost function in general terms in software can present usability challenges. For a battery ES system, the cost scales linearly with the system's power and energy capacity, and fixed cost parameters. For other DERs, which are handled as discrete units, the cost per unit is taken.

Table 1: StorageVET® and DER-VET™ Comparison

	Capability	StorageVET® 2.0	DER-VET™
Technologies	Battery	X	X
	Compressed Air Energy Storage (CAES)	X	X
	PV (photovoltaic)	X	X
	Internal combustion engine generator	X	X

	Capability	StorageVET® 2.0	DER-VET™
	Controllable load		X
	Electric vehicles		X
	Energy efficiency		X
	Thermal storage		X
	Combustion turbine		X
	Combined heat and power		X
Services	Day ahead energy time shift	X	X
	Frequency regulation	X	X
	Spinning reserve	X	X
	Non-spinning reserve	X	X
	Demand charge management	X	X
	Retail energy time shift	X	X
	User-defined service	X	X
	Asset upgrade deferral	X	X
	Reliability	X	X
	Demand response	X	X
	Resource adequacy	X	X
	Load following	X	X
Analysis	Dispatch optimization	X	X
	Size optimization		X
	Multiple technologies		X
	Non-perfect foresight optimization		X
	CalEnviroScreen		X
	Advanced CBA		X
Interface	Python CLI	X	X
	Desktop Application/GUI		X

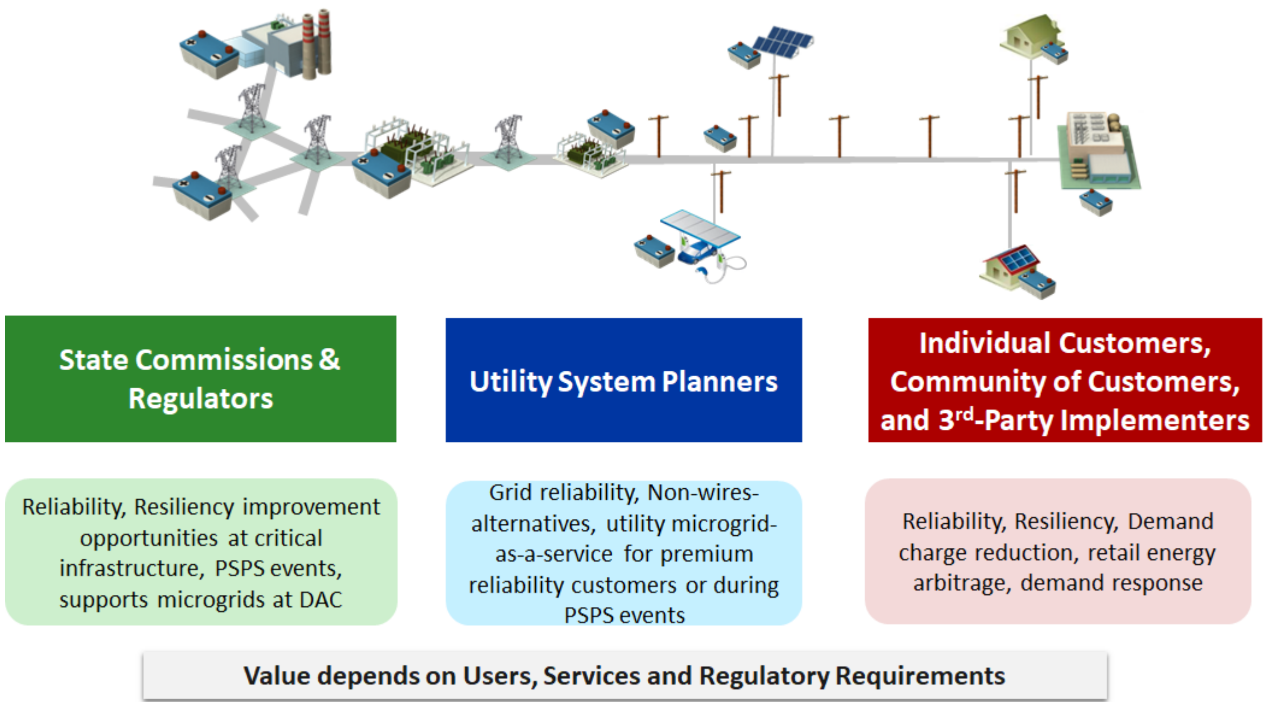
Source: EPRI

CHAPTER 3: Results

Project results for the development of DER-VET™ are illustrated in the following use cases, which are used to validate the tool's functionality. These use cases were selected after careful review and represent practical cases to inform customers, developers, utilities, and regulators (Figure 2). These use cases accommodate the following three target user types:

- State commissions and regulators
- Utility system planners
- Independent customers and planners

Figure 2: Multi-Perspective DER-VET™ Users and Use Cases



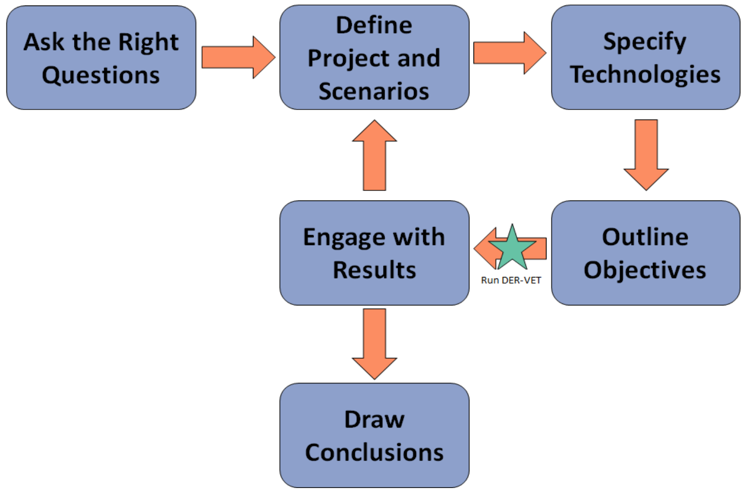
PSPS = public safety power shutoff
DAC = disadvantaged community
Source: EPRI

The following use cases will be used to validate the core elements of DER-VET™:

- Enable integrated decision support and scenario analysis for optimal microgrid design, operational strategy, and location screening.
- Enable multiple value streams based on different data availability levels, including reliability and resilience analysis.
- Enable a microgrid valuation methodology that can address different stakeholder perspectives.

Figure 3 shows a flow diagram of the DER-VET™ validation case study plan.

Figure 3: Validation Case Study Plan



Source: EPRI

Use Cases and Scenarios

The three major use cases are briefly described in Table 2. The first two use cases are customer-sited and customer-owned microgrids, designed for customer utility bill reduction and customer resilience objectives, respectively. The third use case is focused on utility-scale microgrids designed primarily for community resilience. All three use cases correspond to the end customer as the primary stakeholder. More details on the use case goals, objectives, and the metrics used for comparison are included in the table.

Table 2: Use Case List and Description

Case List	Goals (WHY)	Objectives (WHAT)	Outcome (HOW)
Use case #1	The customer DER portfolio is sized for bill reduction and provides customer resilience as an additional benefit. Check whether the DER portfolio sized for bill reduction can also provide backup power to improve customer resilience.	Primary Objective: Customer bill reduction. DER sized for this service. Secondary objective: evaluate reliability in terms of load coverage.	Metrics: - *Net Present Value (NPV) comparisons (CBA), payback period, cost normalization (e.g., $ per kilowatt [kW] of DER installed capacity), avoided costs per service.* - *Critical load coverage comparisons ($ per kW-yr)* - *Critical load coverage comparisons ($ per kW-yr)* - *Reliability performance based on targets and load coverage curve comparison.*

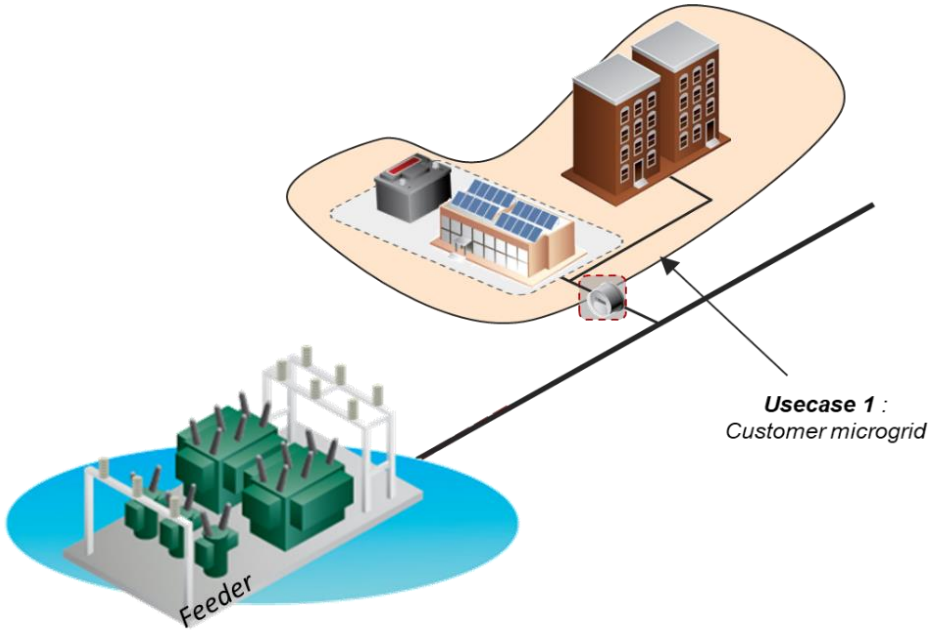
Case List	Goals (WHY)	Objectives (WHAT)	Outcome (HOW)
Use case #2	The customer DER portfolio is sized for reliability and to help reduce customer bills. Check whether the net cost of operation is the same/less than the conventional diesel generator-based microgrid.	Primary objective: reliability/ resilience. Secondary objective: customer bill reduction.	Metrics: - *Critical load coverage comparisons ($ per kW-yr)* - *Reliability performance based on targets and load coverage curve comparison.* NPV comparisons (CBA), pay-back period, cost normalization (e.g., $ per kW of DER installed capacity), avoided costs per service.
Use case #3	Improve community resilience during crises (hurricanes, wildfires, PSPS events) with community and customer PV and storage assets.	Primary objective: community resilience and improve grid reliability. Secondary objective: market participation.	Metrics: - *Critical load coverage comparisons ($ per kW-yr)* - *Reliability performance based on targets and load coverage curve comparison.* NPV comparisons (CBA), pay-back period, cost normalization (e.g., $ per kW of DER installed capacity), avoided costs per service

Source: EPRI

Use Case #1: Economic DER Sizing and Ex Post Facto Reliability Calculation

The objective of the design is to reduce the net cost of the microgrid. As a secondary benefit, the designed microgrid is expected to provide reliability service and backup for a fraction of the site load during a grid outage. Use Case 1 is the microgrid design for the facility shown in Figure 4.

Figure 4: Microgrid Design Overview for Use Case 1



Source: EPRI

Case Description

Base Case

The business as usual operation of the facility is defined as the Base Case in Use Case 1. The base case doesn't comprise any DER, and the total load in the facility is served entirely by the power imported from the utility. Hence, during grid outages, the critical load won't be served.

Investment Case

In the investment case, a microgrid comprising DER is designed. The microgrid is operated with the primary objective of reducing the site's utility bill during grid-connected days and a secondary objective of supporting the critical load available on-site during outages. The baseline's key economic and reliability metrics are used to evaluate the investment case. Three different configurations are analyzed to better understand the impact of each type of DER.

Configuration #1: ES Only

The first configuration involves using an ES system to reduce the customer's bill during grid-connected days and serve the critical load during outage hours. For the given site, the ES system is sized using DER-VET™ to reduce the net cost of serving the critical load.

Configuration #2: PV+ES System

In the second configuration, the ES generation mix is designed using DER-VET™ to reduce the net cost of serving the critical load, using a combination of direct-current (DC) coupled PV and an ES system during grid-connected days. The PV size is predetermined to be

1,000 kW, and the optimal ES size is determined using DER-VET™ to minimize the cost of operating the microgrid. Like the first configuration, the co-located PV+ES system serves the critical load during outage hours.

Configuration #3: PV + ES System + Diesel Generators

The last configuration involves the addition of diesel generators to support the critical load in addition to the PV and ES systems. California's regulatory policies prevent diesel generators from being used for bill reduction, so their usage is limited to outage days to serve the critical load. During the grid connected days, the co-located PV and ES systems help reduce the customer's utility bill. In other words, the grid connected day operation of configuration 3 is like the grid connected day operation of configuration 2.

The DER operation schedule for the various configurations is summarized in Table 3.

Table 3: DER Operation Overview for Use Case 1

Hours	Configuration 1	Configuration 2	Configuration 3
Grid connected — bill reduction service	ES	PV+ES	PV+ES
Outage — reliability service	ES	PV+ES	PV+ES+DG

Source: EPRI

Assumptions and Initial Conditions

All DERs considered are assumed to be available during the entire duration of the outage. The diesel generator is assumed to have sufficient fuel capacity to last the duration of the outage.

Performance Objectives and Metrics

Design Summary

The kilowatt-hour (kWh) design summary of the investment case is provided in Table 4.

Table 4: Use Case 1 Microgrid Design Summary

	Base Case	Configuration 1	Configuration 2	Configuration 3
ES	N/A	1,993 kW 11,958 kWh	1,825 kW 10,950 kWh	1,825 kW 10,950 kWh
PV	N/A	N/A	1,000 kW	1,000 kW
Generators	N/A	N/A	N/A	2 × 750 kW

Source: EPRI

Cost Summary

Based on the comparative analysis of the base case and investment cases, a breakdown summary of owning and operating the microgrid is provided in Table 5. It should be noted that the economic benefit of serving the critical load during outages is not valued for this analysis.

Table 5: Cost Breakdown for Use Case 1 (21-year NPV)

	Base Case	Configuration 1	Configuration 2	Configuration 3
ES Capital Cost	$0	$4,583,900	$4,197,500	$4,197,500
ES O&M Cost	$0	$280,822	$257,150	$257,150
PV Capital Cost	$0	$0	$1,660,000	$1,660,000
Generator Capital Cost	$0	$0	$0	$1,125,000
Utility Bill	$68,889,014	$63,626,525	$61,703,761	$61,703,761
Total Cost	**$68,889,014**	**$68,491,247**	**$67,818,411**	**$68,943,411**

Source: EPRI

The reduction in the cost of serving the load in the facility can be contributed primarily to the reduction in the utility bill. A net reduction comparative analysis of the total microgrid operational cost of the base case and investment case is summarized in Table 6. It is observed that configurations 1 and 2 have a lower microgrid operational cost than the base case. Since the diesel generators are only used for outage hours and not during grid connected days, the total microgrid operational cost is higher in configuration 3 than in the base case.

Table 6: Net Reduction in Cost for Use Case 1 as Compared to the Base Case

	Configuration 1	Configuration 2	Configuration 3
ES Capital Cost Reduction	($4,583,900)	($4,197,500)	($4,197,500)
ES O&M Cost Reduction	($280,922)	($257,150)	($257,150)
PV Capital Cost Reduction	$0	($1,660,000)	($1,660,000)
Generator Capital Cost Reduction	$0	$0	($1,125,000)
Utility Bill Reduction	$5,262,489	$7,185,253	$7,185,253
Total Cost Reduction	**$397,767**	**$1,070,603**	**($54,397)**

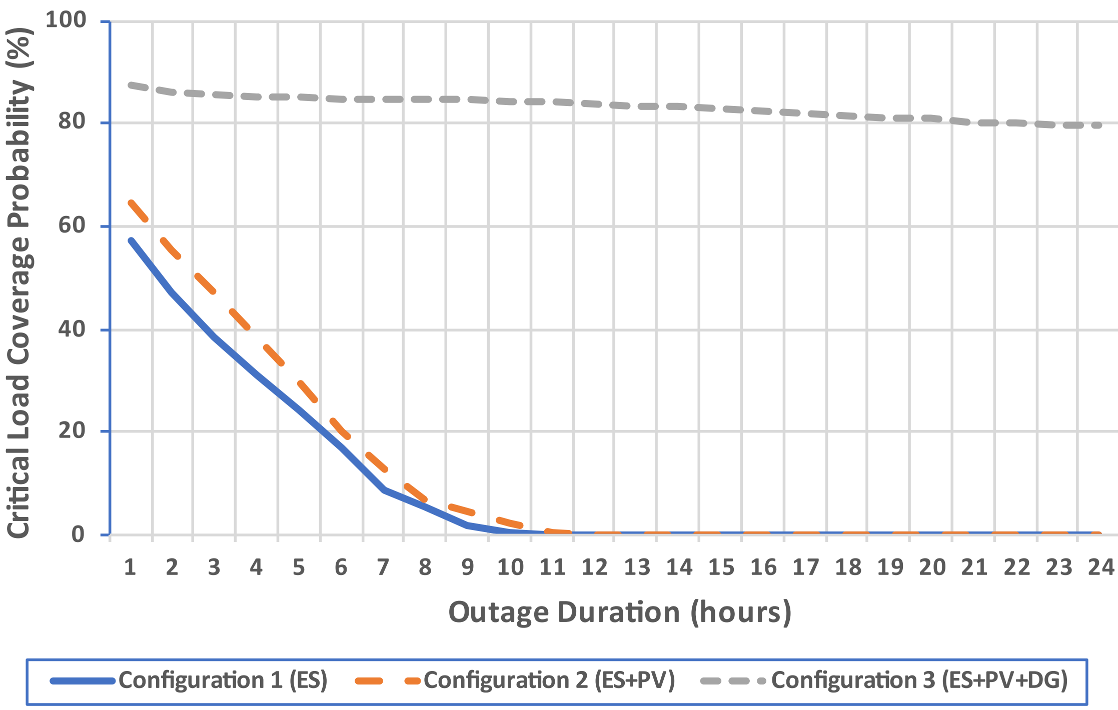
Source: EPRI

Post-Reliability Analysis, State of Charge (SOC) Reservation

Investment Case

The reliability performance of the different investment case configurations is illustrated in Figure 5. It can be observed that configuration 3, which involves a combination of ES, PV, and diesel generators, provides a significantly higher reliability performance than configurations 1 and 2.

Figure 5: Critical Load Coverage Curve for the Investment Case



Source: EPRI

Key Lessons Learned

DERs were configured for an economic objective, that is, to minimize the net cost of operating a microgrid. Reliability was calculated as an ex post facto operation for each configuration. A base case configuration was analyzed first, which involved serving the facility load with the power from the grid. Then a microgrid-based investment case with DER was analyzed. The DER-based microgrid configuration provided a lower net cost than the base case. In addition to reducing the cost of serving critical load, the microgrid also enabled serving critical load during grid outages.

Use Case #2: Validate Behind the Meter DER Sizing for Reliability and Customer Bill Reduction

In this case study, behind the meter DERs are optimally sized and operated primarily for a reliability objective, specified as the fixed probability percentage of covering the critical load profile for a given duration, for example, 100 percent critical load coverage for any four-hour outage. Besides providing the specified reliability service, the microgrid and the DER capacity are used for bill reductions. The microgrid design overview is the same as in Use Case 1 (Figure 4).

Case Description

Base Case

The business as usual operation of the facility is defined as the base case in Use Case 2. The base case does not comprise any DER, and the total load in the facility is served solely by utility grid power. Hence, site and critical loads are not served during an outage.

Investment Case

In the investment case, a microgrid comprising DER is designed. The microgrid is operated with the primary objective of protecting the critical load during an outage. Besides enabling the reliability objective, the DERs reduce the site's utility bill during grid-connected days. The key economic and reliability metrics of the baseline case are used to evaluate the investment case. Three different DER configurations are analyzed to better understand the impact of each type of DER.

Configuration #1: ES Only

The first configuration involves using an ES system to meet the reliability objective and reduce the customer's bill during grid-connected days. For the given site, the ES-based microgrid is sized and operated using DER-VET™ to minimize the net cost of serving the critical load.

Configuration #2: PV + ES System

In the second configuration, ES and PV are designed to meet the reliability objective. The PV size is predetermined to be 1000 kW, and the optimal ES size is determined using DER-VET™. Like the first configuration, the co-located PV+ES system will help reduce the customer's bill during grid-connected days.

Configuration #3: PV + ES System + Diesel Generators

The last configuration involves the addition of diesel generators to support the critical load in addition to the PV and ES systems. ES, PV, and diesel generators are optimally sized to meet the reliability objective during a grid outage.

California's regulatory policies prevent diesel generators from being used for bill reduction so their usage will be limited to islanded days to serve the critical load. During the grid connected days, the co-located PV and ES system will help reduce the customer's utility bill.

The DER operation schedule for the various configurations is summarized in Table 7.

Table 7: DER Operation Overview for Use Case 2

Hours	Configuration 1	Configuration 2	Configuration 3
Outage — reliability service	ES	PV+ES	PV+ES+DG
Grid connected — bill reduction service	ES	PV+ES	PV+ES

Source: EPRI

Assumptions and Initial Conditions

The assumptions and initial conditions for this use case are like those in Use Case 1. The same site data, DER parameters, PV, and load profile are considered for this study, too.

Performance Objectives and Metrics

Design Summary

DER-VET™ design summary results are summarized in Table 8.

Table 8: Use Case 2 Microgrid Design Summary

	Base Case	Configuration 1 ES	Configuration 2 ES+PV	Configuration 3 ES+PV+DG
Energy Storage	N/A	2.5 MW 9.74 MWh	2.3 MW 8.55 MWh	0.8 MW 2.55 MWh
Photovoltaics	N/A	N/A	1 MW	1 MW
Diesel Generators	N/A	N/A	N/A	2 × 750 kW

Source: EPRI

Cost Summary

Based on the comparative analysis of the baseline and investment configurations, a breakdown summary of owning and operating microgrids for different cases is provided in Table 9.

Table 9: Cost Breakdown for Use Case 2 (21-year NPV)

	Base Case	Configuration 1 ES	Configuration 2 ES+PV	Configuration 3 ES+PV+DG
Energy Storage Capital Cost	$0	$4,495,000	$3,980,900	$1,280,900
Energy Storage O&M Cost	$0	$362,828	$324,502	$113,146
PV Capital Cost	$0	$0	$1,660,000	$1,660,000
Generator Capital Cost	$0	$0	$0	$1,125,000
Utility Bill	$68,889,014	$66,810,452	$64,794,902	$65,032,354
Total Cost	**$68,889,014**	**$71,668,220**	**$70,760,304**	**$69,211,400**

Source: EPRI

A net reduction comparative analysis is provided in Table 10.

Table 10: Net Reductions in Cost for Use Case 2 as Compared to the Base Case

	Configuration 1 ES	Configuration 2 ES+PV	Configuration 3 ES+PV+DG
Energy Storage Capital Cost Reduction	($4,495,000)	($3,980,900)	($1,280,900)
Energy Storage O&M Cost Reduction	($362,828)	($324,502)	($113,146)
PV Capital Cost Reduction	$0	($1,660,000)	($1,660,000)
Generator Capital Cost Reduction	$0	$0	($1,125,000)
Utility Bill Reduction	$2,078,562	$4,094,112	$3,856,660
Total Cost Reduction	**($2,779,266)**	**($1,871,290)**	**($322,386)**

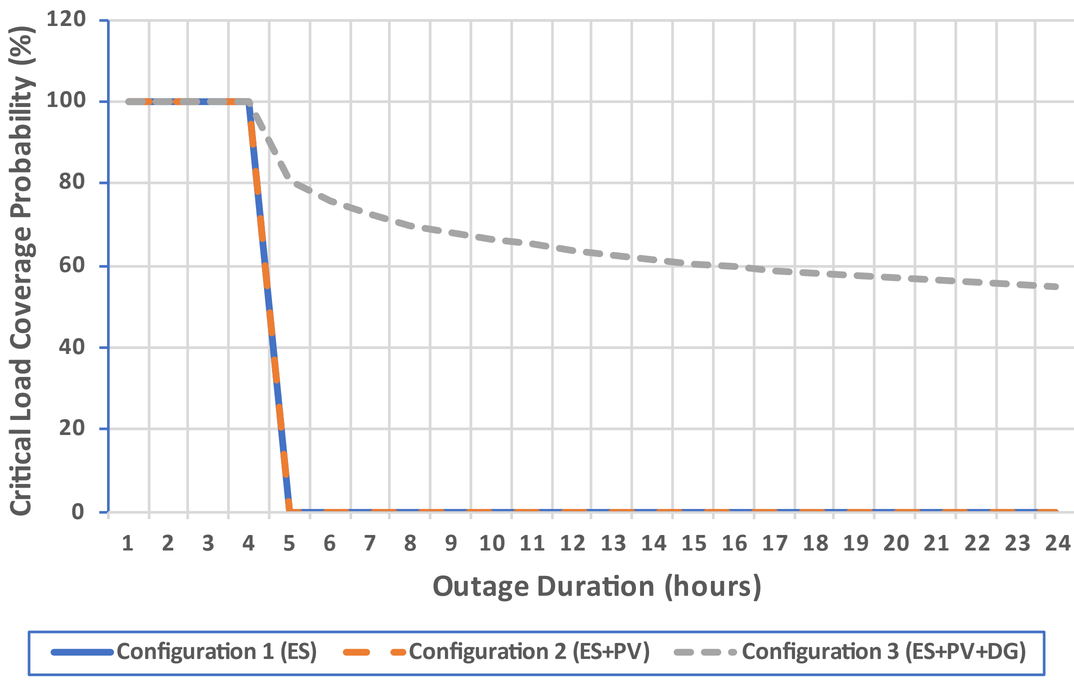
Source: EPRI

Post-Reliability Analysis, SOC Reservation

DER Sizing for Reliability

The reliability performance of the different configurations is described in Figure 6. Reliability target hours for this use case is four hours and all three microgrid scenarios meet the primary target. It can be observed that the probability of covering the critical load for any four-hour outage is 100 percent.

Figure 6: Critical Load Coverage Curve for Use Case 2



Source: EPRI

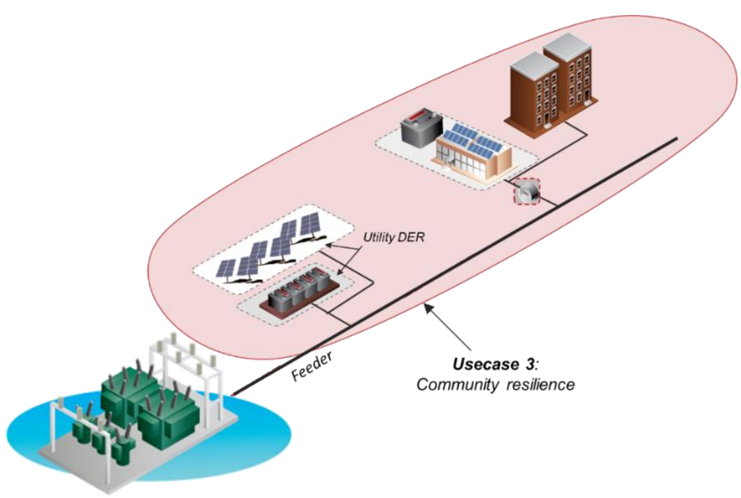
Key Lessons Learned

This section is focused on behind the meter DERs being optimally sized and operated primarily to meet a reliability objective. A 100 percent reliability target for four hours was assumed in this case study. Three microgrid configurations with different DER portfolios were designed. All three configurations met the primary objective. The secondary benefit and the total cost of the microgrids were different. This case study demonstrated the differences between the three microgrid configurations.

Use Case #3: Microgrid Sizing to Improve Community Resilience

Utilities in California strive to maintain high indices for power-quality and reliability. Yet, recent events show that 100 percent reliance on utility power sources may not always be sufficient. To avoid wildfires, in 2019, PSPS events in California left millions of customers without power for days (weeks in some counties). Other natural disasters, like tornadoes and hurricanes, can require a long time to restore power to affected customers. These inevitable planned and unplanned outages can be very expensive, depending on when and where they occur. In this section, DER-VET™ is used to design microgrids to protect large communities from outages and to increase their power supply resilience (Figure 7). The primary objective of the microgrid design is to provide load coverage during outages. To reduce the net costs of the microgrids, its assets can participate in market services to generate additional revenue. The metrics used in this microgrid design are reliability performance curves — to ensure that it has met the desired target and NPV of the microgrid — considering total costs and benefits.

Figure 7: Use Case 3 Involving Resilience Improvement at the Community Level



Source: EPRI

Scenarios

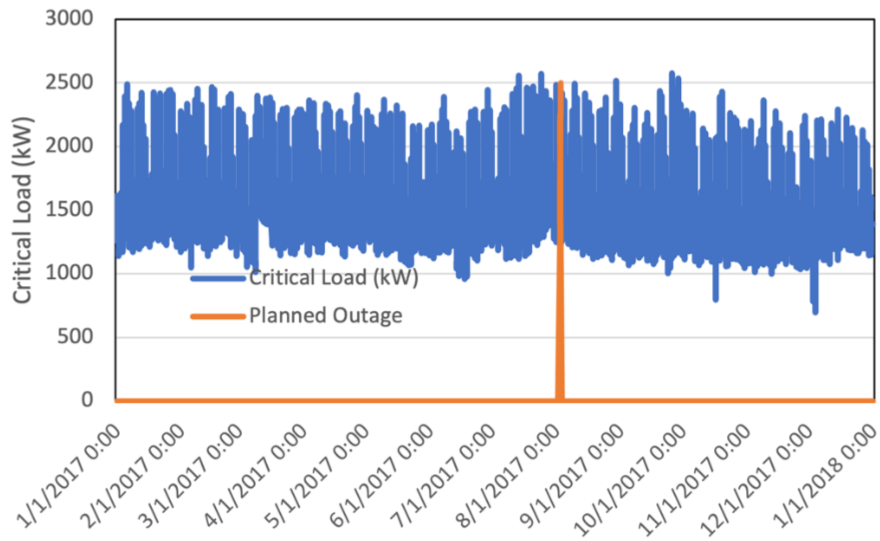
Scenario #1: Community Microgrid Design for Planned Outage Events

The first scenario is DER sizing for planned outage events like PSPS. For any given outage event, the primary objective of the microgrid design is to serve the critical load. The ES

SOC is reserved 100 percent during the planned outage event. At other times during the year, ES and other DER resources can participate in market services.

For this study, a 24-hour window in August, as shown in Figure 8, is assumed to be when a four-hour planned outage could occur. The microgrid is designed for this potential outage event. The worst case four-hour outage, which has the highest energy requirement of all four-hour outages, happens during this period.

Figure 8: Critical Load Served During a PSPS Event



Source: EPRI

Scenario #2: Community Microgrid Design for Unplanned Outage Events

The second scenario is a microgrid design to improve reliability for unplanned outages that can occur at any time and does not include PSPS events. Energy storage's SOC and DER resources are always reserved to support critical loads. After ensuring that the reserved DER resources can provide specified reliability performance, the DER can participate in market services. The reliability target for covering unplanned outages is four hours.

Assumptions and Initial Conditions

The assumptions and initial conditions for this use case are like those in Use Case 1. The same site data, DER parameters, PV, and load profile are considered for this study, too.

Scenario #1: Performance Metrics

Design Summary

DERs are sized to cover the specified planned outage event using DER-VET™. Design results are summarized in Table 11. The reliability target for this use case is four hours and all three microgrid scenarios meet the primary target.

Table 11: Microgrid Design Summary for Use Case 3 (Scenario 1)

	Configuration 1 ES	Configuration 2 ES+PV	Configuration 3 ES+PV+DG
Energy Storage	2.25 MW 42.68 MWh	2.025 MW 40.38 MWh	0.525 MW 4.50 MWh
Photovoltaics	N/A	1 MW	1 MW
Diesel Generators	N/A	N/A	2 x 750 kW

Source: EPRI

Cost Summary

Based on the comparative analysis of the baseline and investment cases, a breakdown summary of owning and operating microgrids for different configurations is provided in Table 12.

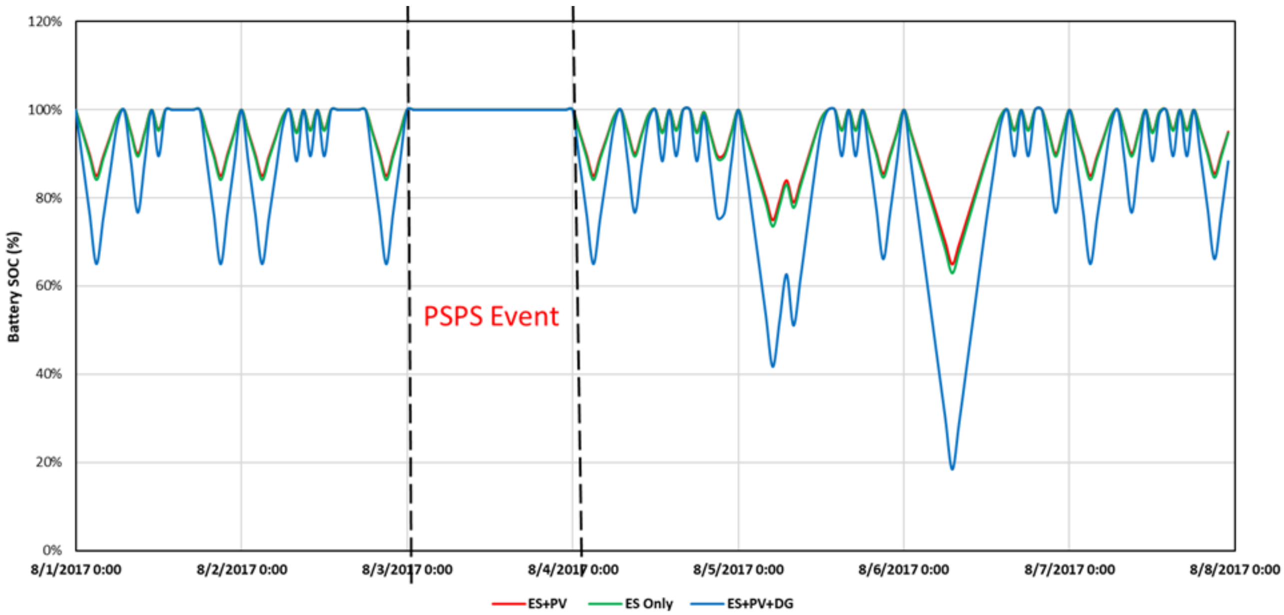
Table 12: Cost Breakdown for Use Case 3 (Scenario 1)

	Configuration 1 ES	Configuration 2 ES+PV	Configuration 3 ES+PV+DG
Energy Storage Capital Cost	$12,475,050	$11,716,000	$1,545,000
Energy Storage O&M Cost	$317,880	$285,331	$73,975
PV Capital Cost	$0	$1,660,000	$1,660,000
Generator Capital Cost	$0	$0	$1,125,000
21-year Utility Bill	$68,889,014	$68,889,014	$68,889,014
Market Participation Revenue	($2,775,468)	($2,973,764)	($1,141,220)
Total Cost	**$78,906,476**	**$79,576,581**	**$72,151,769**

Source: EPRI

Since the primary objective of this use case is to serve the critical load during PSPS events, a power and energy reservation constraint is enforced over 24 hours correspond-ding to August 3 for the three microgrid investment cases. During this 24-hour period, DER assets don't provide any other service and will be reserved exclusively for serving the critical load. This is illustrated in Figure 9 wherein the DER system's SOC is maintained at 100 percent over the course of the day during the PSPS event.

Figure 9: SOC Profile (168 hours) of the DER System for Different Microgrid Configurations



Source: EPRI

Scenario #2: Performance Metrics

Design Summary

For a given reliability target of four hours of any outage that can happen in a year, microgrid design results are summarized in Table 13.

Table 13: Microgrid Design Summary for Use Case 3 (Scenario 2)

	Base Case	ES	ES+PV	ES+PV+DG
Energy Storage	N/A	2.5 MW 9.74 MWh	2.3 MW 8.55 MWh	0.8 MW 2.55 MWh
Photovoltaics	N/A	N/A	1 MW	1 MW
Diesel Generators	N/A	N/A	N/A	2 × 750 kW

Source: EPRI

Cost Summary

Based on the comparative analysis of the baseline and investment cases, a cost breakdown summary of owning and operating microgrids for different cases is provided in Table 14. It can be observed that all the scenarios result in a higher net cost than the Base Case.

Table 14: Cost Breakdown for Use Case 3 (Scenario 2)

	Configuration 1 ES	Configuration 2 ES+PV	Configuration 3 ES+PV+DG
Energy Storage Capital Cost	$4,495,000	$3,980,900	$1,280,900
Energy Storage O&M Cost	$303,092	$324,502	$113,146
PV Capital Cost	$0	$1,660,000	$1,660,000
Generator Capital Cost	$0	$0	$1,125,000
21-year Utility Bill	$68,889,014	$68,889,014	$68,889,014
Market Participation Revenue	($2,306,404)	($2,538,846)	($1,399,828)
Total Cost	**$71,380,702**	**$72,315,570**	**$71,668,232**

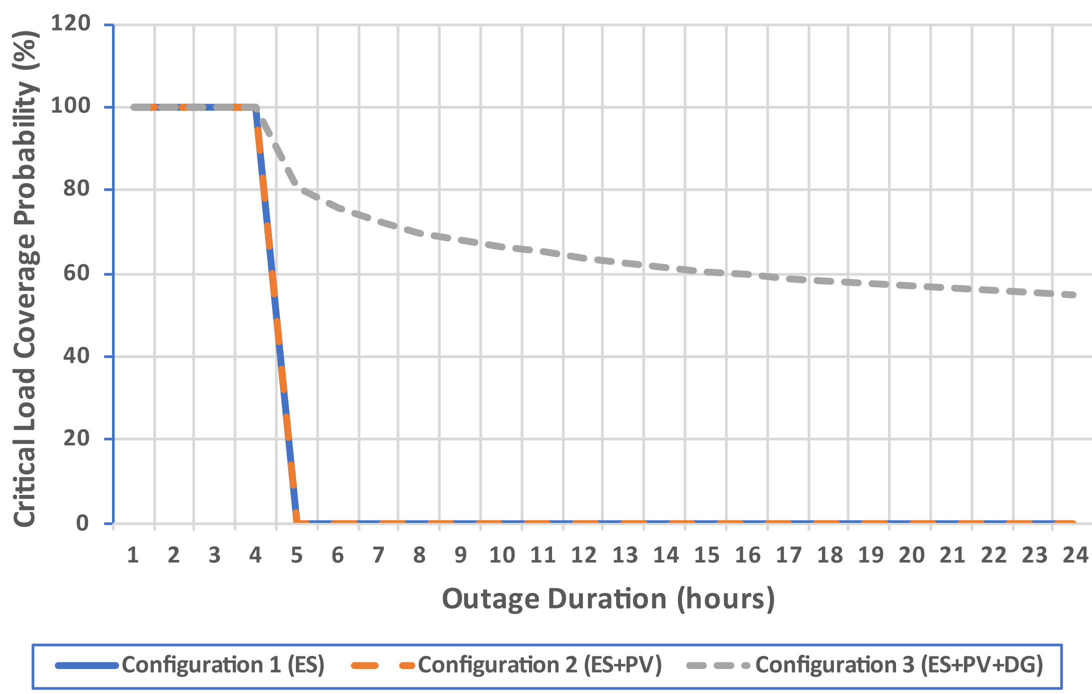
Source: EPRI

Post-Reliability Analysis, SOC Reservation

DER Sizing for Reliability

Figure 10 provides the critical load analysis for different configurations. It can be observed that the probability of covering the critical load for any four-hour outage is 100 percent.

Figure 10: Critical Load Coverage Curve for Use Case 3



Source: EPRI

Key Lessons Learned

This section details a use case where front of the meter DER is sized primarily for a community's resilience. Microgrids were designed for two scenarios. In the first scenario, microgrids were designed for a given 24-hour planned outage, whereas, in the second scenario, microgrids were designed to provide a 100 percent reliability target for any given four-hour outage during a year. Additionally, DERs in the microgrid were allowed to participate in the wholesale market and generate revenue. A detailed CBA was presented for both scenarios in this use case.

Future Developments

With more functionalities being developed in DER-VET™, some of the above reported use cases have been adapted to DER-VET™'s current capabilities. The following points explain such adaptions and have room for further developments that can be addressed in a future DER-VET™ version.

- Load coverage curves reported in these case studies do not consider generator failure probabilities.
- ES degradation and the associated replacement costs haven't been factored into these analyses.
- The current version of DER-VET™ sizes DER in the microgrid for always serving the critical load (100 percent load coverage probability) for a given user provided reliability target duration (for example, four hours). A future improvement may involve having the tool size the DER to meet a user-provided critical load coverage curve as a baseline target.
- Additional functionality in the tool will be developed to track the real-time performance of DER within the microgrid during grid-connected and islanded days.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

This section describes technology and knowledge transfer activities for the DER-VET™ tool.

DER-VET™ Documentation

An important avenue of learning about the tool is through publicly available and easily accessible documentation. There are many ways of documenting the use of the tool, and the team has tailored the style of its documentation to different user groups.

Documentation

- For end-users, the User Guide (https://storagewiki.epri.com/index.php/DER_VET_User_Guide) contains detailed instructions about installing, using, and troubleshooting DER-VET™ including definitions of the terms used in tools, and other topics.
- For researchers and stakeholders interested in the methodology, the details of the assumptions and formulations of DER-VET™ are included in the User Guide.
- For user-developers, an auto-documentation platform serves to capture function or class-level documentation for users who want to develop the code.
- For all stakeholders, a Use Case Development effort informs and structures most other technology transfer efforts.

Public Website

- By using the https://www.der-vet.com/ website, EPRI displays the most up-to-date information and tool release notes, and it can serve as the centralized location for all the documentation listed above.
- EPRI manages the website configuration and allows users to collaborate and inform the content of the website and tool, via the "DER-VET™ User Forum." The website is also laid out to help users navigate the documentation.
- The website is also the repository of all DER-VET™ public webinar and workshop presentation materials and recordings from the activities listed below.

Interacting with the DER-VET™ User Community

To help grow a healthy and productive DER-VET™ community, several pathways have helped facilitate the interaction.

Energy Storage Integration Council (ESIC)

- Through the ESIC, a public and open technical platform around DER, the development team has solicited feedback and engaged with DER-VET™ users to understand current industry needs.
- The ESIC DER-VET™ Task Force serves as a regularly occurring gathering for DER-VET™ users to participate in ongoing engagement, provide feedback, discuss DER-VET™ features, and raise future needs or concerns about the tool.
- Regular ESIC Task Force meetings will continue during the two-year maintenance period, through 2025.

Conferences and Analysis

- EPRI has displayed DER-VET™ at relevant technical conferences using booths to engage with stakeholders, including DistribuTECH 2020.

User Support

- EPRI provides technical help via the user forum and provides a help survey form on the DER-VET™ website.
- EPRI facilitates developer community support through ESIC DER-VET™ Task Force and GitHub.

Final Tool Delivery

The DER-VET™ tool delivery includes the following two activities:

- Post the tool's open-source core modules and GUI to https://www.der-vet.com/ and/or a publicly accessible website for open-source software collaboration (www.github.com or equivalent).
- Two-year support plan for the tool.

Users will have free access to DER-VET™ through several paths during the two-year support period with the following support plan:

- Install and run DER-VET™ locally on users' computers, with an open-source GUI, maintained by EPRI for a minimum of two years.
- Install and run DER-VET™ as a command-line tool in Python, which will continue to be accessible to the public for free in an open-source format beyond the two-year support period.

EPRI will also make DER-VET™ available to other third-party commercial developers to provide additional access options for users. Access to the tool beyond the two-year support period may also be made possible, pending a separate agreement, through additional CEC funding to EPRI for continued hosting of DER-VET™ for free to the public.

CHAPTER 5: Conclusion

DER-VET™ User Community Acceptance and Use

DER-VET™ is a publicly accessible, open-source tool for all stakeholders from customers to technology providers and developers to utilities to regulators across the customer, distribution, transmission, and generation grid domains.

By December 2023, DER-VET™ had roughly 1000 unique users who downloaded the software and spanned many organizations. In addition to direct users, EPRI's developer team has also presented at numerous public workshops and conferences to disseminate learnings to key stakeholders.

DER-VET™ ESIC Task Force Meeting Summary

For over five years, EPRI has leveraged its ESIC to facilitate over 60 monthly task force meetings to collect stakeholder input for requirements and functionality, beta testing, validation with actual DER and microgrid projects, training, ongoing bug fixes, and continuous feature and functionality improvements for DER-VET™. Recent DER-VET™ ESIC Task Force meeting recordings and presentations can be found on the DER-VET™ website at https://www.der-vet.com/esictf/.

Benefits to Ratepayers

Prior to the development of DER-VET™, many microgrid projects were being deployed based on an ad hoc analysis across disparate approaches and tools. The analysis framework and DER-VET™ itself give decision makers the tool set necessary to make informed and streamlined deployment decisions based on standardized guidelines. Rather than one-off analyses, DER-VET™ enables the informed deployment of microgrids throughout California and creates the potential for realizing various benefits, for both the grid and the customers.

The direct benefits of well-planned and operated microgrids include reduced electricity costs, lower CO_2 emissions, greater reliability through better integration of renewable sources, reduced or avoided outage times, and the potential for additional revenue from customer and grid services such as demand response or ancillary service participation. California ratepayers also benefit from greater reliability and lower costs. The tool evaluates how the microgrid systems can be used as potentially flexible resources, which, through the appropriate programs and incentives, utilities can use to support their objectives.

Quantitative Estimates of Benefits

Decision makers using DER-VET™, as opposed to the current industry's ad hoc analysis approach, have quantifiable benefits to California IOU electricity ratepayers through more informed and faster deployment of microgrids. To conduct a quantitative estimate of ratepayer benefits, the estimate will analyze the following benefits (Table 15):

- Reliability and resilience
- Energy value
- Capacity value
- Ancillary services value (from frequency regulation)
- Greenhouse gas (GHG) emissions

Table 15: Summary of Key Assumptions for Benefits

Category	Assumption
IOU Customers	PG&E (5.4 million), SCE (15 million), SDG&E (1.4 million) Total: 21.9 million customers.
Customer Adoption of Microgrid	The use of DER-VET™, which introduces the ability to screen for more cost-effective sites, optimal microgrid sizing, and expanded customer and grid service stacking, has the potential to increase the penetration of microgrids in California by 0.01 percent of the total customer base across the three IOU territories.
Customer Consumption	In the residential sector, California customers use an average of 605 kWh per month (7,200 kWh per year) [5]. Commercial customers are likely to have higher consumption than the residential sector. Therefore, the benefits calculation presented here is conservative and actual benefits of wider microgrid adoption are likely to be much higher.
SAIDI / SAIFI	SAIDI – 10-year average of ~125 minutes across the three IOUs [6]. SAIFI – 10-year average of ~1.0 event across the three IOUs.
Price of Electricity	$0.2954 per kWh (statewide average, residential sector) [7]
Price of Capacity	$6.54 per kW-month (weighted average capacity price for 2022) [8]
Price of Ancillary Services & Storage Participation	$18.29 per MWh (average of California ISO regulation up and down price for 2022. Average regulation up price: $24.74 per MWh, Average regulation down price: $11.85 per MWh). The assumption is that the storage unit will be able to provide ancillary services (frequency regulation) for 12 hours each day (limited to managing the state of charge of storage) [9].
GHG Emission	0.4790 lb. per kWh for electricity (2021 California State Output Emissions Rate) [10].
Cost of PV	$3,160 per kW DC (2022 residential installed cost) [11].
Cost of Storage	$475 per kWh (2022 estimate for 2-hour battery capital cost) [12].

Category	Assumption
GHG Clearing Price	$30.33 per metric ton (CARB auction for May 2023) [13].
Analysis Period	25 years

SAIDI = System Average Interruption Duration Index
SAIFI = System Average Interruption Frequency Index
Source: EPRI

Calculations

- *Number of microgrids adopted as a result of DER-VET™:*
  - 21.9 million customers × 0.01% adoption = 2,190 microgrids
- *Average size and cost of microgrid:*
  - PV is sized to cover annual electricity consumption of 7,200 kWh = 4.5 kW DC.* DER sized to cover peak consumption (~5 kW for residential customers) and average SAIDI duration (125 minutes): 5 kW per 10 kWh.

* The above formula was calculated using the National Renewable Energy Laboratory's (NREL) System Advisor Model using Los Angeles, California, as the reference solar resource location.

Table 16 provides a summary of microgrid calculations.

Table 16: Calculations Summary

	Individual Microgrid	2,190 Microgrids
Solar PV	4.5 kW	9,855 kW
Energy Storage	5 kW/10 kWh	10,950 kW/21,900 kWh
Cost	$\$3{,}160/kW \times 4.5\ kW + \$475/kWh \times 10\ kWh = \$18{,}970$	$\$3{,}160/kW \times 9{,}855\ kW + \$475/kWh \times 21{,}900 kWh = \$41{,}544{,}300$

Source: EPRI

- *Reliability and resilience:*
  - Using DOE's Interruption Cost Estimate Calculator [14], the estimated benefits (avoided cost) of reducing SAIDI and SAIFI is = **$319,865** in savings over 25 years.
- *Energy value:*
  - 2,190 microgrids × 7,200 kWh per microgrid × $0.2954 per kWh × 25 years = **$116,446,680** in savings over 25 years
- *Capacity value:*
  - 2,190 microgrids × 5 kW of ES per microgrid × $6.54 per kW-month × 12 months × 25 years = **$21,483,900** in revenue over 25 years

- *Ancillary services (frequency regulation) value:*
    - 2,190 microgrids × 5 kW of ES per microgrid × $18.29 per MW per hour × 12 hours per day × 365 days per year × 25 years = **$21,930,167** in revenue over 25 years
- *GHG emissions:*
    - 2,190 microgrids × 7,200 kWh per microgrid × 0.479 lb. of CO_2 per kWh × 25 years ÷ 2,204.6 metric tons per lb. = **85,649 metric tons of CO_2** mitigated over 25 years
    - 85,649 metric tons of CO_2 × $30.33 per metric ton clearing price = **$2,597,734** in revenue over 25 years

A benefits summary is provided in Table 17.

Table 17: Summary of Benefits

Category	Costs/Benefits
Reliability and resilience ($)	$319,865
Energy value ($)	$116,446,680
Capacity value ($)	$21,483,900
Ancillary services value ($)	$21,930,167
GHG emissions mitigation ($)	$2,597,734
Cost of microgrids	(−$37,777,500)
Total benefits and costs ($)	**$125.0M**
Total project cost (including cost share)	$2.6M
Benefit-to-cost ratio	**48.0**

Source: EPRI

Qualitative Benefits

Qualitative or intangible benefits to California IOU ratepayers include facilitating communication, collaboration, and consensus on the best approaches for deploying microgrids to support increased DER penetration, grid benefits, and customer resilience. If the tool provides useful and defensible results, stakeholder debate will focus on the choice of model inputs and parameters, rather than a less productive debate of the general merits of one specific analysis approach over another, which have historically been challenging to reconcile and achieve clarity. DER-VET™ addresses a critical barrier to commercialization — available financing. Without a public model credible to regulators, utilities, and project developers alike, it is impossible to document future revenues to the satisfaction of lenders or justify long-term fixed payments from utilities and their ratepayers. DER-VET™ can perform a detailed cost-benefit and financial analysis to support the successful funding of numerous large utilities and commercially funded projects.

DER-VET™ will benefit researchers and members of academia, thus benefitting the scientific community. Students and educators may use the tool to complete their thesis/ research and provide supplemental course material. Many universities and U.S. national labs have downloaded DER-VET™.

GLOSSARY

Acronym/Term	Description/Definition
California ISO	California Independent System Operator. The California ISO maintains reliability on the California power grid, and operates a transparent, accessible wholesale energy market.
CEC	California Energy Commission The California Energy Commission is leading the state to a 100 percent clean energy future for all. As the state's primary energy policy and planning agency, the CEC is committed to reducing energy costs and environmental impacts of energy use while ensuring a safe, resilient, and reliable supply of energy.
CLI	Command-line Interface A command-line interface is a text-based user interface (UI) used to run programs, manage computer files, and interact with the computer. CLIs accept as input commands that are entered by keyboard; the commands invoked at the command prompt are then run by the computer.
CO2	Carbon dioxide g A greenhouse gas. See GHG below.
CPUC	California Public Utilities Commission State agency that regulates privately owned electric, natural gas, telecommunications, water, railroad, rail transit, and passenger transportation companies, in addition to authorizing video franchises.
CBA	Cost-Benefit Analysis A systematic process that businesses use to analyze which decisions to make and which to forgo. The cost-benefit analyst sums the potential rewards expected from a situation or action and then subtracts the total costs associated with taking that action.
CYME	The power engineering software CYME can provide electric cooperatives with the solutions needed to address various aspects of grid modernization including DER integration, data management, and infrastructure improvements. CYME was developed by Eaton, a power management company.
DC	Direct current

Acronym/Term	Description/Definition
DER	Distributed Energy Resource Distributed energy resources are any resource with a first point of interconnection of a utility distribution company or metered subsystem.
DER-VET™	Distributed Energy Resource Value Estimation Tool DER-VET™ provides a free, publicly accessible, open-source platform for calculating, understanding, and optimizing the value of distributed energy resources based on their technical merits and constraints. DER-VET was developed by EPRI with funding from the CEC. DER-VET is the next generation of EPRI's energy storage and DER valuation tool.
EPIC	Electric Program Investment Charge The CEC's EPIC program invests in scientific and technological research to accelerate the transformation of the electricity sector to meet the state's energy and climate goals.
EPRI	Electric Power Research Institute With a foundational mission to benefit society, EPRI delivers independent, objective thought leadership and industry expertise to help the energy sector identify issues, technology gaps, and broader needs that can be addressed through effective, collaborative research and development programs.
ES	Energy Storage Energy storage is the capture of energy produced at one time for use at a later time to reduce imbalances between energy demand and energy production. A device that stores energy is generally called an accumulator or battery. Energy comes in multiple forms including radiation, chemical, gravitational potential, electrical potential, electricity, elevated temperature, latent heat, and kinetic.
ESIC	Energy Storage Integration Council EPRI established ESIC to advance the deployment and integration of energy storage systems through open, technical collaboration. EPRI convenes and coordinates ESIC's working groups and informational sessions and publishes its documents and online resources.

Acronym/Term	Description/Definition
GHG	Greenhouse Gas Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PCFs), and hydrofluorocarbons (HFCs).
GridLab-D	GridLAB-D is a power distribution system simulation and analysis tool that provides valuable information to users who design and operate distribution systems, and to utilities that wish to take advantage of the latest energy technologies. GridLAB-D was developed by the U.S. Department of Energy at Pacific Northwest National Laboratory.
GUI	Graphical User Interface A graphical user interface is an interface through which a user interacts with electronic devices such as computers and smartphones through the use of icons, menus and other visual indicators or representations. GUIs graphically display information and related user controls, unlike text-based interfaces, where data and commands are strictly in text.
IOU	Investor-owned Utilities Investor-owned utilities provide transmission and distribution services to all electric customers in their service territory. The utilities also provide generation service for "bundled" customers, while "unbundled" customers receive electric generation service from an alternate provider, such as a Community Choice Aggregator (CCA). California has three large IOUs offering electricity service: Pacific Gas and Electric, Southern California Edison, and San Diego Gas & Electric.
kW/kWh	kilowatt/kilowatt-hours A measure of 1,000 watts of electrical power and the energy delivered by one kilowatt of power for one hour.
MW/MWh	megawatt/megawatt-hour A measure of 1,000,000 watts of electrical power and the energy delivered by one megawatt of power for one hour.
LADWP	Los Angeles Department of Water & Power The Los Angeles Department of Water & Power, founded in 1902, is the largest municipal utility in the United States, serving more than four million residents and local businesses in the city of Los Angeles.

Acronym/Term	Description/Definition
NPV	Net Present Value Net present value is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyze the profitability of a projected investment or project.
NREL	National Renewable Energy Laboratory The National Renewable Energy Laboratory specializes in the research and development of renewable energy, energy efficiency, energy systems integration, and sustainable transportation. NREL is a federally funded research and development center sponsored by the Department of Energy and operated by the Alliance for Sustainable Energy.
OpenDSS	Open-source Distribution System Simulator Developed by EPRI, is an electric power distribution system simulator designed to support distributed energy resource grid integration and grid modernization.
PSPS	Public Safety Power Shutoff A public safety power shutoff, also known as PSPS, is a system used by utilities to prevent wildfires by proactively turning off electricity when gusty winds and dry conditions present a heightened fire risk.
PV	Photovoltaic Photovoltaic devices generate electricity directly from sunlight via an electronic process that occurs naturally in certain types of material, called semiconductors. Electrons in these materials are freed by solar energy and can be induced to travel through an electrical circuit, powering electrical devices or sending electricity to the grid.
PVSyst	PVsyst is a photovoltaic planning software tool used in energy modeling and can analyze how much solar energy can be harvested into electrical energy from a particular site or location.
SAM	System Advisor Model SAM is developed by the National Renewable Energy Laboratory (NREL) with funds from the U.S. Department of Energy. The System Advisor Model (SAM) is a free techno-economic software model that facilitates decision-making for people in the renewable energy industry.

Acronym/Term	Description/Definition
SOC	State of Charge State of charge is the level of charge of an electric battery relative to its capacity. SOC is usually expressed as percentage (0% = empty; 100% = full).
StorageVET®	Storage Value Estimation Tool StorageVET is a publicly available, open-source, Python-based energy storage project valuation tool developed by EPRI with funding from the California Energy Commission. StorageVET is the second iteration of EPRI's storage valuation tool.

Source: EPRI and CEC Staff

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[13] California Air Resources Board (CARB). *California Cap-and-Trade Project Summary Results Report*. May 2023. https://ww2.arb.ca.gov/sites/default/files/2023-05/nc-may_2023_summary_results_report.pdf

List of Project Deliverables

The content of the DER-VET™ technical deliverables and additional resources are available directly on the DER-VET™ webpage at https://www.der-vet.com/, including but not limited to instructions to download and install the latest version of the DER-VET™ software, user guide, reference cases, how-to videos, and user forum.

- DER-VET Software Download
  https://www.der-vet.com/software/
- DER-VET User Guide (StorageWiki)
  https://storagewiki.epri.com/index.php/DER_VET_User_Guide
  - Running a Case
    https://storagewiki.epri.com/index.php/DER_VET_User_Guide/Getting_Started
  - Installing DER-VET
    https://storagewiki.epri.com/index.php/DER_VET_User_Guide/Installation
  - DER-VET Frequently Asked Questions
    https://storagewiki.epri.com/index.php/DER_VET_User_Guide/FAQ
- DER-VET Reference Cases
  https://www.der-vet.com/referencecases/
- Help Using DER-VET
  https://www.der-vet.com/help/
- DER-VET User Forum
  https://www.der-vet.com/forum/

CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix A:
DER-VET™ User Guide

February 2024| CEC-500-2024-010

APPENDIX A:
DER-VET™ User Guide

Summary of Online Resource

The DER-VET™ User Guide has several sections to describe using the GUI as well as the command line version of the tool. This online resource will see continuous updates from EPRI. The main content is broken into the following sections:

- Installing DER-VET™
- Running a Case
- Model Details
- Services
- Technologies
- Command Line Inputs
- Command Line Outputs
- GUI Inputs
- GUI Results
- GUI Quick Start Cases
- Resolving Issues

Instruction for Online Access

Readers can access these resources on EPRI's "Storage Wiki" at the following publicly available website: https://storagewiki.epri.com/index.php/DER_VET_User_Guide.

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Appendix B:
Details of DER-VET™'s Capabilities

February 2024 | CEC-500-2024-010

APPENDIX B: Details of DER-VET™'s Capabilities

Some of DER-VET™'s core capabilities are explained rigorously in this Section.

Dispatch Optimization

DER-VET™ calculates the optimal operation for ES and other dispatchable DER, within a default or user-specified environment. This means that the economic results returned by DER-VET™ represent the best-case scenario, while still respecting the technical limitations imposed by the user.

In some DER applications, as in generating or shifting energy on a well-defined tariff or power-purchase agreement (PPA), the dispatch optimization will represent real cases well. In other applications, such as a DER system participating in wholesale energy and ancillary service markets, DER-VET™ may produce results that exceed the value a real system could likely achieve, depending on the forecasting and bidding strategies available.

For wholesale energy and ancillary service markets, the dispatch optimization incorporates time-series data on energy and ancillary service prices in hourly, 30-minute, 15-minute, 10-minute, or 5-minute resolution. These prices are fixed in the optimization (DER-VET™ is a "price-taker" model). DER-VET™ does not simulate the markets or capture any changes in market prices due to the DER technologies being modeled.

In addition to many technical parameters of the DER mix being modeled, DER-VET™ also incorporates time-dependent variables for technologies with a persistent state, notably tracking storage systems' SOC. Because the storage system's SOC couples every moment in time (actions now impact the system's future capabilities), a time-series dispatch optimization is required in most cases. When multiple services are being stacked, DER-VET™ will calculate the optimal timing of when to participate in each available service while respecting the technical limitations of the system and any user-imposed constraints.

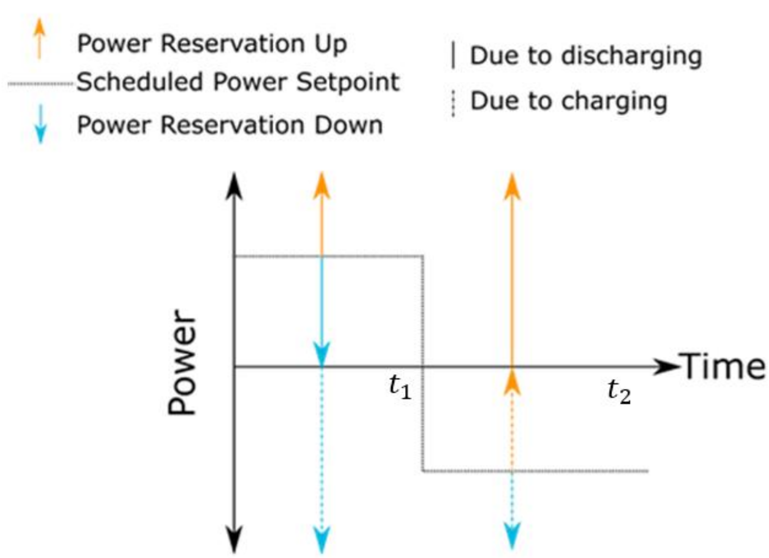
Service Stacking

Depending on the location and applicable regulatory or market rules, DER technologies can offer various services to various actors, including those related to PPA structures, wholesale markets, distribution planning and operations, customer tariffs, and other programs. When DER systems can provide these services jointly, the resulting values from each service are "stacked" on each other to achieve the total value. In these calculations, it is critical not to double count the value of the mix or over-commit the DER systems so that they are physically incapable of providing all promised services together. When the user selects services for analysis, DER-VET™ evaluates the compatibility of services and the DER systems' capabilities when developing the stacked service valuation.

To accommodate the potential for multiple services, DER-VET™ can aggregate services' constraints and compile them into power and energy reservations. These constraints ensure that the DER mix can feasibly provide any services it provides concurrently (that is, a service that requires discharging cannot be provided concurrently with a service that requires charging) and that providing one service now does not preclude another service in the future (that is, a storage system will maintain an acceptable SOC for future applications).

Power reservations reserve the ability to change the power level of the DER system within the timestep from what it is scheduled to provide across the entire timestep. In the case of spinning and non-spinning reserves, this reserves the ability of the system to increase its power output or decrease its power consumption. However, DER-VET™ does not simulate the system ever needing to provide power to fulfill its spinning and non-spinning reserves requirements — it just ensures it is ready to respond in case it is called. In the case of regulation, which actively charges and discharges the system during normal operation, the power reservation will also result in an energy transfer. The DER system must be able to supply any reserved power so the combination of reserved power and the scheduled power in the DER system cannot exceed its capabilities. A hypothetical case showing a storage system over two timesteps is shown in Figure 1. In each one, the entire power capacity of the storage system is reserved for energy and regulation service. In the first timestep, the storage system is scheduled to discharge at a constant power over the timestep, so it can make only a small amount of power reservation available in the up direction. In the second timestep, the system is scheduled to charge.

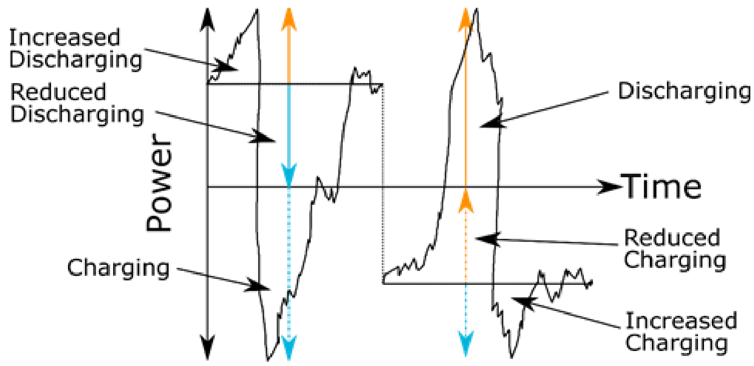
Figure B1: Power Reservation Scheme



Source: EPRI, DER-VET™ User Guide

If the power reservations are for a service like regulation, this power reservation will actively modify the actual power output of the storage system during normal operation. A hypothetical, albeit unrealistic case of this is shown in Figure 2. The solid line shows the actual power profile of the storage system in response to the scheduled power (dotted line) and power reservations (colored arrows). This operation will modify how much energy cumulatively enters and leaves the system over each timestep, modifying its SOC over time. This effect is estimated in DER-VET™, even though it happens on a faster time scale than the tool's timesteps, by parameterizing the energy transfer and including it in the timestep-by-timestep optimization. The user provides this energy throughput as an input to the tool.

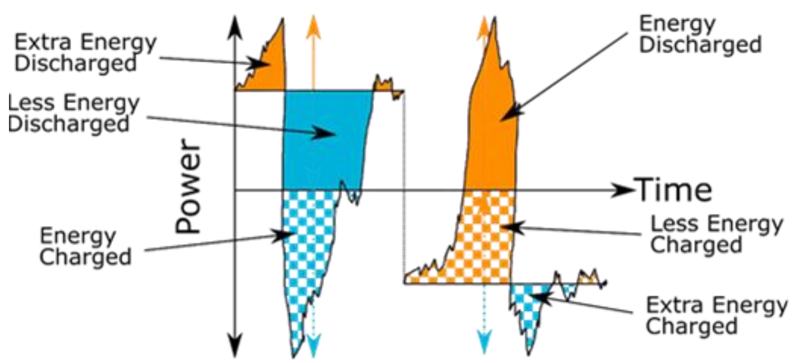
Figure B2: Power with a Timestep Due to Power Reservation



Source: EPRI, DER-VET™ User Guide

The amount that the state of energy will be different from the schedule is shown by the shaded areas in Figure 3. Because charging and discharging impact the state of energy differently, the power reservations for regulation up due to charging, regulation up due to discharging, regulation down due to charging, and regulation down due to discharging need to be kept separate.

Figure B3: Effects of Power Reservations

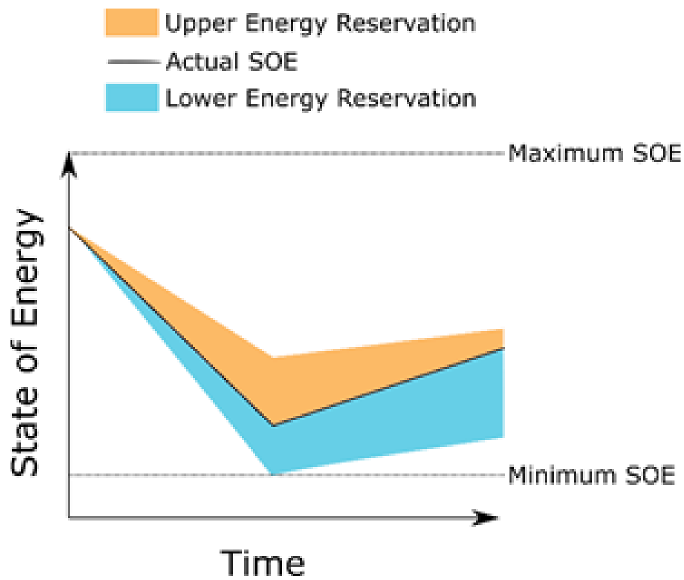


Source: EPRI, DER-VET™ User Guide

Energy Reservation Stacking

Energy can also be reserved to ensure no limits are reached under worst-case conditions or to satisfy market rules. Regulation, spinning reserves, and non-spinning reserves require DERs to have sufficient energy to fulfill discharge obligations or, in the case of regulation, sufficient SOC headroom to avoid running out of room to charge. Figure 4 shows a hypothetical case where a storage system follows a profile similar to that in Figure 2. In the first timestep, the storage system discharges and reserves energy in both directions. At the end of this step, the state of energy is as low as it can be, while maintaining enough SOC buffer to handle the worst-case scenario. This means that the storage could not offer any more services that required an energy reservation in the down direction during timestep one without reducing its scheduled discharge power.

Figure B4: Energy Reservations



Source: EPRI, DER-VET™ User Guide

Size Optimization

DER-VET™ can directly include DER size parameters in the optimization problem that solves stacked service participation. The result of the size optimization is the co-optimized size and operation of all DERs considered in the analysis given their costs and capabilities. While this increases the computational intensity of the optimization problem, it can give a good starting point for continued exploration using scenario analysis and more-detailed assumptions.

Customizable for Location, Sizing, and Use Cases

DER-VET™ allows the user to conduct sensitivity analysis on many input parameters, including location, size, and applications. DER-VET™ can be used to optimally size DER at many locations and compare the financial and operational results between cases. DER-VET™ can capture the expected service value based on a range of inputs that are either optimization-driven or constraint-based services.

Data Options

DER-VET™ includes a small amount of pre-loaded data, and users can upload their data if they are first converted to the appropriate format. The pre-loaded data include hourly and sub-hourly wholesale historical California ISO market prices at a zonal level and load information sourced from the California ISO. They also include a few example tariff structures for retail customers, which have the potential to benefit from DER, particularly those with significant demand charges or time-of-use energy rates. The data sets include illustrative load shapes for customers and distribution loads.

The pre-loaded data are accurate and useful for illustrative purposes but generally insufficient to evaluate projects located at one of the over 3000 California ISO energy pricing nodes or specific distribution level applications. So, DER-VET™ is built with the capability to connect to external data sources. These include the California ISO OASIS data download API, NREL's PVWatts API, etc. The Desktop Application of DER-VET™ can connect to the OpenEI utility rate database and search for tariffs when given a particular zip code and utility. When selected, these complex rate structures feed back into DER-VET™ to define the retail tariff for analysis.

Finally, cost and performance information is provided by EPRI from recent cost studies to provide default characteristics (EPRI 3002008877). ESIC provides templates for supporting data collection related to DER cost and specification. The latest template versions can be found at www.epri.com/esic.

Compatibility with Other Tools

DER-VET™ can interface with other modeling tools that complement its capabilities and offer a more complete picture of DER benefits, costs, objectives, technical operations, and constraints. It is being used by planners with distribution-level power flow simulators and production cost modeling (PCM) tools.

When interfacing with distribution power flow modeling tools, the specific analytical process could be as follows:

1. The power flow model is used to characterize locational and time-varying constraints on the distribution feeder relevant to DER operations (primary service).
2. Those constraints are then incorporated into DER-VET™ optimization to evaluate stacked benefit opportunities.
3. The resulting DER dispatch from DER-VET™ is incorporated back into the power flow model to verify whether the DER operational schedules for secondary applications do not create a negative impact and that there are no second-order violations. Also, this may enable evaluating other performance measures such as asset loading, distribution-related energy losses, and asset degradation.

When interfacing with PCM tools, there are several variations. First, production cost models are typically used to (1) understand the change in production costs, revenue streams, and steady-state reliability impacts from potential changes in system operating procedures or market design, for example, introduction of new services (fast frequency response, flexible ramp products) or scheduling processes, state-of-charge management options, and so on; and (2) determine potential revenue streams, system operations, emissions, aggregate production costs, and hourly marginal prices for certain market services in a future year or set of years. The resulting hourly prices can then be used in DER-VET™ to understand the potential revenue streams of a DER or compare project options on a near-term future time frame across a range of applications. When using DER-VET™ as a price taker model, the following assumptions apply: (1) The DER does not significantly impact the marginal cost/price of energy and/or the service (for example, regulation reserve, spinning reserve) that is being assessed, and (2) the marginal costs being used as input are representative of the scenario that is being reviewed.

Second, DER-VET™ can run multiple sensitivities quickly and easily with the appropriate price data to determine advantages for different power/energy sizing dimensions and state of health implications. DER-VET™ can also provide financial results such as Pro Forma and Net Present Value with appropriate price data over a sufficiently lengthy time. Another example is that a PCM typically has an internal storage technology representation that does not incorporate as many constraints as DER-VET™. In these types of uses, DER-VET™ could similarly be used to clarify the likely dispatch by the DER, which is then returned to the production cost model.

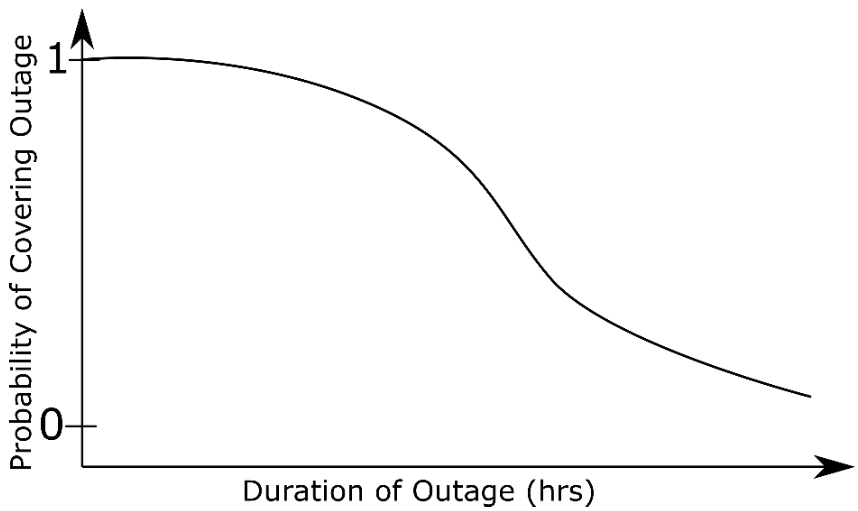
In addition, DER-VET™ could interface with many other types of models or tools. In all these joint-model applications, the uses of DER-VET™ will evolve. EPRI will make additional methodological details available as these become available.

Co-Optimized DER Portfolio Sizing to Address Microgrid Reliability and Customer Resilience

In the past, reliability and resilience were handled in StorageVET® and many other tools by simply reserving some energy capability (stored energy in a storage system or generator, and so on) that would not be used for economic services. DER-VET™ has more-detailed analysis capabilities, expanding the reliability service to include dynamic, time-varying energy reservations, size constraints (energy and power capacities), and reconfigurability. This capability allows the user to specify a desired level of reliability and have the tool automatically ensure that the DERs are sized and operated to ensure that level of reliability. Additionally, the tool can handle reliability as a post-optimization calculation. This measures reliability as a positive side effect of the DER and the other services they provide instead of optimizing for reliability directly.

While reliability has a set of well-defined metrics, resilience is often considered less well-defined. However, they both have to do with the ability of a microgrid to supply power to critical loads. In many cases, reliability metrics exclude extreme events that must be considered for resilience. For these reasons, DER-VET™ adopts the critical load coverage probability approach in handling reliability and resilience (Figure 5). Only the probability of the DER having enough energy and power capability to cover a grid outage of a specified duration is important in DER-VET™, and SAIDI, SAIFI, CAIDI, and so on, are not used to specify reliability outcomes.

Figure B5: Example Critical Load Coverage Probability Curve (to be met or exceeded for all durations)



Source: EPRI, DER-VET™ User Guide

The critical load coverage probability curve, shown in Figure 5, is generated by considering every possible outage of each specified duration and determining whether the DER mix can cover that outage. The probability of covering an outage of a given duration is the fraction of these hypothetical outages the DER mix could cover, which implicitly assumes that the probability of an outage occurring is equal at all timesteps. Additionally, for technologies with a state (for example, storage), the operation of these technologies will be constrained so that, along with the other DER, the DER mix will be capable of meeting or exceeding the coverage probability requirement. When doing size optimization, the operational power and state of energy constraints imposed by this service will, by proxy, constrain the size of the DER so they can meet the reliability objective.

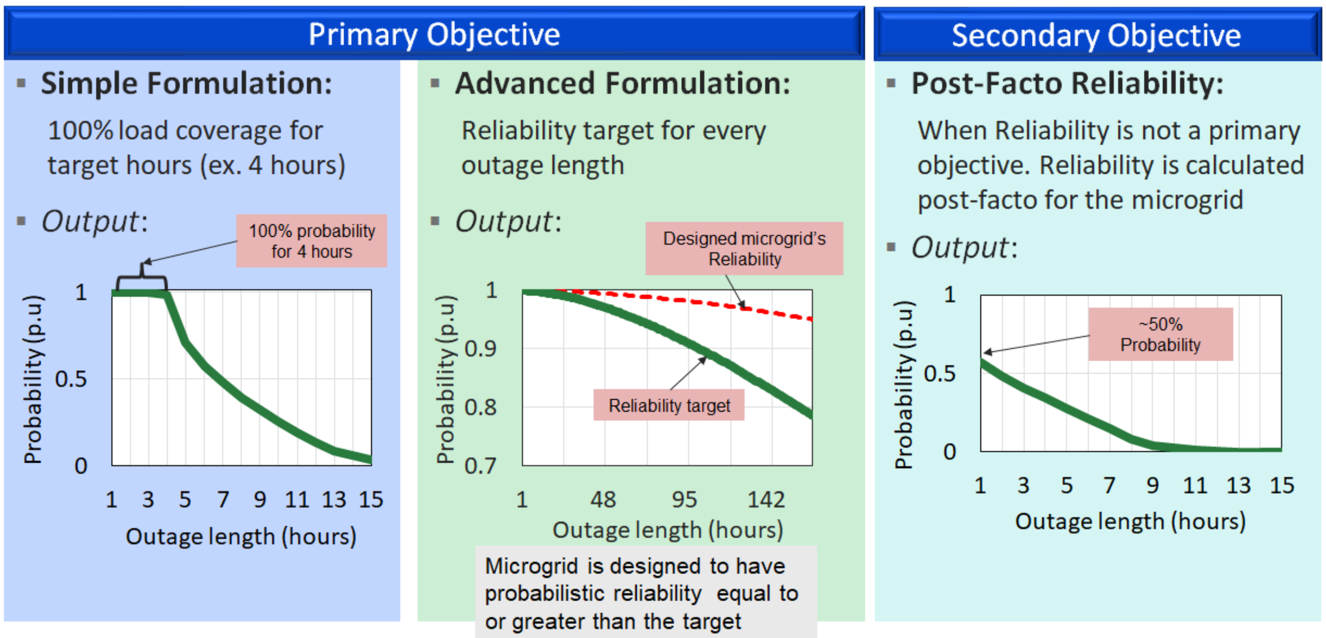
Customer reliability and resilience are measured in terms of the ability of a microgrid to serve critical load during an outage. DER sizing based on reliability and resilience metrics can be achieved using the following two approaches in DER-VET™ (Figure 6):

- The first approach sizes the DER portfolio to always serve critical load (100% probability) for a user-input target outage length *t*. All possible outage scenarios of length *t* within a given load profile are considered in this analysis. This approach is included as a linear optimization constraint in DER-VET™ formulation. It is relatively simple compared to the second approach.
- The second approach incorporates all practical assumptions in the reliability calculation. It considers all possible outage lengths, solar intra-hourly variation, and equipment failure probability (future implementation). A microgrid's reliability is calculated as the ratio of outage scenarios the microgrid can successfully serve to the total scenarios analyzed. The output of this calculation is the probability of serving a critical load (%) for every outage length. This detailed probabilistic reliability calculation is not included as a part of the optimization module but added as an ex post facto calculation, outside

the optimization module. DER sizing using this approach can be done by following methods based on a reliability target:

- If there is no reliability target, the microgrid can be sized for some other economic objective, and the reliability of the designed microgrid can be evaluated as an ex post facto calculation.
- If there is a reliability target, then DER-VET™ can be iteratively called by an external script to meet the reliability target of the desired microgrid.

Figure B6: Customer Reliability Options Considered within DER-VET™



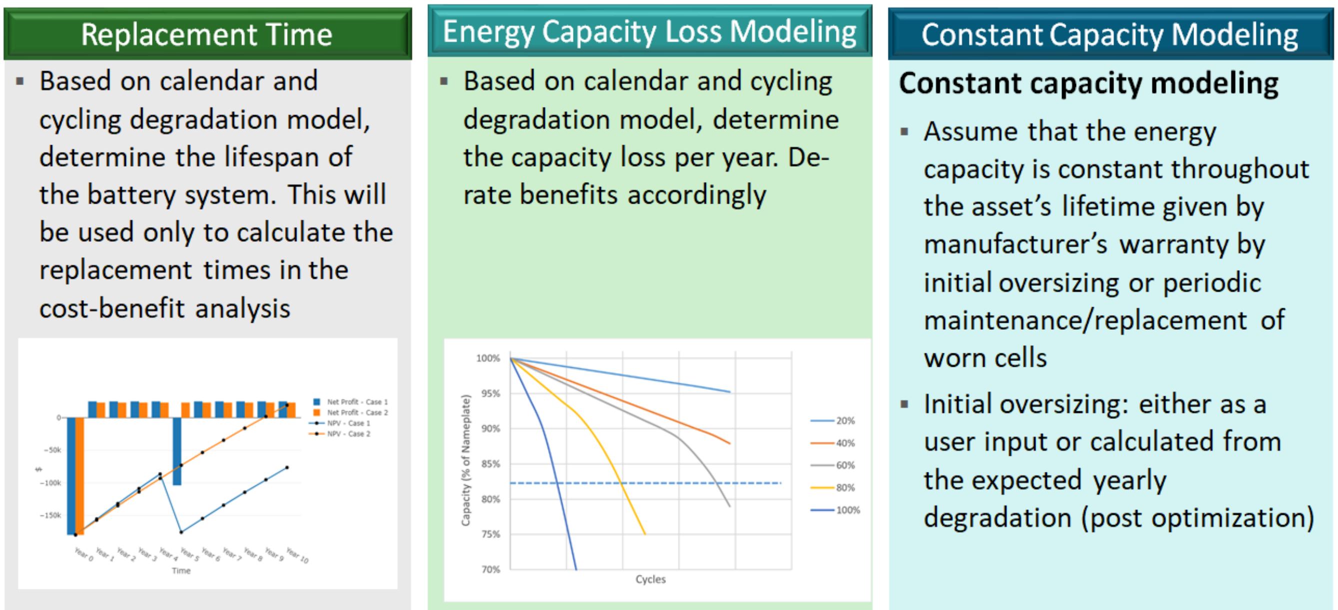
Source: EPRI, DER-VET™ User Guide

Degradation

Li-ion storage degradation is driven by temperature, cycling, and average SOC, among others. Figure 7 describes several degradation modeling approaches. The main effect of degradation is loss of ES capacity. The topic of degradation leads to different questions around storage projects, as follows:

- Should one oversize the system? Or is it better to operate with lower-capacity systems?
- What type of warranty does the vendor provide?
- Is there an operational requirement for a warranty?
- How are costs transferred to the owner?
- What is the optimal strategy to augment ES systems?

Figure B7: Storage Degradation Modeling Approaches



Source: EPRI, DER-VET™ User Guide

Degradation is quantified as the sum of cycling degradation and calendar degradation. Calendar degradation is the yearly degradation that an idle battery system would undergo, and it is parameterized by a user input corresponding to the expected idle life span of the battery. Cycling degradation comes from counting SOC cycles and is parameterized by a life span versus depth of discharge curve. This curve maps different depths of discharge to the battery life span in cycles. This model can represent a battery system in which the operator takes the degradation risk, but it also can represent the case in which the risk is assumed by the vendor (for example, through a warranty).

DER Project-Specific CBA

The fundamental use of DER-VET™ is to valuate DER or microgrid project economics and operations. The tool is adaptable to many settings, including research, policy or regulatory analysis, commercial decisions (by various actors), infrastructure planning, and research. DER-VET™ incorporates realistic financial pro forma outputs that support project finance analysis. With respect to benefits, it can calculate best-case market revenues or avoided costs associated with alternative infrastructure or resources. Salient features are summarized in Figure 8 and described in the following:

- **Multi-perspective value stream**: DER-VET™ can analyze variations in DER value streams across various applications.
- **DER ownership models**: DER-VET™ can analyze different ownership models (utility, customer, third party, PPA).
- **CBA metrics**: DER-VET™ can automatically calculate key CBA outcomes. Some metrics could include project net present value (NPV), benefit-to-cost ratio, return on investment, avoided cost breakdowns based on value streams, and cost of covering a critical

load. An EPRI Technical Brief from 2022 [4] briefly introduces the CBA module for DER-VET™.

- **Value of Resilience / Value of Supply**: DER-VET™ allows the flexibility to evaluate the direct costs of high impact low frequency outages to customers.
- **Tax calculations**: DER-VET™ can calculate federal, state, and property taxes, and potential tax deductions due to FITC qualification.
- **Additional incentives**: DER-VET™ has the functionality to include other external incentives as defined by the user in the financial calculations.

Figure B8: Microgrid Design Variations, Economic Optimization, and Stacked Benefits Considerations within DER-VET™

- **DER Technology Mix:**
  - Technologies:
    - ES
    - PV
    - DG
    - EV
    - CHP
  - Combination of these technologies (ES+PV, ES+DG)
  - Multiple types and units of these technologies

- **DER Sizing & Management:**
  - Objective:
    - Maximize economic benefits (Bill Reduction /Market participation)
    - Customer Reliability/Resilience
    - Feeder reliability
    - Deferral/ Hosting capacity
  - Co-optimization
  - Dispatch optimization
  - Service territory restrictions on DER participation

- **Cost Effectiveness:**
  - DER ownership model
  - Multi-perspective value streams
  - Behind the meter and Front of the meter asset - costs and benefits from services
  - Life time of assets and replacement costs
  - Analysis time horizon
  - Tax credits and other incentives
  - CBA Metrics:
    - Payback period, NPV, IRR, BCR
    - Cost of Critical load coverage

- **Multi-Perspective Value Streams:**
  - Customer bill reduction
  - Market participation
  - Reliability/Resilience Value of Service
- *Output*: Cost/benefit components and avoided costs

- **DER Ownership Models:**
  - Utility
  - Customer
  - 3rd Party
  - PPA
- *Output*:
  - CBA results with different perspectives
  - Value stream validation
  - Stacked services

- **CBA Metrics & Value of Supply:**

Have DER-VET automatically calculate key cost-benefit analysis outcomes (not always applicable in cases with different asset lifetimes)

- Basecase comparison

- *Output*:
  - Project net present value
  - Benefit to cost ratio
  - Return on investment
  - Breakeven cost
  - Cost of covering critical load

Source: EPRI, DER-VET™ User Guide