Market Study of Emerging Residential Energy and Automation Technology

Final Report

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Abbreviations and Acronyms

Acronym	Meaning
AC	Alternating Current
AIO	All In One
BESS	Battery Energy Storage System
CEC	California Energy Commission
DC	Direct Current
DER	Distributed Energy Resource
EE	Energy Efficiency
ET	Emerging Technology
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GHG	Green House Gas
HEMS	Home Energy Management System
IOU	Investor-Owned Utility
kWh	Kilowatt-hour
MWh	Mega-Watt hours
NREL	National Renewable Energy Laboratory
PEV	Plug-in Electric Vehicle
PG&E	Pacific Gas & Electric
PV	Photovoltaic
REA	Residential Energy Automation
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric

Executive Summary

Residential Energy and Automation (REA) systems are an exciting and forward-thinking product category that builds upon the existing capabilities of Home Energy Management Systems (HEMS) by intelligently managing residential Demand-side Energy Resources (DERs) such as solar photovoltaic (PV) systems, battery energy storage systems (BESS), and electric vehicle service equipment (EVSE). The integration of Residential Energy Automation (REA) systems into California homes represents a significant opportunity to enhance energy efficiency, achieve cost savings, and bolster grid resilience.

This project aims to comprehensively explore and assess REA systems, focusing on their capabilities, installation needs, operating requirements, market opportunities, and customer base. To achieve these objectives, the research team adopted a structured approach. They began with a market survey to identify existing and emerging REA systems, using manufacturer data to determine key system characteristics. Based on these insights, the team developed an idealized REA system model that integrates the best performance qualities of each identified system for PV, BESS, and EVSE integration. Subsequently, they created a new construction baseline using publicly available data and California building standards. The idealized REA model was then combined with this baseline and various IOU tariffs to quantify potential impacts on energy and cost savings, peak energy reductions, and GHG reductions. Finally, the team identified IOU customers who would uniquely benefit from REA adoption and quantified the overall grid impact of implementing REA systems.

The research team's comprehensive modeling and analysis revealed that REA systems offer substantial benefits over conventional energy architectures in new residential constructions. Annual energy savings ranging from 18 to 64 percent were calculated with variations attributed to the transmission efficiency of connected DER and the adoption of EVs within the home model. These savings are further enhanced when REA systems shift energy use to off-peak hours, effectively reducing energy costs and mitigating grid demand during peak periods. By enabling households to manage and store energy more efficiently, REA systems contribute significantly to energy resilience and sustainability.

Applying various Californian investor-owned utility (IOU) tariffs identified significant cost savings opportunities, particularly in scenarios involving electric vehicle (EV) charging and peak price load shifting. The integration of REA systems with solar and BESS installations not only allows homes to achieve higher levels of energy independence but also is predicted to save customers $500 to $2500 off their annual energy bill varying mainly by EV integration and available IOUs' time-of-use rates.

Nearly 20 percent of IOU customers, based on IOU reported Title 20 interconnections data, are uniquely positioned to benefit from REA systems due to existing DER installations and equipment. If just five percent of customers with existing DERs installed (1.2 percent of IOU customers) were to adopt a REA system, California would unlock 44 GWh of energy yearly and have a potential peak hour (5 - 6 PM) reduction of 18.51 MW from grid flexibility via load shifting. The savings potential and grid flexibility would scale linearly based on the adoption rate. Full-scale adoption of REAs systems in fully electrified homes has the potential to unlock 6.9 TWh, assuming 17% of California's total energy

consumption being in the residential sector based on EIA’s 2023 California State Energy Profile report. This would reduce the current energy consumption of the residential sector by 19%.

Overall, the study makes a compelling case for the widespread adoption of REA systems, highlighting their potential to contribute towards California's energy efficiency and sustainability goals. By enabling a more resilient and efficient energy infrastructure, REA systems represent a critical advancement in the state's journey toward a cleaner, more reliable energy future.

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Introduction

In recent years, there has been a notable surge in electrification within households in the United States (US) due to a rise of decarbonization efforts and net zero carbon goals within the country. This transformative trend has seen a growing number of households embracing electric vehicles as a sustainable alternative to traditional combustion-engine vehicles, transitioning to fully electric appliances, and adopting solar power generation. These changes are not only reshaping the way we live but are also yielding substantial benefits for consumers. By embracing electrification, many households are experiencing cost savings through reduced fuel expenses, heightened energy efficiency, and a diminished environmental footprint thanks to the elimination of fossil fuel combustion. (Consumer Reports 2020)

Furthermore, electrification extends beyond mere energy substitution; it also ushers in a new era of enhanced capabilities. Companies are actively pushing the boundaries of electric device functionality. For instance, electric vehicles are advancing toward autonomous driving capabilities, while many household appliances can now be controlled via smart phones and other smart devices. In today's market, the term "electrification" is often synonymous with convenience, by promising a more streamlined, connected, and healthy lifestyle. (Marlon 2023)

However, this journey towards an all-electric home is not without its challenges. Grid capacity and reliability have become pressing concerns. With California's ambitious goals for carbon neutrality by 2045, it is estimated that electricity demand will increase by 80%, from 208 TWh of consumption in 2022 to 378 TWh (SCE 2023). Additionally, a report by the California Independent System Operator (CAISO) indicates an increase in California blackouts linked to extreme weather conditions and the growing reliance on renewable energy sources, which has led to a more time-of-use sensitive grid (CAISO 2021). An inadequate response to these conditions could leave households in the dark, impacting people's ability to leave their homes, stay comfortable during harsh weather, or even prepare meals.

How can households strike a balance between the convenience of electrification and the risks associated with an over-reliance on the electricity grid? Enter Residential Energy and Automation (REA) systems—a promising and emerging solution to this issue. REA systems represent a relatively new product category, offering homeowners a means to reduce their dependency on the electrical grid. These systems leverage local power sources, including managing batteries, such as those found in electric vehicles. By storing excess energy and intelligently managing its distribution, REA systems enhance energy resilience, ensuring that households can power essential functions during grid outages. Furthermore, since these systems can integrate with and benefit from existing electrified home infrastructure, the initial cost of entry into the world of extended energy resilience may be significantly lower than anticipated for individuals with existing BESS, EVs, and solar installations.

Background

Residential Energy and Automation (REA) systems are an exciting and forward-thinking product category that builds upon the existing capabilities of Home Energy Management Systems (HEMS) by incorporating intelligent management of residential Demand-side Energy Resources (DERs). These systems can encompass a wide array of functions based on the connected DERs, including the dynamic control of electric vehicle (EV) charging and discharging; efficient management of solar energy production; and integration of battery energy storage systems (BESS) to support home islanding with black start functionality.

REA systems are composed of one or more components installed at the home that have wired or wireless connections to the home's DERs, that can consist of, solar, battery storage, EV charging, and even more exotic DC bound system. The system will monitor the home's electrical generation, backup energy storage capacity based on available sources, and occupant behavior such as charging habits, if applicable.

The most advanced REA systems can adapt to real-time changes in electricity pricing and grid conditions. These systems leverage real-time data and advanced algorithms to make automated, informed decisions about household energy use, allowing occupants to better control their energy consumption to unlock cost savings. By actively responding to fluctuating electricity prices, REA systems empower people to make economically advantageous choices, ultimately putting more money back into their pockets.

REA systems can potentially contribute to the broader energy landscape by offloading excess electricity back into the grid. This two-way interaction between residential properties and the grid can help alleviate grid congestion during peak demand periods and bolster the overall stability of California's energy infrastructure. In essence, REA systems can serve as a conduit for households to actively participate in the energy ecosystem, expanding grid resources and reinforcing the reliability of the entire network.

Objectives

This project's primary objective encapsulates a comprehensive exploration and assessment of REA systems. The project aims to delve deeply into various facets of REA systems, to gain an understanding of their capabilities, installation needs, operating requirements, potential market opportunities, and customer base.

The project will take a snapshot of the current REA market, assessing the current state and expected future developments in these systems. It will examine how REA systems integrate with HEMS and DER hardware to enhance residential energy efficiency and demand flexibility. Project activities will include an assessment of REA systems' claimed electrical efficiency, their ability to provide residential load flexibility, and their overall impact on enhanced grid resilience.

The project aims to assess the benefits of integrating a REA system into new California homes, considering different levels of available DERs and electric appliances and products, under both normal and emergency grid conditions. The project will identify customers uniquely positioned to benefit from a REA system and will utilize that information to quantify potential savings if adopted by California customers.

Methodology & Approach

To accomplish REA project objectives, the research team is following a structured approach that encompasses several key components. The project started with an initial market survey focused on identifying existing and emerging REA systems that boast features and functions related to residential load control, electric vehicle service equipment (EVSE), solar photovoltaic (PV) systems, and BESS. The project team utilized manufacturer data obtained through manufacturer websites or representatives to identify key system characteristics such as energy efficiency between subcomponents, system communication architecture, and unit sizing. Concurrently, the project team conducted a literature review of existing research on HEMS and DER control systems. The review identified reported energy savings of key system features such as intelligent load management, which would be associated with REA systems.

Building upon these findings, the project team conducted energy modeling and analysis. This phase involved the identification and creation of an idealized REA system with associated features. The idealized REA system would combine the best performance qualities of each identified REA system with regard to each branch of DER integration, which include PV and BESS operation and efficiency, and EVSE integration. Systems that do not integrate with PV, BESS, and EVSE have less energy savings potential, due to the inability to apply control strategies to those systems. Additionally, the research team developed a new construction baseline, using publicly available data and California building standards.

The project team applied the modeled systems to the existing California market to quantify their potential impact. By analyzing various IOU tariffs, they assessed energy savings per IOU territory, considering increased energy efficiency, unlocked EV or time-of-use (TOU) rates, and peak demand shifts. Researchers then identified the composition of existing DERs within the IOU territories to determine individuals who are uniquely positioned to benefit from REA adoption and to quantify the grid impact of adopting REA systems within California. Through this modeling and analysis, the project team quantified the energy, demand, and greenhouse gas (GHG) benefits achievable with an REA system, compared with typical, code-compliant new construction homes in California.

Project Findings

To fully understand the potential of REA systems, it is imperative to have a clear and comprehensive understanding of their specifications and features. The first phase of research focused on market characterization and development of applicable energy models. This includes a discussion and evaluation of the baseline home to which various levels of REA integrations were applied. Scenarios include a parametric evaluation of various REA capabilities, such as those enabled through the integration of bi-directional EV chargers and BESS.

Identified Systems

Within the existing market, the research team identified ten REA systems from ten different manufacturers. Four are currently in the prototype stage and limited public information is available. Most REA systems are comprised of multiple components that handle additional functionality, which are often distinguished by the electric loads and energy sources existing within the home. Table 1 lists the identified REAs and their integration capabilities. The corresponding systems are presented in three categories that are tied to REA capabilities, categorized as EV, PV, and BESS. “Integrated” listed in the PV category indicates the system’s ability to manage and redirect power from a solar array. BESS indicates the ability to integrate with a BESS to load shift and provide backup power. EV indicates the ability to charge and/or discharge an EV to unlock additional back up potential. “Not Available” values indicate that the capability was not supported at the time of research.

Table 1: Identified REA Systems And Developmental Status

Identified REAs	EV	PV	BESS	Developmental Status
REA 1	Integrated	Integrated	Integrated	Prototype
REA 2	Integrated	Integrated	Integrated	On Market
REA 3	Integrated	Integrated	Integrated	On Market
REA 4	Integrated	Integrated	Integrated	On Market
REA 5	Not Available	Integrated	Integrated	Prototype
REA 6	Integrated	Integrated	Integrated	On Market
REA 7	Integrated	Not Available	Integrated	On Market
REA 8	Integrated	Integrated	Integrated	Prototype
REA 9	Not Available	Integrated	Integrated	Prototype
REA 10	Not Available	Not Available	Integrated	On Market

Source: Manufacturer Specification Sheets and Representatives.

Manufacturers

Manufacturers with the most mature REA products started in the PV sector and have since expanded, while many newer REA manufacturers are startups or new branches of existing control companies. Systems vary on overall integration priorities. Numerous systems focus on fully optimizing the PV inversion and minimizing DC to AC conversions, while others focus on EV charging and discharging functionality. Understanding a REA system's individual priorities and limitations is key to identifying the underlying benefits of an ideal system.

REA Components and Capabilities

Every REA system identified exhibits distinct capabilities and electrical efficiencies with respect to DER integration. The project team's primary objective was to thoroughly assess and characterize each system's performance in relation to the three most prevalent DERs found in California homes: solar energy, battery energy storage, and EV charging and discharging.

Solar Integration

Almost all identified REA systems support solar integration, which is the ability to manage power produced by solar panels and directed to the home, grid, or available storage. Manufacturers with origins in the solar sector offer the two most energy-efficient options. Although all systems report transmission efficiencies exceeding 96 percent using the CEC inverter testing method, REA 2 leads with 99 percent and REA 3 follows very close behind at 98.4 percent.

While the specific solar input capacity varies from one system to another, it appears to be tailored to match the typical solar sizing requirements of their intended customer base. The highest solar input capacity observed for an individual system is capped at 15.2 kW, most REAs are just under 8 kW which would cover 73 percent of the existing residential solar installations based on the Interconnected project sites data from PG&E, SCE, and SDG&E (Statistics 2023). However, for most REA systems, scalability through redundant units and subcomponents means that the maximum input capacity is less constrained by technical limitations and more influenced by system pricing and the available physical space for system installation. Table 2 provides a detailed characterization of solar integration capabilities.

Table 2: Solar Capabilities Of REA Systems

Identified REAs	Transmission Efficiency (%)	Input (kW)
REA 1	96	10
REA 2	99	7.6
REA 3	98.40	15.2

Identified REAs	Transmission Efficiency (%)	Input (kW)
REA 4	97.50	Unknown
REA 5	96	7.6
REA 6	97	0.245/panel
REA 7	N/A	N/A
REA 8	98	7.7
REA 9	Unknown	9.6
REA 10	N/A	N/A

Source: Manufacturer Specification Sheets and Representatives.

Electrical Vehicle Integration

For EV integration within REA systems, there is a wide range of functionality offered. The potential customer base can be restricted due to the compatibility of charging connector standards, and currently, most systems do not support bidirectional charging and discharging functionality. This feature is pivotal, as it further enhances system flexibility by allowing customers to either offload excess energy or utilize the energy stored in the EV battery within the home, helping to mitigate peak pricing or cope with grid outages. In the absence of the capability to discharge energy to the home or grid, integrated EV functionality remains limited, with flexibility primarily confined to adjusting the timing of EV charging. Table 3 lists the EV integration capabilities for each system.

EV charging output is consistent throughout products and typically ranges from 10 to 12 kW. Several systems offer a boost function that leverages connected DERs to increase charging speed by increasing power density. This feature unlocks higher charging power densities not typically achievable in residential environments, due to limitations associated with grid power throughput to the home.

Table 3: EV Capabilities Of REA Systems

Identified REAs	Connector	Power	Bidirectionality
REA 1	CCS1	10 kW	V2H; V2G
REA 2	SAE J1772-2009	9.6 kW	Not Supported
REA 3	CHAdeMO/CC	15.2kW	V2H; V2G
REA 4	NACS/J1772	11.5 kW	Not Supported
REA 5	N/A	N/A	N/A
REA 6	J1772	11.5 kW	Not Supported
REA 7	SAE J1772	11.5	Not Supported
REA 8	SAE J1772	11.5 kW	Not Supported
REA 9	N/A	N/A	N/A
REA 10	N/A	N/A	N/A

Source: Manufacturer Specification Sheets and Representatives.

BESS Integration

REA systems that offer battery energy storage systems integration have storage capacity that ranges from 5 to 16 kWh. Several systems offer the ability to expand storage further, but this would only increase the backup time, rather than the ability to increase the power available for the attached loads, due to energy throughput limitations. Most REA systems offer compatibility with third-party battery systems along with their own battery options. There are four systems that are currently reliant on third-party batteries, but numerous manufacturers have mentioned a first-party battery being available soon. The most prolific third-party battery option supported by these devices is offered by LG under their residential energy storage unit (RESU) product line. Battery chemistry for all systems is limited to lithium-ion.

Table 4 dives deeper into the individual characteristics, and for systems that are reliant on third-party batteries reflect characteristics found when using the LG RESU, if compatible. For systems with multiple supported batteries, the best-performing battery option is listed in relation to energy efficiency.

Table 4: BESS Capabilities Of REA Systems

Identified REAs	BESS	Efficiency (%)	Capacity (kWh)	Chemistry
REA 1	3rd Party Compatible	97.5	16	Li-Ion NMC
REA 2	1st Party Solution / 3rd Party Compatible	94.5	9.7	Li-Ion NMC
REA 3	1st Party Solution / 3rd Party Compatible	97.5	16	Li-Ion NMC
REA 4	1st Party Solution	90	13.5	Li-Ion NMC
REA 5	1st Party Solution / 3rd Party Compatible	96	17.5	Lithium Iron Phosphate
REA 6	1st Party Solution	89	10	Lithium Iron Phosphate
REA 7	3rd Party Compatible	97.5	16	Li-Ion NMC
REA 8	1st Party Solution / 3rd Party Compatible	Unknown	10	Lithium Iron Phosphate
REA 9	1st Party Solution	Unknown	5 (kWh x n)	Unknown
REA 10	3rd Party Compatible	97.5	16	Li-ion NMC

Source: Manufacturer Specification Sheets and Representatives.

HEMS Component

Home energy management systems are the brain of the REA system, where each subsystem integrates together through wired or wireless connections and where the overall system logic exists. The user will interact with this piece of the system through software either embedded on the REA system, a phone app, or pc download, which is typically accessible through the homes network or direct connection over a wired or wireless protocol. Table 5 outlines the software and connection protocol the HEMs component uses as well as the load control and IOT capabilities.

Table 5: HEMS Capabilities Of REA Systems

Source: Manufacturer Specification Sheets and Representatives.

Identified REAs	Software	Protocol	Load Control	IoT Control
REA 1	Unknown	Wi-Fi	Unknown	Unknown
REA 2	Smartphone App	TCP/IP	networked	yes
REA 3	Smartphone App & Web Portal	RJ45 - TCP/IP Ready	networked	yes
REA 4	Smartphone App	Wi-Fi	no	no
REA 5	Smartphone App	Wi-Fi	integral	no
REA 6	Smartphone App	Wi-Fi	networked	yes
REA 7	Smartphone App	Wi-Fi	panel	no
REA 8	Smartphone App	Wi-Fi	panel	Unknown
REA 9	Smartphone App	Wi-Fi	panel	no
REA 10	Smartphone App	Wi-Fi	panel	no

Modern REA systems are primarily controlled using mobile applications for scheduling DER management. Most systems use Wi-Fi or RJ-45 for communication between components. Load management is achieved in several ways: some systems feature a built-in electrical panel that can cut off individual circuits, others have networked load controllers that can turn high-draw devices on and off, and some include built-in relays to control specific devices or entire circuits.

Certifications

The team gathered the current product certifications for all systems to expand its understanding in relation to industry standards and minimum certified use cases. It is important to note that nearly half of the identified products are in a prototype state so certifications may not be complete and could expand significantly in the future. Certifications are presented as listed on publicly available product documentation.

Table 6: Certifications Of Identified REA Systems

Identified REAs	Inverter/ Interconnection Standards	PV or Battery Safety and Compliance	Electromagnetic compatibility and emissions	Environment and Enclosure	Communication and Cybersecurity	Utility, EV charging or Other
REA 1	UL 1741-SA	No integral battery	None listed (product still in prototype)	NEMA 4, IP-65	None listed (product still in prototype)	UL 2202
REA 2	UL 1741, UL 1741-SA, UL 1741-SB, UL 1741-PCS, IEEE 1547:2018, CA Rule 21, Rule 14H, CSA 22.3 No.9	UL 1699B, UL 9540,	CSA 22.2	None listed	None listed	UL 1998, CSA 22.2, CSA 22.3 No.9
REA 3	Seeking: UL 1741, UL 1741-SA, IEEE 1547.1,	No integral battery	Seeking: FCC Title 47 Part 15	NEMA 3R, IP-54	CC TPM 2.0 at EAL4+, FIPS | Seeking: IEEE 2030.5	UL 9741, UL 2231-1, NFPA 70 (NEC) | Seeking: UL 2594
REA 4	UL 1741, UL 1741-SA, UL 1741-PCS, IEEE 1547, IEEE 1547.1	UL 1699B, UL 3741, UL 1642, UL 1973, UL 9540, UN 38.3	FCC Title 47, part 15 Class B	IEEE 693-2005	None listed	UL 1998, RoHS Directive 211/65/EU, AC156

Identified REAs	Inverter/ Interconnection Standards	PV or Battery Safety and Compliance	Electromagnetic compatibility and emissions	Environment and Enclosure	Communication and Cybersecurity	Utility, EV charging or Other
REA 5	UL 1741, UL 1741-SA, CSA 22.2 No 107.1-01, IEEE 1547, CA Rule 21, Rule 14H	UL 1699B, UN 38.3, UL 1973, UL 9540, UL 9540A	FCC Title 47, part 15 Class B, ICES003	UL 67, UL 916, UL 869A, CSA 22.2 No. 29, CSA 22.2 No 0.19,	CSA 22.2 No. 205	None listed
REA 6	UL 1741, UL 1741-SA, UL 1741-SB, CSA 22.2 No. 107-01, IEE1547:2018, CA Rule 21, NEC 2014, NEC 2017, NEC 2020 section 690.12	Rule 64-218 Rapid shutdown of PV, UL 9540, UL 9540A, UL 991,	FCC Title 47 Part 15 Class B, ICES003, ICES0003 Class B	NEMA 3R		UL 1998, AC156
REA 7	No Integral Inverter	No integral battery	None Listed	NEMA 3R, UL 67, UL 916, UL 869A	TLS 1.2 (minimum)	NEC compliant
REA 8	UL 1741, UL 1741-SA, UL1741-SB, UL 1741-PCS2, UL 1741-PVRSS2, IEEE 1547:2018, CSA 22.2 No. 107.1-16, CA Rule 21	UL 1699B, UL, 9540, UL 9540A, UL95402	FCC Title 47 Part 15, ICES003 Class B, RSS-GEN Issue 5,	None listed (Product still in prototype)	None listed (Product still in prototype)	AC156
REA 9	None listed (Product still in prototype)	UL 9540 A	None listed (Product still in prototype)	None listed (Product still in prototype)	None listed (Product still in prototype)	None listed (Product still in prototype)
REA 10	None listed	None listed	FCC Title 47 Part 15, RSS-Gen, RSP-100	None listed	TLS 1.2 (Minimum)	CSA 22.2: 610610-1

Source: Manufacturer Specification Sheets and Representatives.

Estimating Benefits in California New Construction

To assess the potential advantages of integrating a REA system, it is essential to establish a baseline condition. To ensure comprehensive and pertinent analysis, multiple new construction baseline scenarios are considered to form a well-rounded understanding of REA systems and their benefits.

New Construction Baseline

The new construction baseline is based on California's 2022 Building Energy Efficiency Standards (Energy Code) (CEC 2022) as well as demographic information no more than five years old.

REPRESENTATIVE SOLAR

In the baseline scenario, solar inclusion is required, effective January 1st, 2020, which makes solar installations compulsory for new California homes. The size of the baseline photovoltaic (PV) system is determined by the specifications outlined in §150.1(c)14 of the Residential Solar Ready 2019 Guideline (CEC 2019). The minimum required solar capacity for new construction, kWp, is calculated using the following formula:

$$kWp = 1000\,CFA\,(A) + N_{Dwell}\,(B)$$

Where CFA is the conditioned floor area (ft²), N_{Dwell} is the number of dwelling units within the home, and A and B are defined coefficients based on the climate zone. N_{Dwell} is assumed to be one unit for single-family homes and the conditioned floor area used to calculate the minimum solar size for new home construction is 1,788 square feet, based on the average size of conditioned space in homes with distributed solar generation, per the 2020 residential energy consumption survey (EIA 2020). The minimum required PV sizing is provided in Table 7 for all California climate zones. The average of the listed minimum sizing values for each climate zone, weighted by the zone's population size (California Demographics 2021), equating to 2.486 kilowatt peak (kWp), is used as the baseline new construction solar sizing.

Table 7: Minimum Sizing Of Solar By Climate Zone

Title 24 Climate Zone	A	B	Minimum kWp
1	0.793	1.27	2.69
2	0.621	1.22	2.33
3	0.628	1.12	2.24
4	0.586	1.21	2.26
5	0.585	1.06	2.11

Title 24 Climate Zone	A	B	Minimum kWp
6	0.594	1.23	2.29
7	0.572	1.15	2.17
8	0.586	1.37	2.42
9	0.613	1.36	2.46
10	0.627	1.41	2.53
11	0.836	1.44	2.93
12	0.613	1.40	2.50
13	0.894	1.51	3.11
14	0.741	1.26	2.58
15	1.560	1.47	4.26
16	0.590	1.22	2.27

Source: Project Team.

The project team utilized National Renewable Energy Laboratories' (NREL) PVWatts calculator (NREL 2023) to estimate the energy production of the baseline 2.486 kWp system. The PVWatts tool leverages 30 years of historical data, mainly from the NREL National Solar Radiation Database, which captures solar irradiance and weather patterns within 239 locations within the U.S. The team calculated the solar generation for each climate zone representative city as defined by the California Energy Commission (CEC 2020). Additionally, the team assumed a default module type and a fixed array type to represent a roof-mounted system with no adjustability after installation. System losses, tilt and azimuth were left as defined default values. An efficiency of 96 percent for solar transmission to the home was utilized in line with the typical efficiency values found in existing Californian PV systems. Then a weighted average kWp, based on the population of each climate zone, was utilized to get the representative solar generation value of 4.593 MWh/year for a new construction home (Census 2022) in Table 8.

Table 8: Power Generation From The Representative System For Each California Climate Zone

Climate Zone	Population	Percent of Total State Population (%)	Representative City	Solar Generation (MWh/year)
1	187,942	0.48	Arcata	3.575
2	955,692	2.44	Santa Rosa	4.254
3	4,106,829	10.48	Oakland	4.387
4	2,173,345	5.54	San Jose-Reid	4.558
5	419,049	1.07	Santa Maria	4.684
6	2,876,737	7.34	Torrance	4.667
7	2,243,818	5.72	San Diego-Lindbergh	4.757
8	4,796,462	12.23	Fullerton	4.639
9	5,976,777	15.24	Burbank-Glendale	4.640
10	4,395,589	11.21	Riverside	4.719
11	1,134,717	2.89	Red Bluff	4.265
12	5,202,209	13.27	Sacramento	4.508
13	2,535,722	6.47	Fresno	4.571
14	984,356	2.51	Palmdale	5.095

Climate Zone	Population	Percent of Total State Population (%)	Representative City	Solar Generation (MWh/year)
15	673,399	1.72	Palm Spring-Intl	4.652
16	542,870	1.38	Blue Canyon	4.791

Source: Project Team.

For scenarios where a REA is applied, a transmission efficiency of 99 percent is utilized to represent the idealized case, in line with the highest identified REA specifications. This means solar generation slightly increases to 4.737 MWh/year for an integrated home, due to the enhanced efficiency of an idealized REA system.

REPRESENTATIVE BESS

In the context of a representative BESS, it is important to note that the residential building code for new construction does not mandate its inclusion but does require a BESS-ready interconnection or raceway. Consequently, when establishing baseline conditions, we will examine scenarios without an integrated BESS. In cases with a REA system, the representative BESS will be designed to mirror the performance of the highest-performing and most prolific identified battery: a 16-kWh unit with a round-trip efficiency rating of 97.5 percent (LG RESU).

REPRESENTATIVE VEHICLE

For representative vehicles, the project provides analysis and expected benefits from two viewpoints: with and without an EV connected. In each case the team assumed 2.11 vehicles were present in line with census data for the number of households (Census 2022) and the reported number of registered vehicles in California (BTS 2020). For the scenarios where an EV is not present within the home, a gasoline powered vehicle is utilized. The representative gasoline vehicle has a fuel efficiency of 30.46 mi/gal. This value is gathered from the NREL 2019 California Vehicle Survey (NREL 2023a). The representative EV will utilize a 68.6 kWh battery with an efficiency of 5.13 km/Kwh, based on EV efficiency data from ev-database.org (EVDatabase 2023). With an expected driving range of 35.8 miles per day in line with a 2017 report from the Bureau of Transportation Statistics (BTS 2020) this equates to an 8.43 MWh/year increase in expected energy use per household.

Baseline Energy Utilization (new construction)

Combining the information from the representative systems and utilizing information from the 2019 California Residential Appliance Saturation Study (RASS), which estimates an average annual household energy consumption of 6,174 MWh/year (Claire Palmgren 2021), the project team extracted the baseline annual energy consumption for the pre-REA installation. Baseline outcomes are shown in Table 9, including the energy increase associated with charging the EV in the "With EV/BESS" case. The energy deficit section identifies the necessary power that the home would need to pull from the grid to power the home after solar contributions are applied.

Table 9: Baseline Energy Consumption

	No EV/BESS (MWh/year)	With EV/BESS (MWh/year)
Average household energy consumption	6.174	14.605
Average solar generation	4.593	4.593
Energy Deficit	1.581	10.012

Source: Project Team.

Impact of REA on Baselines

Integrating an ideal REA system into a home enables four primary benefits based on product capabilities. The first benefit is an overall energy consumption reduction due to HEMS implementation enabling advanced control strategies. Second, REA systems often provide advanced charging infrastructure resulting in higher charging efficiencies by leveraging DC bidirectional chargers that integrate directly with other DC components limiting DC to AC conversion losses. Third, REA systems increase solar generation due to higher inverter efficiency due to DC coupling. Last, the systems reduce peak demand by enabling load shifting to allow the home to draw power from local energy storage provided by BESS and/or EV discharging.

HEMS Implementation Benefits

The energy impact of HEMS was extracted from existing published studies. In one study, the University of Oulu conducted a field study where HEMS were installed in 10 households and their use resulted in an average energy savings of 10.1 percent (Sanna Tuomela 2021). A second study found that savings vary depending on the implemented control scheme. Control scheme savings ranged from 13.7 percent to 21.7 percent. The average of all schemes equated to 16.65 percent savings (Bandana Mahapatra 2019). Lastly, according to a pilot program published by Lockheed Martin Energy, which deployed HEMS to 59 homes across the State of New York, reported energy savings reached 16 percent (Lockheed Martin Energy 2017). The project team calculated that HEMS savings, conservatively, may be expressed as the average savings from these studies, which is approximately 14 percent.

DC Charging Benefits

Based on lab data sourced from ev-database.org and the Energy Star EVSE database, the project team determined that DC EVSE present in an ideal REA would consume less energy to charge an electric vehicle than the much more common AC EVSE found in most EV owner garages and parking lots. From a subset of DC EVSE listed in EnergyStar's EVSE database, expected efficiency ranges from 95 percent to 97 percent with an average of 95.8 percent (EnergyStar 2023a). The average efficiency of a subset of Energy Star listed AC EVSE ranged from 98.43 to 99.69 percent with an average of 99.24 percent (EnergyStar 2023). However, EVSE efficiency data does not consider the broader conversions occurring within the vehicle itself and the efficiency of the vehicle's onboard charger and converter that handles the incoming AC or DC power.

DC EVSE converts AC power from the grid to DC power, which then charges the EV battery directly. Therefore, the wall-to-battery efficiency of a DC EVSE system is simply equal to the efficiency of the DC EVSE itself. However, AC EVSE depends on the EV's onboard charger to additionally convert the AC power from the wall into DC power for the battery. According to data sourced from ev-database.org, which analyzed the 10 best-selling EVs in the US, the average onboard charger efficiency is about 85.7 percent (EVDatabase 2023a). Therefore, realized energy at the vehicle is significantly lower when utilizing an AC EVSE versus a DC EVSE. Based on the listed efficiencies, the project team concludes that DC EVSE consumes 10.1 percent less power, compared with an AC EVSE plus on-board conversions, which yields just 85 percent efficiency when combined.

Solar Benefits

Expected solar benefits associated with the idealized REA solution are due to the enhanced inverters exclusive to certain REA products. According to NREL's PVWatts calculator, the typical home solar inverter is 96 percent efficient. Findings show that all identified REAs leverage inverters meet or exceed this value. One REA claims a maximum of 99 percent transmission efficiency. Therefore, homes with an idealized REA system may generate about three percent more solar energy than the baseline new home.

Peak Demand Benefits

Homes with REA systems can island themselves during peak hours by switching from grid-supplied to local energy storage provided by a BESS or bidirectional EV charger coupled with a suitable EV. With an idealized REA system, and BESS size of 16 kWh, homes can expect more than 24 hours of energy availability. Additional hours are available if a discharging-capable EV is also on-site.

Annual Energy Savings with REA

Annual energy savings vary significantly based on the inclusion of an EV. The resulting analysis is computed for four different scenarios: "Baseline w/o EV" applying the baseline model with no EVs in the home, "REA w/o EV" applying a REA system to the baseline model with no EVs in the home, "Baseline w/ EV" applying the baseline model with EVs in the home, and "REA w/ EV" applying a REA system to the baseline model with EVs in the home.

REA ENERGY SAVINGS WITHOUT ELECTRIC VEHICLE

The baseline modeled system architecture consists of a home without an EV. A full schematic is shown in Figure 1. The baseline model includes the representative solar system and paired solar inverters typical of a newly constructed California home compliant with the 2023 Energy Code. Figure 2 displays the general system architecture with a REA system installed. This includes the addition of enhanced solar inverted and integrated BESS.

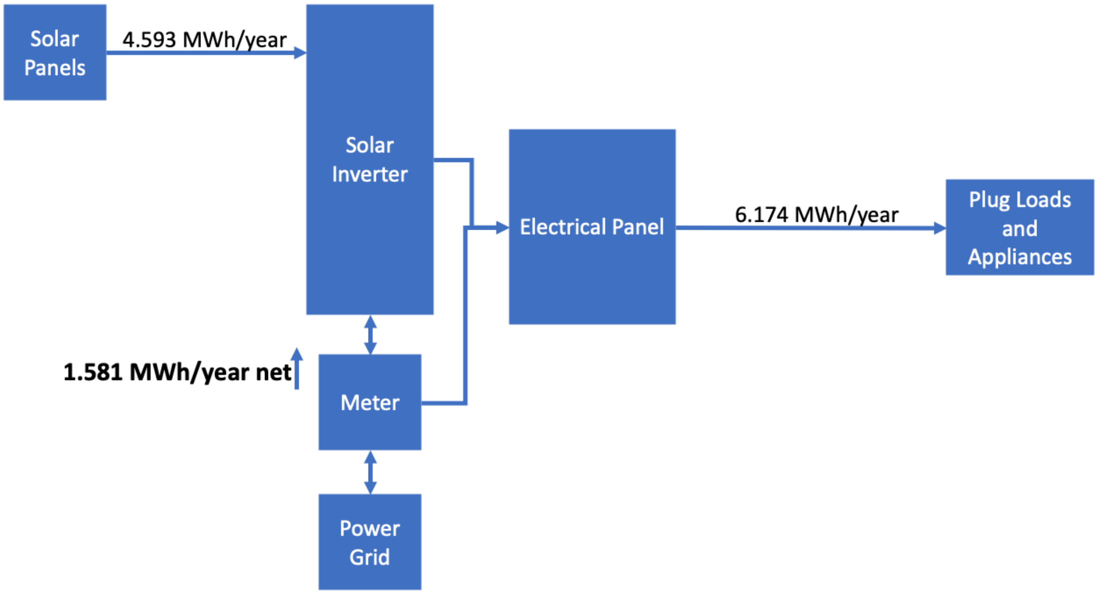


Figure 1: Baseline system architecture without EV (baseline w/o EV).

Source: Project Team.

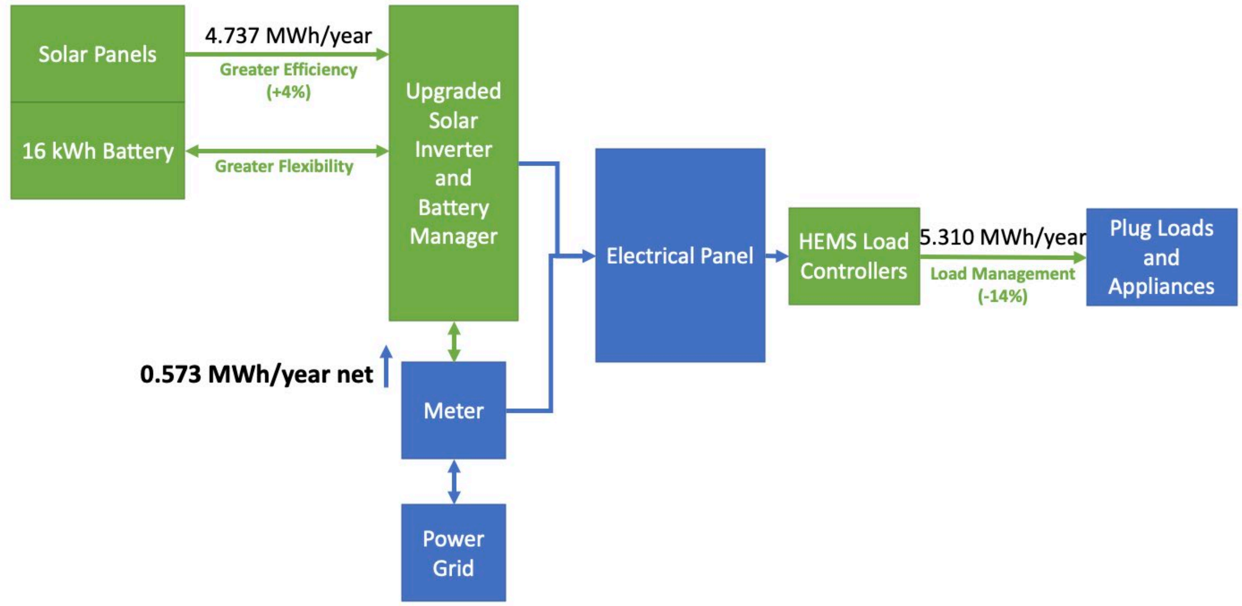


Figure 2: Idealized REA system architecture without EV (REA w/o EV).

Source: Project Team.

With a REA system installed, overall home energy use is reduced, compared with the baseline, due to the aforementioned outlined benefits in REA transmission efficiencies. In the baseline scenario with no EV applied, solar is well suited to offset most of the home's energy use, accounting for 74.4 percent of the home's necessary power, meaning only 1.581 MWh of energy is needed to be sourced from the grid. However, when applying the idealized REA, net energy use can be reduced even further. Net energy use may be reduced by 64 percent, from 1.581 MWh to 0.573 MWh, equating to a 1.008 MWh savings (see Table 10).

Table 10: Energy Utilization

Energy Utilization	Baseline w/o EV Annual Energy Use (MWh)	REA w/o EV Annual Energy Use (MWh)
Home Energy Use	6.174	5.310
Solar Production	(4.593)	(4.737)
Net Use	1.581	0.573

Source: Project Team.

REA ENERGY SAVINGS WITH ELECTRIC VEHICLE

Applying an EV to the model to replace a gasoline vehicle assumes the baseline home utilizes a typical level 2 AC charger. Expected charging efficiency is based on the previously outlined average efficiency of the subset of EnergyStar EVSE systems and average on-board charging efficiency, resulting in a combined transmission efficiency of 85 percent. Figure 3 shows the baseline system architecture with an EVSE installed. In the idealized REA system, the AC EVSE is displaced with an integrated DC EVSE that is DC bound to the inverter, with the identified 95.8 percent efficiency, as seen in Figure 4.

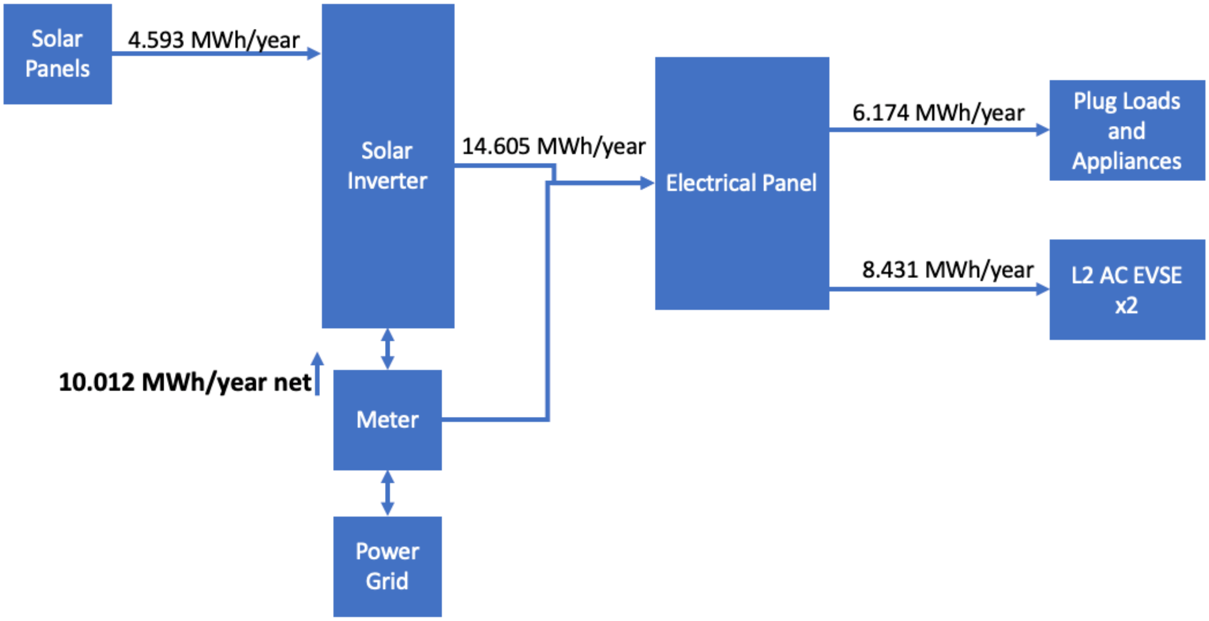


Figure 3: Baseline system architecture with EV (baseline w/EV).

Source: Project Team.

Figure 4

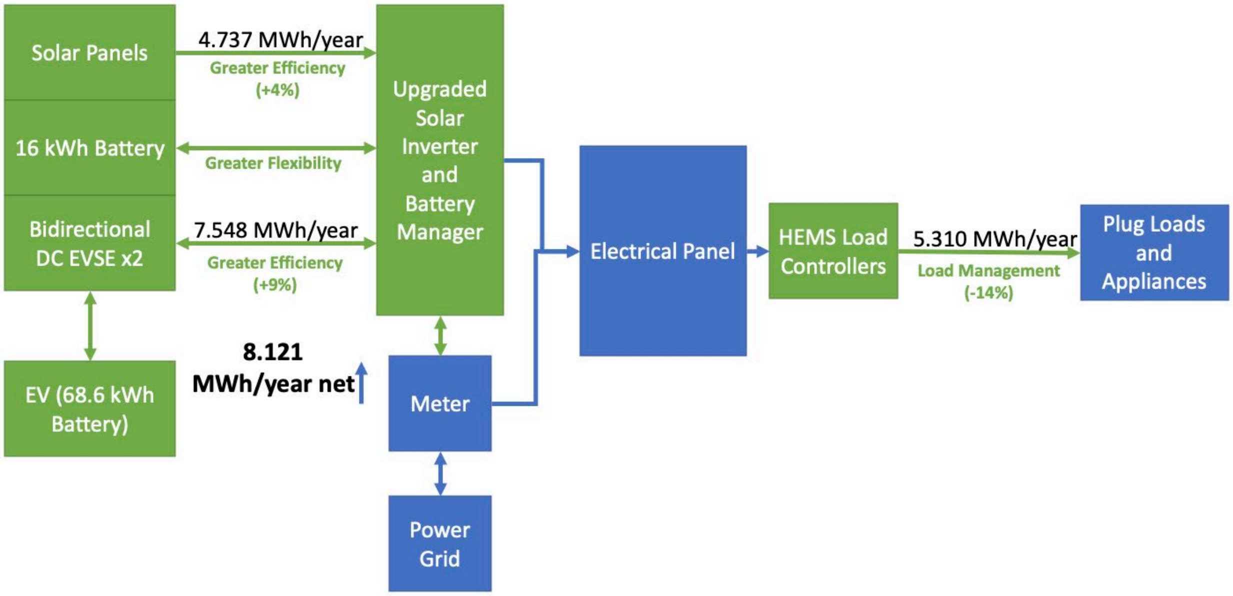


Figure 4: Idealized REA system architecture with EV (REA w/EV).

Source: Project Team.

Consequently, with the inclusion of an EV, electricity use increases significantly. However, since the AC charger is less efficient than the DC charger, when considering power transmission to the EV battery, the actual increase is 10.1 percent less with the DC charger based on the aforementioned DC charging benefits. This in turn means the overall savings when an EV and REA are utilized is 18.89 percent, compared with the baseline, saving 1.891 MWh annually.

Table 11: Energy Utilization (with EV integration)

Energy Utilization	Baseline w/ EV Annual Energy Use (MWh)	REA w/ EV Annual Energy Use (MWh)
Home Energy Use	6.174	5.310
Solar Production	(4.593)	(4.737)
EV Charging	8.431	7.548
Net Use	10.012	8.121

Source: Project Team.

GHG Emissions Reductions with REA

Modeled GHG emissions were reduced in scenarios where the gasoline vehicle was displaced by an electric vehicle. Carbon dioxide emissions from the gasoline vehicle are approximated at 8.03 metric tons (mt) based on the EPA's average reported CO2 emissions for all gasoline vehicles (EPA 2023) and using an average miles traveled per day of 35.80 (BTS 2020). Additionally, CO2 emissions for electricity generation are assumed to be 0.18 kg per kWh, based on total California emissions from electricity and electricity generated in 2021 (EIA 2022).

REA systems enable an emissions reduction of four percent in the baseline scenarios with the gas-powered vehicle, and 20 percent in cases where an EV is utilized. Details are shown in Table 12.

Table 12: Emissions with Baseline and REA Systems

	Baseline: Gas Vehicle (mt)	REA: Gas Vehicle (mt)	Baseline: EV (mt)	REA: EV (mt)
Energy Used within Home	0.34	0.16	0.34	0.16

	Baseline: Gas Vehicle (mt)	REA: Gas Vehicle (mt)	Baseline: EV (mt)	REA: EV (mt)
EV operation	-	-	1.58	1.41
Gas Vehicle operation	8.03	8.03	N/A	N/A
Net emissions	8.37	8.19	1.92	1.57

Source: Project Team.

Annual Cost Savings for REA by IOU

EXISTING IOU TARIFFS

To evaluate cost savings when implementing an REA system, it is necessary to analyze current IOU tariffs. This evaluation focuses on three IOUs: Southern California Edison (SCE), Pacific Gas & Electric (PG&E), and San Diego Gas & Electric (SD&E), which collectively service a majority of California. Each IOU offers various tariff structures, a number of which are only available to customers with specific DERs or functionality within the home, such as energy storage or additional submetering. Due to the flexibility of REA systems and the potential for load shifting, a time-of-use (TOU) rate structure has the most impact on the modeled home. SDG&E has nine currently available relevant TOU structures, SCE has three, and PG&E has six. Many TOU rate structures that offer significant savings during off-peak hours are limited to homes with registered EV vehicles, necessitating an evaluation of multiple rate structures to assess the overall impact. Table 13 identifies the rate structures used for the four defined scenarios, selected based on IOU program recommendations and connected infrastructure. In most scenarios, registering an EV introduces additional rate structures with better off-peak pricing compared to general TOU rates.

Table 13: Selected Tariffs for Scenarios

IOU Rates	Baseline w/o EV	REA w/o EV	Baseline w/ EV	REA w/ EV
SCE	TOU-D-Prime	TOU-D-Prime	TOU-D-Prime	TOU-D-Prime
PG&E	E-TOU-D	E-TOU-D	EV2-A	EV2-A

IOU Rates	Baseline w/o EV	REA w/o EV	Baseline w/ EV	REA w/ EV
SDG&E	TOU-DR-p	TOU-DR-p	EV-TOU-5p	EV-TOU-5p

Source: Project Team, IOU Rate Guides

Figure 5, Figure 6, Figure 7, Figure 8, and Figure 9 illustrate individual rate structures for the selected tariffs (PGE 2024) (SDGE 2024) (SCE 2024). For SCE the selected rate structure applies to all four scenarios, as a solar-only installation includes the same rates as other clean energy technologies, such as EVs and BESS.

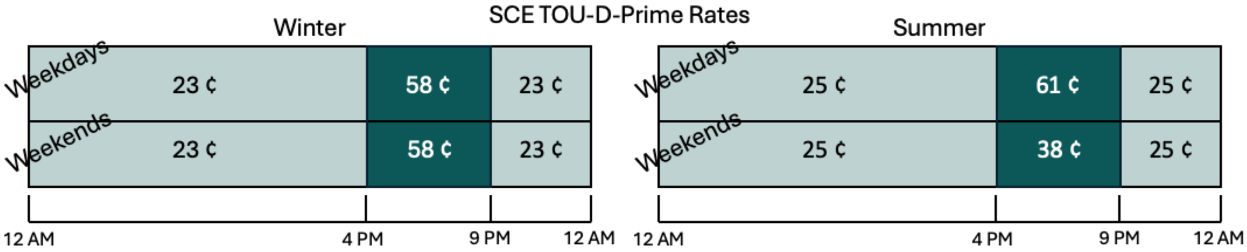


Figure 5: SCE TOU-D-Prime rates.

Source: SCE

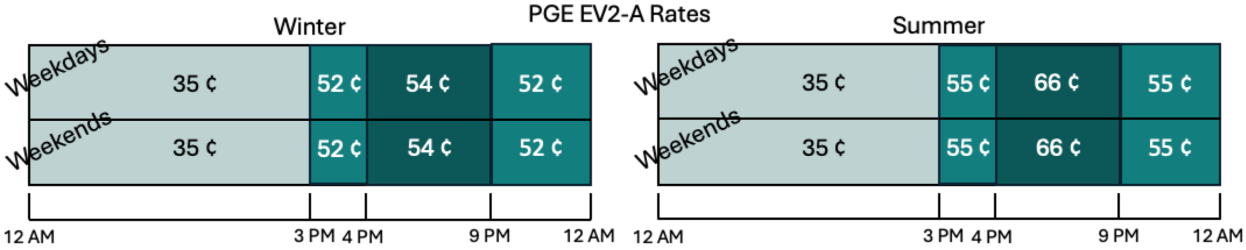


Figure 6: PG&E EV2-A rates.

Source: PG&E

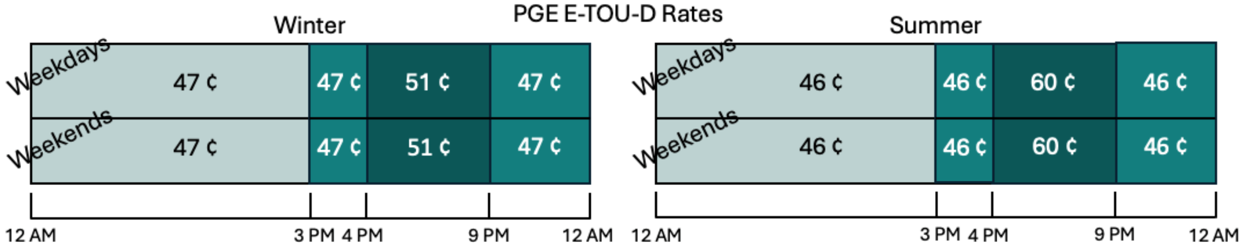


Figure 7: PG&E E-TOU-D rates.

Source: PG&E

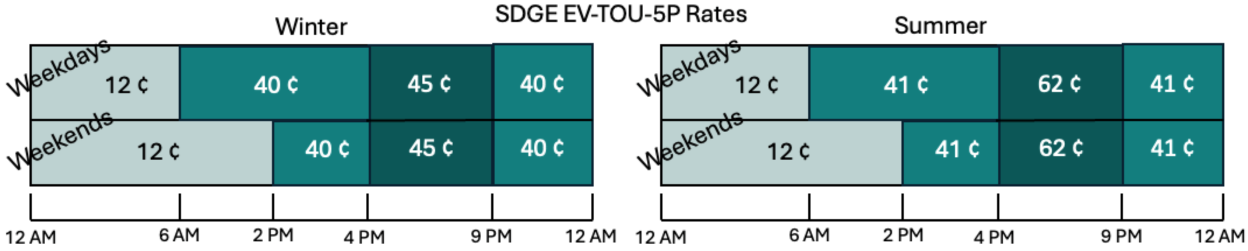


Figure 8: SDG&E EV-TOU-5P rates.

Source: SDG&E

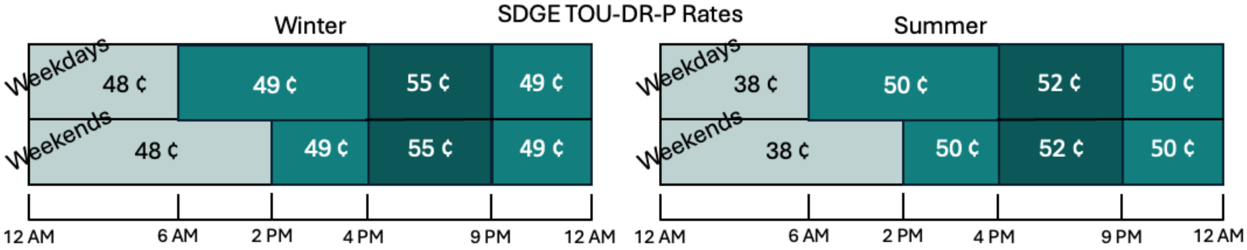


Figure 9: SDG&E TOU-DR-P rates.

Source: SDG&E

To apply the rate tariffs, the research team formatted the computed energy use for a baseline and REA conditions into various hourly rates. The research team used load profiles from NREL's Commercial and Residential Hourly Load Profiles Database (NREL 2014) to compute hourly use for each scenario, distinguishing between weekends, weekdays, winter, and summer. Appendix 1 contains detailed hourly use for each case. Starting analysis does not have solar contributions or load shifting applied to understand pricing solely from the energy use needs of the scenarios. For scenarios with EVs, the baseline scenario is based on charging for three hours starting at 10 pm using a Level 2 AC EVSE, assuming the occupant would start EV charging before going to sleep. In the REA integrated scenario, the system pushes charging to the lowest prices starting at midnight, fully charging the EV in one hour due to the higher energy throughput provided by a DC EVSE.

The resulting daily energy cost for scenarios without solar and load-shifting contributions can be viewed in Table 14.

Table 14: Daily Cost per Scenario

Daily Cost per Scenario	Baseline w/o EV	REA w/o EV	Baseline w/ EV	REA w/ EV
SCE Winter weekday	Tou-D-Prime $ 5.84	Tou-D-Prime $ 5.03	Tou-D-Prime $ 11.14	Tou-D-Prime $ 9.71
SCE Winter weekend	Tou-D-Prime $ 3.72	Tou-D-Prime $ 3.20	Tou-D-Prime $ 9.02	Tou-D-Prime $ 7.88
SCE Summer weekday	Tou-D-Prime $ 7.54	Tou-D-Prime $ 6.49	Tou-D-Prime $ 13.30	Tou-D-Prime $ 11.58
SCE Summer weekend	Tou-D-Prime $ 5.69	Tou-D-Prime $ 4.89	Tou-D-Prime $ 11.45	Tou-D-Prime $ 9.98
PG&E Winter weekday	E-TOU-D $ 8.28	E-TOU-D $ 7.12	EV2-A $ 18.24	EV2-A $ 13.63
PG&E Winter weekend	E-TOU-D $ 5.26	E-TOU-D $ 4.52	EV2-A $ 15.48	EV2-A $ 11.25
PG&E Summer weekday	E-TOU-D $ 10.28	E-TOU-D $ 8.84	EV2-A $ 21.08	EV2-A $ 15.68
PG&E Summer weekend	E-TOU-D $ 9.82	E-TOU-D $ 8.44	EV2-A $ 20.63	EV2-A $ 15.29

Daily Cost per Scenario	Baseline w/o EV	REA w/o EV	Baseline w/ EV	REA w/ EV
SDG&E Winter weekday	TOU-DR-p $ 8.71	TOU-DR-p $ 7.49	EV-TOU-5p $ 13.54	EV-TOU-5p $ 7.95
SDG&E Winter weekend	TOU-DR-p $ 5.49	TOU-DR-p $ 4.72	EV-TOU-5p $ 10.19	EV-TOU-5p $ 5.12
SDG&E Summer weekday	TOU-DR-p $ 9.99	TOU-DR-p $ 8.59	EV-TOU-5p $ 16.22	EV-TOU-5p $ 10.26
SDG&E Summer weekend	TOU-DR-p $ 8.83	TOU-DR-p $ 7.60	EV-TOU-5p $ 14.13	EV-TOU-5p $ 8.41

Source: Project Team

Table 15 shows annual costs, assuming 86 weekdays and 36 weekend days in the summer period, and 149 weekdays and 94 weekend days in the winter period.

Table 15: Annual Cost per Scenario

Annual Cost per Scenario	Baseline w/o EV	REA w/o EV	Baseline w/ EV	REA w/ EV
SCE	$ 2,073.32	$ 1,783.18	$ 4,068.93	$ 3,569.72
PG&E	$ 2,965.56	$ 2,550.56	$ 6,738.86	$ 5,029.31
SDG&E	$ 2,990.93	$ 2,572.38	$ 4,886.08	$ 2,866.06

Source: Project Team

PG&E and SDG&E show significant REA savings, primarily due to differences associated with EV charging. Even with EV charging in the baseline scenarios occurring well after on-peak pricing, full pricing reduction does not occur until after midnight, indicating substantial savings potential with intelligent charging.

When factoring in solar generation and load shifting enabled by BESS, the energy profiles of homes shift significantly. Homes with REAs can shift energy use entirely to off-hours, while baseline homes without BESS can only partially offset based on available solar generation. The Representative Solar section and the California Solar Initiative Working Data Set (California Distributed Generation Statistics 2024) provide the metrics for average hourly solar generation used in these scenarios. If no BESS is available to store excess solar energy, it is calculated that the utility buys the excess at the specified charge rate. Figure 10 shows average solar generation applied to the scenarios, while Appendix 1 details specified daily energy use.

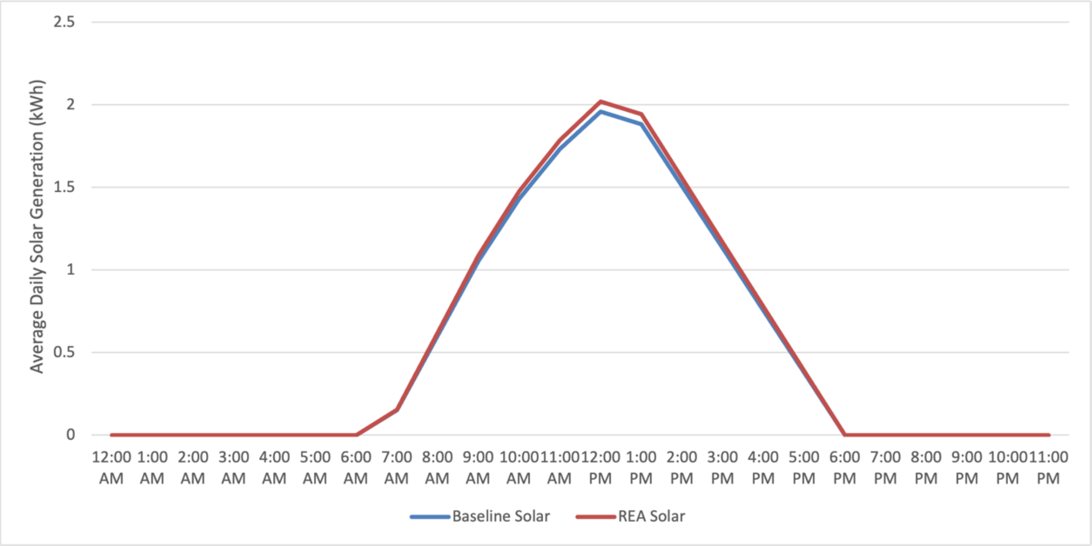


Figure 10: Average daily solar generation.

Source: Project Team, California Solar Initiative

Resulting annual energy cost with solar applied can be viewed in Table 16.

Table 16: Annual Cost Per Scenario With Solar And Load Shifting Applied

Annual Cost per Scenario	Baseline w/o EV	REA w/o EV	Baseline w/ EV	REA w/ EV
SCE	$ 849.82	$ 107.46	$ 2,845.42	$ 1,886.72
PG&E	$ 791.92	$ 212.08	$ 4,962.11	$ 2,762.32
SDG&E	$ 752.15	$ 125.68	$ 3,306.17	$ 623.99

Source: Project Team

Results indicate that customers save in every case where a REA is applied, with substantial savings if a TOU rate is used with low-priced off-peak energy, such as SDG&E. At 12 cents for off-peak kWh, SDG&E customers save significantly more than PG&E and SCE customers, who face 35 cents and 23 to 25 cents off-peak pricing, respectively.

TOU structures, combined with REA systems, offer significant value by avoiding peak pricing and shifting power usage to off-peak hours. With the specified battery and identified home energy use, homes can become entirely grid-independent during on-peak periods, with battery and vehicle charging occurring at night to prepare for the next day.

To provide an adequate pricing comparison between the EV and non-EV scenarios cost inclusion of the vehicle fuel expenses needs to be taken into account. As elaborated on in the Representative Vehicle section for scenarios without EV, a gasoline vehicle with a fuel economy of 30.46 mi/gal (NREL 2023a) is used with an expected driving range of 35.8 miles per day (BTS 2020) for 2.11 vehicles on average. Pairing this with the average price of gasoline, $5.13 /gal, as published by the Energy Information Administration (EIA 2023a), equates to an annual gas bill of $4,637.34. These results can be viewed in Table 17.

Table 17: Annual Cost Per Scenario With Equivalent Vehicles' Gas Bill Applied

Annual Cost per Scenario	Baseline w/o EV	REA w/o EV	Baseline w/ EV	REA w/ EV
SCE	$5,487.16	$4,744.80	$ 2,845.42	$ 1,886.72
PG&E	$5,429.26	$4,849.42	$ 4,962.11	$ 2,762.32
SDG&E	$5,389.49	$4,763.02	$ 3,306.17	$ 623.99

Source: Project Team

REA Adoption Payback

Currently, fully DER-ready REA systems on the market range from $5,000 to $10,000 dollars to purchase, including supplied EVSE charging components. An estimation of the payback period can be viewed in Table 18, assuming that energy pricing grows at 2.6 percent in line with the historic growth reported by the California Public Utilities Commission (CPUC 2024). However, with REA systems at their infancy, pricing is expected to drop as the system matures.

Table 18: Payback Period for REA Systems

Annual Cost per Scenario	Payback w/o EV (years)	Payback w/ EV (years)
SCE	6.28 – 11.68	4.97 – 9.33
PG&E	7.89 – 14.39	2.24 – 4.35
SDG&E	7.34 – 13.49	1.84 – 3.62

Source: Project Team

Applying Benefits to California

To understand the potential impact REA systems can have within California, it is necessary to analyze the existing landscape and customer base and determine the customers with existing DERs that are positioned for easier REA adoption. Table 17 provides a detailed view of IOU electric customers, determined by IOU's Rule 21 Interconnected Project Site Data Set (California Distributed Generation Statistics 2024).

Table 19: Number of Electric Customers Per IOU

IOUs	Electric Customers
PG&E	4,848,617
SCE	5,152,840
SDG&E	1,231,031
Total	11,232,488

Source: Rule 21 Interconnected Project Sites Data Set

Existing Solar Installations and Expected Growth

REA systems are designed with a wide DC input range to support connection to a variety of solar panels, and the majority of existing solar installations can be adapted to support REA integration. Residential solar sites total 1,609,934 installations within the defined IOU territories, distribution can be seen in Table 18. This is 14.33 percent of the total 11.2 million supported electrical customers across the three major IOUs (California Distributed Generation Statistics 2024).

Table 20: Number Of Residential Solar Sites Per IOU

IOUs	Residential solar sites	% of customers
PG&E	752,942	15.53%
SCE	585,135	11.36%
SDG&E	271,857	22.08%
Combined	1,609,934	14.33%

Source: Rule 21 Interconnected Project Sites Data Set, Project Team

SDG&E has the highest ratio of solar adoption at 22.08 percent with PG&E then SCE trailing at 15.53 percent and 11.36 percent, respectively. Average solar size can be determined from data provided by the IOU's rule 21 interconnected reports (California Distributed Generation Statistics 2024) broken down by service territory. Values can be viewed in Table 19.

Table 21: Average Size Of Installed Solar By IOU

IOU	Mean Solar Size (kW)
PG&E	6.423
SCE	6.680
SDG&E	6.502
Combined	6.535

Source: Rule 21 Interconnected Project Sites Data Set, Project Team

Historic approved solar connections can be determined by the rule 21 interconnected reports (California Distributed Generation Statistics 2024) to give an insight into current adoption rates and trends. Over the last decade, solar installations have increased exponentially. Using the Prophet procedure (Meta n.d.) the historical data was applied to an additive model for non-linear growth to forecast installations until 2030. The number of solar installations per year is predicted to reduce over the next few years, compared with 2022, most likely due to the inflated installation in 2022 due to NEM 2.0 ending for new solar customers in 2023. This would result in an expected 2.5 million solar installations by 2028, increasing the adoption rate from 14.33 percent to 22.39 percent.

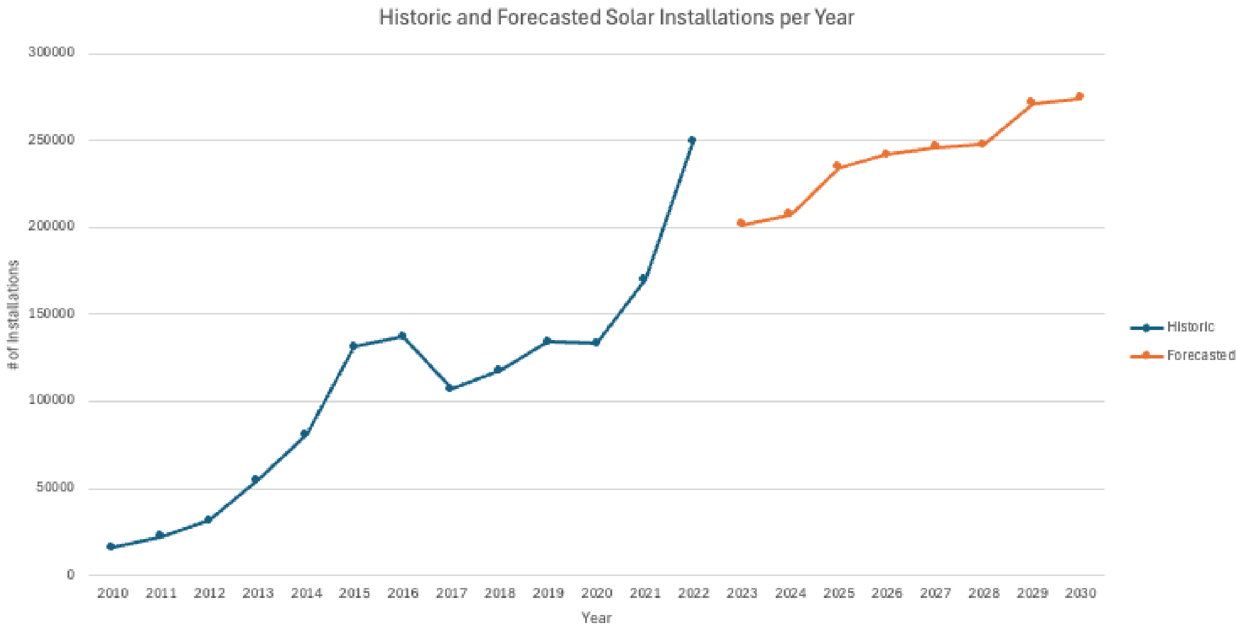


Figure 11: Solar installation forecast, based on historic trends.

Source: Project Team, Rule 21 Interconnected Project Sites Data Set

Existing BESS Installations and Expected Growth

Similar to existing solar connections, most existing BESS installations are able to be integrated with REA installations. However, there may be limitations in terms of data reporting capabilities and management, due to the various communications standards. BESS installations are taking place at a lower rate than solar, only totaling 141,644 installations, attributing to a 1.26 percent adoption rate.

Table 22: Number of Residential BESS interconnections by IOU

IOU	Residential BESS	% of customers
PG&E	73,016	1.51%
SCE	47,152	0.92%
SDG&E	21,473	1.74%
Combined	141,644	1.26%

Source: Rule 21 Interconnected Project Sites Data Set

Average BESS size can be viewed in Table 21.

Table 23: Average Size of Installed BESS by IOU

IOU	Mean BESS size (kWh)
PG&E	7.098
SCE	7.176
SDG&E	6.755
Combined	7.010

Source: California Energy Storage System Survey

The adoption rate of BESS can be determined by data from CEC's California Energy Storage System Survey (CEC 2024). Over the last decade, BESS installations have increased exponentially. Applying a prophet forecast to BESS data predicts installation will continuously increase over the next six years. This would translate to 423,812 installations, equating to a 3.77 percent adoption rate, compared with the existing 1.26 percent.

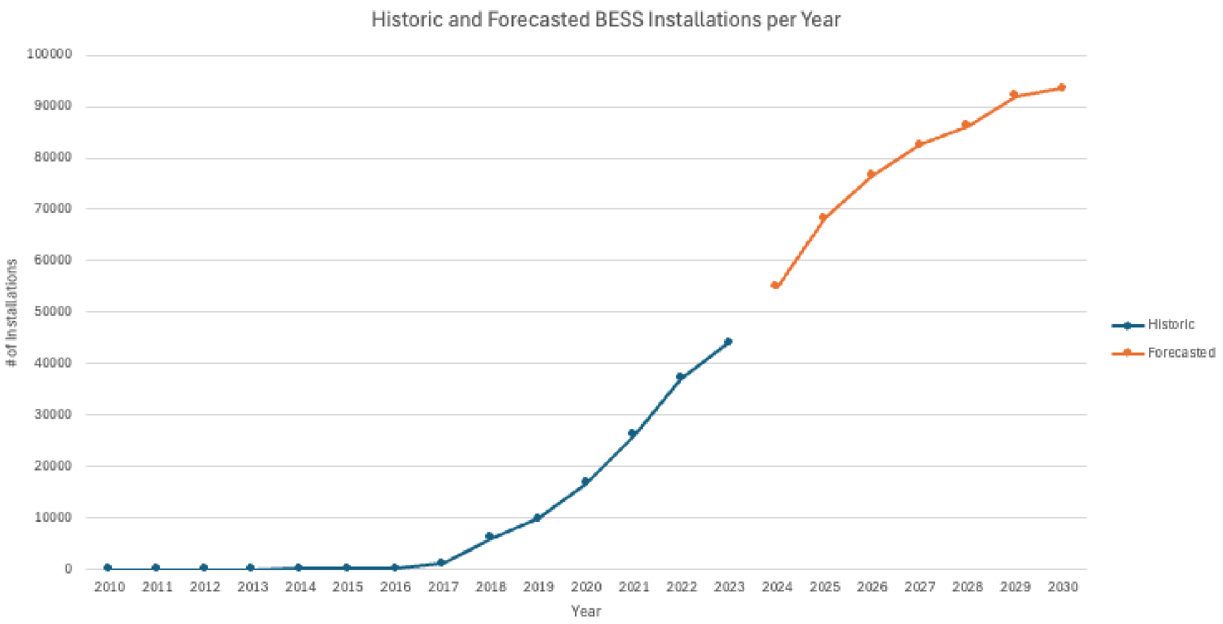


Figure 12: BESS installation forecast, based on historic trends.

Source: Research Team, California Energy Storage System Survey

Expected growth would translate into an additional 1,998 MW of capacity, assuming installation sizes remain constant. A portion of this growth should be attributed to the Self Generation Incentive Program (SGIP). This program started in 2020 and gives rebates to qualifying customers that cover

15 percent to 100 percent of the BESS cost. This program's continued funding would be necessary to maintain the current growth.

Existing EVs and Expected Growth

To understand the historic growth of EVs, the research team utilized CEC's California Light-Duty Fleet Statistics (CEC 2023), which details the light-duty fleet by year, fuel type, county, and zip code. By combining this data with data from the Distributed Generation Interconnection Program (California Distributed Generation Statistics 2024) the team was able to generate the number of zero-emission vehicles (ZEV) and fossil fuel vehicles (FFV)s currently registered in California.

Table 24: Number of ZEV And FFV Per IOU

IOU	Num ZEV	Num FFV	% Electric
PG&E	563,985	9,799,564	5.44%
SCE	590,452	11,239,768	4.99%
SDG&E	151,361	2,572,250	5.56%
Other	210,309	4,217,274	4.75%

Source: California Light Duty Fleet Statistics, Research Team

Future forecasting is based on three sources: historical data from the CEC's California Light Duty Fleet Statistics on the ZEV and FFV population, which goes back to 2010 (CEC 2023); California's new car sales data from the California New Car Dealers Association (California New Car Dealer's Association 2024); and, the goals for ZEV sales percentages set by the California Air Resources Board (California Air Resources Board 2023). Forecasting also makes four assumptions: the ratio of cars removed from the fleet each year remains constant and includes a fair share of ZEVs, car makers will meet milestones set out by the California Air Resources Board, new car sales in California will trend upward linearly at the rate they did from 2010 to 2023, and all cars added to the California fleet are sold in California. Given these sources and assumptions, the data and projected data are shown in Figure 1.

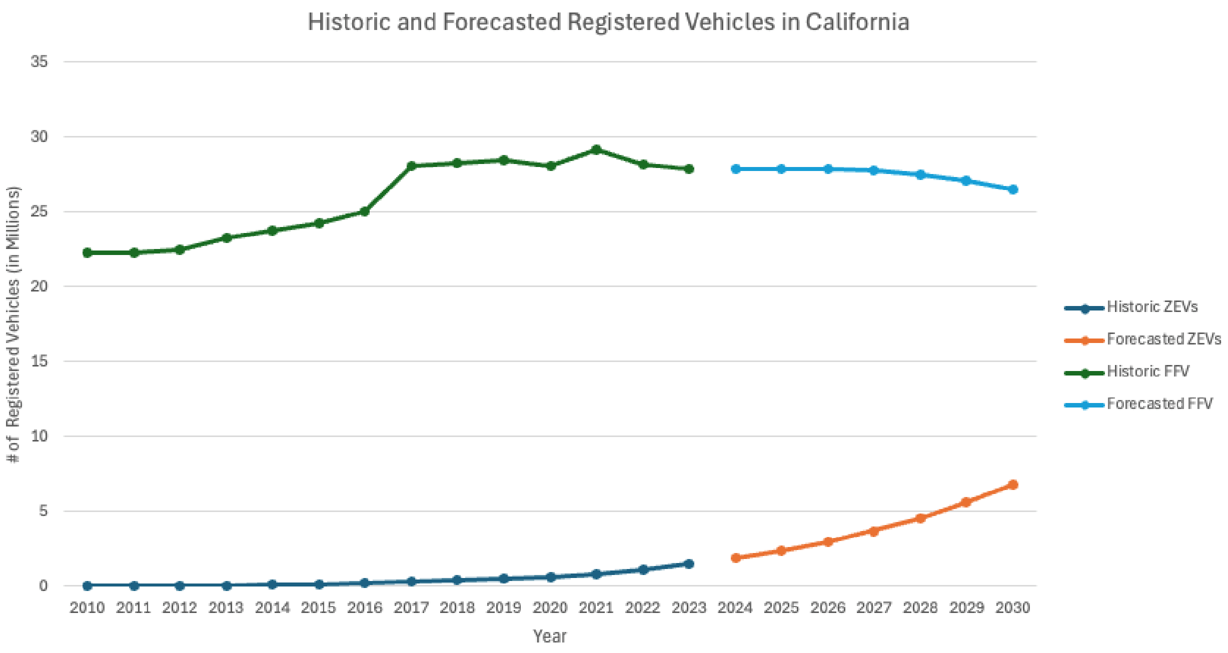


Figure 13: Registered ZEV forecast, based on historic trends.

Source: Research Team, California Light Duty Fleet Statistics, California New Car Dealers Association, CARB

If the ZEV population continues its exponential upward trajectory, the fleet is expected to more than double in size within three years, with an expected 3,716,558 ZEVs by 2028. An overall fleet conversion of 40 percent is expected by 2035, at which time California then aims to mandate ZEVs.

Assessing IOU Customer Base

Based on the Rule 21 interconnected reports, the research team was able to break down the data on the corresponding IOU customers who are in the unique position to benefit from a REA system, and who potentially have an easier adoption path, due to existing DERs within the home. Of the 1,661,430 listed residential interconnections in California IOU territory as of November 2023, 1,516,027 sites, or 91.25 percent, have only solar connected, which accounts for 13.5 percent of the IOU customer base. The second highest breakdown is customers with solar connections and EVs, which makes up 3.02 percent of the IOU customer base. Values for each combination of accepted interconnections can be viewed in Table 23.

Table 25: Interconnection Breakdown, Based On Interconnected Reports

	Reported Interconnections	% of Residential Interconnections	% of IOU Customers
Solar Only	1,516,027	91.25%	13.50%

	Reported Interconnections	% of Residential Interconnections	% of IOU Customers
Solar + EV	50,187	3.02%	0.45%
Storage Only	35,893	2.16%	0.32%
Storage + EV	2,647	0.16%	0.02%
Solar + Storage	47,521	2.86%	0.42%
Solar + Storage + EV	8,332	0.50%	0.07%
Other	823	0.05%	0.01%

Source: Rule 21 Interconnected Reports

Only 8.75 percent of reported interconnections include integration with options outside only solar. The remaining breakdown can be viewed in Figure 14. The “Other” category includes interconnections such as wind, geothermal, and other fringe cases that are outside REA’s targeted consumers.

However, it is important to note that this breakdown only accounts for 61,166 EV owners, which is a relatively small portion compared with the registered 1,516,107 in California. This could be for a number of reasons. First, if homeowners purchased an EV after approved interconnections, then it would not be captured in the dataset. A second reason would be if the EV owner does not have any interconnections within the home, which would put them in an eighth category of households with only EVs available.

To supplement this missing link, researchers used data from NREL’s The Electric Vehicles-Solar Photovoltaic Nexus (NREL 2023) which surveyed Californian EV-PV relationships and found that 25 percent of EV owners also own solar. Applying this ratio to the installation data and registered EVs allowed the researchers to properly group the unaccounted EV households. The resulting install base can be viewed in Table 24, assuming uniform application with the unaccounted-for EVs.

Table 26: Number of Customers With Connected DERs

	# of Customers Interconnection Installation Data	# of Customers Adjusted for unaccounted EVs	% of IOU customers
Solar Only:	1,516,027	1,412,157	12.57%
Solar + EV:	50,187	154,057	1.37%
Storage Only:	35,893	30,415	0.27%
Storage + EV:	2,647	8,125	0.07%
Solar + Storage:	47,521	30,277	0.27%
Solar+Storage+EV:	8,332	25,576	0.23%
EV only:	N/A	538,901	4.80%
Combined:	1,660,607	2,199,508	19.58%

Source: Research Team, Rule 21 Interconnected Report, Solar Photovoltaic Nexus

From this analysis, the project team found that 19.58 percent of IOU customers are positioned to benefit from a REA system at a reduced cost and installation effort, due to existing connected infrastructure. Applying the expected solar, EV, and BESS market growth, there would be an increase of 1.8 million relevant customers/households by 2028. Table 25 shows a table with the expected growth of IOU customers, based on individual technology adoption growth. By 2028, customers that could benefit from REA adoption by utilizing an existing DER would account for 35.6 percent of the IOU customer base.

Table 27: Forecasted Number Of Customers With Connected DER In 2028

	Current Customers by 2024	Predicted Customers by 2028	Predicted % of IOU Customers
Solar Only:	1,255,221	2,189,643	19.49%

	Current Customers by 2024	Predicted Customers by 2028	Predicted % of IOU Customers
Solar + EV:	310,993	238,876	2.13%
Storage Only:	22,137	136,558	1.22%
Storage + EV:	16,403	41,558	0.37%
Solar + Storage:	4,222	46,946	0.42%
Solar+Storage+EV:	51,631	39,658	0.35%
EV only:	1,127,080	1,306,279	11.63%
Combined	2,787,687	3,999,528	35.61%

Source: Research Team

Assuming a uniform five percent REA adoption from the identified current customers, California would unlock 44 GWh of energy savings annually, with peak hour reductions of 18.51 MW, should load islanding occur. Savings would increase linearly, based on adoption rate and further savings could be unlocked by customers acquiring Solar, EV, or BESS should one not already be acquired.

Table 28: Energy Saved And Grid Capacity Unlocked By 5% REA Adoption From Current DER Equipped IOU Customers

5% REA adoption by Customers with DERs	# of households w/ REAs adopted	Annual Energy Saved (MWh)	Peak Hour Reduction (MW)
Solar Only:	70,608	10,167.53	N/A
Solar + EV:	7,703	7,910.84	11.48
Storage Only:	1,521	N/A	2.27
Storage + EV:	406	358.74	0.61

5% REA adoption by Customers with DERs	# of households w/ REAs adopted	Annual Energy Saved (MWh)	Peak Hour Reduction (MW)
Solar + Storage:	1,514	217.99	2.26
Solar + Storage + EV:	1,279	1,313.35	1.91
EV only:	26,945	23,792.46	N/A
Combined	109,975	43,760.91	18.51

Source: Research Team

Applying similar savings to future customers (by 2028), the team found that 90 GWh of energy savings annually would be feasible with peak hour reduction of 37.52 MW, as seen in Table 27.

Table 29: Energy Saved And Grid Capacity Unlocked By 5% REA Adoption, By 2028 DER Equipped IOU Customers

5% REA adoption by Future Customers with DERs	# of REAs adopted	Annual Energy Saved (MWh)	Peak Hour Reduction (MW)
Solar Only:	109,482	15,765.43	N/A
Solar + EV:	11,944	12,266.28	17.80
Storage Only:	6,828	0.00	10.17
Storage + EV:	2,078	1,834.79	3.10
Solar + Storage:	2,347	338.01	3.50
Solar + Storage + EV:	1,983	2,036.44	2.95
EV only:	65,314	57,672.24	N/A

5% REA adoption by Future Customers with DERs	# of REAs adopted	Annual Energy Saved (MWh)	Peak Hour Reduction (MW)
Combined	199,976	89,913.18	37.52

Source: Research Team

California's IOUs and state government offer many programs that incentivize DER adoption, including the aforementioned SGIP, as well as various rebate programs to customers purchasing a pre-owned electric vehicle. Plus, in many territories an EV allows customers to enroll in TOU rates with the lowest off-peak pricing within PG&E and SDG&E territories, allowing for superb cost savings by load shifting away from peak pricing.

Furthermore, select REAs can address electrical service issues that are preventing more adoption of EVs. Select REA systems directly transition power from solar and storage directly to the EVSE. This means that panel and service constraints could be circumvented, which could then enable the placement of high-density EV chargers in homes that otherwise could not support installation.

Conclusion

The findings from this study underscore the significant advantages of adopting residential energy automation (REA) systems in California’s residential sector. By integrating advanced home energy management systems (HEMS) with distributed energy resources (DERs) such as solar photovoltaic (PV) systems, battery energy storage systems (BESS), and electric vehicle service equipment (EVSE), REA systems offer considerable energy and cost savings, enhanced by intelligent load management and the ability to shift energy consumption to off-peak hours.

The data presented in this report highlights several key benefits of REA systems. Homes with REA systems showed calculated energy savings from 18 percent to 64 percent. Additionally, the economic impact of REA systems when applying relevant IOU rates is significant, with customers potentially saving thousands of dollars annually, based on the selected TOU rates and connected DERs. Based on current REA pricing, the payback time period can be as short as less than two years, depending on IOU provider and connected DERs.

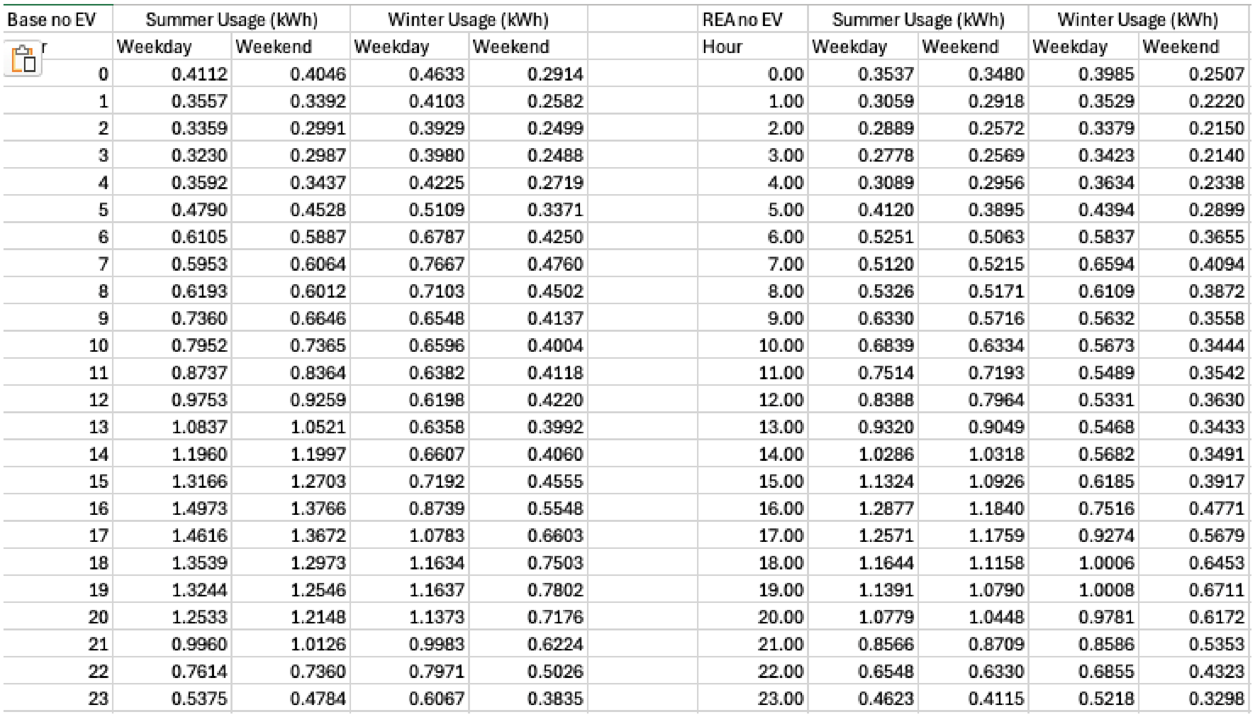
Moreover, the grid impact of widespread REA adoption is profound. Nearly 20 percent of IOU customers are uniquely positioned to benefit from REA systems, due to existing DER installations and equipment. If five percent of customers with existing DERs installed (1.2 percent of IOU customers) were to adopt a REA system, California would unlock 44 GWh of energy yearly and have a potential peak hour reduction of 18.51 MW from grid flexibility via load shifting, with savings potential and grid flexibility linearly scaling based on the adoption rate.

The environmental benefits are equally compelling. In baseline scenarios, EVs, combined with REA integration, resulted in a net emissions reduction of approximately 20 percent. This reduction is critical for supporting California's aggressive decarbonization goals and reducing greenhouse gas (GHG) emissions.

In conclusion, the study provides a compelling case for the widespread adoption of REA systems in California. By optimizing energy use, enhancing grid stability, and reducing costs and emissions, REA systems represent a critical advancement in the state's journey toward a cleaner, more reliable energy future. The integration of REA systems into California homes not only supports the state's energy efficiency and sustainability goals, but also empowers homeowners to achieve greater energy independence and resilience.

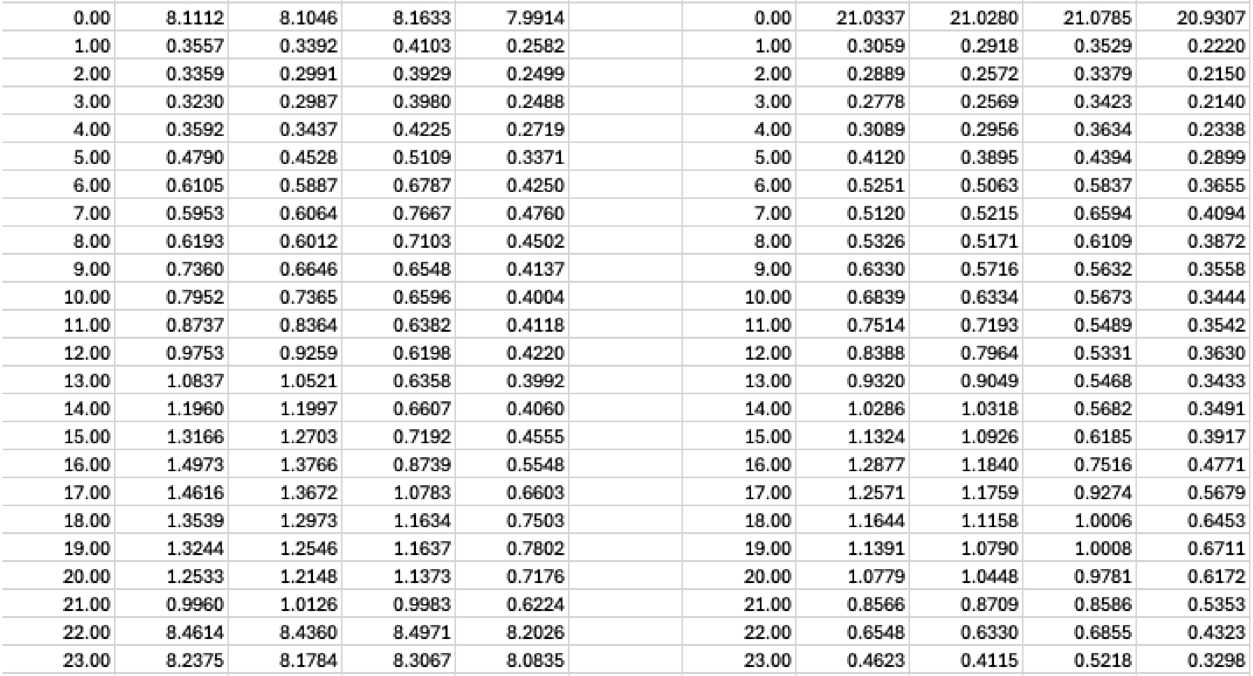
Appendix A: Hourly Energy Use Information

No EV, No Solar or Load Shifting Hourly Energy Use Profiles



Base no EV	Summer Usage (kWh)		Winter Usage (kWh)			REA no EV	Summer Usage (kWh)		Winter Usage (kWh)	
r	Weekday	Weekend	Weekday	Weekend		Hour	Weekday	Weekend	Weekday	Weekend
0	0.4112	0.4046	0.4633	0.2914		0.00	0.3537	0.3480	0.3985	0.2507
1	0.3557	0.3392	0.4103	0.2582		1.00	0.3059	0.2918	0.3529	0.2220
2	0.3359	0.2991	0.3929	0.2499		2.00	0.2889	0.2572	0.3379	0.2150
3	0.3230	0.2987	0.3980	0.2488		3.00	0.2778	0.2569	0.3423	0.2140
4	0.3592	0.3437	0.4225	0.2719		4.00	0.3089	0.2956	0.3634	0.2338
5	0.4790	0.4528	0.5109	0.3371		5.00	0.4120	0.3895	0.4394	0.2899
6	0.6105	0.5887	0.6787	0.4250		6.00	0.5251	0.5063	0.5837	0.3655
7	0.5953	0.6064	0.7667	0.4760		7.00	0.5120	0.5215	0.6594	0.4094
8	0.6193	0.6012	0.7103	0.4502		8.00	0.5326	0.5171	0.6109	0.3872
9	0.7360	0.6646	0.6548	0.4137		9.00	0.6330	0.5716	0.5632	0.3558
10	0.7952	0.7365	0.6596	0.4004		10.00	0.6839	0.6334	0.5673	0.3444
11	0.8737	0.8364	0.6382	0.4118		11.00	0.7514	0.7193	0.5489	0.3542
12	0.9753	0.9259	0.6198	0.4220		12.00	0.8388	0.7964	0.5331	0.3630
13	1.0837	1.0521	0.6358	0.3992		13.00	0.9320	0.9049	0.5468	0.3433
14	1.1960	1.1997	0.6607	0.4060		14.00	1.0286	1.0318	0.5682	0.3491
15	1.3166	1.2703	0.7192	0.4555		15.00	1.1324	1.0926	0.6185	0.3917
16	1.4973	1.3766	0.8739	0.5548		16.00	1.2877	1.1840	0.7516	0.4771
17	1.4616	1.3672	1.0783	0.6603		17.00	1.2571	1.1759	0.9274	0.5679
18	1.3539	1.2973	1.1634	0.7503		18.00	1.1644	1.1158	1.0006	0.6453
19	1.3244	1.2546	1.1637	0.7802		19.00	1.1391	1.0790	1.0008	0.6711
20	1.2533	1.2148	1.1373	0.7176		20.00	1.0779	1.0448	0.9781	0.6172
21	0.9960	1.0126	0.9983	0.6224		21.00	0.8566	0.8709	0.8586	0.5353
22	0.7614	0.7360	0.7971	0.5026		22.00	0.6548	0.6330	0.6855	0.4323
23	0.5375	0.4784	0.6067	0.3835		23.00	0.4623	0.4115	0.5218	0.3298

With EV, No Solar or Load Shifting Hourly Energy Use Profiles



Base w/ EV	Summer Usage (kWh)		Winter Usage (kWh)			REA w/ EV	Summer Usage (kWh)		Winter Usage (kWh)	
Hour	Weekday	Weekend	Weekday	Weekend		Hour	Weekday	Weekend	Weekday	Weekend
0.00	8.1112	8.1046	8.1633	7.9914		0.00	21.0337	21.0280	21.0785	20.9307
1.00	0.3557	0.3392	0.4103	0.2582		1.00	0.3059	0.2918	0.3529	0.2220
2.00	0.3359	0.2991	0.3929	0.2499		2.00	0.2889	0.2572	0.3379	0.2150
3.00	0.3230	0.2987	0.3980	0.2488		3.00	0.2778	0.2569	0.3423	0.2140
4.00	0.3592	0.3437	0.4225	0.2719		4.00	0.3089	0.2956	0.3634	0.2338
5.00	0.4790	0.4528	0.5109	0.3371		5.00	0.4120	0.3895	0.4394	0.2899
6.00	0.6105	0.5887	0.6787	0.4250		6.00	0.5251	0.5063	0.5837	0.3655
7.00	0.5953	0.6064	0.7667	0.4760		7.00	0.5120	0.5215	0.6594	0.4094
8.00	0.6193	0.6012	0.7103	0.4502		8.00	0.5326	0.5171	0.6109	0.3872
9.00	0.7360	0.6646	0.6548	0.4137		9.00	0.6330	0.5716	0.5632	0.3558
10.00	0.7952	0.7365	0.6596	0.4004		10.00	0.6839	0.6334	0.5673	0.3444
11.00	0.8737	0.8364	0.6382	0.4118		11.00	0.7514	0.7193	0.5489	0.3542
12.00	0.9753	0.9259	0.6198	0.4220		12.00	0.8388	0.7964	0.5331	0.3630
13.00	1.0837	1.0521	0.6358	0.3992		13.00	0.9320	0.9049	0.5468	0.3433
14.00	1.1960	1.1997	0.6607	0.4060		14.00	1.0286	1.0318	0.5682	0.3491
15.00	1.3166	1.2703	0.7192	0.4555		15.00	1.1324	1.0926	0.6185	0.3917
16.00	1.4973	1.3766	0.8739	0.5548		16.00	1.2877	1.1840	0.7516	0.4771
17.00	1.4616	1.3672	1.0783	0.6603		17.00	1.2571	1.1759	0.9274	0.5679
18.00	1.3539	1.2973	1.1634	0.7503		18.00	1.1644	1.1158	1.0006	0.6453
19.00	1.3244	1.2546	1.1637	0.7802		19.00	1.1391	1.0790	1.0008	0.6711
20.00	1.2533	1.2148	1.1373	0.7176		20.00	1.0779	1.0448	0.9781	0.6172
21.00	0.9960	1.0126	0.9983	0.6224		21.00	0.8566	0.8709	0.8586	0.5353
22.00	8.4614	8.4360	8.4971	8.2026		22.00	0.6548	0.6330	0.6855	0.4323
23.00	8.2375	8.1784	8.3067	8.0835		23.00	0.4623	0.4115	0.5218	0.3298

No EV, With Solar and Load Shifting Hourly Energy Use Profiles

Base no EV	Summer Usage (kWh)		Winter Usage (kWh)	
Hour	Weekday	Weekend	Weekday	Weekend
0	0.4112	0.4046	0.4633	0.2914
1	0.3557	0.3392	0.4103	0.2582
2	0.3359	0.2991	0.3929	0.2499
3	0.3230	0.2987	0.3980	0.2488
4	0.3592	0.3437	0.4225	0.2719
5	0.4790	0.4528	0.5109	0.3371
6	0.6105	0.5887	0.6787	0.4250
7	0.4446	0.4557	0.6160	0.3253
8	0.0165	-0.0016	0.1075	-0.1526
9	-0.3189	-0.3903	-0.4001	-0.6412
10	-0.6365	-0.6952	-0.7720	-1.0313
11	-0.8594	-0.8967	-1.0948	-1.3212
12	-0.9839	-1.0332	-1.3393	-1.5371
13	-0.8001	-0.8317	-1.2479	-1.4846
14	-0.3110	-0.3073	-0.8463	-1.1011
15	0.1864	0.1401	-0.4111	-0.6748
16	0.7438	0.6231	0.1204	-0.1987
17	1.0849	0.9904	0.7016	0.2836
18	1.3539	1.2973	1.1634	0.7503
19	1.3244	1.2546	1.1637	0.7802
20	1.2533	1.2148	1.1373	0.7176
21	0.9960	1.0126	0.9983	0.6224
22	0.7614	0.7360	0.7971	0.5026
23	0.5375	0.4784	0.6067	0.3835

REA no EV	Summer Usage (kWh)		Winter Usage (kWh)	
Hour	Weekday	Weekend	Weekday	Weekend
0	0.8643	0.7548	0.3729	-0.0493
1	1.1745	1.0791	0.8917	0.4014
2	1.4533	1.3730	1.3385	0.8603
3	1.4169	1.3360	1.3431	0.8851
4	1.3869	1.3404	1.3415	0.8510
5	1.2685	1.2604	1.2980	0.8252
6	1.1799	1.1393	1.2692	0.7978
7	0.8189	0.7776	1.0259	0.5837
8	0.4215	0.3022	-0.0108	-0.2345
9	-0.4550	-0.5164	-0.5248	-0.7322
10	-0.7927	-0.8431	-0.9092	-1.1322
11	-1.0360	-1.0681	-1.2385	-1.4332
12	-1.1818	-1.2242	-1.4875	-1.6576
13	-1.0108	-1.0380	-1.3960	-1.5995
14	-0.5256	-0.5224	-0.9860	-1.2051
15	-0.0333	-0.0731	-0.5472	-0.7740
16	0.0000	0.0000	-0.0256	-0.3000
17	0.0000	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000	0.0000
21	0.0000	0.0000	0.0000	0.0000
22	0.0000	0.0000	0.0000	0.0000
23	0.0000	0.0000	0.0000	0.0000

With EV, With Solar and Load Shifting Hourly Energy Use Profiles

Base w/ EV	Summer Usage (kWh)		Winter Usage (kWh)	
Hour	Weekday	Weekend	Weekday	Weekend
0	8.1112	8.1046	8.1633	7.9914
1	0.3557	0.3392	0.4103	0.2582
2	0.3359	0.2991	0.3929	0.2499
3	0.3230	0.2987	0.3980	0.2488
4	0.3592	0.3437	0.4225	0.2719
5	0.4790	0.4528	0.5109	0.3371
6	0.6105	0.5887	0.6787	0.4250
7	0.4446	0.4557	0.6160	0.3253
8	0.0165	-0.0016	0.1075	-0.1526
9	-0.3189	-0.3903	-0.4001	-0.6412
10	-0.6365	-0.6952	-0.7720	-1.0313
11	-0.8594	-0.8967	-1.0948	-1.3212
12	-0.9839	-1.0332	-1.3393	-1.5371
13	-0.8001	-0.8317	-1.2479	-1.4846
14	-0.3110	-0.3073	-0.8463	-1.1011
15	0.1864	0.1401	-0.4111	-0.6748
16	0.7438	0.6231	0.1204	-0.1987
17	1.0849	0.9904	0.7016	0.2836
18	1.3539	1.2973	1.1634	0.7503
19	1.3244	1.2546	1.1637	0.7802
20	1.2533	1.2148	1.1373	0.7176
21	0.9960	1.0126	0.9983	0.6224
22	8.4614	8.4360	8.4971	8.2026
23	8.2375	8.1784	8.3067	8.0835

REA w/ EV	Summer Usage (kWh)		Winter Usage (kWh)	
Hour	Weekday	Weekend	Weekday	Weekend
0	21.0337	21.0280	21.0785	20.9307
1	1.1745	1.0791	0.8917	0.4014
2	1.4533	1.3730	1.3385	0.8603
3	1.4169	1.3360	1.3431	0.8851
4	1.3869	1.3404	1.3415	0.8510
5	1.2685	1.2604	1.2980	0.8252
6	1.1799	1.1393	1.2692	0.7978
7	0.8189	0.7776	1.0259	0.5837
8	0.4215	0.3022	-0.0108	-0.2345
9	-0.4550	-0.5164	-0.5248	-0.7322
10	-0.7927	-0.8431	-0.9092	-1.1322
11	-1.0360	-1.0681	-1.2385	-1.4332
12	-1.1818	-1.2242	-1.4875	-1.6576
13	-1.0108	-1.0380	-1.3960	-1.5995
14	-0.5256	-0.5224	-0.9860	-1.2051
15	-0.0333	-0.0731	-0.5472	-0.7740
16	0.0000	0.0000	-0.0256	-0.3000
17	0.0000	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000	0.0000
21	0.0000	0.0000	0.0000	0.0000
22	0.0000	0.0000	0.0000	0.0000
23	0.0000	0.0000	0.0000	0.0000

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