CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Building Healthier and More Energy-Efficient Communities in Fresno and the Central Valley

Developing a Holistic Community Action Plan to Improve Access to Clean Energy Technologies

November 2023 | CEC-500-2024-001

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PREFACE

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

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

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

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

This report is the final report for the project EPC-17-035 conducted by Lawrence Berkeley National Lab. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

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

ABSTRACT

Residents in Fresno suffer from poor air quality, increasing heat, some of the highest utility bills in California, and low ownership of clean energy technologies. This work developed an action plan for Fresno that supports California's goal of enhancing climate equity by improving access to clean energy technologies and improving public health outcomes.

The project approach combined community outreach, policy analysis, and technical modeling. Outreach methods included stakeholder interviews and phone surveys. Technical modeling included integrated modeling of residential buildings and vehicles and modeling the benefits of adding solar photovoltaic and battery storage to a community center. The project found that 70 percent of residents are not comfortable in their homes in hot weather and revealed a lack of awareness of existing clean energy incentives. Used electric vehicles are within resident budgets with existing high clean car rebates. Integrated electrification packages (heat pump heating and cooling and heat pump water heating, used electric vehicles, and solar photovoltaic) can achieve a reasonable payback time of 15 to 20 years in many single-family homes. With the Self-Generation Incentive Program Equity Rebate, resilience hub modeling gives favorable economic results for up to 24 hours of planned outages. The research team estimated about $70 million in public health benefits from transitioning all passenger vehicles in Fresno County to zero-emission vehicles and found that low-cost do-it-yourself air filters are an opportunity for greater deployment. Finally, the project generated a substantive action plan for greater climate equity for disadvantaged communities in Fresno.

Effective interventions and policy development are urgently needed to ensure resident safety at home from extreme heat. Adding used electric vehicles and rooftop photovoltaic to building electrification measures can reduce overall household energy costs, but more aggressive financing programs are needed to cover high initial costs. Awareness and transactional barriers can be mitigated with more "one-stop shop" incentive programs. More integrated demonstration projects are needed for "learning-by-doing" and data collection and to scale up equitable decarbonization.

Keywords: climate equity, environmental justice, action plan, disadvantaged communities, community outreach, community science, decarbonization, fuel switching, integrated modeling, air quality, resilience

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EXECUTIVE SUMMARY

Introduction

California is an international leader for progressive climate policies and in the last decade has identified climate equity — the goal of recognizing and addressing the unequal burdens made worse by climate change, while ensuring that all people share the benefits of climate protection efforts — as one of the pillars of its climate policy. Disadvantaged communities bear a disproportionate pollution burden, have fewer economic opportunities, have worse social and health outcomes than their non-disadvantaged counterparts such as high unemployment and low incomes, and have been historically underserved in terms of public and private investment.

At the same time, the state has aggressive goals for decarbonization, as mandated in Senate bills 32 (Pavley, Chapter 249, Statutes of 2016), 1477 (Stern, Chapter 378, Statutes of 2018), and 100 (De León, Chapter 312, Statutes of 2018), and with the goal of carbon neutrality by 2045, climate resilience, defined by the Union of Concerned Scientists as adjusting how we live, work, and play to keep us safe from the impacts of climate change, has become a real and urgent issue. For example, under-resourced and disadvantaged communities face a disproportionate threat from extreme heat, with older housing stock, poor air quality, and fewer financial resources to meet the high electricity bills associated with increased cooling demand. Fresno is the largest city in the Central Valley and has many disadvantaged communities in central and south Fresno in particular. Residents suffer from some of the worst air quality in the state, have among the highest utility bills in the state, and have low ownership of clean energy technologies such as electric vehicles (EVs)/plug-in EVs, and rooftop solar photovoltaic.

There is a critical need to simultaneously address three key issues in disadvantaged communities: climate equity, decarbonization, and climate resilience. Wherever possible, efforts should be made to align policies, programs, and implementation plans to meet these multiple policy objectives. This report describes some cross sectoral measures and combined measures (packages) in two disadvantaged neighborhoods in Fresno designed to address these key issues in support of the state's decarbonization and carbon neutrality goals.

Project Purpose

The project purpose is to explore how the state's climate targets and goals can be realized efficiently in disadvantaged community areas such as Fresno, model the effects of greater clean energy technology adoption in terms of benefits and costs, and delineate key challenges to implement these changes.

Specific project goals include the following:

- Support the state's policy goals for greater environmental justice by developing a holistic action plan to improve access to clean energy technologies in disadvantaged communities.
- Provide the California Energy Commission with an actionable plan for prioritized deployment of energy efficiency measures, electrification, and distributed energy resources in the Fresno area to achieve climate benefits and local air quality

improvements. (See the separate report, "An Action Plan for Greater Climate Equity for Disadvantaged Communities in Fresno.")

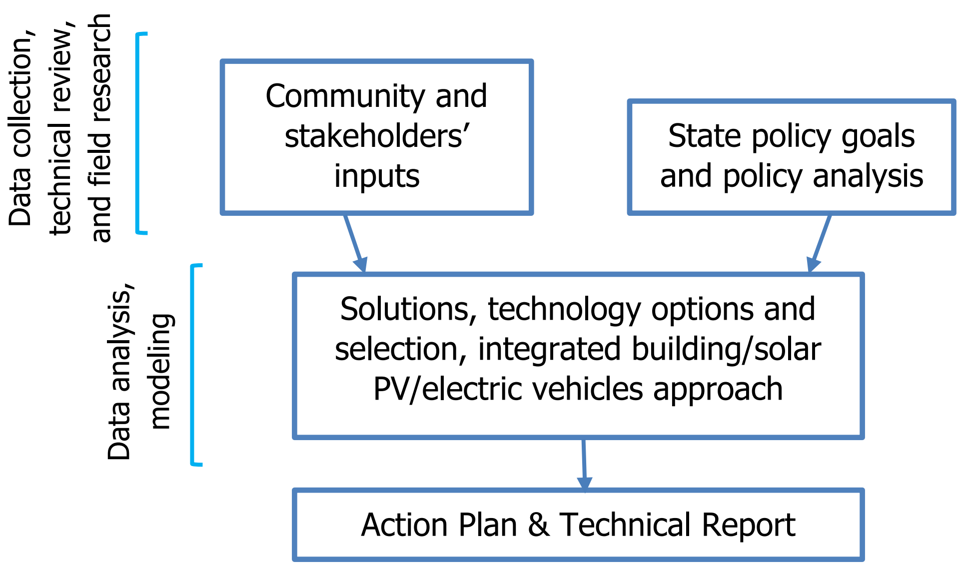
Project Approach

This project developed a holistic community action plan to simultaneously achieve climate benefits and air quality improvements through energy efficiency measures, electrification, and distributed energy resources in the city of Fresno, with a focus on the residential building sector and the light-duty transportation sector. The project approach (Figure ES-1)was a mix of:

- Collecting input from community and local stakeholders.
- Analyzing current policies and policy gaps.
- Integrated building and EV/solar photovoltaic modeling.

Synthesizing the information into an action plan with a concurrent technical report (this document) detailing the data collection and technical modeling.

Figure ES-1: Project Approach



Source: LBNL Authors' figure

Collecting community input to prioritize measures and improve modeling assumptions was a key part of this research. The research team partnered with the city of Fresno, Every Neighborhood Partnership (a local community-based organization) and Rising Sun Center for Opportunity (a non-profit organization) to facilitate community outreach. Community input was critical to shaping an action plan with multiple related outreach approaches for the project, including more than 200 phone surveys, two community meetings, and stakeholder interviews. For example, the Fresno Economic Opportunities Commission, a local non-profit community agency, provided many inputs on weatherization programs and the residential building stock in south Fresno.

The research team performed urban-scale or neighborhood-scale building modeling using the City Building Energy Saver software tool (https://citybes.lbl.gov/), which provides unique capabilities to model entire urban areas for energy efficiency and resilience measures. For this project, the research team developed a residential building dataset for several neighborhoods in south Fresno. The model was then used to estimate energy savings for a single to a group of buildings as a function of various energy efficiency measures such as attic insulation and wall insulation; fuel-switching measures such as heat pump heating and cooling units; other heat resilience measures (e.g., solar control window films); and rooftop solar photovoltaic.

The research team also analyzed combinations of EVs and home upgrades because of the high greenhouse gas reduction potential of EVs (passenger vehicles make up 53 percent of residential sector greenhouse gas emissions in Fresno), greater availability of EV models, and increasing range of EVs. EVs can achieve greater equity from lower operating costs, eliminate vehicle tailpipe pollutants, and improve future resilience to power outages with an onsite battery.

Project Results

Outreach

Key outreach results based on 240 community member surveys, two community meetings with 50 total participants, and other stakeholder inputs included:

- Common concerns for energy-related services include high utility bills, outdoor air quality, transportation costs, and access.
- Awareness of existing solar photovoltaic and clean vehicle rebate programs appeared low and provides an opportunity for greater outreach and/or more program consolidation to avoid missing residents who may inquire about a specific energy efficiency photovoltaic or EV program. For example, 80 percent or more of residents were unaware of Clean Vehicle Rebates and solar installation rebate programs.
- More than 97 percent of surveyed households do not have rooftop solar photovoltaic. About half of single-family homes are not roof-ready for solar photovoltaic.
- Approximately 60 to 70 percent of residents are not comfortable in their homes in hot or cold weather. About 15 percent of older homes have swamp coolers and no air conditioning systems.
- About 60 percent or more of residents drive less than 35 miles per day. Most people expressed a willingness to adopt an electric vehicle if it is affordable.
- About 45 percent of participants reported having a household member(s) with asthma or allergies. Outdoor air quality is a greater concern than indoor air quality. Although residents did not report excessive concern with indoor air quality, the prevalence of indoor air filters seems very low, and residents seem open to adopting do-it-yourself air filters.

Integrated Modeling of Energy Efficiency/Electrification/Solar Photovoltaics, and Electric Vehicles

The integrated modeling was done across all residential buildings in two disadvantaged neighborhoods in south Fresno.

- The research team identified a combination of energy efficiency packages that are less than $1,000 to install with up to a 10 percent annual energy savings, such as adding portable fans, improving water tank insulation, and adding air sealing to seal leaks.
- Upgrading to an efficiency package with LED, portable fans, improved water tank insulation, and higher efficiency gas furnace provides an average 22 percent annual energy savings and less than a five-year payback.
- Major implementation challenges to decarbonizing disadvantaged neighborhoods include high initial costs, the need for roof and/or electric panel upgrades, and the requirement to keep overall energy costs at or below the baseline level.
- Some residential configurations lend themselves more readily to integrated upgrades, and transitioning to used EVs can contribute to substantial operating cost savings from lower fuel costs.
- For individual homes without central heating and cooling, mini split heat pumps can reduce utility bills. Adding solar photovoltaic and EV further reduces annual energy costs.
- Transitioning to mini-split heat pumps for heating and cooling homes with window air conditioners/central air conditioning and gas wall heaters or furnaces provides energy and greenhouse gas savings but has high initial costs.
- Used EVs can be an option for the daily driving habits of many residents in disadvantaged communities and may fit within their household budgets with higher-end Clean Vehicle Rebates of $7,500 or more.
- Integrated electrification (heat pump heating, ventilation, and air conditioning units and heat pump water heaters) plus used EV and photovoltaic can achieve payback within 11 to 20 years.

Improving Health Outcomes and Resilience to Extreme Heat

- Upgrading an existing community cooling center to a community resilience hub with solar photovoltaic and battery storage with the Self-Generation Incentive Program (SGIP) equity rebate for the latter is a promising deployment option technically and economically, assuming that the city of Fresno is eligible for SGIP equity incentives for storage.
- Transitioning all vehicles in Fresno County to zero-emission vehicles can achieve an estimated $62 million to $83 million in public health benefits.
- Low-cost do-it-yourself box fans with high efficiency particulate air filters such as MERV13 can improve indoor air quality, especially during wildfire events with smoky air and are an opportunity for program and outreach expansion.
- During extreme heat events, top-floor residents and people who live in the estimated 15 percent of homes that lack air conditioning are especially vulnerable.

- Solar window films, roof/ceiling insulation, and cool walls are the among the most effective passive cooling measures that do not require electricity, and natural ventilation on top floors is a helpful cooling measure.
- Helpful active cooling measures include fans to reduce electricity costs and mini-split heat pumps that can provide high energy efficiency cooling and heating in homes that lack ductwork.

Key Policy Gaps and Recommendations

- Adequate financing programs to meet decarbonization, equity, and climate resilience goals are lacking for upgrading homes in disadvantaged communities.
- A substantial fraction of residents are renters in single family homes. Many clean energy programs are open only to homeowners, exposing a major gap in equitable financing programs.
- No programs address deferred maintenance upgrades (repairing dilapidated roofs, upgrading old electric panels, installing kitchen and bathroom ventilation fans) in homes in disadvantaged communities. This is an equity priority for resident health and safety, independent of decarbonization and electrification policy goals.
- About 50 percent of single-family homes in Fresno are not roof-ready for solar installation, and no program exists to upgrade single family home roofs for either solar photovoltaic or cool roofs. Adding property owner agreements or covenants to constrain future rent increases and/or develop attractive community solar programs is an area for further exploration in disadvantaged communities.
- No regulations address maximum indoor temperatures. The team estimated that about 15 percent of homes lack air conditioning, which can lead to dangerous indoor conditions during extreme heat waves. The state should consider enacting design standards for maximum indoor temperature; all residents of Fresno and other hot climates should have access to an air conditioner at home.
- Rooftop solar photovoltaic and battery storage with self-generation incentives for storage are an attractive opportunity to develop "community resilience hubs" in disadvantage community areas.
- Used EVs can be a viable option for many residents. Support for zero-emission vehicle rebates of $7,500 and more for disadvantaged communities are needed for affordability.
- More consolidated implementation programs are needed to reduce transaction cost barriers and improve equity among residents. Awareness, education, and transactional barriers are issues that could be addressed with more "one-stop shop" models for incentive and deployment programs.
- Expansion of energy efficiency audits to include assessments such as building electrification readiness and extreme weather resilience audits/assessments, rooftop photovoltaic readiness, and EV readiness could improve the overall efficacy of achieving policy goals, improve equity, and increase the speed of deployment.

- More support for heat pump adoption and market transformation programs in existing buildings could help bring costs down for heat pump-based HVAC and heat pump-based water heating units and increase the number of product offerings in the market including plug-ready, 120V units.
- To meet the state's urgent need to decarbonize the building stock and meet equity objectives, there is a pressing need to collect more data on actual installed costs for building upgrades and vehicle electrification across different housing types and different starting equipment.
- Integration of pilots and demonstration projects in disadvantaged communities would offer important benefits:
    - Consolidation of existing programs would reduce transaction costs to residents.
    - Integrated upgrades could target multiple policy objectives (decarbonization, equity, resilience, better air quality and health outcomes).
    - Integrated upgrades of energy efficiency/electrification/photovoltaic/EV will provide learn-by-doing knowledge and highlight interaction effects of these technologies.
    - Integrated pilots would provide essential data collection and fill data gaps in installation costs as well as help to develop lower cost pathways to scale up disadvantaged community decarbonization, equity, and resilience efforts.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

- The team shared project results with the city of Fresno and with the Fresno community in a community newsletter distributed by community-based organization partner Every Neighborhood Partnership. The team plans to disseminate project results more broadly in the Central Valley with partner CivicWell (formerly known as Local Government Commission) and in follow up meetings with state policy makers.
- A presentation and one-page summary based on this project describing the urgent need for integrated pilot programs focusing on underserved and disadvantaged communities was shared with multiple groups including the California Environmental Protection Agency, Air Resources Board, and with several programs at the U.S. Department of Energy, including Building America Program, and the Advanced Building Construction Initiative.
- The team presented the work at several research and practitioner forums such as the Conference on Building Energy & Environment in July 2022 and the Net Zero 2021 Conference. Presenter Kaiyu Sun won the "Woman in STEM" award from this international conference for her presentation "Exploring Decarbonization and Clean Energy Pathways for Disadvantaged Communities in California."
- This project advanced the capability of the CityBES urban-scale building modeling tool by adding additional residential energy efficiency and electric HP measures and cost data and demonstrating the modeling of two underserved neighborhoods in Fresno.

This work was highlighted in the awarding of the CityBES tool with a prestigious R&D100 Award in August 2022.

- The project research and findings have had ongoing policy impact for equitable building decarbonization. For example, the research team's principal investigator met Senator Anna Caballero of Senate District 14 (including south Fresno), shared the project's findings on lack of adequate cooling in many homes in south Fresno, and subsequently provided input to her proposed bill to amend equitable building decarbonization related sections in Section 25665.3 of the Public Resources Code.

Benefits to California

This work sets the groundwork for state policy makers to support more aggressive, systematic, and comprehensive programs to support greater climate equity to Fresno area residents across the building, transportation, and rooftop photovoltaic energy supply sectors and in doing so to support the state's overall goals for decarbonization and carbon neutrality. More investments, programs, and partnerships in this area would improve housing equity, improve indoor and outdoor air quality, and lead to improved health and safety outcomes for Fresno residents. This report identifies many existing state measures and packages that could be applied in Fresno across the residential building and passenger vehicle sectors including rooftop photovoltaic to give operational cost savings for overall energy costs.

This project highlighted some key gaps and policy needs for upgrading more homes in disadvantaged community areas to achieve climate equity. More programs to provide adequate financing, address deferred maintenance in older homes, improve public awareness of existing programs, and increase program eligibility for renters in single family homes would help address these gaps and provide more equity in basic livability and access to clean energy technologies such as solar photovoltaic, and reduce the utility bill energy burden.

This project provides recommendations for design standards for maximum indoor temperature and access to an air conditioner at home that helps ensure the health and safety for underserved residents in Fresno and other hot climate zones during increasingly extreme heat waves, especially for those with underlying health conditions.

Continued support for equity incentives would help to ensure resilient communities during extreme heat events or other emergencies and provide better air quality. The self-generated incentive equity program for storage can provide one or two days of critical load service for disadvantaged community residents. Zero-emission vehicle disadvantaged community rebates could improve local air quality by making it more affordable to replace older gasoline-based vehicles with zero-emission vehicles. Additional funding to disseminate low-cost do-it-yourself air filters would be an inexpensive way to improve indoor air quality in residents' homes and would be especially helpful in situations with high amounts of outdoor smoke from wildfires.

Demonstrating and piloting more consolidated assessments and integrated upgrade programs would reduce transaction costs, provide maximum benefits and equity to residents in disadvantaged communities, provide much needed data about the implementation costs and benefits of integrated upgrades and thus encourage more integrated upgrades, quantify possible cost reduction opportunities compared to serial upgrades, and provide learning and potential pathways for scaling up equitable building decarbonization.

CHAPTER 1: Introduction

California is an international leader in progressive climate policies and, in the last decade, has identified climate equity as one of the pillars of its climate policy. Disadvantaged communities bear a disproportionate pollution burden, have worse social and health outcomes than non-disadvantaged community areas such as high unemployment and low incomes, have fewer economic opportunities, and are historically underserved in terms of public and private investment. In the past, many of these areas were also targets for racial discrimination with "redlining" housing policies and subsequent inequities in neighborhood capital, healthcare access, and education.[1]

Senate Bill 535 (SB 535; De León, Chapter 830, Statutes of 2012) and Assembly Bill 1550 (AB 1550; Gomez, Chapter 369, Statutes of 2016) are two foundational pieces of legislation supporting investments in disadvantaged communities. SB 535 requires that 25 percent of the Greenhouse Gas Reduction Fund (GGRF) go to projects that benefit disadvantaged communities. The California Environmental Protection Agency (CalEPA) has responsibility for identifying those communities and uses the CalEnviroScreen tool.[2] AB 1550 requires that 25 percent of proceeds from the GGRF be spent on projects located in disadvantaged communities.[3] These investments support programs across sectors from clean transportation vehicle rebates and electric charging infrastructure to energy efficiency upgrades in building and larger regional projects such as high-speed rail. More recently, AB 523 (Reyes, Chapter 551, Statutes of 2017) requires the California Energy Commission (CEC) to allocate at least 25 percent of the funds in the Electric Program Investment Charge (EPIC) program for technology demonstration and deployment at sites located in, and benefiting, disadvantaged communities and 10 percent of the funds in the EPIC program for technology demonstration and deployment at sites located in, and benefiting, low-income communities in the state until July 1, 2023.[4]

At the same time the state has aggressive goals for decarbonization mandated by SB 32 (Pavley, Chapter 249, Statutes of 2016), SB 1477 (Stern, Chapter 378, Statutes of 2018), and SB 100 (De León, Chapter 312, Statutes of 2018). California has a statewide target of 40 percent greenhouse gas (GHG) reductions by 2030 compared to the level of 1990 and a 100 percent zero-carbon electricity target (for retail sales) by 2045.Then-Governor Jerry Brown also issued an Executive Order for the state to achieve carbon neutrality by 2045 (Executive Order B-55-18, 2018). Climate resilience is becoming a real and urgent issue. For example, under-resourced and disadvantaged communities face a disproportionate threat from extreme heat, with older housing stock, poor air quality, and fewer financial resources to afford higher summer electricity bills from increased cooling demand.

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[1] https://www.publichealth.columbia.edu/research/niehs-center-environmental-health-northern-manhattan/historical-redlining-and-birth-outcomes-california, accessed 2 November 2021.
[2] https://oehha.ca.gov/calenviroscreen/sb535, accessed 2 November 2021.
[3] *Ibid*.
[4] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180AB523

Access to clean energy technology options (e.g., solar photovoltaic (PV), storage, microgrids, major energy efficiency upgrades, electric heat pumps, and EVs) is constrained in disadvantaged communities by many structural barriers (Canizares et al., 2019; Mandarano and Meenar, 2017; Maru et al., 2014). These barriers include low incomes, lack of access to capital, transactional and informational barriers, lack of trust in utilities and contractors, deferred maintenance issues, and split incentives for renters and owners. To address these barriers, this project generated a holistic community action plan that simultaneously achieves climate benefits and air quality improvements through energy efficiency measures, electrification, and distributed energy resources in the city of Fresno, with a focus on the residential building sector and light-duty transportation sectors.

Fresno is the largest city in the Central Valley and has many disadvantaged communities in central and south Fresno in particular (Figure 2). Residents suffer from among the worst air quality in the state,[5] have among the highest utility bills in the state and have low ownership of clean energy technologies such as EV/plug-in electric vehicles (PEVs) and rooftop solar PV. Fresno residents will experience more extreme heat days in the next 20 years, from a historical level of 4 days per year to 22 days by 2040.[6] In terms of very hot days, in 2021, Fresno broke the record for the number of days above 100°F, with 69 days.[7] South Fresno in particular is historically underserved with an older housing stock and is the focus of this work. Figure 3 shows residential sector GHG for the city of Fresno: passenger vehicles comprise more than half of GHG, natural gas about 20 percent, and high global warming-potential refrigerants (GWP) and solid waste together about 11 percent. The research team addressed residential gas and electricity and passenger vehicles in this study but not high GWP refrigerants and solid waste.

Community Outreach

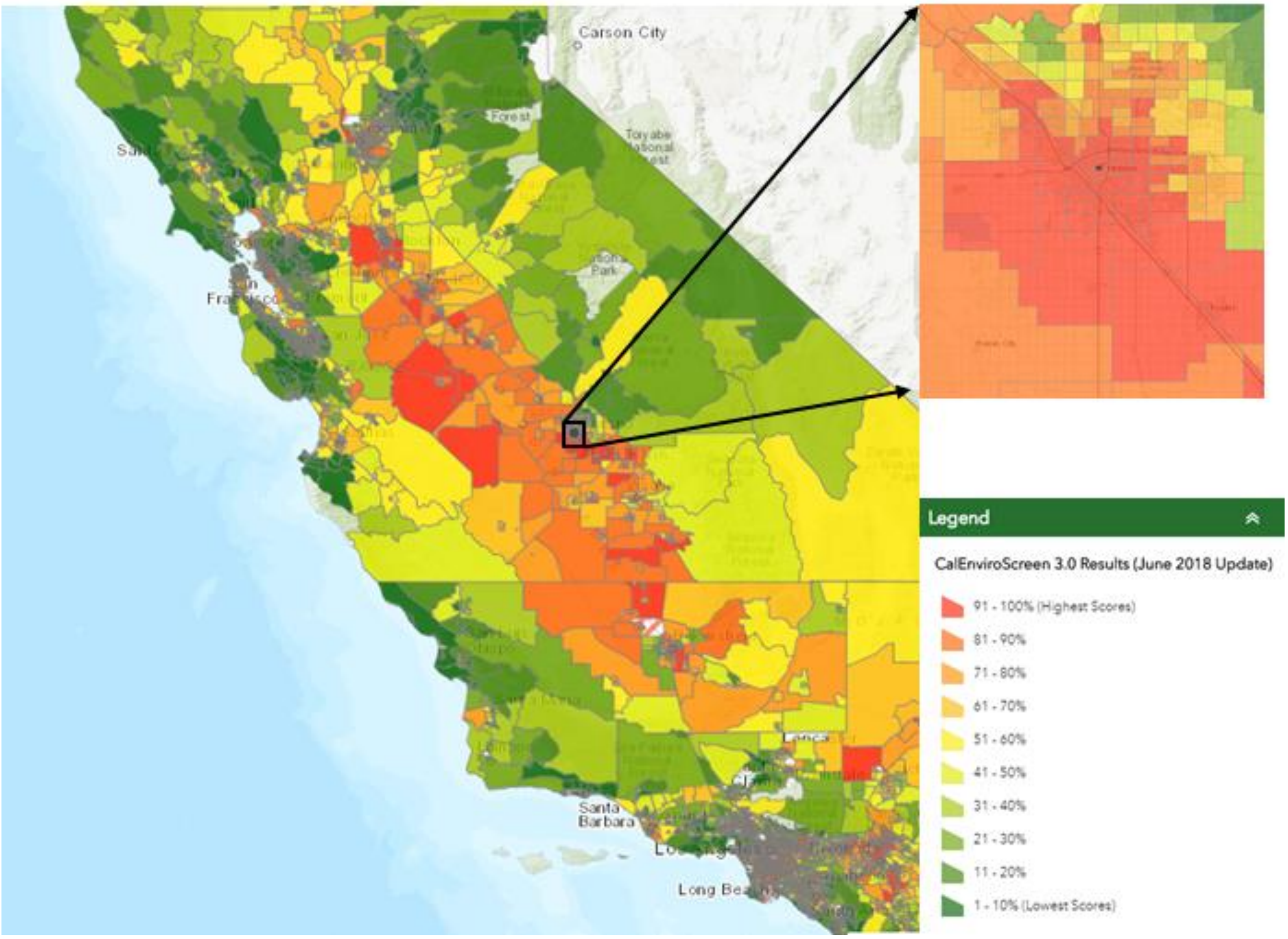
To understand the challenges many residents in the disadvantaged and low-income communities are facing, a research program using direct community engagement approaches was developed. This research piloted a comprehensive field data collection that included an initial community meeting, multiple phone surveys and household interviews, followed by virtual walk-throughs, and finally, a follow-up community meeting. This research was conducted in selected areas within Fresno, California. Wide-ranging topics were investigated, including space heating and cooling systems, air quality issues, solar photovoltaics, and transportation. The information provided important insights into household and home characteristics associated with the high energy costs and health burdens reported by the community. These insights along with the accumulated data informed subsequent techno-economic analysis and the action plan development.

5 https://abc30.com/state-of-the-air-report-american-lung-association-central-ca-pollution-quality/10534815/ Accessed 30 October 2021.

6 Data from https://cal-adapt.org/tools/extreme-heat/ accessed 1 August 2021. Note that the definition of extreme heat is location specific and is defined in California as those days above the 98th percentile of maximum temperatures, based on 1961-1990 data for a given location’s warmest months and that threshold is 106.1 °F in Fresno.

7 https://www.fresnobee.com article254041618, accessed 3 November 2021

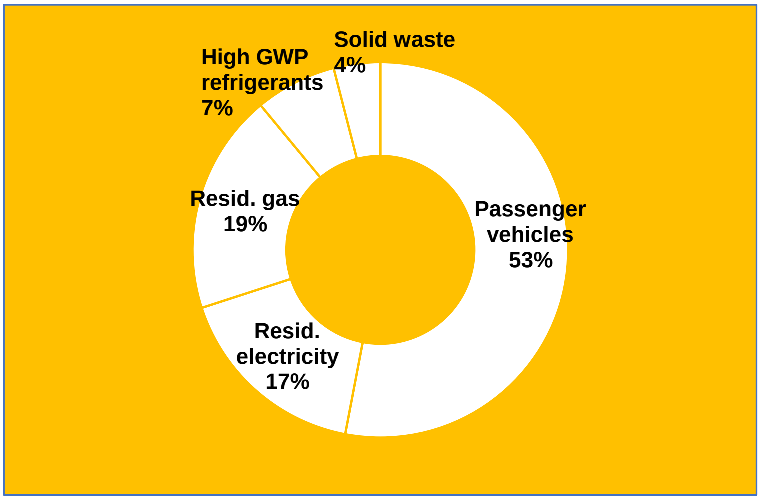
Figure 2: Map of Disadvantaged Communities in Central California



Map of Central California highlighting many disadvantaged communities per CalEnviroScreen. Fresno shown in inset has many disadvantaged communities in central and south Fresno in particular. Note: a higher score represents a more disadvantaged community.

Source: CalEnviroScreen 3.0

Figure 3: Residential Sector GHGs for the City of Fresno



Source: City of Fresno (2020)

Integrated Building/EV/PV Modeling

This project modeled the building stock in the disadvantaged community neighborhoods to evaluate the effectiveness of energy efficiency measures (EEMs) on improving energy efficiency, reducing carbon emission, and improving air quality and access to clean energy. Cost effectiveness of the EEMs was evaluated as well. The zero-net energy (ZNE) potential of the disadvantaged communities was evaluated with installation of rooftop solar PV systems integrated with the energy retrofit measures and electric vehicle adoption. CityBES, a web-based urban-scale retrofit modeling and analysis tool developed by Lawrence Berkeley National Laboratory (LBNL), was adopted as the building stock simulation and analysis tool for this project. New features were added particularly to fulfill the modeling needs of this project, such as the capability of modeling residential buildings, new EEMs applicable to residential buildings, and time-of-use utility rates. This report summarizes the technical tasks of building stock modeling and EEM analysis, including the overall analysis approach, energy efficiency measure description, modeling method, and results and analysis.

Cooling Center Energy Efficiency and Resilience Hub Modeling

The project modeled a community cooling center in Fresno in two phases: energy efficiency measures and solar plus battery storage modeling as a resilience hub. The research team chose the Mosqueda Center in Fresno since it has refrigeration facilities and thus was a good candidate for an emergency response center or future community resilience hub. The site was also proximate to or about 1 mile east of the Winchell neighborhood that was a focal neighborhood in this study. A resilience hub can provide safe shelter and services to community members in a variety of emergency situations, including but not limited to extreme heat events, power outages, and earthquakes.[8] The objectives of this modeling are to inform the city of the costs and benefits of solar plus storage as a function of distributed energy resource incentives (e.g., Self-Generation Incentive Program [SGIP]), resilience provisions provided, and energy efficiency measures installed.

Passenger Vehicle Health Impact Modeling

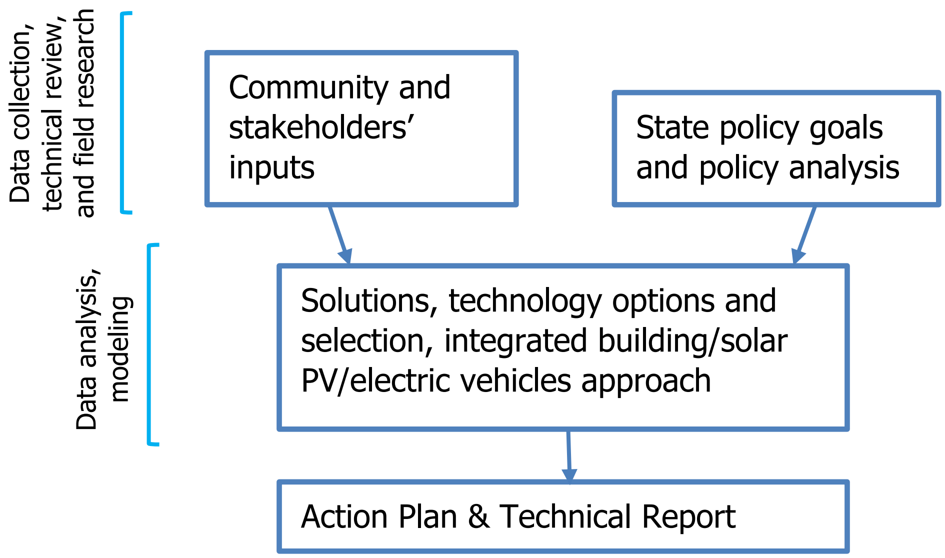
The project used InMAP (Intervention Model for Air Pollution), a closed-form health impact model, to estimate the spatial distribution of annual health damages resulting from input source emissions (Tessum et al., 2017) using the California Air Resources Board (CARB) emissions inventory. InMAP models the evolution of primary source pollutants into secondary $PM_{2.5}$ and maps the health consequences that come as a result of exposure to that $PM_{2.5}$ through the application of a concentration-response function (or "hazard ratio") that describes the relationship between mortality and increased exposure to $PM_{2.5}$ (Krewski et al., 2009; Thind et al., 2022). Total health damages in Fresno County from light duty vehicles in 2020 using the closed-form (reduced complexity) InMap model were estimated to be between $62 million and $83 million in health damages based on the CARBARB emissions inventory and InMap modeling.

[8] The city of Fresno is at the boundary between high risk and moderate risk areas in the state for a "damaging earthquake shaking in 100 years." Per a U.S. Geological Survey update from 2018, the city is located at the border between a region with a greater than 74 percent chance and a region between 36 and 74 percent chance (Petersen et al., 2020).

CHAPTER 2: Project Approach

Figure 4 shows the project approach: first, to collect community and local inputs; second, to do policy analysis of current policies and policy gaps; third, to do integrated building and EV/solar PV modeling; and fourth, to synthesize information into an action plan with a concurrent technical report (this document) detailing the data collection and technical modeling.

Figure 4: Project Approach



Source: LBNL authors

A summary of measures and technologies considered for the climate equity action plan is included in Appendix B. Key mid-project policy-related findings are also included in Appendix C, and more policy-related discussion is found in the companion action plan.

The research team considered 34 measures and technologies for the action plan across energy supply, residential buildings, residential sector transportation, and air quality. From a synthesis of community outreach, community stakeholder interviews, and state and local policy objectives and priorities, the team down-selected eight items for technical modeling:

- Rooftop solar PV
- Energy efficiency upgrades such as attic and wall insulation
- Heat resilience measures such as solar control window films and portable fans
- Evaporative coolers (or swamp coolers) upgraded to air conditioning units
- Electrification of gas-based space heating (such as furnaces and wall heaters) to heat pump-based heating (such as air-source ducted and mini-split ductless heat pumps)
- Gas-based water heating and electric water heaters to electric heat-pump water heating

- Resilience hubs for community support during emergencies such as wildfire smoke and earthquakes and potential future power interruptions
- Passenger vehicles shifting from gasoline vehicles to EVs

Some topics were discussed with the community but not prioritized. For example, electric bikes and electric scooters were not prioritized since there was an evident lack of interest from the community in these measures, and lengthy distances in Fresno between work and commercial areas and increasingly hot summer weather are limiting factors for adoption of these alternative modes of transportation. Expanded transit for bus systems was also noted as a key need in southwest Fresno, but for equity reasons, the research team felt that it was important to include zero-emission vehicles (ZEVs) for disadvantaged community residents in the modeling and subsequent action plan. Similarly, city stakeholders such as the city of Fresno indicated that microgrids are not a current priority for the city as the area does not typically experience extended power outages and has not had public safety power shutoffs (PSPS). The city is actively pursuing energy efficiency and rooftop solar PV for its community centers and the research team also modeled these measures at one community cooling center site together with battery storage as an example of the costs and benefits of developing a community resilience hub.

The research team describes the project approach for the community outreach, integrated modeling, resilience hub modeling, and passenger vehicle health impact modeling in this chapter.

Community Outreach Approach

Between August 2019 and August 2021, a total of 242 households participated in phone surveys and interviews, 21 households participated in virtual home walk-throughs, and 50 participants attended two community meetings.

First Community Meeting

The first community meeting was conducted in the evening of August 27, 2019, at the Columbia Elementary School. A total of 15 participants from the general public attended the meeting, with additional representatives from a California electric vehicle assistance program and a non-profit clean and renewable energy organization. The meeting was held in English, with a Spanish translator on site to assist participants who speak only Spanish. The meeting program included introduction to the research project, a sharing session by the program representatives on EVs and solar equity, and a break-out session with multiple focus group topics such as comfort and health, energy efficiency, transportation options, and cleaner vehicles. Technical materials used in the meeting are included in Appendix A.

Phone Survey – Phase 1

Following the community meeting, a community outreach was carried out to seek public participation in a phone survey. The areas of interest were Columbia and Winchell elementary school districts in Fresno. The outreach efforts were done through local school events and food distribution programs. In total there were eight events resulting in 400 sign-ups for the study. All sign-ups were contacted between October 7 and December 18, 2019. A total number of 151 participants agreed to taking the phase 1 survey of the study. The survey was conducted in English or Spanish language. The survey contained 27 questions, which included basic demographic information, types of space conditioning equipment, presence of solar panels, mode of transportation, and other concerns related to thermal comfort and air quality. On average, the survey took about 10 minutes to complete. The survey material is included in Appendix B.

Phone Interview – Phase 2

Based on the phase 1 phone survey results, a more detailed survey in the form of a participant interview was developed. The outreach efforts were carried out through community canvassing where a recruitment team contacted or visited the homes in the targeted disadvantaged community areas, talked about the study, and requested participation. Those who agreed to participate were contacted by the interviewer at a later time. Phone interviews were conducted between July and September of 2020. A total number of 91 households participated in the interview or phase 2 of the study. The interview was conducted in English or Spanish following interviewees' preference. The interview questions were divided into eight sections: house characteristics, heating equipment, cooling equipment, water heating equipment, home ventilation and air quality, energy assessment, transportation, and demographic information. Each section contained between 6 and 22 questions. On average, the interview required about 40 minutes to complete. Most interviews were completed in one session; however, about 10 percent of the interviews required another follow-up session. The survey material is included in Appendix B.

Virtual Walk-through – Phase 3

The initial plan of the study was to conduct a site walk-through, with the goals of collecting details of the house characteristics through direct observation and photographic records; and performing some diagnostic measurements to assess energy efficiency, thermal comfort, and air quality. However, because of the COVID-19 pandemic health and safety concerns, it was determined that in-home walk-throughs should not be conducted. Instead, the study opted to conduct a virtual walk-through, involving a video tour or a combination of phone chat and photo-taking efforts. No diagnostic measurements were conducted. The walk-throughs were carried out between June and August 2021. Twenty-one participants signed up and completed the walk-through. Each walk-through was guided by several key topics that focus on evaluation of the heating and cooling systems, factors affecting respiratory illnesses, energy costs data, solar panel installation issues, and driving mileage and transportation issues. The entire walk-through took about 30 minutes to complete. More details can be found in Appendix B.

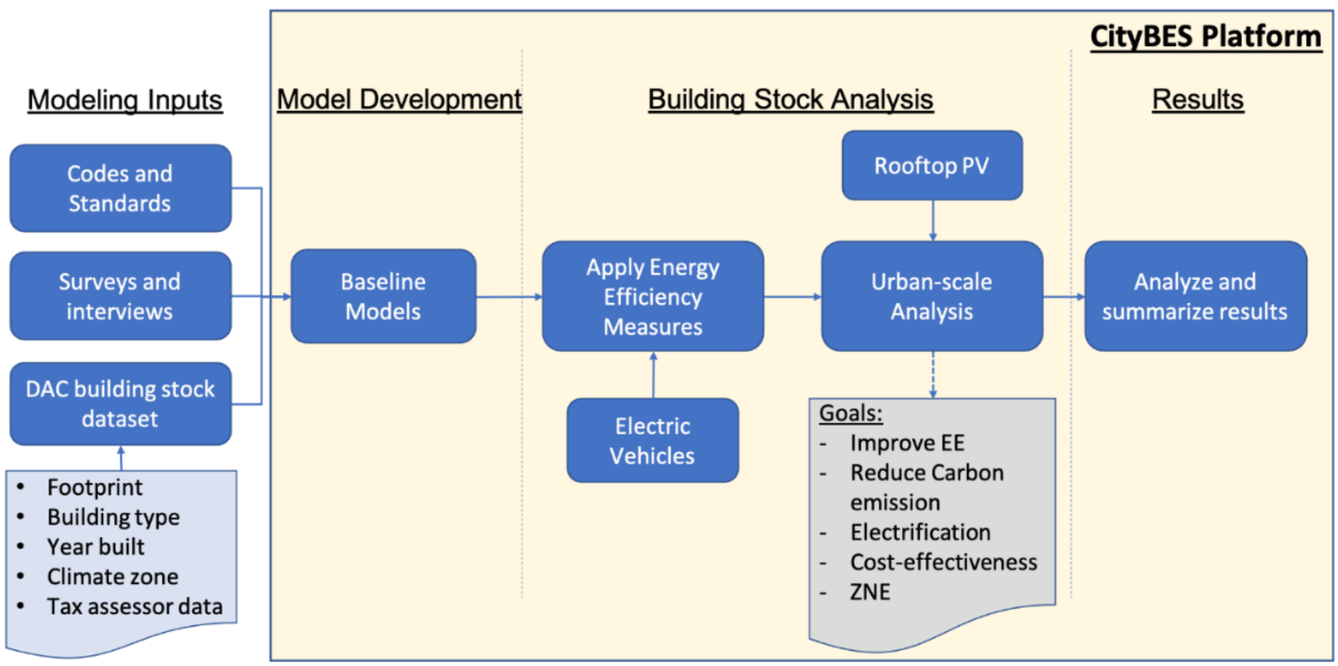
Second Community Meeting

The second (last) community meeting was conducted on September 30, 2021. The goal of this meeting was to present the recent findings from the study, share the action plan, and seek further input or feedback from the community to refine the plan and prioritize the proposed measures. The one-hour meeting was conducted virtually through a Zoom app. A simultaneous breakout session broadcasted the Spanish translation of the main session conducted in English. The session consisted of a mix of listening to a presentation, answering polling questions throughout, and providing feedback directly or through the Zoom chat feature. Thirty-five participants attended the meeting, mostly from the Winchell district of Fresno. The polling questions were designed to obtain the community's perspective on the measures proposed in the action plan and their willingness and readiness to adopt the changes.

Integrated Building/EV/PV Modeling

Figure 5 illustrates the overall workflow of the modeling and analysis approach. First, input data for the model was collected from multiple sources, including Title 24 codes and standards, site surveys and interviews, tax assessor data, and building characteristics compiled from the city's public data sources for the disadvantaged community buildings into a CityBES dataset. Second, the baseline models of the disadvantaged community buildings were created in CityBES based on the model inputs. Third, energy efficiency measures for buildings and EVs for transportation were applied to the baseline models to evaluate their effectiveness in improving energy efficiency, reducing carbon emission, and facilitating clean energy access. They were first evaluated individually, then compiled as packages based on their performance. Cost-effectiveness of the EEMs was also evaluated. The ZNE potential of the single-family homes was evaluated by adding rooftop PV systems, integrated with energy retrofit packages. Each part will be described in detail in the following sections.

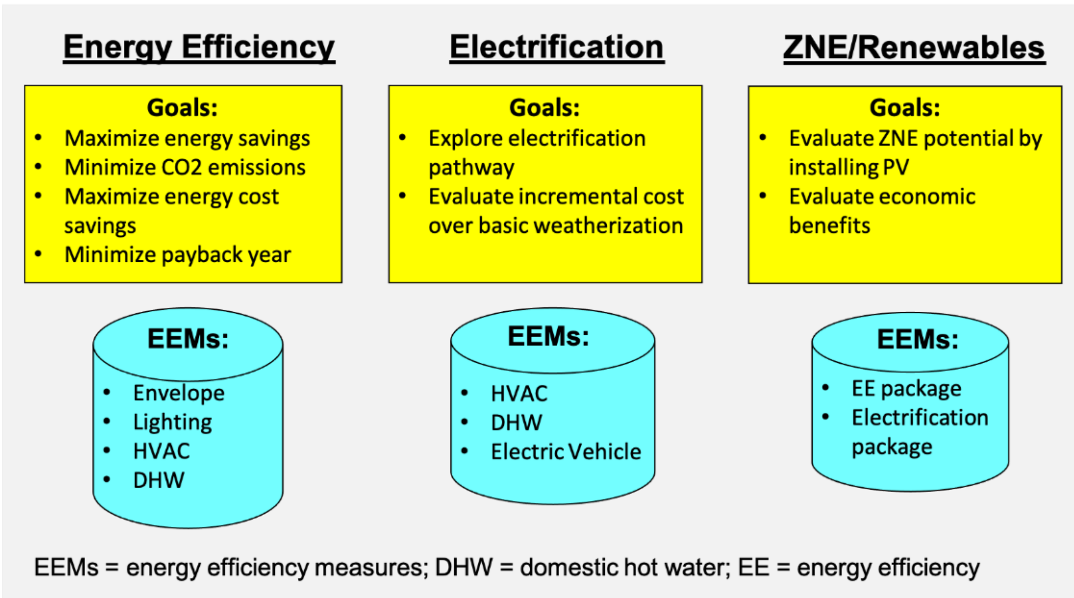
Figure 5: Overall Workflow of the Modeling and Analysis Approach



Source: LBNL authors

Figure 6 summarizes the main scope and goals of the building modeling tasks. This project aimed to improve energy efficiency, promote fuel switching and clean energy, and achieve zero net energy for the disadvantaged community areas. The EEMs mainly include the efficiency improvement of the envelope, lighting, HVAC, and domestic hot water systems. A key metric here is the payback time — the time in years that it takes to cover the higher initial investment cost of a more energy-efficient measure with annual operating cost savings from higher energy efficiency. The goal is to maximize energy savings and energy cost savings while minimizing carbon dioxide (CO_2) emissions and payback period. The electrification measures mainly cover HVAC, domestic hot water (DHW), and EVs. The goal was to explore electrification pathways and to understand how much more residents and policy makers need to invest to adopt clean energy and the extra benefits compared with the traditional weatherization programs, which only do like-for-like retrofits with no fuel switching. The ZNE analysis evaluates the ZNE potential by adding rooftop PV systems and integrating them with energy retrofit measures and EVs.

Figure 6: Scope and Goals of Building Modeling Tasks



Source: LBNL authors

Single- and multi-family home prototypes based on prescriptive requirements in California's Title 24, Part 6 building energy efficiency standards (hereinafter, "Title 24") (California Energy Commission, 2018a) were used to model single-building performance, using EnergyPlus version 9.2 as the simulation engine. EnergyPlus (Crawley et al., 2001) is the U.S. Department of Energy's flagship building energy software for simulating the dynamic energy and environmental performance of buildings. An EnergyPlus simulation calculates a building's thermal loads, system response to those loads, and resulting energy use, along with related metrics like occupant comfort and energy costs. EnergyPlus has been widely used to support development of building energy codes and standards, code compliance, performance rating, and the design and operation of energy efficient buildings. EnergyPlus was verified according to ASHRAE Standard 140, Standard Method of Test for Building Energy Simulation Computer Programs (Henninger and Witte, 2004).

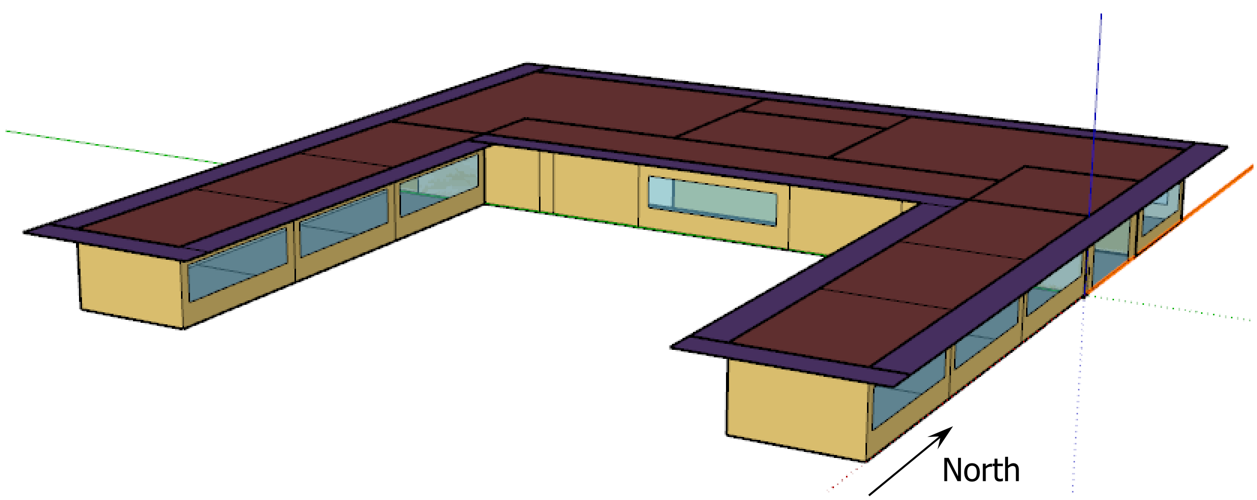
CityBES is used for district-scale modeling and analysis. CityBES is a web-based data and computing platform developed by LBNL (Chen et al., 2020, 2017; Hong et al., 2016). It focuses on energy modeling and analysis of a city's building stock to support district or city-scale efficiency programs. CityBES uses an international open data standard, CityGML, to represent and exchange three-dimensional city models. CityBES employs EnergyPlus to simulate building energy use and savings from energy efficient retrofits. CityBES provides a suite of features for urban planners, city energy managers, building owners, utilities, energy consultants, and researchers. CityBES was originally developed for commercial buildings and this project, along with a few other projects, extends the tool to residential neighborhoods in several cities including Fresno. New features were added particularly to meet the modeling needs of this project, such as the capability of modeling residential buildings, new EEMs applicable to residential buildings, EVs, and time-of-use utility rates. For the concurrent Cal-THRIVES heat resilience project, additional heat resilience modeling capabilities have also been added to neighborhoods in south Fresno (Sun et al., 2021).

Details of energy efficiency measures and other modeling assumptions for the integrated building/EV/PV modeling can be found in Appendix D.

Community Center Energy Efficiency and Resilience Hub Modeling

For the energy modeling development for Mosqueda Community Center (Figure 7), the research team leveraged the small school prototype model used for California Building Energy Code Compliance for Commercial buildings (CBECC-Com).[9] The total floor area of the small school prototype model is 2,269 meters squared (m^2), which is much larger than the Community Center building size. The team modified the prototype model removing some classroom spaces and developed an energy model of a 1,240 m^2 building that could represent the Mosqueda Community Center building with two classroom wings, open office, cafeteria, restroom, mechanical/electrical room, lobby, and corridor spaces. The team added overhangs to the roof to shade windows as observed in Mosqueda Community Center. Then, the team updated the modeling to represent the construction condition built in 1976. This update covered properties of the envelope, infiltration, lighting systems, HVAC systems, and refrigeration load. Figure 8 shows the Mosqueda Community Center energy model developed using EnergyPlus screen captured in the Sketchup application and Table 1 shows the space and envelope area information.

Figure 7: Mosqueda Community Center Main Building



Source: LBNL authors

[9] CBECC-Com: California Building Energy Code Compliance (for Commercial/Nonresidential buildings) software: http://bees.archenergy.com/

Table 1: Mosqueda Community Center Space Information

Space	Area [m²]	Volume [m³]	Wall Area [m²]	Window Glass Area [m²]
Cafeteria	265.7	1,195.6	160.9	85.1
Corridor	160.0	720.0	144.0	16.8
Lobby	63.0	283.5	40.5	21.2
Mechanical/Electrical room	41.5	186.7	46.7	-
Office	204.5	920.3	121.0	51.4
Restroom	93.3	420.0	-	-
Classroom Wing1	210.0	945.0	301.5	107.5
Classroom Wing2	210.0	945.0	301.5	107.5
Total	1,248.0	5,616.0	1,116.0	389.4

Lighting and HVAC system energy efficiency measures were applied to the calibrated community center model. Lighting measures included lighting fixture upgrade and lighting control with daylighting sensors. HVAC system measures included rooftop unit replacement with more efficient cooling and heating systems and also an HVAC control measure that widens zone temperature setpoint dead band.[10] Energy efficiency measures were from Commercial Building Energy Saver.[11] The following information shows selected measures that were applied to the community center building. Each measure includes CBES measure ID for the measure technical specification details.

Lighting fixture upgrade

- Pre-1980 condition (around 20 Watts per square meter [W/m2]) to LED fixture 6.5 W/m2 (CBES ID 3)

Lighting daylighting control

- Add daylighting sensors to control lighting dimming levels (CBES ID 31)

HVAC system upgrade

- Cooling EER from 12 to 14 (CBES ID 5)
- Heating annual fuel utilization efficiency from 0.6 to 0.95 (CBES ID 10)

HVAC control

- Widen zone temperature dead band (cooling: +2 F, heating -2 F) (CBES ID 46)

[10] Thermostat dead band for heating represents the range of temperatures below the set point at which the thermostat does not call for heat. For example, at a 70-degree set point and a 2-degree dead band, the temperature will drop to 68 degrees before heating is activated, raising the temperature back to 70. (https://feds.pnnl.gov/faq/what-thermostat-dead-band#:~:text=Thermostat%20dead%20band%20for%20heating,the%20temperature%20back%20to%2070)

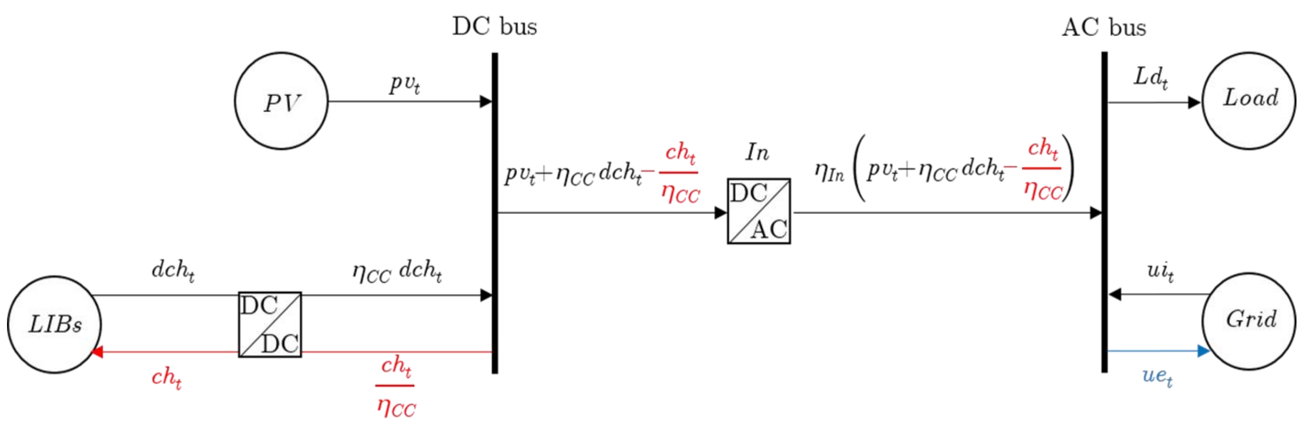
[11] Commercial Building Energy Saver: http://cbes.lbl.gov/

Resilience Hub PV and Storage Sizing Methodology

For the resilience hub modeling the research team modeled the Mosqueda Community Center with solar PV and optional battery storage subject to various resilience requirements, with and without the energy efficiency measures above, and with and without a battery storage subsidy. The team defined resilience as the ability of the system to withstand interruptions of grid-supplied electricity service for various user-specified outage durations.

The system is composed of the inverter (in), the converter (cc), the battery energy storage system and the PV panel. Figure 8 shows a schematic diagram of the connection of these technologies. For this installation, the team considered that the PV system as well as the storage technologies share the same DC bus. The storage requires a dedicated DC/DC converter to interface with the bus. The DC bus is connected through a DC/AC inverter to an AC bus that connects the building load as well as the point of common coupling with the utility. Figure 8 also demonstrates that some energy flows can be bidirectional: on the DC side, batteries can be charged and discharged depending on the energy balance; on the AC side, the electricity can be exported to and imported from the grid. The team also assumed that the power electronics e.g. the DC/AC converter, is capable of being a "grid forming inverter" or that in the event of a grid power outage, the PV and battery storage can be safely islanded from the grid and still serve loads to the facility.

Figure 8: PV and Battery Storage Schematic for Mosqueda Community Center



Source: LBNL authors

Resilience Criteria

For the purpose of sizing the PV and storage system, the research team defined resilience as the ability of the system to withstand long-duration interruptions of service at the point of common coupling with the utility. In other words, the team imposed specific criteria *H* relative to a number of hours of energy autonomy that has to be ensured, at any point in time, by the system design. The team considered two autonomy criteria, depending on the type of interruption:

- Criterion 1 (H=c1): is the minimum number of hours the system has to be able to support a critical load (*Lc*), at any point in time, after an <u>unexpected interruption</u>.
- Criterion 2 (H=c2): is the minimum number of hours the system must be able to support a critical load (*Lc*), at any point in time, after an <u>expected interruption</u>.

The type of interruption determines the ability of the system to respond and sustain the load. In the team's definition, an unexpected event corresponds to unpredictable interruptions of utility power service, i.e. normal distribution network power outages, caused by vegetation, equipment failure, short circuits, etc. These types of outages cannot be predicted in advance, which means that they do not allow the system to prepare for them, for example by pre-charging the batteries to improve the ability to withstand the outage. In this type of outage, the system is "caught off guard" and must respond to the loss of power with the energy resources available in the moment of the interruption. Equation (1) presents the constraint associated with the criterion (c1) of the design. As seen in the equation, the battery state-of-charge, at any point in time, must be able to supply the critical AC netload during a number of hours C1.

$$soc_t \cdot \eta dch \cdot \eta cc \cdot \eta in \geq \sum_{\tau=t}^{t+c1} \left(Lc_\tau - \eta in \cdot pv_\tau \right) \tag{1}$$

In contrast, expected interruptions of service are the ones that can be predicted a few hours ahead. An example of this type of outage is the utility PSPS, well known in California during hot and dry seasons. From the system operation perspective, when an alert of a PSPS event is received, the system has at least a few hours to prepare for it, including charging the battery to full capacity. Therefore, when outages are expected, the system design is not limited by the state of charge, but instead by the capacity of the storage assets. As shown in equation (2), the capacity of the battery must be large enough to supply the critical AC netload during C2 hours.

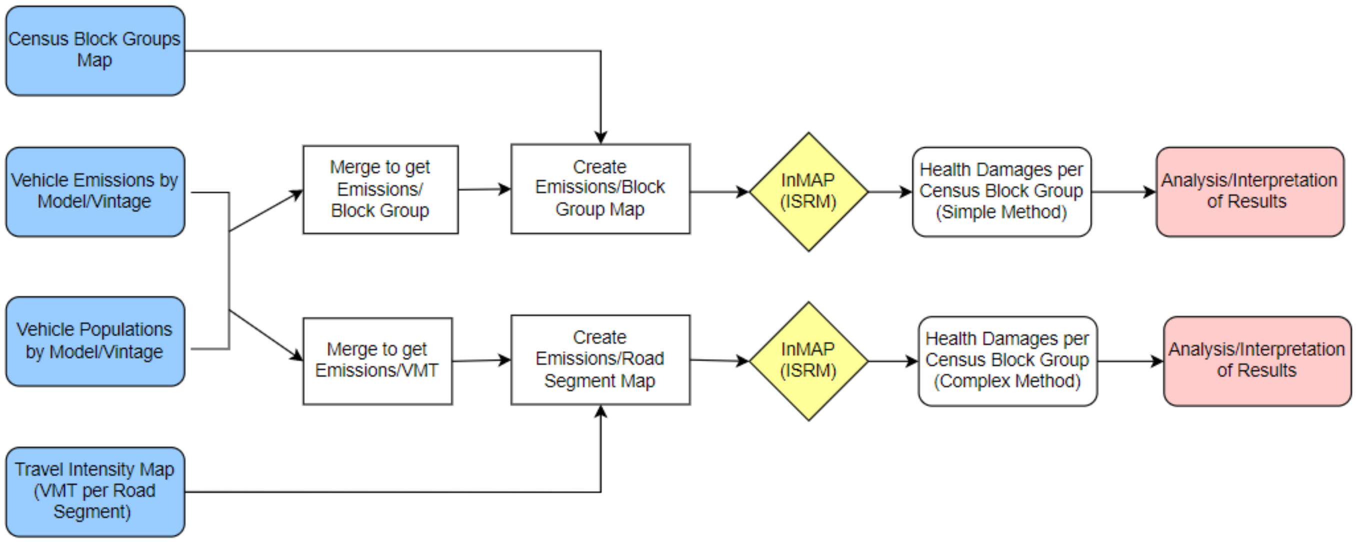
$$cap_s \cdot \eta dch \cdot \eta cc \cdot \eta in \geq \sum_{\tau=t}^{t+c2} \left(Lc_\tau - \eta in \cdot pv_\tau \right) \tag{2}$$

Other cost and modeling assumptions for the resilience hub modeling are in Appendix E.

Passenger Vehicle Health Impacts Modeling

The research team used Intervention Model for Air Pollution (InMAP), a variable-resolution spatial air quality model, to estimate the spatial distribution of total $PM_{2.5}$ concentration and corresponding annual health damages resulting from input source emissions (Tessum, Hill, & Marshall, 2017). InMAP models the evolution of primary source pollutants into secondary $PM_{2.5}$ and maps the health consequences that are a result of exposure to that $PM_{2.5}$ through the application of a concentration-response function (or "hazard ratio") that describes the relationship between mortality and increased exposure to $PM_{2.5}$ (Krewski et al., 2009; Thind et al., 2022). The workflow for health impact modeling is demonstrated in Figure 9 and explained in greater detail below.

Figure 9: Workflow for Passenger Vehicle Health Damages



Source: LBNL authors

InMAP was used in this study for spatially capturing the travel of primary source emissions across Fresno County and calculating subsequent exposure to secondary $PM_{2.5}$ at receptor sites. It was designed to carry out these calculations based on specific input source emissions data provided by the user, modified to fit a Shapefile (".shp") format, a file format widely used in geographic information system (GIS) software for viewing spatial data. Input source emissions consist of primary $PM_{2.5}$, NO_x, SO_x, NH_3, and volatile organic compounds (VOCs), and evolution to secondary $PM_{2.5}$ pollutants is modeled by InMAP, which includes pNH_4, pSO_4, pNO_3, and secondary organic aerosols (SOAs). These input emissions are fed into the InMAP "grid," a dynamic computational platform that models source emissions considering physical and chemical atmospheric parameters to simulate the travel and exposure to these emissions in a manner that is technically consistent with conventional chemical transport models (CTM). To avoid the computation power required to run such CTMs, InMAP uses a variable-resolution grid, where more computational power is devoted to those regions with the highest population density. By allowing the user to define input source emissions and demographic data, InMAP can be leveraged to estimate the health impacts of specific industrial sectors and measure how certain groups of people may be more heavily impacted than others. Thind et al. (2019), for example, used InMAP to show how racial and economic disparities were prevalent in health impacts stemming from electricity generating units across the U.S. Accordingly, using user-submitted input emissions data, InMAP produces a mapped grid of the United States with associated results as accumulated concentrations of $PM_{2.5}$ and associated health impacts calculated for each grid square, where the size of these squares is proportional to population density and pollutant concentration in these regions. InMAP calculates and maps the accumulation of source emissions and their evolution into pNH_4, pSO_4, pNO_3, and SOA, which are summed with primary $PM_{2.5}$, to form total $PM_{2.5}$. Health impacts are modeled as a function of exposure to total $PM_{2.5}$.

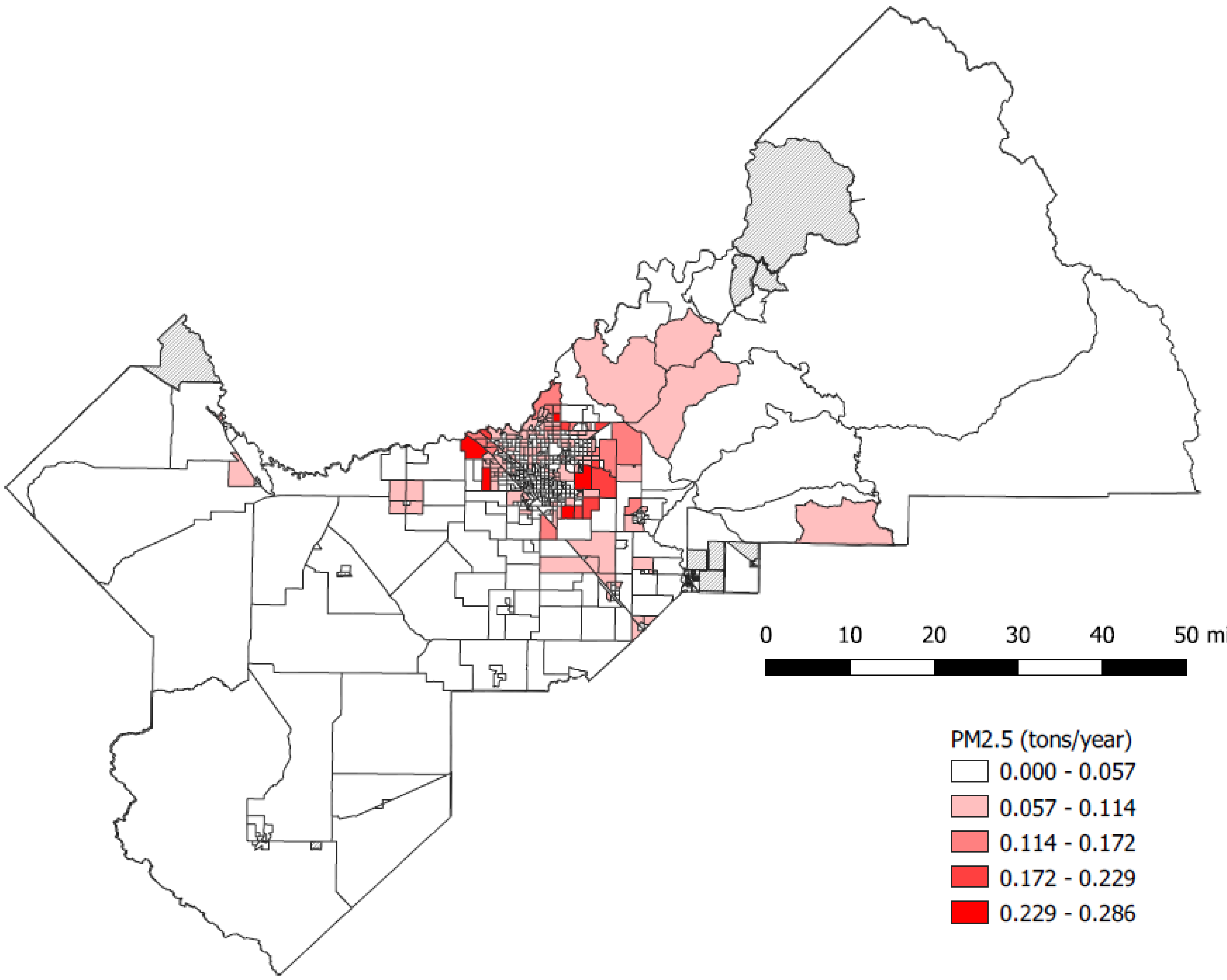
Whereas InMAP handles all computations involved in spatially allocating source emissions, the primary challenge of this study involved knowing where these source emissions emerged, a challenge given the non-stationary mobile nature of these source emissions. Since this input data needed to be supplied in shapefile format, any emissions data would need to be joined to an existing shapefile, where the team specifically used a shapefile polygon of Fresno County boundaries. Emissions source data to be joined to this shapefile were obtained through the EMFAC (EMissions FACtors) Emissions Inventory tool, available from CARB. This tool allowed the team to obtain emissions inventory (EI) data for Fresno County consisting of annual emissions (in tons) for all vehicle classes and vintages, with corresponding vehicle populations for each. Emissions of interest used to make up the study's input emissions included the precursor emissions of total $PM_{2.5}$, consisting of primary $PM_{2.5}$, NO_x, SO_x, NH_3, and VOCs. While this data could be simply joined to the study's Fresno County boundaries shapefile, the subsequent input emissions shapefile would contain single emissions values for $PM_{2.5}$, NO_X, SO_X, NH_3, and VOCS, and thus not provide any depth into where within the county these source emissions were emerging. This means that while this input emissions shapefile could surely be supplied to InMAP to have countywide emissions and accumulation spatially allocated, results would not account for which neighborhoods and regions source emissions were coming from, and thus not allow the research team to capture potential inequities in where vehicle activity was most heavily concentrated and which communities were most severely being impacted.

Whereas EMFAC Emissions Inventory data does not contain annual emissions values for unique block groups, the EMFAC Fleet Database (FD) provides vehicle population values for all listed vehicle types addressed to each county block group, with population values containing a corresponding county-level FIPS (Federal Information Processing System) code. These FIPS codes and corresponding population values could be mapped to the study's Fresno County block groups polygons shapefile through a simple table join, since each Fresno County block group polygon contains a corresponding FIPS code, allowing data to be merged by matching FIPS codes. Hence the primary challenge in constructing the study's neighborhood-scale resolved imputed emissions shapefile concerned merging EMFAC EI emissions values for each vehicle type to the vehicle populations in the fleet database. This required knowing: 1) the volume of emissions that should be expected for each vehicle type, and 2) how many of each vehicle type are located in each neighborhood, where vehicle type indicates a unique pair of vehicle class (e.g., light-duty truck) and vehicle vintage. Since it was difficult to adequately delineate neighborhood boundaries, the team relied on census block groups and individual road segments as best approximations for siting source emissions at the neighborhood spatial scale. This led to two approaches in mapping source emissions: 1) a simple approach where emissions quantities were calculated for each block group, and 2) a more complex approach that accounted for vehicle travel and mapping emissions to road segments rather than block groups.

Simple Approach

The first, or simple approach, involved taking the EI data, which contained emissions quantities for each vehicle type's total population, and dividing by the total population for each vehicle type, to find the total emissions for a single vehicle of each type. These emissions/per vehicle type rates were multiplied by the population values for each vehicle type assigned to each block group. This produced a single data frame containing annual emissions of all precursor emissions for each block group, which was then merged to the Fresno County block group polygons shapefile by corresponding FIPS codes, and subsequently entered to be run through InMAP as input emissions. This input emissions shapefile accordingly displays precursor source emissions quantities for each county block group, as portrayed in Figure 10.

Figure 10: Input Emissions Shapefile Showing $PM_{2.5}$ Produced Through Simplified Method



Source: LBNL authors

The important note to be made here, however, is that this approach assumes that vehicles are geographically static, meaning that they are evenly distributed throughout block group space and do not move within and across block groups. In other words, vehicle source emissions emerge equally from all space within a block group, rather than specifically from the road regions where cars are actually being driven. This means that for larger and less-populated block groups with less road infrastructure, emissions are assumed to be sourced from remote regions with few roads just the same as those regions near multiple high-traffic roads. While this simple approach may be adequate for quicker, high-level analysis and insight into which block groups are most impacted, it may be difficult to reconcile the resolution of the input emissions with the resolution of results sought. Whereas this simple approach may from a computational and programming perspective be the most direct and intuitive, the lack of consideration for vehicle travel along road networks, unable to be derived from block group geometries, may prove troublesome when trying to pinpoint which precise neighborhoods are contributing the most to county-level emissions compared to others.

Complex Method

Complementing the simplified method, the team's complex method seeks to more accurately capture the spatial resolution of allocated EMFAC EI relative to where vehicles are actually being driven throughout Fresno County. While similar in scope, the complex method attempts to build upon the simplified method by accounting for vehicle travel within and across block groups as a function of traffic levels across road segments. This method is described more fully in Appendix F.

Health Impact Calculations

After input emissions were processed (whether through the simple or complex method) and spatially distributed by InMAP to receptor locations, modeled health impacts, here measured as premature mortalities, were calculated as a function of exposure to total primary and secondary $PM_{2.5}$, as displayed in calculation (3).

$$\text{Total } PM_{2.5} = \text{Primary}PM_{2.5} + pNH_4 + pSO_4 + pNO_3 + SOA \qquad (3)$$

Where:

Total $PM_{2.5}$: Total primary and secondary $PM_{2.5}$

Primary $PM_{2.5}$: Primary $PM_{2.5}$ concentration

pNH_4: Particulate ammonium (secondary $PM_{2.5}$)

PSO_4: Particulate sulfate (secondary $PM_{2.5}$)

pNO_3: Particulate nitrate (secondary $PM_{2.5}$)

SOA: Particulate secondary organic aerosol (secondary $PM_{2.5}$)

Here pNH_4, PSO_4, pNO_3, and SOA, along with Primary $PM_{2.5}$, are all recognized as $PM_{2.5}$ species, and collectively contribute to the Total $PM_{2.5}$. All secondary pollutants at receptor locations are provided by InMAP as concentrations of $\mu g/m^3$.

Deaths were calculated as a function of present total $PM_{2.5}$ concentration, based on the "Cox proportional hazards equation," expressed as:

$$\text{Total deaths} = (\exp(\log(1.06)/10 * \text{Total}PM_{2.5}) - 1) \times \text{TotalPop} \times 1.047 \times \text{MortalityRate} / 100000 \times 1.025 \qquad (4)$$

This formula assumes that total deaths will increase by an estimated 6 percent for every 10 $\mu g/m^3$ increase in exposure to total $PM_{2.5}$, as detailed by Kreskwi et al. (2009), and thus termed as "Krewski deaths." The value of 1.047 was used as a ratio to best relate 2010 population values to 2016 population values, and the value of 1.025 was used as a ratio to best relate 2005 mortality rates to 2016 mortality rates, with 2016 in both cases being the projected year currently suggested through InMAP documentation. Economic impact attributed to $PM_{2.5}$ exposure was calculated by multiplying total death counts by the team's designated value of statistical life (VSL) of $10.5 million. These methods are detailed in the InMAP source-receptor matrices documentation (Tessum, 2019). As InMAP calculated secondary pollution concentrations at receptor sites based solely on those input source emissions that were supplied, the team's calculated health impacts were directly and only attributed to the study's supplied source emissions from EMFAC, for both the simple and complex methods, thus demonstrating health impact as a function of marginal (incremental) changes to source emissions.

Monetized health damages are calculated by multiplying projected premature deaths by a $10.5 million VSL, originally set to a VSL of $7.9 million "in 2008 dollars" (EPA, 2010) and then adjusted to 2021 dollars, accounting for inflation. The research team then provided analysis and interpretation of results to understand health impact inequities in Fresno County from vehicle-source emissions.

CHAPTER 3: Project Results

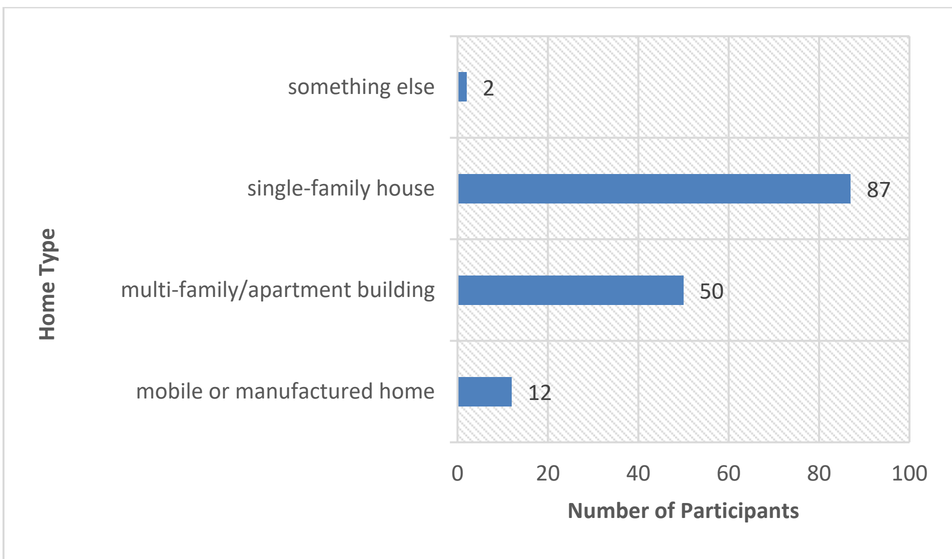
The authors provide results for the community outreach, integrated building/EV/PV modeling, resilience hub modeling, and passenger vehicle health impacts modeling in this chapter.

Outreach Results

Results of Phone Surveys (Phase 1)

Figure 11 shows the distribution of homes by type from all participants located in the Winchell and Columbia districts of Fresno. About 58% (87 out of 151) of participants lived in single-family homes, followed by 33% (50 out of 151) in multi-family and apartment buildings. The phone surveys further revealed that 83% of the participants were renters (124 out of 151), and among renters, about half lived in single-family homes, while the rest lived in multi-family and other types of homes.

Figure 11: Distribution of Home Types

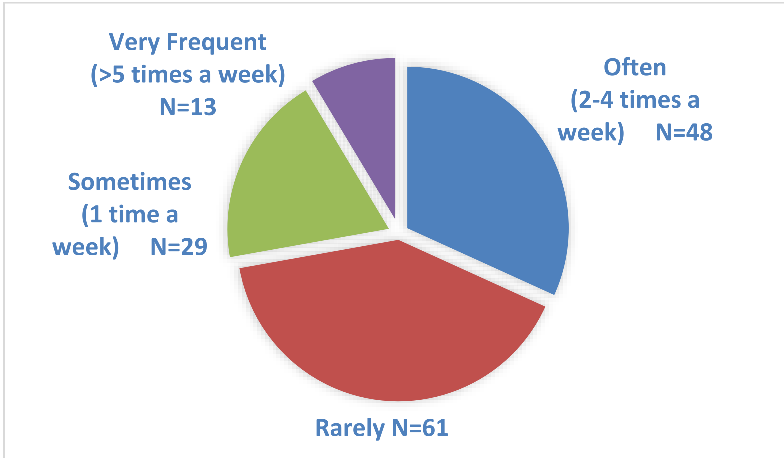


Source: LBNL authors

To meet their space heating needs, about 34% of the homes used a central furnace and 23 percent used central heat pump systems. Though residents identified their units as central heat pumps, it is not likely that these were electric heat pump units since these are uncommon in the state. This means many of the households did not have centralized heating systems in their homes. For example, up to 20% of single-family homes used portable heaters or wall heaters as their primary heating system. In terms of fuel types, about 55% and 35% of the homes used gas and electricity as energy sources for heating, respectively. The substantial use of electricity for heating was mostly contributed by the use of portable heaters.

Figure 12 shows the number of times participants were experiencing thermal discomfort during the heating season. About 60% of the participants reported feeling discomfort at least once a week with a large portion (57%) attributable to participants without a central heating system.

Figure 12: Frequency of Thermal Discomfort During Heating Season

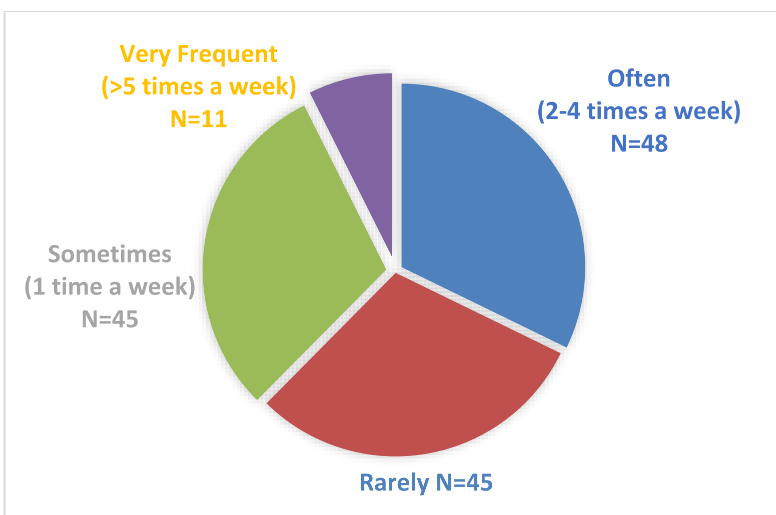


Source: LBNL authors

More homes used a centralized system for space cooling than heating. About 45% of the homes used a central air conditioner as their primary cooling system. The use of window air conditioners was also quite prevalent (33%) among all the participants, and even more so for single-family homes, where the use of window air conditioners was almost equal to the central air conditioners. Further analysis shows that almost a quarter of the single-family homes used portable cooling appliances such as a portable air conditioner, a portable fan, or a ceiling fan as primary means for cooling. The primary energy source for all cooling systems, both centralized and portable, was electricity.

Figure 13 shows the number of times participants were experiencing thermal discomfort during the cooling season. About 70% of the participants reported feeling discomfort at least once a week, of which about 60% did not have a central cooling system.

Figure 13: Frequency of Thermal Discomfort During Cooling Season



Source: LBNL authors

Almost 80% of the participants expressed concern over their high utility bills during the summer (cooling) and winter (heating) seasons, even though more than half of them received a monthly discount in their utility bills through Pacific Gas and Electric Company's (PG&E's) California Alternate Rates for Energy (CARE) program.

When asked about their concerns related to air quality issues, the participants seemed to be more concerned about air quality from outside their homes. More than 60% of the participants felt moderate to seriously concerned about their outdoor air quality, traffic pollution, and factory/industrial pollution sources. On the other hand, about slightly more than 30% of the participants felt the same about their indoor air quality.

The majority of the households (96%) did not have a roof solar panel installed. Only three homes reported using solar photovoltaic panels. Almost all participants (93%) noted that access to solar panel program was difficult.

About 70% of the participants used cars powered by gas as the main transportation mode, while the rest used public transportation services. Of all participants who used a car, 40% drove 10 miles or less per day, 50% drove between 10 and 50 miles per day, and the rest drove more than 50 miles per day. Almost all participants (94%) reported difficulties accessing or owning zero-emission EVs.

Summary of Community Outreach Findings

- Common concerns for energy related services were high utility bills, poor outdoor air quality, and transportation costs and access.
- Most residents are not comfortable in their homes in hot (70%) or cold weather (60%) at least once a week. This is an area to improve equity – to provide better indoor comfort during the summer and winter without increasing energy bills.
- For passenger vehicle transportation – authors estimate that 60% or more of residents drive less than 35 miles per day; thus, EV could be an option instead of a gasoline vehicle with Level 1 charging. The dominant fraction of people was willing to adopt an electric vehicle if it is affordable.
- Authors found a general lack of interest in e-scooters-sharing or bike sharing due to long travel distances, but more interest in carpooling.
- Outdoor air quality is a greater concern than indoor air quality. Although residents did not report excessive concern with indoor air quality, the prevalence of indoor air filters seems very low, and residents seem quite open to adopting DIY air filters. More education on HVAC furnace/AC filter cleaning or replacement is another opportunity.
- Awareness of existing rooftop solar PV and clean vehicle rebate programs appears low (80% or more unaware of these programs) and is an opportunity for greater outreach and/or more program consolidation to avoid missing residents who may inquire about a specific EE/PV or EV program.

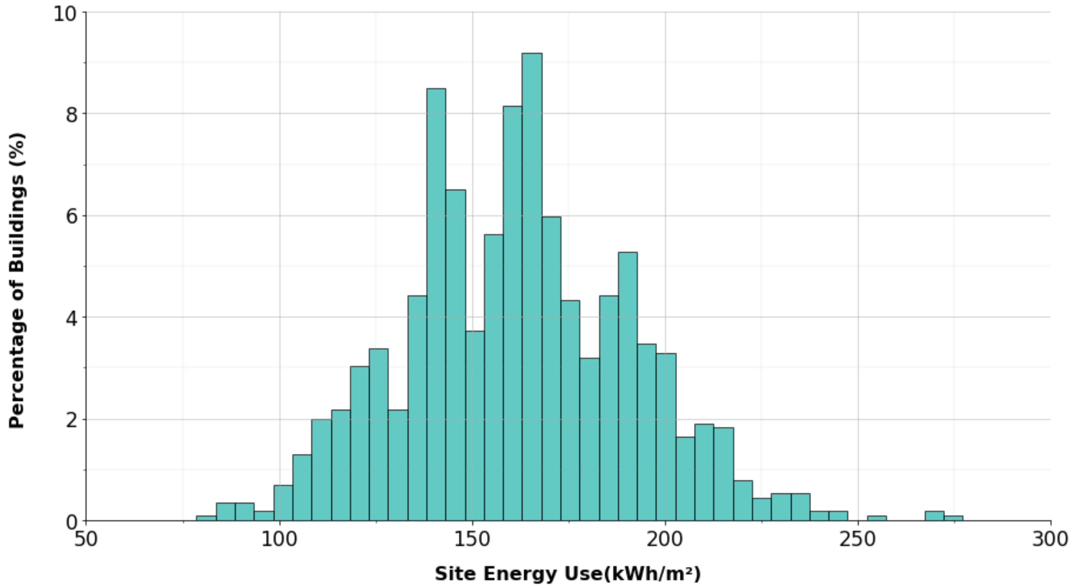
Integrated Building/EV/PV Modeling

A total of 22 energy efficiency measures (EEM) were selected and modeled in CityBES to explore potential solutions to improve energy efficiency and promote clean energy accessibility in the disadvantaged community (DAC) areas. The goal was to determine the top performing EEMs and EEM packages that can maximize energy savings, maximize energy cost savings, minimize CO_2 emissions, or minimize payback period. The selected EEMs were first applied to the baseline models individually, and their effectiveness was evaluated and ranked according to the goals above. The EEMs were then combined as packages based on their categories and performance. The packages were further modeled and analyzed. For different performance goals, different packages were selected as appropriate.

Baseline Models

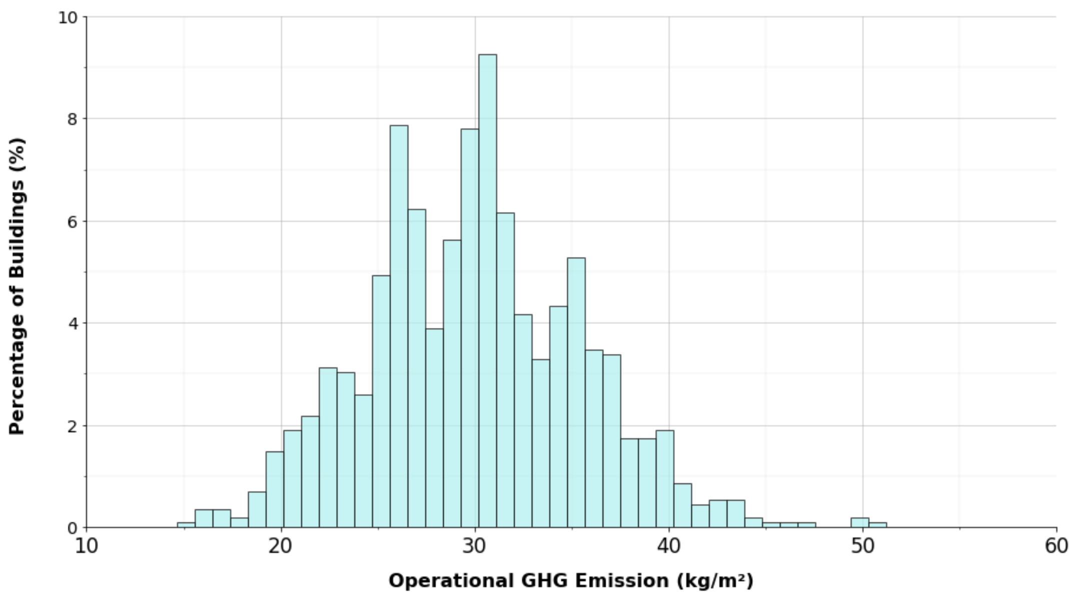
As described in Appendix D, the residential buildings, including single-family and multi-family homes, in the Winchell and Columbia districts primarily use three types of air conditioning systems: evaporative coolers, window air conditioners, and central air conditioners. The heating system for the first two cooling types was assumed to be a gas-based wall heater, and a gas furnace for the third cooling type. The domestic hot water system was assumed to be a natural gas water heater with storage tanks. These baseline systems were modeled and evaluated in terms of their site energy use and CO_2 emission, as well as the proportion of electricity and natural gas consumption. As shown in Figure 14 and Figure 15, the annual site energy use intensity and CO2 emission intensity of all residential buildings share a similar distribution and vary within the ranges of 75-275 kWh/m^2 and 15-52 kg/m^2, respectively. This similar distribution of energy consumption and CO_2 emission is mainly due to two reasons: (1) The CO_2 emission factors of electricity and natural gas are similar. The CO_2 emission factor for electricity is 420.39 lbs (194.8 kg) CO_2/MWh in California, based on the Emissions & Generation Resource Integrated Database (eGRID) (U.S. Environmental Protection Agency, 2018) and for natural gas is 399.48 lbs (181.2 kg) CO_2/MWh; (2) The electricity and natural gas consumptions are quite close for each building, with gas taking up a slightly higher proportion, as shown in Figure 16. If further analyzed, the distribution for proportion of electricity and natural gas can be clustered into three groups based on the baseline HVAC system types: central AC with central gas furnace, window AC with gas-fired wall furnace, and swamp cooler with gas-fired wall furnace. Buildings equipped with swamp coolers and gas-fired wall furnace consume significantly lower electricity than buildings equipped with the other two system types because swamp coolers do not have compressors and use only fans to distribute cooled air. For the two conventional vapor compression-based system types, central ACs with central gas furnaces generally use more electricity and gas than window ACs with gas-fired wall furnaces, because the former distributes conditioned air to the whole house and therefore consumes more fan energy and at the same time also suffers from efficiency loss due to duct leakage.

Figure 14: Baseline Analysis of Residential Buildings' Annual Site Energy Use for Winchell Neighborhood



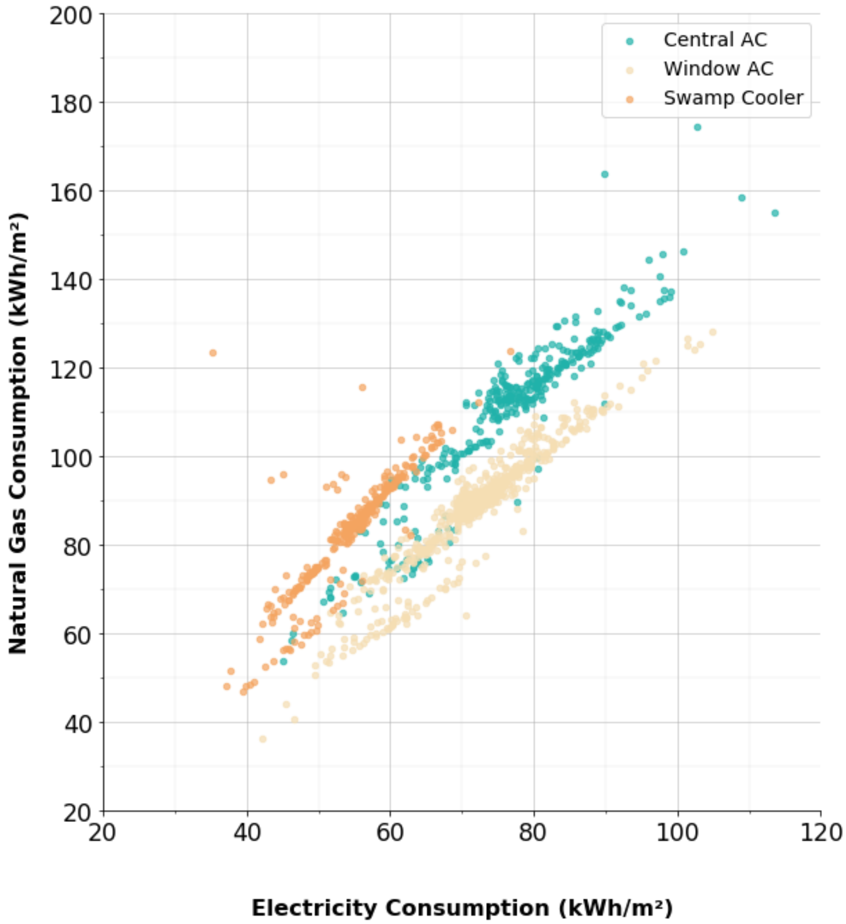
Source: LBNL authors

Figure 15: Baseline Analysis of Residential Buildings' Annual CO_2 Emission for Winchell Neighborhood



Source: LBNL authors

Figure 16: Baseline Analysis of Proportion of Annual Energy Use by Source Types for Residential Buildings in Winchell Neighborhood



Source: LBNL authors

Appendix D2 has modeling results for energy efficiency packages (without EV or PV) for baseline homes developed for various objectives: maximum energy and CO_2 savings, maximal utility bill savings, initial costs limited to $1,000 and $5,000, or payback times of less than 10 or 20 years.

Authors identified a combination of energy efficiency packages that are less than $1,000 with up to 10% annual energy savings (adding portable fans, improving water tank insulation, and adding air sealing to seal leaks), and upgrading to an efficiency package with LED upgrade, portable fans, improving water tank insulation, and higher efficiency gas furnace provide up to 22% annual energy savings and less than a five-year payback.

The most favorable package for energy savings and CO_2 emissions reduction is described in Appendix D2: replacing existing lighting with LED (0.6 W/sf), applying ceiling insulation (R-38), upgrading to mini-split heat pump system (3.66 COP cooling, 3.7 COP heating), upgrading to heat pump water heater (COP 3.3), reroofing and roof with insulation (R-24.83), adding an interior storm window layer, applying wall insulation (R-21), and adding window film. This measure package can reduce energy consumption by a median of 63%, and a median reduction of 63% in CO_2 as well. However, while the measure package can achieve large energy savings and CO_2 emission reduction, the package has high initial investment cost and generally a long payback period.

Electrification Analysis

This section explores the viable pathways towards electrification by evaluating the performance and cost-effectiveness of electrification measures considering incremental costs relative to like-for-like upgrades of gas-based space heating units and gas-based water heating. Four measures out of 22 EEMs were selected and evaluated for fuel switching: (1) upgrade to air-source heat pump system; (2) upgrade to mini-split system; (3) upgrade to heat pump water heater; (4) replace fuel vehicle with electric vehicle. Electrification is first analyzed without EV, focusing on the first three measures only. These three measures perform fuel switching for the HVAC and domestic hot water systems, which are responsible for the majority of buildings' natural gas consumption. Two electrification packages were built upon them: (1) + (3) and (2) + (3). Their effectiveness on electrifying the buildings were evaluated. Authors also analyzed the incremental cost of the electrification measures over the traditional weatherization programs, which generally do like-for-like retrofits at the end of equipment service life. The goal was to understand how much more the residents and policy makers need to invest in fuel switching and the impacts to energy saving, GHG reduction, and energy cost saving.

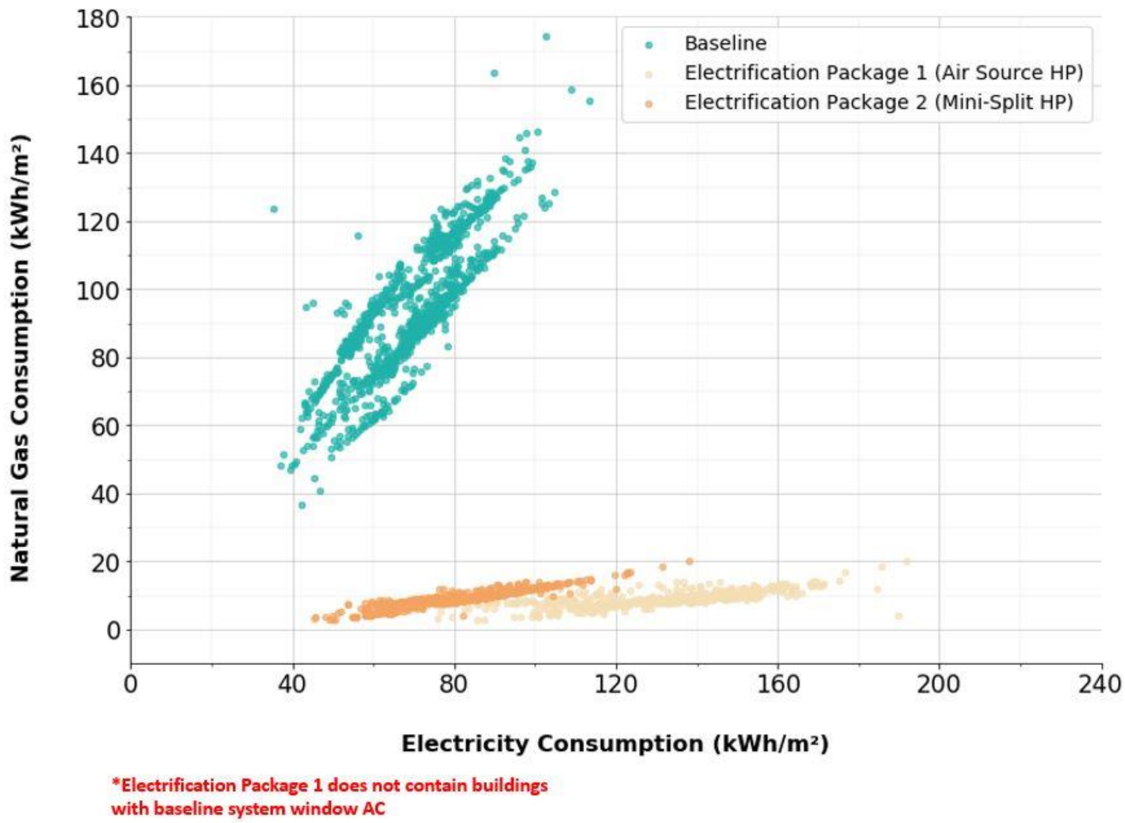
The EV measure was then evaluated, both independently and also combined with the other three measures as two electrification packages: (1) EV + heat pump water heater + air-source heat pump (3.22 COP cooling, 3.3 COP heating); (2) EV + heat pump water heater + mini-split heat pump (3.66 COP cooling, 3.7 COP heating). They were all evaluated on energy savings, CO_2 emission reduction, energy cost savings, and payback year. The time-of-use (TOU) rate for EV ("EV2-A" rate plan) was adopted for the energy cost analysis of the EV measure and the two electrification packages.

Electrification Packages without EV

Two measure packages were evaluated for fuel switching. For both packages, the existing gas storage water heaters were replaced with heat pump water heaters. The HVAC system could either be upgraded to an air-source heat pump (without window AC baseline system) or a mini-split heat pump. As shown in Figure 17, the electricity and natural gas consumption of the baseline buildings are very close to each other, with natural gas being slightly higher. Both measure packages can reduce natural gas consumption sharply to only 0-20 kWh/m² from the initial 40-180 kWh/m². Figure 18 illustrates the natural gas consumption reduction of the two packages overlaps at approximately 85-95%, indicating that both packages reduce the same amount of natural gas. Natural gas consumption was not entirely eliminated because aside from the HVAC and domestic hot water system, there are also home appliances like gas stove and gas dryers that still consume natural gas. The electrification of these end use equipment types was not investigated in this study. Figure 17 also shows a significant increase in the proportion of electricity usage. While the baseline buildings consumed no more than 120 kWh/m², the electrification packages increased the electricity consumption to as high as 200 kWh/m². More specifically, Figure 19 reveals that the package with the air-source heat pump caused an increase of 60-160% of electricity consumption, whereas the package with the mini-split heat pump mostly increased the electricity consumption up to 60%. This discrepancy was mainly caused by the two systems' different efficiency levels: 3.66 cooling COP and 3.7

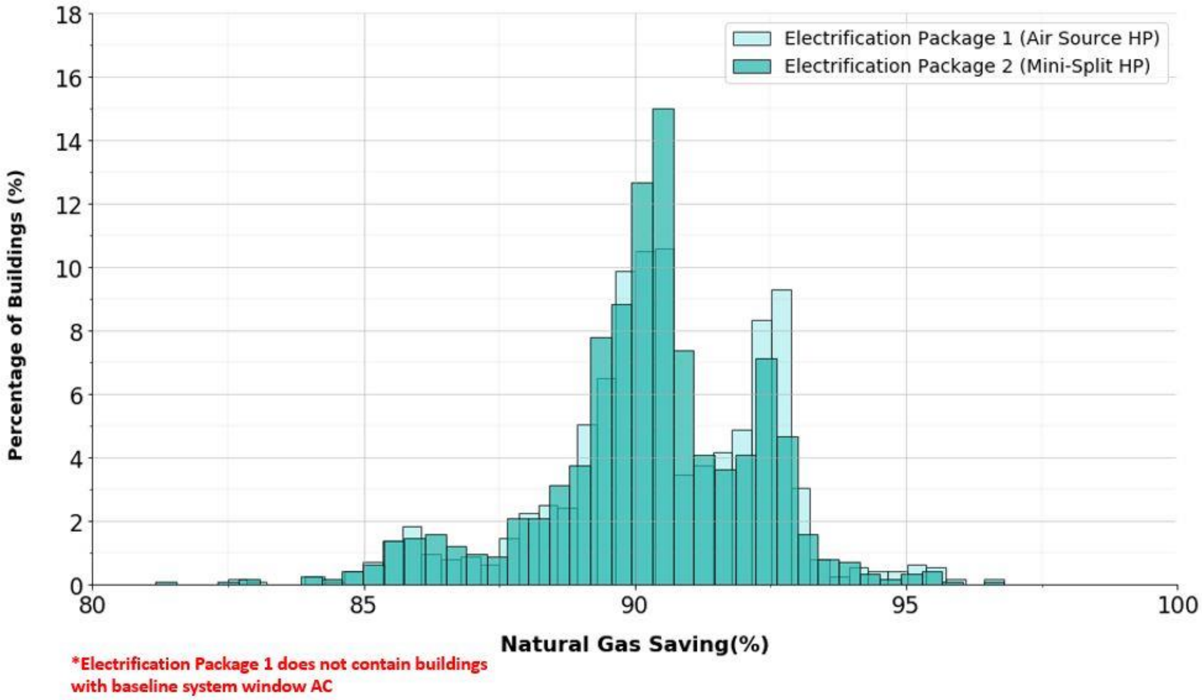
heating COP with the mini-split heat pump vs. 3.22 cooling COP and 3.3 heating COP with the air-source heat pump. Moreover, the mini-split heat pump also had higher efficiency during the partial load condition than the air-source heat pump. Therefore, even though both packages can sharply reduce the natural gas consumption from the baseline buildings, the resulting additional electricity consumption as part of the conversion was a key metric for comparing different options.

Figure 17: Comparison of Proportions of Electricity and Natural Gas in Annual Energy Use for Residential Buildings in Winchell Neighborhood Between Baseline and Two Electrification Packages



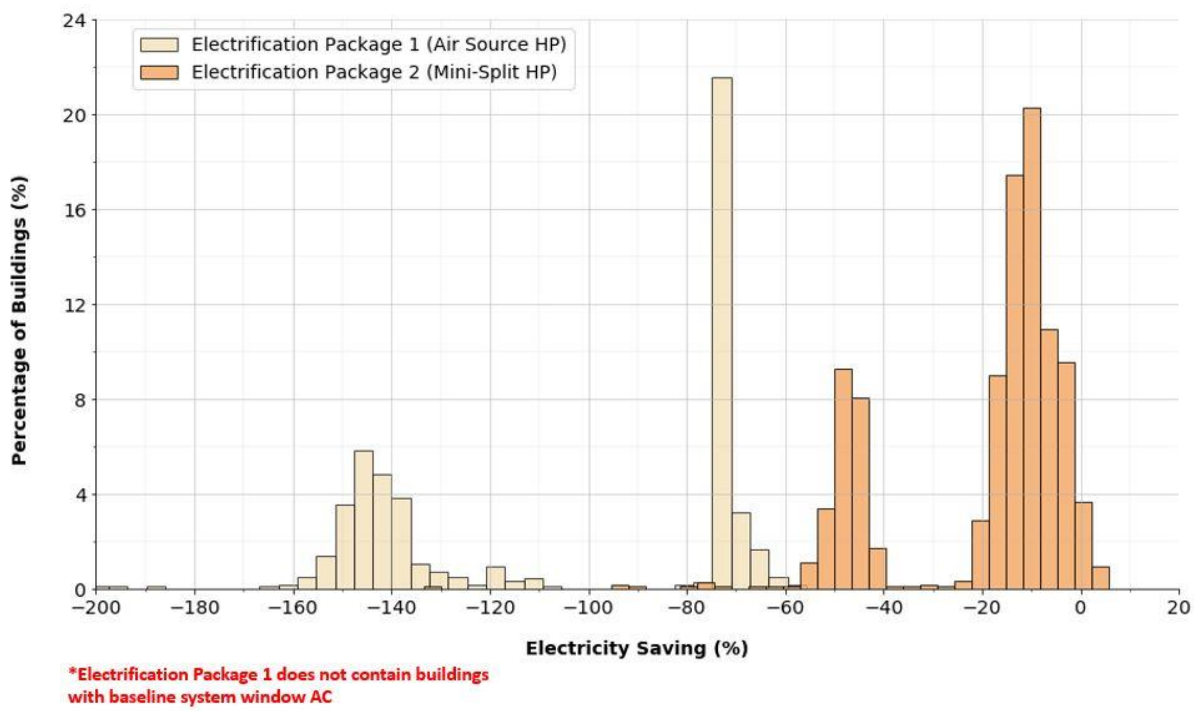
Source: LBNL authors

Figure 18: Comparison of Annual Natural Gas Use Reduction Percentage Between Two Electrification Measures for Residential Buildings in Winchell Neighborhood



Source: LBNL authors

Figure 19: Comparison of Annual Electricity Consumption Reduction Percentage Between Two Electrification Packages for Residential Buildings in Winchell Neighborhood



Negative reduction means the package increases electricity consumption

Source: LBNL authors

Incremental Cost Analysis

Although there is a large benefit in energy saving and GHG reduction in the electrification of HVAC and domestic hot water systems, this pathway is out of reach to most residents in the Winchell neighborhood due to the expensive cost of electrifying these systems. As a disadvantaged community, the cost of upgrading measures is not affordable for most households in this neighborhood. Basic weatherization upgrades are more affordable and accessible. Due to this reason, the concept of incremental cost was used to explain how much more programs would need to pay from like-for-like upgrades to electrification of HVAC and water heating, and how much benefits residents would obtain in terms of energy saving, GHG reduction, energy cost saving, as well as payback times. Thus, the incremental cost in this case was the installed equipment cost difference between electrification and like-for-like upgrade. For this simulation, individual measures, as well as packaged measures between HVAC and domestic hot water systems were analyzed.

Incremental cost analysis of electrification measure packages is described below. The measure packages are summarized in Table 2. Incremental cost analysis of individual measures is presented in Appendix D2.

Table 2: Scenarios of Incremental Cost Analysis for Measure Packages

<table>
<tr><th>Baseline</th><th>Like-for-like upgrade</th><th>Electrification 1</th><th>Electrification 2</th></tr>
<tr><td>Swamp Cooler + Wall Heater
+
Gas Storage Water Heater</td><td>Swamp Cooler + Wall Heater Efficiency upgrade
+
Gas Storage Water Heater Efficiency Upgrade</td><td rowspan="2">Air-Source Heat Pump +
Heat Pump Water Heat</td><td rowspan="3">Mini-Split Heat Pump
+
Heat Pump Water Heater</td></tr>
<tr><td>Central AC
+
Gas Storage Water Heater</td><td>Residential Central AC Efficiency Upgrade
+
Gas Storage Water Heater Efficiency Upgrade</td></tr>
<tr><td>Window AC + Wall Heater
+
Gas Storage Water Heater</td><td>Window AC + Wall Heater Efficiency Upgrade
+
Gas Storage Water Heater Efficiency Upgrade</td><td>-</td></tr>
</table>

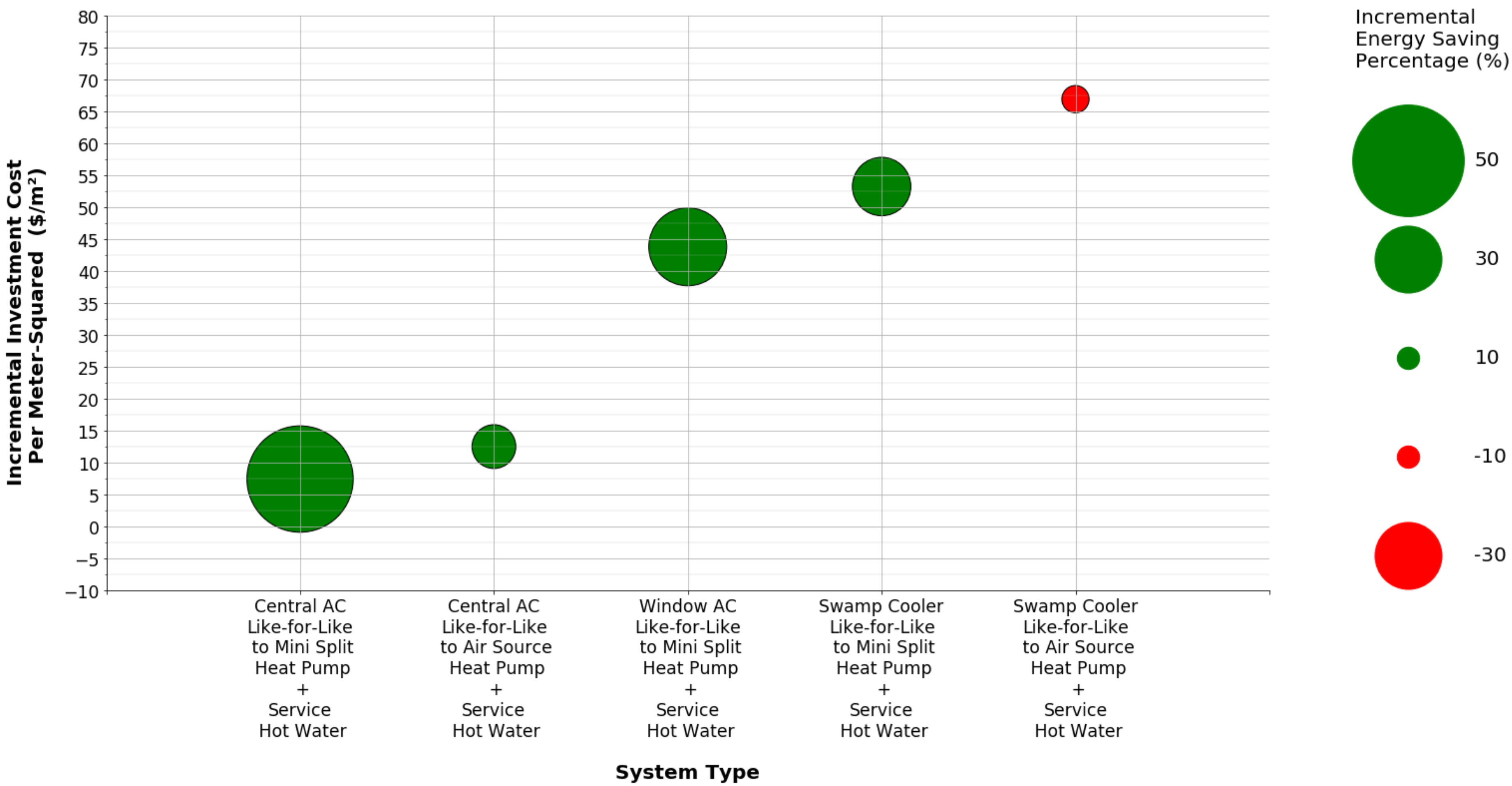
Here the domestic hot water system upgrade measure was combined with the HVAC system upgrade measure to measure packages and analyzed for incremental cost. The like-for-like upgrade only improved the system's efficiency without fuel switching. The electrification packages in contrast eliminated the natural gas use for space and water heating and converted it to electricity.

Based on the results in Figure 20, all incremental costs result in positive incremental energy saving, except for the scenario from swamp cooler like-for-like upgrades to air-source heat pumps. Correspondingly, this negative result of incremental energy saving also caused a negative GHG reduction (Figure 21), which meant the system emitted more GHG. In all of the packages within the same baseline type, electrification to mini-split heat pump still performed better than the air-source heat pump package, with both incremental energy savings and GHG reduction of up to 50%. This was due to the higher efficiency of mini-split heat pump compared to the air-source heat pump. Thus, the electrification to mini-split heat pumps reduced energy consumption and GHG emission more than any like-for-like upgrade and electrification to air source heat pumps.

However, on the incremental energy cost saving, these electrification packages actually caused a higher operational energy cost, except for two scenarios: central AC like-for-like retrofit to mini-split heat pump and window AC like-for-like to mini-split heat pump. As the air-source heat pump was less efficient than the mini-split heat pump, its higher energy consumption also resulted in higher energy cost, causing it to have a large energy cost increase as illustrated in Figure 22. The addition of domestic hot water system electrification did not add more energy cost savings due to limited energy savings and high electricity price in Fresno.

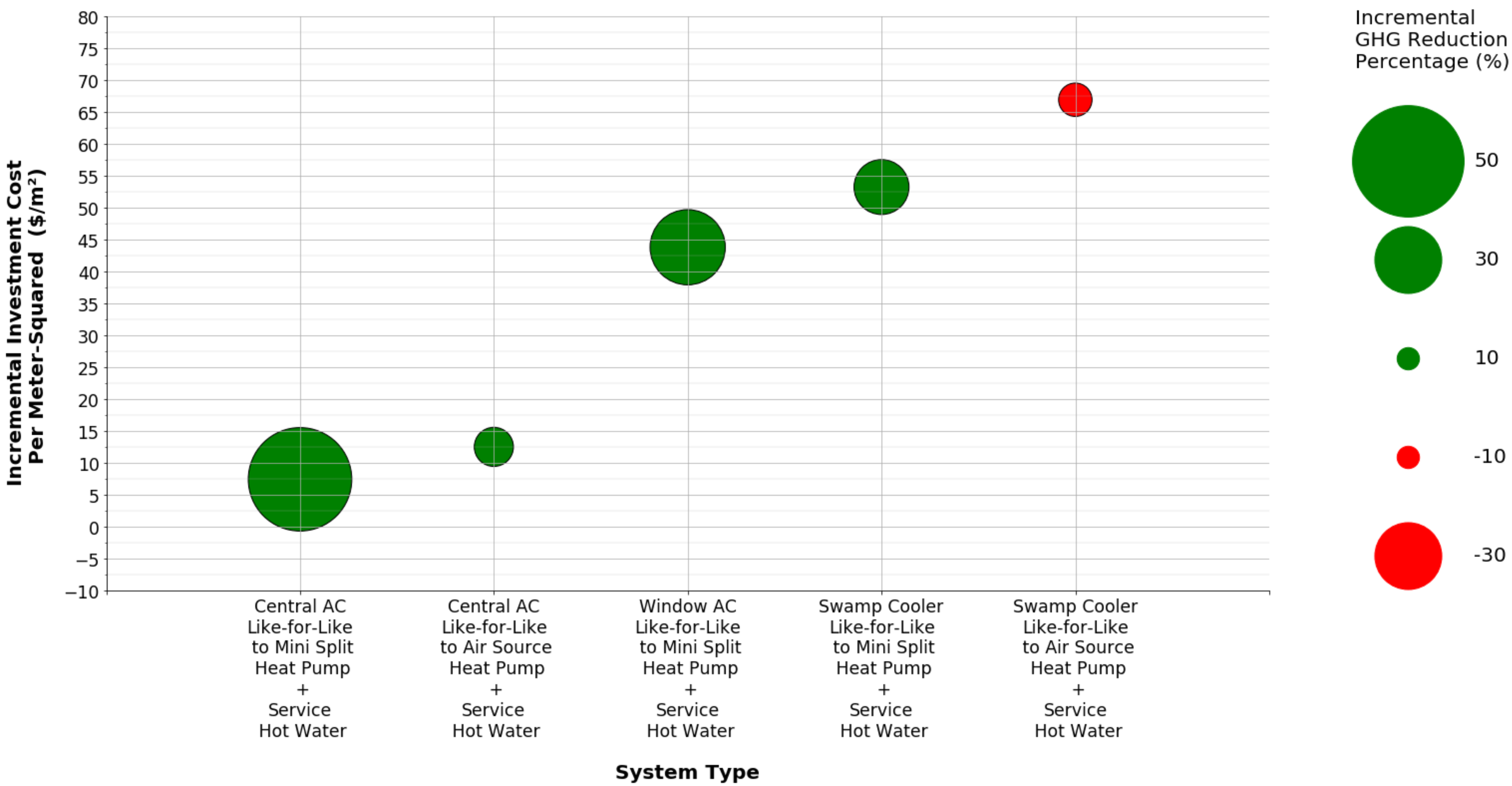
For the payback year, as shown in Figure 23, there are three packages that do not have payback year because of their negative incremental energy cost savings. In other words, the extra investment towards electrification in these four scenarios cannot be paid back because of higher operational energy cost. For the scenarios that do have payback year, the package with higher energy cost saving, which is the central AC like-for-like to mini-split heat pump, has a lower payback period of only 2.1 years compared to the window AC like-for-like to mini-split heat pump, which requires 34 years to payback. If a panel upgrade and electric circuit upgrade is required, assuming the main panel upgrade costs $4,000 and a circuit upgrade costs $500 (HVAC and SHW systems both need one), the payback time is an estimated 13.7 years for the former case and 66.7 for the latter case.

Figure 20: Incremental Energy Saving Percentage and Incremental Investment Cost of Measure Packages for Residential Buildings in Winchell Neighborhood



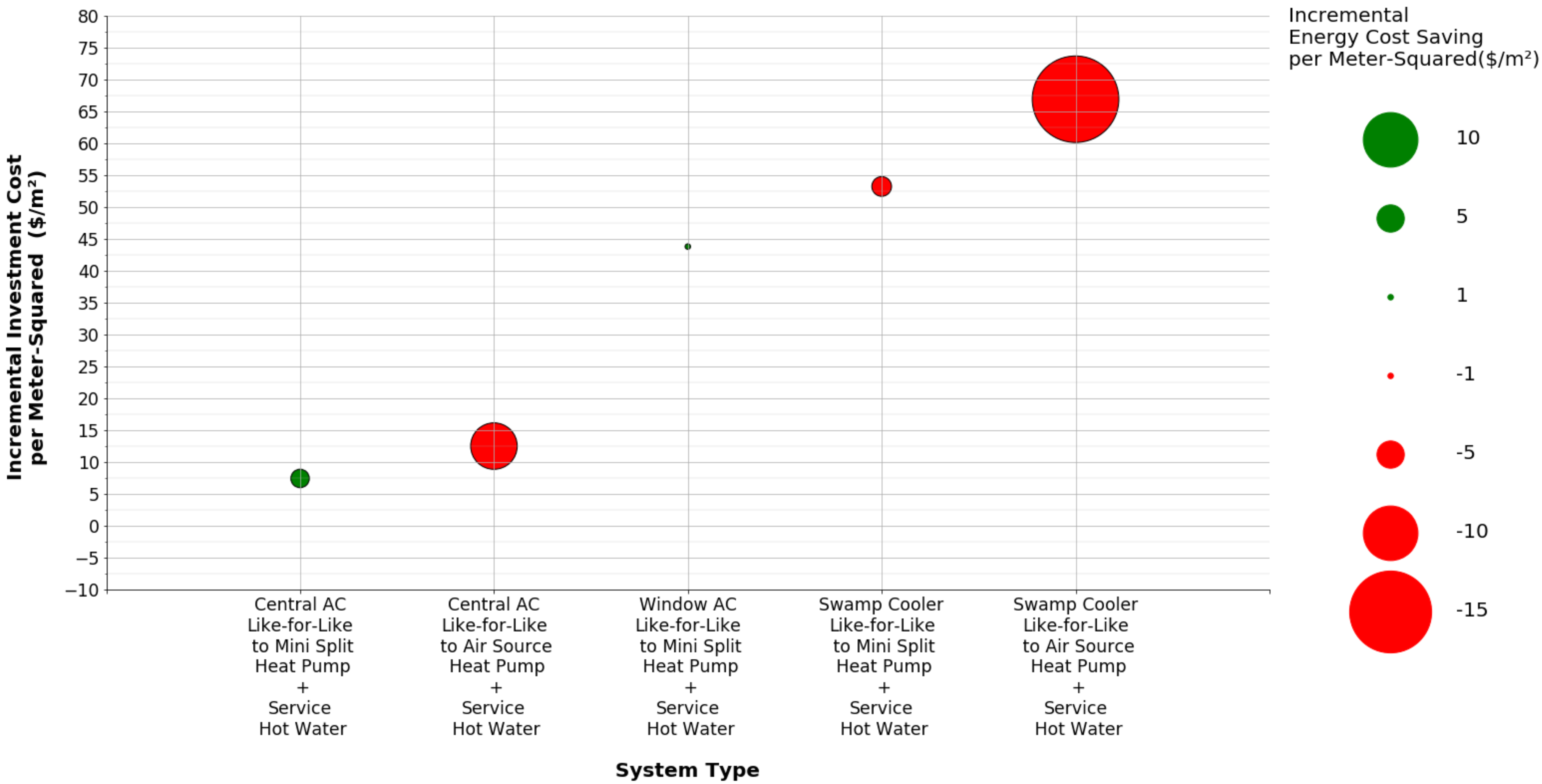
Source: LBNL authors

Figure 21: Incremental GHG Reduction Percentage and Incremental Investment Cost of Measure Packages for Residential Buildings in Winchell Neighborhood



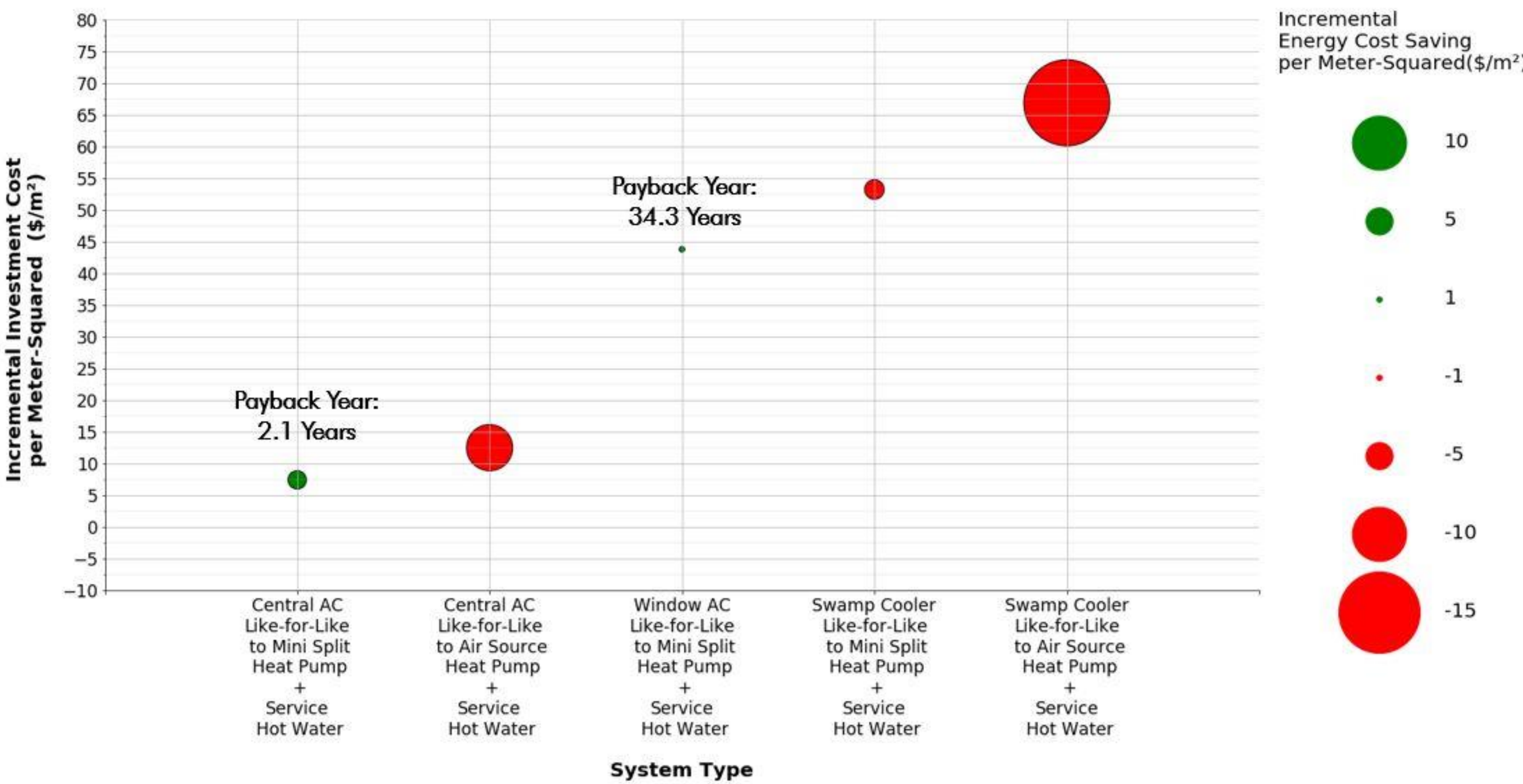
Source: LBNL authors

Figure 22: Incremental Energy Cost Saving Percentage and Incremental Investment Cost of Measure Packages for Residential Buildings in Winchell Neighborhood



Source: LBNL authors

Figure 23: Incremental Payback year, Incremental Energy Cost Saving Percentage, and Incremental Investment Cost of Measure Packages for Residential Buildings in Winchell Neighborhood



Source: LBNL authors

Electrification with EV

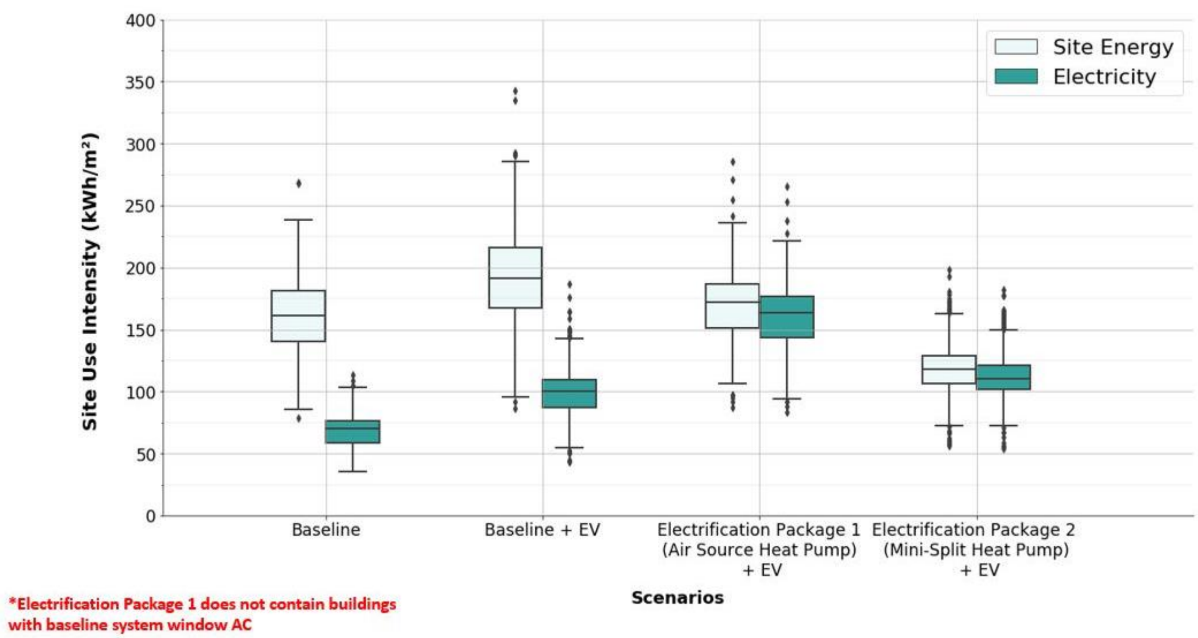
The EV measure was evaluated independently, and also combined with HVAC and domestic hot water systems as two electrification packages: (1) EV + heat pump water heater + air-source heat pump; (2) EV + heat pump water heater + mini-split heat pump. They were evaluated on energy savings, CO_2 emission reduction, energy cost savings, and payback year. The TOU rate for EV ("EV2-A" rate plan), was adopted for the energy cost analysis of the EV measure and the two electrification packages.

Energy Savings

As shown in Figure 24, most buildings in the baseline model consume approximately 60-80 kWh/m² of electricity and 140-180 kWh/m² of site energy annually. When EV was added, the electricity consumption increased to mostly 87-110 kWh/m² due to the additional EV charging load. This increase was followed proportionately by the increase of site energy consumption since the natural gas consumption stayed unchanged. For the first electrification package, the electricity consumption more than doubled from the baseline due to the additional EV load along with the electrification of domestic hot water and HVAC system to the heat pump water heater and air-source heat pump. Though natural gas for HVAC and water heating were eliminated, the overall site energy use increased slightly from the baseline.

However, for the second electrification package, the electricity consumption was only slightly higher (100-125 kWh/m²) than the EV individual scenario, and less than double of the baseline. Although this package contained the same EV and heat pump water heater measure as the first electrification package, it upgraded the HVAC system to a mini-split heat pump, which is generally more efficient than an air-source heat pump. Therefore, this electrification package can suppress its site energy use to approximately 110-130kWh /m², which is even lower than the baseline.

Figure 24: Annual Electricity and Site Energy Use for Baseline and EV Scenarios for Residential Buildings in Winchell Neighborhood

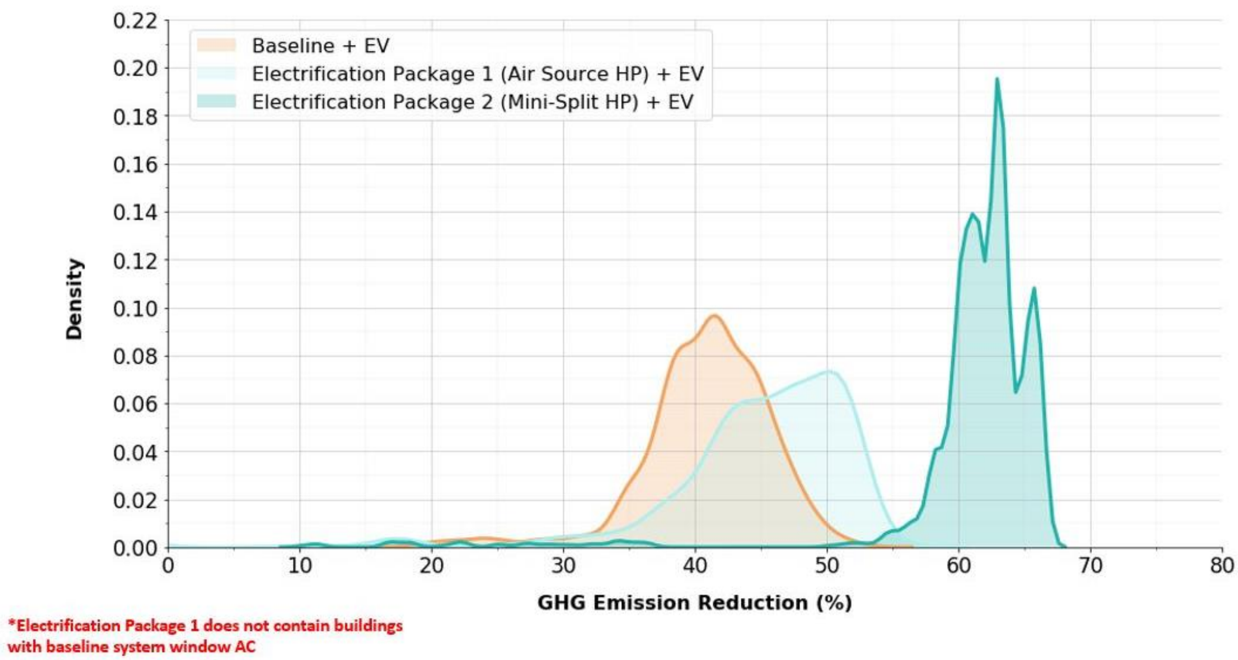


Source: LBNL authors

CO_2 Emission Reduction

The electrification of vehicles eliminates gasoline consumption and replaces it with electricity as its fuel source. This is an important contribution to the goal of clean energy because gasoline emits 536 lbs CO_2/MWh, which is much higher than electricity at 420.39 lbs CO_2/MWh, and electric motors are much more energy efficient than internal combustion engines. For this evaluation, CO_2 emission from both the building's operation and the vehicles were accounted for. Figure 25 shows that the baseline + EV scenario reduced CO_2 emission by an average of 40%. Since no other measures were implemented in this scenario, this value indicates that eliminating gasoline alone could reduce that amount of CO_2 emission. For the first electrification package, it had an average of 47% CO_2 emission reduction by eliminating both gasoline and natural gas use. It was only slightly higher than the EV individual because the electricity consumption increased due to the electrification of the HVAC and domestic hot water systems. However, the result from the second electrification package showed that CO_2 emission can be reduced by an average of 60% and up to 67%. In this package, aside from gasoline and natural gas elimination, electricity was also greatly reduced due to the high efficiency of the mini-split heat pump. Thus, CO_2 emissions were only emitted from the remaining limited electricity consumption and gas equipment like dryer and cooking ranges.

Figure 25: Annual GHG Emission Reduction for EV Scenarios for Residential Buildings in Winchell Neighborhood

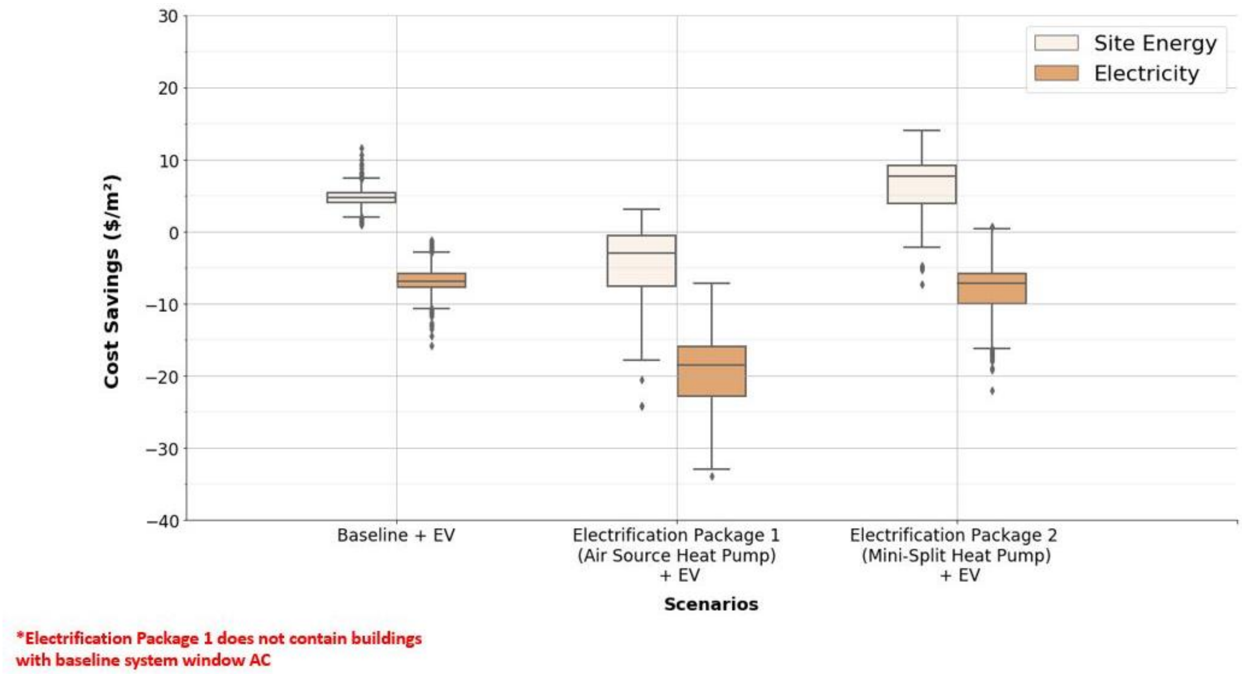


Source: LBNL authors

Energy Cost Savings

Aside from evaluating its energy saving and CO_2 emission, the electrification of vehicles also needs to be assessed financially for the DAC neighborhoods. Figure 26 illustrates the electricity and total energy cost saving of the three scenarios, where negative values indicate cost increase. The individual EV scenario shows an increase in electricity cost due to the additional electricity consumption from charging the vehicles. However, this increase was offset by the reduction in gasoline cost, resulting in an average annual net positive energy cost saving of $350. For the first electrification package, both electricity and energy costs experienced an increase because as seen in previous results, both electricity and site energy use consumption increased. While for the second electrification package, the electricity cost increased much less than the first package thanks to the high efficiency of the mini-split heat pumps, and the total net energy cost savings was $4-9/m².

Figure 26: Annual Electricity and Total Energy Cost Savings for EV Scenarios for Residential Buildings in Winchell Neighborhood



Source: LBNL authors

Payback Years

The payback year was also estimated for the three scenarios. As shown in Figure 27, for the individual EV scenario, all households have a simple payback time of 15-20 years. For the first electrification package, all of the buildings can never be paid back due to their negative energy cost savings as discussed previously. For the second electrification package, despite having a relatively higher energy cost saving than the individual EV scenario, the overall payback year was still high (generally more than 15 years) due to the high investment cost of the mini-split heat pump and heat pump water heater.

Figure 27: Payback Year for EV Scenarios for Residential Buildings in Winchell Neighborhood

Source: LBNL authors

The research team also considered an applicable rebate on EV from the Drive Clean in the San Joaquin program. This rebate provides up to $7500 for California residents who upgrade or replace an older, high-polluting vehicle with an eligible new Battery Electric Vehicle (BEV) or a plug-in Hybrid Electric Vehicle (PHEV). Since the modelled EV is a used BEV type, this EV qualifies for an average rebate of $7,500. With this rebate, all of the buildings for the individual EV scenario were reduced to 5-10 payback years. There was no change for the first electrification package. For the second electrification package, the payback period of buildings with initially 15-20 years decreased to 10-15 years, while more than half of the homes with more than 20 years of payback could be paid back within 15-20 years. A few factors led to the overall high payback year for all the scenarios: (1) electricity is expensive relative to natural gas; (2) the high first cost of heat pumps for HVAC and water heating; (3) non-optimized EV charging. The EV charging profile can be further optimized to fully leverage the EV TOU rate, for example, by scheduling EV to start charging only after midnight.

Zero-Net-Energy (ZNE) Analysis

Zero Net Energy (ZNE) buildings can be achieved when total site energy consumed during buildings' operation are offset by energy generated from on-site renewable sources. In this simulation, all the single-family homes in the Winchell neighborhood were assumed to install rooftop solar PV panels to evaluate their ZNE potential under different roof coverage scenarios. Multi-family buildings were not considered in this study as single-family buildings make up most of the homes in these neighborhoods, and any shading effects from trees or other obstructions were not considered. Multi-family buildings' barriers to deploy PV systems include ownership and governance of apartment buildings, regulation of the energy market, and electricity tariff policies (Roberts et al., 2019).

To achieve ZNE, these buildings need to balance their electricity generation from PV panels with their electricity consumption. This study considered three scenarios for PV system installation: the baseline, the energy-saving package, and the electrification package. The definitions of the three scenarios are listed in Table 3. Each of these three scenarios was simulated along with three different PV roof coverage: 0% (i.e., no PV installed), 15 percent, and 30 percent. Both the baseline and energy saving packages adopted the E-TOU-C rate, while the electrification package adopted the EV2-A TOU rate. The investment cost and payback period of PV systems were also evaluated.

Table 3: Definition of Three ZNE Analysis Scenarios

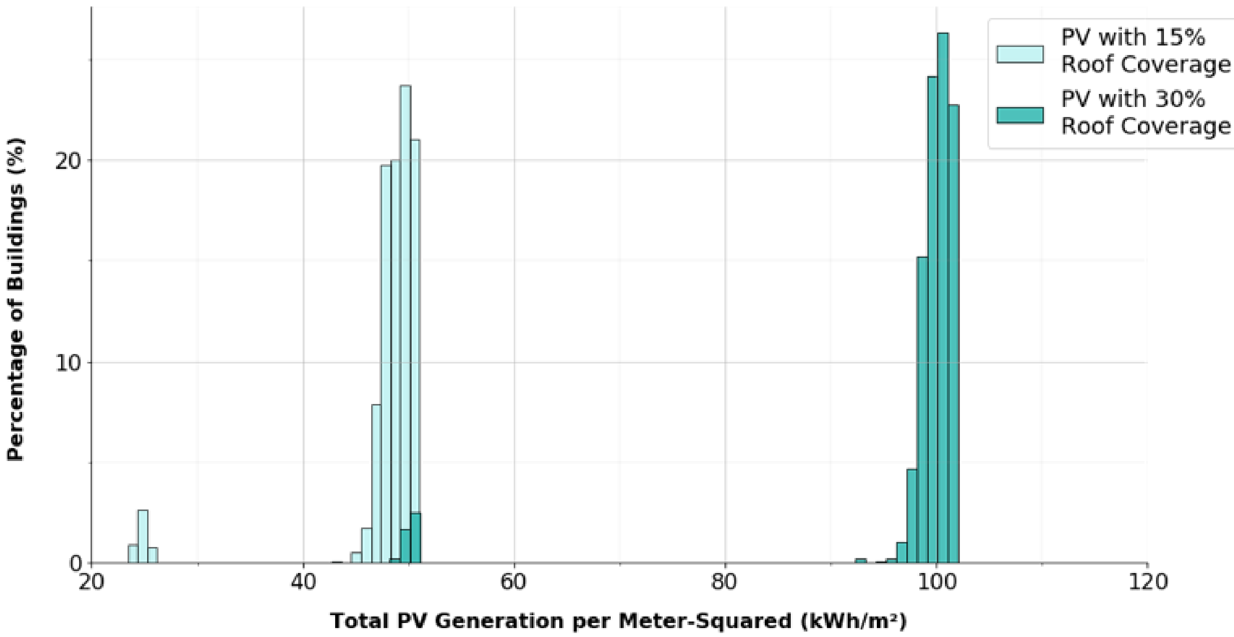
Scenarios	Definition
Baseline	Represents the current status of the neighborhood, with no retrofit implemented. It acts as a benchmark and comparison for other scenarios
Energy-saving package	Assumes that the buildings in the neighborhood are retrofitted with the selected eight measures which are targeted to maximize energy-saving and CO_2 emission reduction, as explained in Section 4.3.1.
Electrification package	Assumes that the buildings are electrified by replacing the existing HVAC systems with mini-split heat pump systems, replacing the gas storage water heaters with heat pump water heaters, and replacing one gasoline vehicle with an electric vehicle

PV Electricity Generation

First, PV panels with 15 percent and 30 percent roof coverage were analyzed to understand their electricity generation distribution. Some basic assumptions for the PV panels were as follows: all single-family homes were assumed to have pitched roofs, with actual orientations that were obtained from buildings' footprint. The PV panels had crystalline silicon cell type with 60 cells for each module and area of 1.65 m² for each module; the maximum current was 7.5 A, with maximum power voltage of 30 V; short circuit current was 8.3A and open circuit voltage was 36.4 V; and the PV panels were tilted at an optimal angle of 31º from horizontal and oriented towards the south. The optimal tilt angle was calculated from Fresno's latitude using a formula developed by Landau (Landau, 2017).

Figure 28 shows that a PV system with 15 percent roof coverage generated approximately 50 kWh/m² where the denominator represents total floor area of the home (same for all per square meter in section 4.6), while a PV system with 30 percent roof coverage generated approximately 100 kWh/m². This normalization was adopted since other energy consumption metrics were also normalized to the total floor area of the home. Smaller output at 25 kWh/m² and 50 kWh/m² for 15 percent and 30 percent roof coverages respectively were found due to the larger area for two-story single-family homes. Since the PV generation results were normalized by the total floor area of the buildings, two-story buildings experienced lower PV generation intensity due to larger total floor area. As a result, two-story homes were at a disadvantage to achieve ZNE compared with single-story homes.

Figure 28: Annual Total PV Generation per Square Meter for Single-family Homes in Winchell Neighborhood

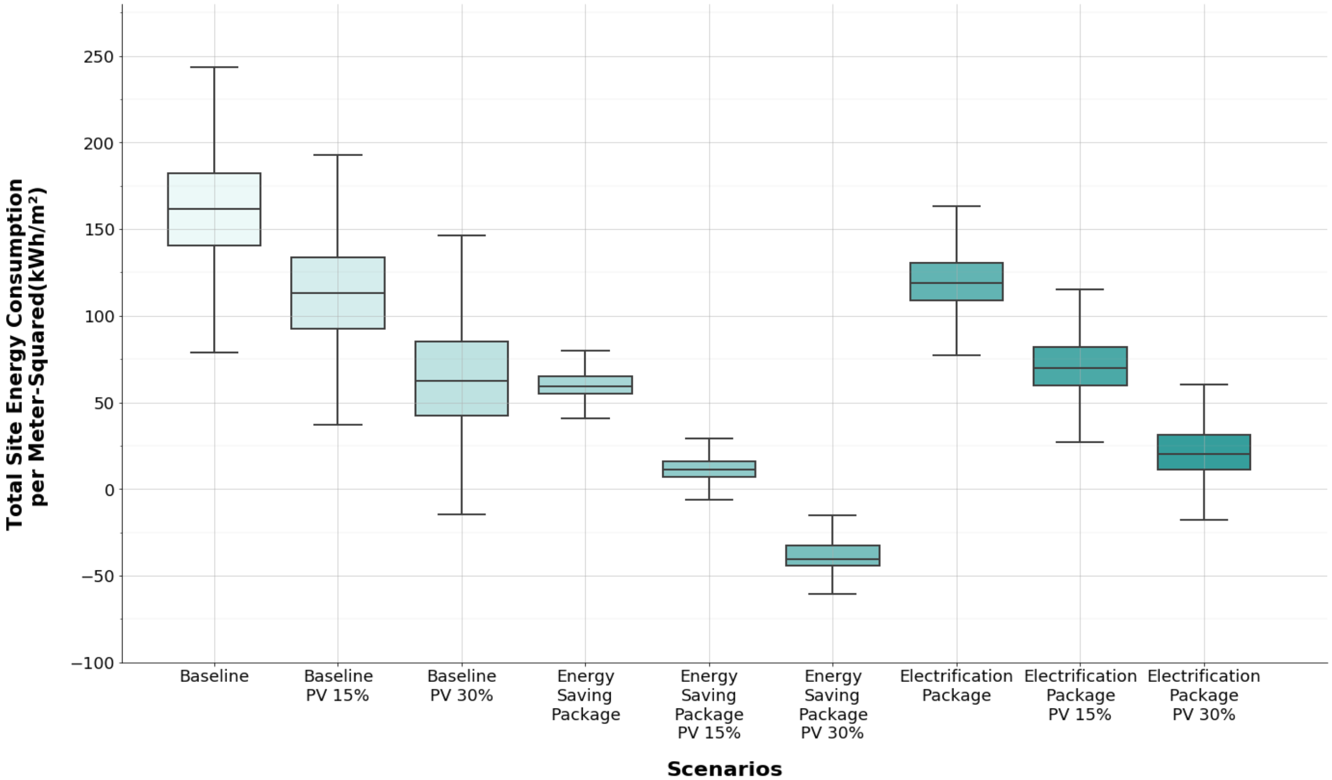


Source: LBNL authors

ZNE Potential

The research team simulated the annual net site energy consumption intensity under different PV roof coverage scenarios, to evaluate different single-family homes' ZNE potential and their minimal roof coverage requirements. In Figure 29, each scenario reveals a decreasing trend of net site energy consumption with increasing PV panels roof percentage coverage. This increasing PV roof coverage increased buildings' electricity generation, ultimately lowering its total net site energy consumption. With 15 percent roof coverage, none of the baseline buildings can reach ZNE, while approximately half of the buildings with the energy saving package can achieve ZNE. With 30 percent roof coverage, all buildings under the energy-saving package scenarios can reach ZNE. For the electrification package scenario, 15 percent and 30 percent roof coverage cannot offset the buildings' site energy consumption for any home. The electrification package scenario required more than 30 percent roof coverage for installing PV to reach ZNE. This was due to the additional electricity consumption from electrified equipment and EV. The box plot also shows the outliers of the distribution for each scenario. These outliers were the two-story buildings with lower PV generation intensity. These buildings required higher capacities of PV systems to offset their site energy consumption to achieve ZNE compared with single-story buildings.

Figure 29: Annual Total Net Site Energy Consumption per Square Meter for Single-family Homes in Winchell Neighborhood



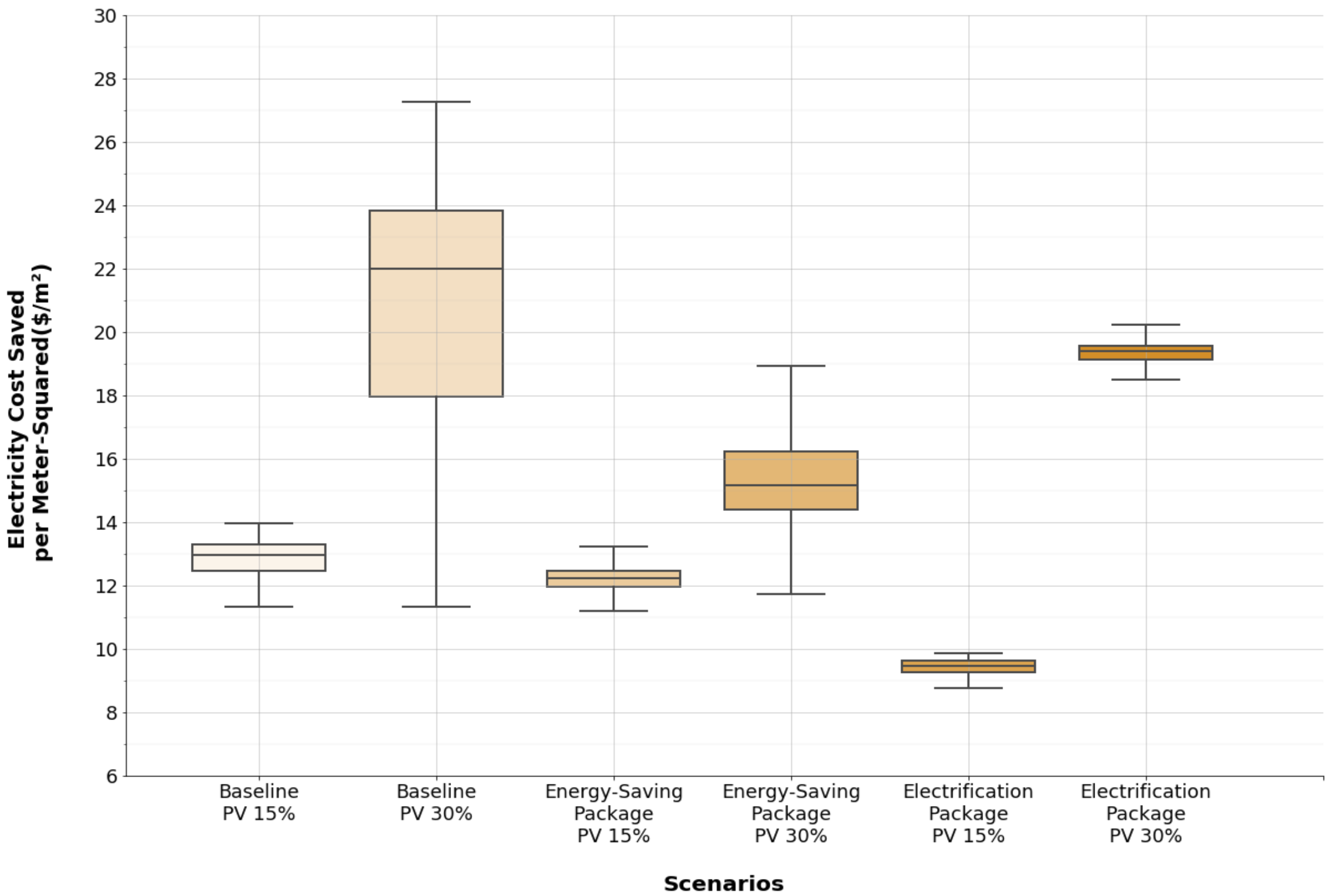
Energy Savings and Electrification Packages are defined in Table 2.

Source: LBNL authors

Energy Cost Savings

The PV panels reduced the buildings' net electricity use by compensating with its electricity generation. The resultant energy cost savings were estimated. Figure 30 illustrates the electricity cost savings per square meter of the PV systems compare to each scenario without PV. The baseline has an average of $13/m² of electricity cost saved by installing PV with 15 percent roof coverage. This amount was increased to approximately $22/m² by increasing the PV panels roof coverage to 30 percent. The cost savings for PV 30 percent had a larger distribution than those of PV 15 percent. This was because with 15 percent roof coverage, only a small portion of buildings can reach ZNE and few buildings have surplus generations, so all the PV generated electricity was fully leveraged to save energy cost; but with 30 percent roof coverage, almost all buildings can reach ZNE but with different levels of surplus generation, the actual cost savings were in fact decided by the energy use intensity of the buildings. As described below, surplus generation earns little credit due to the NEM 2.0 policy, so the cost savings distribution has a similarly wide range as the buildings' energy use intensity. The energy-saving package has a similar result to the baseline scenario, but at lower values. This was because the baseline case already experiences a reduction in electricity consumption, which leaves less room for cost savings. For the electrification package, PV 15 percent saves $9/m² and PV 30 percent saves $19/m². The narrow distribution compared to other scenarios was because the buildings in these two scenarios still have not achieved ZNE. Similar to the baseline with PV 15 percent scenario, these buildings consumed all the PV generated electricity, so the electricity cost savings is associated with the PV generation intensity, which is basically the same for all single-family homes with the same PV settings. As in the result in Figure 30, the low-end outliers in the two 30 percent PV cases are the double-story single-family homes that have lower electricity generation intensity.

Figure 30: Annual Electricity Cost Savings per Square Meter for Single-family Homes in Winchell Neighborhood

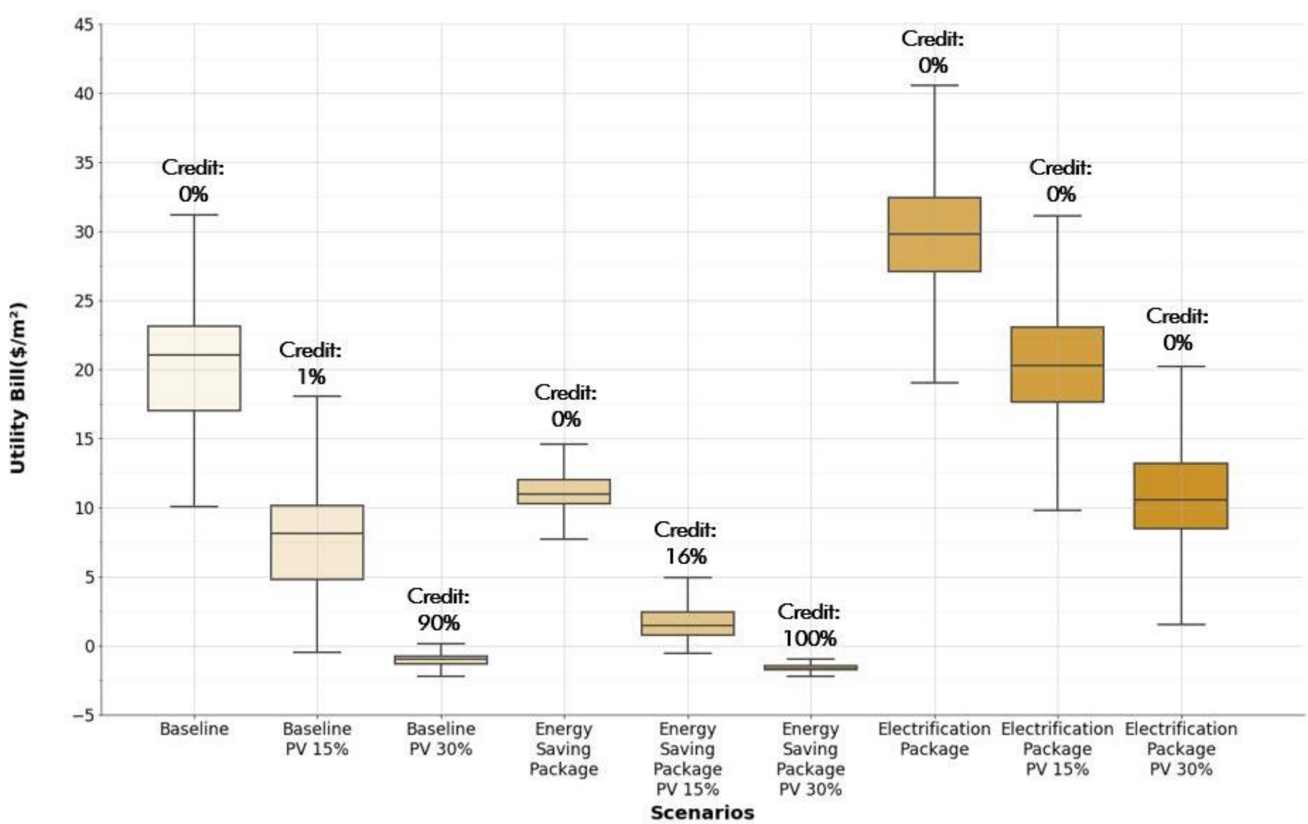


Source: LBNL authors

Aside from achieving ZNE, installing PV systems can potentially result in a credit in the utility bills, which means that the residents can receive money instead of paying the usual charge of utility bills. The credit from this bill originates from selling back surplus generated electricity to the grid at a rate determined from the net surplus compensation (NSC). In this simulation, the NSC rate is $0.0335/kWh, which is an average NSC value from 2019 from PG&E. However, NSC is only applicable if the total electricity consumption is less than the total electricity generation. The NSC rate is set very low to penalize oversized PV systems. Aside from NSC, the monthly delivery charge was also included in the simulation, which is $5 for CARE program users. This amount is half of the delivery charge to non-CARE customers. Figure 31 illustrates the proportion of homes that end up with credit in their electricity utility bills. For the baseline scenario, the credit proportion increases from 1 to 90 percent with PV panels roof coverage increasing from 15 to 30 percent. Similar increase also occurs in the energy saving package scenario, from 16 to 100 percent. For the electrification package scenario, while slightly more than half of the buildings can reach ZNE with 30 percent roof coverage, none of the buildings can earn credit in the utility bills with delivery charges and TOU rates considered. In particular, the EV2-A plan defines off-peak pricing period from midnight to 3:00 p.m. (Appendix D), during when the PV generation is usually higher than building consumption, but the surplus can only be sold back to the grid at the off-peak price; on the other hand, EV charging starts at around 9:00 p.m., which belongs to the mid-peak pricing period.

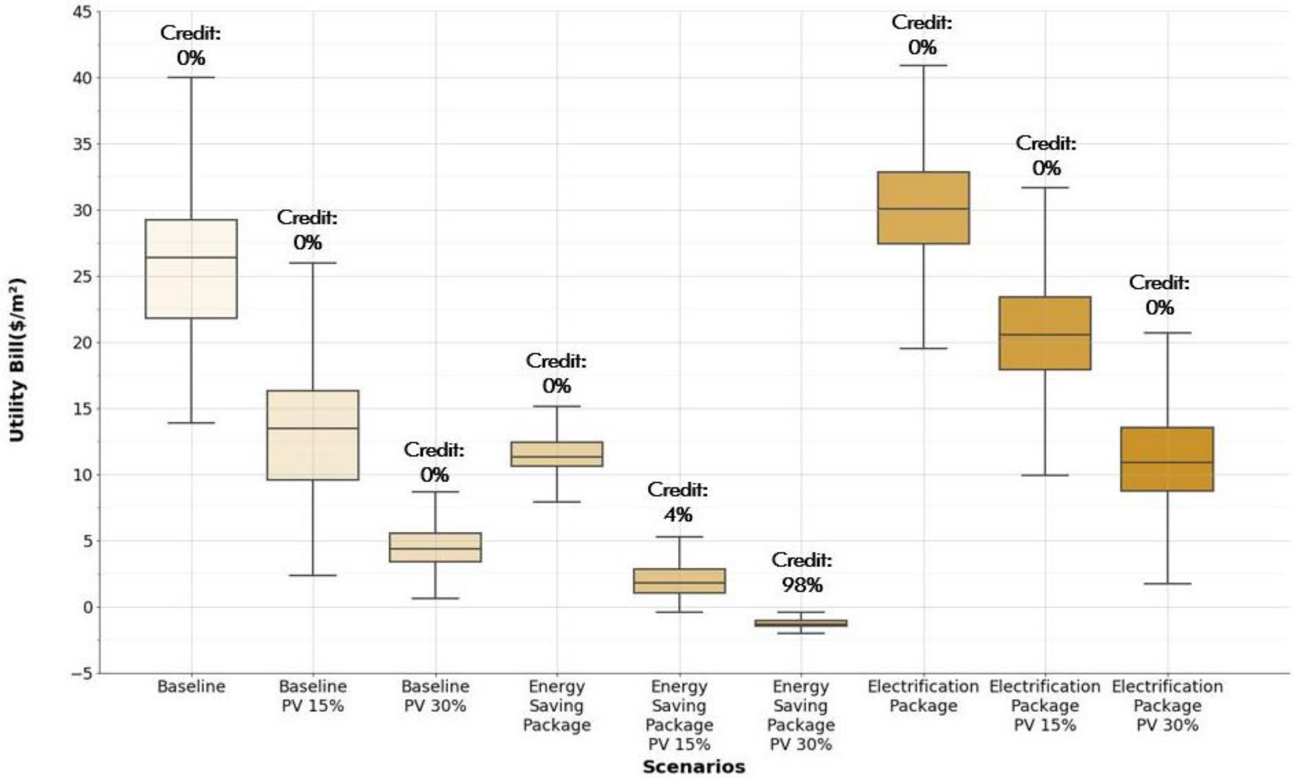
The electricity cost can be further reduced if the EV charging profile can be further optimized so that the charging load only happens during off-peak periods. However, when the natural gas utility bill is accounted in the calculation, the biggest change occurs in the baseline scenario with 30 percent PV coverage where none of the buildings can achieve an overall utility bill credit anymore. This is because in baseline scenario, buildings use more natural gas than electricity. Thus, the credit received from the electricity utility bill is offset by the natural gas utility bill. While ZNE is evaluated using total site energy in this study, the sizing of the PV systems should still be based on the buildings' actual electricity consumption to avoid over-generation, which is penalized by the Net Metering policy.

Figure 31: Annual Electricity Utility Bill per Square Meter and Proportion of Credit in Utility Bill for Single-family Homes in Winchell Neighborhood



Source: LBNL authors

Figure 32: Annual Electricity and Natural Gas Utility Bill per Square Meter and Proportion of Credit in Utility Bill for Single-family Homes in Winchell Neighborhood

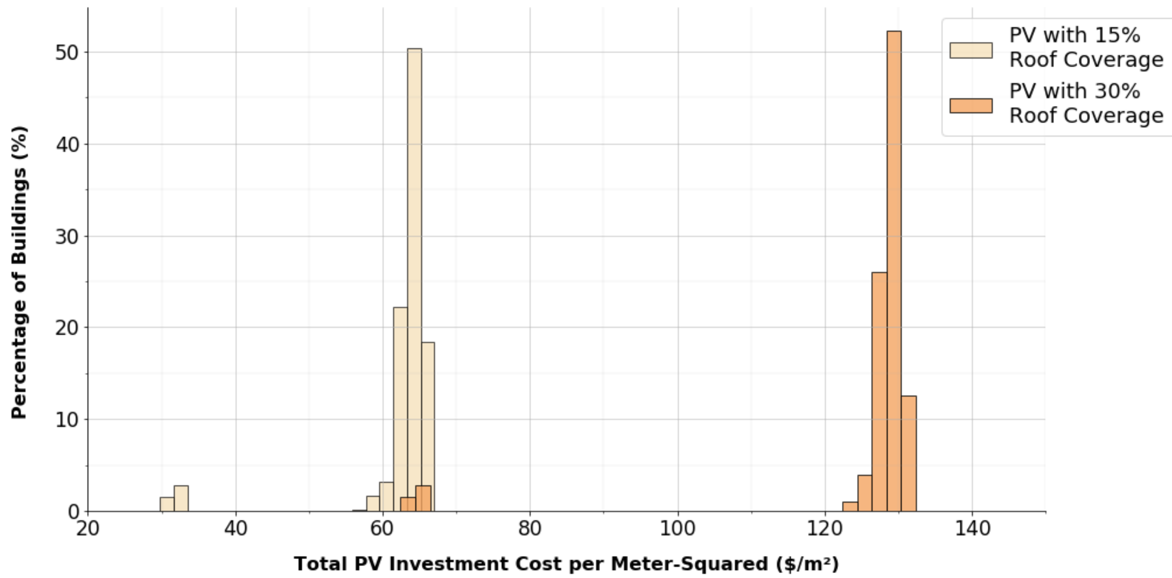


Source: LBNL authors

Payback Year

Still pertaining to the financial metric of achieving ZNE, it was important to account for the investment cost of installing these PV panels particularly for low income and disadvantage community residents. This investment cost of the PV panels can be broken down into the interconnecting fee and installation cost. The interconnecting fee is a one-time fee of $145 that must be paid to PG&E when the PV panels are installed (Pacific Gas and Electric Company, 2021h). The PV installation cost is adopted from the 2020 value of National Renewable Energy Laboratory's (NREL) solar cost analysis research, which is $2.71/W (National Renewable Energy Laboratory, 2021). In Figure 33, the PV investment cost for 15 percent roof coverage is approximately $63/m², and this value doubles to approximately $125/m² with a doubling of PV roof coverage.

Figure 33: PV Investment Cost per Square Meter for Single-family Homes in the Winchell Neighborhood

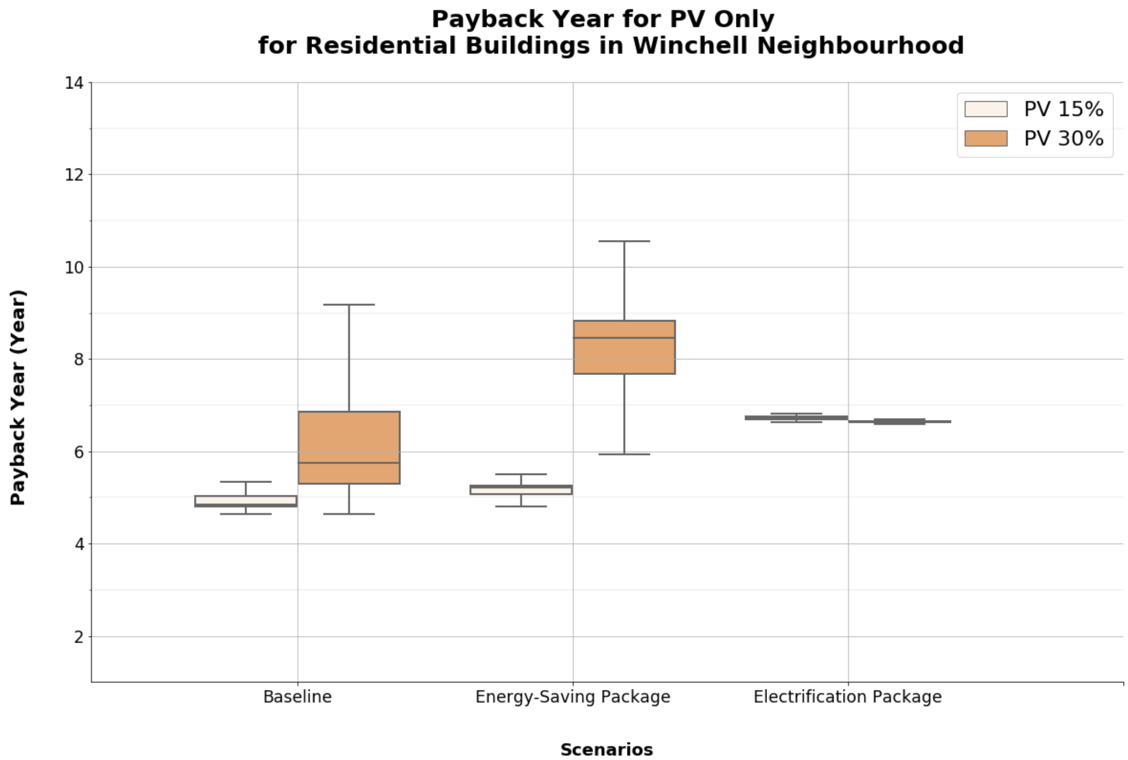


Source: LBNL authors

The research team then calculated the number of years needed to completely pay off the PV investment cost through the annual electricity cost savings (Figure 34). For baseline and energy saving package scenarios, it requires less than six years to pay back PV with 15 percent roof coverage. However, when the PV capacity increases, the payback year also increases because the surplus generation is sold to the grid at a much lower price than retail price, which cannot compensate for the extra investment cost brought by the additional PV capacity. The electrification package has a median of less than seven years to pay back the investment cost for both roof coverage percentages. If a panel and circuit upgrade is required for the electrification scenario, assuming the main panel upgrade costs $4,000 and a circuit upgrade costs $500 (HVAC and solar hot water systems both need one), the median payback year will increase to 11.2 years with 15 percent of PV roof coverage and to 8.9 years with 30 percent of PV roof coverage.

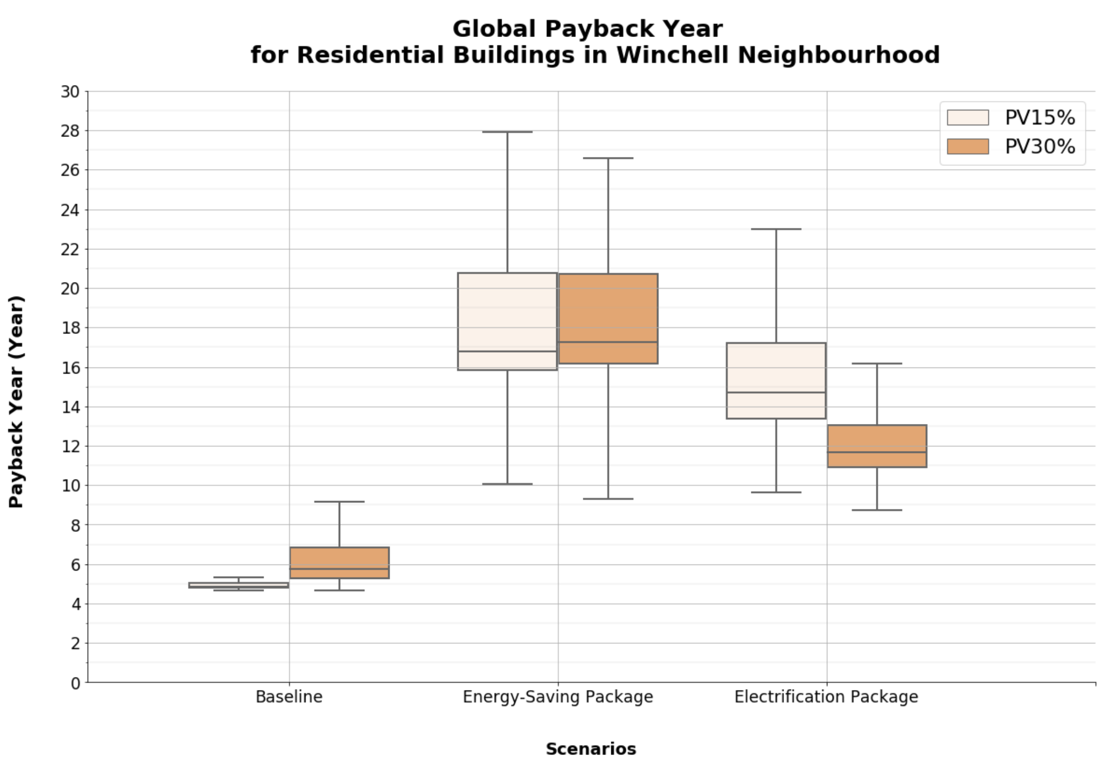
However, as shown in Figure 35, the global payback for the energy saving and electrification scenario is much higher than the PV only payback year because it also accounts for payback year of the energy efficiency measures of the packages. With panel/circuit upgrades, the global payback year for electrification scenario will increase to 17.2 years and 13.4 years with 15 percent and 30 percent of PV roof coverage respectively.

Figure 34: PV Payback Year for Single-family Homes in the Winchell Neighborhood



Source: LBNL authors

Figure 35: Global Payback Year for Single-family Homes in the Winchell Neighborhood



Source: LBNL authors

Table 4 shows a summary comparison of used EV, energy-saving packages, and electrification packages with an assessment of initial costs, annual energy cost savings, GHG savings, and environmental benefits for each option. From the table and analysis above, several conclusions can be drawn. Adopting a used EV has substantial annual cost savings and GHG reduction. The energy-saving packages (heat pumps + conventional EE measures) provide the most energy cost savings but have high initial costs and have relatively small GHG savings since vehicle electrification is not adopted. The electrification package (HPs only) with EV and PV has the highest initial cost but also highest annual energy cost savings with the largest GHG savings and environmental benefits.

Table 4: Comparison of Used EV, Energy-saving and Electrification Packages

	Initial costs	Annual energy cost savings	Payback	Environ-mental benefits
1) Used EV only	◑	◑	◑	◕
2) Energy-saving package	○	◕	○	◑
3) Energy-saving package with PV	○	●	◔	◑
4) Electrification package	◑	◑	○	◑
5) Electrification package with EV, PV	○	●	◔	●

○ ◔ ◑ ◕ ●
Less favorable → More favorable

Energy-saving package (8 measures): replacing existing lighting with LED (0.6 W/sf), applying ceiling insulation (R-38), upgrading to mini-split heat pump system (3.66 COP cooling, 3.7 COP heating), upgrading to heat pump water heater (COP 3.3), reroofing and roof with insulation (R-24.83), adding an interior storm window layer, applying wall insulation (R-21), and adding window film (No EV).
Electrification package (3 measures): replacing the existing HVAC systems with mini-split heat pump systems, replacing the gas storage water heaters with heat pump water heaters, and replacing one gasoline vehicle with an electric vehicle. The project did not quantify the environmental benefits for electric heat pumps, but qualitative credit is given for HPs since they eliminate indoor fossil-fuel based combustion from gas heating equipment.

It should be noted that an incentive or rebate for the PV system was not included in the analysis. However, there is a potential applicable rebate for this area, which is the Disadvantaged Communities – Single-Family Solar Homes (DAC-SASH) provided by GRID Alternatives (GRID Alternatives, 2021). The purpose of this rebate is to increase the adoption of clean and affordable solar energy for residents living in disadvantaged communities by offering an incentive up to $3/W installed PV. To be eligible for this program, residents need to live in the top 25 percent of the most disadvantaged communities statewide based on the CalEnviroScreen, as a billing customer of PG&E, Southern California Edison (SCE), or San Diego Gas & Electric Company (SDG&E), and must qualify for the CARE or Family Electric Rate Assistance (FERA) program. Most of the residents in the investigated disadvantaged community neighborhoods qualify for these requirements. The research team did not include it in the analysis as the actual incentive level for each house varies largely with the qualifications of the applicants. The state's solar compensation policy (NEM 2.0) is also under discussion for further updates.

However, with these potential incentives, the payback time for the scenarios with PV panels could be reduced even further.

Discussion – Integrated Building/EV/PV Modeling

The building modeling tasks of this project aimed to identify and evaluate potential solutions to improve energy efficiency, reduce carbon emissions, and promote clean energy equity of the disadvantaged communities in Fresno and serve as a key input for the project's Action Plan to improve clean energy equity in Fresno and the Central Valley. This report presents the methodology, workflow, results, and analysis of energy efficiency measures (EEMs) to achieve this goal. The methodology and workflow developed in this study are applicable to other neighborhoods and communities in California and across the United States through customization of related data and model inputs.

A total of 22 EEMs were modeled for all residential buildings in the two disadvantaged communities (the Columbia and Winchell neighborhoods) in Fresno. The most effective energy saving package can save total energy use by 60 percent but has relatively longer payback periods of 12–70 years. With a limited budget such as $1,000 per home, the package of adding portable fans, improving water tank insulation, and adding duct sealing to minimize leakage can be a good choice, which can save up to 14 percent energy use. If a short payback period of less than five years is prioritized, the package of LED upgrade, adding portable fans, improving water tank insulation, and upgrading gas furnace efficiency is a good choice for most of the homes with up to 20 percent energy savings. The package of LED upgrade, adding portable fans, improving water tank insulation, and upgrading to mini-split heat pump system is also a very good option with up to 65 percent energy savings, and many homes can achieve payback time of 5–8 years.

With limited investment resources in disadvantaged communities for technological solutions evaluated in this study, there are low- or no-cost human solutions that are possible but not modeled here. For example, residents in California could change their energy use behavior including raising the cooling thermostat setpoint, lowering the heating thermostat setpoint, opening windows when outdoor conditions favor free cooling in summer, wearing short sleeves during summer and warm clothing during winter, turning off lights or unneeded appliances, and reducing shower time.

For fuel switching purposes, both HVAC and domestic hot water systems were electrified in this study by upgrading to heat pump water heat and upgrading to air-source heat pump or mini-split heat pump systems. These electrification measures are effective in reducing CO_2 emissions, but in many cases are not showing a significant advantage in terms of energy cost savings over the traditional like-for-like retrofits. This is partially because the electricity price is much higher than the natural gas price. Any relative cost difference decreases in the future e.g., lower heat pump equipment prices, higher relative gas prices to electricity or increasing carbon credit prices, would be more favorable economically for the electrification measures. If the existing HVAC system is central AC or window AC and has reached the end of service life, replacing it with a mini-split heat pump can save extra energy cost and emit less CO_2 than a like-for-like upgrade with the same system type. If no panel/circuit upgrade is required, the electrification upgrade to mini-split heat pump can be cheaper than the like-for-like upgrade for the central AC system, while its incremental investment over like-for-like window AC upgrade can be paid back in an average of 5.8 years. If a main panel upgrade and electric circuit upgrade is required, the electrification upgrade to mini-split heat pump will cost more than the like-for-like upgrade for the central AC system, but can still be paid back within 3.6 years, while the incremental payback for window AC is increased to 15.7 years.

In addition, the research team also modeled gasoline fueled vehicles being replaced with used EVs. The EV measure by itself can reduce CO_2 emission by an average of 38 percent at the household level. EV is also combined with other fuel switching measures for HVAC and domestic hot water systems. The package of EV, heat pump water heater, and mini-split heat pump together can reduce CO_2 emission by up to 65 percent and an average of 60 percent. Financially, EVs can save an average of $350 of annual fuel costs compared to gasoline vehicles. Due to high electricity prices and low gasoline prices, the payback period of EVs is still generally longer than 15 years without rebates and can be reduced to 5-10 years with rebates but has the potential to drop significantly in the future as the purchase price of EVs decreases as the EV market expands.

Achieving zero net energy by installing PV panels on the rooftop is promising for the homes in disadvantaged communities to reduce energy bills but is limited by roof-readiness and the large number of renters in single-family homes in south Fresno that are not eligible for PV rebates. Most single-family homes with deep retrofit packages can achieve the ZNE goal with on-site rooftop PV covering 15 percent to 20 percent of the roof area, while most electrified single-family homes need PV capacity of more than 30 percent roof coverage to reach ZNE. With appropriate sizing, the PV investment can be paid back within ten years. Due to the Net Energy Metering 2.0 (NEM 2.0) policy, if PV is oversized, the surplus generation cannot bring extra benefits. The initial investment cost of PV systems is a hurdle to adoption. But the low-income homeowners in disadvantaged communities have a high chance of being eligible for the PV rebate program, which can compensate for most of the PV investment thus further promoting PV adoption.

However, there are also policy gaps that limit PV adoption in single family homes in disadvantaged community areas such as Fresno. Most homes in Fresno are rentals, and rental homes are not eligible for rooftop solar PV incentives or disadvantaged community-specific programs. About 50 percent of single-family homes are also not roof-ready for solar installation according to Grid Alternatives and the Fresno Economic Opportunities Commission, and there is no specific program to upgrade single family home roofs for either solar PV or roof insulation. These gaps need to be addressed to facilitate greater rooftop PV adoption.

Finally, it should be noted that the modeling and analysis results are based on assumptions that inherently introduce some uncertainty: (1) the use of typical year weather data is different from the actual weather data, (2) occupant behaviors can differ from modeled assumptions, (3) the house characteristics, although based on the best information the project team could obtain, can differ from reality especially at individual house levels, and (4) economic analysis assumes various types of cost data that can be highly variable and change quickly. Therefore, the results and findings are valid with the model and economic assumptions; however, the methodology and model/analysis workflow are generic and can be adopted for other districts and cities through the use of local data and appropriate model inputs and assumptions. In particular, costs were assumed to be pre-COVID costs, and the research team did not account for post-COVID spikes in prices that are due to supply chain issues or labor shortages.

Future work can focus on improving the quantification of electrification costs including any panel or circuit upgrades, modeling future worst-case projected weather, considering climate change on future heating and cooling demands, and implementing pilot programs to validate/ test the assumptions and results of this work. Due to limitations on in-home visits due to COVID, the research team was not able to collect detailed data on electric panels and electric circuits in representative homes. Since most homes in Fresno are older and built prior to 1980, many homes would require electrical upgrades when their HVAC and/or domestic hot water systems get electrified. The additional cost to upgrade these items could be very high (up to $10,000) in the case that both a new electric panel and several new electric circuits are both required. However, there are several mitigating factors that can reduce or contain these costs:

- If homes have older panels that are less safe than newer panels, they should be upgraded by state or federal programs for health and safety reasons, independent of climate policies that call for widespread building electrification. This could be viewed in many cases as a "deferred maintenance" issue as much as an electrification issue, and not necessarily as a cost of electrification.
- There are many heat pump appliances that are "plug-in" ready and that have standard voltages (120V) instead of higher voltages for most HP HVAC and HP water heating units today (220/230V). 120V mini-split heat pumps, packaged terminal heat pumps, and combo washer and dryer units are all commercially available today with the ENERGY STAR rating (i.e., with good energy efficiency), and 120V heat pump water heaters are expected to be commercially available within the next year (2022). These appliances offer more choices for residential electrification, and while they may not work for all households (e.g., those with a large number of residents may need a larger capacity hot water heater than what a 120V model can provide), they could work for many homes and mitigate the need for costly electrical upgrades.
- There are a new set of devices such as smart panels, and smart switches that can control appliance operation schedules and EV charging to control the maximum current draw to the panel and mitigate the need for panel upgrades.

Finally, to meet the state's urgent need to decarbonize the building stock and meet the equity objective, there is also the pressing need to collect more data on actual costs for installation upgrades and electrification across different housing types and different starting equipment. This would also provide the opportunity to assess occupant comfort before and after equipment upgrades and other data collection such as indoor air quality (CO_2, PM for example). This could be accomplished with targeted pilot and data collection programs in the Fresno area building on some of the key findings of this study.

Community Center Energy Efficiency Modeling Results

The city of Fresno provided the actual energy consumption for the period from March 2019 to February 2020 for the Mosqueda Community Center. The research team simulated the Community Center model using the actual 2019 weather data, then compared the monthly simulated energy consumptions with the actual Community Center energy consumptions.

Normalized Mean Bias Error (NMBE) and Coefficient of Variance of Root Mean Square Error (CVRMSE) per ASHRAE Guideline 14 were utilized to check the validity of the energy model. NMBE and CVRMSE are commonly used to determine the goodness of fit between two sets of data from energy simulation results and actual measured data[12]. Monthly site energy was used for the comparison. If NMBE and CVRMSE results are no greater than 5 percent and 15 percent, respectively for Monthly data comparison, they are deemed to agree with each other, and these criteria confirmed the community center energy model represents the actual energy consumption reasonably well.

Table 5 shows the energy savings when the selected energy efficiency measures are applied to the Community Center. The table shows absolute savings of the total site energy, electricity and natural gas consumption in kWh and fractional savings in percentage for each energy measure as well as all measures integrated compared to the baseline community center energy consumption. Lighting measures have the most savings in electricity and HVAC system upgrades and control measures have more savings in natural gas. It is expected that all of the measures as an integrated package save 35 percent of site energy savings, 3 percent from site electricity and 29 percent from site natural gas.

Table 5: Energy Savings from Energy Efficiency Measures

Energy model ID	Absolute site energy saving [kWh]	Fractional site energy saving [%]	Absolute electricity saving [kWh]	Fractional electricity saving [%]	Absolute natural gas saving [kWh]	Fractional natural gas saving [%]
Lighting fixture upgrade	64,862	14.0%	81,033	25.7%	(16,171)	-10.8%
Lighting daylighting control	59,103	12.7%	62,123	19.7%	(3,021)	-2.0%
HVAC system upgrade	48,434	10.4%	9,563	3.0%	38,871	26.1%
HVAC control	37,102	8.0%	13,009	4.1%	24,093	16.2%
All measures	161,646	34.8%	118,109	37.5%	43,537	29.2%

Resilience Hub Results

In this section, the optimization model presented above for the community resilience hub will be used to optimally size the community building potential assets (PV system, battery, inverter and converter), considering the assumptions presented above. The research team analyzed how the optimal system size varies across three main aspects:

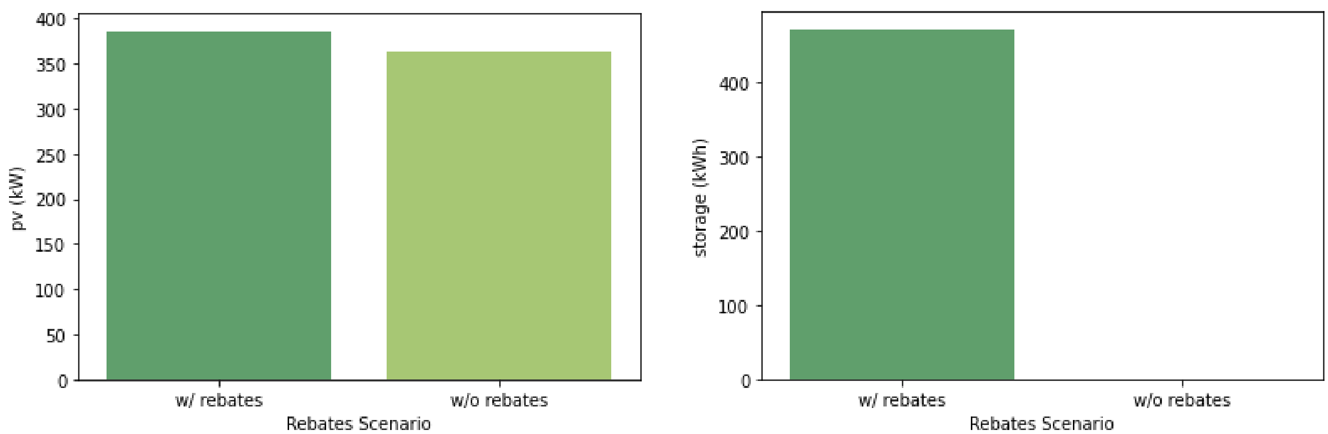
- The storage rebates introduced by the SGIP Equity Rebate
- The resilience criteria assumed for the optimal design
- The effect of the energy efficiency measures (efficiency measures were modeled separately)

[12] ASHRAE Guideline 14-2014 Measurement of Energy, Demand, and Water Savings

Base Case Results Considering Storage Rebates from SGIP

Figure 36 below compares the optimal PV and storage sizes for a scenario with and without the SGIP rebates. As shown in the figure, storage technologies are not economically viable without the existence of SGIP rebates. In contrast, when rebates are available, the presence of storage also creates an incentive and small increase in PV capacity.

Figure 36: Optimal PV and Storage Sizes



PV investments | Storage investments

Source: LBNL Authors' figure

In both cases (with and without rebates), the investment in distributed resources significantly reduces the energy bill and improves the system's economic performance, as shown in Table 6 below. When comparing the annual savings between the two cases, it is possible to observe that PV investments are responsible for most of the electricity bill reduction ($99.50k).

When rebates are allowed and storage is added to the system, the total savings become $109.27k, i.e., a very marginal increase in comparison with the effect of the PV installation. Nonetheless, these bill savings are enough to cover the additional investments required to install subsidized storage (from $76.53k to $83.54k per year).

These results reinforce the idea that, when considering just the normal revenue streams, storage is not economically viable, since it does not produce significant economic gains. This can be explained by the nature of the net-metering tariff - in which solar export is remunerated at a value close to the electricity rate - that does not create significant incentives to store PV and shift the netload throughout the day. However, the SGIP rebates and the corresponding 85 percent reduction in the overall investments make storage more attractive even in these circumstances.

Table 6: Solar Plus Storage Economic Performance

	Without Storage Rebate	With Storage Rebate
System Economics		
Annualized Investments (k$)	76.53	83.54
Annual Bill Baseline (k$)	114.68	114.68
Annual Bill w/ investments (k$)	15.18	5.51
Bill Savings (k$)	99.50	109.17
Overall Annual Economic Gains (k$)	22.97	25.63
Optimal System Size		
Storage (kWh)	0.00	470.87
PV (kW)	364.19	386.24
Inv (kW)	290.61	207.68
CC (kW)	0.00	115.69

Resilience Criteria

As discussed above, the research team's methodology considered two types of resilience criteria:

- Criterion 1 (H=c1): is the minimum number of hours the system must be able to support a critical load (*Lc*), at any point in time, after an unexpected interruption.
- Criterion 2 (H=c2) the minimum number of hours the system must be able to support a critical load (*Lc*), at any point in time, after an expected interruption.

Criteria 1 is related to the ability of the system to withstand routine outage events that can happen at any time, are typically unexpected, and may last a few hours. On the other hand, criteria 2 is related to extreme events, such as storms or heat waves, which can be predicted a few hours ahead (and give enough time to charge to prepare for it by charging the batteries), but they can last several hours, sometimes days. Thus, different hour criteria for C1 and C2 were developed:

- Criterion 1 (unexpected routine outages) - duration 2, 4 and 8 hours
- Criterion 2 (expected extreme outages) - duration: 12, 24, 48 hours

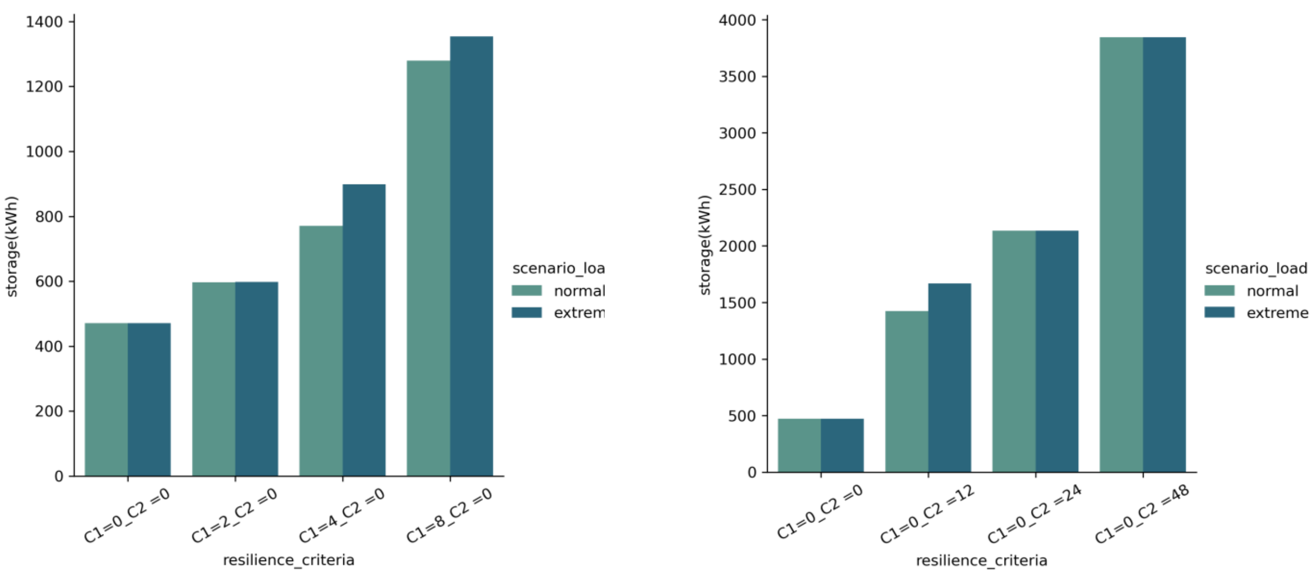
To analyze the optimal system design to accommodate these two criteria, two scenarios of critical load were considered:

- *Normal:* during an outage, the system must supply the normal load of the system during the entire year.
- *Extreme:* during an outage, the system must supply the normal load of the system during most of the year, except during 4 consecutive days in July, when system load is replaced by its historically "extreme" load, which occurred during a heat wave in 2006.

The introduction of these criteria changes the amount of storage required in the system in relation to the simple economic optimal results previously discussed. Figure 37 below shows the optimal storage installation sizes as criterion 1 (left panel) and criterion 2 (right panel) increase, considering the existence of SGIP rebates. For example, to guarantee that the system can withstand an unexpected outage of 8 hours at any point in time, almost 1.4 MWh of storage is needed. On the other hand, to ensure that the system is prepared to face a 48-hour outage as a consequence of an extreme event, the required battery capacity would be 4 MWh.

For medium size outage durations criteria (C1=8 hours and C2=12 hours), it is possible to observe an increase in the storage required when the "extreme" load of the heat wave in 2006 is considered.

Figure 37: Optimal Storage Investments to Meeting Criteria 1 and 2 (with Rebates)



Optimal storage Investments to meet Criterion 1 (case with rebates)

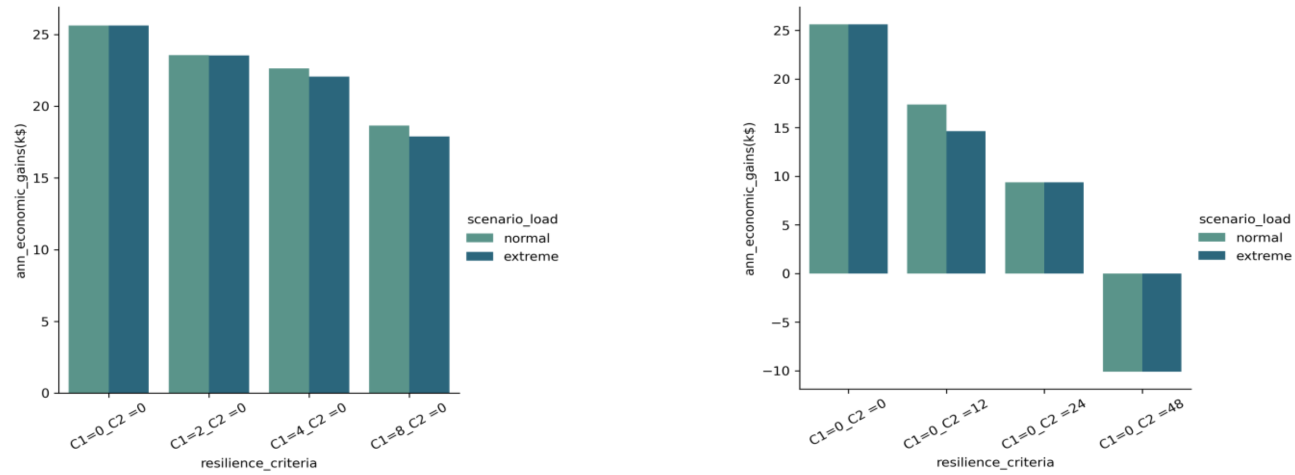
Optimal storage Investments to meet Criterion 2 (case with rebates)

Source: LBNL authors

It is important to note that the introduction of these design criteria has a significant impact on the overall economics of the system. As discussed above, more storage in the system implies higher investment costs and relatively small impact on bill savings. Thus, when increasing C1 and C2, the corresponding improvements in system resilience come with a cost in terms of overall economic system performance.

This impact can be observed in the Figure 38 that shows a decrease in the annual system economic gains as C1 and C2 increase. In fact, this reduction can be seen as "a price to pay" for the increase in system resilience.

Figure 38: Annual Economic Gains vs Increasing Resilience Criteria



Annual economic gains when meeting Criterion 1

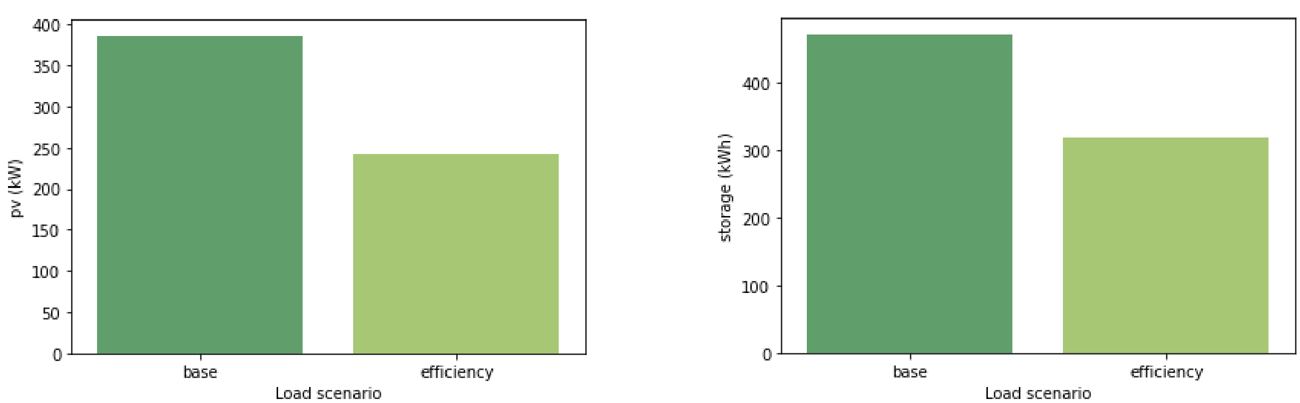
Annual economic gains when meeting Criterion 2

Source: LBNL authors

Resilience Hub with Energy Efficiency Upgrades

The energy efficiency measures describe above significantly reduce the needs for PV and storage assets, as shown in Figure 39 below. Considering a scenario with SGIP rebates, when comparing the optimal sizes of a system with and without energy efficiency, it is possible to observe a substantial reduction in the size of both PV and storage.

Figure 39: PV and Storage Investments with Energy Efficiency Investments



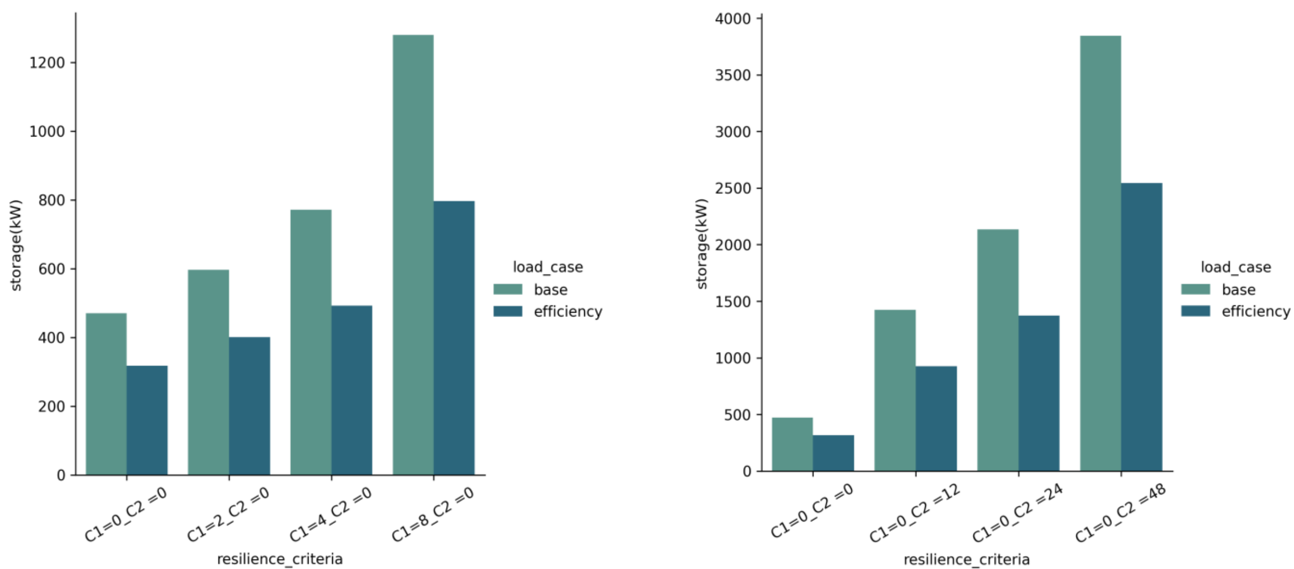
PV investments

Storage investments

Source: LBNL authors

It is important to note that this reduction of the investment needs also happens when resilience criteria C1 and C2 are applied to the system design. As shown in Figure 40 below, the required amount of storage to meet the different hour criteria for C1 and C2 significantly reduces if energy efficiency measures are considered.

Figure 40: Optimal Storage Investments with Energy Efficiency Investment for Criteria 1 and 2



Optimal storage investments to meet Criterion 1 (case with rebates)

Optimal storage investments to meet Criterion 2 (case with rebates)

Source: LBNL authors

The benefits of energy efficiency measures can be seen in different dimensions of the economic performance of the system (Table 7). The efficiency scenario can achieve slightly higher bill savings (in comparison with the base case) with significantly lower annualized investment costs. This effect more than doubles the overall economic gains in comparison with a scenario where only distributed energy resource (DER) investments are considered.

Table 7: Economic Performance with Energy Efficiency Measures

	Without Energy Efficiency Measures	With Energy Efficiency Measures	Difference
System Economics			
Annualized Investments (k$)	83.54	52.94	30.59
Annual Bill Baseline (k$)	114.68	114.68	0
Annual Bill with investments (k$)	5.51	3.75	1.76

	Without Energy Efficiency Measures	With Energy Efficiency Measures	Difference
Bill Savings (k$)	109.17	110.93	-1.76
Overall Annual Economic Gains (k$)	25.63	57.99	32.36
Optimal System Size			
Storage (kWh)	470.87	317.54	153.33
PV (kW)	386.24	243.02	143.22
Inv (kW)	207.68	127.23	80.45
CC (kW)	115.69	76.62	39.07

* This analysis does not include the annualized investments associated with the energy efficiency measures. The "breakeven" point for energy efficiency investments is roughly equal to the difference in overall economic gains or about $32k from the table above.

Discussion: Resilience Hub Analysis

For the resilience hub analysis, battery storage is not economically viable without the SGIP equity rebates. In normal operations (without resilience criteria), PV investments are the main driver of bill savings and economic gains. Adding system resilience criteria significantly increases the storage requirements in the system and the overall system costs. This can be seen as a "price to pay" for resilience, i.e., some kind of "insurance policy" that guarantees that the system is able to withstand certain types of outages. Energy efficiency measures such as LED lighting, upgraded HVAC units, and improved building controls have an important role in reducing investment needs both from an economic and resilience perspective. Thus, energy efficiency has the potential to significantly decrease the costs associated with resilience investments.

Some limitations and recommendations for future analysis are also highlighted. Energy efficiency measures should be jointly optimized with the rest of DER investments but here they were treated independently. The SGIP rebate was modeled as an 85 percent discount in the investment cost. However, a deeper analysis on the application of the rebate policy is required, including the impact on project cash flows. The economic conclusions are strongly dependent on the tariff magnitude and structure used in this analysis. It would be important to repeat the analysis for different tariffs and different solar compensation mechanisms to obtain more robust results.

Passenger Vehicle Health Impacts Modeling

To understand how the research source emissions allocation procedures varied, county-wide source emissions for each species summed across all block groups produced from both the simple and complex methods are listed below and compared to the county-wide source emissions for those same species originally supplied by the EMFAC Emissions Inventory (EI), as detailed in Table 8. Here additionally a correction factor is presented showing the proportional relationship between the original EMFAC EI values for each species and final source emissions values of each species after either the simple or complex method was implemented.

Table 8: Total Fresno County Emissions (in Tons) for All Emissions Species

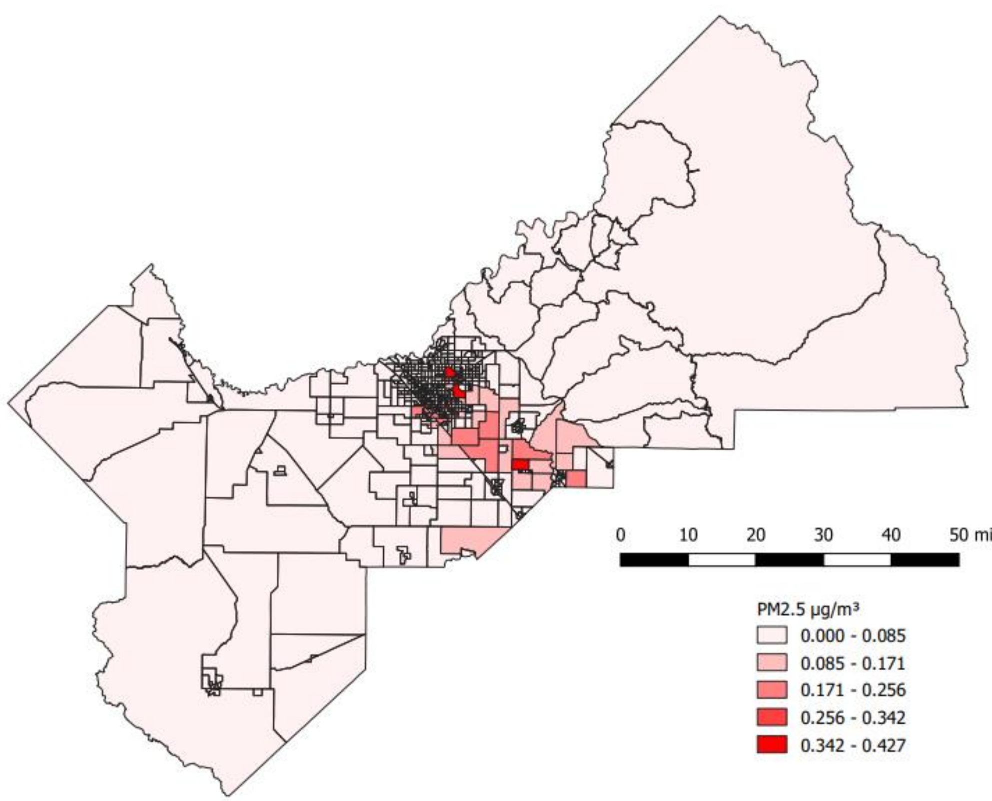
	Primary $PM_{2.5}$	NO_x	SO_x	NH_3	VOC
EMFAC	35.2	898.3	19.8	186.7	1295.8
Simplified	27.4	792.2	15.6	141.3	1143.4
Simplified Correction Factor	1.3	1.1	1.3	1.3	1.1
Complex	39.5	1335.8	21.1	210.4	1923.4
Complex Correction Factor	0.9	0.7	0.9	0.9	0.7

Fresno County emissions given for EMFAC, followed by calculated total county emissions for simplified and complex methods, with correction factors calculated for each to match total county emissions supplied by EMFAC. All units for each emissions species are in annual tons.

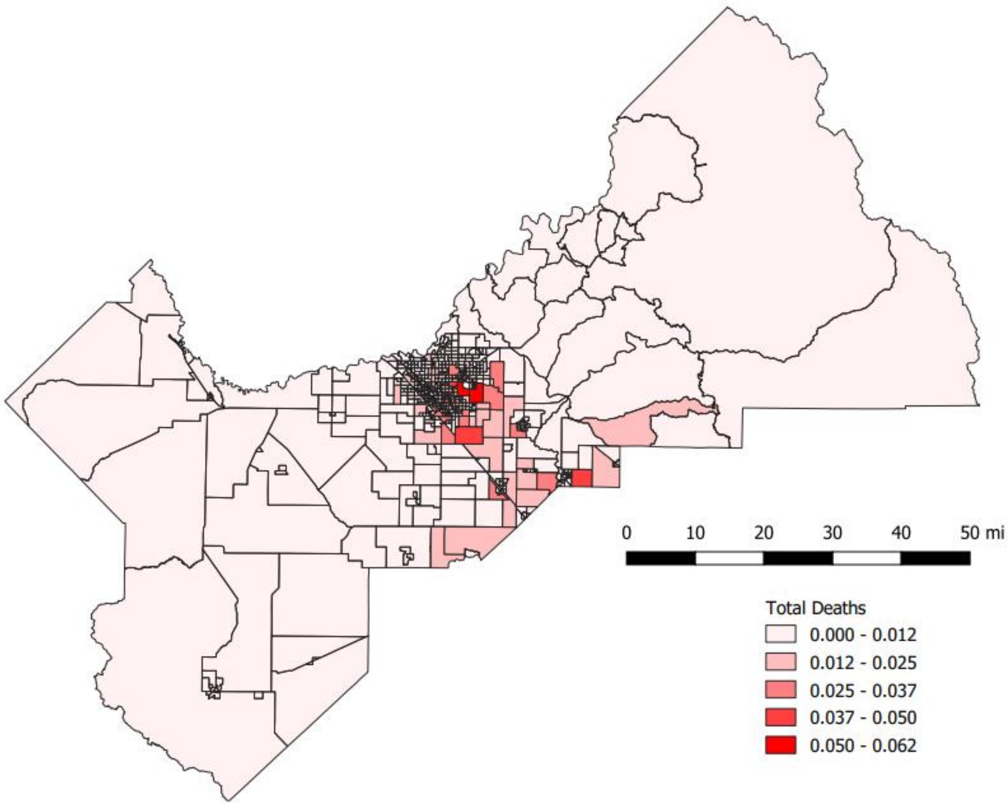
Primary results for this study include $PM_{2.5}$ concentrations and associated health and monetized impacts at both the block group and county-level. Block group-level results are portrayed through block group-scale choropleth maps, or maps that show a range of target values as varying color intensities, here depicting emissions concentration levels and health and monetized impact intensity ranging across the county, displayed in Figure 41 for the complex method. Emissions distributions at both source and receptor sites for all species are reported in μg/m³.

Figure 41: InMAP Output Results Across Block Groups

(a)



(b)



These output maps for (a) $PM_{2.5}$ concentrations and (b) Krewski deaths are from the complex method (corrected) after areal interpolation.

Source: LBNL authors

To complement these findings, death counts and block group-specific monetized impact readings are summed to produce a single death count and monetized impact across the InMAP grid, as detailed in Table 9, and across specifically Fresno Counties after gridded values where distributed to individual block groups through areal interpolation, as detailed in Table 10. Since health and monetized impact results first mapped to the InMAP grid would incorporate areas beyond strictly Fresno County boundaries, countywide results mapped to the InMAP grid are noticeably higher compared to results only incorporating pollution impacts from within Fresno County boundaries for both the simple and complex methods, as was expected.

Table 9: Total Health and Monetized Impacts from LDV Emissions in Fresno County

	Total Deaths	Total Damages ($ mil)	Total Deaths (Adjusted)	Total Damages (Adjusted) ($ mil)
Simple	6.7	70.3	8.0	83.4
Complex	8.1	84.3	5.9	62.0

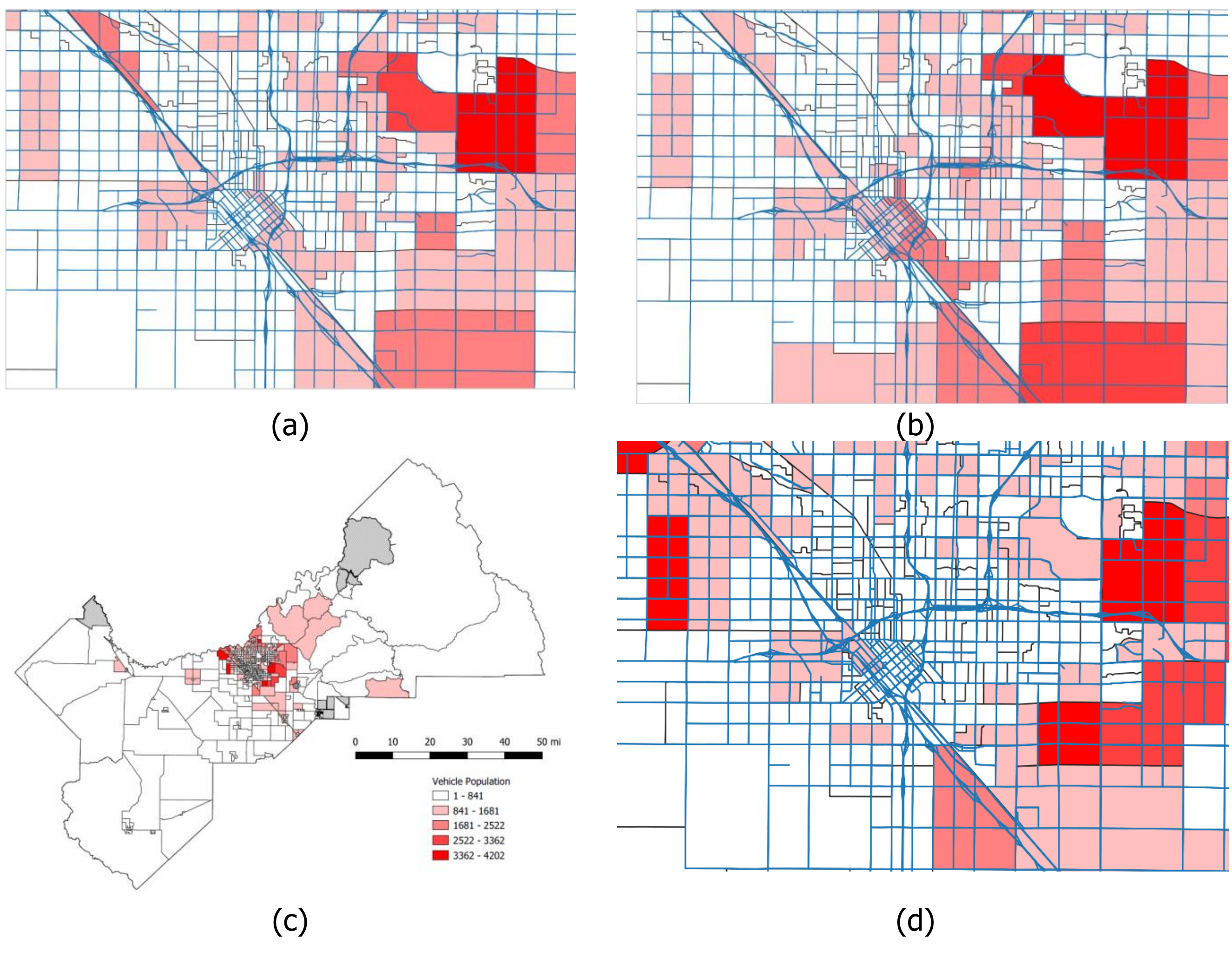
Adjusted deaths and damages were calculated after input emissions were corrected to EMFAC levels in Table 8. Adjusted values here refer to results calculated from input emissions being multiplied by associated correction factors. Impacts presented here cover the entire United States (note that impacts far beyond California will be largely negligible).

Table 10: Health and Monetized Impacts to only Fresno County Population Only from Emissions in Fresno County

	Total Deaths	Total Damages ($ mil)	Total Deaths (Adjusted)	Total Damages (Adjusted) ($ mil)
Simple	5.3	55.9	6.3	66.2
Complex	5.7	60.0	4.2	44.1

Higher health and monetized impacts were generally shown to cluster around the central focal point of Fresno County, with significantly less impact in the larger and more remote block groups, for both the simple and complex methods. The distribution of impacts around the Central Fresno district, within and adjacent to the central highway, is shown in Figure 42(a) and (b).

Figure 42: Krewski Deaths Within Fresno's Urban Core from (a) Simplified Method and (b) Complex Method by Block Group



Panel (c) shows the vehicle population across the county and (d) at the urban core by block group.

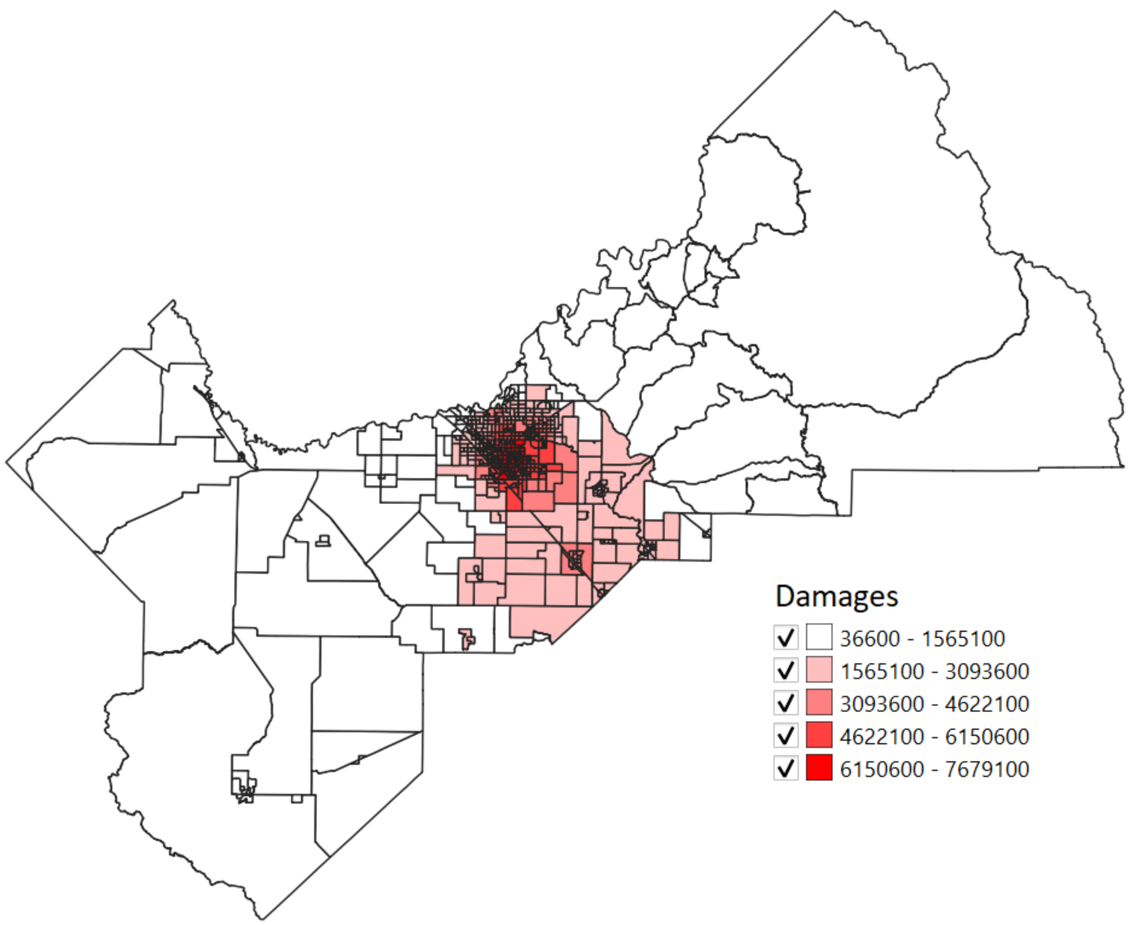
Source: LBNL authors

The distribution of vehicle population across Fresno County is shown in Figure 42(c) and (d). Figure 42(d) can be compared to Figure 43(a) and (b), and correlation can be seen between the vehicle population map and the mortality map in areas with the higher vehicle counts correlated with higher mortality counts.

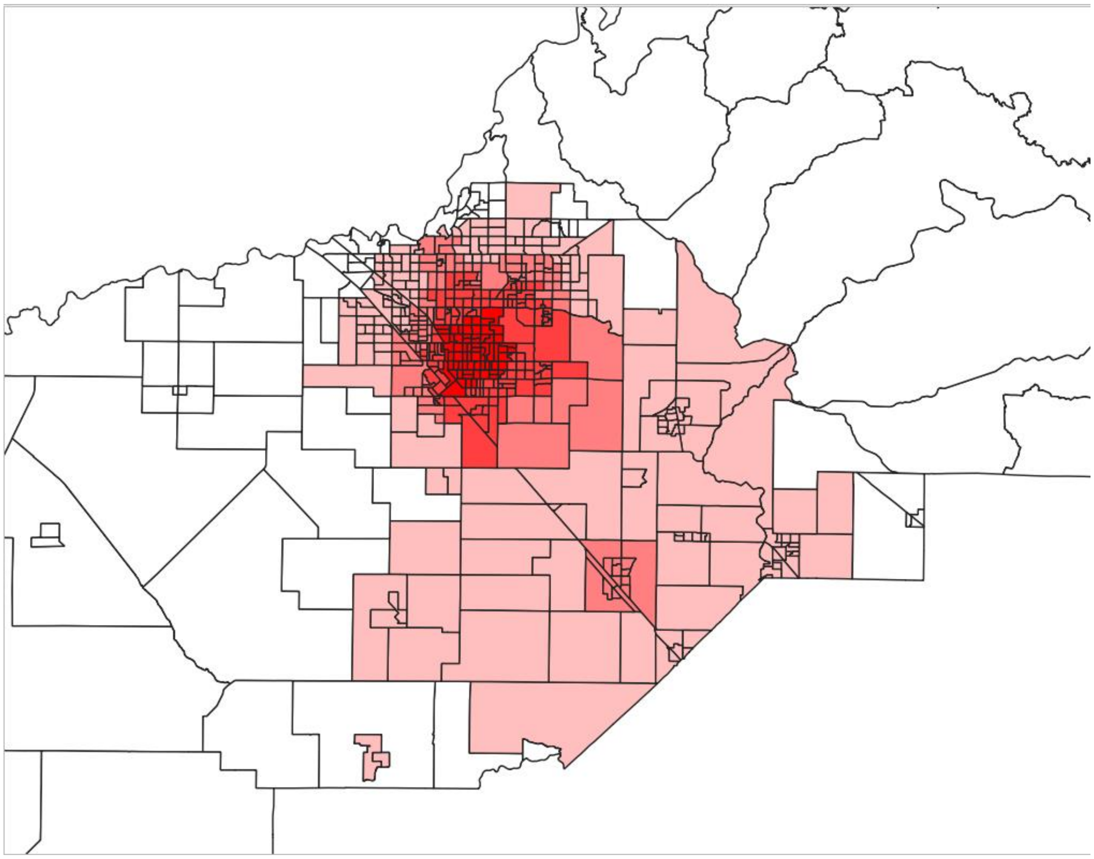
To better understand which underlying factors may have the most influence in the revealed distribution of health impacts, the research team looked into whether health impacts were most heavily attributed to vehicle population, vehicle vintage, or population (people). First results were normalized by population (i.e., damages per 100,000 people) to reveal whether similar patterns are seen and overall to show the degree of influence population had on final health and monetized impacts, as shown in Figure 43. More damages are seen in the central area of Fresno with decreasing damage in areas further away from the central area. Additional maps for vehicle ages are provided in the Appendix.

Figure 43: Fresno Area Total Damages ($) Normalized by 100,000 People

(a)



(b)



The figures are adjusted total damages ($) using the complex method normalized by 100,000 people (a) across the whole county and (b) within the county's urban core, both by block group.

Source: LBNL authors

Discussion: Passenger Vehicle Health Impacts Analysis

There are several limitations in calculating vehicle emissions' health impact for Fresno County that are discussed here. The research team only considered the health impacts of light-duty vehicle emissions from Fresno County. This relies on the assumption that Fresno County is a closed system and only sees travel from vehicles actually tied to the county, an assumption was necessary given the complexity of accounting for travel from outside vehicles for which data was unavailable. The complexity in this largely draws from drawing the boundary where travel from outside the county should be considered, and where specifically that boundary should be drawn. Vehicle miles traveled (VMT) provides a usable proxy for vehicle activity, but it is difficult to determine whether a specific VMT value should be attributed to a vehicle from Fresno County or from outside the county.

Regarding data sourced from EMFAC, the Emissions Inventory and Fleet Database have their own limitations and inconsistencies. There are vehicle population discrepancies between the EI and FD, which result from certain vehicles not being registered to a specific census block group code. This causes the EI to slightly overestimate its emission values, given that they are accounting for vehicles that are not detailed within the FD. Further, when using the FD to spatially allocate EI emissions values, the spatial resolution is limited to the block group boundaries. This means that the location within Fresno County block groups where each vehicle is located is not known, which is an issue for the larger block groups, requiring the research team to assume they are evenly spatially distributed throughout each block group. Regarding limitations for the roads segments layer, only annual VMT values were available, which provides no indication of which types of vehicles these VMT are associated with, which is key missing information needed to most accurately determine which emissions rates should be applied.

To address the observed differences in results between the simple and complex methods for health damages at the county and block group levels, initial inconsistencies are noted between the EMFAC EI and FD. Specifically, a reason for why results for the complex method raw results are less than for the simple method is the simple method accounts for emissions from all registered vehicles, even if not actually being driven, while the complex method only accounts for emissions from cars that are driving on those specific roads in the data. After correcting this difference by normalizing the emissions from both methods to be matched, any difference in county and block group level health damages can be attributed to the spatial layout of the input emissions shapefiles for both the simple and complex methods. The different emissions configuration at the source results in different concentrations output from the InMAP modeling. Additional limitations of the air quality modeling and health impact assessment using InMAP include the following:

- Selection of concentration-response (C-R) function reflects the one most commonly used in the scientific literature and by the U.S. EPA. There are alternative C-R functions and hazard ratios that are available to use. Future work can test the results using state-of-the-science C-R functions including functions that are non-linear in nature.
- Detailed quantification of uncertainty in the C-R, via meta-analysis or other techniques, is outside the scope of research for this work.
- The air quality model uses 2005 meteorology and physical and chemistry parameters to model pollutant concentrations.

Beyond these limitations, the research team recognizes the significant complexity in accurately modeling and representing vehicle mobility from annual emissions data. The team's methods for the complex approach using vehicle trip distance buffers as a means for approximating where vehicles will likely cross between block groups, is an incremental improvement in incorporating vehicle travel, but cannot sufficiently account for the nuance in determining how and where people drive.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

The knowledge produced through this study is being transferred in several ways. First, this report discusses the methods and results in detail and will be made available to other research, environmental justice and climate equity groups, and deployment teams.

The team shared project results with the city of Fresno and with the Fresno community in a community newsletter distributed by community-based organization partner Every Neighborhood Partnership. The team plans to disseminate project results more broadly in the Central Valley with partner CivicWell (formerly known as Local Government Commission) and in follow up-meetings with state policy makers.

A presentation and one-page summary based on this project describing the urgent need for integrated pilot programs focusing on underserved and disadvantaged communities was shared with multiple groups including the CalEPA, CARB, California State Senator Anna Caballero's office (District 14 including south Fresno), and with several programs at the U.S. Department of Energy including the Building America Program and the Advanced Building Construction Initiative.

The team presented and will continue to present the work at several research and practitioner forums, for example, at the Net Zero Conference "Cost Effective ZNE Retrofit Solutions in Underserved Markets" session on September 15, 2021, and at the Conference on Building Energy & Environment (COBEE) in July 2022.

This project advanced the capability of the CityBES urban-scale building modeling tool by adding additional residential energy efficiency measures, electric heat pump measures, and additional cost data. The tool demonstrated the modeling of two underserved neighborhoods in Fresno. This work was recognized as part of a prestigious R&D 100 Award[13] for CityBES awarded in August 2022. CityBES is a modeling tool that offers detailed building energy modeling and analysis at the district and urban scales using the EnergyPlus simulation engine and integrates open datasets of buildings, land use, assessor records, and energy use. For this project, CityBES was used to model 21 energy efficiency measures for all residential buildings in two disadvantaged communities. The measures cover building envelope, lighting, HVAC, and operations and maintenance. The most effective ECM package (including eight measures) can save total energy use and reduce CO_2 emissions by 60 percent. CityBES was also used to identify which sets of homes were most cost effective to fuel switch from natural gas heating to heat pump-based water heaters and heat pumps for heating and cooling.

[13] Established in 1963, the R&D 100 Awards is the only science and technology award competition that recognizes new commercial products, technologies, and materials for their technological significance. The R&D 100 Awards program identifies and celebrates the top 100 revolutionary technologies of the past year. (https://www.rd100awards.com/about/)

The CityBES tool has growing use through the free CityBES web app (CityBES.lbl.gov) and the commercial-ready CityBES API. Building upon the added residential features from this project, the tool is expanding to cover more cities and other building types and is continually adding new features (e.g., PV, storage, and demand response) to support decarbonization of commercial and residential buildings in California and other states.

Finally, LBNL anticipates publishing the results of this analysis in one journal article on the integrated modeling of multiple sectors in Fresno's disadvantaged communities. The article is in preparation; publication is expected later in 2023. This will make the policy analysis, data, methods, and results of this work broadly available to the research, development, and deployment (RD&D) communities on a national and international level.

In addition to communicating and archiving the key findings of this work to a wider audience, these two publications will also provide an opportunity to highlight to other RD&D stakeholders key areas and opportunities for other important areas for follow-up work (for example, lower cost, higher energy efficiency heat pump designs, and market development programs and financing programs for low income/disadvantaged community areas).

CHAPTER 5: Conclusions/Recommendations

This report presented detailed descriptions of the community outreach, data collection, and technical modeling of disadvantaged neighborhoods in south Fresno that were used in support of the companion report "An Action Plan for Greater Climate Equity for Disadvantaged Communities in Fresno." The project used extensive community outreach; analysis of existing clean energy policies for low income and disadvantaged communities; integrated residential sector modeling across buildings and passenger vehicles including energy efficiency measures, fuel switching to heat pump-based space and water heating, solar PV, and EVs; resilience hub modeling; and assessment of public health benefits of transitioning to plug-in EVs.

The integrated modeling was done across all residential buildings in two disadvantaged neighborhoods in south Fresno. For example, a combination of energy efficiency packages that have less than a $1,000 installation cost with up to 10 percent annual energy savings (adding portable fans, improving water tank insulation, and adding air sealing to seal leaks) were identified, and upgrading to an efficiency package with LED, portable fans, improved water tank insulation, and higher efficiency gas furnace provides up to 22 percent annual energy savings and less than a five-year payback. There are major implementation challenges, however, to decarbonizing these neighborhoods such as high initial costs, the need for roof and/or electric panel upgrades, and the requirement to keep overall energy costs at or below the baseline level. Some residential configurations that lend themselves more readily to integrated upgrades and transitioning to EVs can contribute to substantial operating cost savings from lower fuel costs. For example, transitioning to mini-split heat pumps for heating and cooling in homes that lack central heating and cooling provides energy and GHG savings but has high initial costs. Used EVs can be an option for many residents in terms of daily driving range requirements and savings of $62 million to $83 million in public health benefits are estimated from transitioning all vehicles in Fresno County to zero-emission vehicles. As a rough estimate, if it is assumed that the 20 percent of oldest vehicles contribute 80 percent of the air quality-related health damages, the health benefits of replacing these oldest vehicles would amount to about 20–40 percent of the total initial replacement costs, and the annual operating cost savings to owners would be about $1.3 billion per year.

Upgrading an existing community cooling center to a community resilience hub with solar PV and battery storage was found to be a promising deployment option technically and economically, although the Fresno area has not historically suffered from extended grid power outages.

Regarding policy gaps, a large fraction of homes in south Fresno (70 percent) are single family homes, and about two-thirds of those are rentals. These residents are not eligible for several clean energy-related programs. For example, single-family home renters in disadvantaged communities in southwest Fresno are not able to access rooftop solar PV since renters are not eligible for solar PV rebates; one mitigation for this could be the development of more attractive community solar programs. About half of single-family homes are not "solar PV-ready" and there is no program to address this (repairing dilapidated roofs and upgrading electric panels). Fresno is becoming increasingly hot in the summer with a record 69 days above 100°F. Gaps in heat resilience are the lack of requirements for maximum temperatures indoors; and an estimated 15 percent of homes lack air conditioning units, which can lead to dangerous indoor conditions during extreme heat waves. The state should consider enacting design requirements for maximum allowed temperatures in all buildings; and all residents of Fresno should have access to an air conditioning unit at home. Low-cost do-it-yourself air filters (box fans with MERV air filters) can improve indoor air quality, especially during wildfire events with smoky air, and are an opportunity for program and outreach expansion.

The project found a general lack of awareness among residents surveyed for existing programs in community solar, rooftop PV, and clean cars. More outreach is needed to improve resident awareness of existing programs, and more consolidated programs are needed to reduce transaction cost barriers and improve equity among residents. This echoes the call from AB 1232 to integrate both healthy home and energy efficiency objectives in home inspections and upgrades.

There is also the need for more integrated pilots and demonstration projects in disadvantaged communities to "learn-by-doing" and to develop best practices. More demonstration and pilot projects in the building sector are needed to determine what works best for residents and to develop best practices for inspection, implementation, and monitoring in terms of building electrification. More integrated pilot and demonstration projects that increase access to rooftop solar PV, and electrified end-use options in both the building and transportation sectors in Fresno disadvantaged communities would help meet multiple policy objectives: building decarbonization, climate equity, improved public health, and increased overall resilience to climate extremes in disadvantaged communities. There are elements in existing programs that include some of the above (e.g., EV and charging programs), but no consolidated programs that include all of the items above (energy efficiency measures, electrification of heating, solar PV, and ZEVs) for disadvantaged community areas.

Appendix G includes key takeaways from the Action Plan.

CHAPTER 6: Benefits to Ratepayers

This report contributed understandings from community outreach that are critical to implement the transition to clean energy; the report used a variety of methods to identify attractive options for homes in disadvantaged community areas of Fresno; and the report identified some key challenges that must be grappled with and addressed to realize an equitable clean energy transition.

The state has multiple policy objectives for building and transportation decarbonization, improving climate equity, and ensuring resilience to extreme weather. This report identifies many measures and packages in Fresno across the residential building and passenger vehicle sectors including rooftop PV that give operational cost savings for overall energy costs. But first costs are high in many cases and deferred maintenance (e.g., roof repairs, old electric panels) are two key challenges.

Authors highlighted some key gaps and policy needs to upgrade more homes in disadvantaged community areas. More programs to provide adequate financing, address deferred maintenance in older homes, improve public awareness of existing programs, and increase program eligibility for renters in single-family homes would help address these gaps and provide more equity in basic livability, access to clean energy technologies such as solar PV, and reduced utility bill energy burden.

The researchers' recommendations to provide design standards for maximum indoor temperature and access to an air conditioner at home would help ensure the health and safety for underserved residents in Fresno and other hot climate zones during increasingly extreme heat waves, especially for those residents with underlying health conditions.

Continued support for equity incentives such as the SGIP-equity program for storage and ZEV-DAC rebates would help to ensure resilient communities during extreme heat or other emergencies and better air quality. The SGIP-equity program for storage can help improve community resilience through development of community resilience hubs that can provide 1–2 days of critical load service for disadvantaged community residents and ZEV-DAC rebates improve local air quality by making it more affordable to replace older gasoline-based vehicles with zero emission vehicles. Additional funding to disseminate low-cost DIY air filters would be an inexpensive way to improve indoor air quality in residents' homes and would be especially helpful in situations with high amounts of outdoor smoke from wildfires.

If more consolidated "climate assessments" encompassing climate resilience assessment and HP electrification, solar PV, and EV readiness were piloted and then implemented, disadvantaged community resident transaction costs would be greatly reduced, and this type of consolidated assessment would facilitate the possibility of more integrated upgrades. Demonstrating and piloting more consolidated assessments and integrated upgrade programs would provide maximum benefits and equity to residents in disadvantaged community areas, provide much needed data about the implementation costs and benefits of integrated upgrades, quantify possible cost reduction opportunities compared to serial upgrades, and provide learning and potential pathways to scaling up equitable building decarbonization.

This work sets the groundwork for state policy makers to support more aggressive, systematic, and comprehensive programs to support greater equity in the Fresno area across the building, transportation, and energy supply sectors. More investments, programs, and partnerships in this area would improve housing equity, improve indoor and outdoor air quality, and lead to improved health outcomes in Fresno.

GLOSSARY OR LIST OF ACRONYMS

Term	Definition
ACH	Air change per hour
API	application programming interface
CalEPA	California Environmental Protection Agency
CARB	California Air Resources Board
CARE	California Alternative Rates for Energy
CCA	community choice aggregation
CEC	California Energy Commission
CityBES	City Building Energy Saver, urban scale building modeling tool
COP	coefficient of performance
CO_2	Carbon dioxide
CTM	Chemical transport models
CZ	climate zone
DAC	disadvantaged community
DHW	Domestic hot water
DIY	do-it-yourself
EEM	energy efficiency measure
EI	emissions inventory
EMFAC	EMissions FACtor Emissions Inventory
EV	electric vehicle
FERA	Family Electric Rate Assistance
FD	(EMFAC) fleet database
FIPS	Federal Information Processing System
Fresno EOC	Fresno Economic Opportunities Commission
GGRF	greenhouse gas reduction fund
GHG	greenhouse gas
GIS	geographic information system
GWP	global warming potential
HP	heat pump
HVAC	heating, ventilation, and cooling
InMAP	Intervention Model for Air Pollution
LBNL	Lawrence Berkeley National Laboratory
LDV	light duty vehicle

Term	Definition
LI	low income
m^2	Meters squared
NEM	net energy metering
NH_3	anhydrous ammonia
NOx	oxides of nitrogen
PG&E	Pacific Gas and Electric Company
PM	Particulate matter; PM_{10} and $PM_{2.5}$ refer to aerodynamic diameter of 10 micrometers and 2.5 micrometers, respectively
PSPS	Public safety power shutoff
PV	photovoltaic
RD&D	Research, development, and deployment
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric Company
SGIP	self-generation incentive program
SOA	secondary organic aerosols
SOx	oxides of sulfur
STEM	science, technology, engineering, and mathematics
Title 24 ACM	Title 24 alternative calculation method
TMY	typical meteorological year
TOU	time-of-use
U.S. DOE	United States Department of Energy
VMT	vehicle miles travelled
VOC	volatile organic compounds
VRF	variable refrigerant flow system
VSL	Value of statistical life
ZEV	Zero-emissions vehicles
ZNE	zero-net-energy

REFERENCES

Integrated building modeling references:

Air Conditioning Installation, 2017. Which to Go for – Mini-splits, Multisplits or VRF? [WWW Document]. URL https://www.actionac.net/air-conditioning-ramona-options/

Althoff, M., 2020. 5, 15 or 20? Your Commercial HVAC Life Expectancy, Althoff Industries.

ASHRAE, 2020. 2020 ASHRAE Handbook—HVAC Systems and Equipment, chapter 41 Evaporative air-cooling equipment. ASHRAE.

Brook, M., 2021. SB 1477: Pilot Guidelines and Parameters of BUILD and TECH - slide 7.

Bunns HVAC, 2017. Reducing Attic Temperatures in The Summer, Bunn's & Bennett Heating & Air Conditioning.

Burton, R., Robeson, A., Nevins, R., 1975. The effect of temperature on preferred air velocity for sedentary subjects dressed in shorts. ASHRAE Transactions 81, 157–158.

California Energy Commission, 2018a. 2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24, Part 6) (No. CEC-400-2018-020-CMF). Sacramento, CA.

California Energy Commission, 2018b. 2019 Residential Compliance Manual for the 2019 Building Energy Efficiency Standards.

California Energy Commission, 2016a. 2016 Residential Alternative Calculation Method Reference Manual for the 2016 Building Energy Efficiency Standards.

California Energy Commission, 2016b. 2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings.

Executive Order B-55-18, 2018. Executive Order B-55-18 To Achieve Carbon Neutrality, Executive Department of State of California.

Canizares, C., Nathwani, J., Kammen, D., 2019. Electricity for All: Issues, Challenges, and Solutions for Energy-Disadvantaged Communities [Scanning the Issue]. Proceedings of IEEE 107, 1775–1779. https://doi.org/10.1109/JPROC.2019.2935856

Chen, Y., Deng, Z., Hong, T., 2020. Automatic and rapid calibration of urban building energy models by learning from energy performance database. Applied Energy 277, 115584. https://doi.org/10.1016/j.apenergy.2020.115584

Chen, Y., Hong, T., Piette, M.A., 2017. Automatic generation and simulation of urban building energy models based on city datasets for city-scale building retrofit analysis. Applied Energy 205, 323–335. https://doi.org/10.1016/j.apenergy.2017.07.128

Crawley, D.B., Lawrie, L.K., Winkelmann, F.C., Buhl, W.F., Huang, Y.J., Pedersen, C.O., Strand, R.K., Liesen, R.J., Fisher, D.E., Witte, M.J., Glazer, J., 2001. EnergyPlus: Creating a new generation building energy simulation program. Energy and Buildings 33, 319–331. https://doi.org/10.1016/S0378-7788(00)00114-6

Fenaughty, K., Parker, D., 2018. Evaluation of Air Conditioning Performance Degradation: Opportunities from Diagnostic Methods, in 2018 ACEEE Summer Study on Energy

Efficiency in Buildings. http://Publications.Energyresearch.Ucf.Edu/Wp-Content/Uploads/2018/09/FSEC-PF-474-18.Pdf.

Passenger vehicle health impact modeling references:

Baker, K. R., Amend, M., Penn, S., Bankert, J., Simon, H., Chan, E., ... & Roman, H. (2020). A database for evaluating the InMAP, APEEP, and EASIUR reduced complexity air-quality modeling tools. *Data in brief*, *28*, 104886. *An equity analysis of clean vehicle rebate programs in California | SpringerLink*. (n.d.). Retrieved April 15, 2022, from https://link.springer.com/article/10.1007/s10584-020-02836-w

Ayres, L., & Eisinger S., D. (2016). The Fresno TREES Program: Tree planting along Roads to help Eliminate pollution Exposure and Sequester carbon (p. 59). California Air Resources Board.

de Foy, B., Schauer, J. J., Helmig, D., & Goldstein, A. (2019). Changes in speciated PM2. 5 concentrations in Fresno, California, due to NOx reductions and variations in diurnal emission profiles by day of week. *Elementa: Science of the Anthropocene*, *7*.

Clean-air plan for San Joaquin Valley first to meet all federal standards for fine particle pollution | California Air Resources Board (No. 19–04). (2019). California Air Resources Board. https://ww2.arb.ca.gov/news/clean-air-plan-san-joaquin-valley-first-meet-all-federal-standards-fine-particle-pollution

Eilert, P., Rubin, E., Chase, A., & Zhang, Y. (n.d.). *Codes and Standards Climate Strategy*. 16.

Evaluation of on-road vehicle CO and NOx National Emission Inventories using an urban-scale source-oriented air quality model. (2014). *Atmospheric Environment*, *85*, 99–108. https://doi.org/10.1016/j.atmosenv.2013.11.020

Gilmore, E. A., Heo, J., Muller, N. Z., Tessum, C. W., Hill, J. D., Marshall, J. D., & Adams, P. J. (2019). An inter-comparison of the social costs of air quality from reduced-complexity models. *Environmental Research Letters*, *14*(7), 074016. https://doi.org/10.1088/1748-9326/ab1ab5

Gurney, K. R., Liang, J., Patarasuk, R., Song, Y., Huang, J., & Roest, G. (2020). The Vulcan Version 3.0 High-Resolution Fossil Fuel CO2 Emissions for the United States. *Journal of Geophysical Research. Atmospheres*, *125*(19). https://doi.org/10.1029/2020JD032974

Health benefits of decreases in on-road transportation emissions in the United States from 2008 to 2017. (n.d.). PNAS. Retrieved April 15, 2022, from https://www.pnas.org/doi/abs/10.1073/pnas.2107402118

Kheirbek, I., Haney, J., Douglas, S., Ito, K., & Matte, T. (2016). The contribution of motor vehicle emissions to ambient fine particulate matter public health impacts in New York City: A health burden assessment. *Environmental Health*, *15*(1), 89. https://doi.org/10.1186/s12940-016-0172-6

Krewski, D., Jerrett, M., Burnett, R. T., Ma, R., Hughes, E., Shi, Y., ... & Tempalski, B. (2009). *Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality* (Vol. 140). Boston, MA: Health Effects Institute.

Lee, M. M., & Jr, J. A. C. (2017). *Fresno County at a Crossroads:* (p. 17). PolicyLink.

Muehlegger, E., & Rapson, D. (2017). Barriers to Low-Income Electric Vehicle Adoption in California: An Assessment of Price Discrimination and Vehicle Availability. *ITS Reports*, *2017*(51). https://doi.org/10.7922/G2SB43XR

Prioritizing the control of emission sources to mitigate $PM_{2.5}$ disparity in California. (2020). *Atmospheric Environment*, *224*, 117316. https://doi.org/10.1016/j.atmosenv.2020.117316

Reichmuth, D. (2019). *Inequitable Exposure to Air Pollution from Vehicles in California*. Union of Concerned Scientists. https://www.ucsusa.org/resources/inequitable-exposure-air-pollution-vehicles-california-2019

Samuelsen, S., Zhu, S., Kinnon, M. M., Yang, O. K., Dabdub, D., & Brouwer, J. (2020). An Episodic Assessment of Vehicle Emission Regulations on Saving Lives in California. *Environmental Science & Technology*. https://doi.org/10.1021/acs.est.0c04060

State of the Air 2021. (2021). American Lung Association.

Tessum CW, Hill JD, Marshall JD (2017) InMAP: A model for air pollution interventions. PLoS ONE 12(4): e0176131. https://doi.org/10.1371/journal.pone.0176131

Tessum, C. (2019, April 20). *Working with source-receptor matrices using https://inmap.run and GeoPandas in Python*. InMAP. https://www.inmap.run/blog/2019/04/20/sr/

Transportation Electrification Activities Pursuant to Senate Bill 350. (n.d.-a). Retrieved April 15, 2022, from https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/transportation-electrification/transportation-electrification-activities-pursuant-to-senate-bill-350

Transportation Electrification Activities Pursuant to Senate Bill 350. (n.d.-b). Retrieved April 15, 2022, from https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/transportation-electrification/transportation-electrification-activities-pursuant-to-senate-bill-350

U.S. EPA, National Center for Environmental Economics. (2010, December 17, Updated 2014, May 1). *Guidelines for Preparing Economic Analysis*. EE-0568. https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analysis-2010-revised-2014

U.S. EPA, O. (2014, April 20). *Mortality Risk Valuation* [Overviews and Factsheets]. https://www.epa.gov/environmental-economics/mortality-risk-valuation

U.S. EPA, R. 09. (2013, March 7). *EPA Activities for Cleaner Air* (California) [Overviews and Factsheets]. https://www.epa.gov/sanjoaquinvalley/epa-activities-cleaner-air

Xing, Y.-F., Xu, Y.-H., Shi, M.-H., & Lian, Y.-X. (2016). The impact of $PM_{2.5}$ on the human respiratory system. *Journal of Thoracic Disease*, *8*(1), E69. https://doi.org/10.3978/j.issn.2072-1439.2016.01.19

Zeise, L., & Blumenfeld, J. (2021). *CalEnviroScreen 4.0* (p. 207). California Environmental Protection Agency.