# Decarbonization at a District Scale

# Colorado Residential Retrofit District

July 20, 2021

# Agenda

1. Project Overview
   (DOE)
2. CORRED Phase 1 Key findings
   (NREL team)
3. Relevance
   (CEO, Xcel, RMI)
4. Q&A

# Presenters

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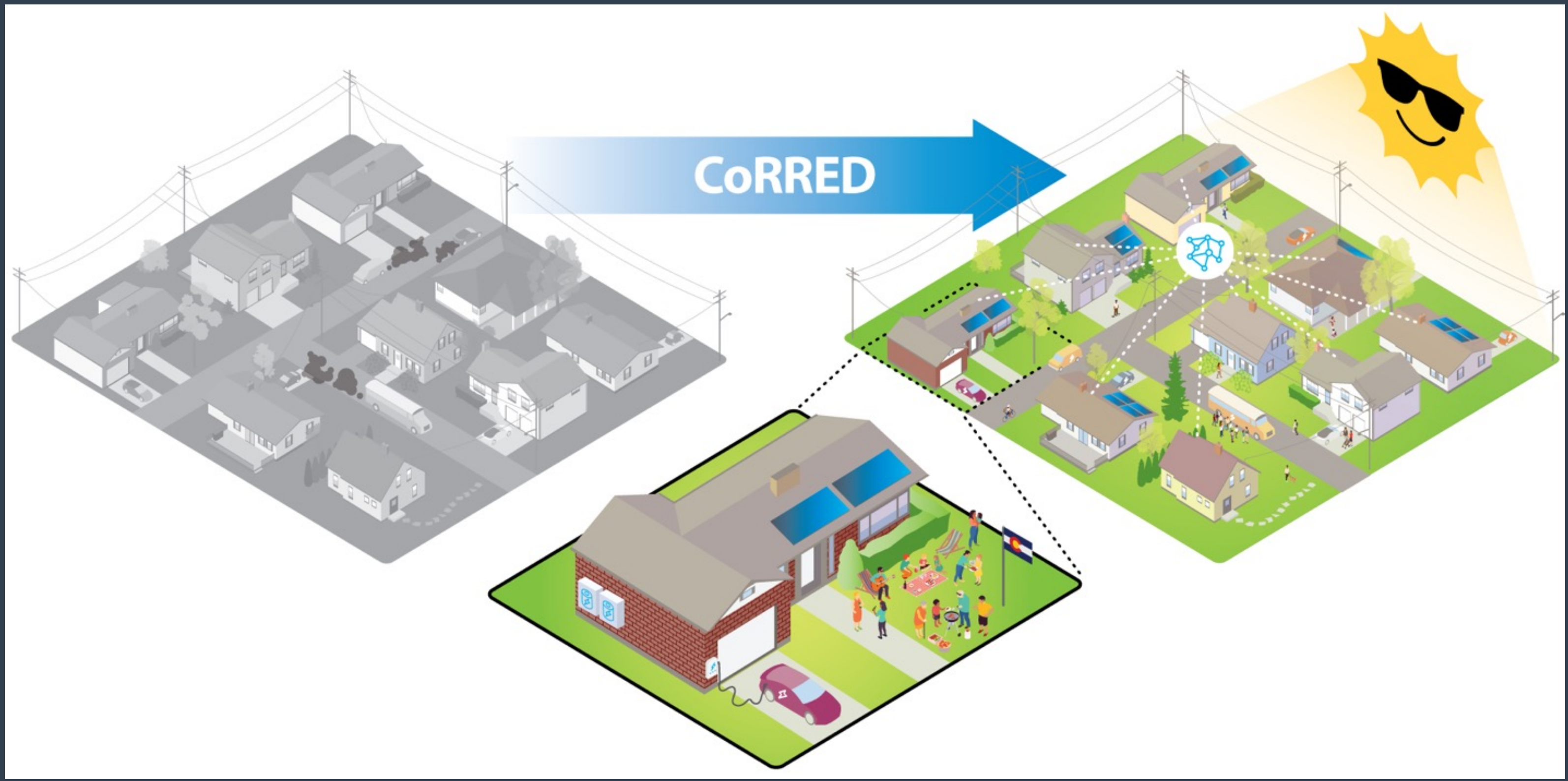
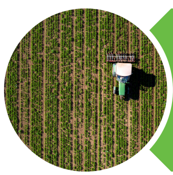



# Project Overview

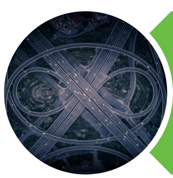
# EERE Priorities

100% Decarbonized Electric Grid by 2035

Decarbonize Energy Intensive Industries



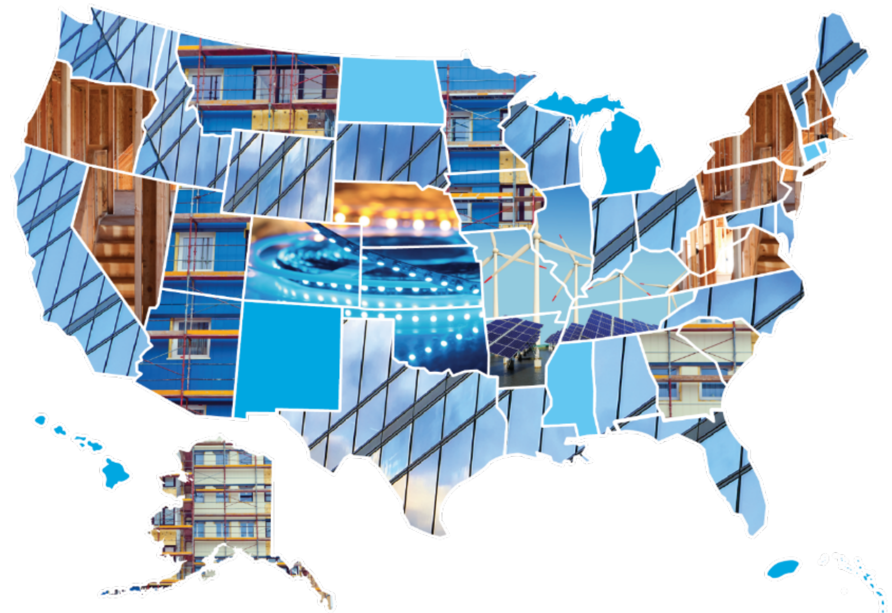
Enable a Net-zero Agricultural Sector



Decarbonize Transportation Across All Modes

Reduce the Carbon Footprint of Buildings

## State Energy Program



Provides funding and technical assistance to states, territories, and the District of Columbia to:

- **Enhance energy security**
- **Advance state-led energy initiatives**
- **Increase energy affordability**

# State Energy Program


**$300 million** to grantees over the past five years

via **formula grants** and **competitive awards**

# Colorado Residential Retrofit Energy District

## Overview:

**Prime:** Colorado Energy Office
**DOE Funding:** $300,000
**Cost Match*:*** $60,000

**Partners:** Xcel Energy, NREL, and the Rocky Mountain Institute

## Project Goals:

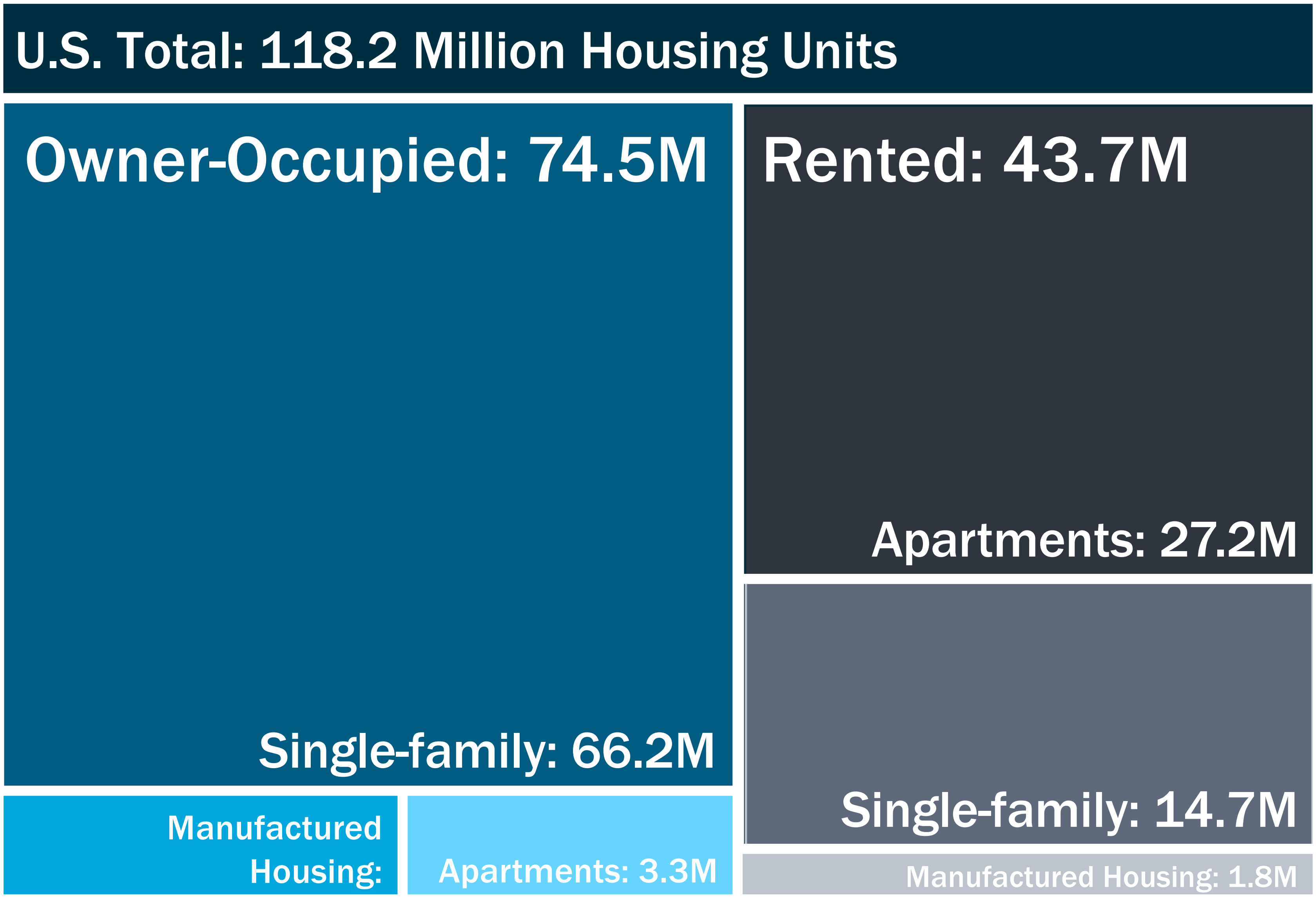
- Create a model for evaluating energy efficiency and renewable energy investments at a community scale (referred to as "energy districts"- interconnected buildings incorporating energy efficiency, distributed energy resource storage and controls) versus individual buildings/residences.
- Address the growing challenge of traditional utility energy efficiency programs meeting cost-effectiveness thresholds due to current low cost of electricity in many areas.



## Impact:

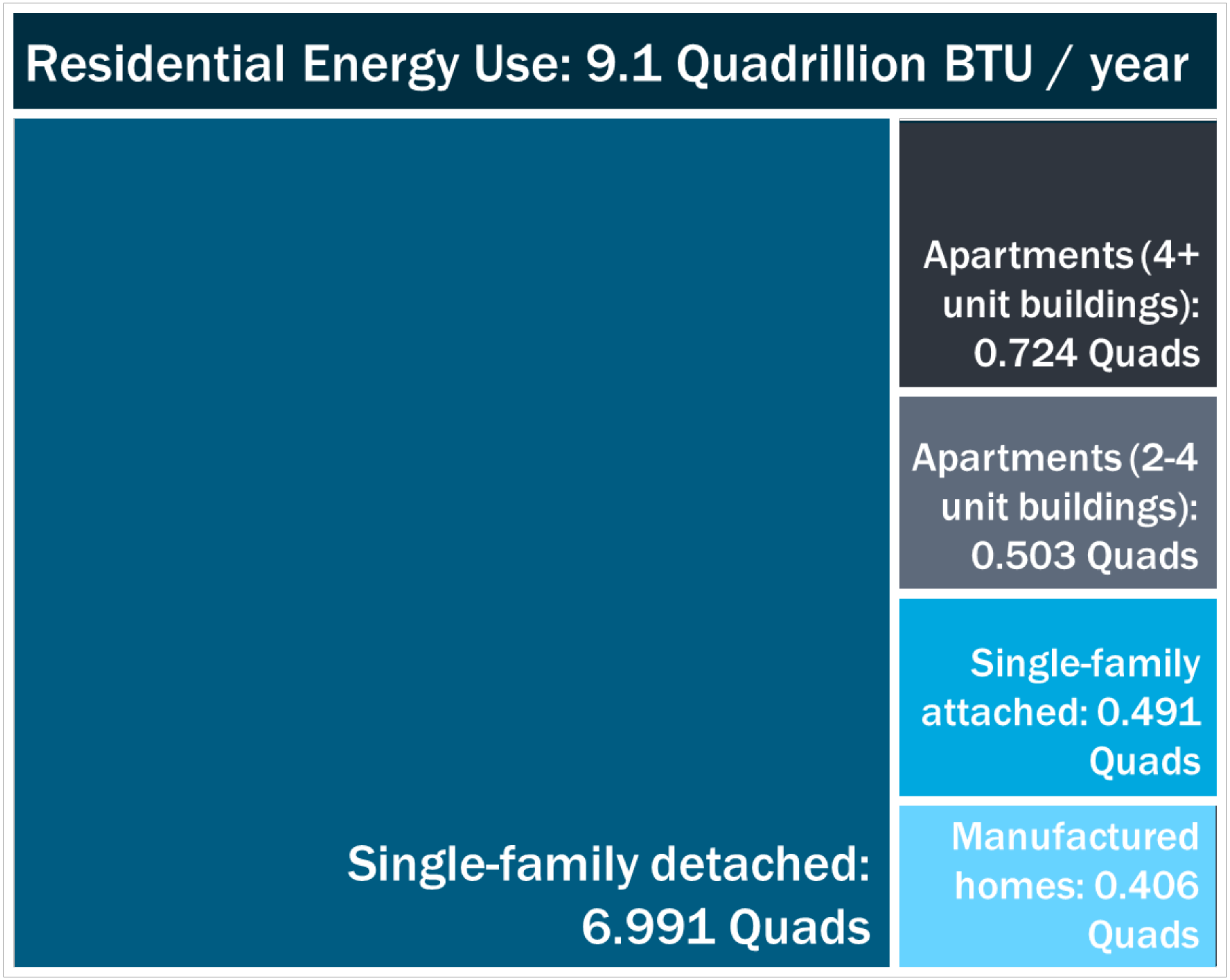
- Colorado will test new approaches to demand-side management (DSM), demand response, and renewable energy integration in existing residential buildings that ensure customer affordability.
- Data and analysis will inform future state intervention in regulatory, utility demand side management, and generation resource planning.
- The project will support market penetration energy efficiency and renewable energy into Colorado's over 2.3M residential households.

# U.S. Housing by Type & Ownership



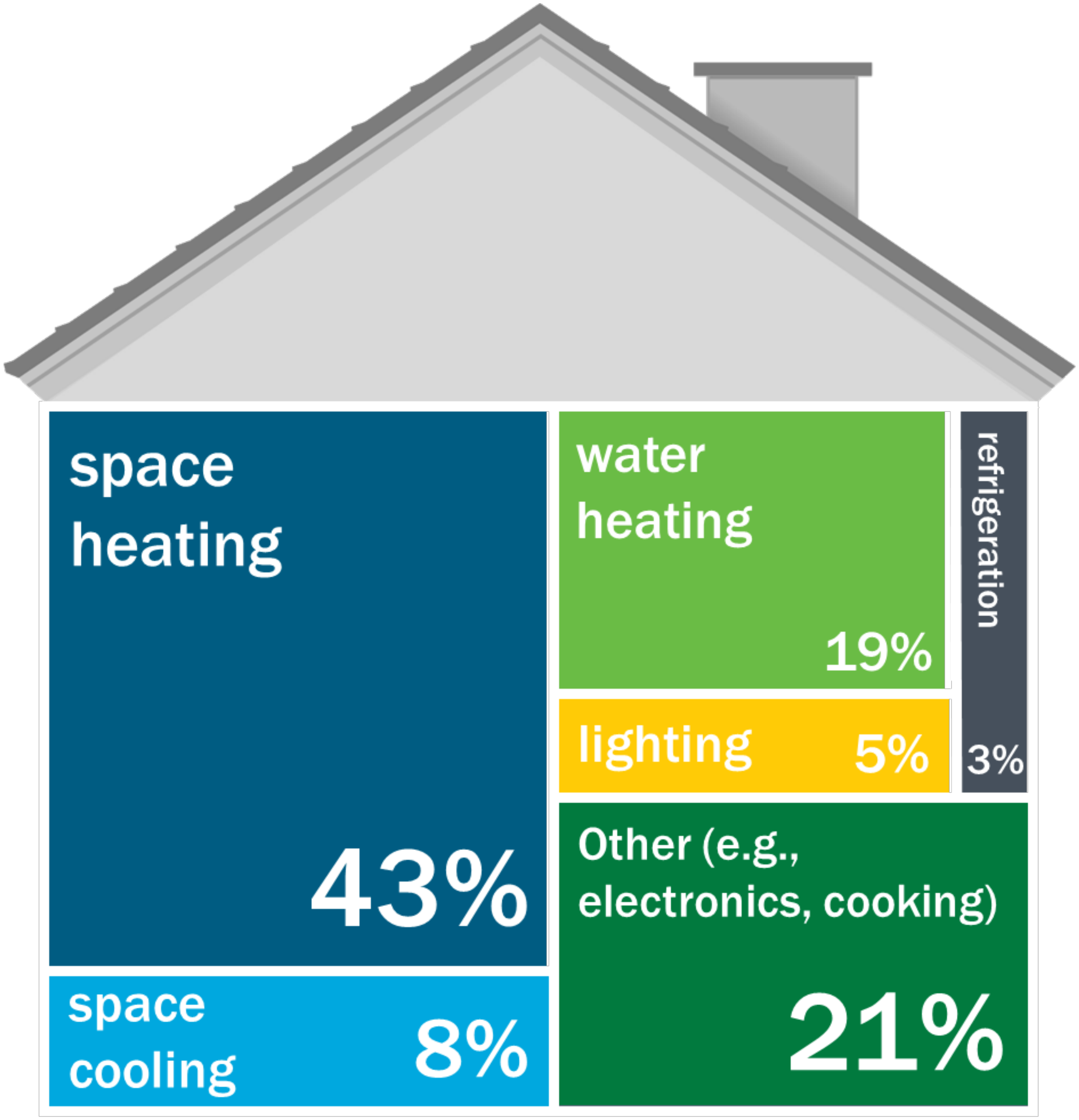

Source: U.S. Department of Energy (2020)

# U.S. Housing by Type & Energy Use



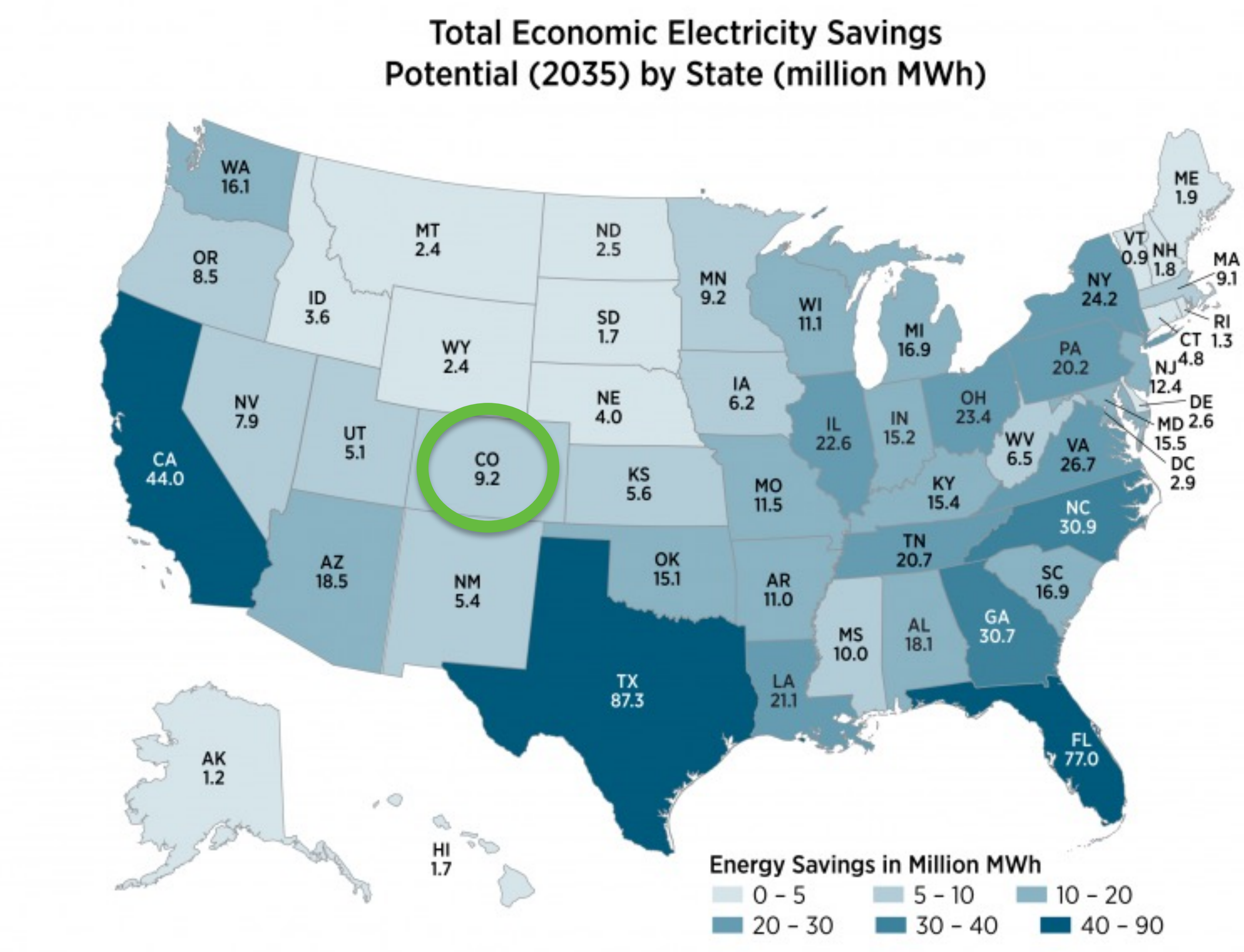

Source: U.S. Department of Energy (2020)

# Residential Energy Facts




Source: U.S. Energy Information Administration (2020)

# Unlocking EE Potential




Source: EPRI, 2017. State-Level Electric Energy Efficiency Potential Estimates

# Key Findings

# Decarbonization at a District Scale: Colorado Residential Retrofit Energy District (CoRRED)

U.S. Dept. of Energy State Energy Program Webinar

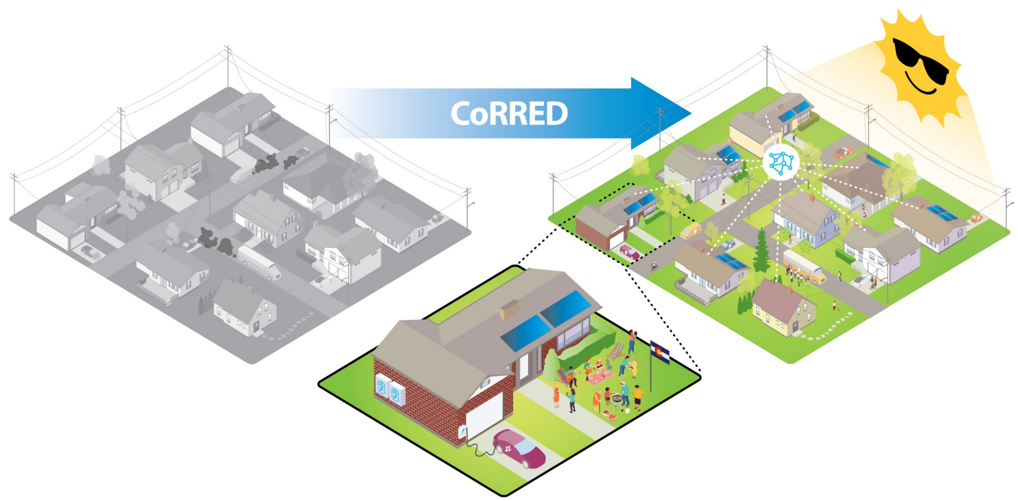
July 20, 2021

# Outline

1. Project Background & Objectives
2. Modeling Framework & Analysis Approach
3. Retrofit Impacts on:
    - Utility Bills, Load Profiles, & Carbon Emissions
    - Distribution System
4. Conclusions & Future Work

# 1. Project Background & Objectives

- Funded by DOE State Energy Program
- 3-year scoping study to explore how to design a retrofit energy district
- Address growing list of technical, regulatory, financial questions
- Replicable, collaborative model that can be broadly applied




1. Articulate research questions and achieve collaboration alignment → 2. Develop range of promising solutions using advanced energy system modeling software → 3. Develop experimental design to address key questions and challenges → 4. Explore opportunities and partners to execute Phase II: Implementation

# What is an energy district?

A system of grid-interactive, efficient buildings (GEBs) that incorporates:

- distributed energy resources,
- energy-efficiency (EE) technologies,
- energy storage, and
- advanced building controls

to optimize energy load and performance.

# Timely project for Colorado

Aggressive climate goals:

- State committed to reduce GHG emissions by 50% by 2030 and 90% by 2050 (relative to 2005 levels.)
- Xcel Energy, our State's largest utility, has committed to 80% carbon-free electricity system by 2030 and 100% by 2050.

We expect that distributed energy resources (DERs) and GEB will play essential roles in achieving this carbon-neutral electricity system in Colorado.

# Research Question

What are the most promising *combinations* of conventional EE measures and advanced DER technologies to implement in a community-scale retrofit program that provide the greatest system-level benefits, including:

- Demand flexibility for utility planning and operation,
- Value identification and optimization for residents and utilities, and
- Resident and utility satisfaction and engagement?

*Photo: Dennis Schroeder / NREL*

*Photo: Ron Coppock Photography Inc.*

*Photo: Dennis Schroeder / NREL*

*Photo: Angela Costanzo / NREL*

*Photo: Ed Hancock/ NREL*

## NREL’s role in project:

- Simulation study using building and grid modeling tools
- Collaborate with team on experimental plan based on the results.

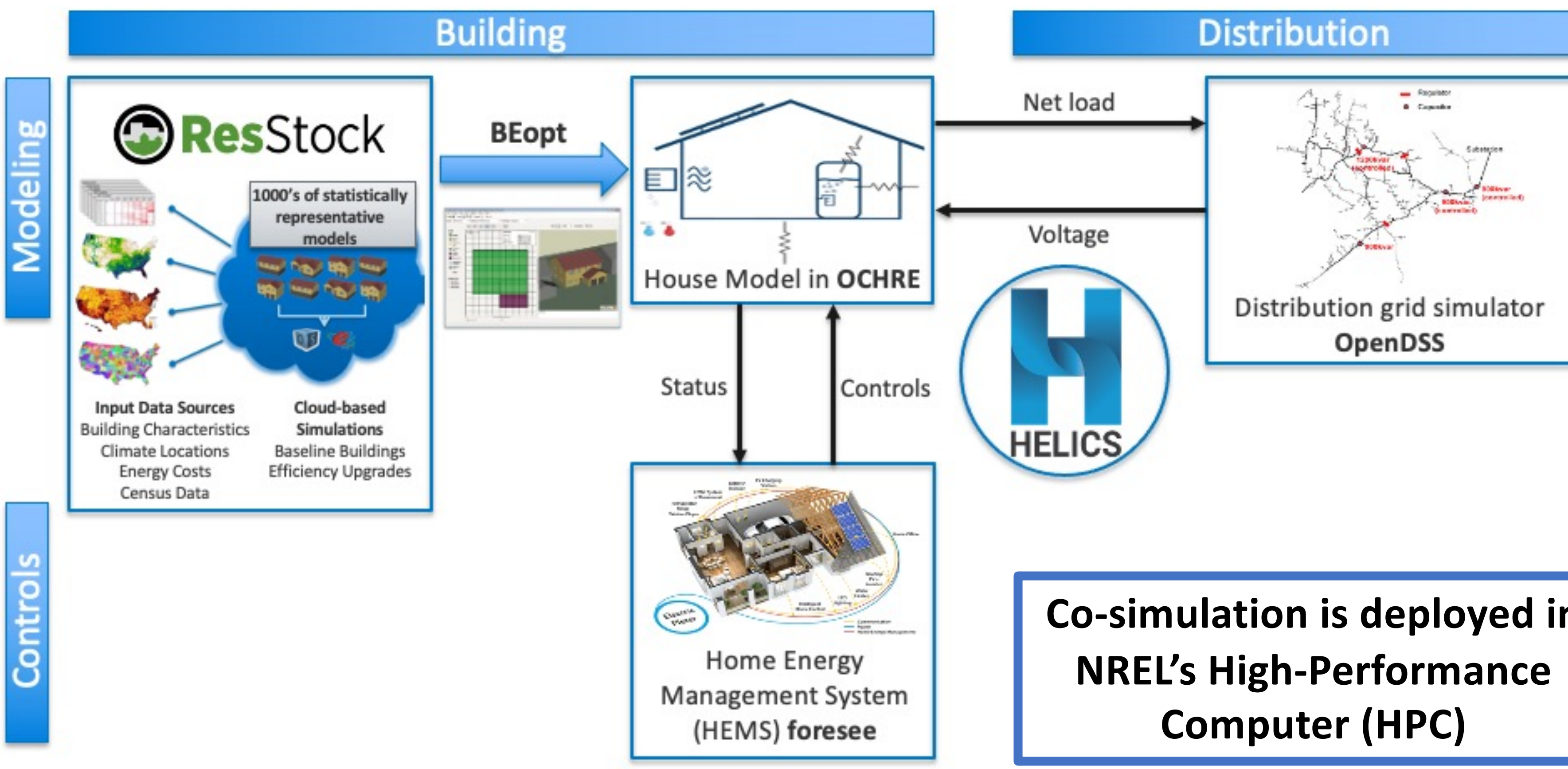
## Modeling effort objectives

Characterize the grid flexibility potential and limitations for a range of retrofit scenarios incorporating conventional EE and more advanced DER technologies.

Build out a functional and robust co-simulation platform that can accommodate additional technologies and scenario studies.

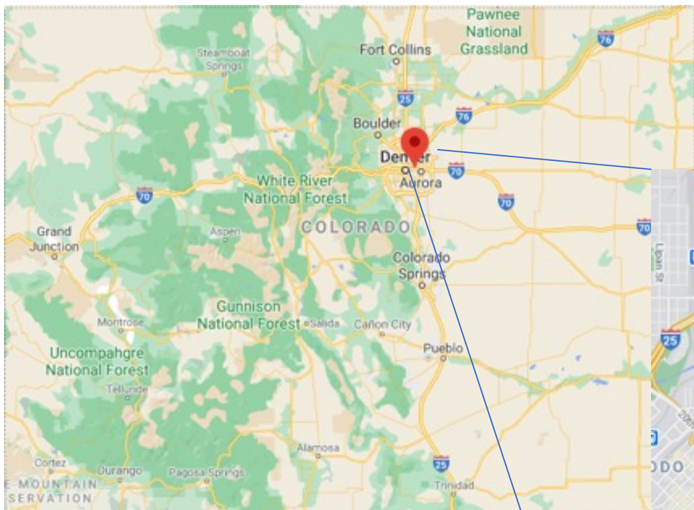
# 2. Modeling Framework & Analysis Approach

# Co-simulation Framework

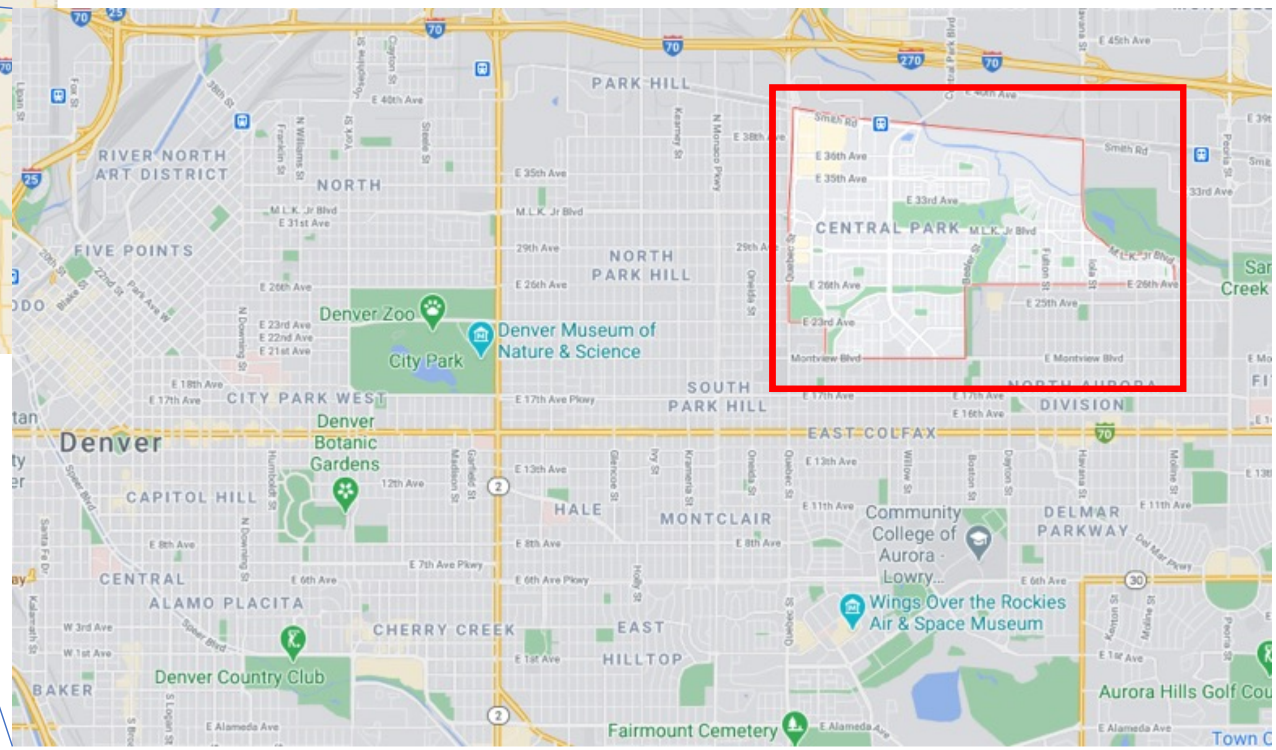



**Co-simulation is deployed in NREL's High-Performance Computer (HPC)**

# “Inspirational” location

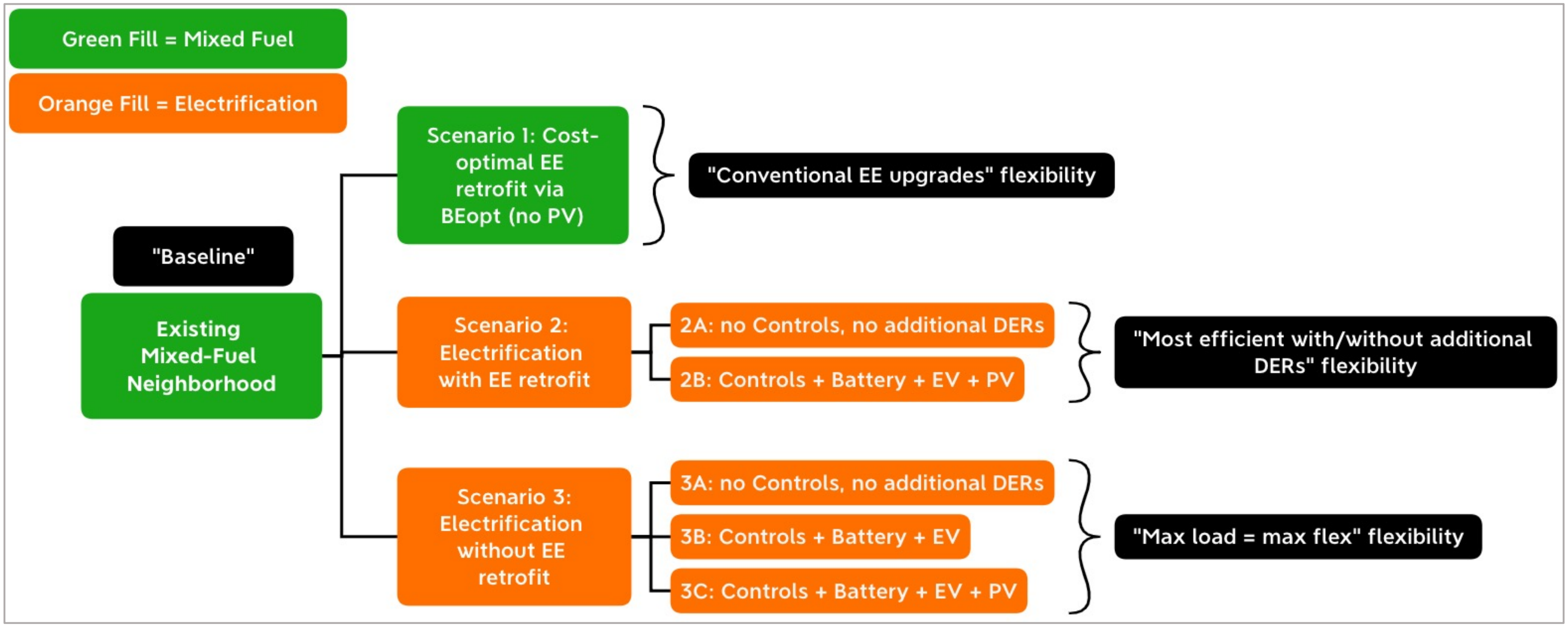



Central Park neighborhood in Denver, Colorado




Used as basis for synthetic community used in modeling

# Scenarios Modeled



<table>
<tr><th colspan="7">RETROFIT MEASURES SELECTED</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Scenario 1: Energy Efficiency (EE) Retrofit</th><th colspan="2">Scenario 2: Electrification with EE</th><th colspan="3">Scenario 3: Electrification without EE</th></tr>
<tr><th>2A</th><th>2B</th><th>3A</th><th>3B</th><th>3C</th></tr>
<tr><td>Attic Insulation</td><td colspan="3">R-49</td><td colspan="3">-</td></tr>
<tr><td>Basement Insulation</td><td colspan="3">R-30</td><td colspan="3">-</td></tr>
<tr><td>Air Sealing</td><td colspan="3">Reduce infiltration by 30% (each home starting at different $ACH_{50}$ level)</td><td colspan="3">-</td></tr>
<tr><td>Heating</td><td>98% AFUE gas furnace</td><td colspan="2" rowspan="2">ASHP, SEER 22 HSPF 10.0</td><td colspan="3" rowspan="2">ASHP, SEER 13 HSPF 8.2</td></tr>
<tr><td>Cooling</td><td>SEER 17 central AC</td></tr>
<tr><td>Domestic Hot Water</td><td>Gas standard, UEF 0.60</td><td colspan="2">HPWH, UEF 3.45</td><td colspan="3">Electric resistance standard</td></tr>
<tr><td>Lighting</td><td colspan="3">Replace with 100% LED</td><td colspan="3">-</td></tr>
<tr><td>Major Appliances</td><td colspan="3">Replace with ENERGY STAR</td><td colspan="3">Replace gas appliances with standard electric</td></tr>
<tr><td>Photovoltaics (PV)</td><td colspan="2">-</td><td>Maximized, limited by roof area or 120% rule</td><td colspan="2">-</td><td>Maximized, limited by roof area or 120% rule</td></tr>
<tr><td>Battery</td><td colspan="2">-</td><td>6kWh</td><td>-</td><td colspan="2">6kWh</td></tr>
<tr><td>Electric Vehicle (EV)</td><td colspan="2">-</td><td>Yes</td><td>-</td><td colspan="2">Yes</td></tr>
<tr><td>Controls</td><td colspan="2">-</td><td>HEMS</td><td>-</td><td colspan="2">HEMS</td></tr>
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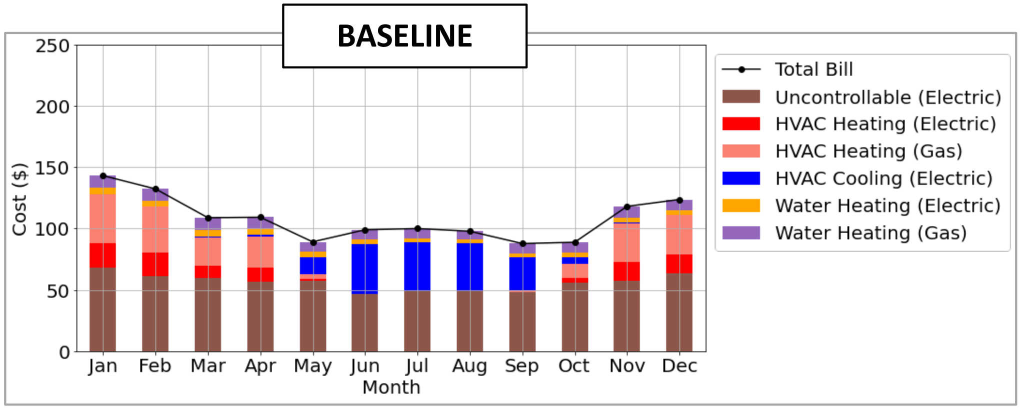
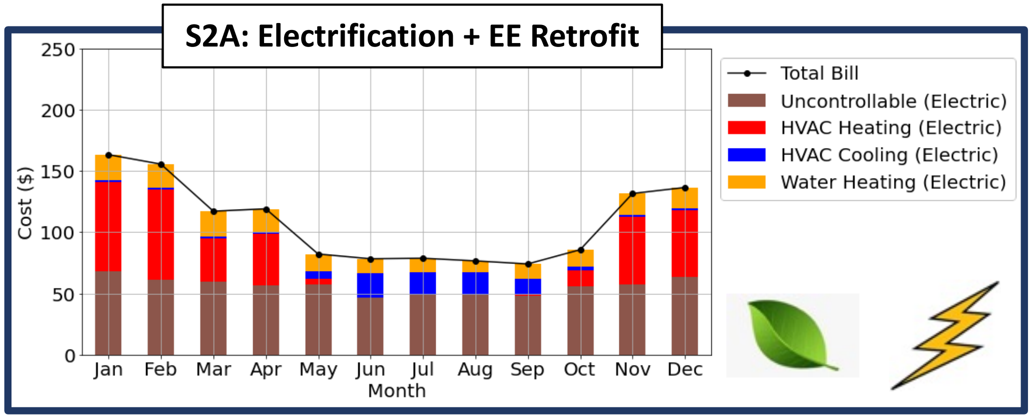
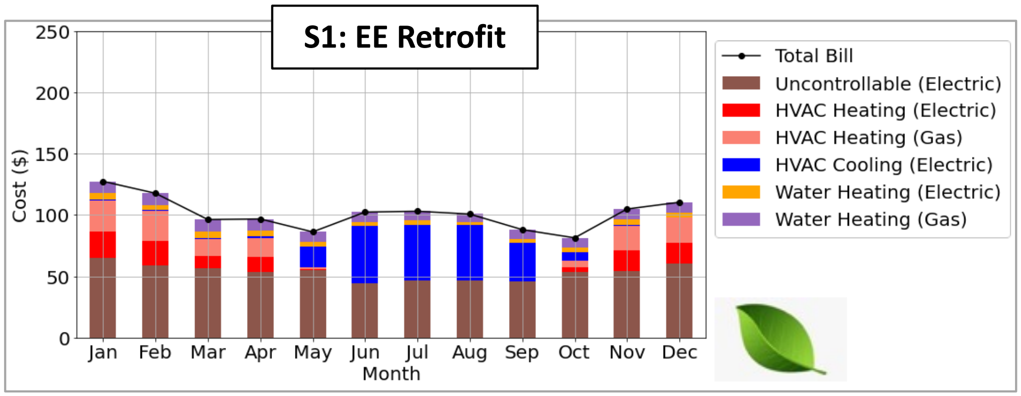
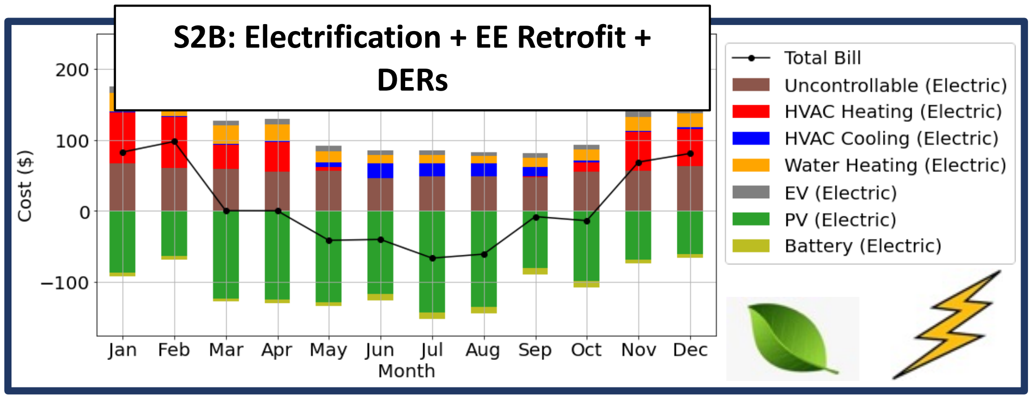
3. Retrofit Impacts on:
    - Energy, Load Profiles, & Carbon Emissions
    - Distribution System

# Efficient Electrification: Utility Bills

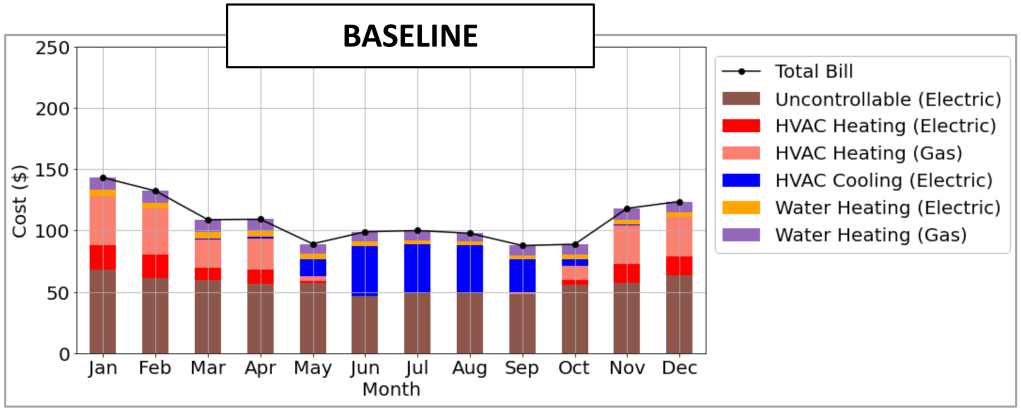


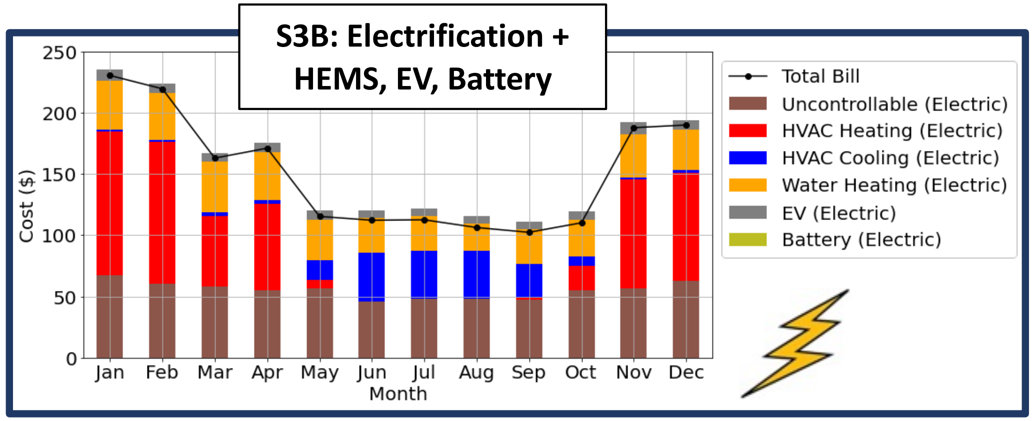



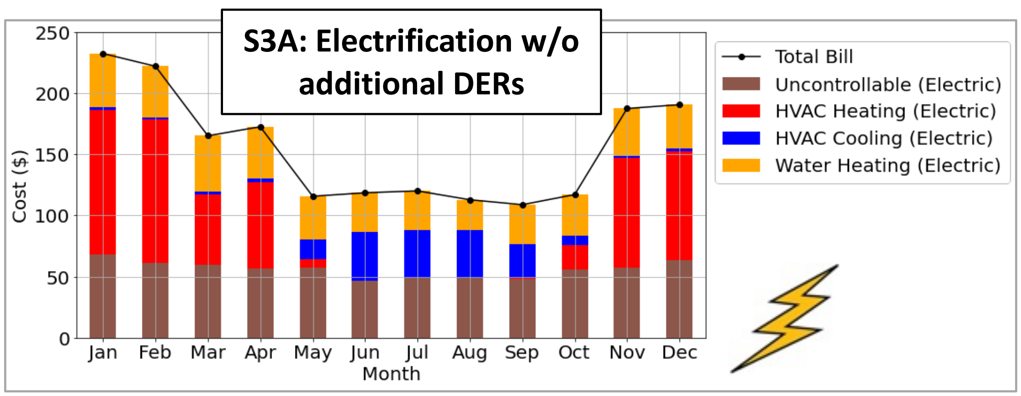



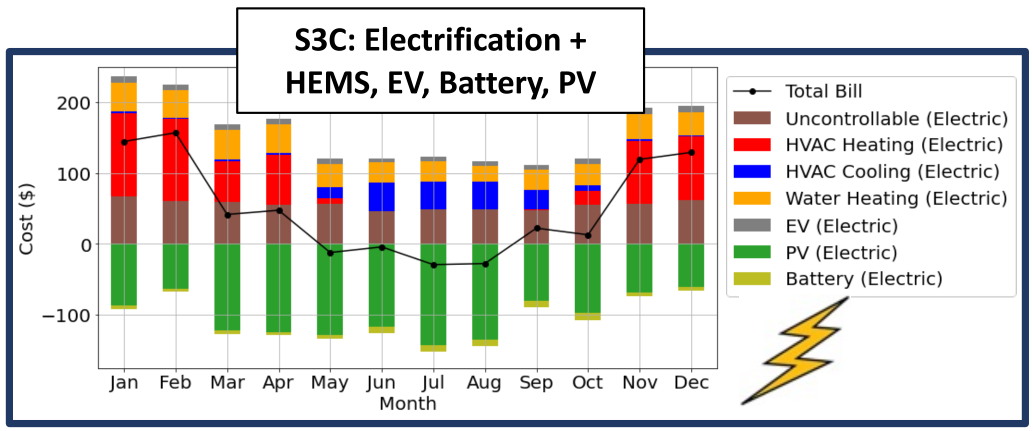



# Electrification Without Efficiency: Utility Bills

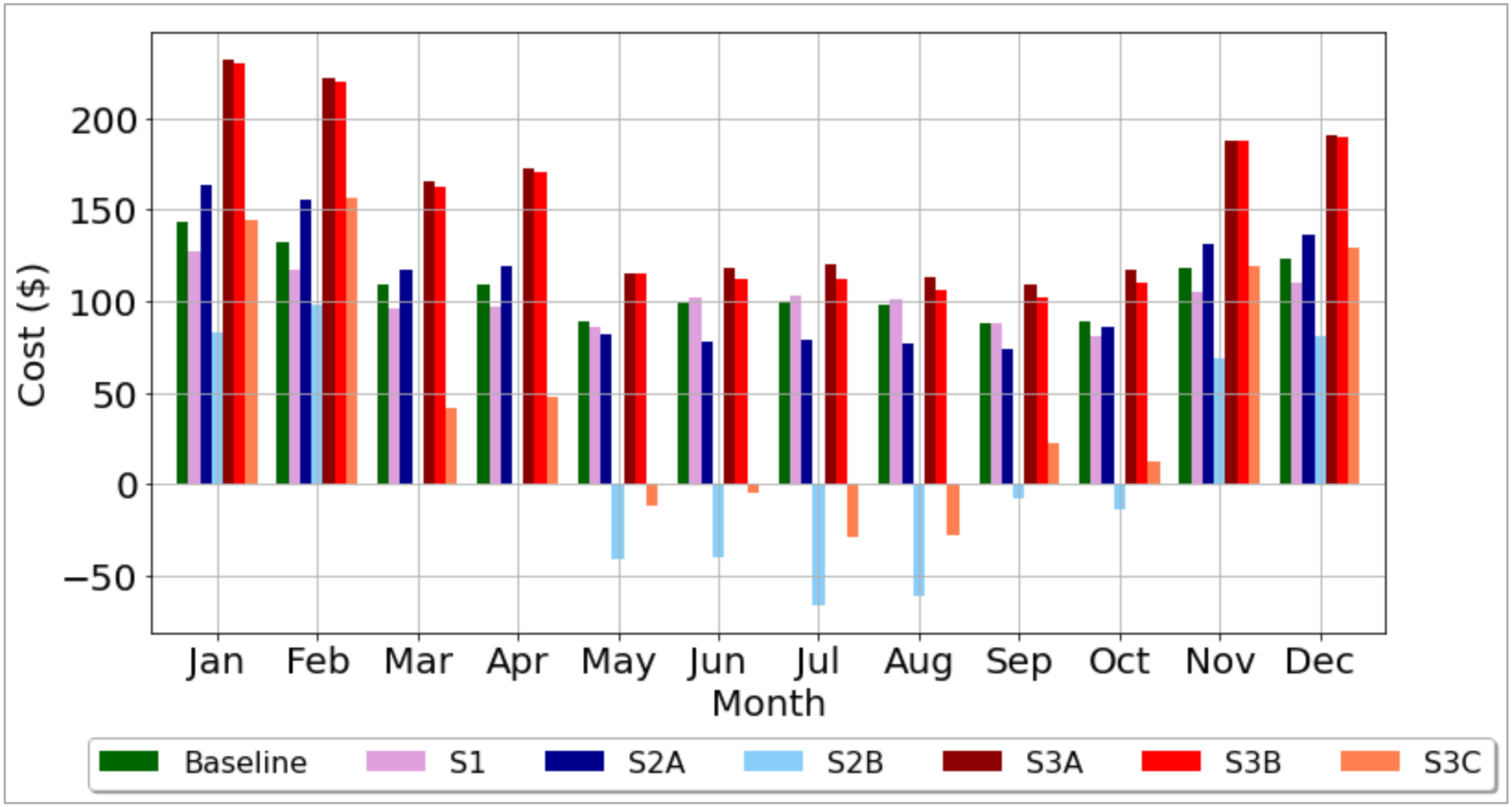


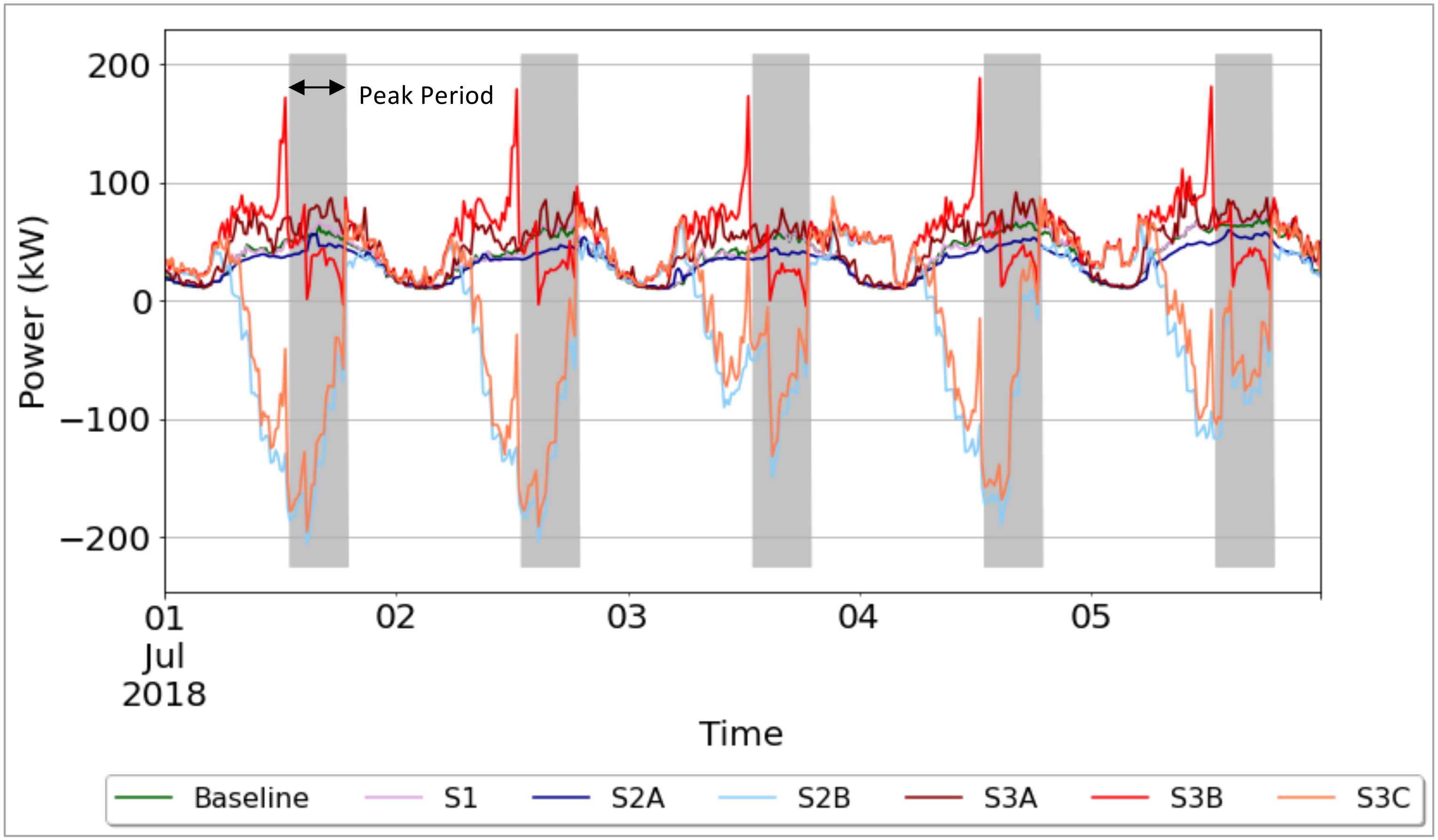



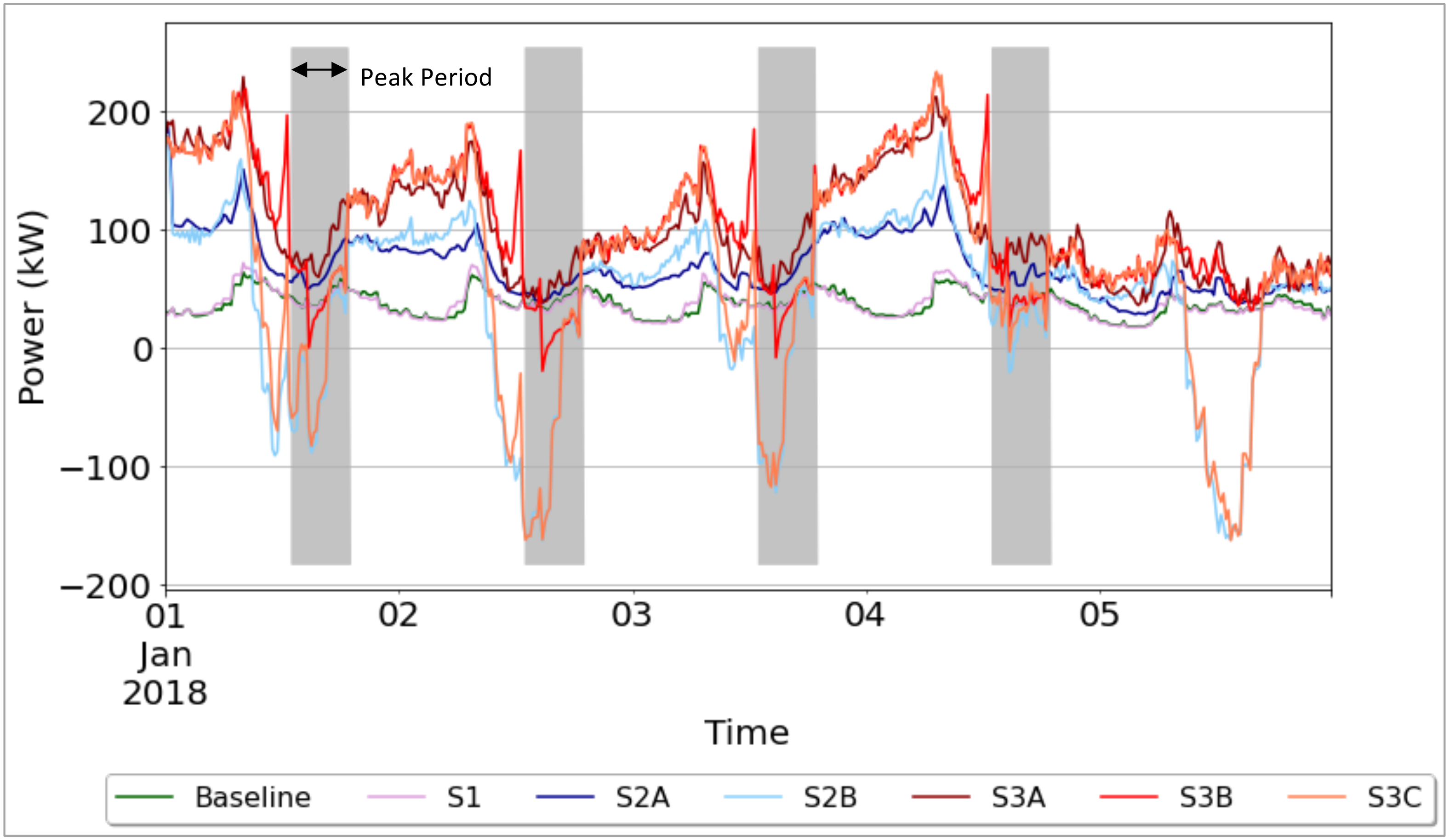
# Average Utility Bills Across All 3 Scenarios



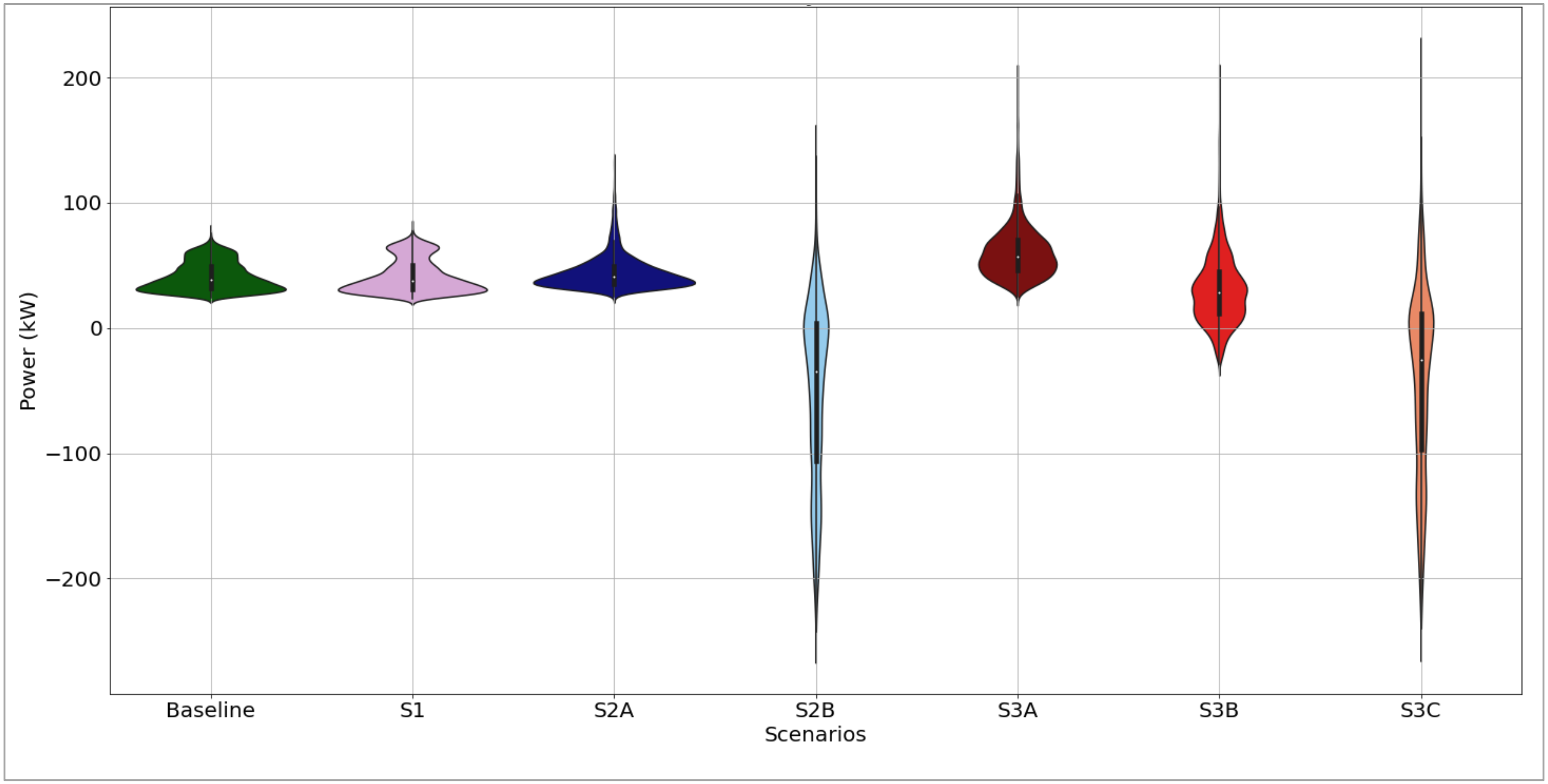
# Summer Load Profile for Community



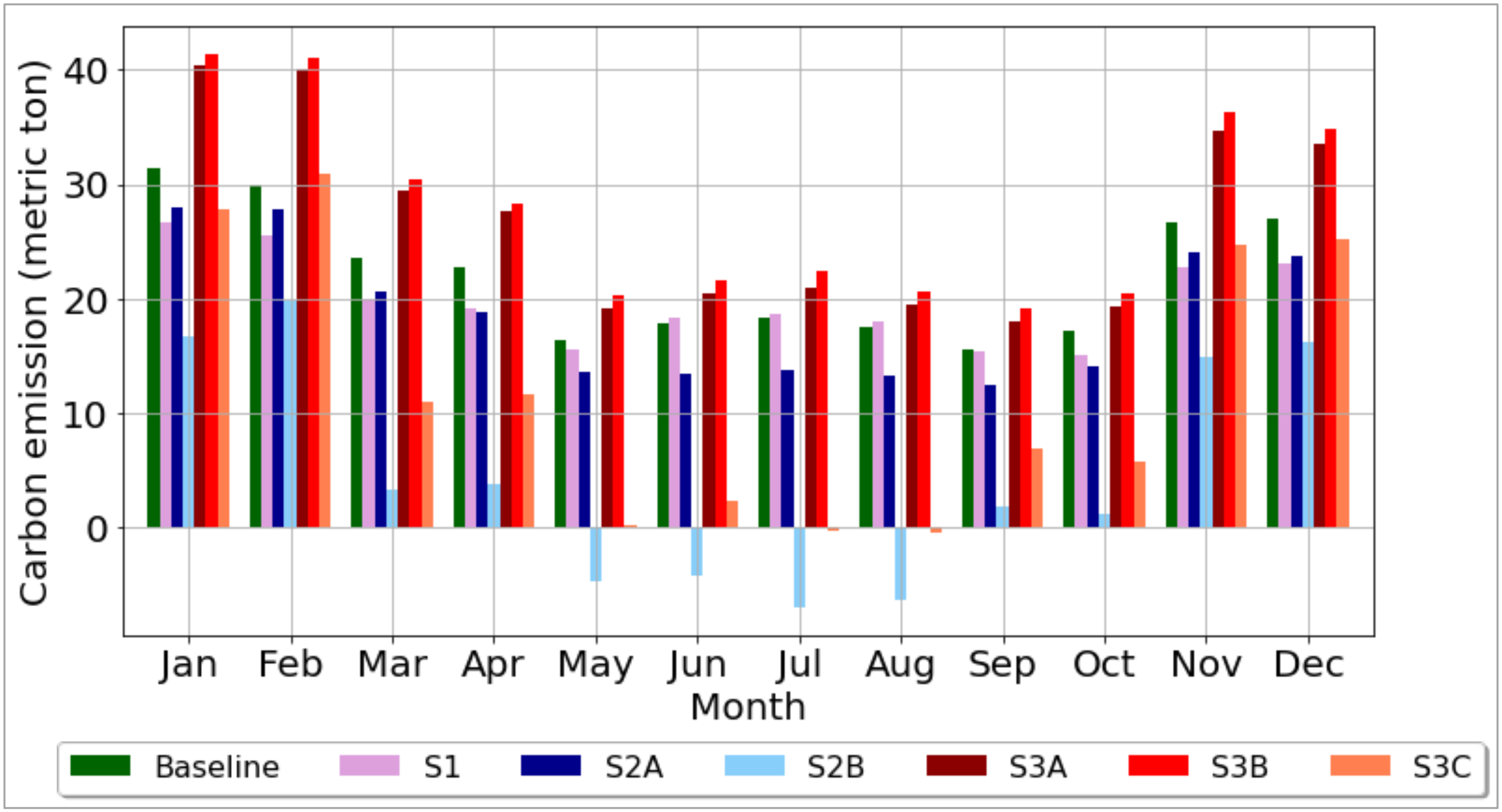
# Winter Load Profile for Community



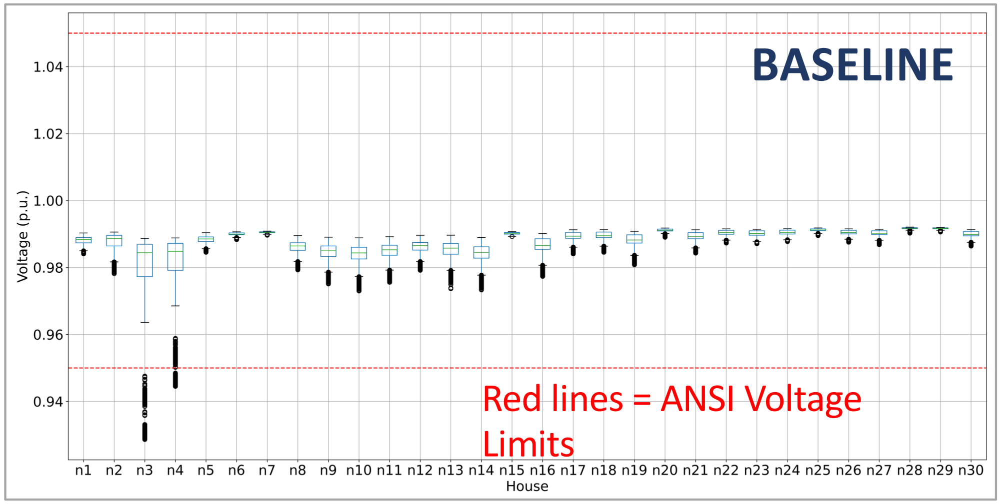
# Community Load Distribution During Peak Hours

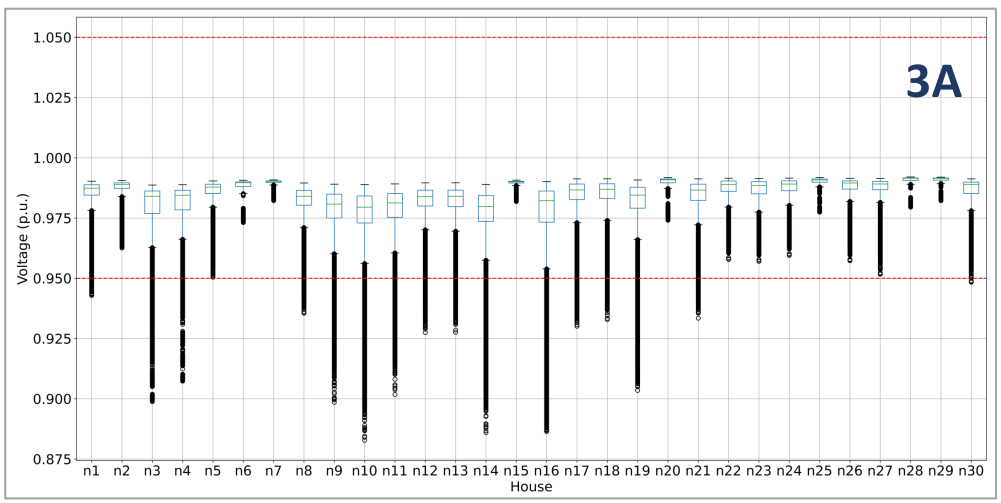


# Comparison of Carbon Emissions

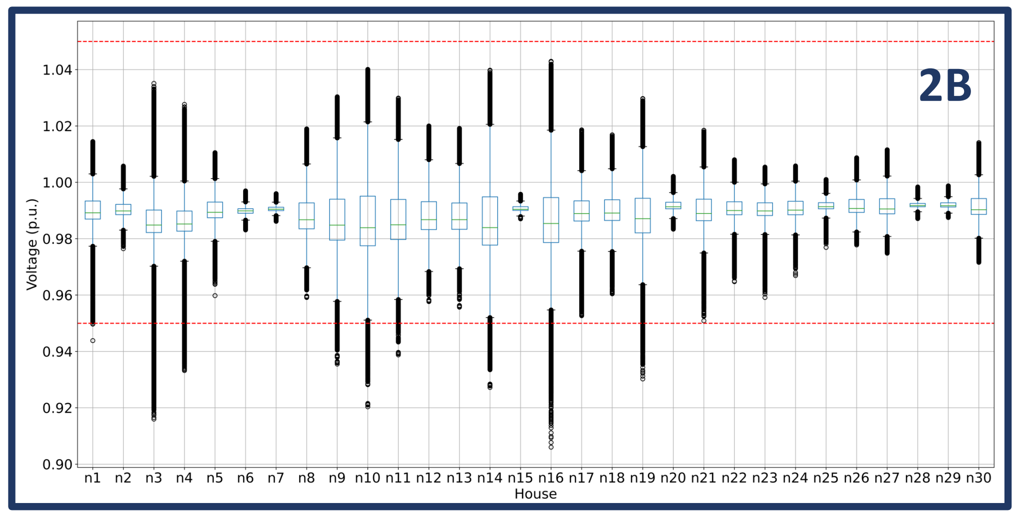


# House-level Voltage Profiles




**Electrification without Efficiency**

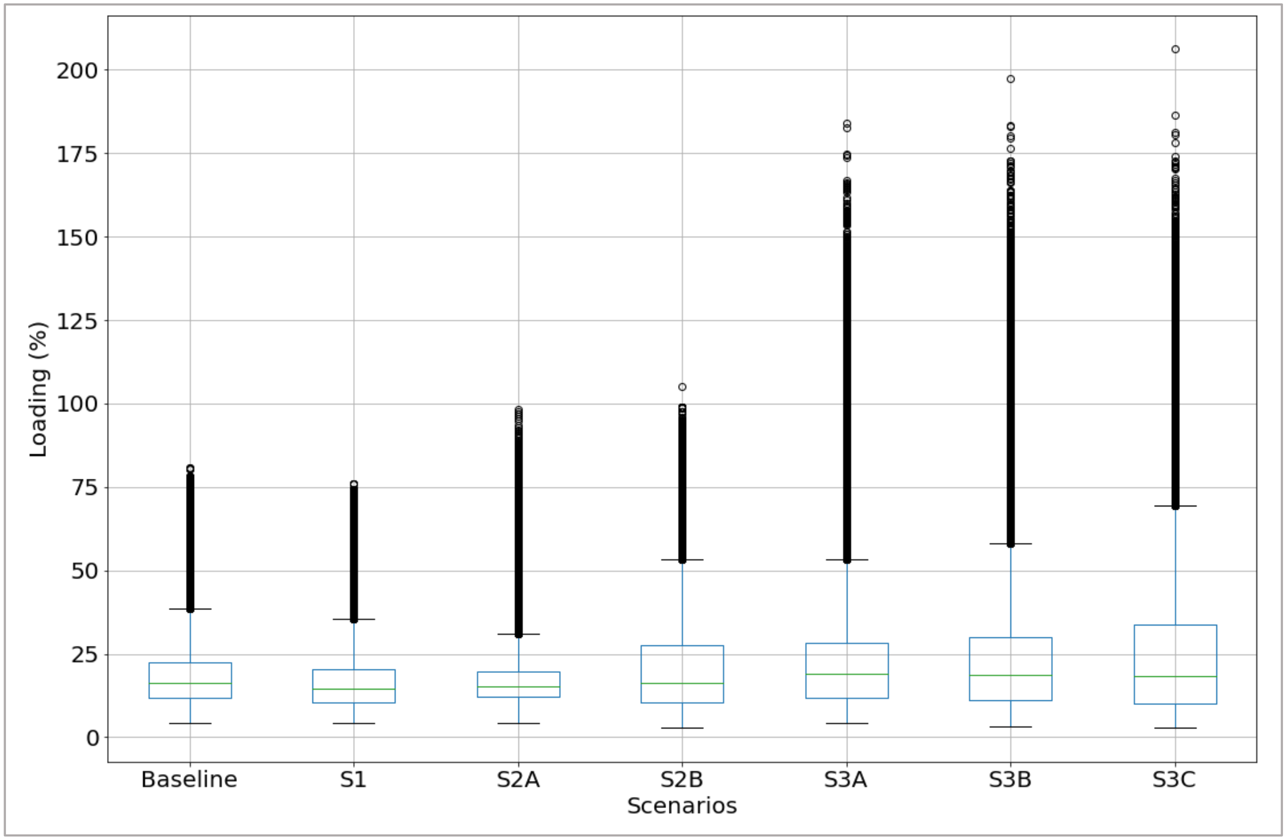



**Electrification with Efficiency + DERs**

# Transformer loading

$$Transformer\ Loading\ (\%) = \frac{Demand\ kVA}{Transformer\ rated\ kVA} \times 100\ \%$$

- Average transformer loading increased by 80-90% in Scenario 3 compared to baseline scenario
- Lower transformer loading in Scenario 2 than Scenario 3



# 4. Conclusions & Future Work

| Scenario | Electrification | Energy Efficiency (EE) | HEMS | Battery | EV | PV | Key Results |
|---|---|---|---|---|---|---|---|
| **1** | | X | | | | | • ~15% decrease in winter energy use from pre-retrofit, largely due to more efficient heating equipment. |
| **2A** | X | X | | | | | • Efficiency improvements result in source energy savings over Baseline or Scenario 1 (despite electrification).<br>• Utility bill costs are similar to Baseline (because electricity is relatively more expensive than natural gas, on a per-unit energy basis). |
| **2B** | X | X | X | X | X | X | • Lowest source energy use of any scenario.<br>• Lowest carbon emissions of any scenario.<br>• EVs represent a substantial community load (higher than space cooling) despite its adoption in only one-third of homes.<br>• Although the battery has a small net positive load on the homes due to roundtrip efficiency losses, it contributes to energy bill savings because it enables arbitrage via load shifting.<br>• Utility bill increase is entirely attributable to EV addition, so the average homeowner actually saves money over the Baseline. (EV charging costs less than equivalent gasoline per mile driven.)<br>• PV sizing based on pre-retrofit energy bills, so maximum size allowable is insufficient to meet electrification demands. Community is a slight net consumer of electricity annually but there are periods of net production. |
| **3A** | X | | | | | | • Utility bills increase by 40% for the average homeowner. |
| **3B** | X | | X | X | X | | • Highest source energy use of any scenario.<br>• Highest carbon emissions of any scenario.<br>• Slightly lower bills than 3A despite the overall energy use increase because of HEMS and battery. |
| **3C** | X | | X | X | X | X | • Addition of PV saves homeowners 60% relative to 3B, but community is a net consumer of electricity annually.<br>• PV sizing based on pre-retrofit energy bills, so maximum size allowable is insufficient to meet electrification demands. |

# Highlights

- **Electrification can be achieved without negatively impacting the monthly utility bill**
  - Scenario 2B shows overall lower source energy use, lower carbon emissions, and lower utility bills.
  - Energy efficiency, electrification, and DERs can and should go hand-in-hand.

- **Electrification of a neighborhood increases the system load and thus creates stress in the distribution system.**
  - Inefficient electrification could cause substantial damage to the distribution transformers if a neighborhood is not designed to handle the larger loads.

- **We developed and demonstrated an analysis framework and a functional co-simulation platform for this type of analysis.**
  - But, to obtain more detailed and nuanced results that realistically predict electrification scenarios it is necessary to model the actual buildings and electrical infrastructure that serves those buildings.

# Future Work

- **How to tackle upfront costs of electrification**

  Long payback periods are not appealing to most homeowners. Adding DERs (especially PV) as part of efficient electrification produces much bigger savings than efficient electrification without DERs.

- **PV Sizing**

  120% limit is based on past utility bills. How should utilities address the expected load increase in electrification retrofits, or even just EV acquisition?

- **Looking forward: Load management when broader system electrifies**

  Once entire communities electrify and the community peak shifts to a winter peak, what are the implications for the load-shifting capabilities of PV? (peak occurs in morning) How does this impact the economics of home batteries?

- **Prioritizing carbon reduction**

  What if HEMS optimized based on minimizing carbon emissions? How would that impact other benefits? Can tariffs be structured to incentivize this?

# Context

# Putting the results into perspective

How does this project and these results support the mission of your organization, agency, utility?

# Q&A

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