

Taking Down Barriers – How an Innovative Solution is Enabling Cities and Utilities to Jointly Decarbonize Existing Homes

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ABSTRACT

Retrofitting the single-family residential sector for decarbonization has been challenging due to the sector's fragmented owner base and low returns on investments. And yet, this is a critical sector to address if cities, states, and utilities are to meet their decarbonization goals. Single-family homes represent 63% of United States (US) building stock by area and 47% of US building energy use – the largest among all US building types by far¹. With electricity generation increasingly moving to clean, renewable sources, electrification and efficiency upgrades can dramatically reduce carbon emissions in single-family homes.

Barriers to scaling-up residential energy retrofits include, demonstrating the financial benefits of electrification upgrades where electricity rates are higher compared to natural gas, developing customized analysis for individual homes at scale, and engaging and informing homeowners.

This paper describes a two-pronged approach to overcoming these challenges featuring a portfolio-scale dashboard for the city or utility, and a web-based interface for homeowners. This approach is implemented through an innovative new software application called XeroHome™. XeroHome combines publicly available data on homes with web-based building energy modeling to conduct individually customized home energy analysis. It generates recommendations for energy efficiency and electrification packages without on-site energy audits. Through example implementations, this paper shows how the approach can be a strategic tool in the hands of cities and utilities, enabling them to sculpt residential retrofit programs according to local needs and scale up carbon reduction from the existing building stock.

The Path to Decarbonization Runs Through Our Homes

As part of the 2021 White House roundtable on building efficiency, United States (US) Secretary of Energy Jennifer M. Granholm noted that “America's path to a net-zero carbon economy runs straight through our buildings.” (US DOE 2021) We would argue that more specifically, this path runs through our existing single-family residential buildings. Single-family homes represent 47% of the total energy use in the entire US building sector. Energy use in single family homes is more than six times greater than that of the next largest building type – office buildings (Figure 1, left side chart). This is because single-family homes make up the largest percentage of the overall building stock area (Figure 1, right side chart).

¹ See Figure 1 created with data from US Energy Information Administration (EIA)

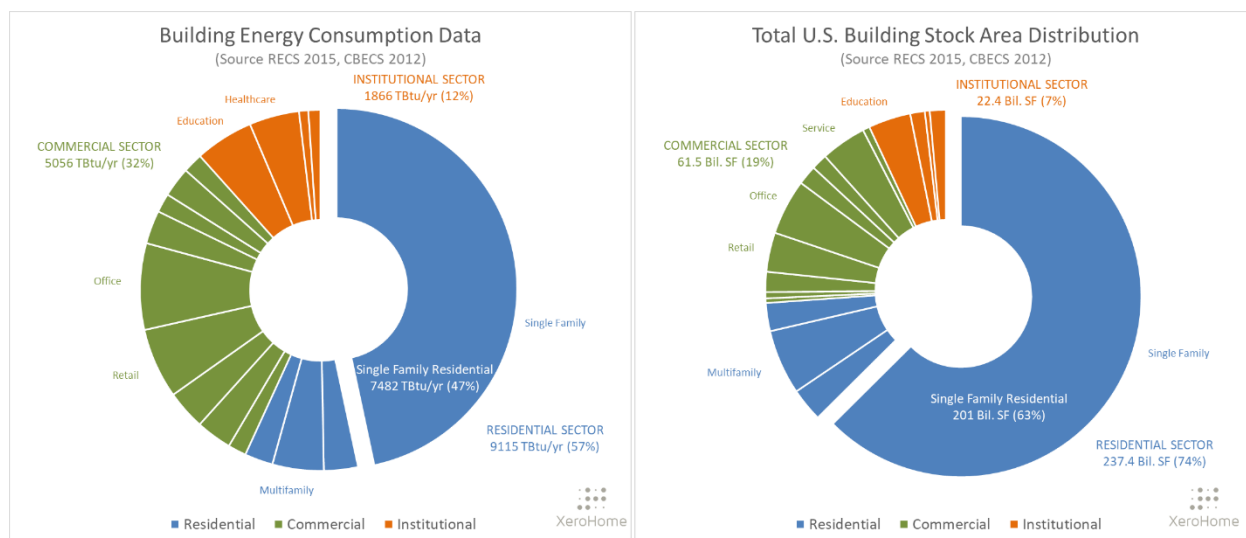


Figure 1: Total US building energy consumption and stock area distribution. *Source:* US EIA – Residential Energy Consumption Survey (US EIA. 2015) and Commercial Buildings Energy Consumption Survey (US EIA 2012).

As renewable electricity generation rapidly ramps up, electrification of heating in homes is widely considered the pathway to large-scale decarbonization of existing buildings. This involves replacing natural-gas-based heating equipment with high-efficiency electric heat pumps. In a state like California, where nearly 90 percent of homes use natural gas for space heating, water heating, or both (Hopkins, et al. 2018), building electrification is the lowest-cost path to reducing large-scale greenhouse gas (GHG) emissions (Mahone, et al. 2019).

Although an expensive upgrade, rebates and financing programs from utilities, state agencies, and local governments are bringing electrification within reach for many homeowners. Additionally, when electrification upgrades are combined (or packaged) with other home efficiency upgrades, they can offer financially compelling solutions.

Perspectives of Key Stakeholders for Implementation

Implementation of residential energy retrofits happens at the local jurisdiction level. Besides the homeowners themselves, cities and their energy utilities are the key stakeholders. Jurisdictions are responsible for setting local carbon reduction targets with climate action plans, developing local policies such as building codes that extend above state minimums, implementing energy efficiency programs, and permitting and code enforcement for projects as they occur. Utilities engage through incentive programs to offset costs and by responding to changing infrastructure needs for the homes, neighborhood, and the larger grid.

The Perspective of Cities and Utilities

Benefits. Cities and utilities across the country are setting ambitious decarbonization goals. As Figure 1 illustrates, reducing energy use in single-family homes would be a highly impactful pathway to achieving decarbonization goals.

Challenges. Implementing cost-effective residential energy efficiency programs is growing increasingly challenging. Getting buy-in from each homeowner incurs a higher administrative cost when compared to the more economical savings possible from the Commercial and Industrial sectors. Figure 2, created by EIA in 2020 with data from the Annual Electric Power Industry Report shows that the residential sector had the highest cost of saved energy² in each of the five years, averaging 3.4 cents per kilowatt-hour (kWh) saved on a lifecycle basis in 2018 (US EIA, 2020). This problem is exacerbated in single-family homes compared to multifamily homes because of greater fragmentation of ownership. Single-family homes represent a significant portion of the carbon emission reductions still on the table.

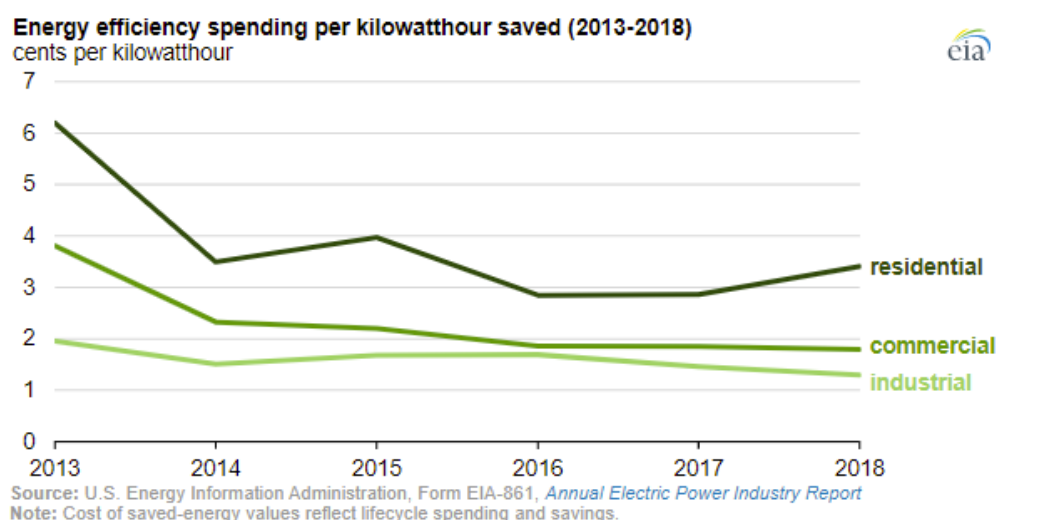


Figure 2. The relative cost of energy efficiency spending per kWh saved. *Source:* US EIA 2020.

The Perspective of Homeowners

Benefits. A home represents both a shelter and a financial asset to a homeowner. There are several compelling reasons for homeowners to invest in efficiency upgrades. Several studies — (Fuller, et al. 2010), (Hoffmeyer 2016), (Cluett and Amann 2014), (Amann, Srivastava and Henner 2021) — indicate that homeowners look for value in one or more of the following categories when deciding to invest in energy upgrades.

1. Financial benefit: A reduction in utility bills or an improvement in the home's market value because of the upgrade. Homeowners may weigh the cost of installing an energy upgrade against the cumulative savings in utility bills over a reasonable timespan to determine if it is worth their consideration.
2. Health, safety and comfort benefit: Better thermal comfort, or an improvement in indoor air quality. Homeowners may actively seek upgrades that can provide a healthier and more comfortable environment for their families.
3. Environmental benefit: Reduction in GHG emissions, often represented as an individual's carbon footprint. Homeowners may be motivated to reduce their carbon footprint and

² Cost of saved-energy values reflect lifecycle spending and savings

compare the environmental impact of a home energy upgrade to other actions, such as reducing gasoline-powered vehicle use, flying fewer miles on airplanes, or planting more trees.

Challenges. Calculating and communicating these benefits, especially financial benefits, is often challenging because a variety of factors impact the economic outcome of an electrification upgrade.

One key factor is that natural gas fuel rates are currently lower than electricity rates almost everywhere in the US. The left side chart in Figure 3 shows the range of residential utility cost data for electricity and natural gas across all 50 US states³ (each converted to \$/kBtu for comparison). The ratio of electricity to natural gas prices (right side chart) shows how much more expensive electricity is than natural gas. In most locations in the US, this ratio is between 3.1 and 4.3, but it can be as high as 6.3.

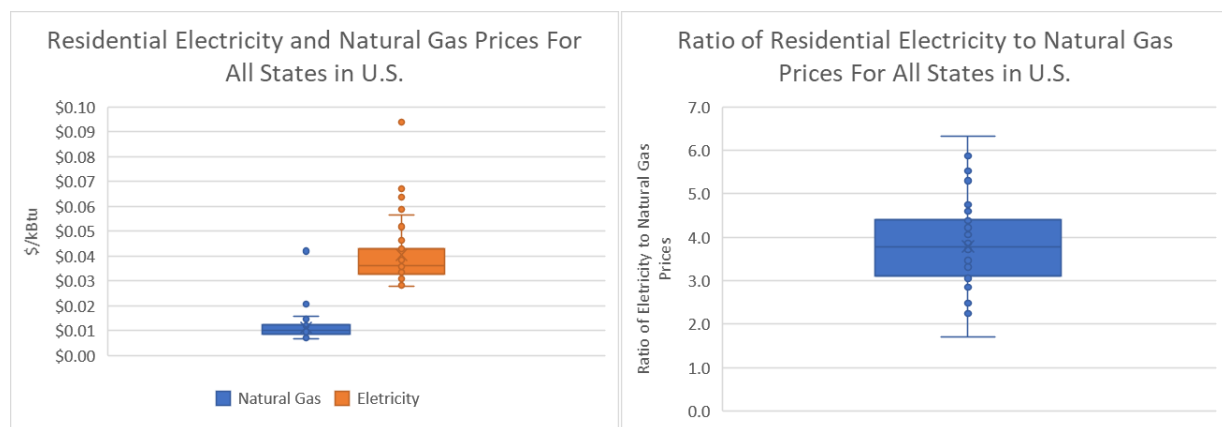


Figure 3: Residential electricity and natural gas prices by state and ratio of fuel costs – Derived from EIA database of natural gas and electricity prices. *Source:* (US. EIA 2020).

In places where electricity costs two to six times the cost of natural gas, an electrification upgrade offers very little financial benefit to the homeowner. A building electrification upgrade that can result in significant efficiency improvements as well as GHG emissions reductions, can also result in low overall utility bill savings, making it an unattractive prospect for the building owner motivated primarily by financial benefit. For example, heat pump water heaters can be up to three to four times more efficient than standard gas water heaters and are desirable from a decarbonization perspective. However, in a location where electricity costs four times more than natural gas, the higher efficiency may not result in combined (natural gas and electric) utility bill savings. In the case of an heating, ventilation, and air conditioning (HVAC) upgrade that replaces a traditional air conditioner and natural gas furnace for a home with a heat pump, the cost-effectiveness of the upgrade will depend on several factors – age and efficiency of existing equipment, existing home’s envelope condition and efficiency, local weather, and the cost of electricity and natural gas. The payback period can vary from one home to another based on

³ The data from US Energy Information Administration (EIA) database is for natural gas and electricity prices for 2019.

these factors, even in the same climate. In such cases, a heat pump upgrade may become a ‘stranded measure’⁴.

Thus, it is crucial to start with quality estimates of savings based on the specifics of each home. This ensures that the right upgrades are recommended to the homeowner. Since this answer can be specific to the unique conditions of a home and the applicable utility rates, the calculation must be customized for each home. To be a truly effective and scalable solution, this analysis can be provided without a traditional, in-person home energy assessment, which some homeowners may eschew due to scheduling barriers, cost, or lack of subsidized programs in the region.

Given these challenges, offering an approach that can achieve decarbonization for existing homes at scale, while benefiting cities, utilities, and homeowners, is a timely and beneficial solution to all stakeholders.

A Two-Pronged Approach for Cities and Utilities to Achieve Home Decarbonization at Scale

To overcome the challenges of scaling up residential retrofits, we propose a two-pronged approach for cities or utilities. In this approach, the city or utility first develop a portfolio-scale dashboard showing upgrade opportunities for all homes in their region. This information could then be strategically used to develop decarbonization policies and programs tailored to the region’s specific climate, utility rates, and building types. Next, the city or utility would make available a web-based interface where homeowners can easily identify opportunities to reduce their energy use and their home’s carbon footprint.

The implementation of this approach has been made possible with the development of a new, innovative building energy modeling (BEM)-based application called XeroHome™ (Saxena, Coffey, et al. 2018). XeroHome takes publicly available data on homes and combines it with web-based building energy modeling to conduct customized home energy analysis for individual homes. This can be expanded to a portfolio-scale analysis visualized over a dashboard for cities and utilities.

XeroHome generates recommendations for energy efficiency and electrification packages without on-site energy audits. This makes it possible to scale the development of quality estimates of energy savings and upgrade recommendations for all homes in a region. EnergyPlus™, the building energy simulation tool developed by the US Department of Energy (DOE), powers the building energy models for individual homes in XeroHome. These are first developed using publicly available information, such as property assessment data, building permits and GIS-based 3D geometry. These models can then be accessed on a web platform and improved with a virtual home energy audit performed by homeowners. Homeowners access their home’s energy model over XeroHome’s web-based user interface, while utilities and cities access the same data aggregated for all homes in the region through a dashboard.

As a whole-building energy modeling-based application, XeroHome can identify specific combinations of upgrades that are cost-effective. Using this, the city or utility can strategically develop packages that combine electrification upgrades with energy efficiency or solar options.

⁴ ‘Stranded measures’ or ‘stranded savings’ refers to those measures that by themselves do not present a very attractive investment option using a simple payback approach and are hence left unconsidered.

This combination increases the overall package cost-effectiveness, overcoming the barrier of promoting electrification where the economics are currently challenging.

1. **A portfolio-scale dashboard for cities and utilities.** The dashboard aggregates output from the individual home energy models. It provides information such as energy savings, carbon reduction, and cost-effectiveness of energy upgrade measures across all homes in the region. This enables the city and utility to strategically develop decarbonization strategies for the community and encourage efficiency upgrades in the residential building sector. For example, data showing a spread of cost-effectiveness for an energy upgrade across individual energy models in the region can provide valuable insights. This information can then be used by the city to develop appropriate local messaging, programs, or policies that encourage decarbonization, or by a utility or other incentive provider (such as a Regional Energy Network) to design targeted energy efficiency programs and outreach messaging.
2. **A web-based interface for homeowners.** The web interface allows homeowners to review the output of an energy model of any single home within the boundaries of the study. They receive customized home energy analysis, and an interface to review cost-effectiveness of energy upgrades for their home. They also receive information about relevant rebates and programs available to them. The models can be verified and improved with a virtual home energy audit performed by the homeowners. To encourage electrification, the homeowner receives information on upgrade packages where electrification upgrades are strategically combined with other efficiency and rooftop solar measures to give a positive return on investment.

Key Advantages of a Two-Pronged Approach

By providing a solution for both the city/utility and the homeowners, the two-pronged approach addresses the previously discussed barriers to large-scale residential building decarbonization. The following are the key advantages of the web-based interface for homeowners.

- The approach engages homeowners and provides analysis on the financial benefits, and information on health, safety, comfort, as well as environmental benefits of their home's energy improvement options.
- The web interface provides immediate retrofit recommendations for homeowners that do not have access to an affordable or subsidized in-person home energy assessment or would prefer not to participate in an in-person assessment service.
- Combining electrification measures – such as heat pump water heaters or heat pump HVAC systems – with cost-effective energy upgrades – such as envelope improvements or rooftop solar – ensures that the overall package will have an acceptable payback and return on the initial investment. This provides a compelling economic proposition to the homeowner and puts them on a path to decarbonization.

Aggregate data built from individual home energy models can be a powerful analysis basis for developing strategic policies and programs. The following are the key advantages of the portfolio-scale dashboard for cities and utilities.

- Cities can use this data to develop a roadmap to decarbonize their existing building stock in accordance with their climate action plans and carbon reduction goals.
- Aggregate data from individual home energy models and information on cost-effective electrification and efficiency packages can provide the necessary research basis for the development and successful deployment of hyper-local programs or policies.
- Cities can craft local policies that encourage building decarbonization such as reach or stretch codes (building energy codes that go beyond local energy codes).
- Utilities or other incentive providers can develop programs that are more specifically tuned to needs of a region, and develop messaging informed by the energy models of homes in that region.

Deploying the Approach

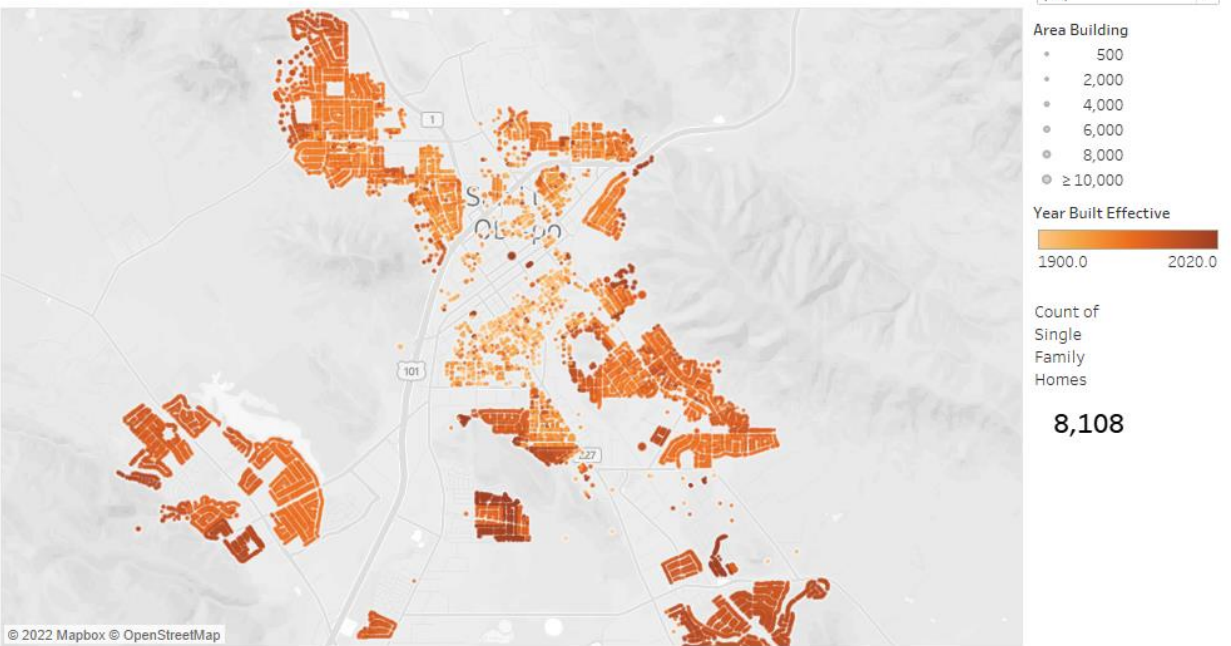
We use an example of a recent deployment of the XeroHome platform in the city of San Luis Obispo, California to illustrate how this approach is implemented in a real-world scenario. XeroHome's portfolio-scale analysis was used by the city of San Luis Obispo to evaluate opportunities for electrification and carbon reduction at the community level. A web-based interface for homeowners is also being provided for the residents, results from which will be available soon.

Datasets for building energy model development. Publicly available datasets with information on homes in San Luis Obispo were acquired by the project team to develop the energy models.

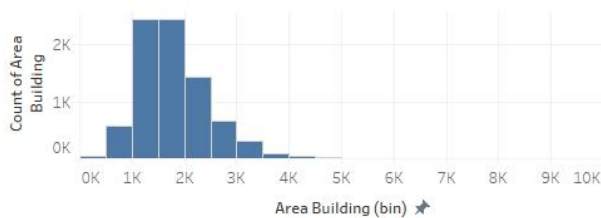
1. Property assessment data: Figure 4 provides a visualization of the property assessment data showing year built, area, and physical characteristics of each home. The physical characteristics include such things as number of bedrooms, stories, heating fuel type, etc.
2. Building permit data: Residential permits for the past ~30 years were acquired directly from the city of San Luis Obispo for each home. This data includes the date and description of any major renovations or retrofits to the home.
3. Multiple Listing Service (MLS) data: This provided data for all homes with a recorded real estate transaction. MLS data typically includes information on the home's heating and cooling systems along with other useful data on home upgrades.
4. GIS data: 3D geometry for all San Luis Obispo homes was acquired from OpenStreetMaps data using a method to extract the three-dimensional form of a building from its footprint and LiDAR (Light Detection and Ranging) -based building height data.

Using these datasets, efficiencies were assigned to envelope and system components of the energy model. Not all upgrades require a building permit, and MLS data is not available for all homes in the city. So, while this information is by no means comprehensive, it is instrumental in improving the accuracy of the building energy model to represent a home's actual conditions.

Map - SLO



HISTOGRAM - Home Area



HISTOGRAM - Year Built (Effective)

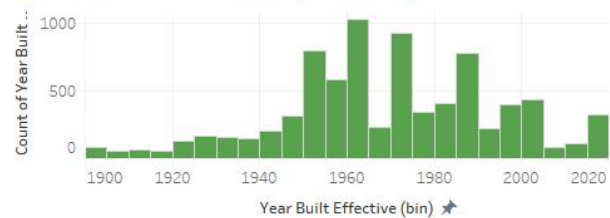


Figure 4: A visualization of property assessment data for all single-family homes in the city of San Luis Obispo.
Source: XeroHome City Dashboard.

Energy model development and parametric analysis. A base EnergyPlus home energy model was developed in XeroHome for each home, using inferences made from the public data sources discussed in the last section. Figure 5 provides a graphical description of the energy model development process.

An energy model provides a flexible tool that can be used to run various upgrade scenarios. XeroHome uses a scalable cloud-computing platform and a proprietary machine learning-based surrogate modeling technique (Saxena, Coffey, et al. 2018) which significantly reduces simulation times without significant loss in accuracy. This key innovation makes it possible to scale the tool's energy modeling and run comprehensive parametric analysis across all homes in a city or region.

Parametric analyses with home energy models in San Luis Obispo were run to determine if electrification measures provide a good return on investment, and to determine which combinations of energy efficiency and electrification upgrades were attractive for most homes.

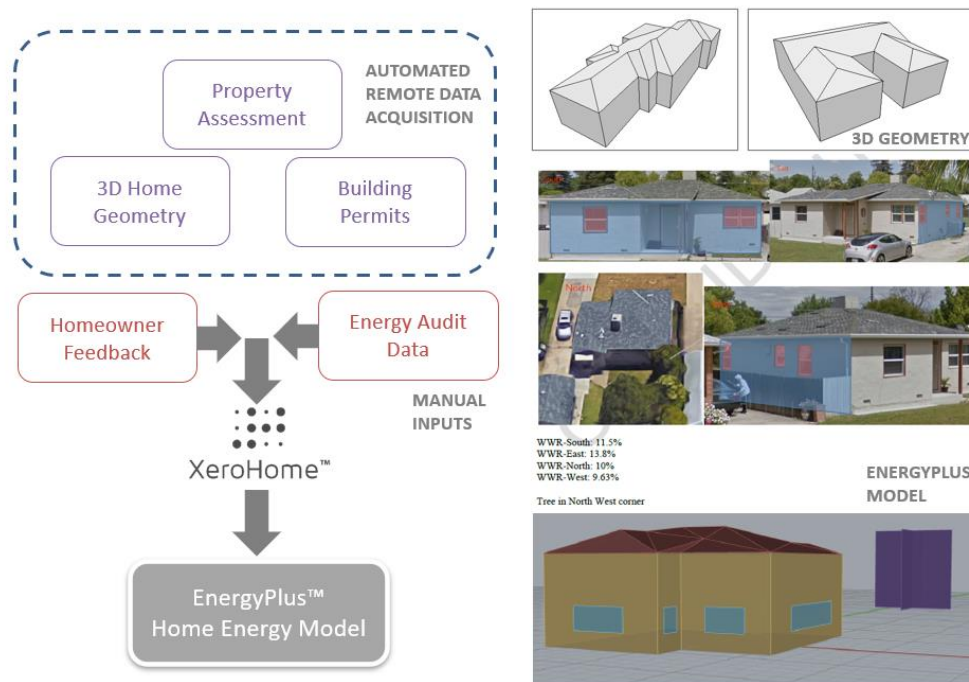


Figure 5: XeroHome's building energy model development process and example.

Evaluating cost-effectiveness of electrification and solar upgrades. The project team ran analyses with the San Luis Obispo home energy models to evaluate the cost-effectiveness of electrification-only upgrades. For example, replacing a natural gas water heater with a heat pump water heater (HPWH), or a gas furnace with a heat pump HVAC (HP HVAC), and rooftop solar upgrades. Figure 6 (left side graph) shows the results of this analysis. The box and whisker plots represent the spread of Net Present Value (NPV)⁵ calculated for each of the ~8,100 homes in San Luis Obispo for these upgrades. The shaded (box) region of the plot represents the 1st and 3rd quartile homes, while the line in the middle of the shaded region, represents the median. The ends of the plots (whiskers) show the upper and lower bounds. As seen in the plot, the two heat pump upgrades **were not cost-effective** as a full cost replacement (all homes have negative NPV), while solar upgrade **was cost-effective** (all homes have positive NPV).⁶

Next the team looked at two combinations or packages: Solar + HPWH, and Solar + HP HVAC. Both packages were found to be **cost-effective for most homes** in San Luis Obispo. Figure 6 (right side graph) provides the scatter plot of NPV for the two packages.

⁵ Net Present Value (NPV) is a metric used to determine if a measure is cost-effective. NPV is the initial cost of the measure subtracted from the cumulative, discounted savings from that measure over its lifetime. A positive NPV represents a cost-effective measure.

⁶ The analysis used the full costs of the electrification measures, not incremental costs (compared to an equivalent gas water heater replacement) and did not include any existing or proposed rebates from the utility or statewide program. These assumptions were made to keep the analysis conservative.

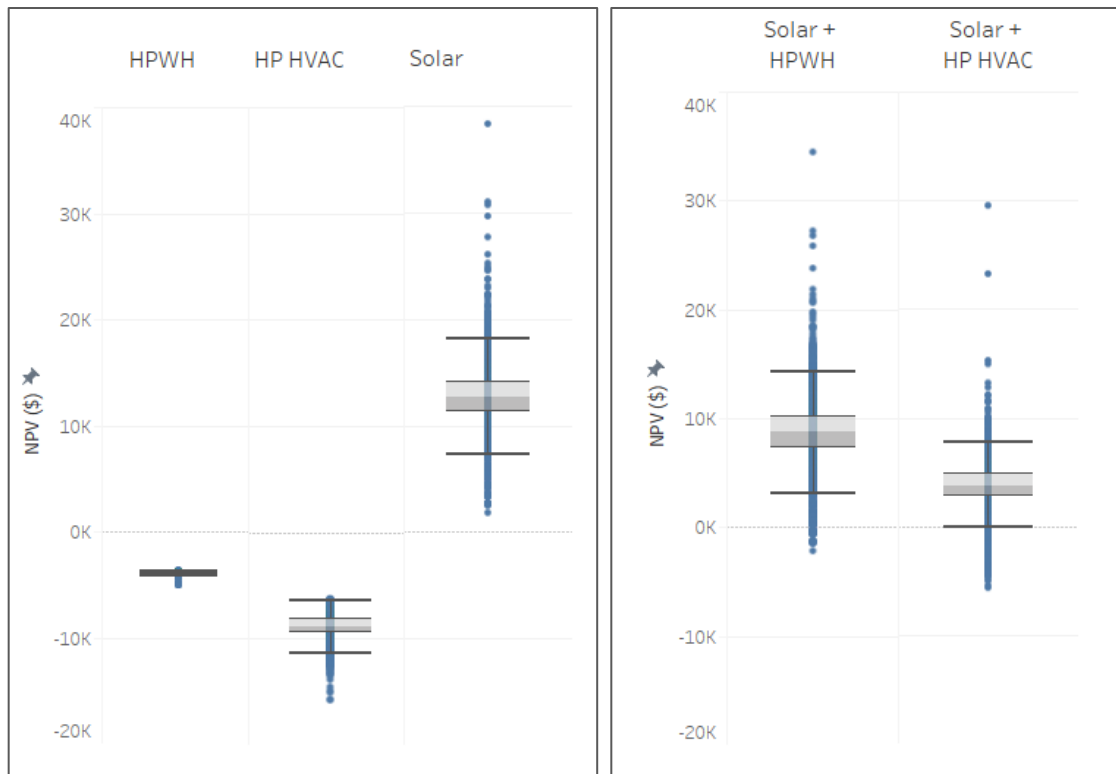


Figure 6: NPV (\$) scatter plots - Electrification only HPWH, HP HVAC, and Solar measures (left) and combination of ‘Solar + HPWH’ and ‘Solar + HP HVAC’ measures (right).

Electrification reach code option with solar. Based on this analysis, the team suggested exploring a reach code that would require qualifying permitted retrofit projects to install a HPWH along with rooftop solar, with a potential trigger at the time of permitting for solar. The code could include meaningful exemptions for homes where the package of the two measures was not cost-effective or did not make sense.

To identify which homes should be exempted, the project team looked at the NPV of the Solar + HPWH package plotted against the size of recommended rooftop solar. The analysis found that the package was cost-effective for all homes except where the size of recommended rooftop solar was less than ~1 kW. Figure 7 provides the scatter plot, and the point where the NPV becomes positive is seen to be close to the 1 kW solar size on the X-axis.

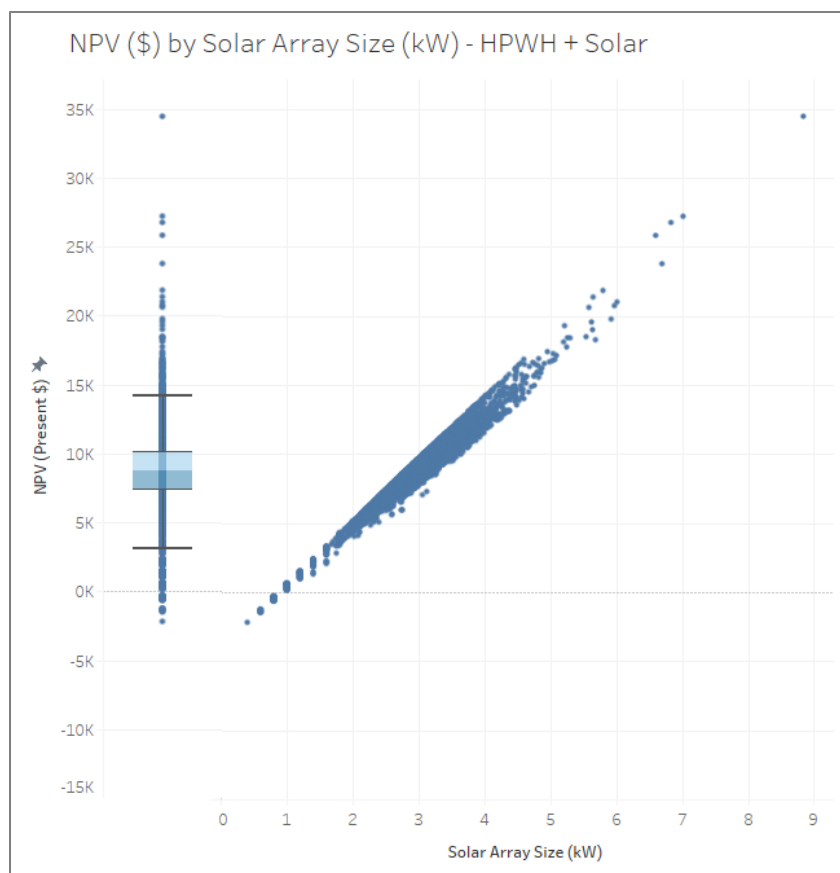


Figure 7: NPV (\$) and Savings (\$/yr.) scatter plot of HPWH and rooftop solar package.

This analysis supported development of a local ordinance requiring homes installing solar to also install a heat pump water heater. A conservative exception was recommended to exempt any home installing less than 1.5 kW or 2 kW of solar array size. The project team also explored other packages that were cost-effective, such as heat pump HVACs in combination with energy efficiency upgrades and solar. These could be explored as other options for reach codes.

Home level analysis. When visiting XeroHome’s web-based interface, the homeowner starts by providing their address. After confirming a few basic assumptions about their home, the portal:

1. Shows specific packages of energy efficiency, electrification and solar measures that would be cost-effective for that home.
2. Gives each package’s expected annual utility bill savings, and carbon emissions reductions, as well as information about how each measure can improve comfort.
3. Shows expected costs for each package, available rebates, and the expected investment recovery (payback) period.
4. Gives access to utility program resources and links to find a qualified contractor to take the next step in installing the package.

The web portal also offers the option to create a custom package, by adding specific energy efficiency, electrification, and solar measures, based on their own priorities.

The city can also use the web portal as a tool to communicate with homeowners and to gauge support for potential electrification policies. The web portal is designed to communicate not only the financial, but also the environmental, comfort, and wellbeing benefits of these electrification and solar package. This helps deliver the complete value proposition of electrification to the homeowner.

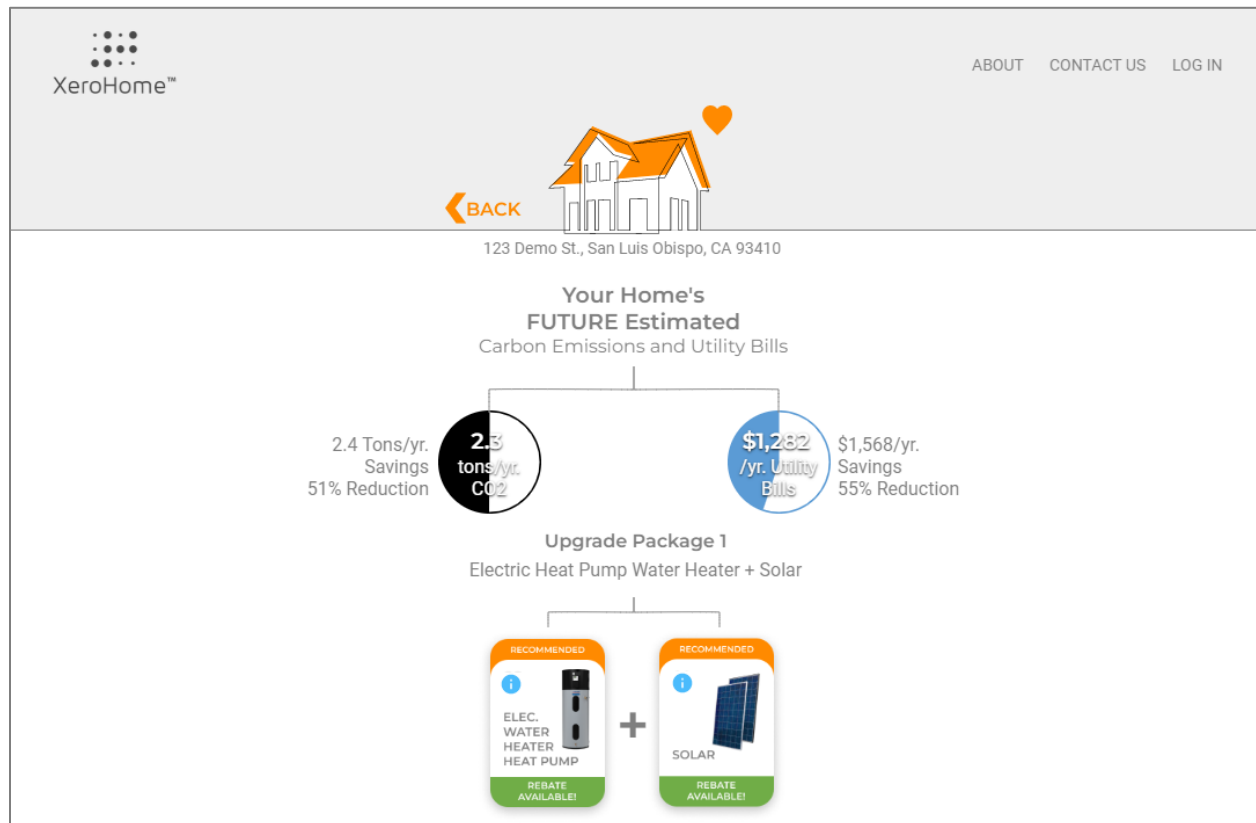


Figure 8: Homeowner web portal showing an electrification package with heat pump water heater and solar.

In addition to providing recommendations, the web portal is also designed to accept input from the homeowner. The homeowner can follow a self-guided virtual home energy audit and provide details about their home or add energy use data. These details are immediately used to update their home's energy model, and changes are reflected in all recommendations.

Validation: City of Santa Monica with Southern California Edison

The effectiveness of XeroHome as a web-based interface for homeowners, and its reliability in providing accurate calculations and upgrade recommendations to homeowners was recently evaluated by Southern California Edison through the emerging technologies assessment program. An accompanying paper presented at this conference (Saxena, Dhir, et al. 2022) goes into more detail about this evaluation.

For this evaluation, XeroHome was used to develop EnergyPlus energy models at scale, for all ~8,000 homes in the city of Santa Monica, California. The energy models of the homes

were accessible over the web-based interface for homeowners.⁷ Over the first six months, 796 Santa Monica homeowners accessed the platform to review their home's energy upgrade recommendation. Of those, 95 completed a virtual energy assessment for improving their home's energy model.

The results were validated by on-site evaluation. For the evaluation, a professional energy assessor completed professional in-home energy audits in seven homes and developed energy models as they traditionally would to ascertain the optimal efficiency measure packages. The recommendations and predictive results were compared to those developed by the energy assessor. The evaluation found that XeroHome's energy models were within 10% of those from the professional energy assessor, for five out of the seven homes. The study concluded that this approach has promising potential to make home energy upgrade recommendations accessible to a large number of households, as an alternative to traditional home energy audits for most homes.

Scaling up: City of San Luis Obispo with Pacific Gas and Electric

Building on insights learned from the initial deployment of XeroHome in Santa Monica, Pacific Gas and Electric company (PG&E) supported applying this new approach in the city of San Luis Obispo (SLO), California. The city has about 8,100 existing single-family homes, and its Climate Action Plan (City of San Luis Obispo, CA 2022) establishes a community-wide goal of carbon neutrality by 2035. The plan includes a distinct focus on buildings that calls for 50% reduction in existing building onsite emissions by 2030. To achieve this, city staff were interested in exploring ways to increase deep energy retrofits that reduce onsite emissions through electrification.

XeroHome's portfolio-scale analysis was used in this project to evaluate electrification and carbon reduction opportunities through home energy retrofits. Later in the project, the web-based interface for homeowners will be provided to San Luis Obispo residents.

Moving Forward: Cities of Sacramento, Petaluma, Atlanta, and Richmond Heights

As cities and utilities focus their efforts on decarbonizing the existing building stock, the two-pronged approach discussed in this paper provides a practical solution. It provides a combination of levers that cities and utilities can use to develop a unique strategy for each region. The portfolio-scale analysis shows which upgrades are cost-effective when combined as packages. Those can then be promoted to homeowners through incentive programs or reach codes with the help of the web-based interface for homeowners.

The city of Sacramento, California recognized the potential in developing an existing-buildings electrification strategy (City of Sacramento, CA 2022). Working with XeroHome, the city is implementing a portfolio-scale analysis and deploying a web-based interface for residents of its over 120,000 single-family homes. Once it is deployed, homeowners will be able to use the web interface to explore options for decarbonizing their homes. A similar project is also underway in the city of Petaluma, California. There, this approach will be rolled out to help residents of its over 17,000 single-family homes achieve the city's Climate Ready 2030 (City of Petaluma, CA 2022) goal of greenhouse gas and carbon neutrality by 2030. The approach is also

⁷ XeroHome's Santa Monica deployment can be accessed via the web portal: <https://my.xerohome.com>

being piloted in the city of Atlanta, Georgia with funding from the Southern Company, and city of Richmond Heights, Missouri with funding from Ameren Missouri.

Deployments in these cities, along with the current deployments in San Luis Obispo, and Santa Monica, allow the project team to test the efficacy of the two-pronged strategy and improve its implementation, with the goal of increasing the uptake of decarbonization and electrification upgrades.

Conclusion

The two-pronged approach described in this paper is not a new concept. Other industries have implemented similar approaches to successfully disrupt stagnant markets and spur activity. The home real-estate information market is one such example. Companies like Zillow and Redfin⁸ introduced a web interface for anyone interested in buying or selling a home, and a portfolio-scale dashboard for realtors. Having both solutions together made it possible for interested home buyers and sellers to quickly check a home's estimated value on the web interface, and for realtors to reach out and connect with them and pursue the next step towards a transaction. The availability of these web-based platforms has changed how all parties conduct the processes related to home real-estate transaction – from buying and selling a home, to financing or re-financing home loans.

The development of XeroHome and the implementation of the approach described in this paper has the potential to reenergize the home energy upgrade market. Over the past two years, remodels and renovations have accelerated significantly. Factors driving this range from the desire to improve aesthetics or home reconfiguration, to the availability of low-interest rate loans, increasing home values, and more time spent at home for many households (Joint Center for Housing Studies 2022). With activity predicted to slow, the benefits from energy-based retrofits must be clearly outlined to encourage homeowners considering initial or additional changes. By providing reliable, relevant and well researched information at no cost, the homeowner may pursue energy upgrades where prior decisions may have been informed primarily by other factors and energy system upgrades may have been left out. Parallel to the example of Zillow, XeroHome providing an easy-to-use web interface is a familiar and accessible modality for many homeowners. Along with that, a portfolio-level analysis for a region enables cities and utilities to design better programs and policies and conduct better outreach.

The deployment of XeroHome in Santa Monica provided an initial validation of the application's accuracy compared to traditional home energy audits and demonstrated its ability to engage homeowners with a web-based interface. With the deployment in San Luis Obispo, the portfolio-scale analysis was used to identify cost-effective electrification packages and to propose a potential reach code for the city. As the approach is implemented in more cities and data and feedback are collected, the approach will be further refined towards the goal of promoting greater uptake of home decarbonization upgrades.

Acknowledgements

The project with the cities of San Luis Obispo and Petaluma discussed in this paper are funded through the PG&E Emerging Technologies program, which is part of the Energy

⁸ Zillow: <https://www.zillow.com/>; Redfin: <https://www.redfin.com/>

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