The value of proactive customer targeting for meeting utility goals

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ABSTRACT

This paper proposes a cloud-based methodology to identify the best performing residential energy efficiency programs for income qualified customers using DTE Energy as a case study. In this study, the data from DTE Energy was analyzed to find correlations within the dataset. Next, program performance evaluation was conducted on past program participation data to calculate their efficacy. Over 17,000 performance evaluations were conducted based on customer advanced metering infrastructure (AMI) data, with an average of 2.5% annual measured energy savings per household. Lastly, a digital twin was created of approximately 200,000 households and 42 electrification and energy efficiency measures were run on the digital twins using the cloud, demonstrating a highly scalable process. Air Sealing proved to be the best performing individual measure in the simulation as well as the past program evaluation. Furthermore, the results indicated that the average energy burden reduction for the best performing measure of each highly burdened home was four times that of the average energy burden reduction across all measures and households with energy burden data. The methodology demonstrates the value of using the cloud to run multiple measures on each household in a utility's service territory, and determining the best performing measure for each household, thus giving utilities the opportunity to create more targeted residential energy efficiency programs.

INTRODUCTION

Utility energy efficiency and electrification programs have been pivotal components of the energy landscape for several decades, originating in response to the energy crises of the 1970s (York 2012). These initiatives were catalyzed by the urgent need to address energy consumption patterns and reduce dependence on fossil fuels. Subsequently, in the early 1990s, beneficial electrification programs emerged, aiming to optimize energy use by promoting the adoption of efficient electric technologies (Pickles, Sheehy, and DiBella 2016).

Fast forward to the present day, and utilities nationwide are increasingly recognizing the imperative to set ambitious emissions reduction targets as part of broader efforts to mitigate the impacts of climate change. The urgency of this task is underscored by the plethora of pathways available for decarbonization, each with its unique set of costs, benefits, and challenges. Moreover, the regulatory landscape and societal pressures further complicate decision-making, highlighting the need for comprehensive and adaptable strategies.

Customer programs represent a diverse array of initiatives that offer utilities a multifaceted approach to addressing energy efficiency, equity, and decarbonization. These programs encompass a wide range of activities, from incentivizing the adoption of energy-efficient appliances through rebate programs to conducting comprehensive home retrofit assessments aimed at identifying and implementing tailored energy-saving measures. Nevertheless, certain programs, such as home retrofit, necessitate on-site visits by personnel who inspect households and propose potential electrification and energy efficiency measures. This approach incurs substantial overhead costs and presents challenges in scaling up to address the needs of tens of thousands of households within reasonable timeframes and costs.

However, the past two decades has witnessed a seismic shift in the utility sector with the proliferation of big data. The widespread deployment of smart meters has led to the generation of vast datasets, providing utilities with unprecedented insights into customer energy usage patterns (Zhang et al. 2019). By leveraging advanced analytics and machine learning techniques, utilities can harness this wealth of data to uncover hidden trends, identify areas for improvement, and optimize resource allocation.

DTE Energy, a prominent electric and gas utility based in Detroit, is at the forefront of this data-driven revolution. With a customer base exceeding two million, DTE Energy has embarked on a journey to leverage its advanced metering infrastructure (AMI) data, combined with historical program participation data, to gain deeper insights into customer behavior and energy usage patterns ("Who We Are" n.d.). In particular, DTE Energy has chosen to focus its efforts on a subset of low to middle-income customers, recognizing the disproportionate energy burden faced by this demographic.

Through collaboration with industry experts at ICF, DTE Energy aims to extract actionable insights, evaluate the efficacy of past programs, and project potential energy savings from a myriad of energy efficiency and electrification measures. By adopting a data-driven approach, DTE Energy seeks to enhance customer engagement, optimize program offerings, and advance its sustainability objectives in a rapidly evolving energy landscape.

METHODOLOGY

Datasets

DTE Energy supplied the ICF team with a collection of discrete datasets, which can be broadly categorized into two primary groups.

The first dataset comprised a comprehensive timeseries dataset, featuring the advanced metering infrastructure (AMI) data of approximately 200,000 low to middle-income customers. This dataset provided energy usage in 15-minute intervals, spanning from 2019 to 2022 for each individual customer, offering a granular insight into their energy consumption patterns over time.

The second dataset consisted of several smaller datasets, collectively offering insights into customers actively engaged in Energy Waste Reduction (EWR) programs. This dataset encompassed a range of demographic information, details regarding the specific programs in which customers participated, as well as corresponding electric and gas savings metrics, among other relevant data points. The data ranged from 2009 to 2022. Furthermore, this dataset was augmented with additional information, including energy burden data for each customer, sourced from third-party datasets such as Experian and others.

Digital Twin

DTE Energy embarked on an extensive evaluation aimed at assessing the potential energy savings derived from over 40 electrification and energy efficiency measures. These measures spanned a diverse spectrum, ranging from electrification, HVAC to envelope and appliance equipment measures, among other strategies.

To facilitate this comprehensive assessment, a sophisticated digital twin was created for each customer household. These digital twins served as analytical representations of real-world premises, allowing for the simulation of various energy-saving measures. Initially, approximately 1,000 premises were carefully chosen that mirror the building stock within DTE Energy's service territory, and they were simulated using National Renewable Energy Laboratory's (NREL) OpenStudio software (Guglielmetti, Macumber, and Long 2011). The building characteristics of the nearly 1,000 households were based on multiple sources such as the U.S. Census data, U.S. Energy Information Administration Residential Energy Consumption Survey (EIA RECS) among others to ensure accuracy.

Given the computational complexity of simulating thousands of building energy models, the simulations were conducted on cloud infrastructure to leverage its scalable processing power. The cloud environment facilitated parallel processing, enabling the execution of over 40,000 individual OpenStudio models. These included the simulation of the approximately 1,000 premises as well as the simulation of the premises after applying the 40+ measures to each premise.

Following the simulation phase, each customer household was matched to a corresponding OpenStudio model. This matching process, facilitated by a patent pending proprietary algorithm developed by ICF, involved comparing the AMI data of each customer with the energy consumption profiles generated by the OpenStudio models. The energy consumption profile generated by the OpenStudio model is an annual load profile at hourly interval, i.e., 8760 data points. Consequently, the customer AMI data was aggregated from 15-minute interval to hourly interval data for an apples-to-apples comparison. Since about 200,000 premises' AMI data were matched to the energy consumption profile of approximately 1,000 simulated OpenStudio models, multiple customers could be matched to the same model. This is valid since the building codes within a state ensure that multiple homes are built with similar building characteristics.

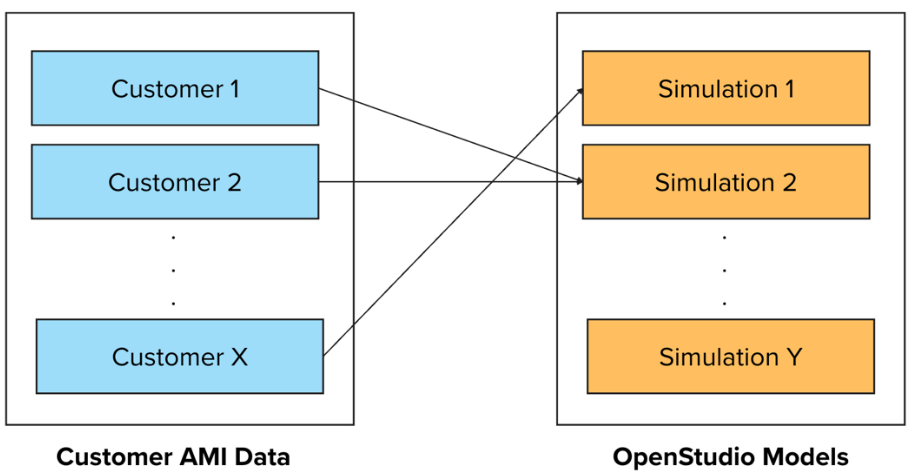

Figure 1. Diagram illustrating the matching of customer AMI data to the corresponding simulated OpenStudio model.

After the matching process, the energy savings for a customer for a measure was simply calculated as the energy savings of the matched OpenStudio model.

$$E_{ij} = M_{i0} - M_{ij}$$

where E_{ij} is the energy savings for customer *i* and measure *j*, M_{i0} is the baseline energy consumption of the model matched to customer *i*, and M_{ij} is the energy consumption of the model matched to customer *i* with measure *j* applied to it.

Given the computational intensity of the matching algorithm, it was deployed on a PaaS (platform as a service) solution for scalability and efficiency purposes. The algorithm itself, written in Python and utilizing libraries such as Pandas and NumPy, was packaged as a Python library and deployed on the cloud. The entire algorithm was executed within a five-hour timeframe. This meticulous approach not only underscored DTE Energy's commitment to precision and efficiency but also showcased the transformative potential of cloud-based technologies in driving innovation within the energy sector.

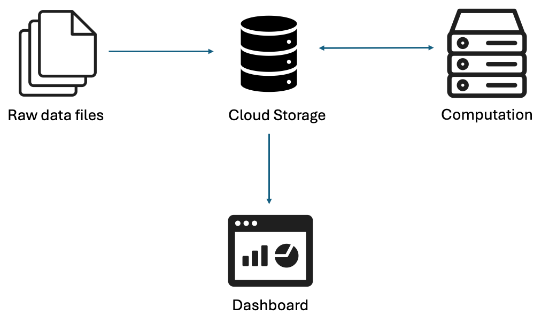

Figure 2. Data platform architecture.

The results of the matching process and the energy savings for each model and measure were stored in the cloud as tables. These tables served as repositories for the wealth of information generated throughout the evaluation process, ensuring accessibility and ease of retrieval for subsequent analyses.

To facilitate interpretation and decision-making, the data stored in the delta tables was leveraged to create visually engaging and informative dashboards using Microsoft Power BI. These dashboards served as powerful tools for querying and visualizing data, providing stakeholders with actionable insights into the efficacy of the evaluated measures and the associated energy savings. By querying data directly from the delta tables in the backend, the Power BI dashboard offered real-time access to the latest evaluation results, enabling stakeholders to make informed decisions based on up-to-date information.

In summary, the integration of delta tables and Microsoft Power BI facilitated the seamless transition from data storage to visualization, empowering stakeholders with the information needed to drive strategic initiatives and optimize energy efficiency and electrification efforts.

Past program performance evaluation

The program data provided by DTE Energy was evaluated for its performance using CalTRACK methodologies (Ngo 2023). CalTRACK provides a standardized framework for evaluating the energy savings achieved through energy efficiency programs, ensuring consistency and comparability across different programs, utilities, and regions. This standardization allows for meaningful benchmarking and performance assessment, enabling utilities to gauge the effectiveness of their programs accurately.

Similar to the Digital Twin methodology, a python library was developed that utilized CalTRACK methodologies with past program participation and AMI data, and the analysis was run on the cloud in parallel.

RESULTS

A little over 100,000 projects were identified in the dataset (from 2009 – 2022) provided to the ICF team by DTE Energy. The most prevalent project was Home Energy Consultation, accounting for 27.8% of all projects, followed by Home Energy Survey at 17.9% and Appliance Recycling at 16.9%.

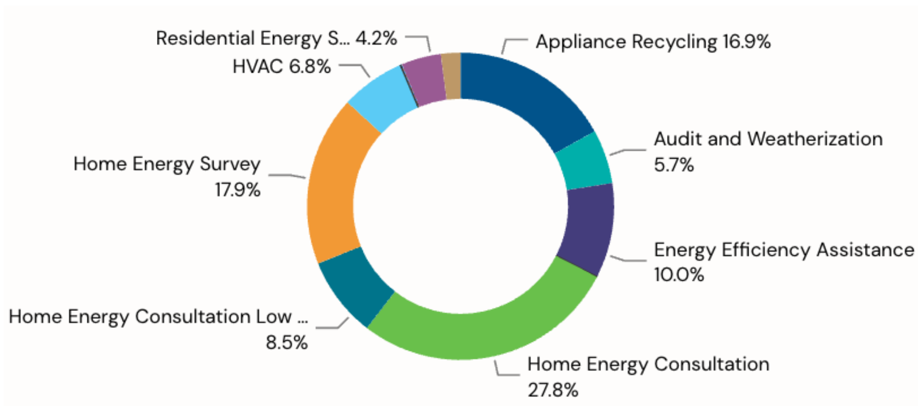

Figure 1. Breakdown of projects.

Interestingly, despite constituting approximately a fifth of all projects, Appliance Recycling stood out for its significant electric savings, surpassing that of other projects. These findings align with research indicating that low-income households often lack energy-efficient appliances, highlighting the potential for substantial energy savings through the modernization of appliances (Xu and Chen 2019). Additionally, in terms of gas savings, the Home Energy Consultation and Energy Efficiency Assistance projects emerged as the most impactful, achieving savings of 27.2% and 24.2% respectively.

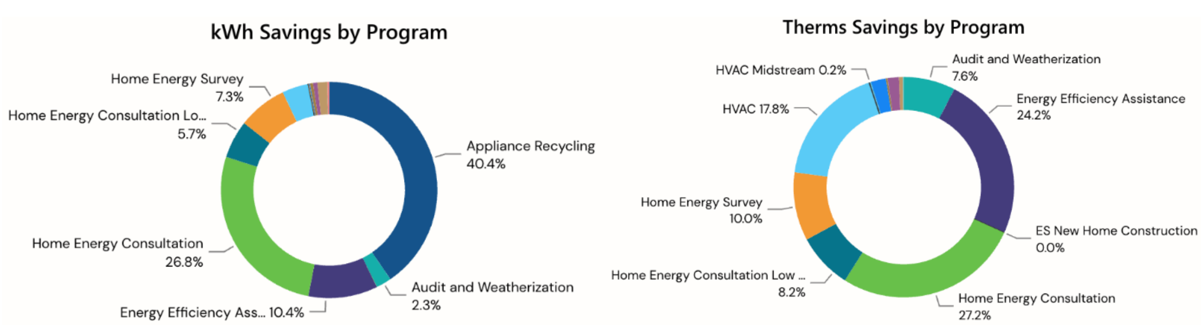

Figure 2. Breakdown of projects by electric savings (left) and gas savings (right)

Past Program Performance Evaluation

The evaluation of the performance of the past programs run by DTE Energy on the dataset provided unveiled an average annual electric savings of 2.5% across all households and programs, indicating a notable reduction in electric consumption attributable to the different programs. Among programs with a single measure, HVAC performed the best in terms of average annual electric savings. Moreover, among programs with multiple measures “Appliance Recycling + Home Energy Consultation + Home Energy Survey” showcased the most significant average annual electric savings, underscoring the synergistic effects of combined interventions.

Parallelly, the evaluation indicated an average annual gas savings of 5.4% across all households and programs, signifying the success of measures in curbing gas consumption. “Revolving Loans Fund” emerged as a leader in individual gas savings measures, highlighting the impact of financial mechanisms in promoting energy efficiency. Furthermore, among grouped measures, the combination of "Audit and Weatherization + HVAC + Residential Energy Star and Lighting" demonstrated the highest average annual gas savings, suggesting the complementarity and effectiveness of these measures when implemented collectively.

Digital Twin

Across all households and measures, air sealing and air source heat pumps proved to be the best performing individual energy efficiency and electrification measures respectively.

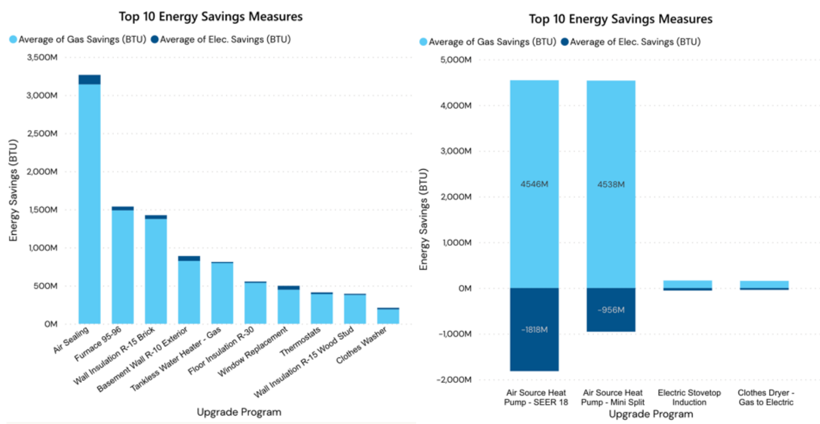

Figure 2. Top 10 Measures for Energy Efficiency (left) and Electrification (right).

The results are consistent with the building characteristics represented in the OpenStudio models which are characterized by lower infiltration levels and the dominance of gas equipment for heating.

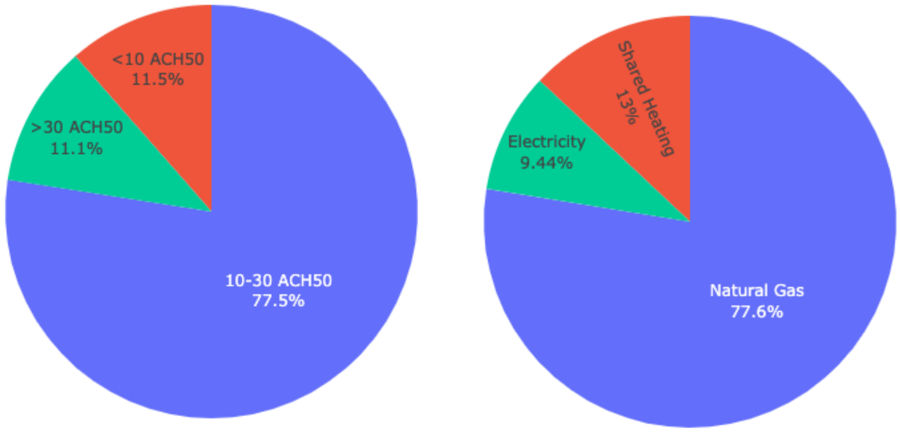

Figure 3. Breakdown of Infiltration levels (left) and Fuel Type (right) of the simulated buildings.

The past program performance evaluation established a baseline of 2.5% savings across all households and programs and laid the groundwork for a more nuanced understanding of energy-saving measures. Leveraging the digital twin methodology, we advanced beyond the conventional program-wide analysis to assess the impact of multiple measures on individual households. This approach recognizes the inherent diversity among households, acknowledging that the effectiveness of energy-saving interventions varies based on factors such as dwelling characteristics and regional climates.

The digital twin methodology not only captures the intricacies of each household's energy profile but also unlocks the potential to optimize customer programs. The tailored evaluation of multiple measures on a household level facilitates the identification of the most effective program for each specific context. The personalized approach can ensure that households receive interventions that align with their specific energy consumption patterns, ultimately leading to the highest achievable energy savings.

Consequently, the selection of the most effective measures was a pivotal outcome, tailored individually for each household participating in Energy Waste Reduction (EWR) and Electrification programs. The criterion for determining the "best performing measure" hinged on achieving the highest cumulative savings, encompassing both electric and gas consumption. For electrification initiatives, the analysis revealed a remarkable average of -142.71% savings in electricity and an impressive 70.2% savings in gas. This substantial percentage is primarily attributable to the complete replacement of traditional gas heating equipment with more energy-efficient heat pumps. It is noteworthy that the extensive modeling conducted with OpenStudio encompassed various household components, including fireplaces and stovetops among others, which can utilize natural gas. Hence why the observed gas savings may not reach 100%.

Conversely, for Energy Waste Reduction measures, the findings disclosed an average electric savings of 3.33% and an average gas savings of 11.46%. This represents a substantial increase from the baseline savings, signifying the efficacy of the chosen measures in achieving noteworthy energy savings across both electricity and gas consumption domains. These insights underscore the importance of carefully selecting and customizing energy efficiency measures to maximize their impact and contribute significantly to overall energy conservation goals.

Energy Burden

An essential facet of optimizing customer programs lies in their potential to alleviate the energy burden experienced by households facing the greatest impact. Within this context, DTE Energy has strategically focused on a key metric: the reduction in energy burden among low to middle-income households. The study reveals that, on average, the implementation of various measures resulted in a reduction of the overall energy burden from 5.45% to 5.01%, constituting a decrease of 0.44%.

However, a more nuanced examination, considering the best-performing measure tailored to each household, unveils a more substantial reduction in energy burden. Specifically, this reduction increased from 5.46% to 4.73%, translating to a notable decrease of 0.73%. Moreover, when focusing on a subset of customers facing high energy burden (>6%), the reduction heightened from 10.74% to 8.99%, marking a significant decrease of 1.75% which is almost four times the average energy burden reduction across all measures and households. This emphasizes the effectiveness of personalized energy efficiency interventions in significantly mitigating the financial strain on individual households. The findings underscore the importance of tailoring programs to specific household needs, showcasing the potential for targeted measures to yield more pronounced and impactful outcomes in reducing the energy burden on vulnerable communities.

FUTURE

In moving forward, it is imperative to acknowledge that the present study predominantly focuses on the technical potential of various energy efficiency and electrification measures, thus omitting a crucial consideration—the associated costs. Future applications should prioritize the integration of cost analysis into the assessment framework to provide a more comprehensive understanding of the economic feasibility and practical implications of implementing these measures. Incorporating cost considerations will enable utilities and policymakers to make more informed decisions, optimizing the balance between achieving energy savings, promoting equity, and adhering to budget constraints. Additionally, exploring innovative financing mechanisms and subsidy programs could further enhance the applicability and accessibility of these measures, fostering a more holistic and sustainable approach to residential customer programs. By combining technical potential with economic viability, future investigations can offer nuanced insights crucial for the effective design and implementation of scalable and cost-effective initiatives within the dynamic landscape of energy efficiency, equity, and decarbonization.

Lastly, the current analysis has been conducted on a specific subset of DTE Energy's customers—those belonging to low-income households with high arrears. While this subset provides valuable insights into targeted interventions, future applications should aspire to extend the analysis to encompass the entirety of DTE Energy's customer base. Conducting an analysis on the entire customer population would not only enhance the generalizability of the results but also provide a more comprehensive understanding of the diverse energy consumption patterns and needs within DTE Energy's service territory.

CONCLUSION

This paper presents a cloud-based methodology for optimizing residential energy efficiency programs, with a specific focus on income-qualified customers, and using DTE Energy as a case study. Leveraging vast datasets and cutting-edge analytics, the study delves into the intricacies of customer energy usage patterns, program effectiveness, and the potential impact of diverse energy efficiency and electrification measures.

Air Sealing proved to be the best performing measure, both in digital twin and past program evaluations, showcasing its efficacy in achieving significant energy savings. The digital twin approach not only recognized the diversity among households but also ensured the identification of the most effective measures for individual contexts, leading to highly targeted and impactful programs.

The study's focus on reducing the energy burden for low to middle-income households was particularly noteworthy. The results indicated a substantial reduction in energy burden, especially when employing the best-performing measure tailored to each household. This personalized approach resulted in a reduction that was almost four times higher for households facing high energy burden, emphasizing the potential of targeted interventions in mitigating financial strain.

Looking ahead, the paper acknowledges the need to incorporate cost considerations into future assessments to provide a more holistic understanding of economic feasibility. By balancing technical potential with economic viability, future investigations can guide utilities and policymakers in making well-informed decisions that align with budget constraints while promoting equity. Furthermore, the call to extend the analysis to encompass the entire customer base of DTE Energy would not only enhance result generalizability but also shed light on diverse energy consumption patterns within the service territory, informing future strategies and initiatives.

In essence, this paper demonstrates the transformative potential of cloud-based methodologies, advanced analytics, and customer-centric approaches in shaping the future of residential energy efficiency programs. Unlike conventional methods of evaluating customer programs which depend on general metrics, the cloud-based methodology enables a detailed analysis of each household within a utility's service territory. Due to the cost-effectiveness of cloud computing, each program's effect on each home can be simulated, and scaling from thousands to millions of homes incurs minimal additional expenses. This can be used to tailor recommendations for each home, and this not only enhances the precision of energy efficiency and electrification initiatives but also optimizes resource allocation, ultimately leading to more impactful and efficient programs.

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