MODELING HOW LARGE-SCALE, RESIDENTIAL, ENERGY EFFICIENCY INVESTMENTS IMPACT POWER SECTOR DISPATCH AND EMISSIONS

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Overview

In the United States, the residential building sector accounts for 22% of primary energy consumption and 20% of carbon dioxide (CO_2) emissions, as well as other forms of air pollution. Energy efficiency policies and investments provide one avenue for reducing the energy and environmental impacts of residential buildings. The impacts of these policies and investments can be difficult to predict, namely concerning how large amounts of energy efficiency investments might change the electricity supply dispatch and associated emissions. This study introduces a large-scale building simulation method that can help improve these predictions and enable better decisions about energy efficiency policy and investments.

Building energy simulations typically use thermal-physical models that combine climate data, building construction information, heat transfer calculations, and occupancy behaviour to calculate a building's energy demand. While these models can accurately predict the demand of a controlled, experimental building, they struggle to consistently predict demand for real world, occupied buildings. Human behavior drives this limitation, since consumer habits significantly influence building energy demand but are difficult to model or anticipate. Thus, the diversity of energy demand for buildings of similar type and quality might be significant, while the average energy demand across multiple buildings will more closely match the results of a building energy simulation.

Rather than modeling individual residential buildings, this study models aggregations of buildings by simulating the energy demand of a hypothetical building archetype that represents the average quality and consumer behaviour of a group of similar buildings. We test the accuracy of this approach and then scale up these aggregate energy simulations to represent large portions of a city's residential sector to quantify the impact of energy efficiency policies on a city's overall energy consumption, peak demand, and utilization of grid infrastructure. Finally, we quantify how changes in a city's electricity demand will impact the regional power sector's generation dispatch and emissions.

Methods

This paper quantifies how residential energy efficiency investments impact urban electricity demand, regional power plant dispatch, and power sector emissions. It uses a combination of data analysis, building energy simulation, and power plant dispatch modeling methods outlined below.

First, the study sorts a sample of single family houses into different archetypes based on their construction and energy efficiency characteristics. To accomplish this categorization, we use energy audits and energy consumption data to correlate energy consumption with different building qualities (e.g. attic insulation, air conditioner efficiency, or window type). Then, we apply K-Means clustering analysis to define the characteristics of each archetype.

Second, we simulate sub-hourly energy demand for each archetype and validate the simulated demand profiles against historical, 2015, energy consumption data for Austin, Texas. Modeling at the sub-hourly scale reveals trends in peak electric demand, grid utilization, ramp rates, and other important temporal aspects of electricity demand. We use the EnergyPlus building energy modeling tool to simulate the archetypes' demand profiles.

Third, the study uses these simulated demand profiles to quantify how energy efficiency investments will impact urban electricity demand, power plant dispatch, and power sector emissions. By describing a city's residential energy demand as the weighted sum of its building archetypes' simulated demand profiles, we can equate energy efficiency investments with a change in the city's mix of building archetypes. This change in building mix influences the city's demand profile. We use a simple dispatch modeling tool to quantify how altering the city's demand profile will impact power plant dispatch and power sector emissions.

The methods are illustrated using a case study of the residential housing stock in Austin, Texas and the power plant fleet in the Electric Reliability Council of Texas.

Results

The study's results present a validation of the energy building modeling techniques and an analysis of the impacts of energy efficiency investments on the power sector.

In the validation section, simulated electricity demand is compared against historical electricity demand for each of the building archetypes. The results show that the simulated demand profiles accurately represent the aggregated historical demand profiles for different archetypes.

In the analysis section, we calculate how different energy investment policies will impact Austin's overall residential demand profile, the dispatch of power plants in Texas, and emissions in the Texas power sector. The results show that different energy efficiency policies have distinct impacts on the electric grid, and that optimal investment strategies might depend on the economic, environmental, and other goals that policymakers are trying to achieve.

Conclusions

Building archetype clustering coupled with building energy simulation is a beneficial tool for modeling the sub-hourly electricity demand for large groups of buildings without requiring detailed information about each unique building in the group. This method can be scaled to represent the electricity demand profile of large urban areas.

Investing in residential building efficiency influences the timing, peak demand, and overall scale of urban electricity consumption. The analysis tools in this study help discern how different energy efficiency policies align with policymakers' economic or environmental goals.

Future work on this study will expand the methods to major urban areas across the entire United States. These national-scale results will show how the impacts of energy efficiency measures on the power sector vary geographically.

References

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