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Data-driven algorithms for energy justice in Detroit

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Funded by NSF Smart & Connected Communities Program Grant ECCS-1952038 + UM OVPR

Energy Justice + Power System Research

→ How can power systems researchers contribute to energy justice?

Two parts to this talk:

→ An energy justice research agenda for power system researchers [J.L. Mathieu. “Algorithms for Energy Justice”. In: Women in Power Volume – Springer Women in Engineering and Science Series. Ed. by Jill Tietjen, Marija Ilic, Lina Bertling Tjernberg, and Noel Schulz. Springer (Forthcoming).]

→ NSF Smart & Connected Communities Project

The Just Transition

- The “Energy Transition” (shift to renewables + electrification) may exacerbate existing inequalities
  - For example, low-income households and African-American households have the highest **energy burdens** in the U.S., defined as “the percent of household income that is spent on energy bills” [Drehobl and Ross 2016]
- “Energy transitions are about people: the ones who make the decisions and the ones affected by those decisions. A ‘just transition’ approach ensures that the affected people are considered by those making decisions” [International Institute for Sustainable Development]

Environmental Justice

Environmental Justice is “the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations and policies” [US EPA].

Environmental Justice

Environmental Justice

The Biden Administration created…

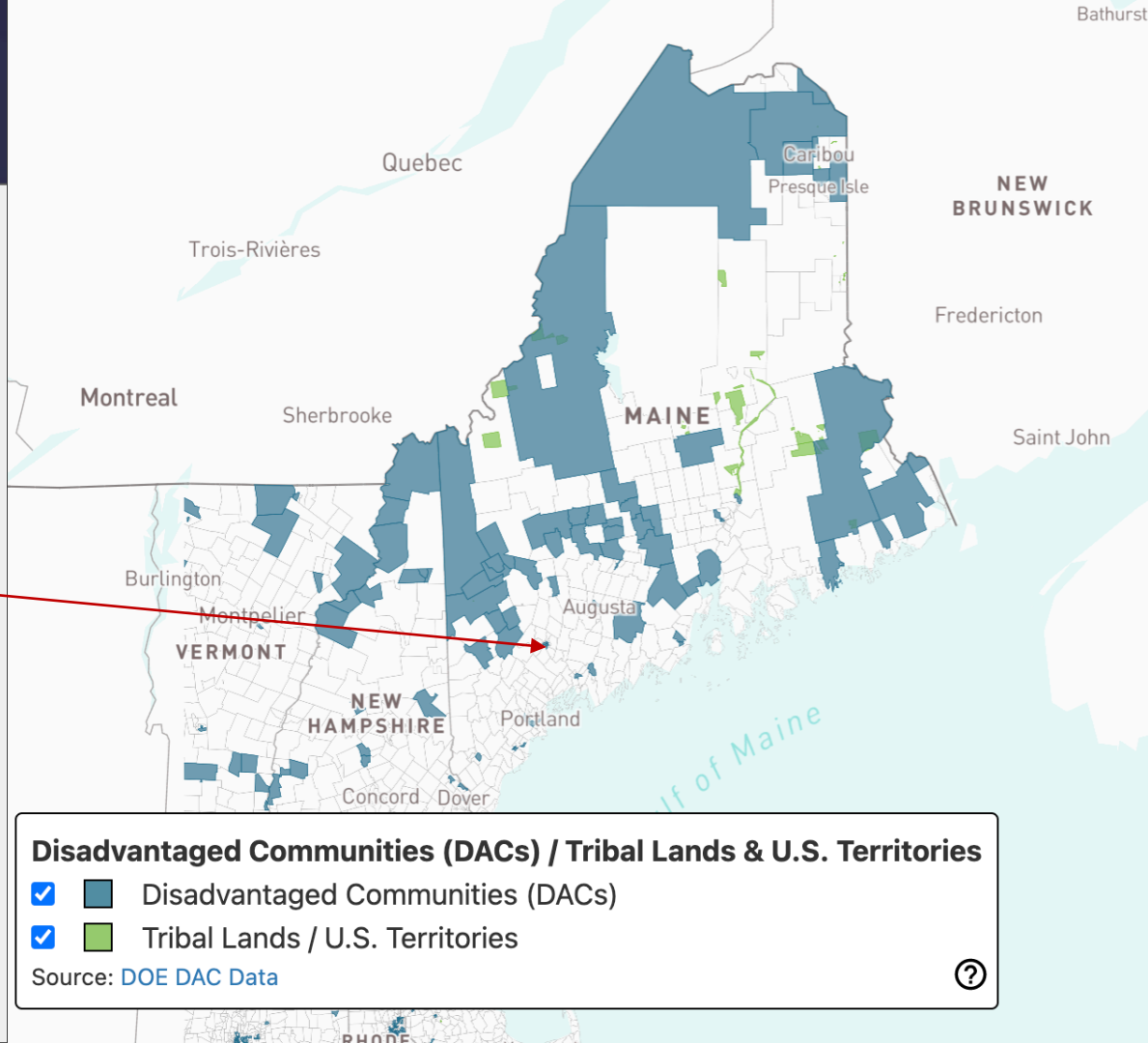
- “a White House Environmental Justice Interagency Council … to prioritize environmental justice and ensure a whole-of-government approach to addressing current and historical environmental injustices, including strengthening environmental justice monitoring and enforcement…” [White House Fact Sheet 2021]

- “Justice40 Initiative with the goal of delivering 40 percent of the overall benefits of relevant federal investments to disadvantaged communities...” [White House Fact Sheet 2021]
  - Focused broadly on environmental investments
  - Also targets energy efficiency and clean energy investments [Young, Mallory, McCarthy 2021].

Justice40 Map

https://energyjustice.egs.anl.gov/

Lewiston, Maine
Energy burden ~6%



Where do we fit in?

- The technologies that we design and develop have a direct or indirect impact on people's lives – through the cost of electricity, the frequency of power outages, the health impacts of fossil fuel plants, …

- Examples,
  - Minority households in Detroit, Michigan are disproportionally impacted by sulfur dioxide (SO_2) pollution from nearby power plants [Martenies et al 2018].

  - Increased adoption of solar PV by high-income homes can increase electricity costs for low-to-moderate (LMI) homes without solar PV [Johnson et al 2017; O'Shaughnessy et al 2021].

  - LMI households less able to afford the switch to electric heating, water heating, and clothes drying will be stuck paying for legacy gas infrastructure cost [Davis and Hausman 2022].

Contributing to Energy Justice

"Energy justice refers to the goal of achieving equity in both the social and economic participation in the energy system, while also remediating social, economic, and health burdens on those historically harmed by the energy system ("frontline communities"). Energy justice explicitly centers the concerns of marginalized communities and aims to make energy more accessible, affordable, and clean and democratically managed for all communities."

initiative for energy justice

Initiative for Energy Justice, "Section 1 – Defining Energy Justice: Connections to Environmental Justice, Climate Justice, and the Just Transition," https://iejusa.org/section-1-defining-energy-justice/,

What is Energy Justice?

Distributive

Equitable allocation of benefits and burdens

Procedural

Fair access to process

Recognition

Acknowledgement of and respect for all peoples

Restorative

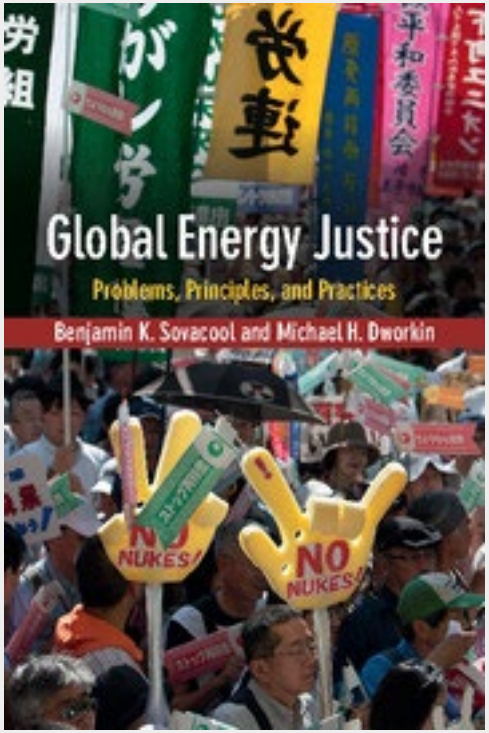
Addresses issues of past harms

Cognitive Justice

Recognizes the right for different understandings and ways of life to coexist

Slide adapted from Tony Reames and Karl Hoesch course notes for UM EAS 525: Energy Justice

Energy Justice Literature



ELSEVIER

Energy Research & Social Science
Volume 11, January 2016, Pages 174-182

Review

Energy justice: A conceptual review

Kirsten Jenkins [a], Darren McCauley [a], Raphael Heffron [b], Hannes Stephan [c], Robert Rehner [a]

Environmental Justice > Vol. 8, No. 4 > Original Articles

Full Access

Sacrifice Along the Energy Continuum: A Call for Energy Justice

Diana Hernández

Published Online: 18 Aug 2015 | https://doi.org/10.1089/env.2015.0015

More Technical Studies

- Data-driven models used to explore disparities in heating energy use intensity (EUI) in Kansas City, Missouri [Reames 2016] and Detroit, Michigan [Bednar et al. 2017].
  - Found significant correlations between heating efficiency and both racial/ethnic makeup and income, i.e., houses in areas with lower incomes and/or more racial/ethnic minority households had higher heating EUIs.

- Analysis of fine-scale spatial data from Tallahassee, Florida and St. Paul, Minnesota to explore relationships between EUI and income/race for both electricity and gas energy consumption [Tong et al. 2021].

More Technical Studies

- Hidden energy poverty [Cong et al. 2022]
  - Quantifies energy-limiting behavior, specifically delaying turning on air conditioning
  - Energy equity gap measures difference in when low and high income households start using air conditioning

- Challenges of and solutions to including qualitative understandings of stakeholder preferences within quantitative electricity system models used for sustainable and equitable electricity system planning [Baker et al. 2021]

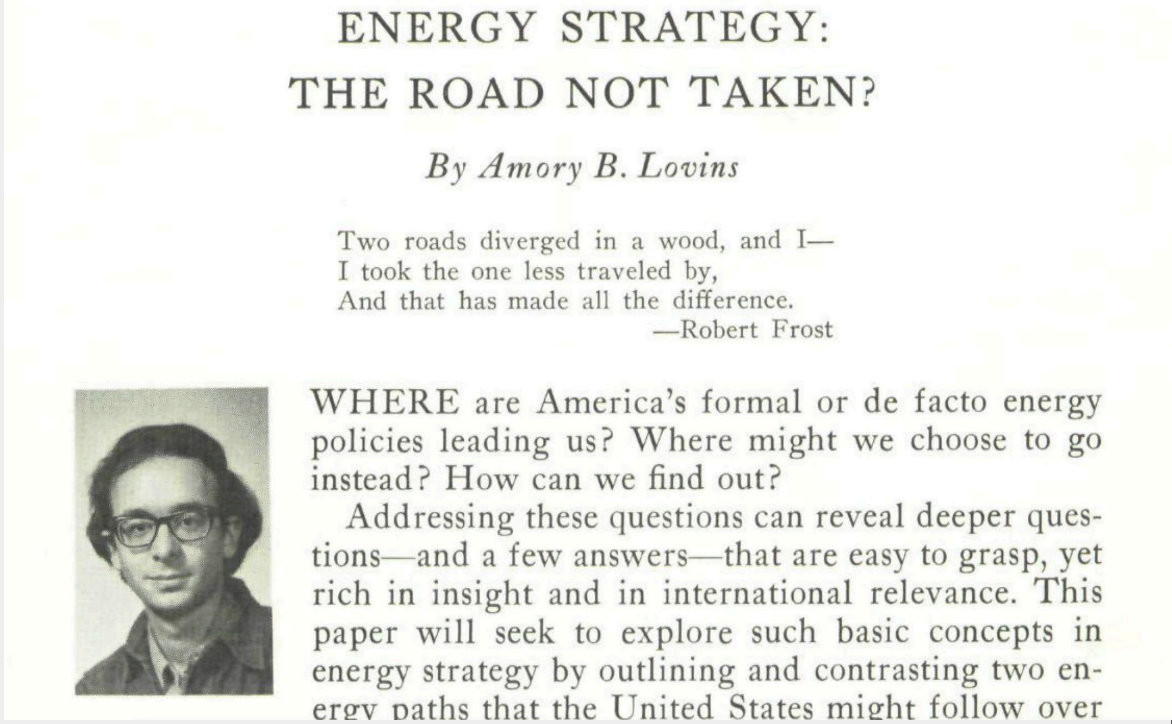
Energy Justice in Power Systems Papers?

- Search for “energy justice” in IEEE Xplore → 4 items!
  - Agent based modeling for electrification expansion [Tarekegne and Rouleau 2019] built upon prior work by [Alfaro et al. 2017]
  - High-level conference panel abstract [Kostyk et al 2011]
  - Growth patterns of solar PV in Connecticut [Holt and Sunter 2021]
  - Just electricity pricing [Mustafaoglu et al 2022]

- Of course, not all power systems papers are published in IEEE. And, of course, not all related research uses the term energy justice.
  - Generation expansion planning incorporating preferences for equity and budget [Nock et al. 2020]
  - IEEE PES PowerAfrica Papers on renewable energy microgrids [Hubble and Ustun 2016; Babayomi and Okharedia 2019; Babayomi et al. 2020]
  - Transitioning remote communities in Northern Ontario, Canada away from diesel to renewable energy resources [Arriaga et al. 2013].
  - Approach to coordinate energy storage with diesel generation for a rural community in the Philippines and how prepaid electricity tariffs can be used to finance storage investment [Porter et al. 2015]
  - … and many many more

Distributed Energy Resources + Energy Justice

- Amory Lovins's seminal 1976 article "Energy Strategy: The Road not Taken?" argues for the "soft" energy technologies – renewable, diverse, flexible, low-technology, and matched in scale and quality to end-user needs.
- Taylor et al. (2016) later linked this argument directly to the need for and benefits of DERs.



ENERGY STRATEGY:
THE ROAD NOT TAKEN?

By Amory B. Lovins

Two roads diverged in a wood, and I—
I took the one less traveled by,
And that has made all the difference.
—Robert Frost

WHERE are America's formal or de facto energy policies leading us? Where might we choose to go instead? How can we find out?

Addressing these questions can reveal deeper questions—and a few answers—that are easy to grasp, yet rich in insight and in international relevance. This paper will seek to explore such basic concepts in energy strategy by outlining and contrasting two energy paths that the United States might follow over

More from Lovins…

“The soft path has novel and important international implications. Just as improvements in end use efficiency can be used at home (via innovative financing and neighborhood self-help schemes) to lessen first the disproportionate burden of energy waste on the poor, so can soft technologies and reduced pressure on oil markets especially benefit the poor abroad. Soft technologies are ideally suited for rural villagers and urban poor alike, directly helping the more than two billion people who have no electric outlet nor anything to plug into it but who need ways to heat, cook, light and pump. Soft technologies do not carry with them inappropriate cultural patterns or values; they capitalize on poor countries' most abundant resources (including such protein-poor plants as cassava, eminently suited to making fuel alcohols), helping to redress the severe energy imbalance between temperate and tropical regions; they can often be made locally from local materials and do not require a technical elite to maintain them; they resist technological dependence and commercial monopoly; they conform to modern concepts of agriculturally based eco-development from the bottom up, particularly in the rural villages.“ [Lovins 1976]

One way we can contribute to energy justice?

- Taylor et al. (2016) do not link back to Lovins argument about the role of “soft” energy technologies/DERs in mitigating inequities and therefore advancing energy justice.

- If we do make this link, it opens up a wide array of research questions that we, as power systems researchers, are uniquely positioned to tackle!

An Energy Justice Research Agenda

- Given the definition of energy justice above, all work we as power systems researchers do to increase the affordability of electrical energy (which can increase access) and/or enable a cleaner energy system (e.g., through renewables) is nominally related to energy justice.

- But how can we place energy justice front and center in our work?

An Energy Justice Research Agenda

1. Equitable electricity system planning

- Most straightforward way of integrating energy justice into power systems research?

- How to define quantitative energy justice metrics that can be used to evaluate simulation outcomes and/or can be embedded within optimization formulations?
  - “cost” of unequal electricity reliability or unequal health impacts due to fuel extraction, processing?
  - should we include constraints to enforce more equitable solutions?

- Do the answers to these questions differ when we consider traditional grid development and expansion versus the development and deployment of DERS?

- How will the distributional impacts of power systems change throughout the energy transition, and how can we steer the transition to achieve energy justice?

An Energy Justice Research Agenda

2. Equitable electricity system operation and control

- How can we embed energy justice metrics within the economic dispatch problem, for example, by penalizing spatially unequal reliability and pollutant emissions outcomes?

- How can we design power system controls to achieve more equitable outcomes, for example, by ensuring that emergency load shedding does not always affect the same neighborhoods?

- The energy transition will lead to the need for fundamentally different approaches to operate and control grids dominated by highly-distributed inverter-interfaced energy resources [Taylor et al. 2016]; how do we embed energy equity objectives within these approaches?

An Energy Justice Research Agenda

3. Equitable DER adoption and coordination

- How can we increase equitable adoption, for example, through the design of innovative business models linking DER adoption and coordination for LMI households?
  - Example: Aggregator owns/operates DERs within homes, delivering contracted services to the homes for a fee, while coordinating the DERs to provide grid services, in turn providing income to the aggregator, some of which is passed on the homeowner.
  - The economics of this model are a function of the ability of the aggregator to provide reliable grid services with the DERs, which is a power systems research topic.

- How to design DER coordination algorithms that do not place additional burdens on LMI households? Can DER coordination also serve to mitigate *existing* inequality, for example, by *increasing* the comfort of LMI households?
  - LMI may be more likely to shift appliance load and vehicle charging to inconvenient times and/or to reduce heating/air conditioning to uncomfortable temperatures.
  - LMI homes may choose to offer more flexibility to the utility or aggregator.

An Energy Justice Research Agenda

4. Equitable electricity rate and demand-side management program design

- Topic often explored by economists, e.g., [Borenstein et al. 2021] explored how electricity rates in California should change to ensure equity through the energy transition.
- Also appears in power systems literature (new IEEE PES Transactions…)
  - Rate and demand-side management program designs affect electricity consumption patterns, which directly affect the operation of power grids – inherently connected with our work.

- How proposed “equitable” rates affect consumption, and in turn operations and control, and subsequently grid costs, reliability across space and time, and health impacts across populations?
- Can we design equitable rates through formulations that specifically consider these dependencies?
- If we agree that a basic level of electricity access is a human right [Walker et al. 2016], how can we design electricity rates to provide that level for free or very low cost while ensuring sufficient cost recovery for the utility and dynamic stability?
- How should we consider energy justice goals within demand response programs?

An Energy Justice Research Agenda

5. Recommender systems for electricity rates and demand-side management programs

- More to come!

6. Reducing bias in data-driven algorithms for power systems

- National Renewable Energy Laboratory Workshop on Responsibly and Trustworthy AI in Clean Energy

NSF Smart & Connected Communities Project

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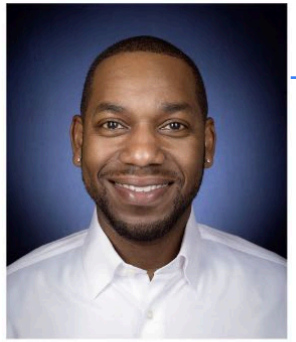

Tony Reames
(PI - On Leave)
UM School for Environment and Sustainability

→ Founded UM Urban Energy Justice Lab

Now Senior Advisor, Office of Economic Impact and Diversity, DOE

UNIVERSITY OF MICHIGAN

FRIENDS OF PARKSIDE
Working to make our community a great place to live, work, and do business!

Jefferson East, Inc. Go East

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eco WORKS

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“Our premise is that energy is a basic human right. With a better understanding of energy consumption, we can determine if there is a free block of ‘essential’ energy that everyone should get—and if not everyone, then those least likely to be able to afford it.” Dr. Tony Reames

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Research Questions

What is the efficacy of a neighborhood-embedded energy case management intervention to facilitate reducing household energy insecurity through i) increased energy program utilization, ii) reduced energy consumption, and iii) reduced energy burden?

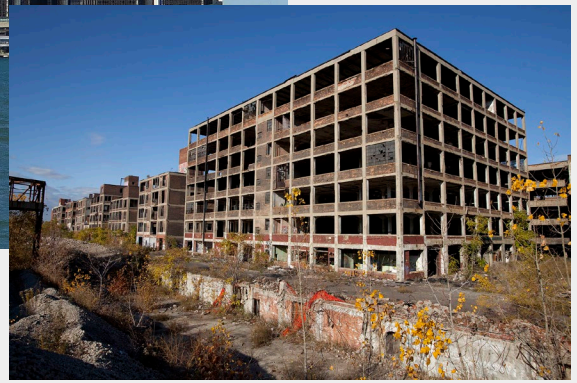
How can integrated social and technological methods help determine the amount of electricity that should be considered a basic right in LMI households and communities?

How can integrated social and technological methods facilitate development of new electricity rate paradigms that achieves the following objectives:

i) a free level of basic electricity,
ii) supplemental electricity priced to cover utility provider costs,
iii) dynamic stability, and
iv) rates that encourage energy efficiency and renewable energy investments?

Detroit

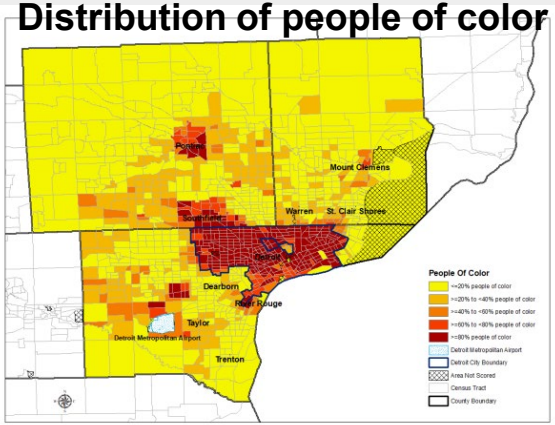
Former Packard Plant



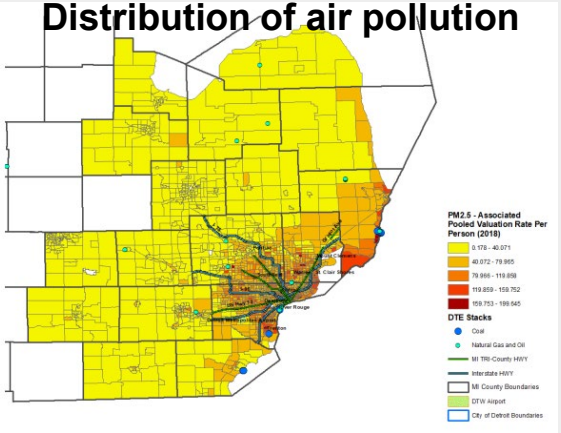
Current population 639,000; down from 1.85 million in 1950

Disparities in Metro Detroit

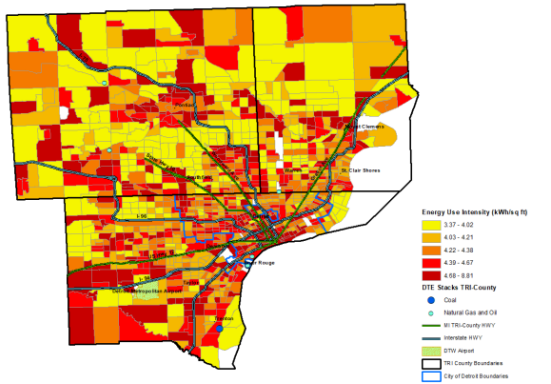
Distribution of people of color



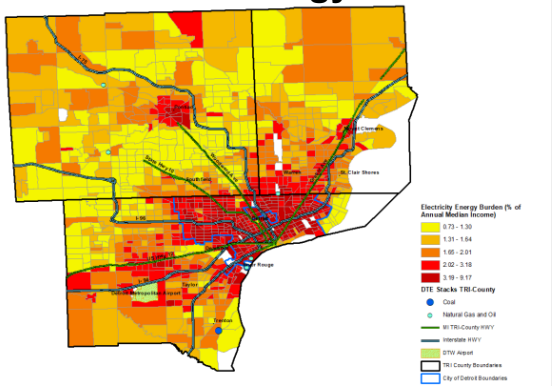
Distribution of air pollution



Distribution of EUI



Distribution of energy cost burden



N. Ignaczak, “MPSC considers requiring utilities to account for public health costs of future electricity generation”, *Planet Detroit,* May 7, 2021. https://planetdetroit.org/2021/05/mpsc-considers-how-to-account-for-the-inequitable-public-health-costs-of-future-electricity-generation/

Energy Case Managers

- Community members who work directly with LMI households to help them access assistance programs, efficiency programs, and rate programs
- Energy Case Manager Intervention – enrolling 100 LMI households in two Detroit neighborhoods
- The engineering part – how much better can the case managers do if they have data-driven tools to help them provide their guidance and recommendations?
  - Smart meter data
  - Detailed household appliance data
  - Sub-metering data

75 homes!

Gibran Washington
Energy Educator
EcoWorks

Rebecca Nikodem
Housing Sustainability Manager
Jefferson East, Inc.

PECAN STREET

Technical Challenges

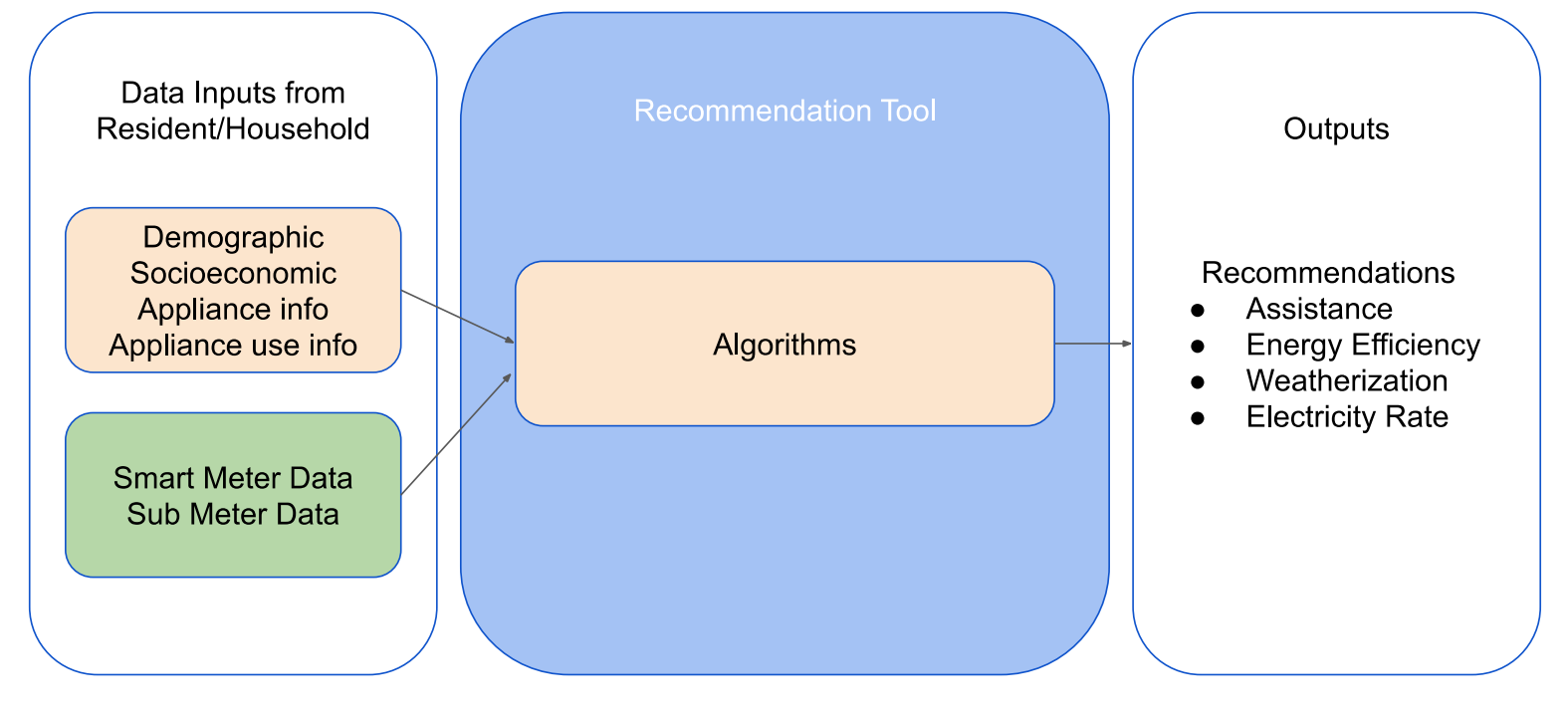
- Most of the high quality, high frequency datasets available to researchers do not include data from low-to-moderate (LMI) income households
- Tools and algorithms designed without this in mind may not work as efficiently on LMI houses
- Many of the homes in our study do not have AC, central or window units, so existing techniques for weather normalizing their data do not work as well

Ongoing work

- Comparing Detroit LMI homeowner load profiles to “typical” profiles – will tools that work on “typical” homes work here?

- Extending/developing recommendation tools
  - What programs exist?
  - What qualifies a home for these programs?
    - Many homes don’t qualify because their home doesn’t meet basic requirements of “because of significant repair needs, health or safety concerns, or exceedingly high repair costs.”
    - Laura Benshoff, “A low-income energy-efficiency program gets $3.5B boost, but leaves out many in need”, NPR News, 2022 https://www.npr.org/2022/05/13/1096114029/low-income-energy-efficient-weatherization-program-3-5b-needy
  - How can we leverage their data?

Energy Case Manager Tool



Ongoing work

- Data-driven algorithms
  - For energy assistance/efficiency programs…
    - Model the household's electricity consumption, leveraging available household data to parameterize the models
    - Simulate how the household's electricity consumption would change if the house were weatherized, old appliances were replaced, etc.

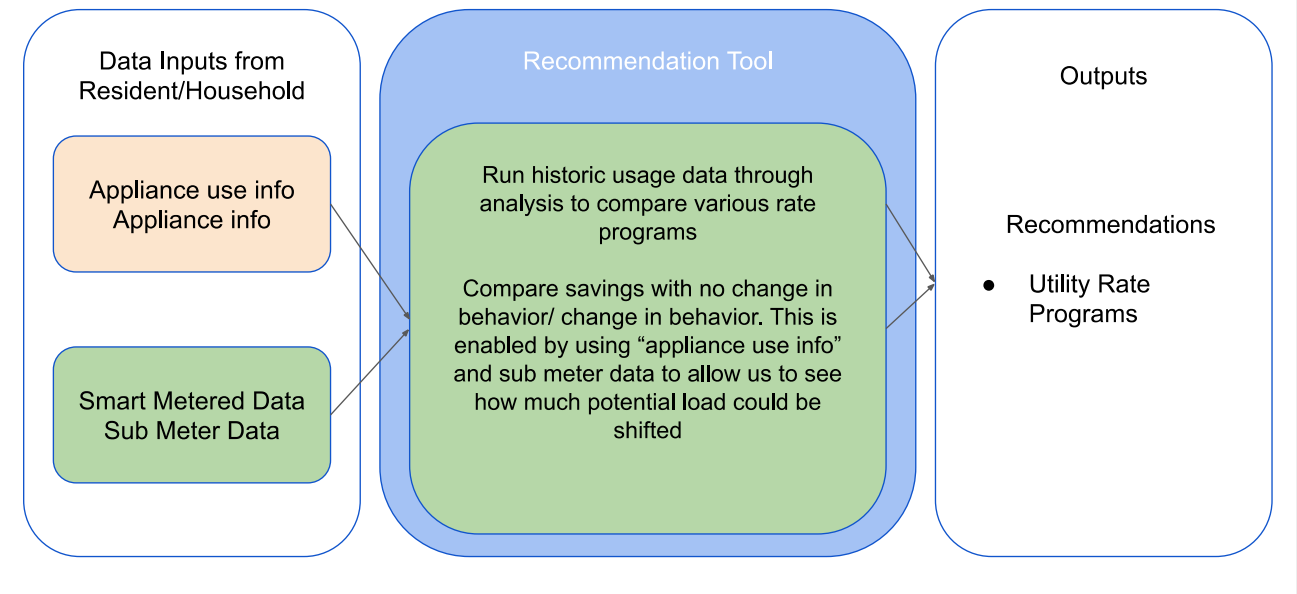
    → Non-intrusive load monitoring / energy disaggregation algorithms are helpful when submetering data is unavailable

  - For electricity rate programs…
    - Run historic consumption data through alternate rate structures to determine whether homes would save money simply by switching to another rate
    - To estimate the benefits of a new rate plus behavioral change, one can again use models to simulate how the household's electricity consumption would change

While modeling the *impact* of behavioral change on electricity consumption is difficult, modeling the behavioral change itself is much much harder!

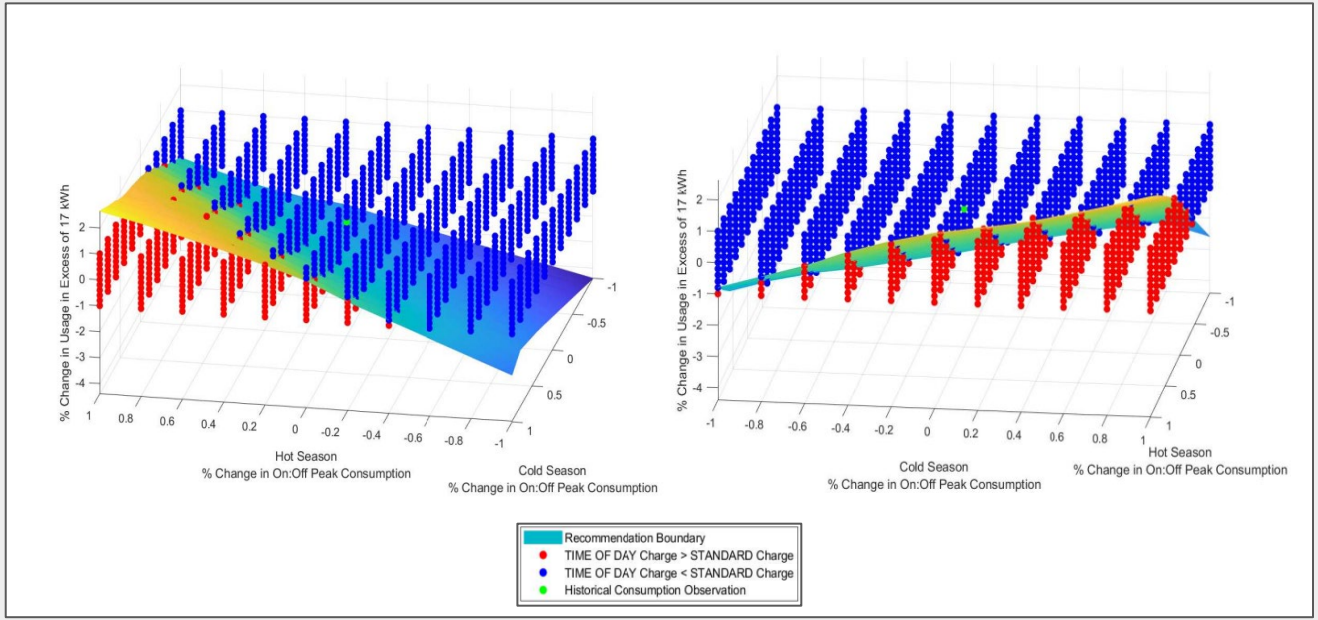
Estimating Recommendation Confidence

Consider a rate plan recommender…



- Given that LMI households are often on fixed budgets, we’d also like to give a confidence measurement of our recommendation.
- The rate plans DTE Energy offers require a 12-month commitment, so we would like to look at if they would save money over the course of the 12 months as well as month to month consistency.

Estimating Recommendation Confidence

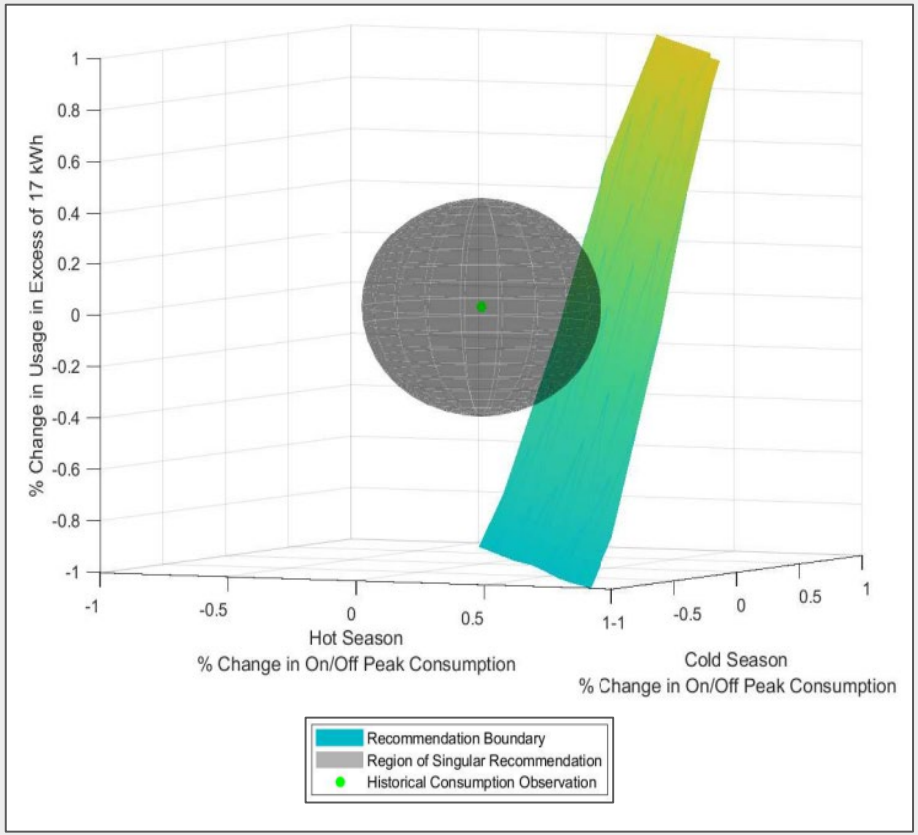


Left: Recommending the rate plan of lowest cost is a function of the load characteristics. The axes are in percent change with the reference point being the load characteristics observed in historical data.

Right: The surface intersecting the mesh visualizes an estimate for the boundary at which further deviations from the historical data would result in recommendation different from that given for the historical data.

Estimating Recommendation Confidence

Spherical region with a radius constrained by the minimum distance between the origin (denoted by the green point) and the recommendation boundary. This distance can be interpreted as the minimum deviation of future consumption from historic observations required to result in a recommendation potentially being unsuitable for the household.



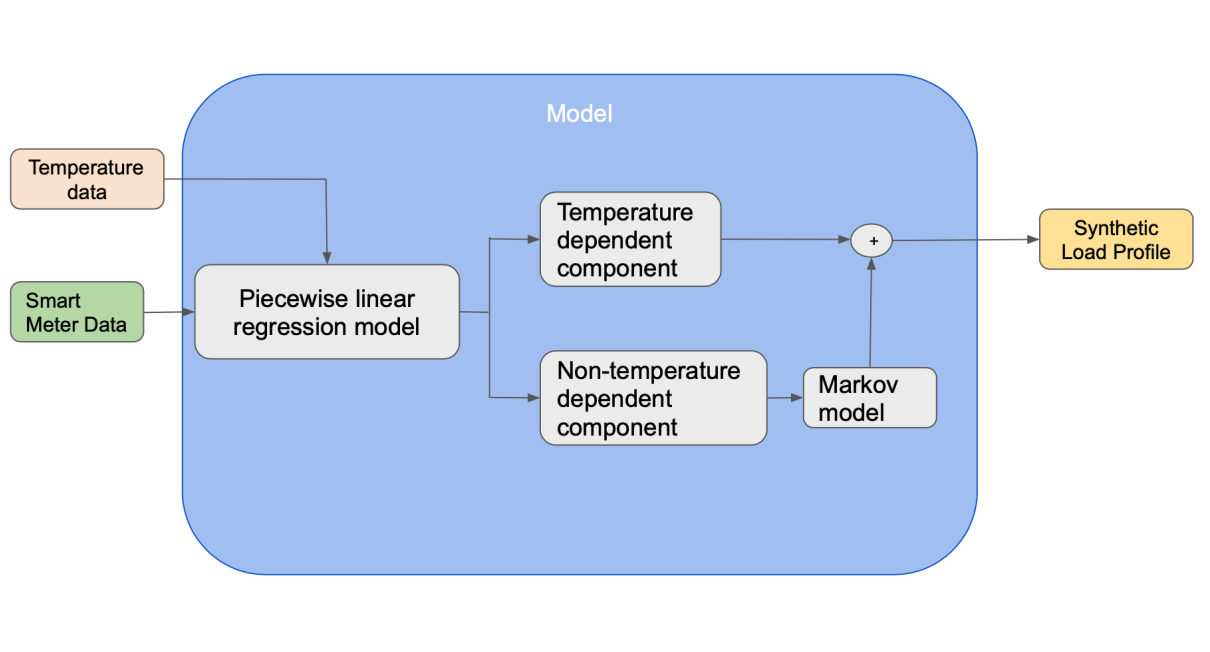
How do we model individual homes?

- We would like to be able to create an hour-by-hour model of a customers energy use that can we can modify to help see what sort of changes efficiency upgrades, behavior changes and weather has on energy usage.

- Currently adapting a method first proposed by Damiano Toffain
  - D. Toffanin, (2016). *Generation of customer load profiles based on smart-metering time series, building-level data and aggregated measurements.* Swiss Federal Institute of Technology (ETH).

- This method was used to to model consumption in buildings that did not have smart meters in Basel, Switzerland using the AMI data from buildings in the city that did.

Synthetic Load Profile Creation



By separating out the temperature dependent and non-temperature dependent load we can create variations of a person's load profile based on their own historic data.

Then by using a Monte Carlo simulation we can see if variations of load profile change the recommendation of rate plan.

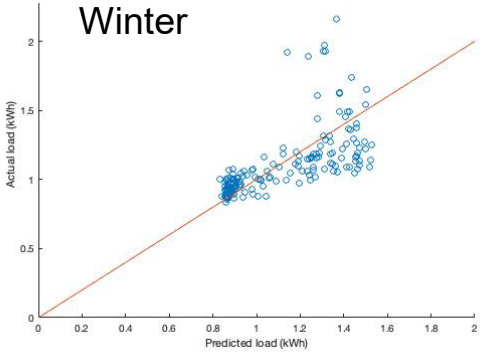
Limitations of this Approach

- The ideas of using regression and Markov chains to model energy usage are not new, e.g., Bourdeau et al. *Modeling and forecasting building energy consumption: A review of data-driven techniques*. Sustainable Cities and Society, 2019.
- We have found, as others have found, that modeling an individual homes energy use is difficult in comparison to more automated commercial buildings.
- A residential load profile fluctuates much more than aggregate load profiles (averaging!) or commercial load profiles (automation!). Capturing this behavior is very difficult.

Modeling Load with Piecewise Linear Regressions

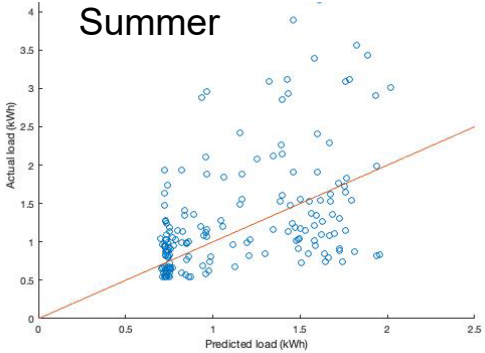
Actual vs predicted load

Winter



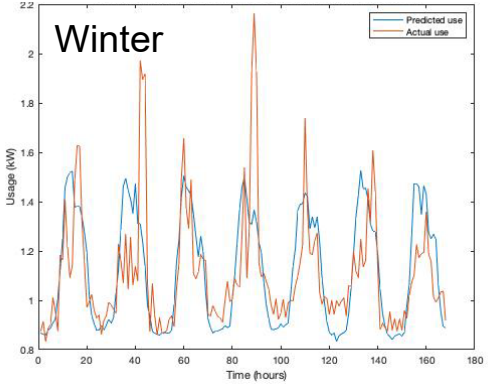
Actual vs predicted load

Summer



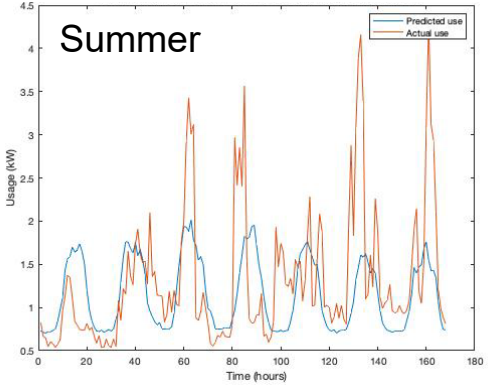
Time series prediction

Winter



Time series prediction

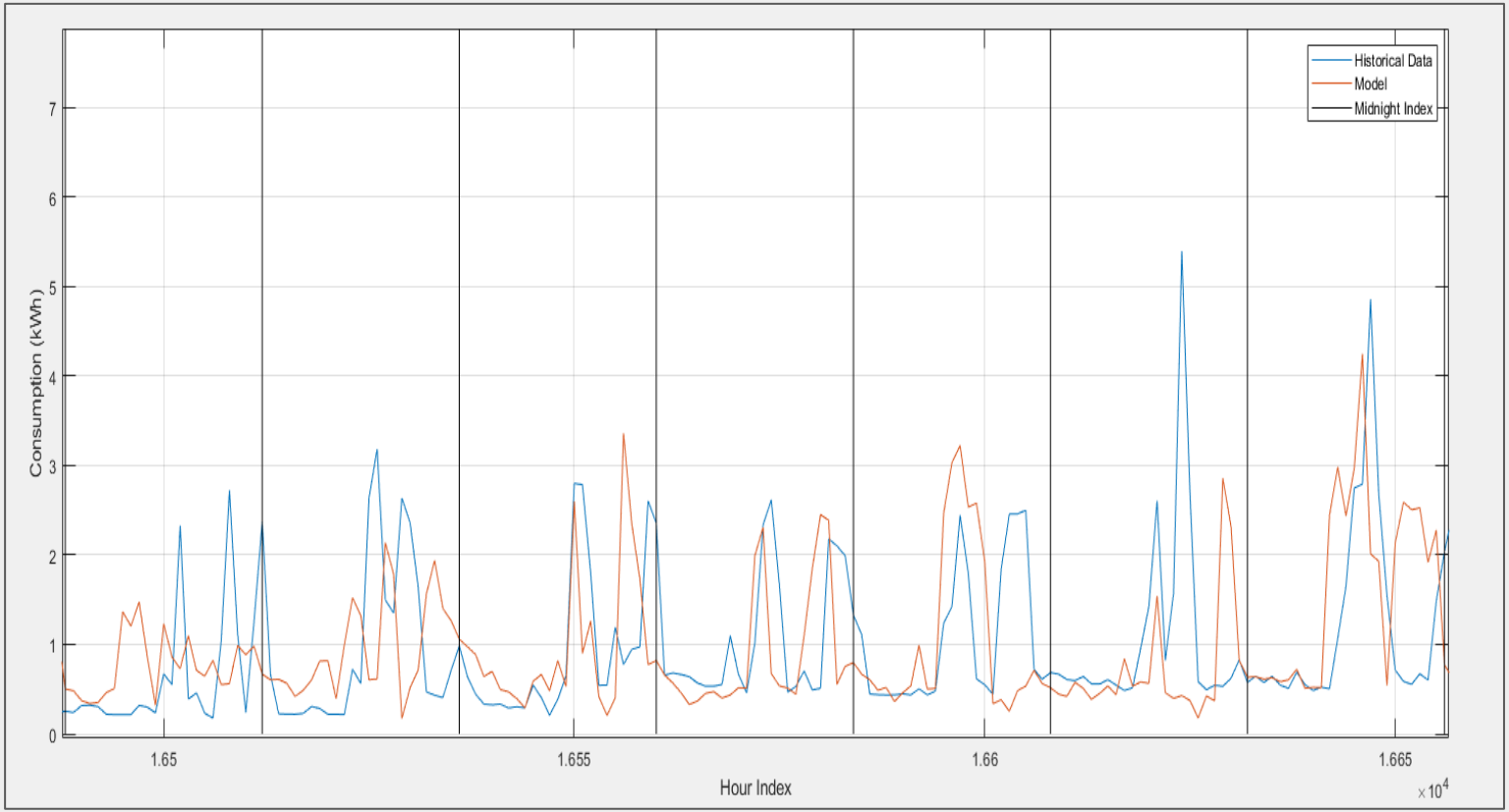
Summer



$$L_o(t_i, T(t)) = \alpha_i + \Sigma^8_{j=1} \beta_j T_{c,j}(t_i)$$

Using the formula shown above for the predicted occupied load. Where α is a time of week indicator and each β_j is a temperature component parameter.

Synthetic Load Profile



Using a state transition matrix based on the time of day and current energy use a Markov Chain Model was used to simulate a synthetic profile for a week.

Conclusions

- Power system researchers have a unique role to play in supporting and directly contributing to energy justice
- To make an impact, we must do this work in collaboration with social scientists, and ideally community-based stakeholders
- And we must be willing to learn new things!
  - IRB Applications & Amendments…

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