Multi-Sector Modeling of the Future Energy Systems

Yixing Xu, Former Research Director at Breakthrough Energy


Every Year, The World Adds
51 Billion Tons of Greenhouse Gases
to the Atmosphere

We need to get to zero

Every year, the world adds approximately 51 billion tons of greenhouse gases to the atmosphere, trapping heat and driving up global temperatures. The only way to avoid the worst impacts of climate change is to stop adding greenhouse gases by 2050.

Getting to Zero

Getting to net-zero will be an enormous challenge. It means transforming virtually every activity in modern life and every major sector of the economy: electricity, agriculture, manufacturing, transportation, and buildings. Yet we're optimistic that the world can rise to this challenge.

GETTING TO ZERO REQUIRES

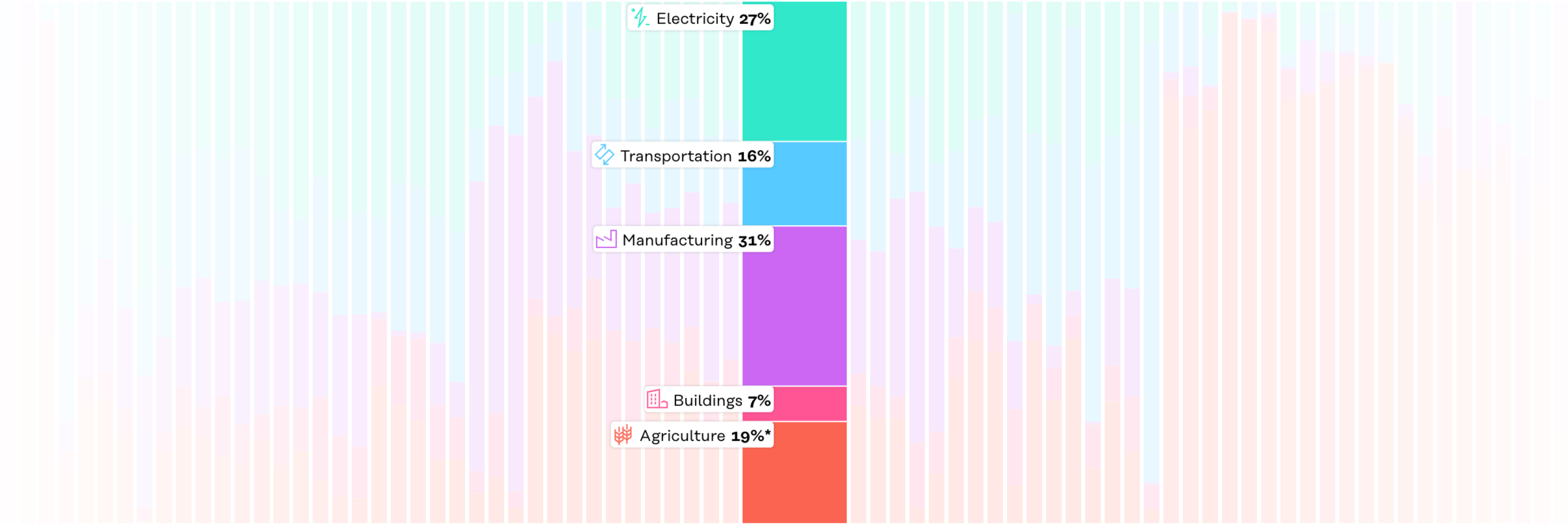
Understanding the problem

Developing solutions

Working together

Emissions

Global

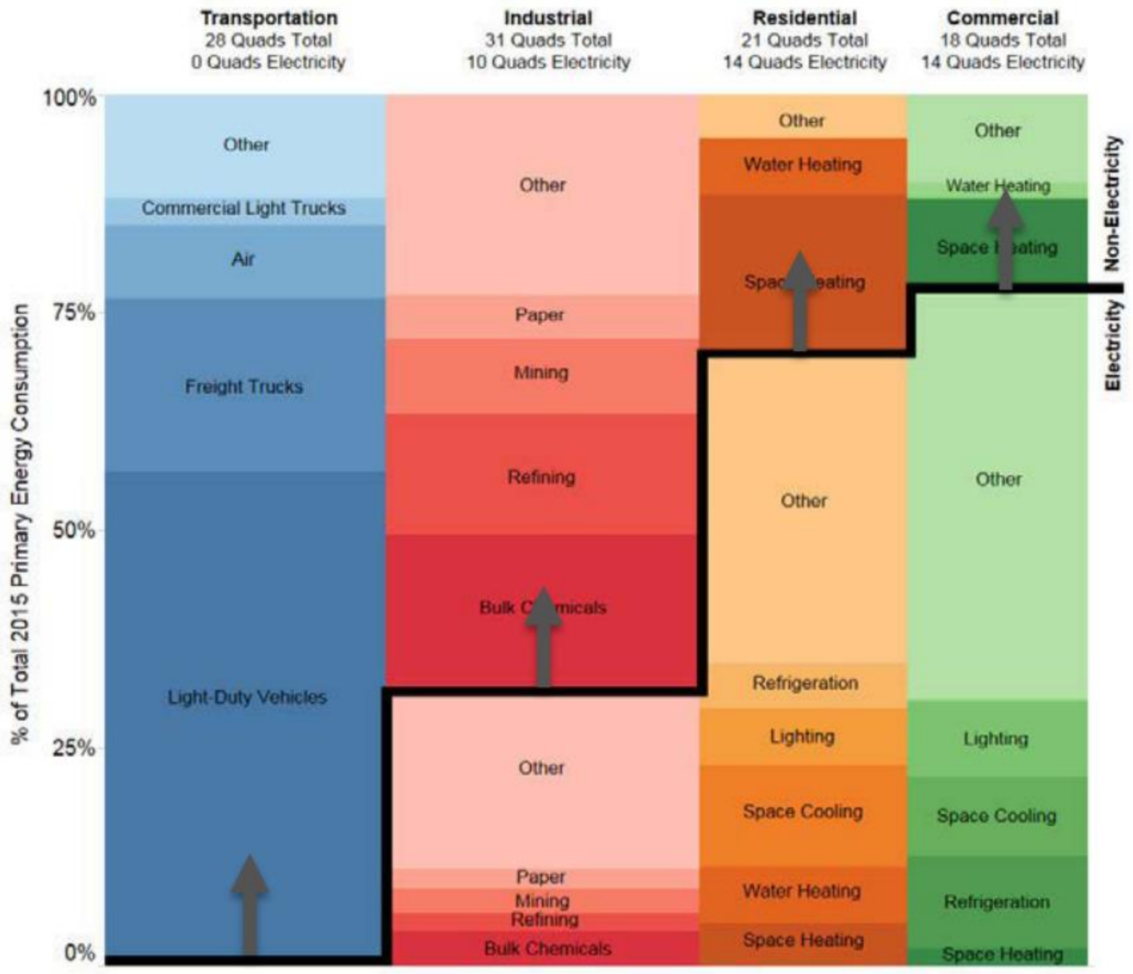


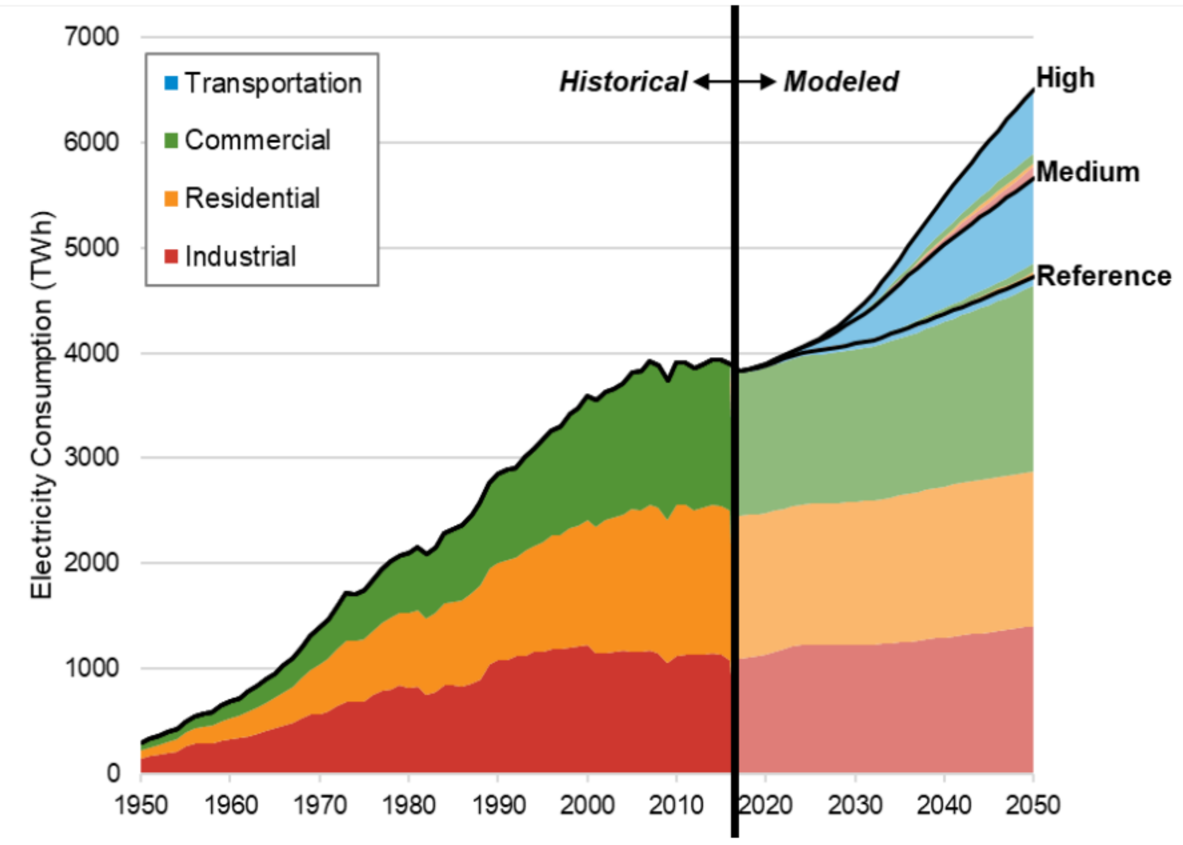
*includes **1.9k mmt CO_2** from Land use and Forestry

DEFINING THE PROBLEM

The Five Grand Challenges

Electrification and Energy Demand till 2050

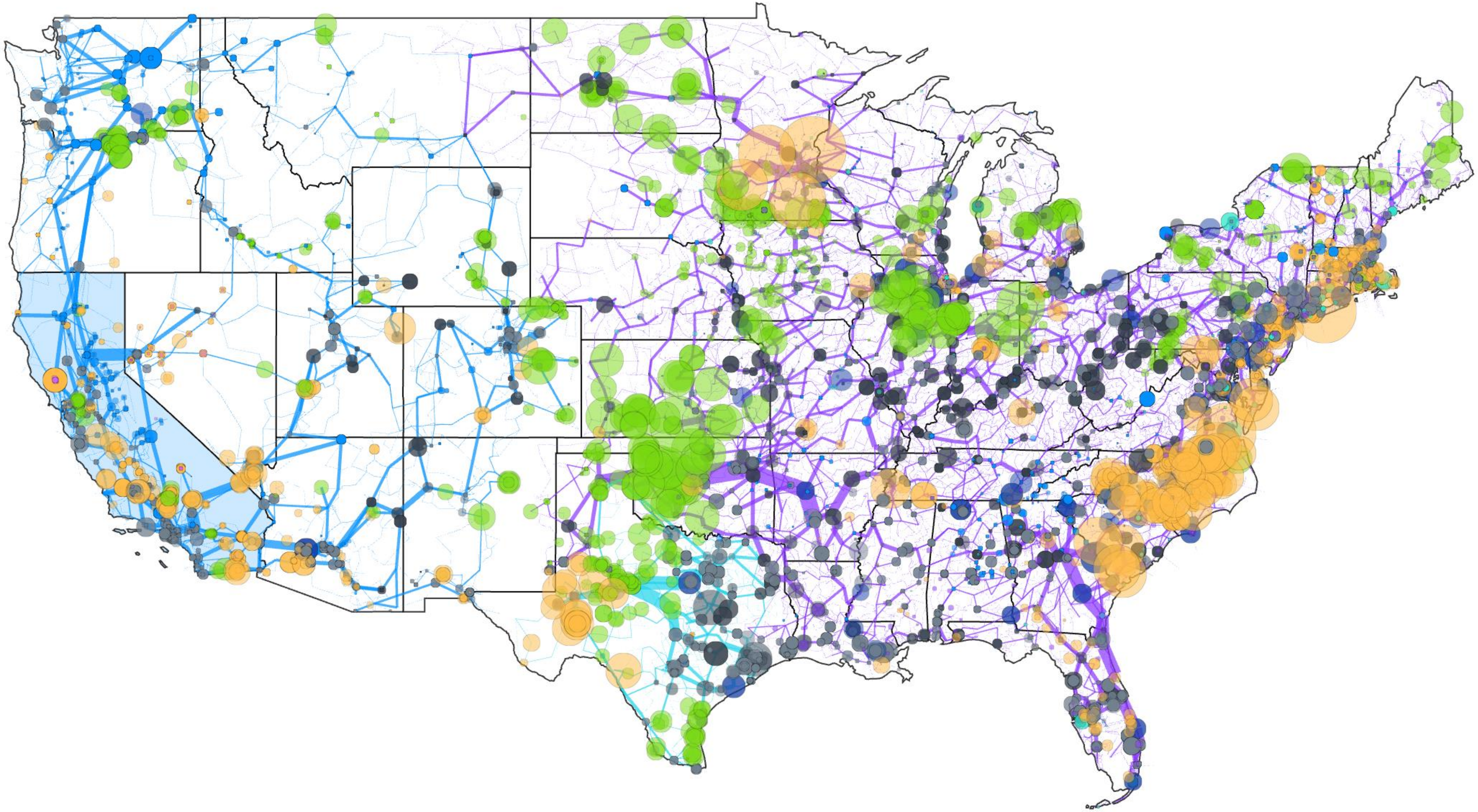




Greater electricity consumption

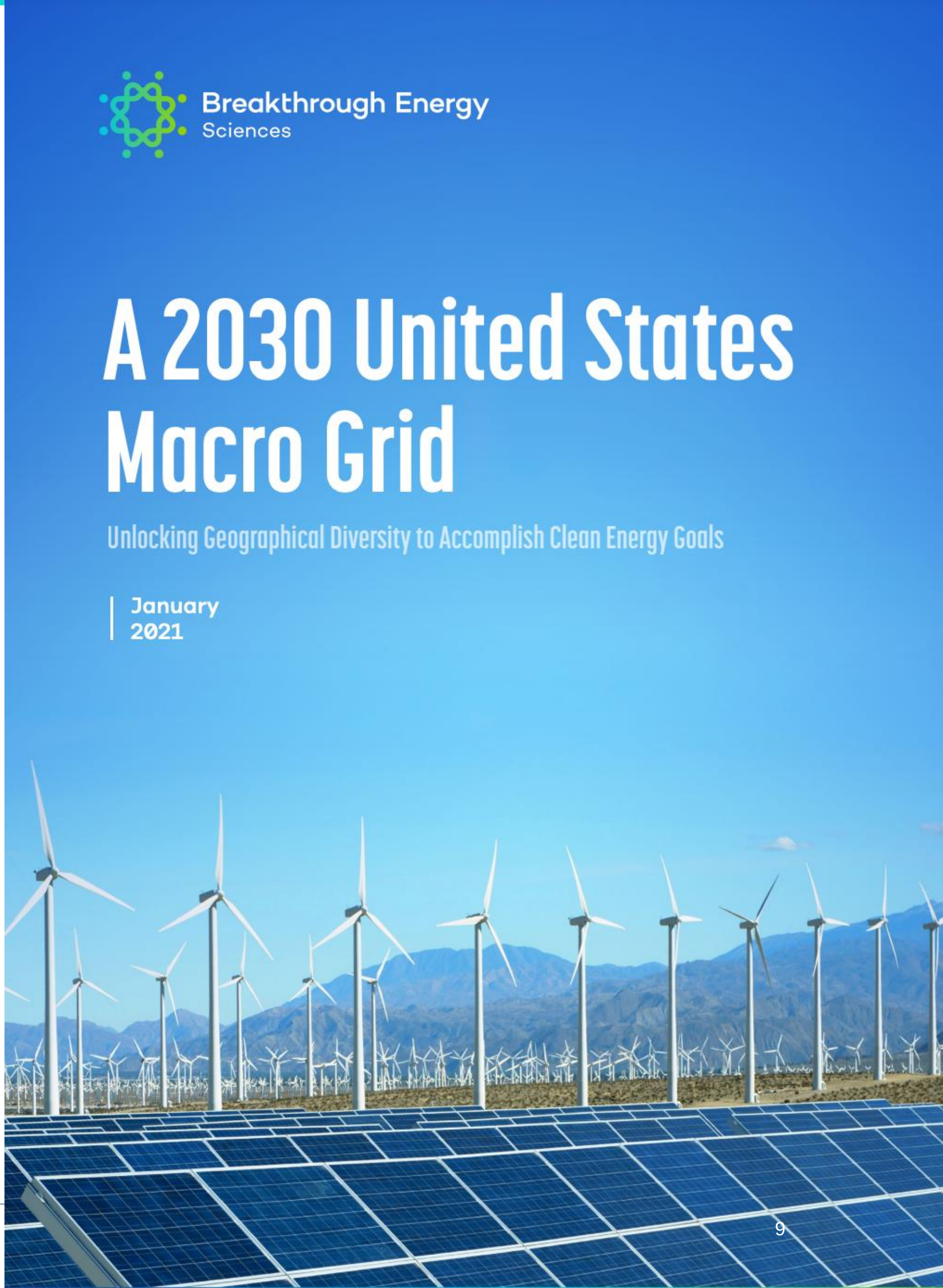
Source: NREL

How to Build a Future Energy System

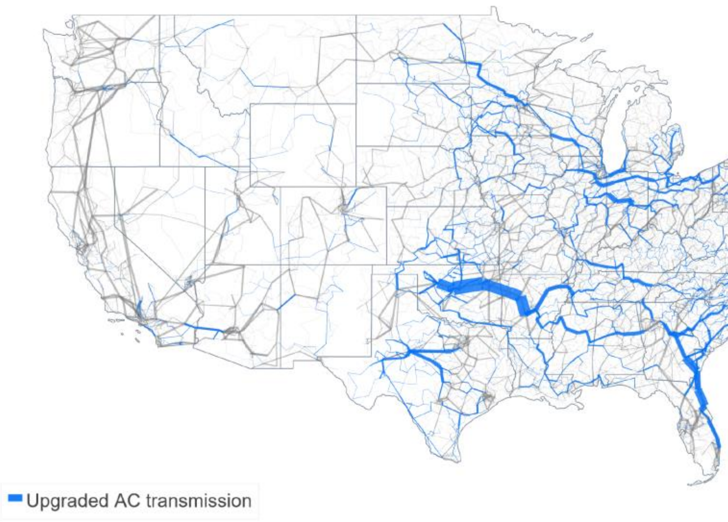


Macro Grid Studies

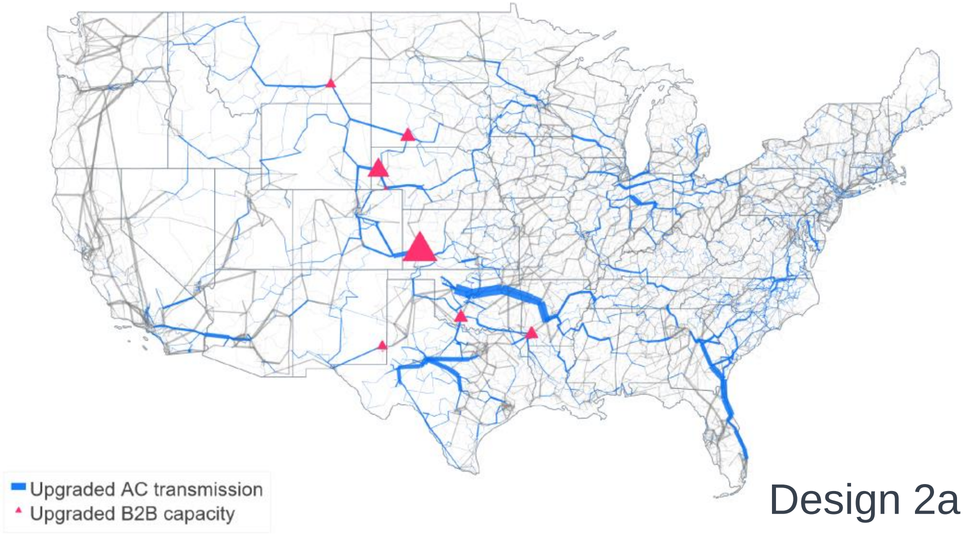
- **Meeting ambitious clean energy goals will require significant increases in transmission. What should that transmission buildout look like?**
- **Four network designs, modeled after NREL Seams Study**
  - **Design 1**: AC transmission buildout only
  - **Design 2a**: Increase HVDC back-to-back (B2B) converters at ‘seams’, plus AC transmission
  - **Design 2b**: Increase HVDC B2Bs, plus three new HVDC lines, plus AC transmission
  - **Design 3**: Sixteen new HVDC lines, plus AC transmission



Macro Grid – Example Designs

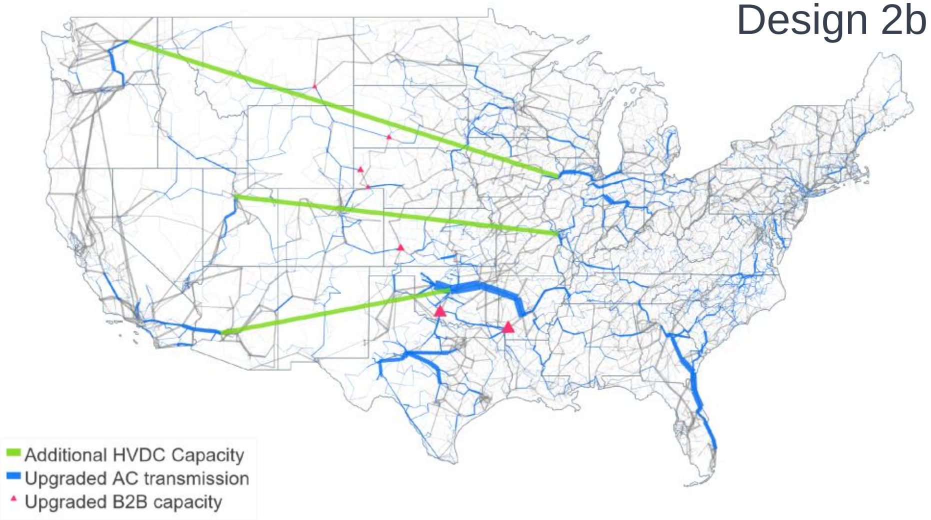


Design 1

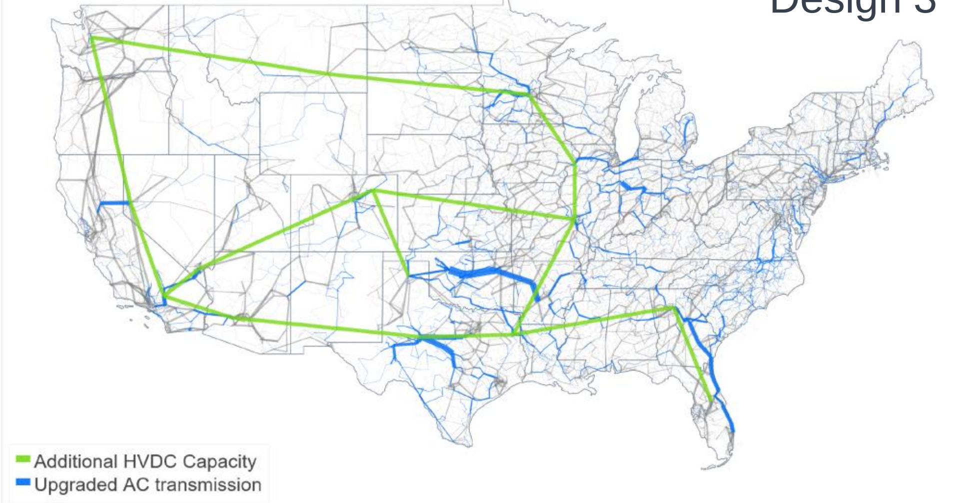


Design 2a

Design 2b

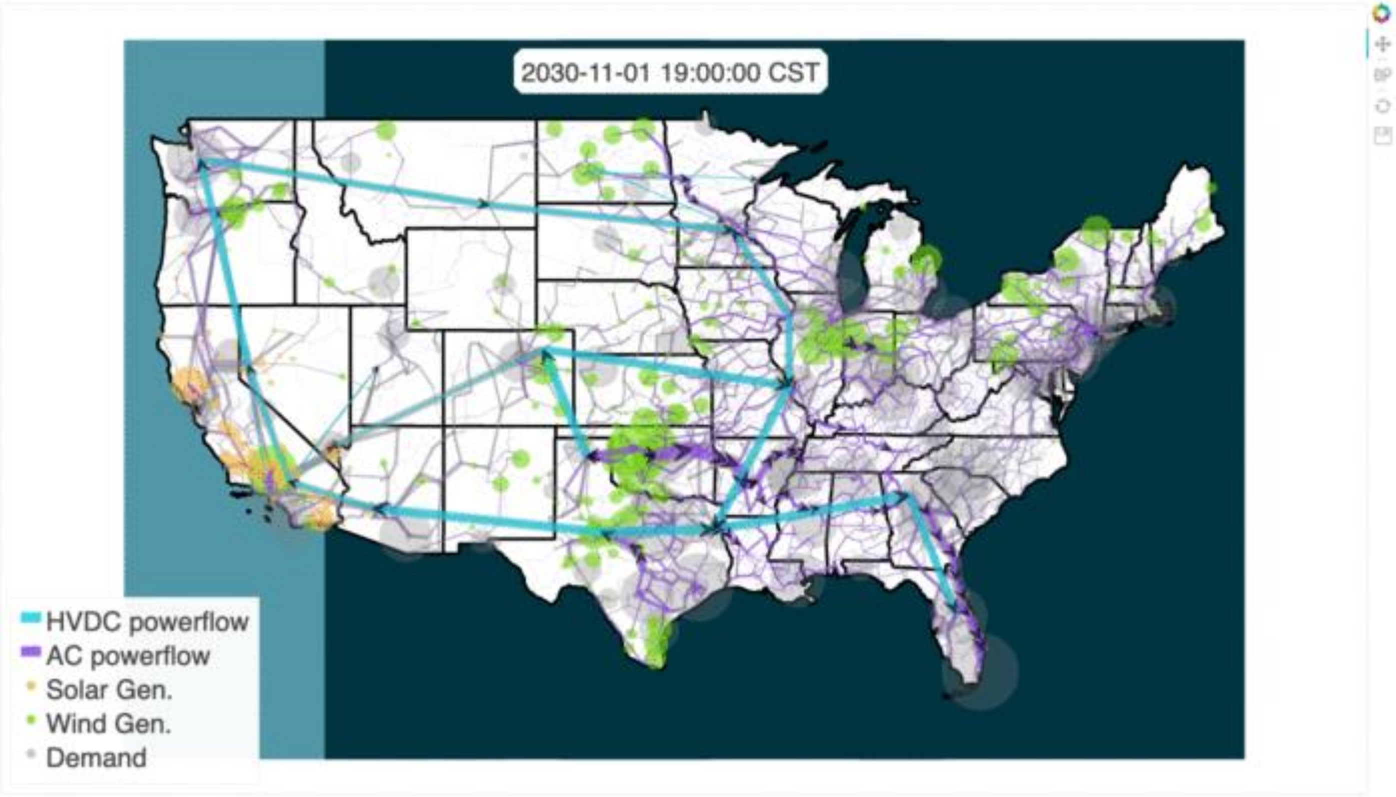


Design 3



Macro Grid – Power flow in Design 3

- **HVDC overlay and AC Transmission upgrades**
- **How much?**
  - 16 new HVDC lines, 8GW each
  - 69 terawatt-miles of AC upgrades, equivalent to a 23% increase in capacity, compared to the current grid
- **Where?**
  - Connects the three interconnections
  - Oklahoma to Arkansas and the HVDC overlay (large wind buildout needs to get to demand)



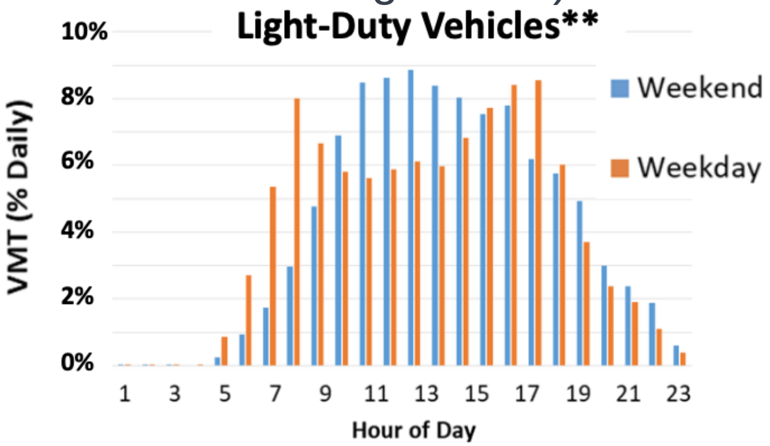
Model Transportation Electrification to Understand Its Impact

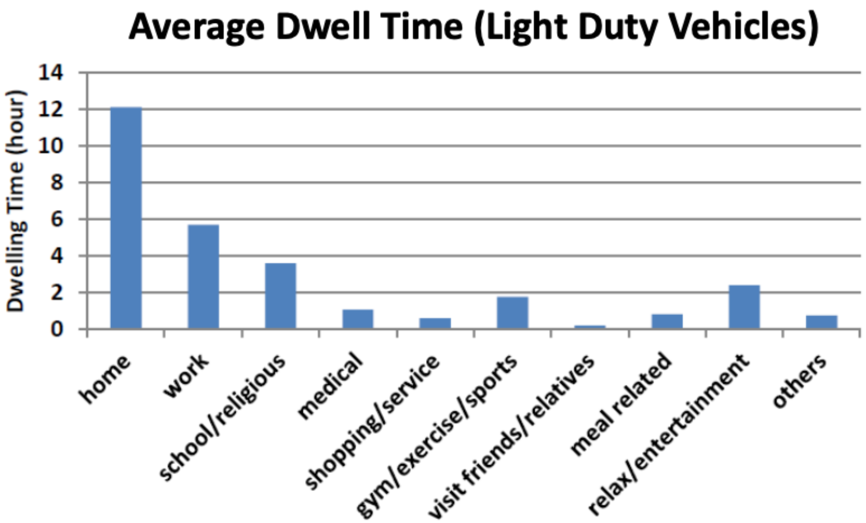
Goal: Estimate on the road electric vehicle charging in the future

High resolution: all urban (481) and rural areas (48) hourly charging demand

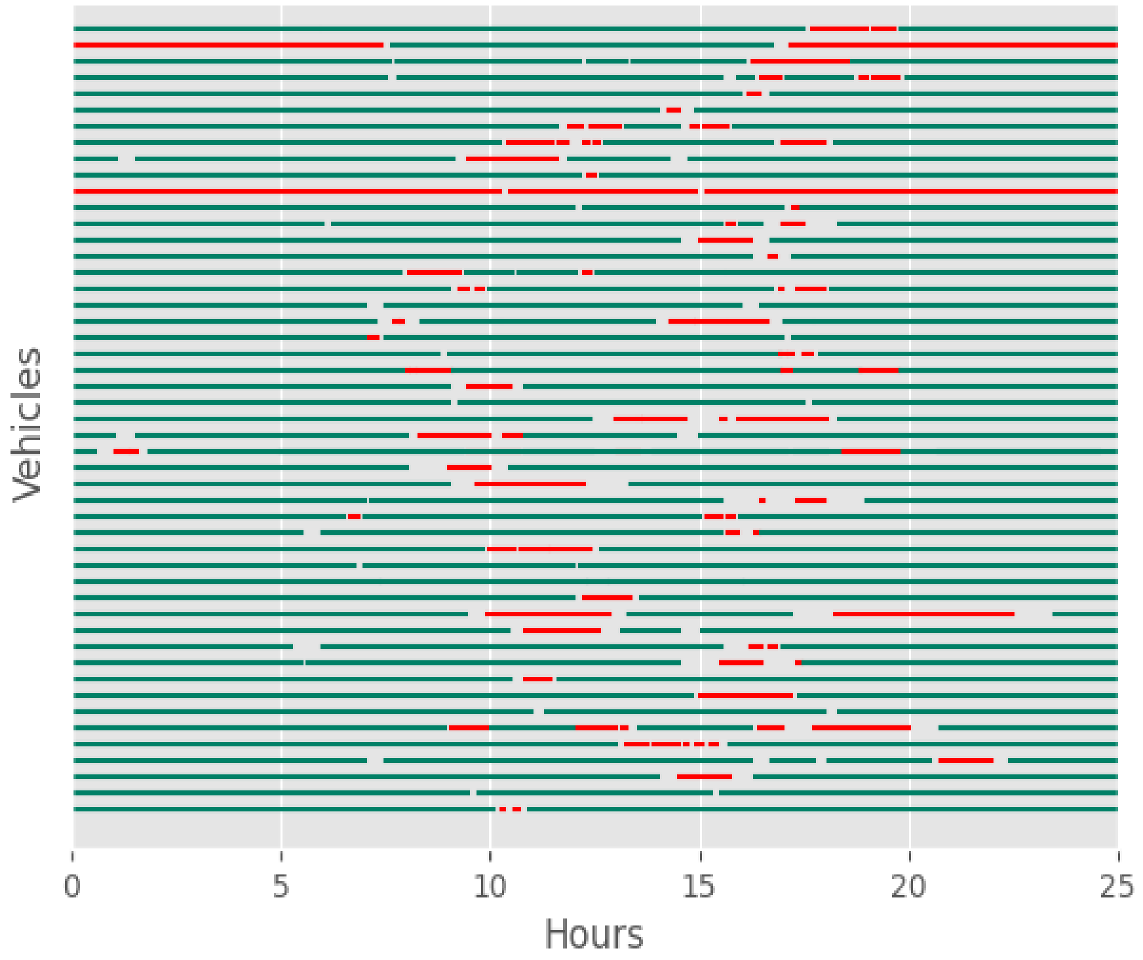
Based on National Household Travel Survey trip data (half a million driving events)

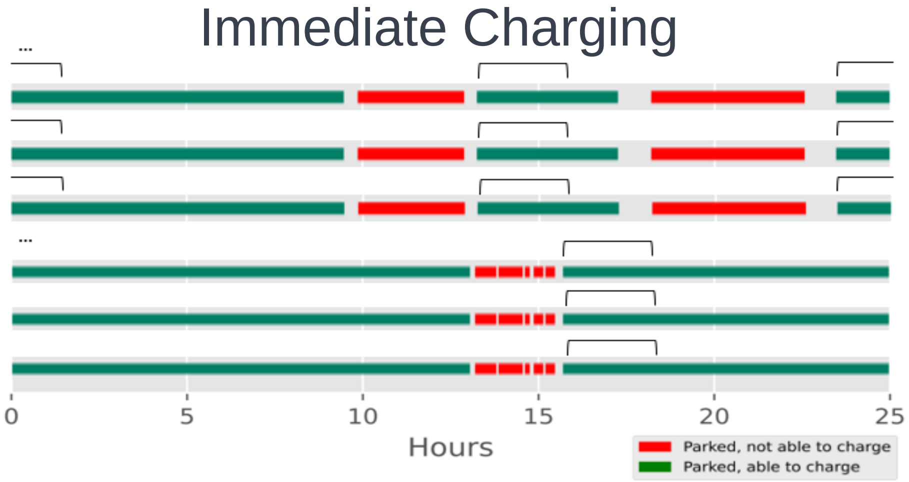
- **Light-duty vehicles have a bi-modal distribution of VMT and trips on weekdays**
- **Data sourced from National Household Transportation Surveys (NHTS)**
- **Dominant LDV dwell locations: Home (~45%) and Work (20%)**
  - **Charging level options at home: Level 1 and 2**
  - **Public charging: levels 1-3**

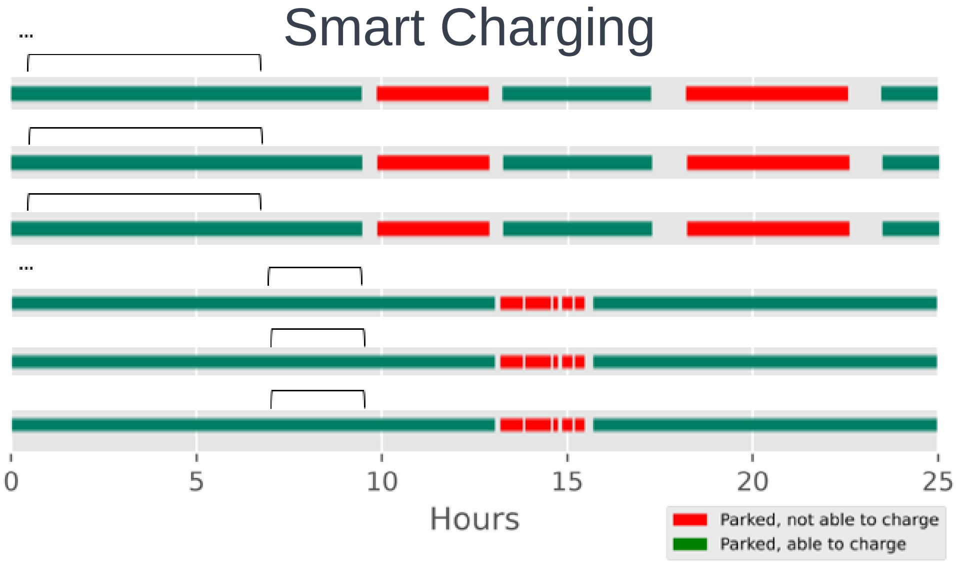




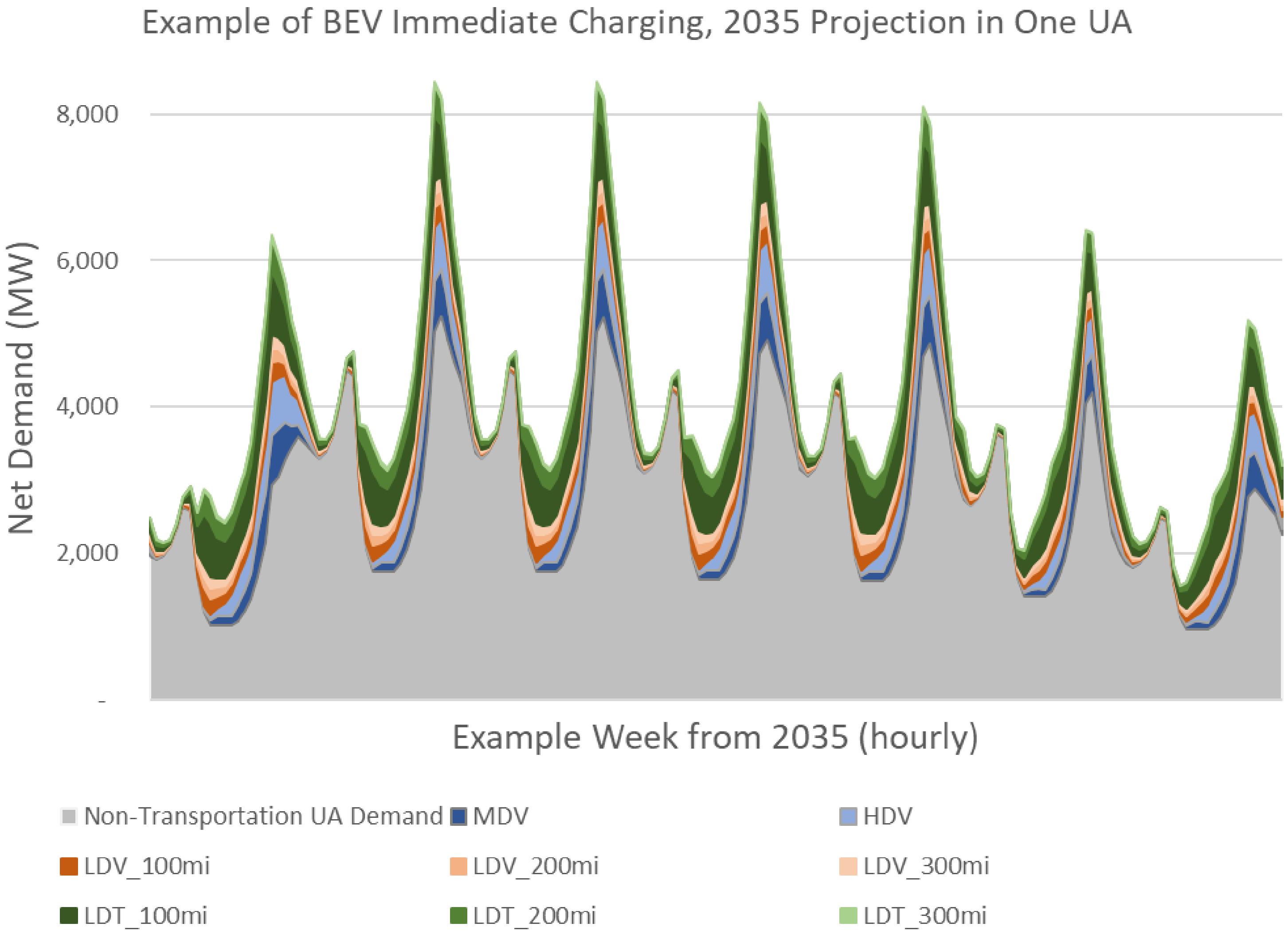
Approach: Model Vehicle Driving, Parking, and Charging Patterns in Immediate Charging and Smart Charging Mode Using Real World Trip Data



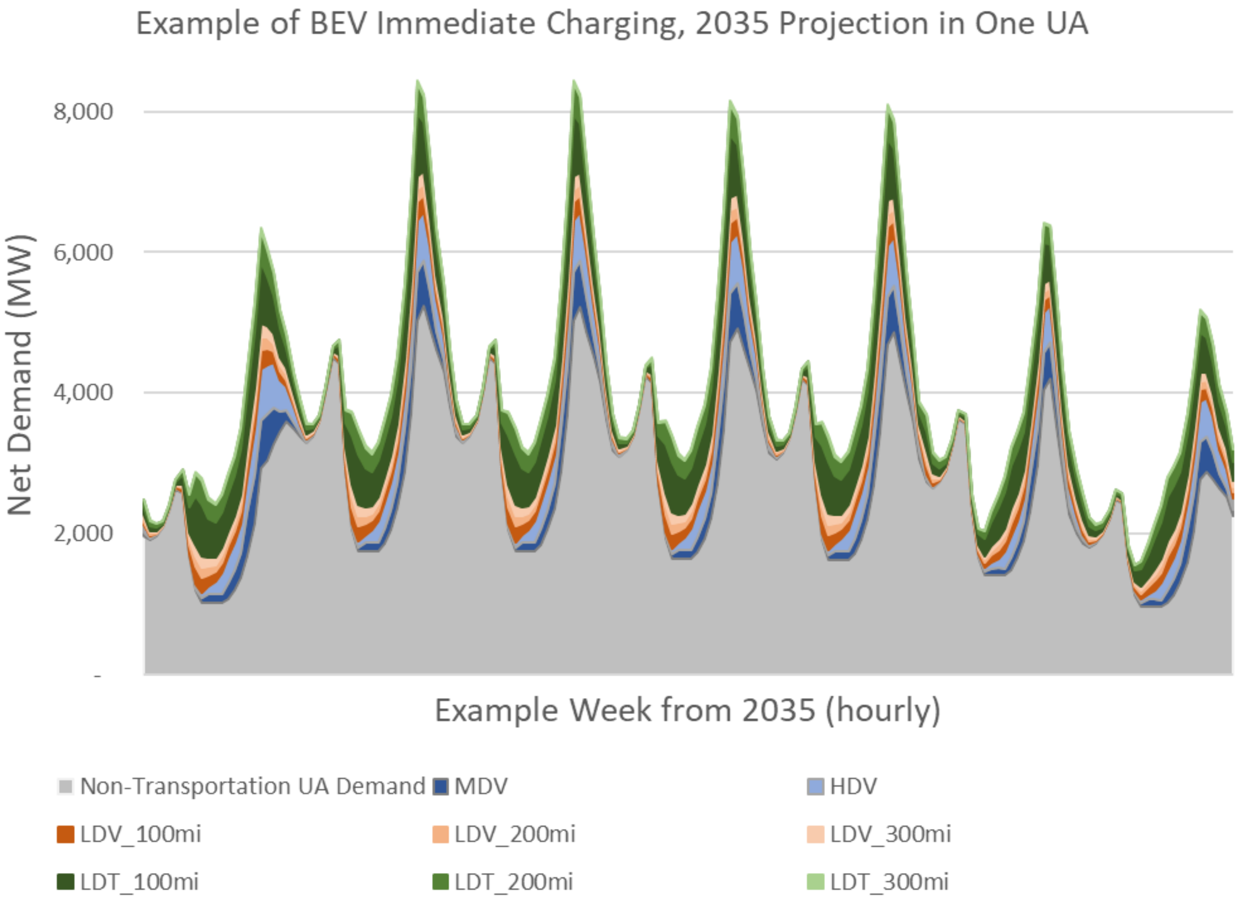


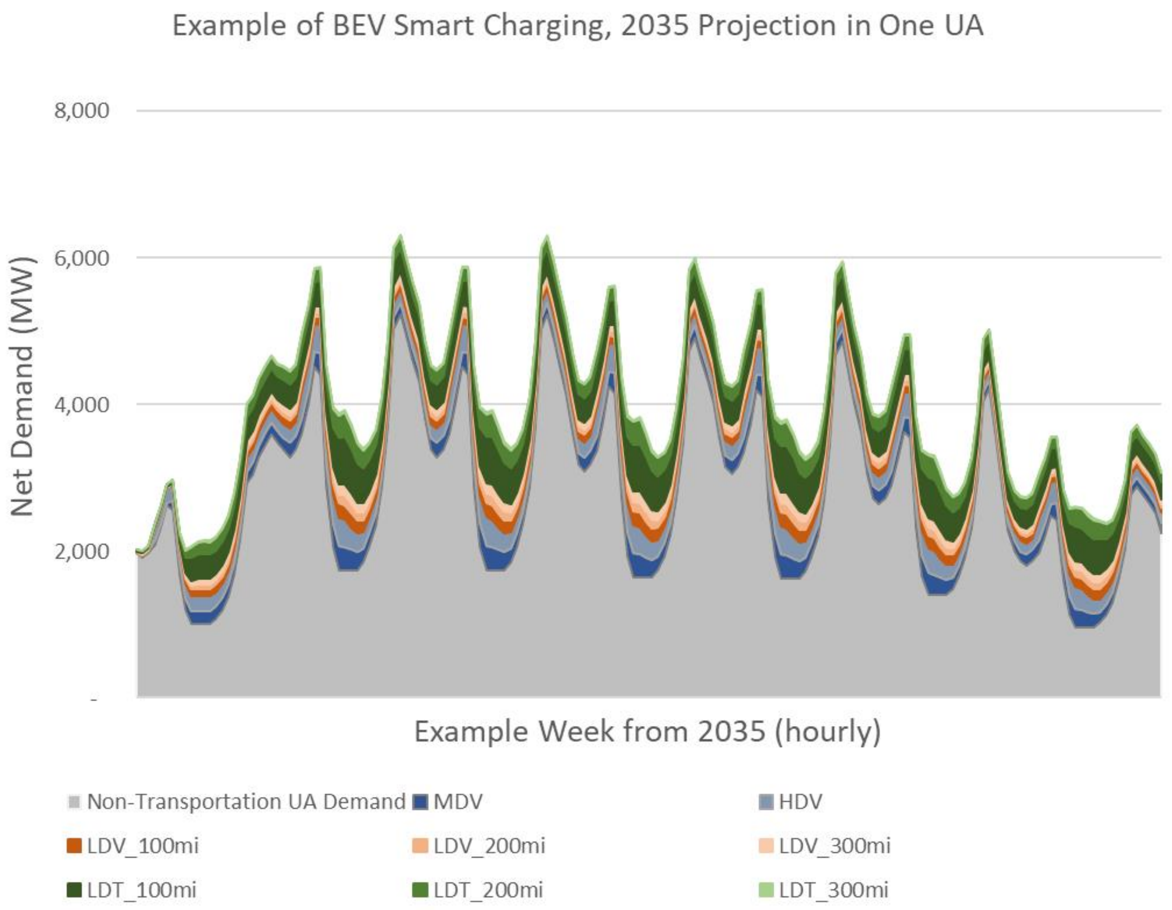


Transportation Electrification Could Bring Down the Grid If Charging Not Managed Intelligently



Smart Charging Takes Advantage of Cheap Renewable Energy and Poses Minimal Stress on the Electric Grid

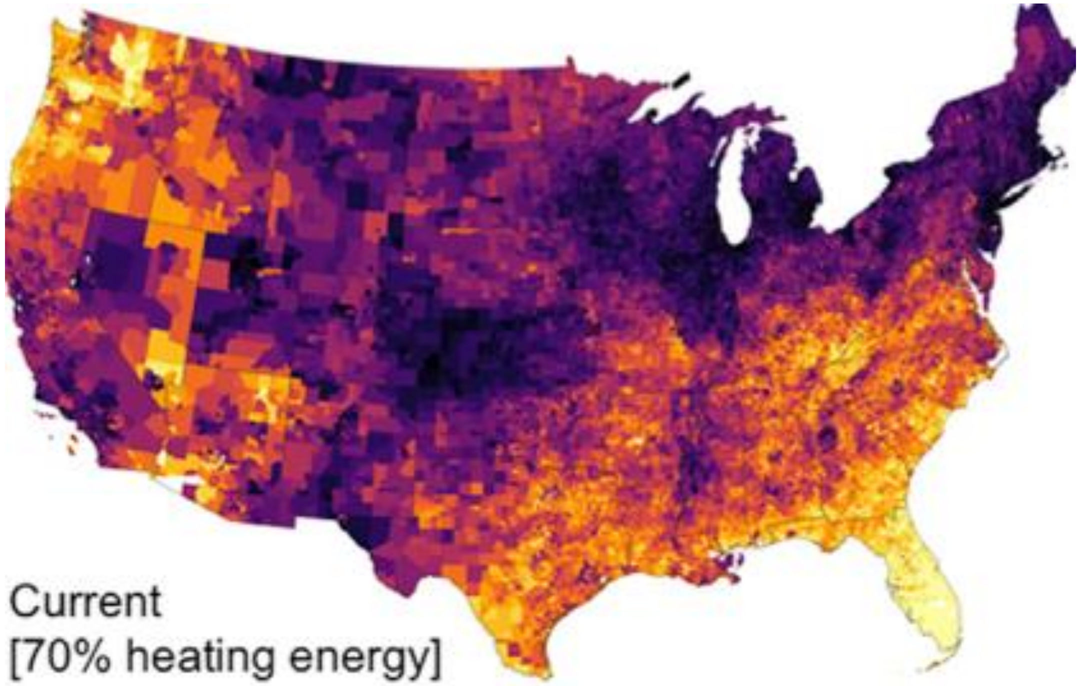




Model Building Electrification to Understand Its Impact

Goal: Estimate future building electrification including space heating, water heating, and cooking

- Fossil fuel model and electricity demand model in buildings
- High resolution: Public Use Microdata Areas (PUMA), Balancing Authority, hourly for 10 years



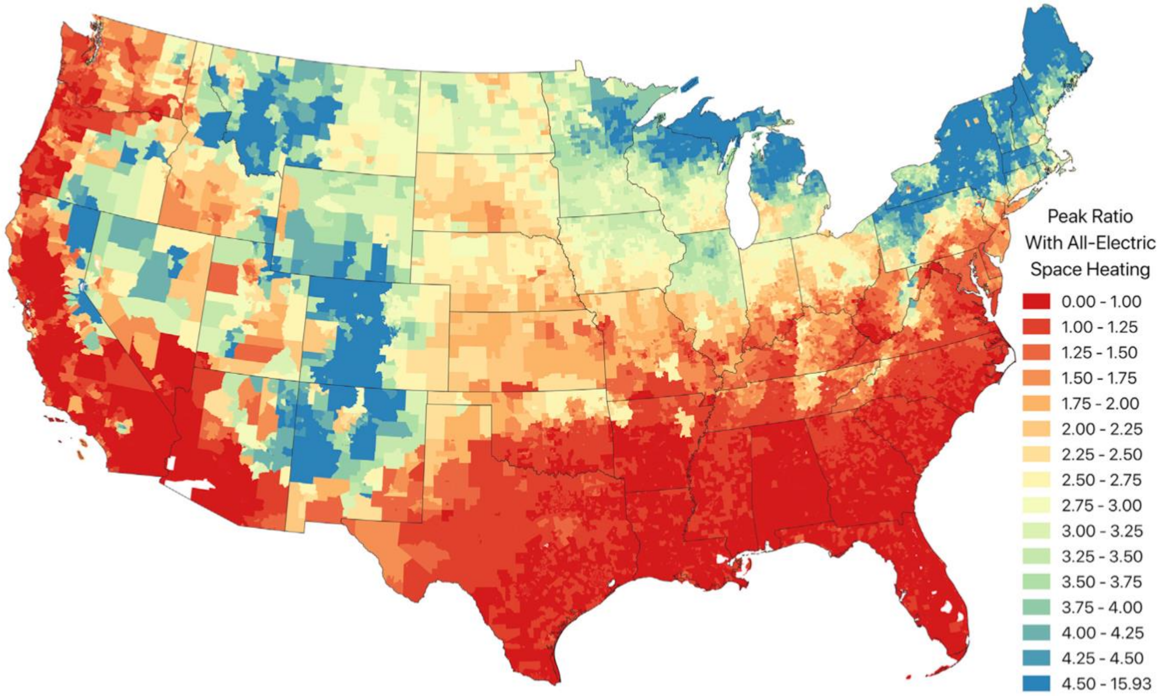


Figure 3. Census Tract Electricity Peak Ratios in an All-Electric Space Heating Scenario-Base Heat Pump Model

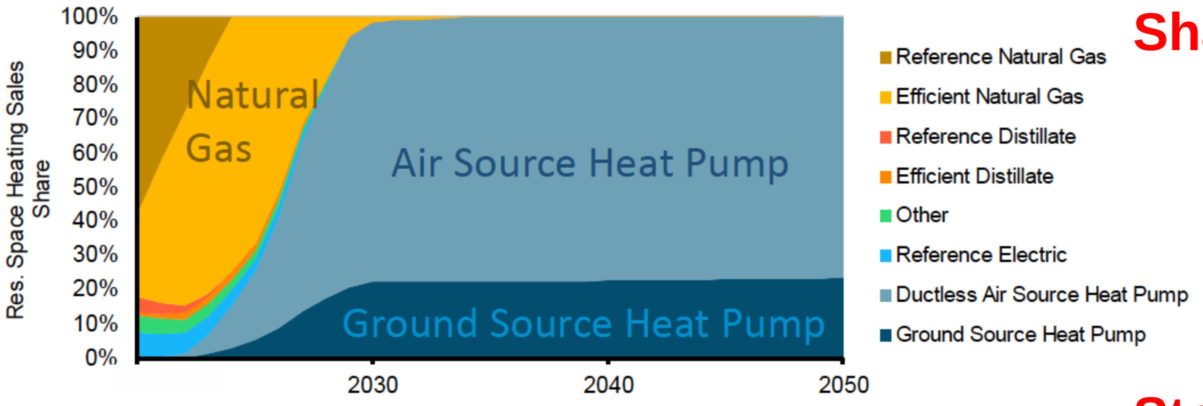
Replacing Fossil Fuel with Heat Pump

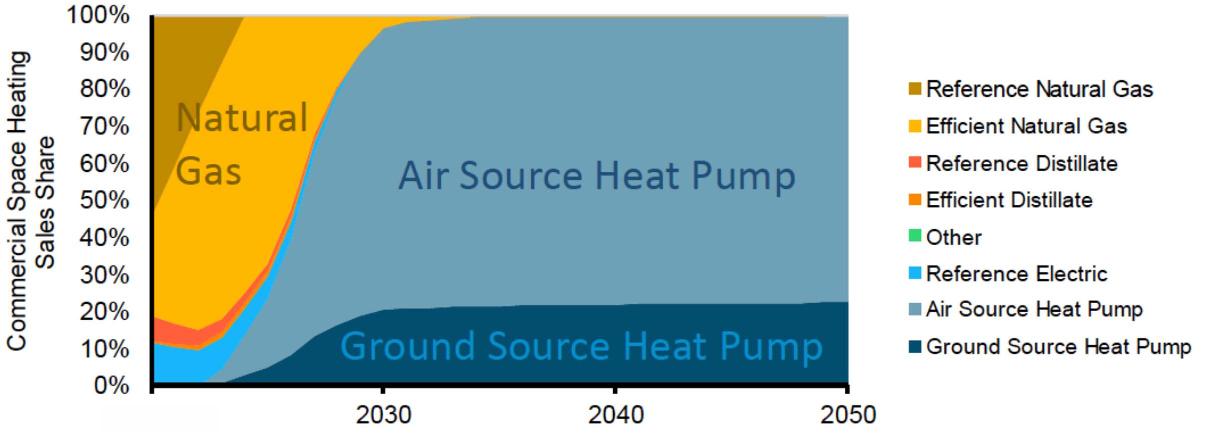
- Based on monthly fossil fuel usage data
- High resolution: Public Use Microdata Areas (PUMA), hourly for 10 years
- Space heating, hot water, and cooking

Residential Space Heating

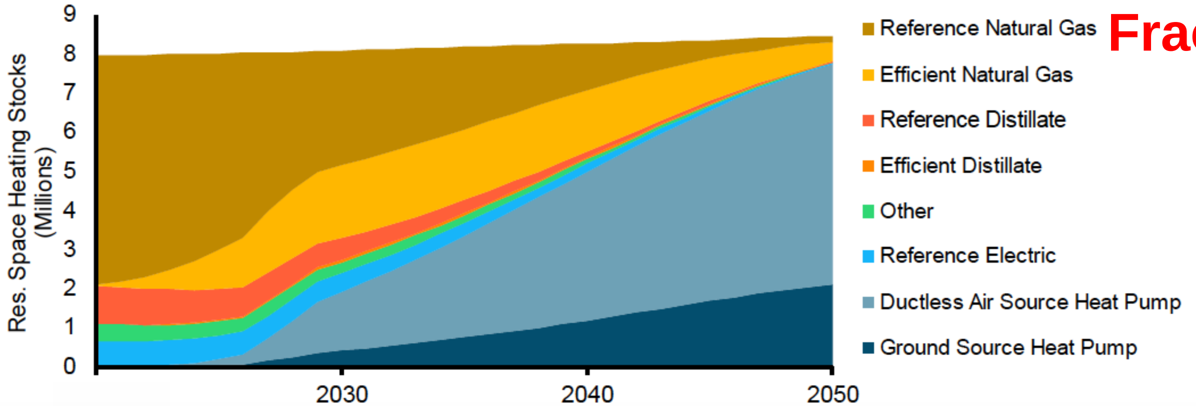
Commercial Space Heating

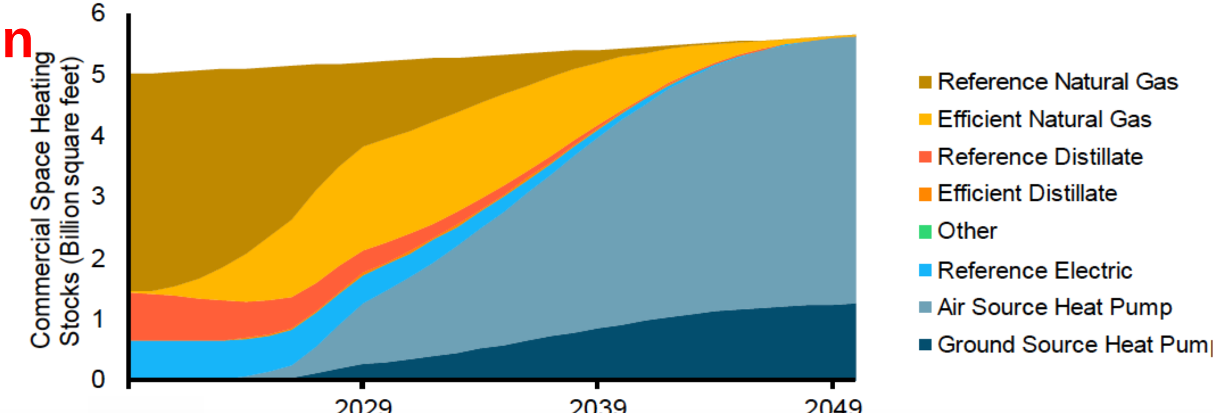
Sales Share



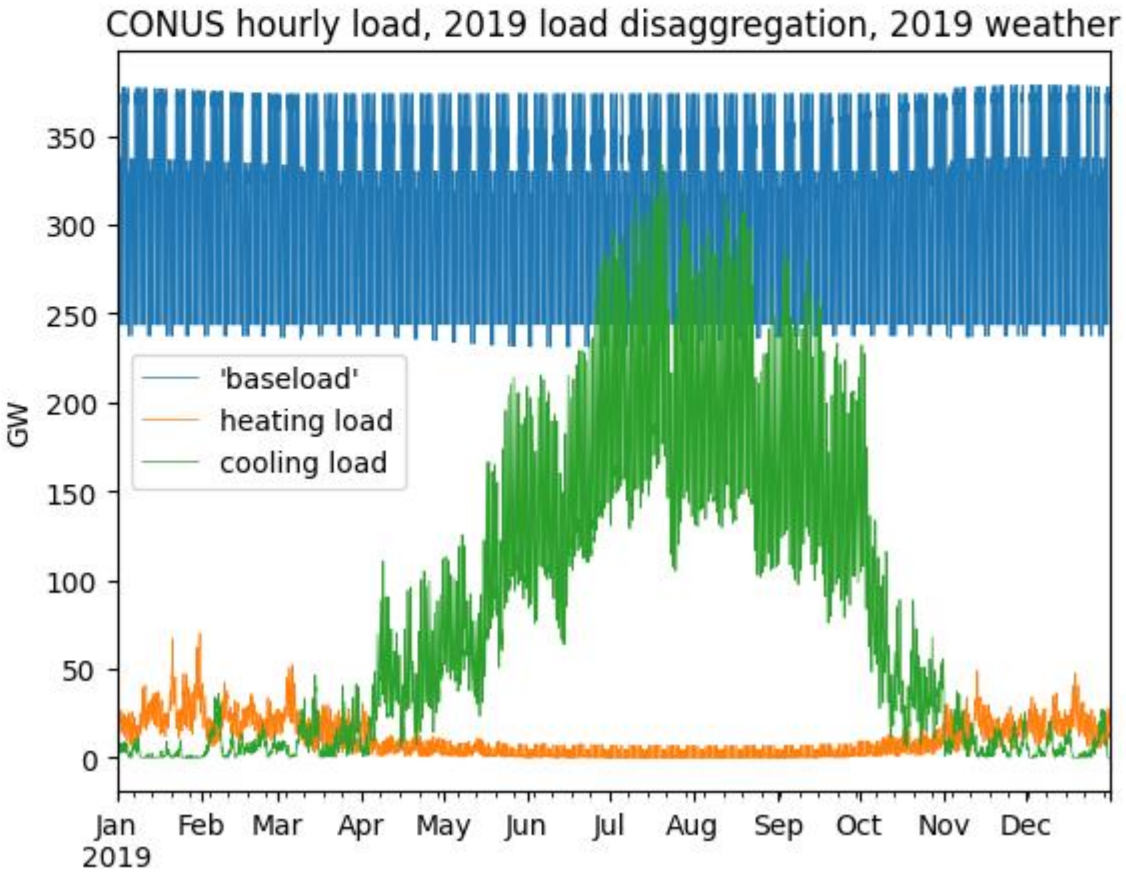


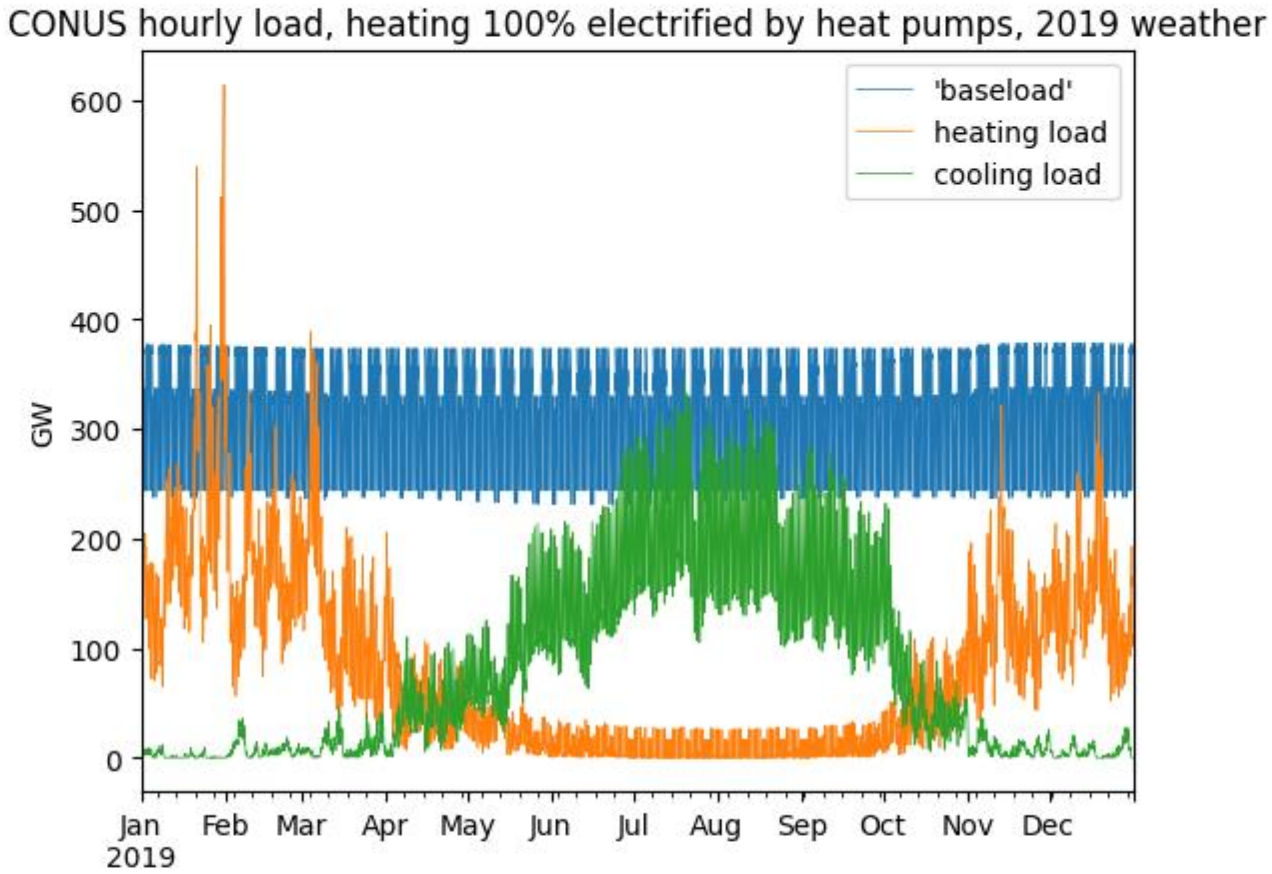
Stock Fraction



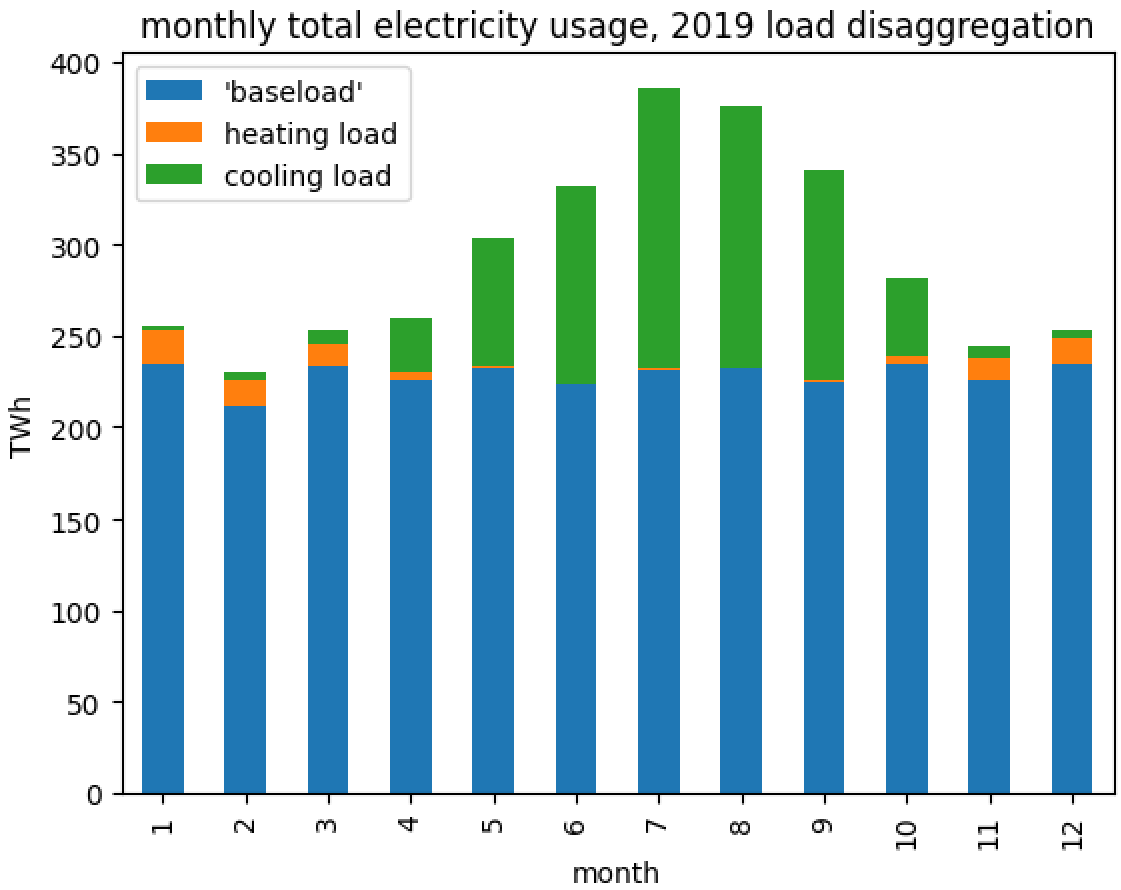


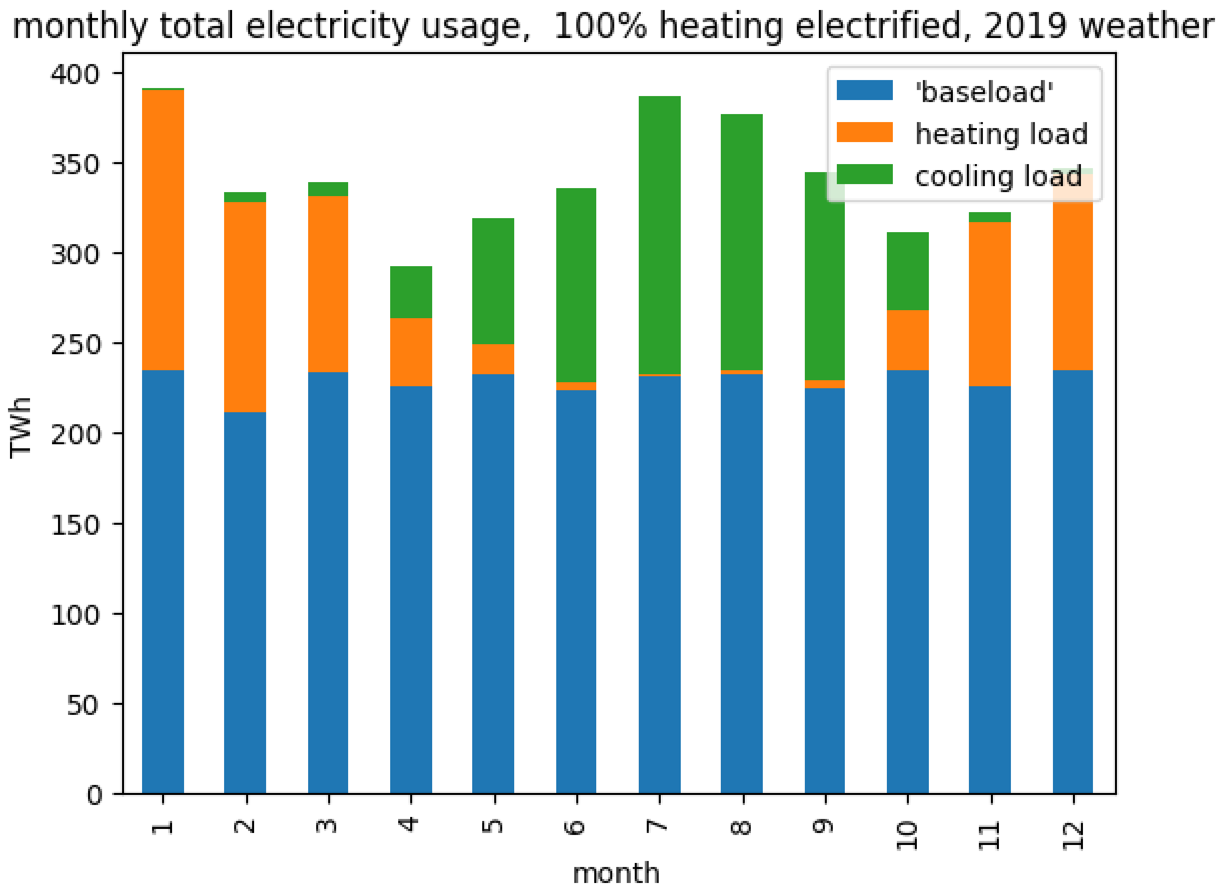
Space Heating Electrification Creates Winter Electricity Demand Peak



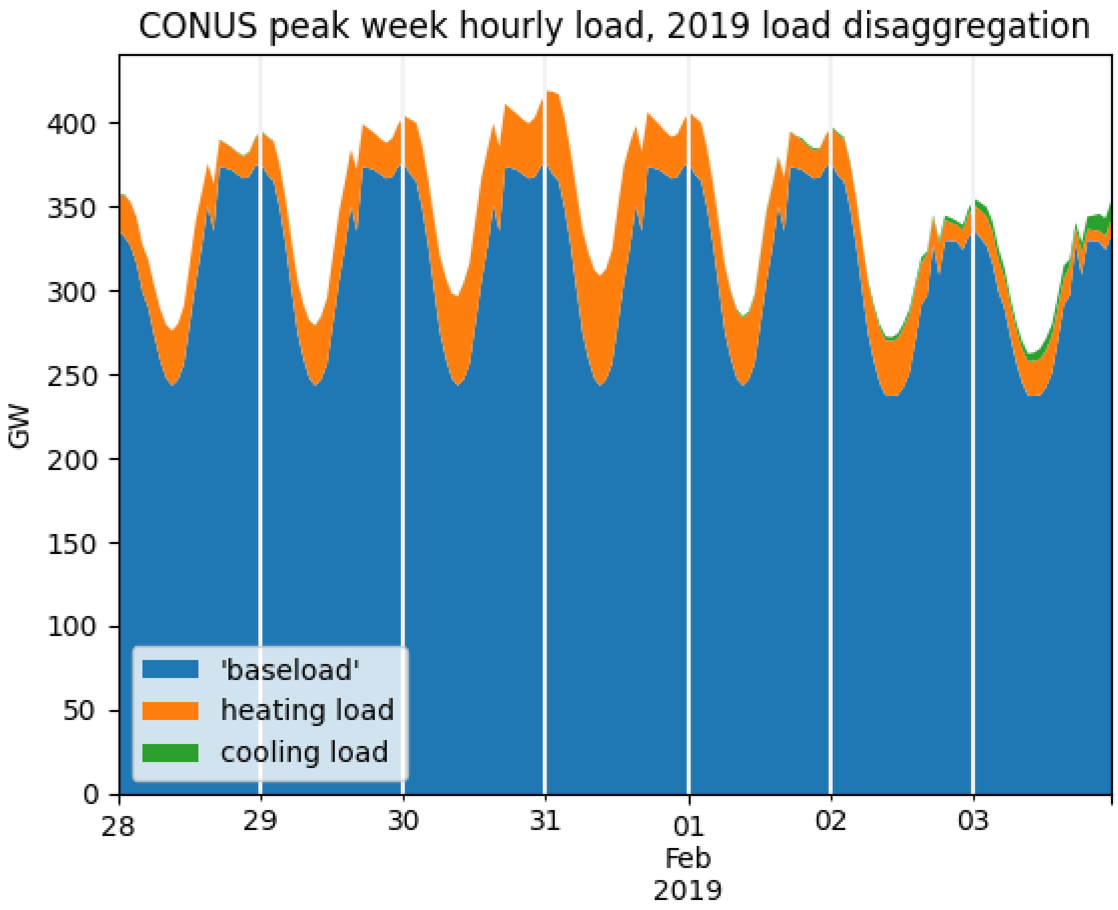


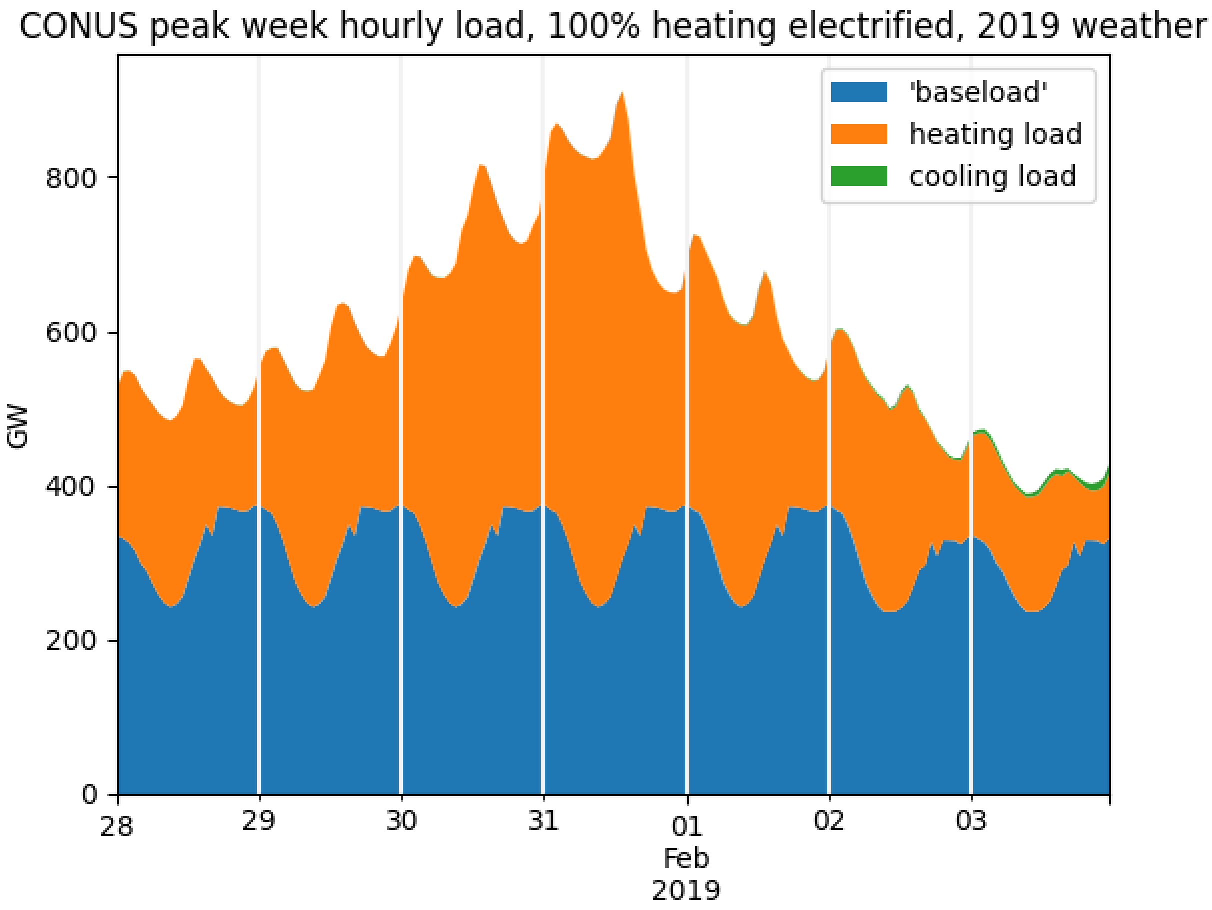
Electricity Consumption Will Soar During Winter Months



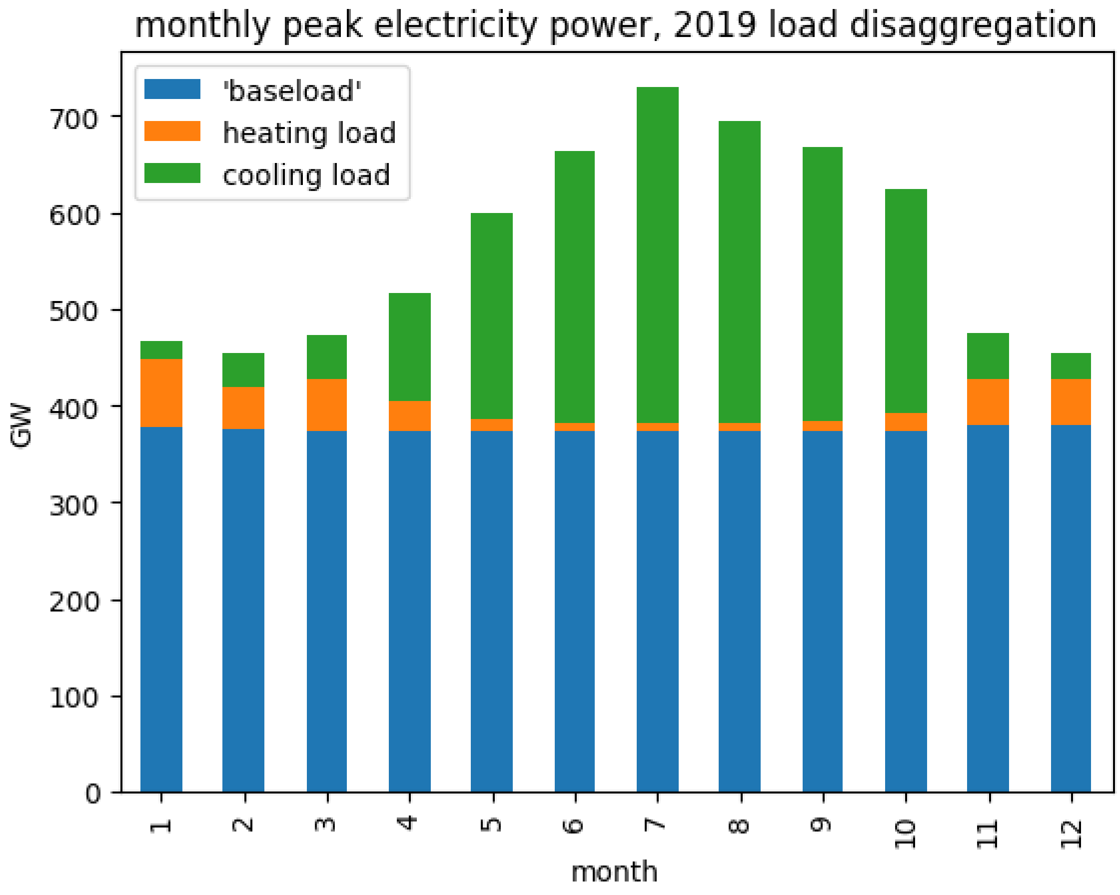


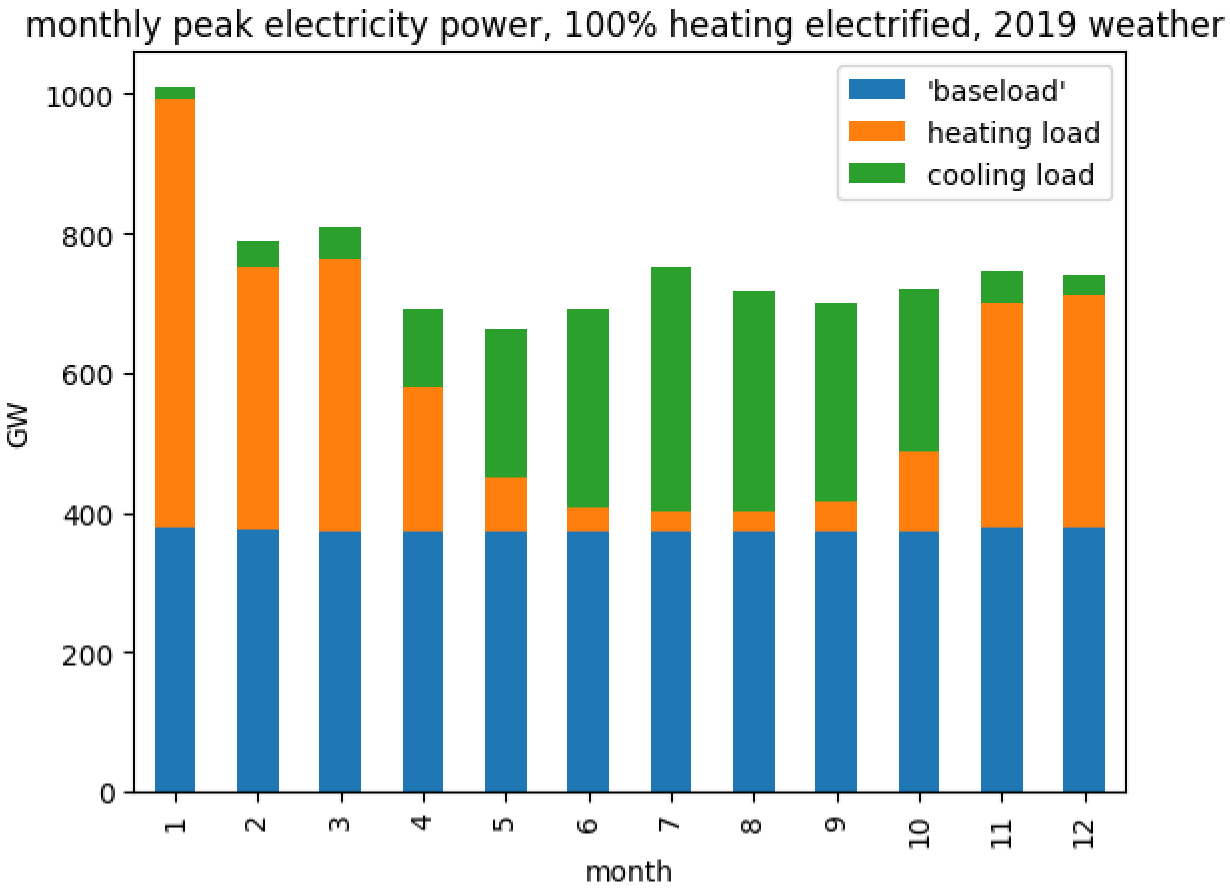
Extreme Cold Weather May Add Extreme Stress To The Grid





Higher Winter Peak Requires Energy System Planning to Consider Both Summer and Winter Resource Adequacy





Demand Response and Flexibility

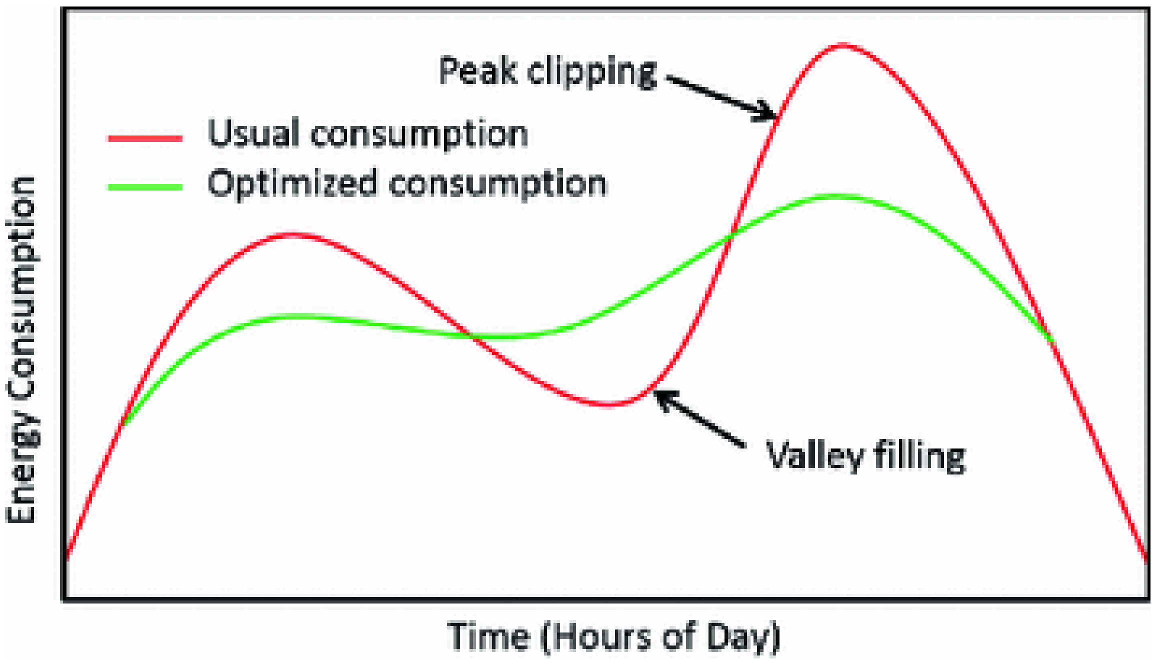
Demand response provides an opportunity for consumers to play a significant role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods in response to time-based rates or other forms of financial incentives.

Goal:

How much demand response is available at a certain location and time? At what cost?

How to optimally utilize the demand response in future energy system with high renewables and electrification?

- High resolution: utility level, hourly for 5+ years, residential, commercial and industry.
- Demand response optimization capability: load shifting, load, shedding, response cost, flexibility boundary



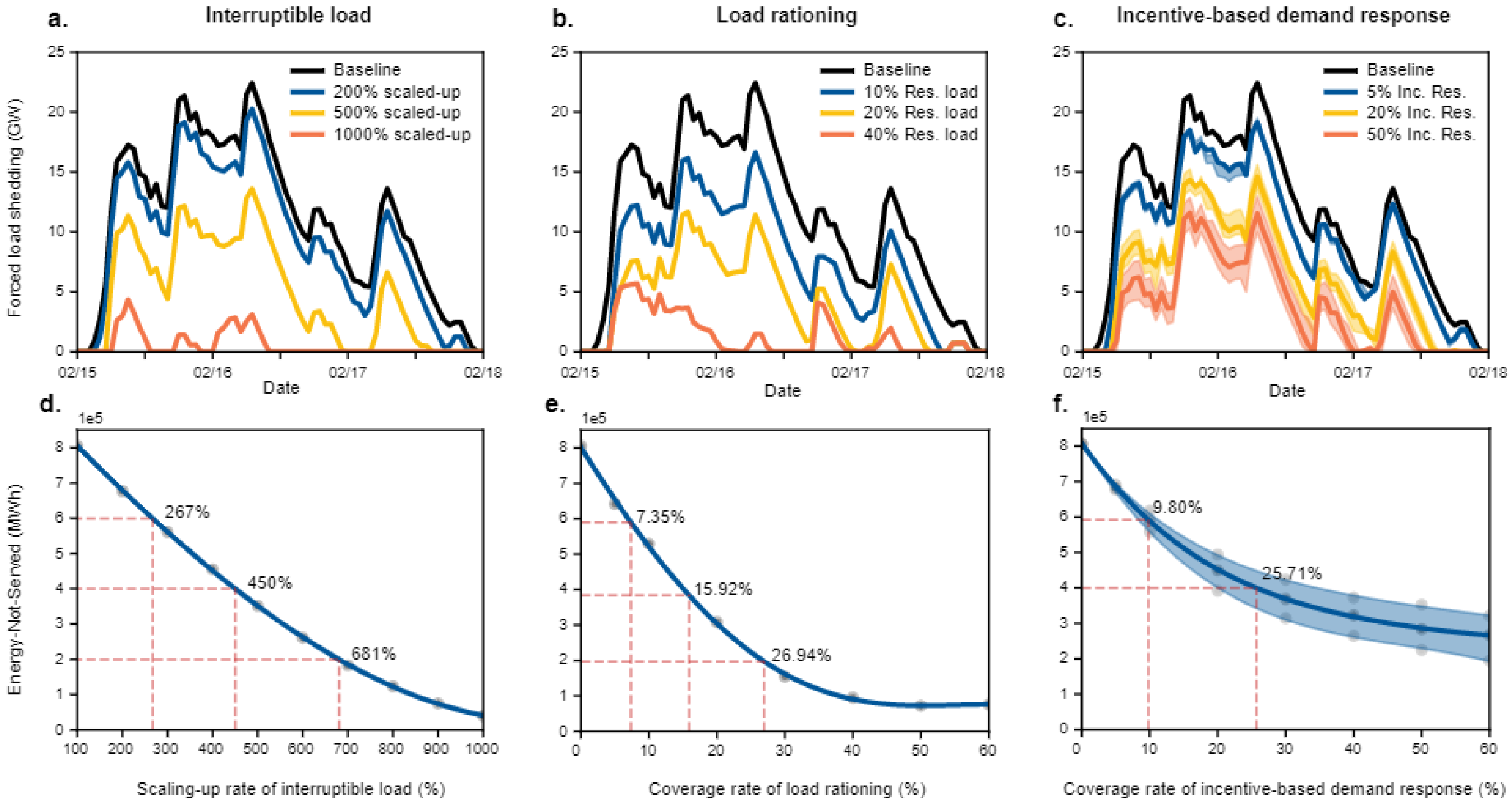
Demand Response and Flexibility: Texas Case Study

Massive electric power outage across the state of Texas caused by the severe winter storm Uri

- Around 4.5 million homes / businesses lost power. 20000 MW peak load shed on Feb. 15 evening. Over $195 billion economy loss

How can we mitigate the outage using strategic Demand Response programs?

- Residential load rationing – Allow all customers to power necessities
- Interruptible load contract – Upscaled participation
- Incentivized demand curtailment – On-the-spot load reduction



Thoughts on the Complexity of the Future Energy Systems

- Deep understanding of each sector’s electrification characteristics
- Integration of multiple sectors into one system to understand their interaction and explore optimization
- Weather and climate model
- Communication and control model
- Organization and business model

Questions? Comments? Contact Me!

XUYIXING2005@GMAIL.COM