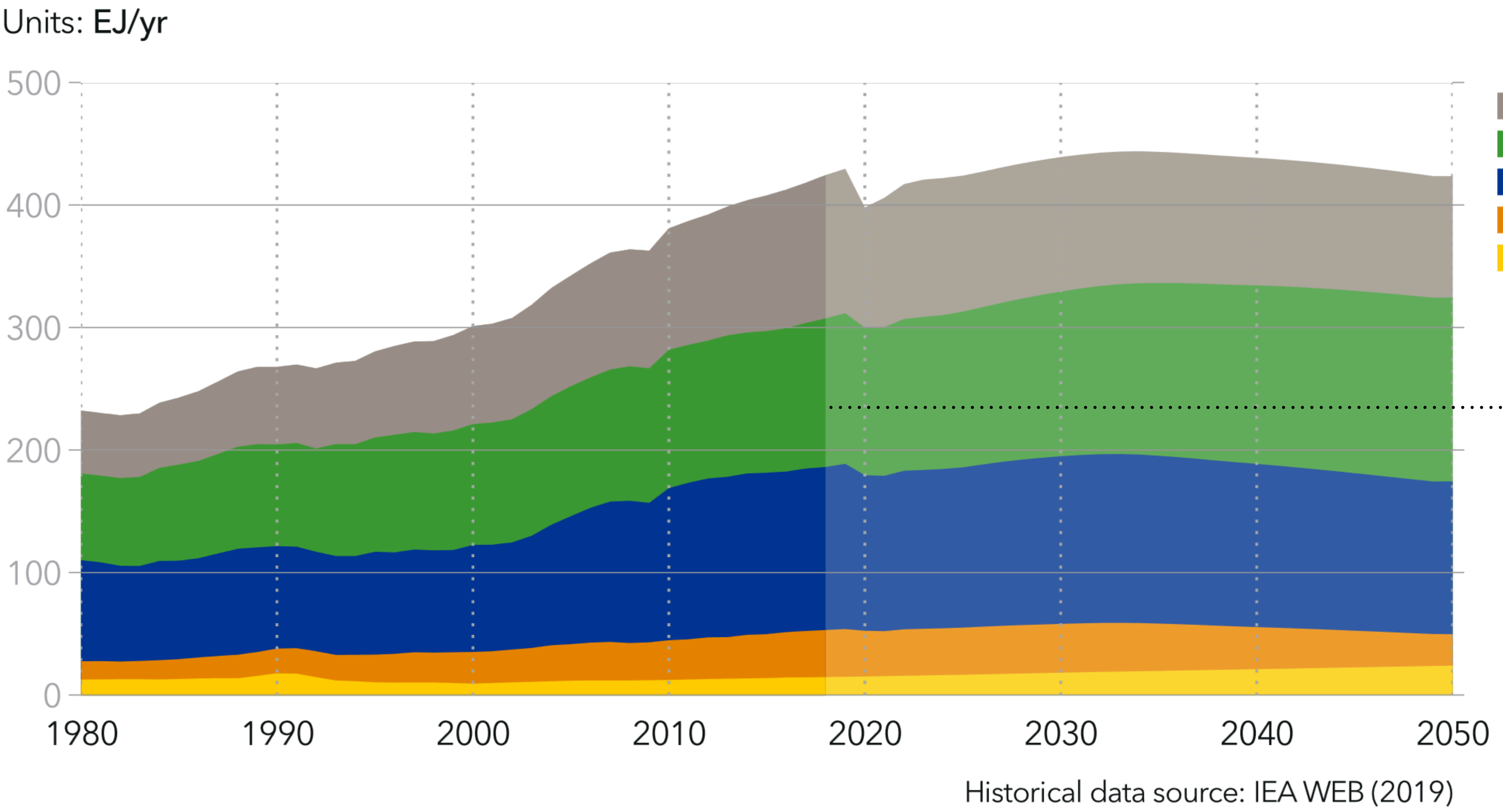
Empowering User-Centered Carbon Management:

Bridging Individual Preferences and Sociotechnical Advancements

Abel Souza, Mihir Shenoy, Camellia Zakaria

Global Energy Demand

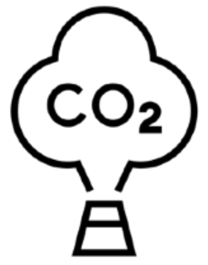
Buildings will collectively consume 24% more energy in 2050 than in 2018



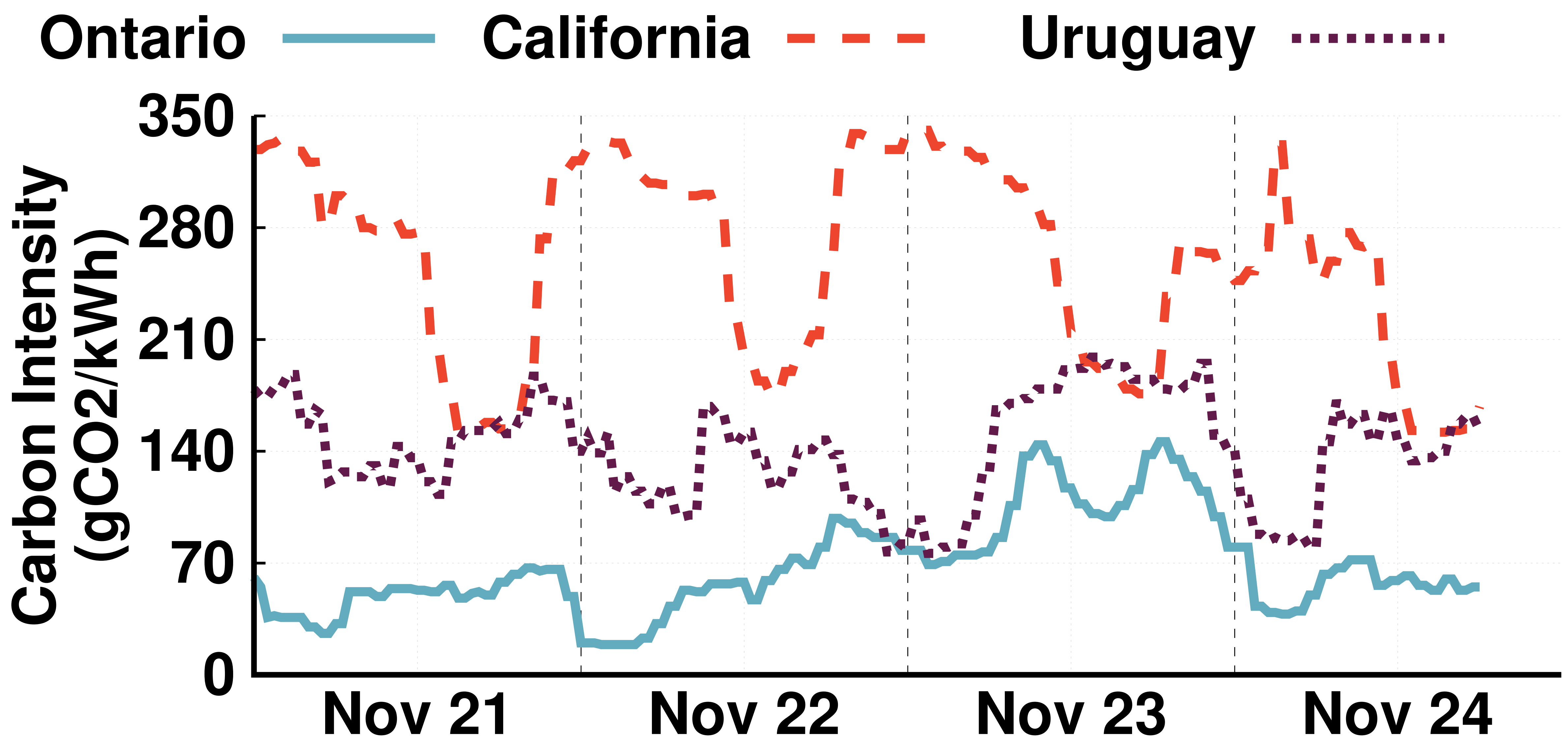
Buildings responsible for ~19% of GHG in the US

The Sustainability Problem

- Energy demand doubling every ~30 years
- Rising energy usage is not *really* the problem
- We must (eventually) **reduce emissions to ~0**
- Shift focus from energy to **carbon:**



`= Energy x Carbon_Intensity`



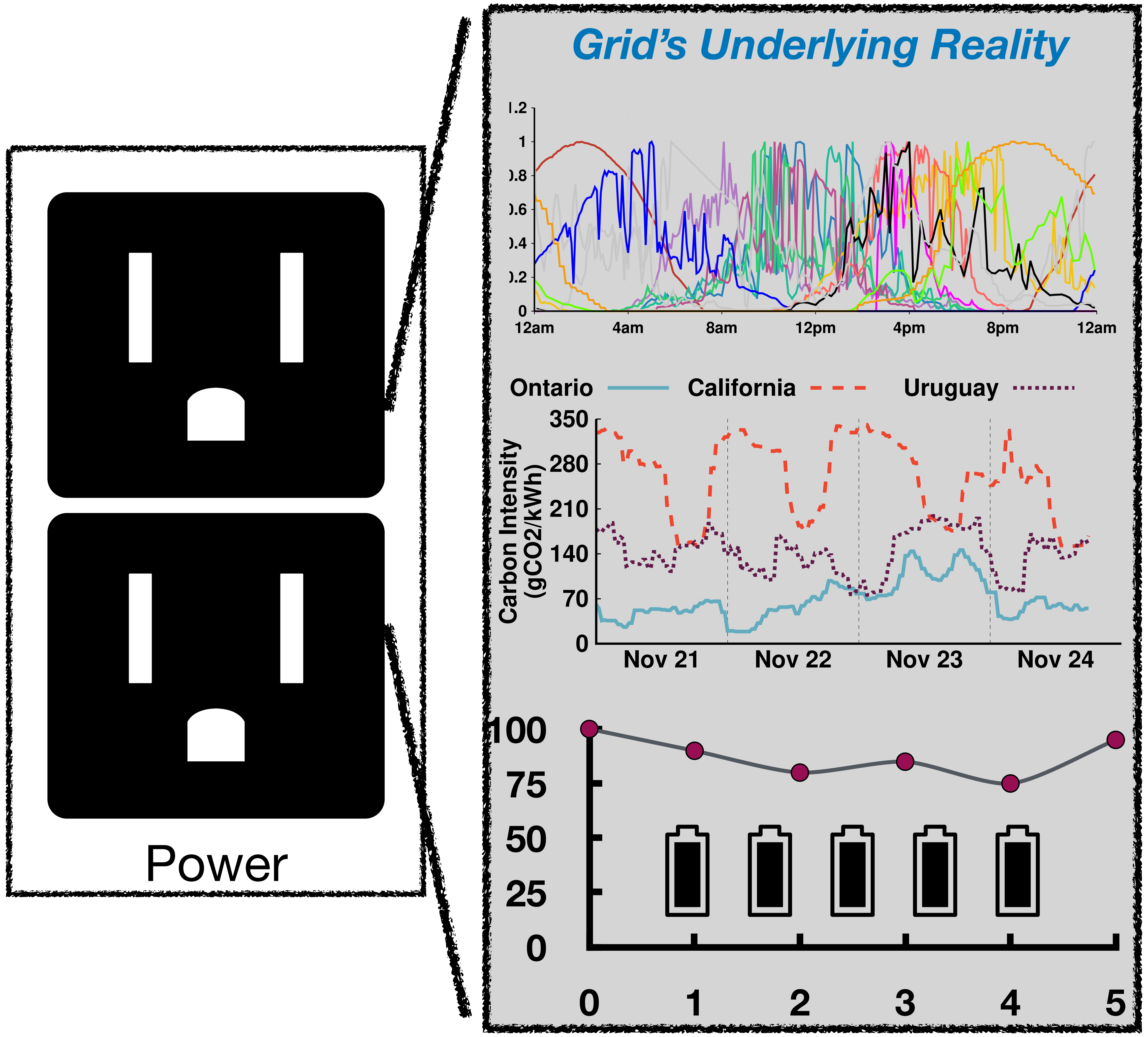
Carbon intensity* can vary from **less than 50g** to **more than 700g** across time and geographical regions.

Clean Energy is Unreliable, and varies widely both temporally and geographically.

* Source: Electricity Maps, 2021

Issue: Energy's Reliability Abstraction Limits Sustainability Potential

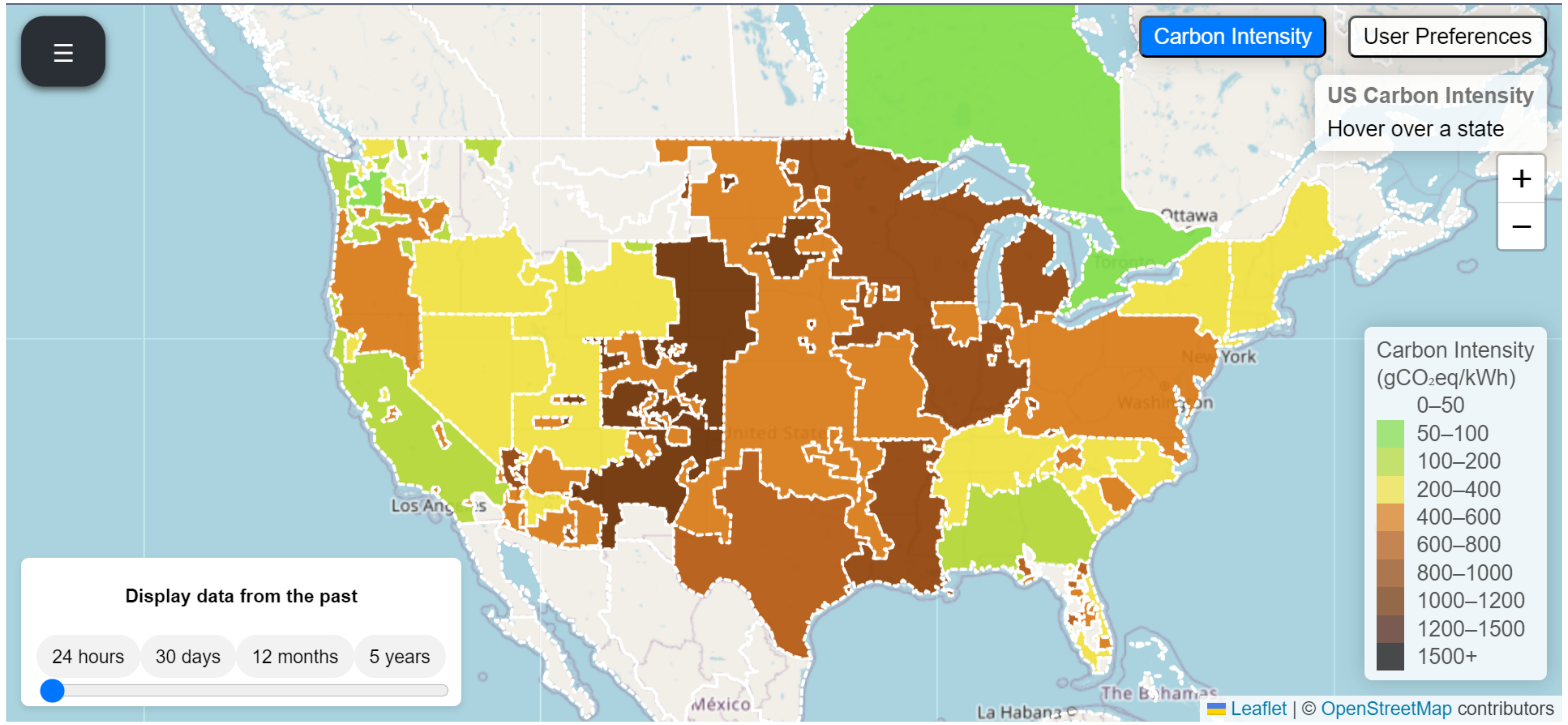
- The only abstraction is a reliable supply of power on demand:
  - Devices, including servers, via their electrical **socket interface**
- Energy system now includes a connection to not only the grid:
  - Energy storage, e.g., batteries
  - Access to solar/wind



Without visibility into the Grid's reality, users cannot influence their energy demand.

Opportunity: Exposing Visibility and Control to Users and Appliances

Leverage Carbon Information Services



North American grid overview for 2022 – Greener colors represent cleaner electricity. The low number of green regions indicate heavy reliance on fossil-fuel-based energy generation continent-wide.
CarbonCastUI — github.com/carbonfirst/CarbonCast

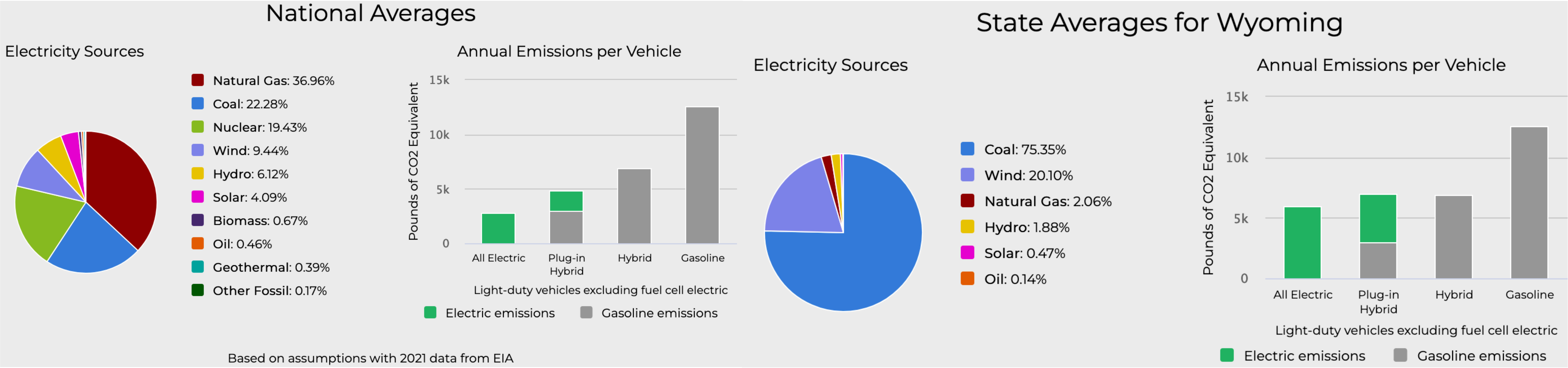
- Users should be exposed to fine-grained energy usage data
  - Exposing visibility useless without any means of control
  - Many ways to control carbon by adapting energy usage
    - E.g., dish-washing with different load profiles.

Appliances should expose means for controlling energy usage

Our Key FOCUS

Operational Carbon Efficiency

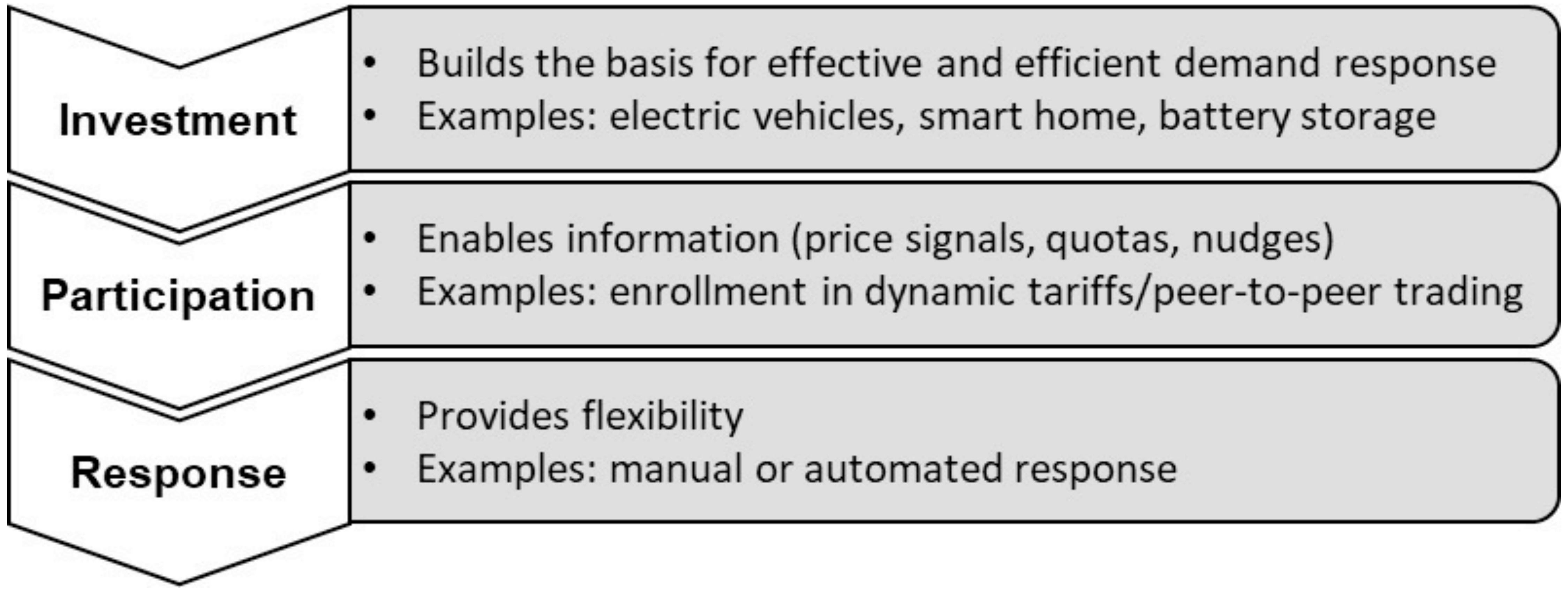
- **Carbon-efficiency** — work per kg-carbon emitted
- **Energy-efficiency** — work per joule of energy consumed
- **Carbon-efficiency != Energy-efficiency**



Consumer: A Challenge

Incentivizing Behavioral Change

- Monetary benefits alone are insufficient for behavioral change
  - **Economical incentives recommend user demand shift to worse moments. E.g., Laundry at night for lower $/Wh and low availability of renewables**
- Behavioral change in real-world significantly influenced by personal habits and routines
- Moral obligation — e.g., climate change — suggested to strengthen such intentions

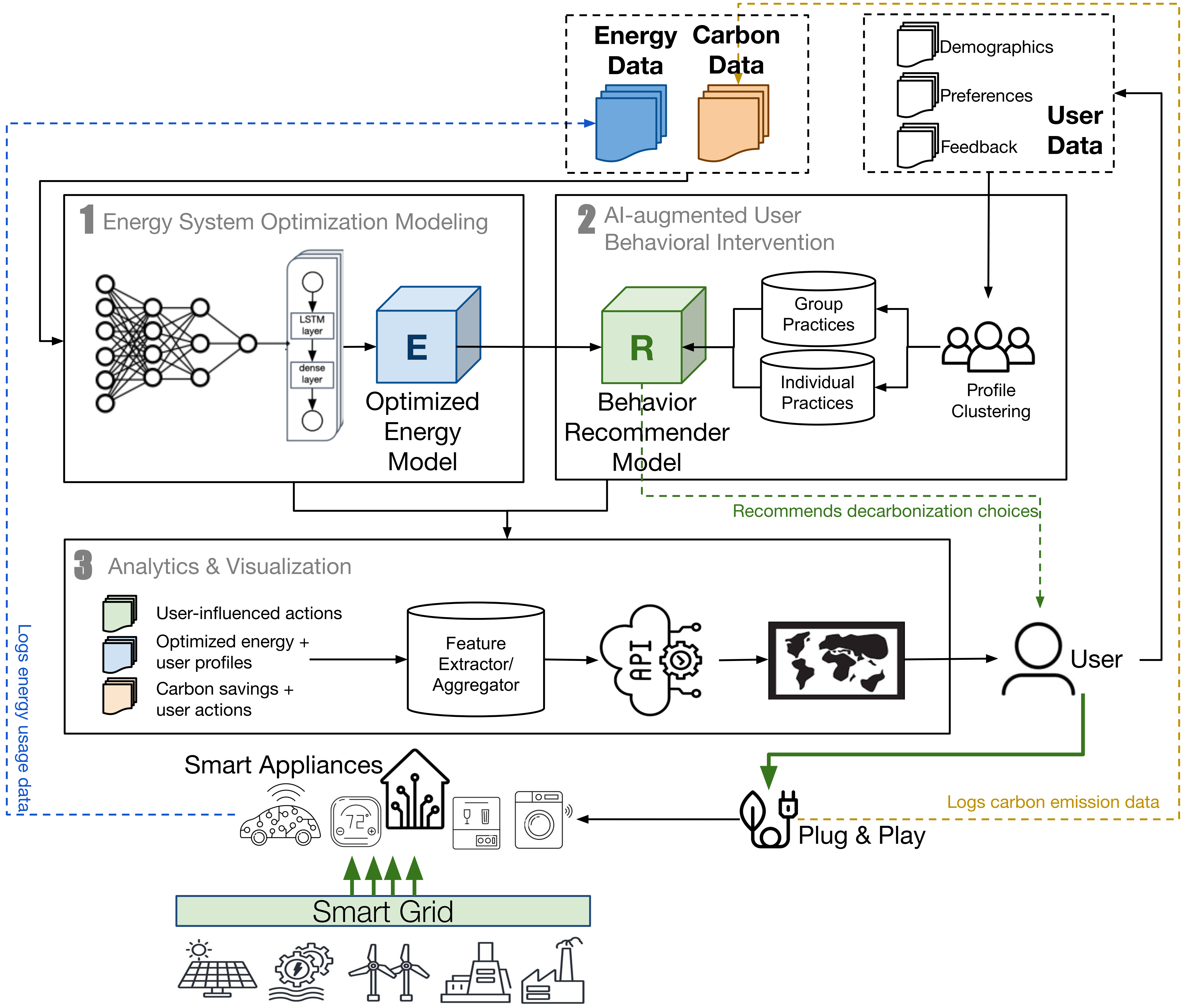


Grid Forecast is a new feature in the Apple Home app that tells you when your power grid has cleaner energy available. (Apple, 2023)

Our Vision

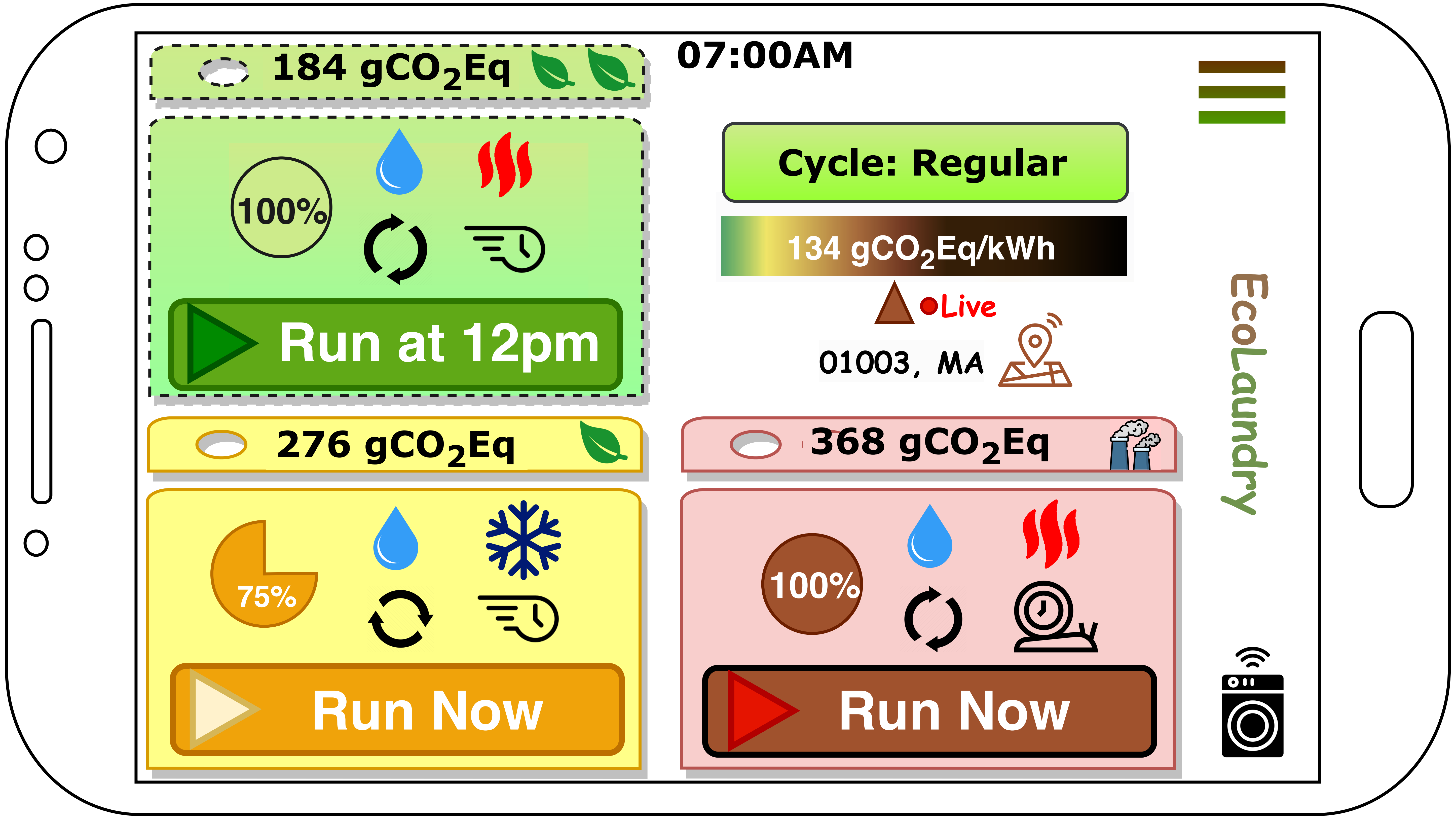
User-Centered Management Cyber-Physical System

1. **Energy System Optimization**
   - Responsible for modeling the energy profiles of smart appliances with data from the smart grid
2. **AI-augmented User Behavioral Intervention**
   - Derive typical consumption behaviors and serve as a resource for estimating users' willingness to reduce their footprint
3. **Analytics and Visualization**
   - Provides overview of the effects of users carbon footprint, segmented by profile and energy usage temporal patterns.



Objectives - Use Cases

1. Encourage meaningful user-informed actions



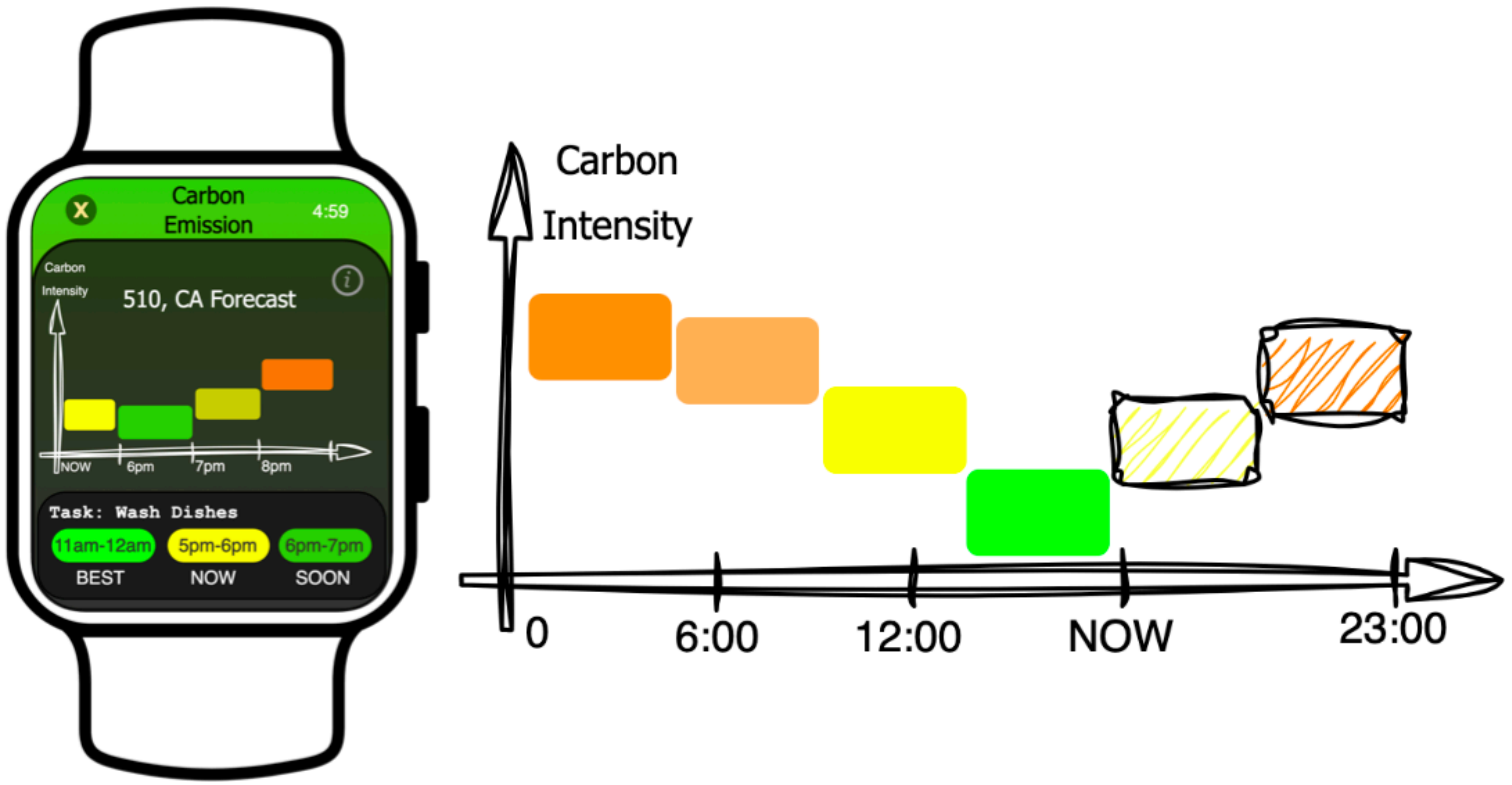
EcoLaundry provides users with recommendations for scheduling their laundry loads based on carbon footprint.

- For a laundry load
  - Selection of water temperature and time of use translate to how much carbon a user can potentially avoid.
  - Users schedule loads during low-carbon periods (green), or
  - Opt for a fast setting with cold water that reduces energy consumption (yellow), or
  - Freely select the highest-intensity profile without any energy-saving constraints (red).
- Gamification may encourage users to select the most sustainable choices.

Objectives - Use Cases

2. Assist in Scheduling Based on Carbon Footprint

- For a dish washer:
  - Schedule loads based on carbon intensity through forecast integration to automate smart appliances
  - Understanding of washing cycles enable users to take informed decisions that follow low carbon periods.
  - More convenient and engaging.
- Goal is to provide readily available, less carbon-intensive options, even if they require slight adjustments.

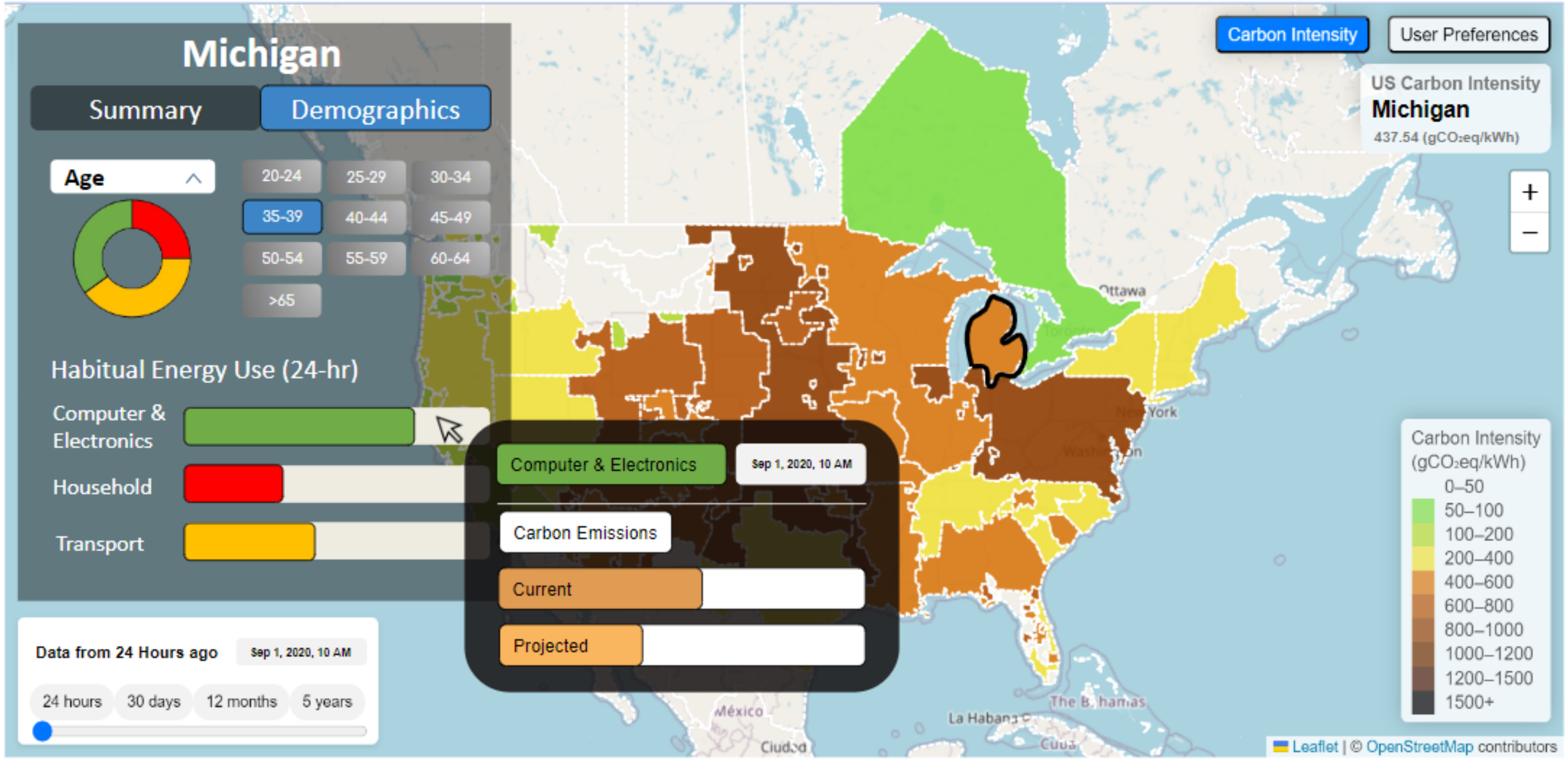


Similar to weather forecasting, the EcoWatch assists users in scheduling dish-washing, with carbon intensity forecasts (left), and historical data visualization (right) to enhance user awareness about daily temporal patterns.

Implications and Challenges

User behavior present a significant challenge to future carbon-aware Cyber-Physical systems

- Information perception translating carbon emissions to GHG reduction
- Standardization of digital applications to provide flexibility in user control
- Transition Within the Local Grid
- *What constitutes meaning and long-term behavioral change among everyday users?*



Carbon intensity information by user profiles and device usage via our dashboard. Valuable resource for policy-makers and researchers, enabling them to visualize trends in footprint by population demographics and geographic regions.

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asouza@cs.umas.edu