Carbon Intensity

Introduction

There is a need to consider the interactions between electrical grids and building energy systems, both new and existing, to enable building energy system decarbonization.

ASHRAE's Task Force for Building Decarbonization (TFBD) was formed in Spring 2021 as an initiative of President Chuck Gulledge and President-Elect Mick Schwedler. Jurisdictions globally are confronting climate change and recognizing that building decarbonization is an important component in their efforts. The worldwide building sector accounts for about 40% of energy-related carbon emissions and buildings remain a major sector that lacks sufficient mitigation policies. As the standards authority for energy usage in buildings, ASHRAE recognizes that our long-standing initiatives in energy efficiency should be expanded to building decarbonization. [1]

To be successful, the electrification of building energy systems must be actively coordinated with the grid. The decarbonization of vehicles is increasing demand on utilities and onsite electrical systems. The demand-side electrical load increases that are required for building energy system and vehicular decarbonization to occur may not be possible with the existing infrastructure in many jurisdictions that have existing electrical infrastructure constraints.

Additionally, the sources of electricity and efficiency of electricity generation systems must be considered when the intent is to reduce GHG emissions through electrification.

Combined with the increased demand from decarbonization of onsite energy systems and vehicles, the addition of new, intermittent renewable electricity sources such as solar and wind leads to increased value for dynamic demand-side management.

To achieve optimal demand-side management, control systems must be designed to be able to respond to signals from the grid, and the grid must be designed to be able to send signals to control systems. Onsite energy systems can be configured to shift their electrical load (e.g., through storing energy), to align with times when electricity is both most available and has a low carbon intensity. The grid needs to be able to provide these two indicators separately; having zero carbon energy available at the source and being able to get it to the consumers when they need it can be two very different things.

This paper describes the need for appropriate grid-building interactions (GBIs) to enable the transition to electrification using renewable energy sources, within the timeframes that jurisdictions have targeted. Challenges and emerging trends are then discussed. Finally, opportunities are presented.

The Need for Carbon Intensity Signaling

The cost and carbon intensity of operating the grid can vary substantially by region, time of day, and time of year. The geographic example in **Figure 1 – Carbon Intensity Map** [2] below illustrates an example of the instantaneous carbon intensity, with low carbon intensity regions (e.g., California, Pacific Northwest, Scandinavia, Tasmania) versus high carbon intensity regions (e.g., Midwest USA, Eastern Europe, Queensland).

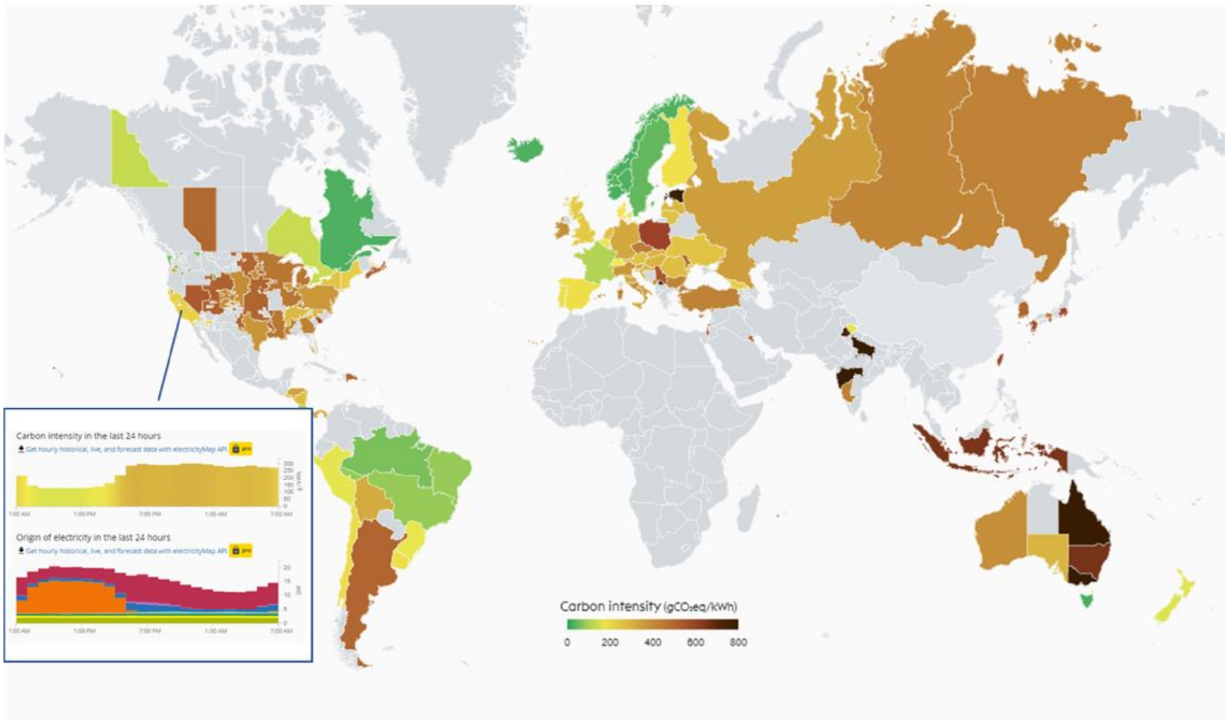

Figure 1 – Carbon Intensity Map

The temporal example for California in **Figure 2 – Daily Carbon Intensity Profile** [2] illustrates that the change in carbon intensity in can vary by more than a factor of two within a day. On other days, the same region can have much higher changes in carbon intensity.

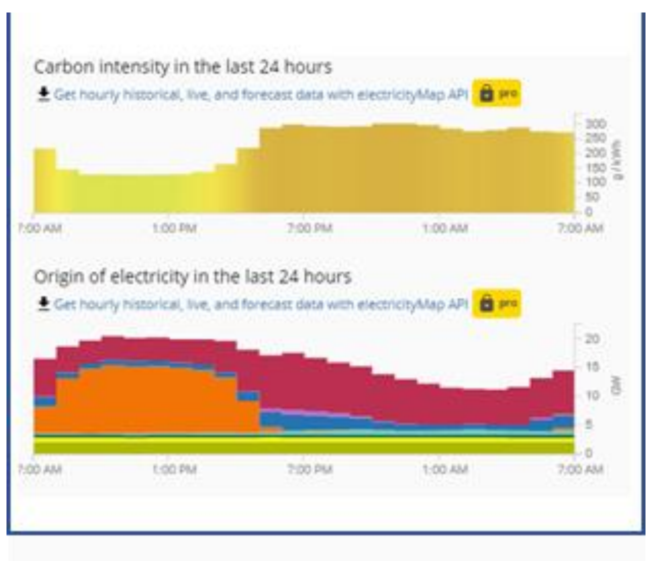

Figure 2 – Daily Carbon Intensity Profile

Recent research has shown that, depending on the region and building type, annual average regional carbon accounting can sometimes overpredict or underpredict the instantaneous carbon impact of electricity consumption by +/-35% [3]. Bias will be greater in regions with high variation in carbon intensity, and for end-users with high variation in their electricity consumption across hours and seasons. Additionally, there can be sub-regional or localized variations in carbon intensity that occur in short timeframes. In some cases, excess renewable energy is available locally, but cannot be transferred away from a sub-regional grid due to infrastructure limitations.

The long-term trends of the ongoing electrical energy generation transition are illustrated in **Figure 3 – Rate of Change of Power Production Sources by Region** below. These transitions impact the cost of electricity and affect grid carbon emissions. The rate of change and types of changes vary widely by region.

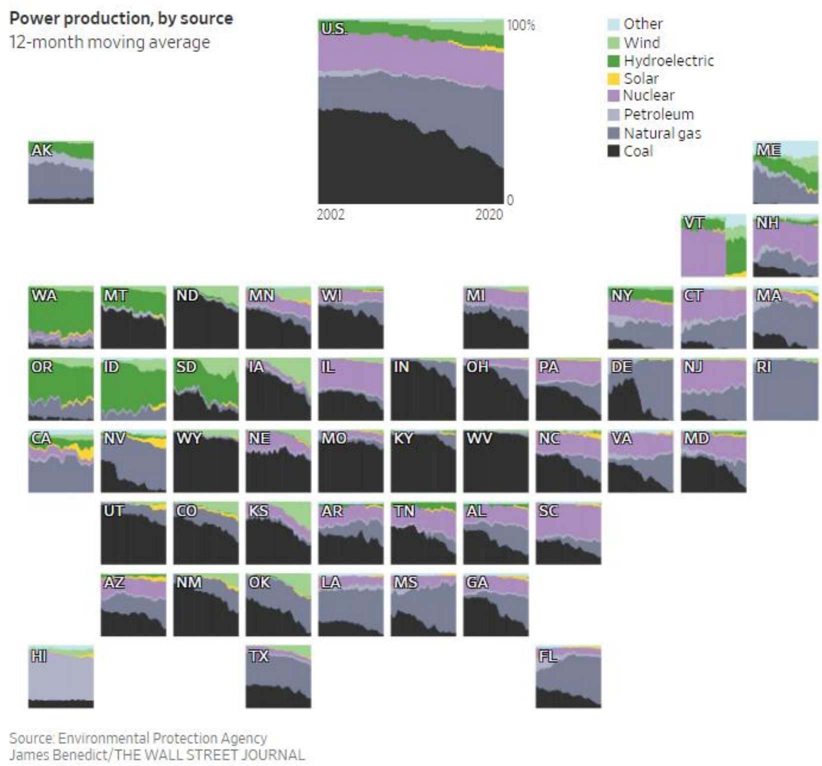

Figure 3 – Rate of Change of Power Production Sources by Region

Traditionally, building design and operation has not considered carbon emissions as a primary criterion. However, to decrease the carbon intensity of building operation, the geographic and temporal variation of the grid's carbon intensity needs to be considered. The carbon intensity of fossil fuel consumption, both onsite and upstream, also needs to be considered on a geographic and temporal basis. The carbon intensity of fossil fuels delivered to a building will vary by region, production practices (e.g., is any methane being vented or flared, such as the Bakken North Dakota gas fields where 20-35% of the gas is flared), pipeline leaks, distribution differences (pipelines versus liquified gas), and how much of the fossil fuel is imported from another country. When both temporal and geographic carbon intensity profiles are known, they can be compared, and informed decisions can be made.

Realtime carbon intensity signaling is required, and it is required in a manner that enables building control system professionals to continuously gather the signaling from the grid operator and use the data to dynamically adjust operations. The grid-building communication has to be both secure and easy to implement.

Challenges

A key challenge is the fact that building design and equipment decisions can last for decades, whereas grid carbon intensity profiles will change rapidly with the widespread effort to quickly decarbonize the grid, and the sources and distribution of fossil fuels to buildings will change. An electrical source may have a high carbon intensity now but may have a much lower carbon intensity within the life of the building energy system. If a fossil fuels based system is installed based on comparable emissions from electrical generation at the time of system selection, the fossil fuel system will maintain the same level of onsite emissions while electric systems will decarbonize. The selection of an electric system at the beginning of a project, even if current emissions are similar to a non-renewable system, is still highly beneficial based on the rapid evolution of grid decarbonization.

Some jurisdictions have adopted or are considering building codes that encourage or require electrification of new and/or renovated buildings. While electrification eliminates onsite fossil fuel combustion, the holistic carbon intensity of the grid is still a factor. If a lower efficiency air-source heat pump or back-up electric resistance heater is being used, it may have a higher upstream carbon footprint than burning natural gas for heating. Again, this will most likely change within the life of the energy system. The real challenge is to reduce carbon immediately by using holistic carbon accounting practices to make fuel choices based on real time carbon signaling for all types of energy being used by the building.

Once a signaling practice has been created, the next challenges will be getting the signals to building control systems and ensuring that buildings are able to use them as intended. Traditional control systems are designed with the original programming set to automatically act according to a set sequence of operations. Changes from day to day are based on schedules that an operator can change. While many systems act according to set time of use (TOU) pricing schedules, carbon intensity and dynamic electrical price signals are not typically factored into calculations that are made by the building control systems.

Emerging Trends

There are efforts underway to make the operation of the grid more transparent, with regards to both the cost and the carbon intensity of operation. The time varying cost of operation is starting to be reflected in time-varying retail rates (e.g., TOU and dynamic rates). The emerging services, tools and examples of providing time-varying carbon intensity data include:

- Singularity Energy: https://singularity.energy/
- WattTime https://www.watttime.org/
- WattCarbon https://www.wattcarbon.com/

- NREL Cambium https://www.nrel.gov/analysis/cambium.html
- Arizona Public Service (APS)
  - sending C signal to thermostats
- LBNL time use of efficiency calculator.
- https://emp.lbl.gov/publications/time-sensitive-value-calculator
- electricityMap https://app.electricitymap.org/map
- California Market Informed Demand Automation Server (MIDAS)
  - Time-varying rates, greenhouse gas emission signals, and reliability alerts
  - https://www.energy.ca.gov/proceedings/energy-commission-proceedings/load-management-rulemaking/market-informed-demand

Opportunities

Analysis has shown that aligning electric vehicle (EV) charging with carbon signals could reduce the associated emissions by 8-14% on average across 14 states. [5] This presents opportunities for integration between building systems and EV charging systems.

Simulation results indicate that carbon responsive controllers applied to residential buildings can reduce the homes' annual carbon emissions by 6.0% to 20.5%. [6]

Electric grid carbon content is a subset of value. The value of electricity includes carbon, energy costs, congestion, scarcity, reliability, social and environmental impacts, and all other internalized and externalized costs of electricity supply. The decarbonization movement provides opportunities for grid and building operators to include these values in their decision making to achieve a sustainable built environment.

Holistic quantification of carbon content (including upstream emissions) associated with energy system fossil fuel consumption is a key value element to be considered in decarbonization decision making. It also supports the argument for real time carbon pricing of fossil fuel consumption, which in turn creates a stronger case for using electrification and opportunities for innovation, research, and development in the decarbonization industry.

There are many opportunities for studies to be conducted. The following guiding questions illustrate some of them:

- What potential exists for changes in building operation and use based on information from carbon signals for all energy sources used by the building?
  - How does this potential change with the increased electrification of buildings?
  - What does this pathway look like?
- Given variation of carbon intensity on the grid and of different fossil fuels that can be used by a building, where does electrification have the biggest impact?
  - How does electrification affect overall life cycle carbon emissions of buildings located in various regions?
- What signals are already available and how can they be used by practitioners?

- Should marginal and total real-time signals for all energy sources be used, or are annual average carbon intensity values sufficient?
- Are there innovative ways to store thermal energy when the carbon intensity of the grid is lower, and then use the stored thermal energy when the grid carbon intensity is higher?
- At what point does it create fewer GHG emissions to burn natural gas compared to running back-up electrical resistance heat to supplement air-source heat pumps that are working at their lowest efficiency and capacity during the coldest days of winter, while at the same time winter peaking utilities are using fossil fuels in their peaking plants? On the coldest days, is imported LNG or CNG with higher carbon contents being used to supplement the gas system? Will winter peaking utilities be able to utilize energy storage systems in place of fossil fuel "peaker" plants?
    - What regions would this benefit, and during which parts of the year?
- When carbon intensity and value is factored in, is the higher efficiency of a ground source heat pump system a significant factor to consider in comparison to an air source heat pump or in comparison to a fossil fuel heating system?
- How much water bypasses dams during peak storm events in wet climates?
    - Could this low carbon intensity energy be delivered at a lower rate during the peak event so it can be stored and used later when the utility will be generating or buying power that has a higher carbon intensity?
- How can EV charging system controls integrate with building energy system controls?
    - Why do they speak different languages?
    - Can a gateway be developed between the OCPP 2.0 protocol and BACnet?
    - Could a gateway be created to enable building energy system controls to regulate chargers based on carbon signaling?
- Is there a simple way to securely deliver real time carbon intensity and dynamic pricing signals to energy system controls?
    - Should ASHRAE create a standard for integration between energy system controls, EV chargers, and electrical grids?
- Is there an ideal phase change material that melts at around 105 °F, so heat pumps can be used for warm thermal energy storage when the wind is blowing, or the sun is shining?
    - What would the economics of this look like?

To effectively decarbonize, building designers, regulators, and equipment manufacturers will have the most impact by working together to optimize buildings and renewable or fossil-fueled distributed energy resource (DER) deployments.

ASHRAE's knowledge, reach and leadership will allow us to help guide the way towards building decarbonization on a global scale. Together we will chart the course to standardizing grid-building interactions and enable carbon intensity signaling to be used for automated demand side management.

[1] https://www.ashrae.org/about/ashrae-task-force-for-building-decarbonization

[2] https://app.electricitymap.org/map

[3] https://iopscience.iop.org/article/10.1088/1748-9326/ac6147/pdf

[4] https://www.wsj.com/articles/americas-power-grid-is-increasingly-unreliable-11645196772?mod=Searchresults_pos1&page=1

[5] https://sense.com/whitepapers/Sense-EV-Carbon-Research.pdf

[6] https://www.sciencedirect.com/science/article/pii/S0306261922003336?via%3Dihub