# Team seeks to provide tools for predicting building emissions across the U.S.

September 21 2021, by Andrew Logan

Each region of the United States has unique characteristics that will cause building emissions to vary widely across the entire nation. An MIT team sought to understand—and respond to—these regional variations. Credit: Andrew Logan/MIT Concrete Sustainability Hub

The United States is entering a building boom. Between 2017 and 2050, it will build the equivalent of New York City 20 times over. Yet, to meet climate targets, the nation must also significantly reduce the greenhouse gas (GHG) emissions of its buildings, which comprise 27 percent of the nation's total emissions.

A team of current and former MIT Concrete Sustainability Hub (CSHub) researchers is addressing these conflicting demands with the aim of giving policymakers the tools and information to act. They have detailed the results of their collaboration in a recent paper in the journal *Applied Energy* that projects emissions for all buildings across the United States under two GHG reduction scenarios.

Their paper found that "embodied" emissions—those from materials production and construction—would represent around a quarter of emissions between 2016 and 2050 despite extensive construction.

Further, many regions would have varying priorities for GHG reductions; some, like the West, would benefit most from reductions to embodied emissions, while others, like parts of the Midwest, would see the greatest payoff from interventions to emissions from energy consumption. If these regional priorities were addressed aggressively, building sector emissions could be reduced by around 30 percent between 2016 and 2050.

## Quantifying contradictions

Modern buildings are far more complex—and efficient—than their predecessors. Due to new technologies and more stringent building codes, they can offer lower energy consumption and operational emissions. And yet, more-efficient materials and improved construction standards can also generate greater embodied emissions.

Concrete, in many ways, epitomizes this tradeoff. Though its durability can minimize energy-intensive repairs over a building's operational life, the scale of its production means that it contributes to a large proportion of the embodied impacts in the building sector.

As such, the team centered GHG reductions for concrete in its analysis.

"We took a bottom-up approach, developing reference designs based on a set of residential and commercial building models," explains Ehsan Vahidi, an assistant professor at the University of Nevada at Reno and a former CSHub postdoc. "These designs were differentiated by roof and slab insulation, HVAC efficiency, and construction materials—chiefly concrete and wood."

After measuring the operational and embodied GHG emissions for each reference design, the team scaled up their results to the county level and then national level based on building stock forecasts. This allowed them to estimate the emissions of the entire building sector between 2016 and 2050.

To understand how various interventions could cut GHG emissions, researchers ran two different scenarios—a "projected" and an "ambitious" scenario—through their framework.

The projected scenario corresponded to current trends. It assumed grid decarbonization would follow Energy Information Administration predictions; the widespread adoption of new energy codes; efficiency improvement of lighting and appliances; and for concrete, the implementation of 50 percent low-carbon cements and binders in all new concrete construction and the adoption of full carbon capture, storage, and utilization (CCUS) of all cement and concrete emissions.

"Our ambitious scenario was intended to reflect a future where more aggressive actions are taken to reduce GHG emissions and achieve the targets," says Vahidi. "Therefore, the ambitious scenario took these same strategies [of the projected scenario] but featured more aggressive targets for their implementation."

For instance, it assumed a 33 percent reduction in grid emissions by 2050 and moved the projected deadlines for lighting and appliances and thermal insulation forward by five and 10 years, respectively. Concrete decarbonization occurred far more quickly as well.

## Reductions and variations

The extensive growth forecast for the U.S. building sector will inevitably generate a sizable number of emissions. But how much can this figure be minimized?

Without the implementation of any GHG reduction strategies, the team found that the building sector would emit 62 gigatons $CO_2$ equivalent between 2016 and 2050. That's comparable to the emissions generated from 156 trillion passenger vehicle miles traveled.

But both GHG reduction scenarios could cut the emissions from this unmitigated, business-as-usual scenario significantly.

Under the projected scenario, emissions would fall to 45 gigatons $CO_2$ equivalent—a 27 percent decrease over the analysis period. The ambitious scenario would offer a further 6 percent reduction over the projected scenario, reaching 40 gigatons $CO_2$ equivalent—like removing around 55 trillion passenger vehicle miles from the road over the period.

"In both scenarios, the largest contributor to reductions was the greening of the energy grid," notes Vahidi. "Other notable opportunities for reductions were from increasing the efficiency of lighting, HVAC, and appliances. Combined, these four attributes contributed to 85 percent of the emissions over the analysis period. Improvements to them offered the greatest potential emissions reductions."

The remaining attributes, such as thermal insulation and low-carbon concrete, had a smaller impact on emissions, and consequently, offered smaller reduction opportunities. That's because these two attributes were only applied to new construction in the analysis, which was outnumbered by existing structures throughout the period.

The disparities in impact between strategies aimed at new and existing structures underscore a broader finding: Despite extensive construction over the period, embodied emissions would comprise just 23 percent of cumulative emissions between 2016 and 2050, with the remainder coming primarily from operation.

"This is a consequence of existing structures far outnumbering new structures," explains Jasmina Burek, a CSHub postdoc and an incoming assistant professor at the University of Massachusetts Lowell. "The operational emissions generated by all new and existing structures between 2016 and 2050 will always greatly exceed the embodied emissions of new structures at any given time, even as buildings become more efficient and the grid gets greener."

Yet the emissions reductions from both scenarios were not distributed evenly across the entire country. The team identified several regional variations that could have implications for how policymakers must act to reduce building sector emissions.

"We found that western regions in the United States would see the greatest reduction opportunities from interventions to residential emissions, which would constitute 90 percent of the region's total emissions over the analysis period," says Vahidi.

The predominance of residential emissions stems from the region's ongoing population surge and its subsequent growth in housing stock. Proposed solutions would include CCUS and low-carbon binders for concrete production, and improvements to energy codes aimed at residential buildings.

As with the West, ideal solutions for the Southeast would include CCUS, low-carbon binders, and improved energy codes.

"In the case of Southeastern regions, interventions should equally target commercial and residential buildings, which we found were split more evenly among the building stock," explains Burek. "Due to the stringent energy codes in both regions, interventions to operational emissions were less impactful than those to embodied emissions."

Much of the Midwest saw the inverse outcome. Its energy mix remains one of the most carbon-intensive in the nation and improvements to energy efficiency and the grid would have a large payoff—particularly in Missouri, Kansas, and Colorado.

New England and California would see the smallest reductions. As their already-strict energy codes would limit further operational reductions, opportunities to reduce embodied emissions would be the most impactful.

This tremendous regional variation uncovered by the MIT team is in many ways a reflection of the great demographic and geographic diversity of the nation as a whole. And there are still further variables to consider.

In addition to GHG emissions, future research could consider other environmental impacts, like water consumption and air quality. Other mitigation strategies to consider include longer building lifespans, retrofitting, rooftop solar, and recycling and reuse.

In this sense, their findings represent the lower bounds of what is possible in the building sector. And even if further improvements are ultimately possible, they've shown that regional variation will invariably inform those environmental impact reductions.

**More information:** Ehsan Vahidi et al, Regional variation of greenhouse gas mitigation strategies for the United States building sector, *Applied Energy* (2021). DOI: 10.1016/j.apenergy.2021.117527

Provided by Massachusetts Institute of Technology