APPENDIX B: OPPORTUNITIES FOR EXPANDING RESEARCH

Throughout this pilot study the authors, contributors, and pilot cities identified multiple opportunities to expand the accuracy, scope, and functionality of the calculators. The types of future research and developments identified fall into two primary categories:

1. **Additional Research Required:** For some gaps in data, there is simply not adequate research currently available. This type of gap will require more significant research, time, and funding to address.
2. **Expanding Calculator Functionality:** Due to the short timeline of this proof-of-concept study, the research team had to prioritize which functionality could be built into the tool. Functionality of the calculators could be expanded with currently available data in many cases if additional time and funding were secured.

B.1 Additional Research Required

While this proof-of-concept study proved the concept and potential of the calculators, additional research is critical before they can be used at scale to support policy decision-making. Sensitivity analyses revealed that the following factors in Table B1 are the most urgent to address with additional research to develop future versions of the calculators and move beyond the proof of concept phase.

Table B1. Gaps in data identified to reduce uncertainty around results of prototype calculators.

Data Gap	Priority	Potential Data Sources
Regionally and typologically specific BECI values Additional research is urgently needed to provide regionally specific embodied carbon values for BECI that reflect the construction typologies of each city as well as capture the missing physical scopes of the calculators and provide a more accurate and comprehensive picture of the total embodied carbon impacts of buildings. The BECI values used in this study are order-of-magnitude estimates for each building typology. No available research quantifies the BECI of buildings in the United States with enough regional and typological specificity to provide representative estimates for the building typologies in this study. Most current BECI benchmarks also exclude physical scope beyond structure, enclosure, and interiors, such as mechanical, electrical, and plumbing systems (MEP).	High	Building benchmarking studies by building typology by the Carbon Leadership Forum and other research organizations Benchmarks collected by governments that have policy requirements to disclose whole building life cycle assessment results. In the future, this may be a larger dataset, but currently this data source does not exist and/or is not publicly available.

Inclusion of life cycle stages beyond A1-A3 The scope of the prototype calculators is limited to A1-A3, which is indicative of the scale of life cycle impacts but excludes key life cycle stages for decision-making. This also means that the projections included in Section 3 may be low (i.e., they underestimate the baseline and potential carbon savings of policies). If this data is used alongside other metrics related to carbon to communicate the importance of policies, it is important that the scale of emissions is appropriately communicated. Pilot cities highlighted that impacts from other life cycle impacts, such as construction equipment (A5), local transportation (A4), and replacement/end-of-life (stages B and C), would be helpful, but did not highlight as a high priority.	High/ Medium	Requires additional data, most of which is readily available.
City data on building size Differences in building height and size can dictate multiple variables that have significant ramifications for total embodied carbon such as structural system, foundation design, level of interior finishes, and MEP system selection. This data would help provide more accurate calculations across all calculators. This item is a 'medium/low' rather than high priority because this may be difficult to integrate, depending on the scope of future versions of the calculators. This would potentially require pre-determining which cities could use the calculators, so that appropriate building size data could be included.	Medium/ Low	City building permit databases City LIDAR and other GIS building data layers by local cities
City-specific data on construction type Construction type varies widely due to regional structural necessities, preferences, and market factors. This would indicate the structural system typical for each building typology, which would influence the volume of concrete assumed for each building typology for the Low Carbon Concrete Calculator. This item is a 'medium/low' rather than high priority because this may be difficult to integrate, depending on the scope of future versions of the calculators. This would potentially require pre-determining which cities could use the calculators, so that appropriate construction type mix data could be included.	Medium/ Low	City building permit databases, taxlot information, or GIS data

B.2 Expanding Calculator Functionality

There are multiple ways the calculators could be expanded both in terms of scope and functionality that improve their utility for policymakers in developing and communicating embodied carbon policies. Table B2 lists additional features identified by the authors, contributors, and pilot cities and their priority for future work.

Table B2. Additional functionality that could be added to the calculators to expand their utility for policymakers and better reflect policy mechanisms.

Additional Function	Priority	Requires New Data Sources
Stepped Policy Limits All reduction scenarios modeled for this study assume that a policy (reduction strategy) is immediately passed or implemented, rather than phased in over time.	High	No
Infrastructure and Parking The impacts from infrastructure were not included in any of the calculators for this pilot study. Physical buildings only represent a portion of the total embodied carbon impacts of the larger built environment. The embodied carbon impacts from constructing roadways, parking lots, sewer and water systems, and power distribution networks, contribute significantly to the carbon footprint of cities. Furthermore, the demands for infrastructure typically increase as cities grow. Parking spaces, for instance, are often required by law for certain types of housing developments. Future versions of this calculator could attempt to capture the embodied carbon impacts from the associated infrastructure that would be required for additional growth in buildings	High	Yes
Demolition impacts The adaptive reuse calculator does not capture the impacts from demolishing existing buildings, disposing of their materials, or any reuse/recycling. Including these end-of-life impacts could have substantial effects on the total carbon savings potentials of the reuse calculator.	Medium	Yes
Adding additional policies These calculators can estimate the impacts of only 4 types of embodied carbon policies. There are many additional policy paths that could be modeled, each of which have their own data availability challenges. For example, pilot cities highlighted that other material-specific policies (such as wood, steel, insulation, etc.) would be interesting to see results from, in addition to concrete. Also of interest were policies targeting material reuse, procurement, and others targeting additional planning and zoning measures.	Medium	Yes
Time Value of Carbon and Nonlinear Growth Near-term reductions in carbon emissions are critical for meeting larger climate change targets because carbon emitted today has more potential for amplifying the negative effects of climate change than emitting the same amount of carbon in the future[42]. However, this report does not attempt to apply numerical value factors to carbon emitted either in the near-term or long-term. All carbon emissions are treated equally. Furthermore, all calculators in the pilot study apply embodied carbon intensities to the total projected growth assuming a linear growth rate for cities, which does not capture the potential nonlinear climate change impacts of cities that grow faster in the near term. Future versions of these calculators could integrate both predictions about the fluctuations of growth that cities might experience over time, as well as the time-dependent values of those carbon emissions.	Medium/Low	No

42 Council of Economic Advisors. (July 2014). *The Cost of Delaying Action to Stem Climate Change.* https://scholar.harvard.edu/files/stock/files/cost_of_delaying_action.pdf