Embodied carbon of Germany's residential stock and the emission cost of retrofitting it

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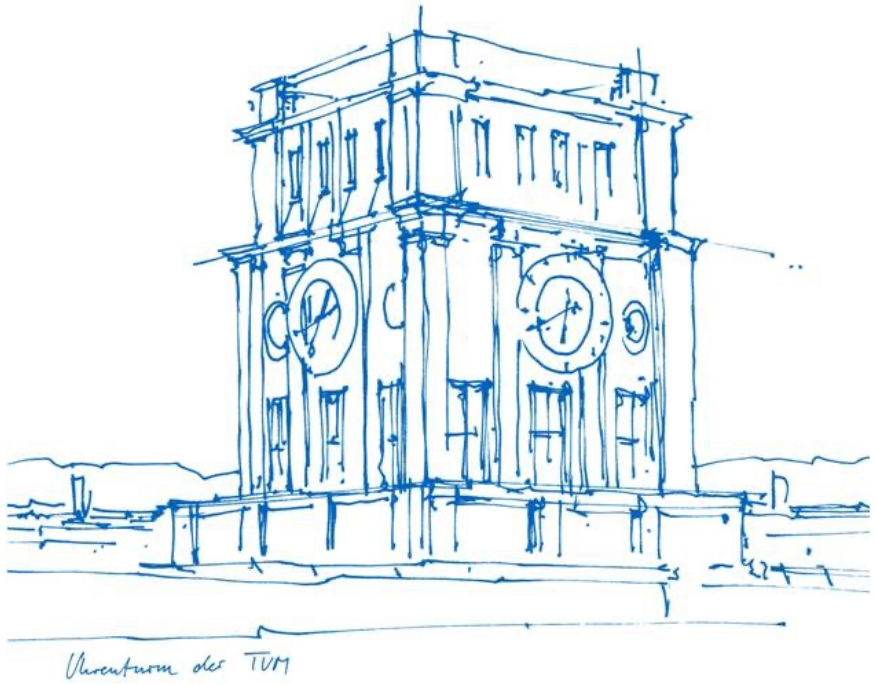


Motivation

Urban areas are responsible for 70% of global CO_2 emissions, with **transport and buildings being among the largest contributors**.

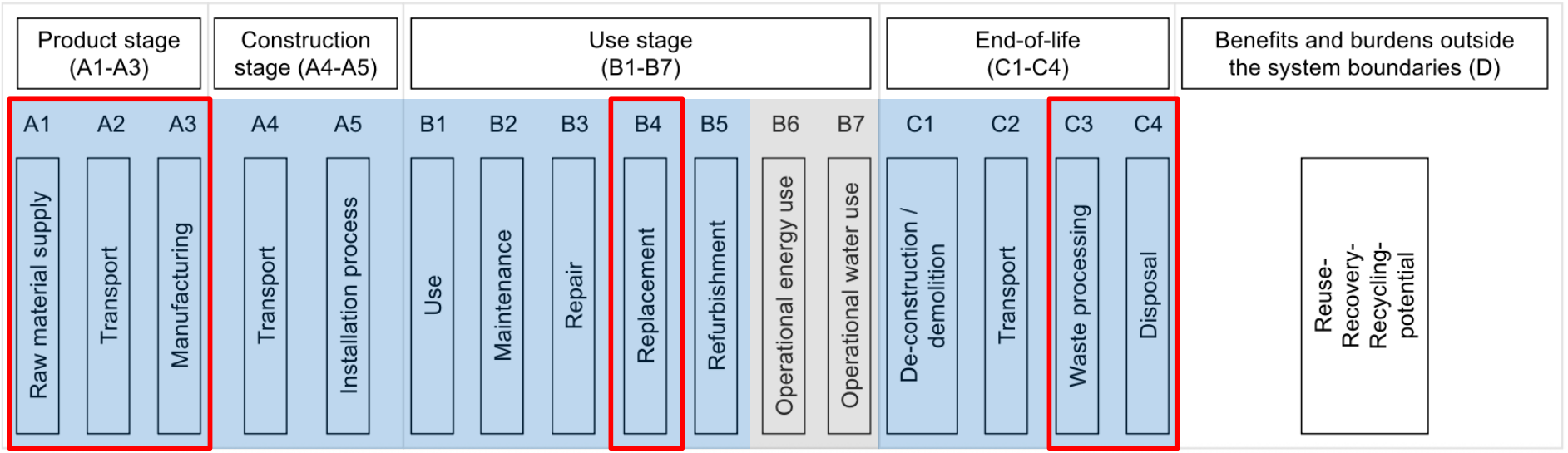
Energy Performance of Buildings Directive (EPBD):

- Global Warming Potential (GWP)-Roadmap
- Targets and limits for embodied carbon emissions → **Carbon Emissions Budget**
- National building renovation plans
- National database for energy efficiency of buildings

- **Switching from "operational emissions only" to a whole life cycle approach!**

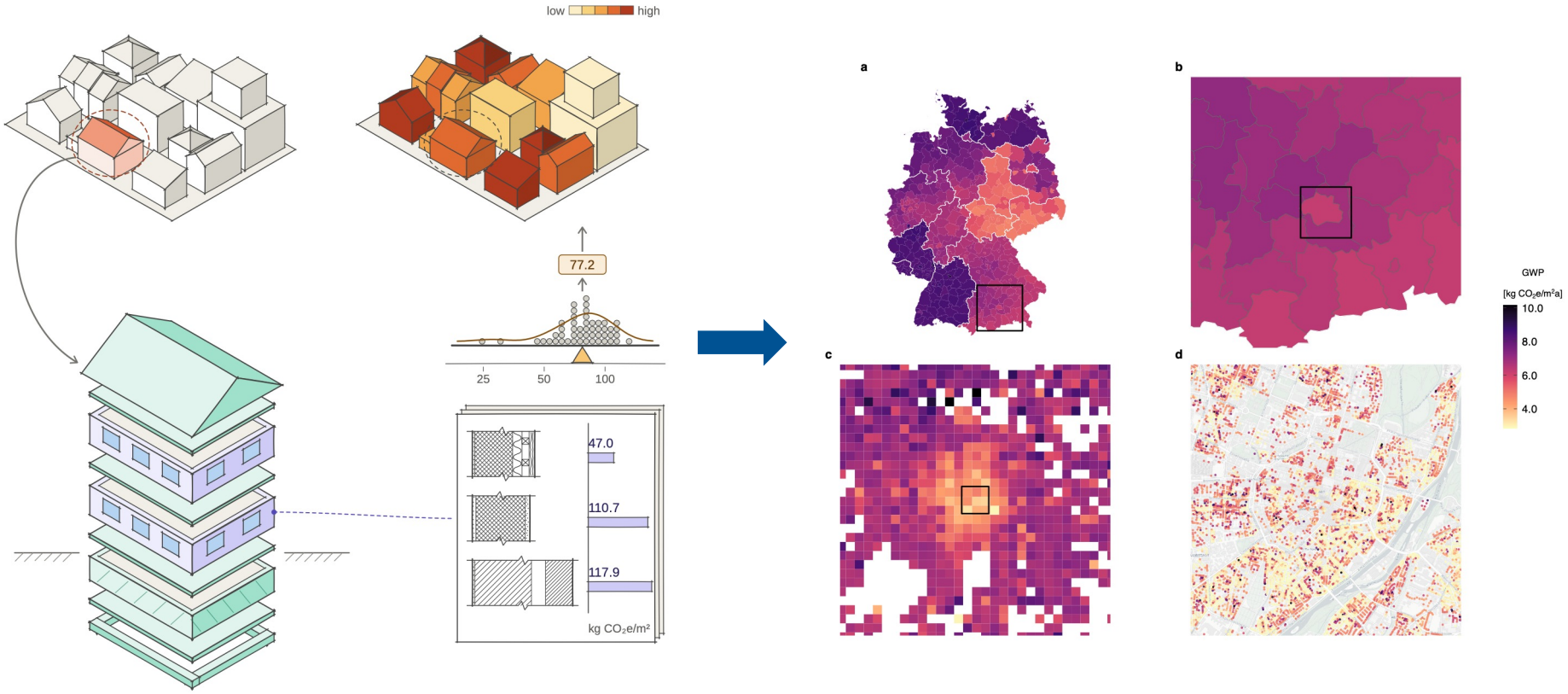
Background

- A building's whole life cycle can be decomposed into life cycle phases
- Life cycle assessment (LCA) captures the environmental impact of each life cycle phase
- Environmental impact is measured as Global Warming Potential (GWP) [$kgCO_2$-eq/(m^2×a)]
- Distinction between embodied and operational GWP



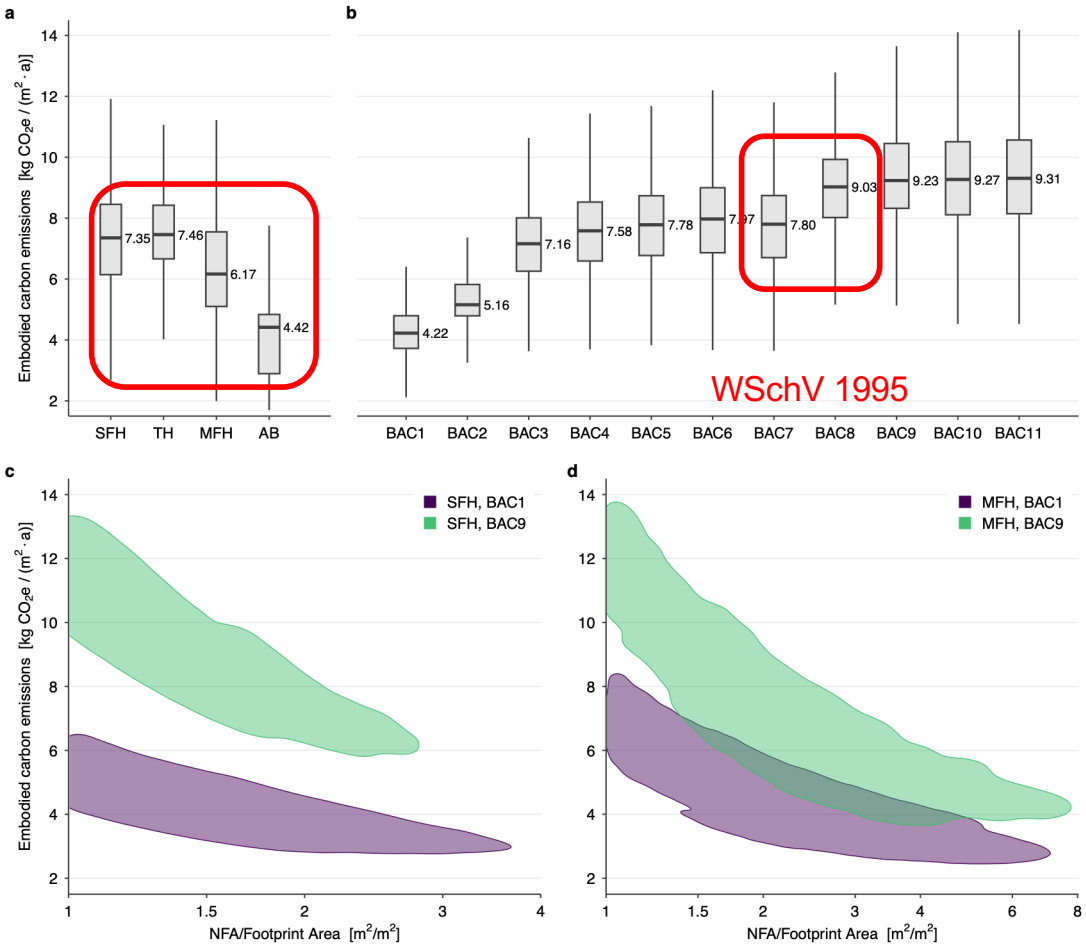
Approach

Bottom-up approach: Combining real geometries with age-specific constructions



Results

Current typology based LCA approaches miss most of the variation in the stock



The bigger, the more GWP-efficient

- Embodied GWP is distributed across more net floor area in MFH and AB

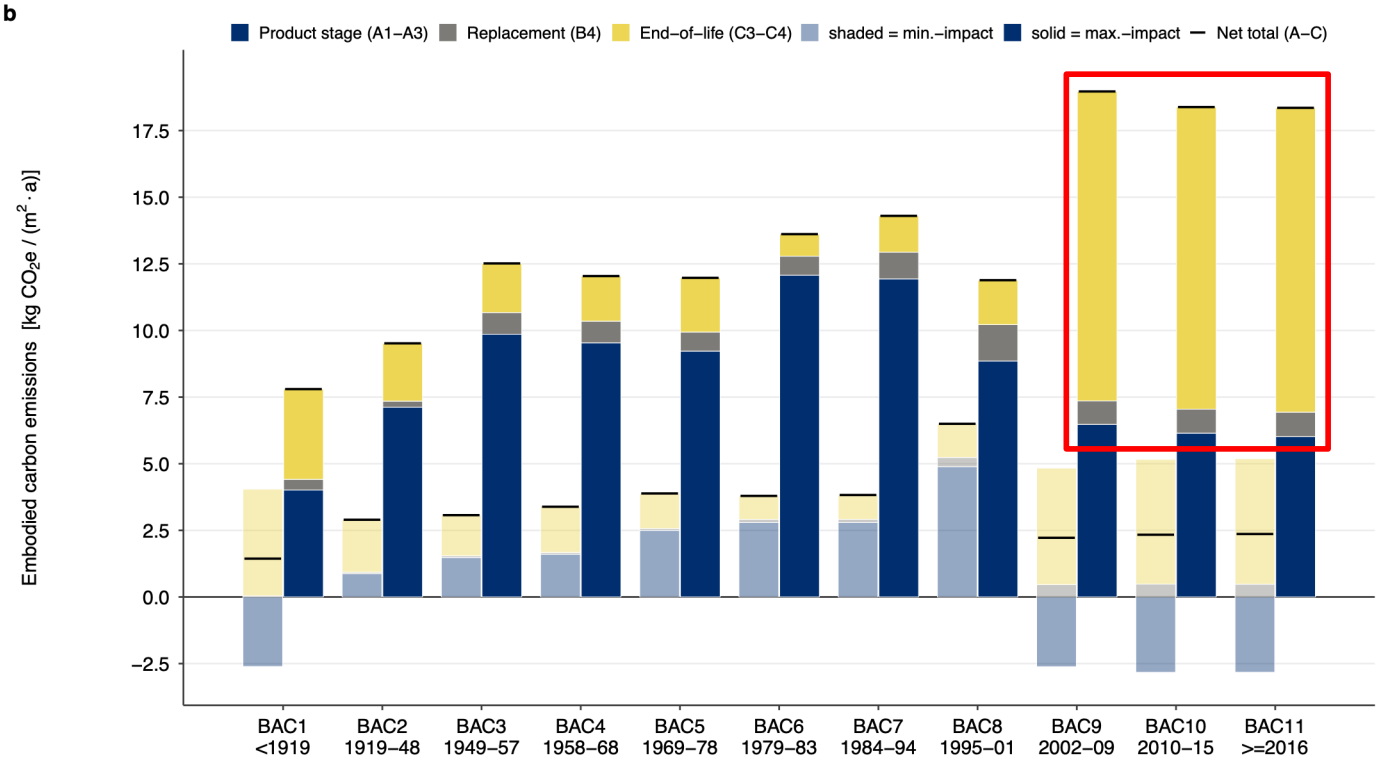
The newer, the higher the material emissions

- Increased energy efficiency requirements → Insulation

Typology-based LCA approaches understate the large variation in the building stock!

Results

Retention is a climate change mitigation instrument



End-of-life emissions become greater with timber-based constructions

End-of-life emissions are avoidable by extending service lives of existing buildings

- Replacement and end-of-life emissions influence the future limited emission budget for the construction sector!
- Retrofits?

Background

Construction sector lives on a limited budget to comply with German national climate target

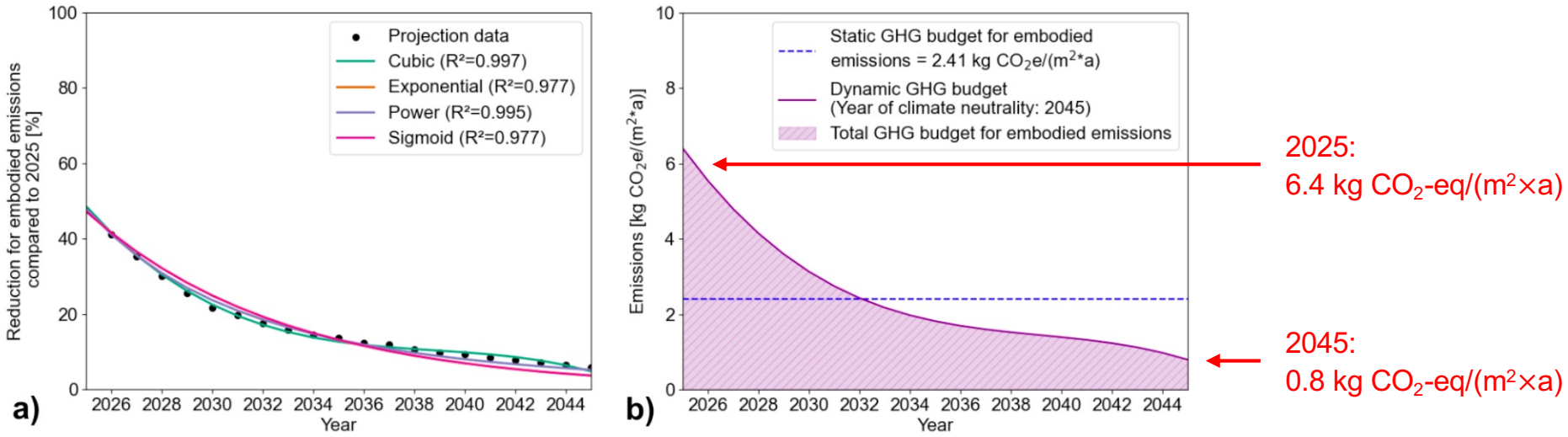


Figure 3: a) Projections for the development of embodied emissions in Germany (based on [12]) with calculated functions and their R^2 value. b) Static and dynamic GHG budget for embodied emissions.

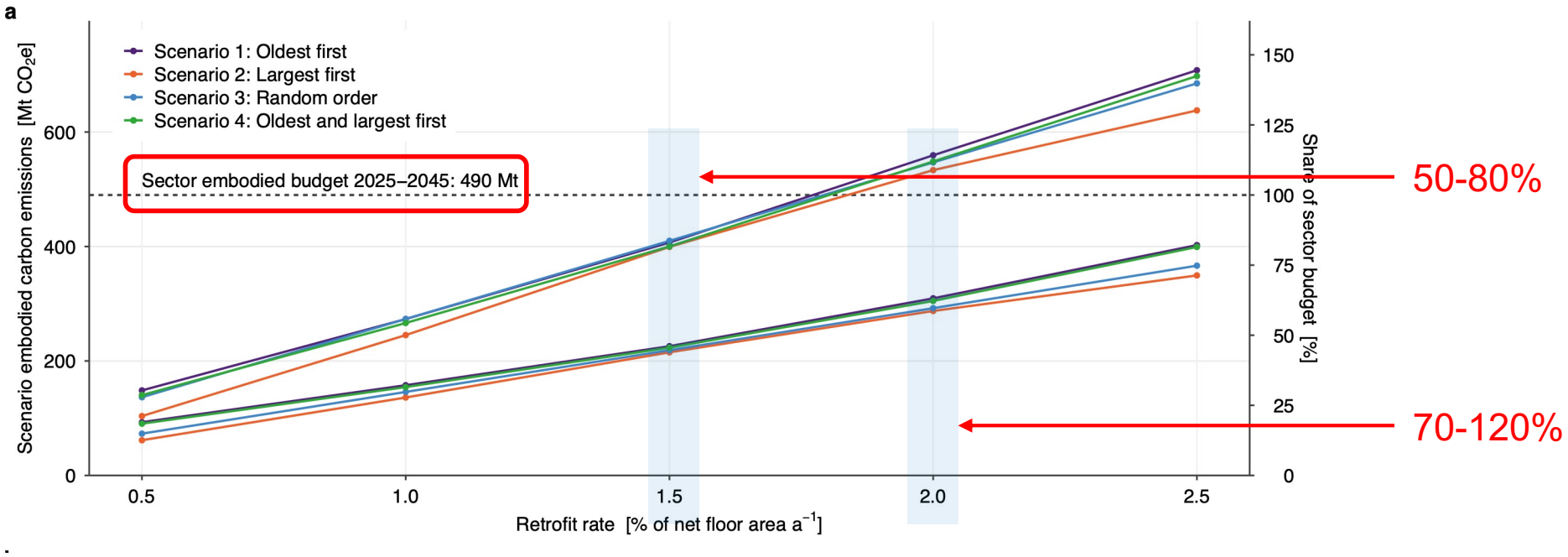
Graphic: Woytowicz, J., Stöckle, L., Präger, L. & Lang, W. Determination of a dynamic top-down greenhouse gas budget for buildings in Germany. IOP Conference Series: Earth and Environmental Science 1554, 012121 (2025).

No official embodied emission roadmap as demanded by EPBD yet!

- Suggested embodied carbon budget pathway for the German construction sector
- **Between 2025 and 2045 Germany is allowed to spend 490 Mt CO²-eq**
- **Includes all new construction activity**

Results

Retrofitting using conventional techniques and materials to increase energy efficiency can consume most of the sector embodied carbon budget



These are just renovations of residential buildings in increase energy efficiency!

It does not include any newly constructed apartments, renovations or new construction of offices, hotels, data centers, logistics facilities, schools, …

Conclusion

Retrofitting is among the most important climate change mitigation policies.
But, we need to consider their embodied emissions when implementing them!

Climate policy asks whether a building meets an opertional efficiency standard. Not whether it should be preserved to avoid end-of-life emissions.

- **Retention should be treated as a climate protection measure.**

How renovations are carried out determines whether they remain within climate limits.

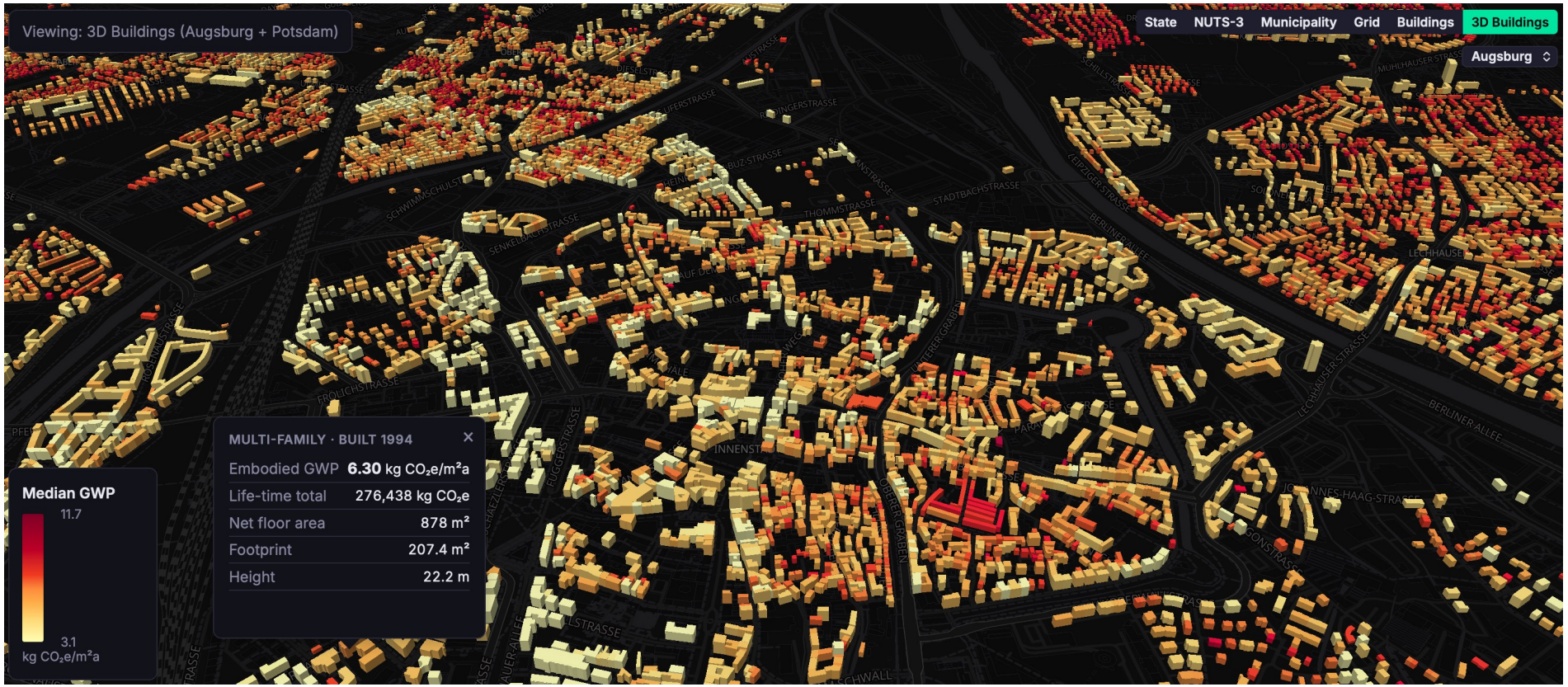
- **A renovation must be evaluated based on the embodied emissions it entails, not just the energy it saves.**

Emissions resulting from renovation work are not attributed to the building sector, but rather to the industrial sector.

- **The sector that mandates renovations should take responsibility for the associated emissions to enable well-informed decision-making.**

Urban Carbon Atlas

A database for urban carbon emissions for Germany



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