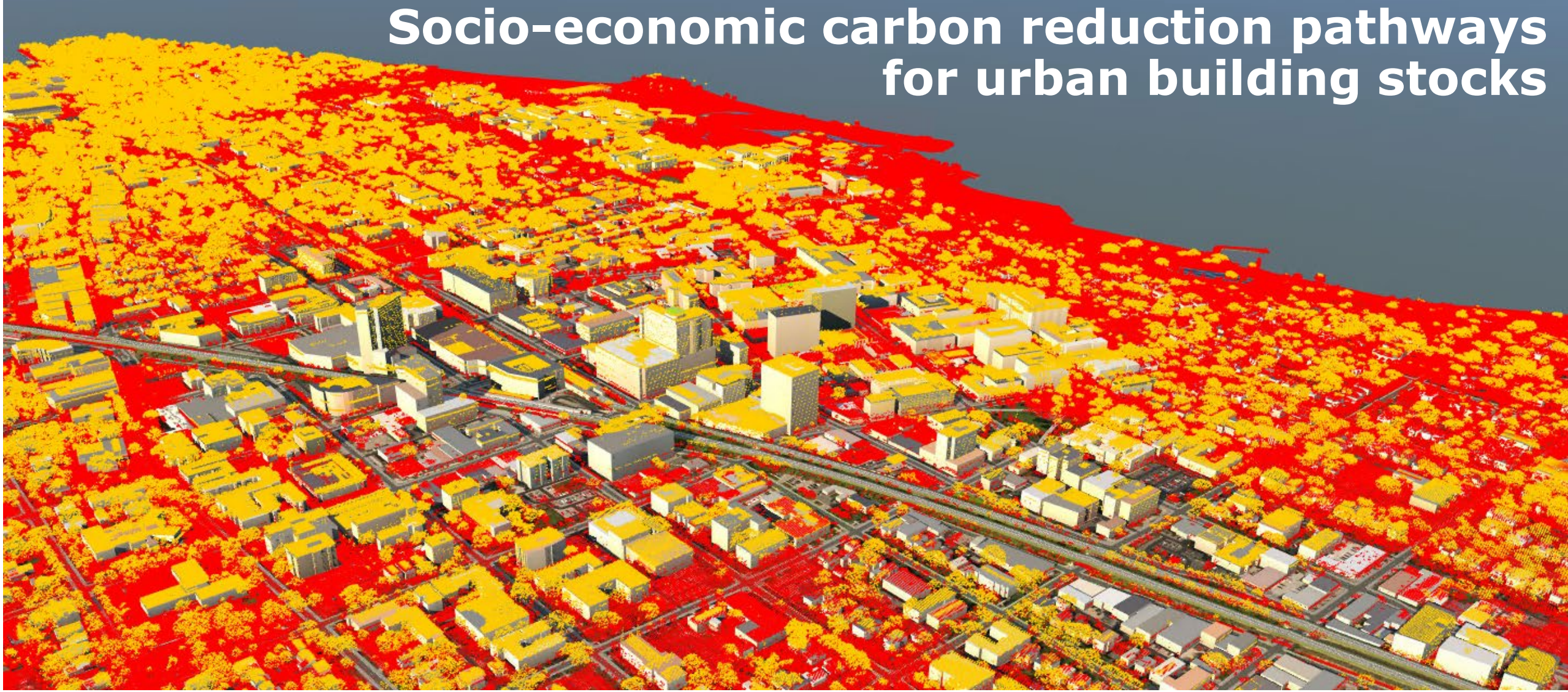
Socio-economic carbon reduction pathways for urban building stocks



UBEM of Evanston, IL, by YU Qian Ang

Christoph Reinhart

Climate Neutral Heating and Cooling: RD&D needs and perspectives for international collaboration, April 20, 2023

MIT SUSTAINABLE DESIGN LAB

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SOLEMMA

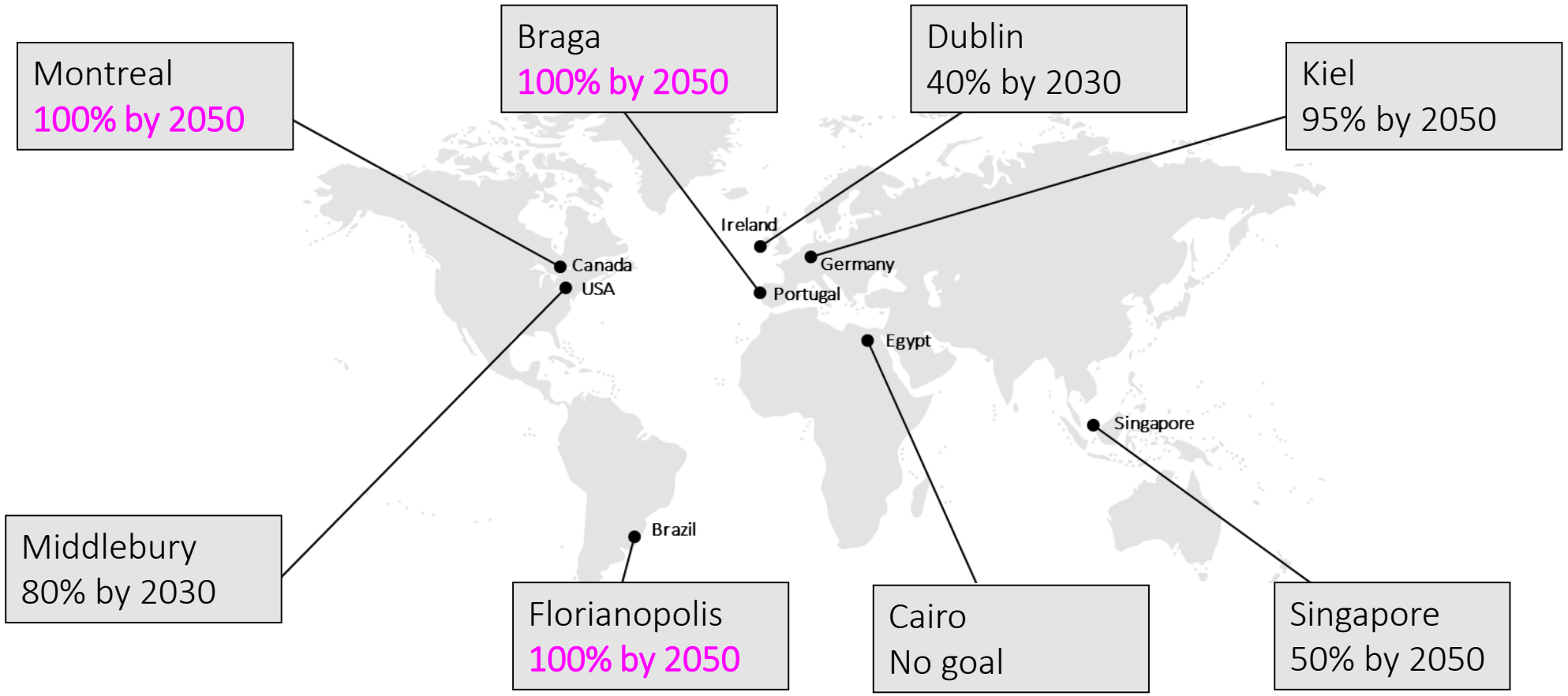
Christoph Reinhart MIT Sustainable Design Lab Yu Qian Ang + Khadija Benis + Zack Berzolla + Zoe De Simone + Ali Irani + Svenja Herb + Amanda Kirkeby + Zoe Le Hong + Lauren Moore + Ellen Reinhard + Cody Rose+ Nada Tarkhan + Tristan Searight + Leilah Sory + Ramon Weber Solemma Demi Chang + Timur Dogan + Alstan Jakubiec + Jeff Niemasz + Jon Sargent SDL/G(SD)^2 Alumni Alpha Arsano + Jamie Bemis + Carlos Cerezo + Timur Dogan + Karthik Dondeti + Jay Dhariwal + Jamie Farrell + Elliot Glassman + Jeff Geisinger + Jared Hanson + Seth Holmes + Diego Ibarra + Lukas Debiasi + Alstan Jakubiec + Nathaniel Jones + Cynthia Kwan + Kera Lagios + Sam Letellier-Duchesne + Mariana Liebman-Pelaez + Rohit Manudhane + Rashida Mogri + Azadeh Omidfar + Aiko Nagano + Shreshth Nagpal + Debashree Pal + Krista Palen + Tiffany Otis + Tarek Rakha + Cody Rose + Holly W Samuelson + Manos Saratsis + Devon Sparks + Julia Sokol + Jiamin Sun + Jennifer Sze + John Sullivan + Bradley Tran + Irmak Turan + Elizabeth Young

We develop design workflows, planning tools and metrics for education and practice to evaluate the environmental performance of buildings and neighborhoods. Our expertise lies in computational Environmental Performance Analysis.

Our goal

Develop decision support tools to help society to transition to a carbon free economy.

Carbon emissions - What are cities doing today?

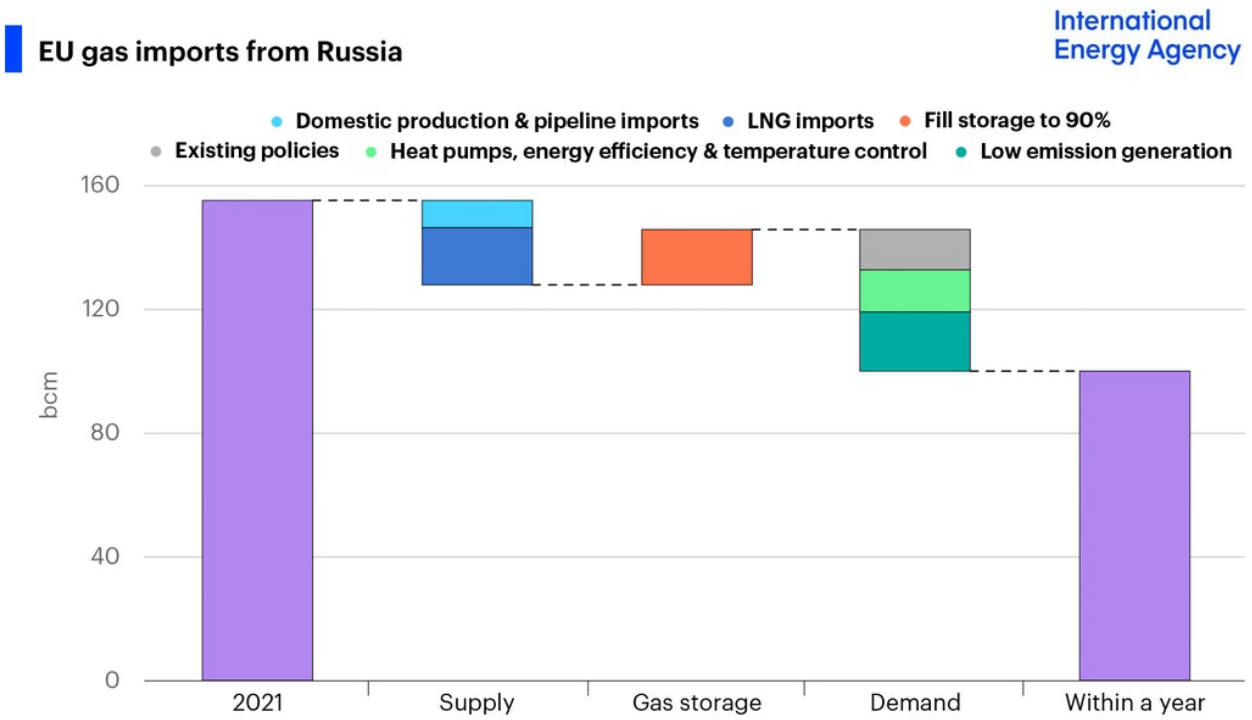


What are the drivers behind these unprecedented goals?

Changing Societal Attitudes

Sources https://www.fridaysforfuture.org/

Changing Geopolitical Realities

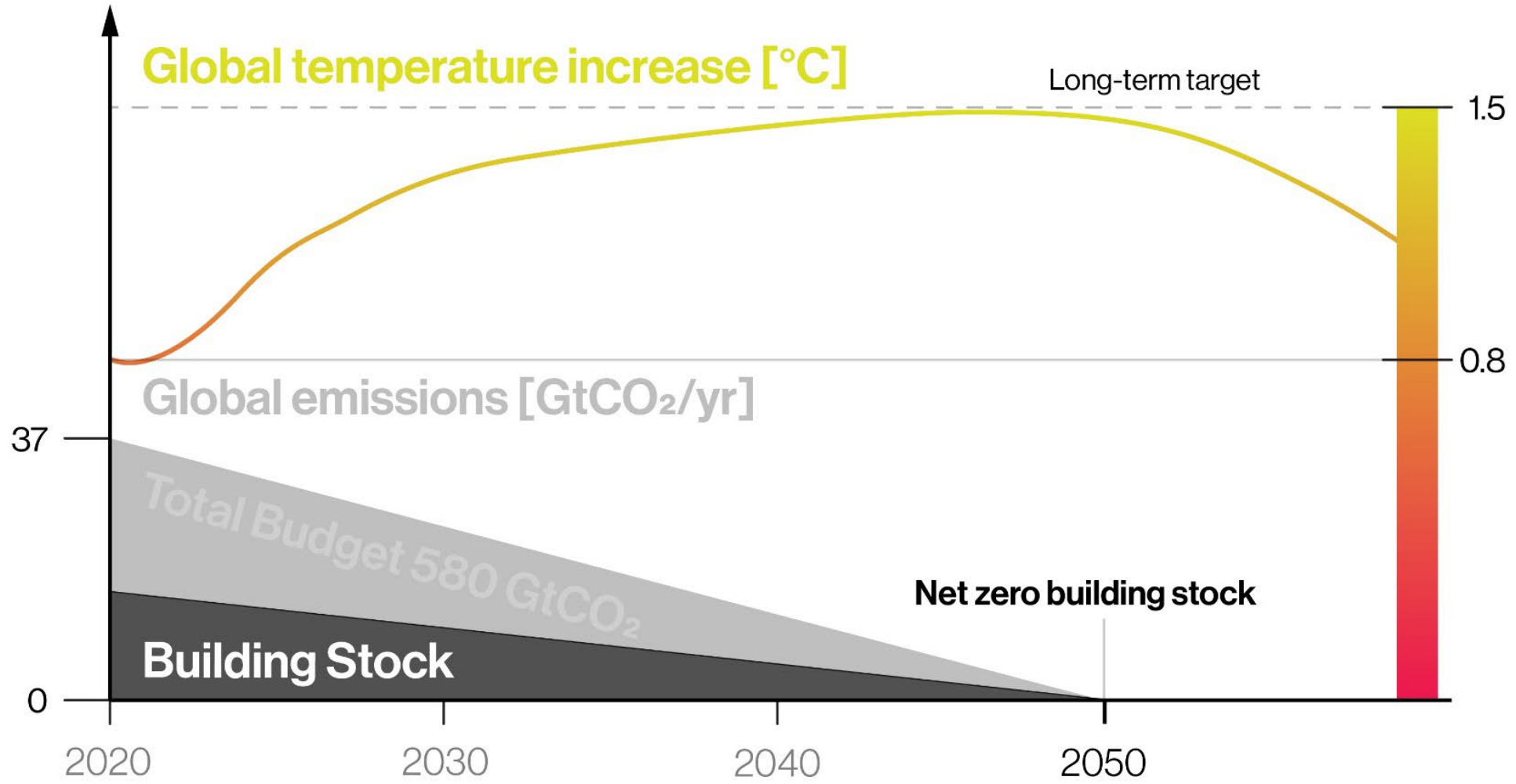


IEA Ten Point Plan (March 2022)

1. No new gas supply contracts with Russia.
2. Replace Russian supplies with gas from alternative sources
3. Introduce minimum gas storage obligations
4. Accelerate the deployment of new wind and solar projects
5. Maximize power generation from bioenergy and nuclear
6. Enact short-term tax measures
7. Speed up the replacement of gas boilers with heat pumps
8. Accelerate energy efficiency improvements in buildings
9. Encourage a temporary thermostat reduction of 1 °C
10. Diversify and decarbonize sources of power system flexibility

Sources https://www.iea.org/news/how-europe-can-cut-natural-gas-imports-from-russia-significantly-within-a-year; https://www.nytimes.com/2022/02/22/business/nord-stream-russia-putin-germany.html

Climate Change and the Built Environment

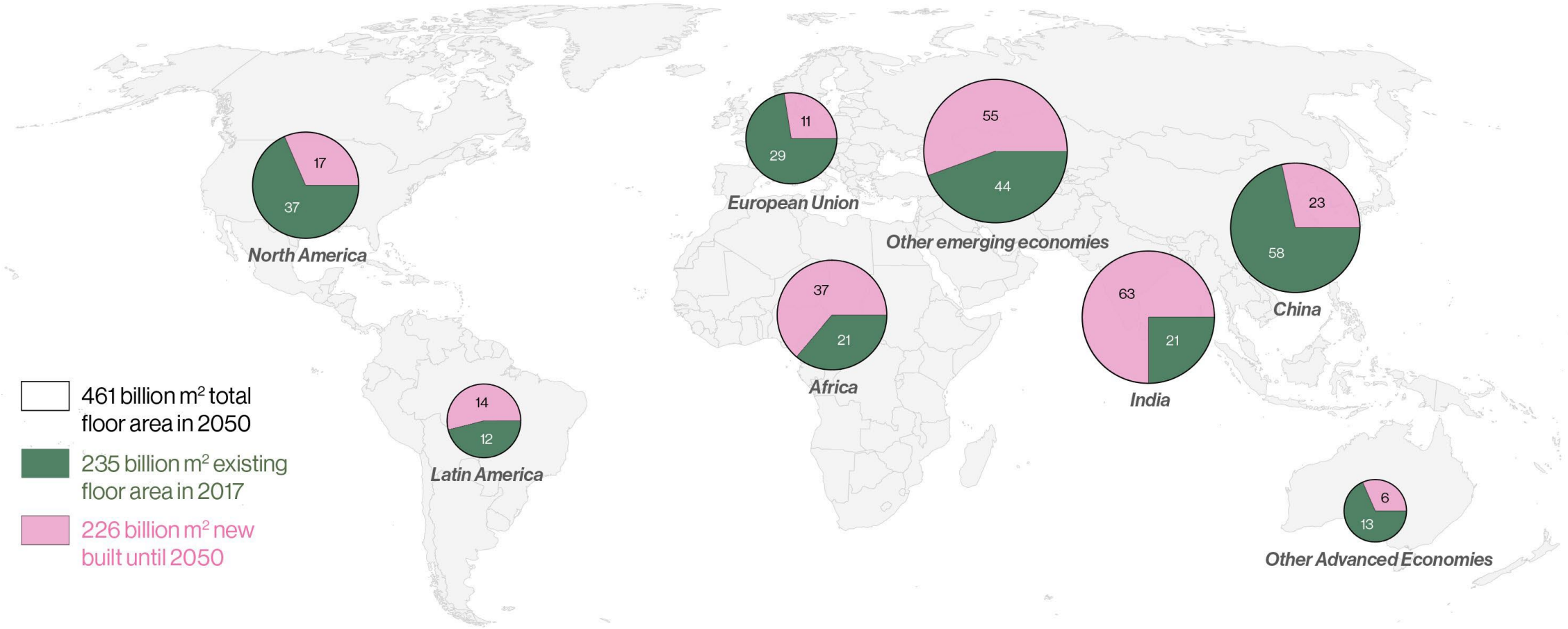


R Weber, C Mueller and C Reinhart, Christoph, Building for Zero, The Grand Challenge of Architecture without Carbon (October 8, 2021). http://dx.doi.org/10.2139/ssrn.3939009

Our Challenge

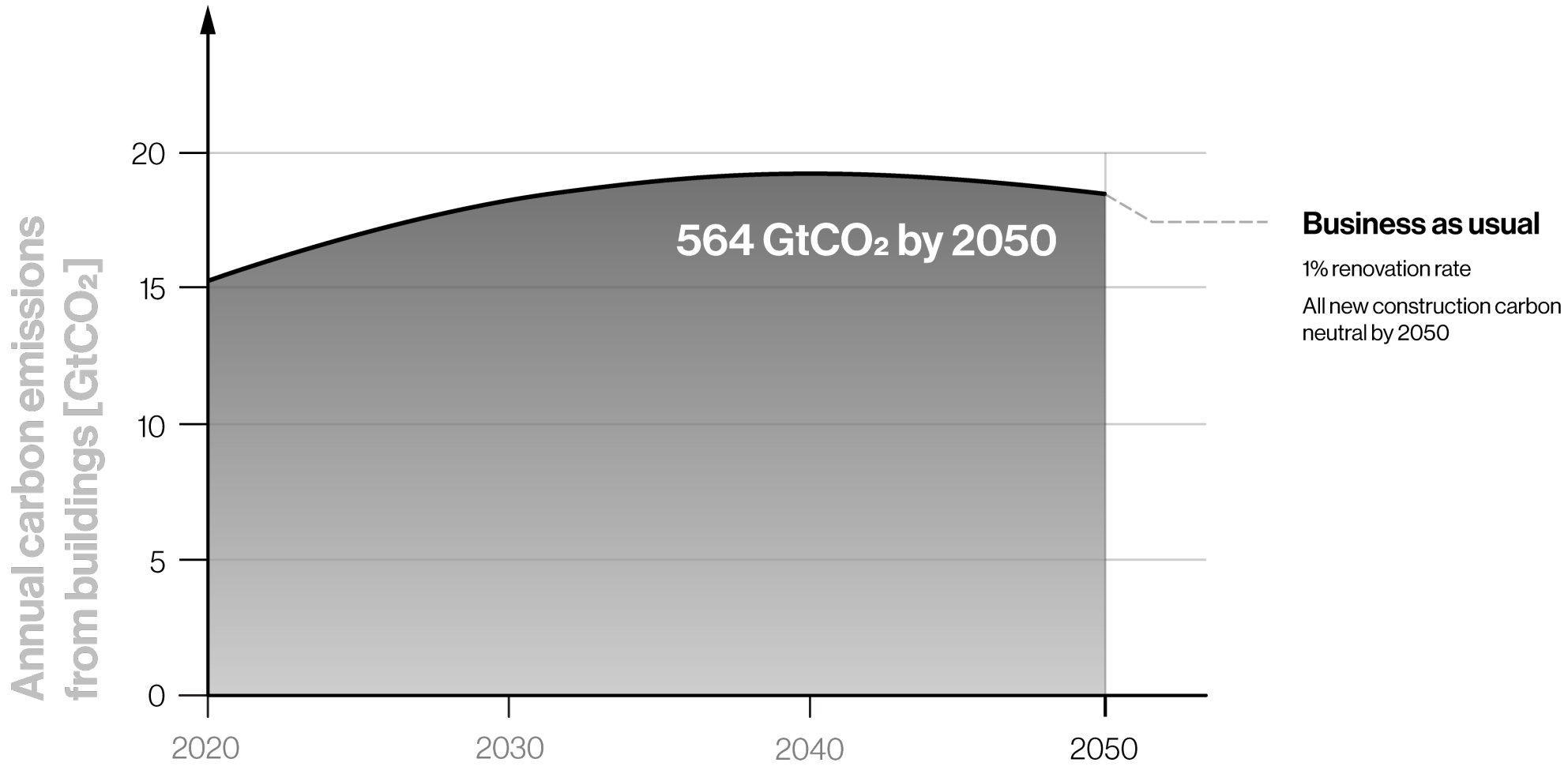
We have 300 $GtCO_2$ and 30 years left to make the global building stock carbon neutral.

The building stock is going to double until 2050



R Weber, C Mueller and C Reinhart, Christoph, Building for Zero, The Grand Challenge of Architecture without Carbon (October 8, 2021). http://dx.doi.org/10.2139/ssrn.3939009

Total annual carbon emissions from buildings



R Weber, C Mueller and C Reinhart, Christoph, Building for Zero, The Grand Challenge of Architecture without Carbon (October 8, 2021). http://dx.doi.org/10.2139/ssrn.3939009

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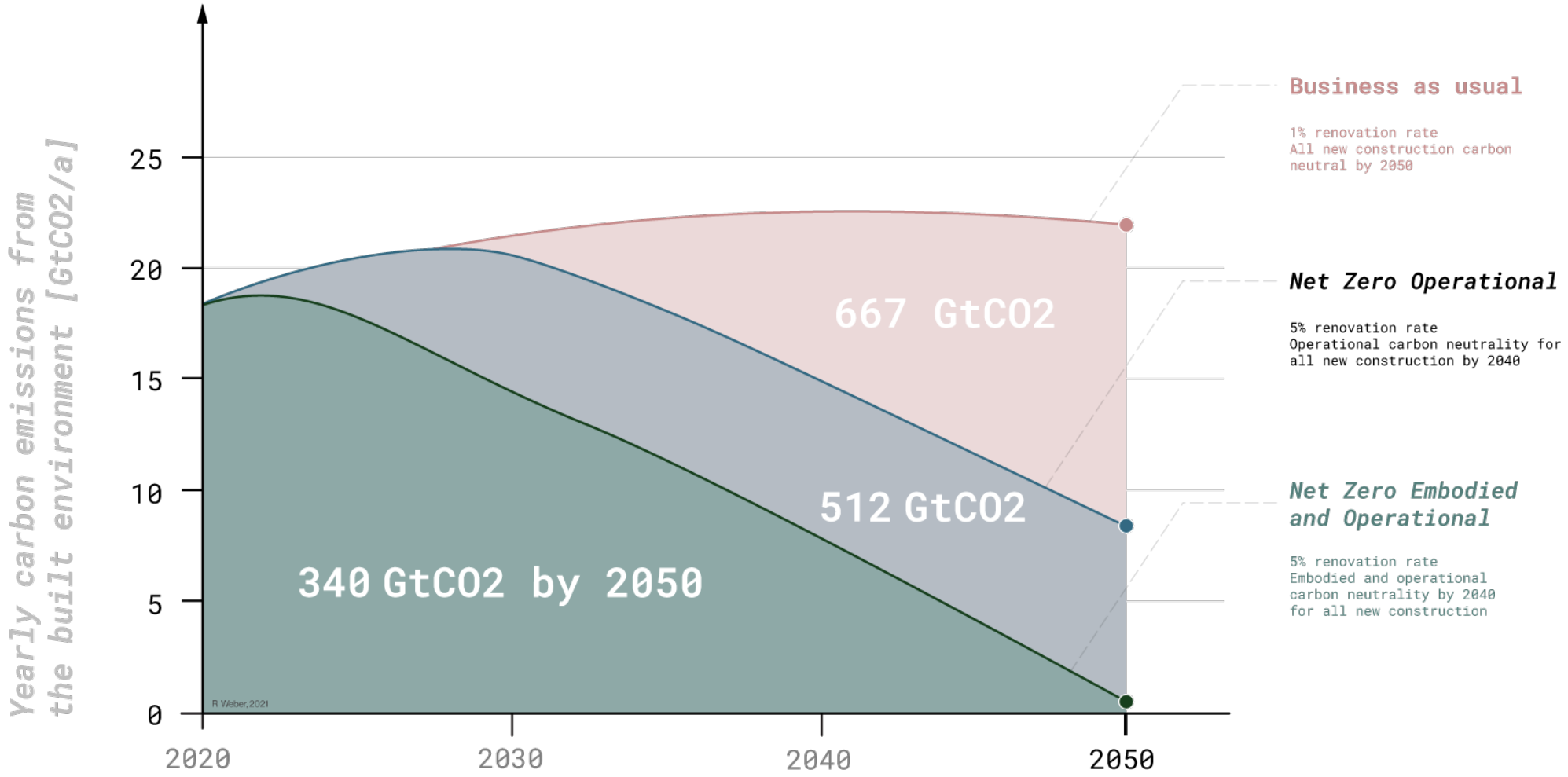


R Weber, C Mueller and C Reinhart, Christoph, Building for Zero, The Grand Challenge of Architecture without Carbon (October 8, 2021). http://dx.doi.org/10.2139/ssrn.3939009

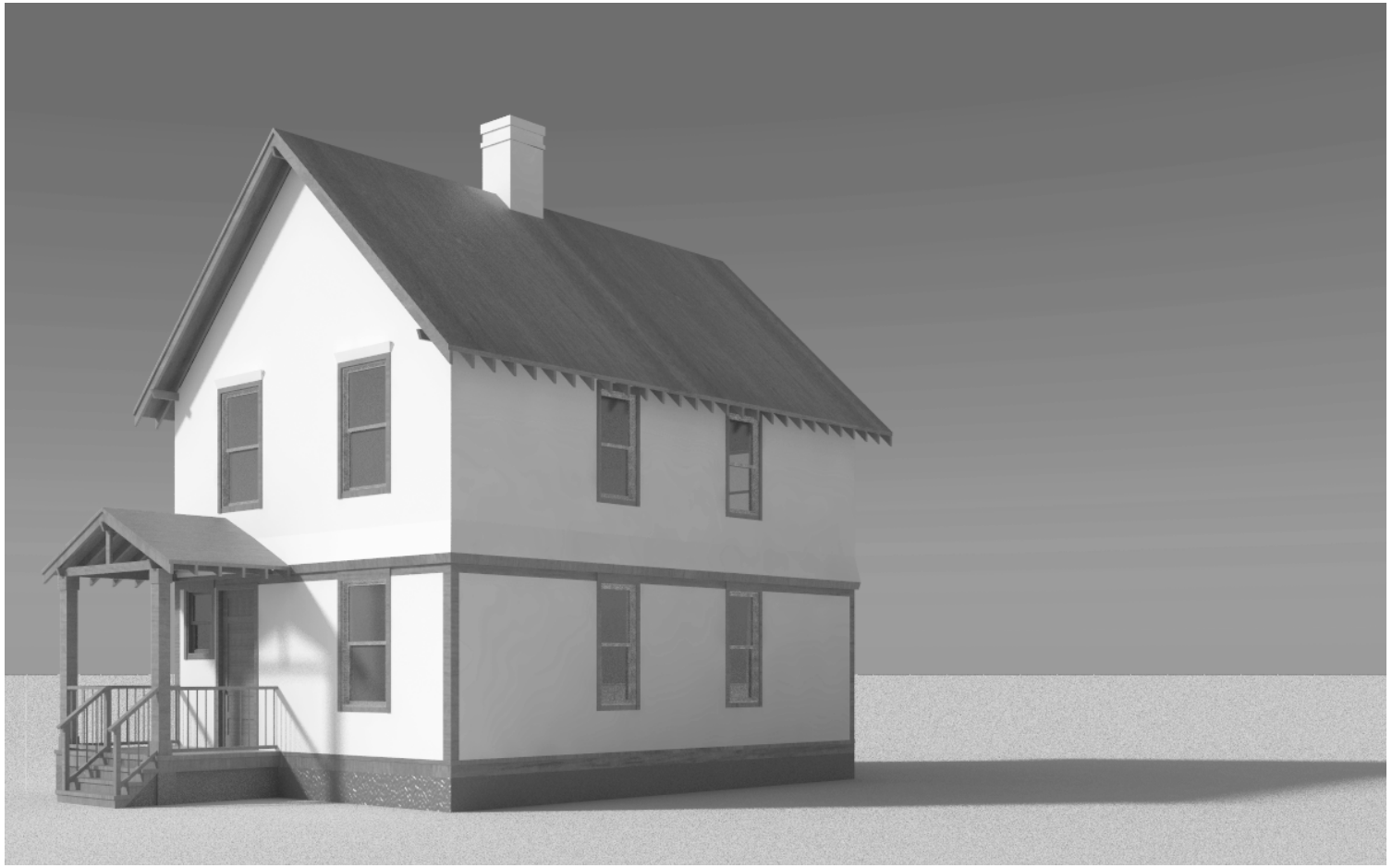
Our goals for 2030

Increase annual retrofitting rate to 5%

All new construction is carbon neutral.

What technology pathways lead to net zero retrofits?

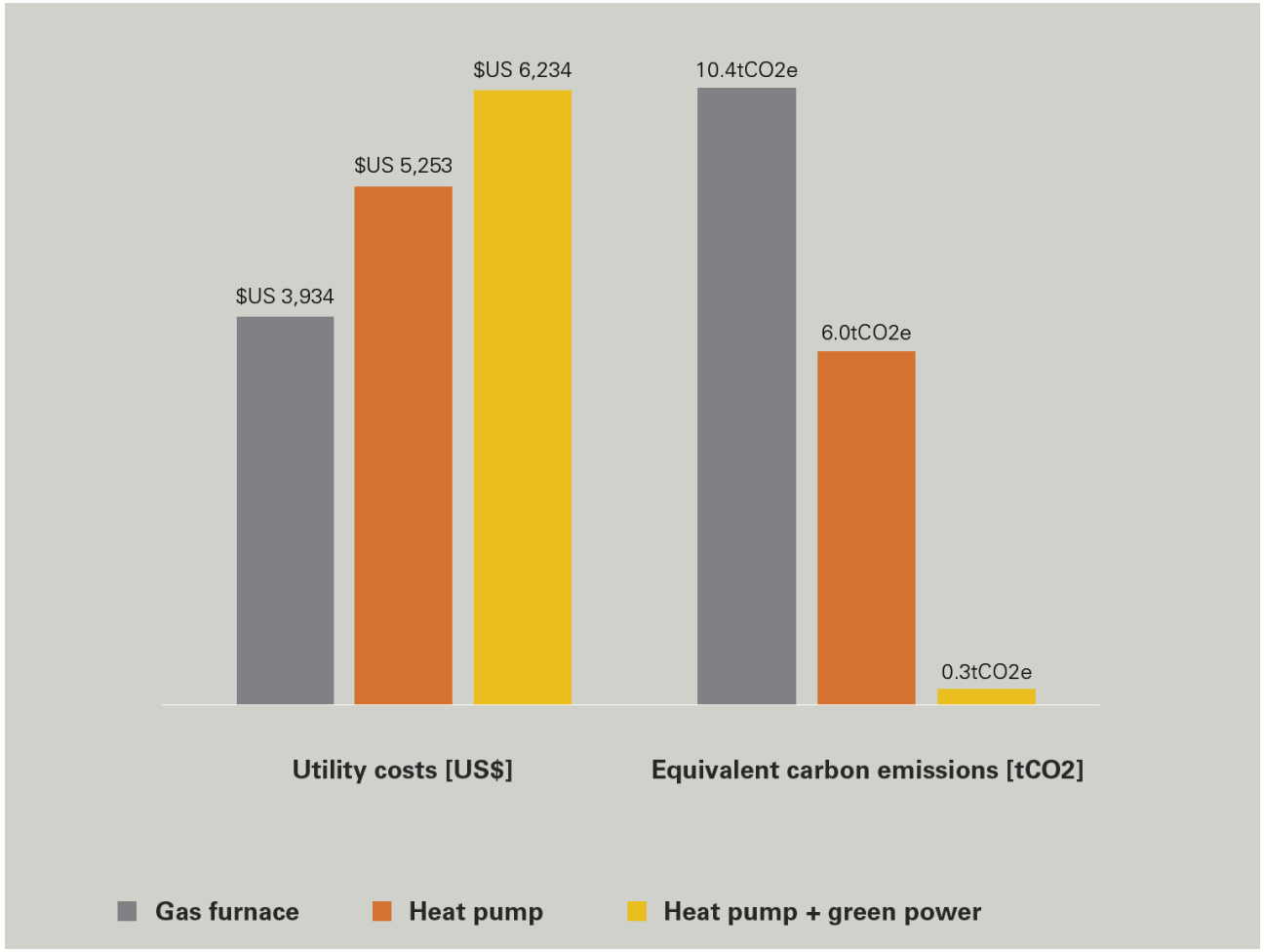
Case Study - New England Home



- The New England home is a fictional, detached single-family 125m^2 (1350ft^2) home located in Boston and constructed around the 1920s. It is inhabited by a family of four and has not been retrofitted since its construction.
- We will go through the journey of an owner trying to get to net zero while living in the house.

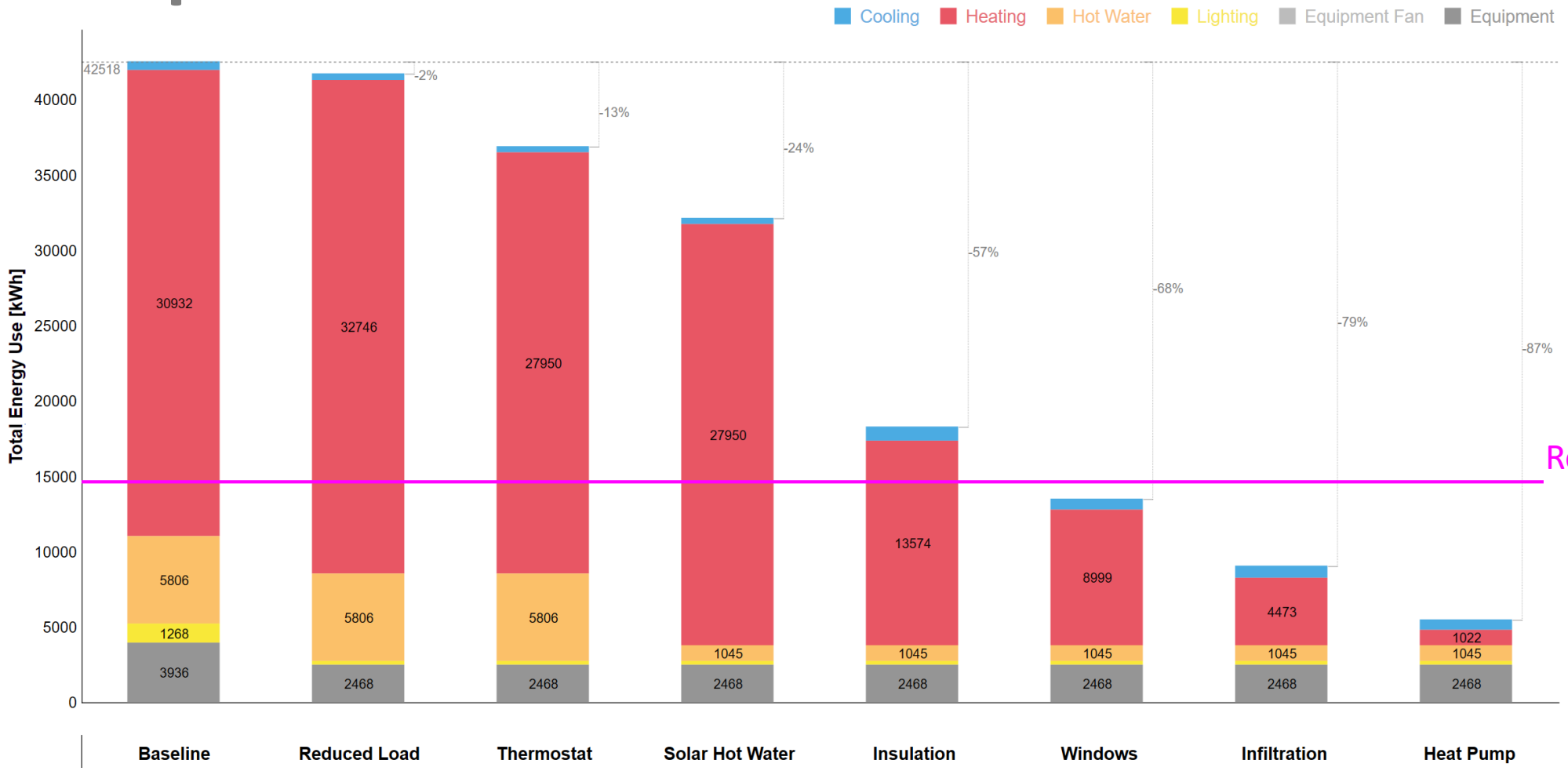
Graphic: Climate Driven Design (C Reinhart)

Going “all electric”



- ❑ Replacing a gas furnace with a heat pump safes GHG emissions but increases operational costs
- ❑ In New England, energy costs and environmental impact are not aligned.
- ❑ Those upgrades use the grid as a seasonal battery.

Do a deep retrofit instead



	Baseline	Reduced Load	Thermostat	Solar Hot Water	Insulation	Windows	Infiltration	Heat Pump
Carbon Emissions	10.1tCO_2	9.8tCO_2	8.7tCO_2	7.5tCO_2	4.3tCO_2	3.2tCO_2	2.2tCO_2	1.4tCO_2
Operating Costs	$3,844	$3,328	$3,129	$2,058	$1,602	$1,371	$1,207	$1,232
Retrofit costs		Varies	$100	$7,800	$14,000	$18,000	$500	$24,000

How can city governments convince their constituents to energy retrofit/add PV to their homes?

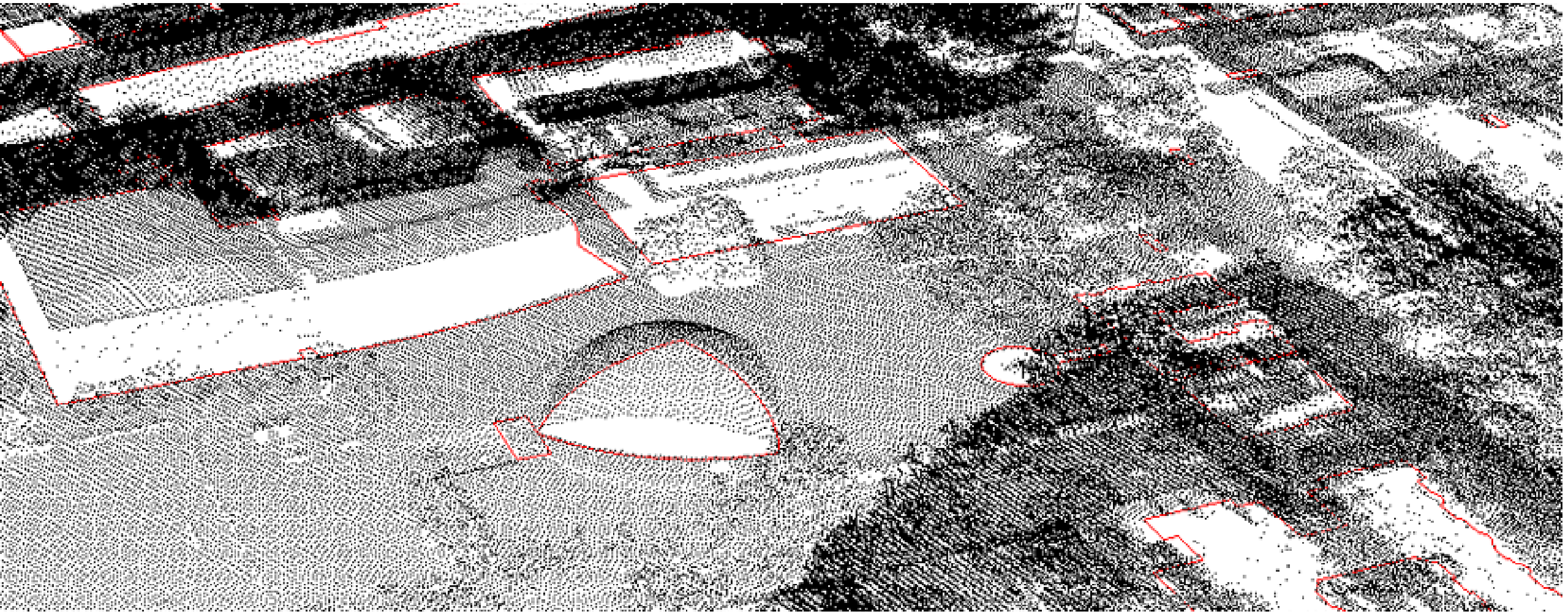
Rooftop PV

Modeling Rooftop PV Potential

Photo of the MIT Campus (Google Maps)

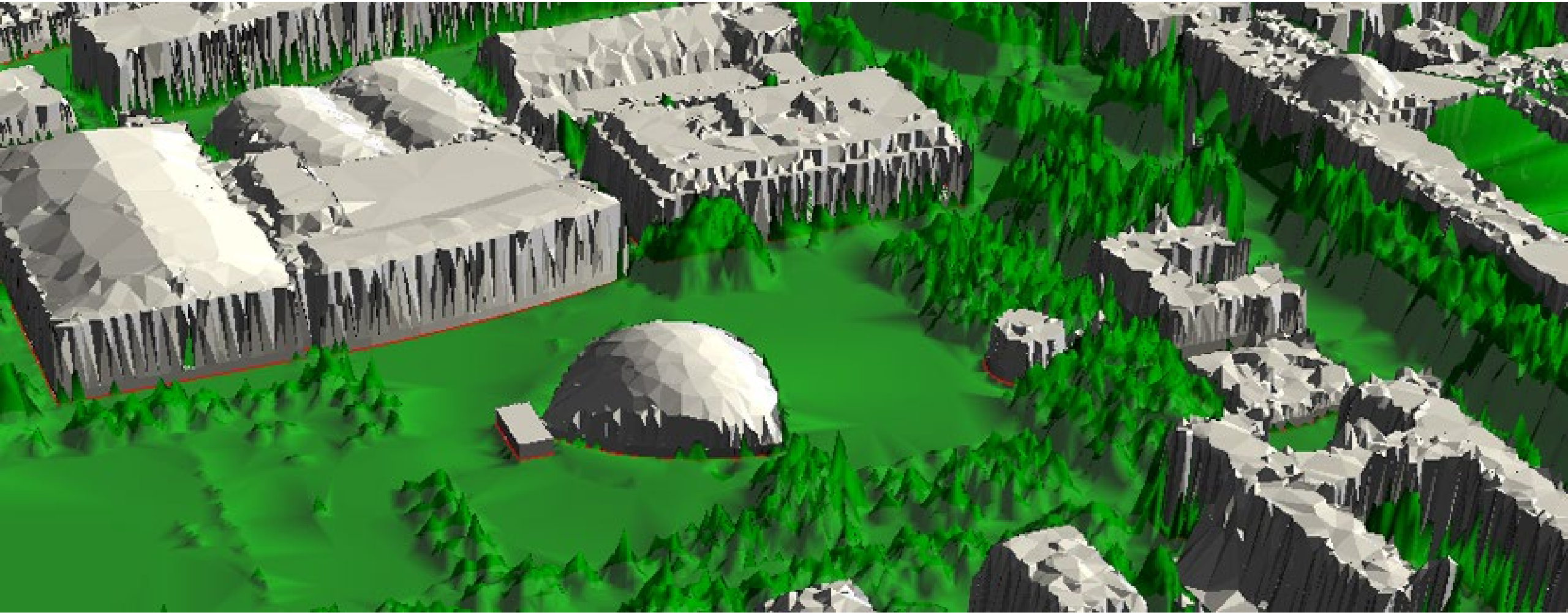
A Jakubiec and C F Reinhart, 2013, “A Method for Predicting City-Wide Electricity Gains from Photovoltaic Panels Based on LiDAR and GIS Data Combined with Hourly DAYSIM Simulations,” Solar Energy 93, pp. 127-143

LIDAR Data of the MIT Campus



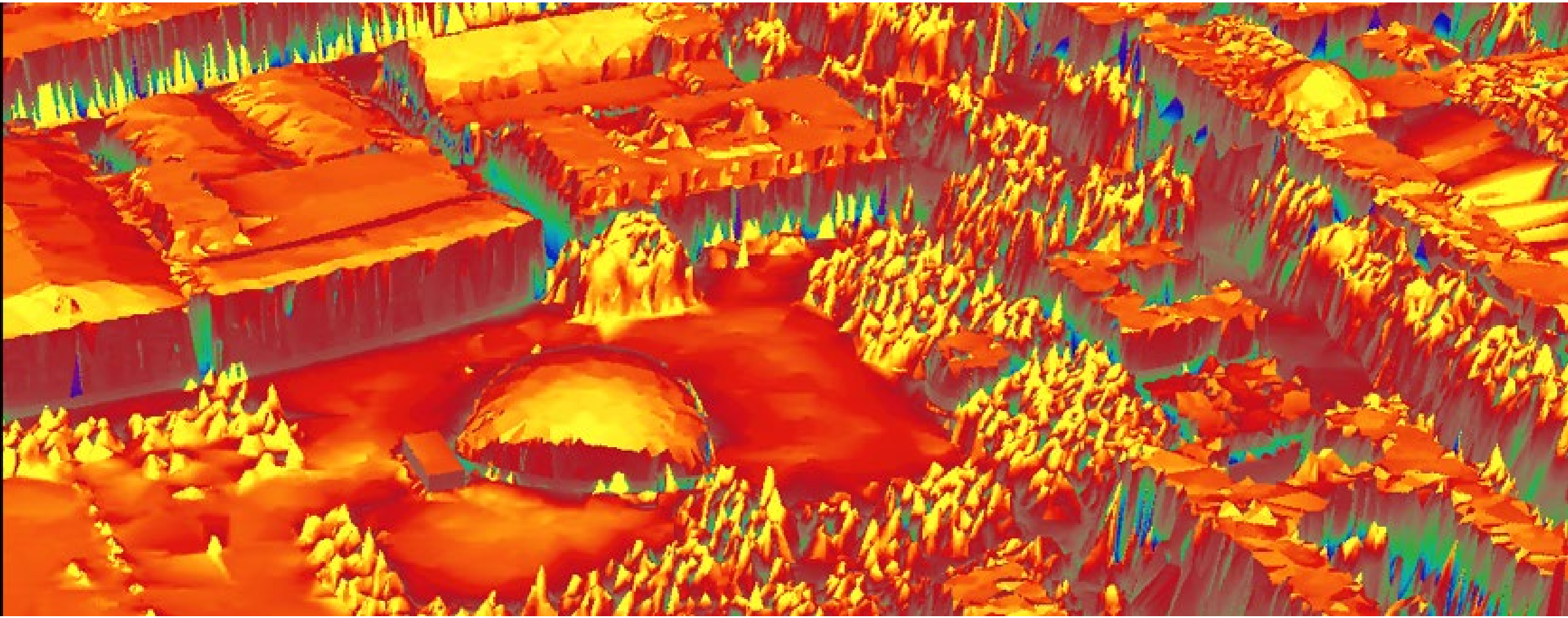
3 dimensional point cloud (126 million points)

3D Model of the MIT Campus

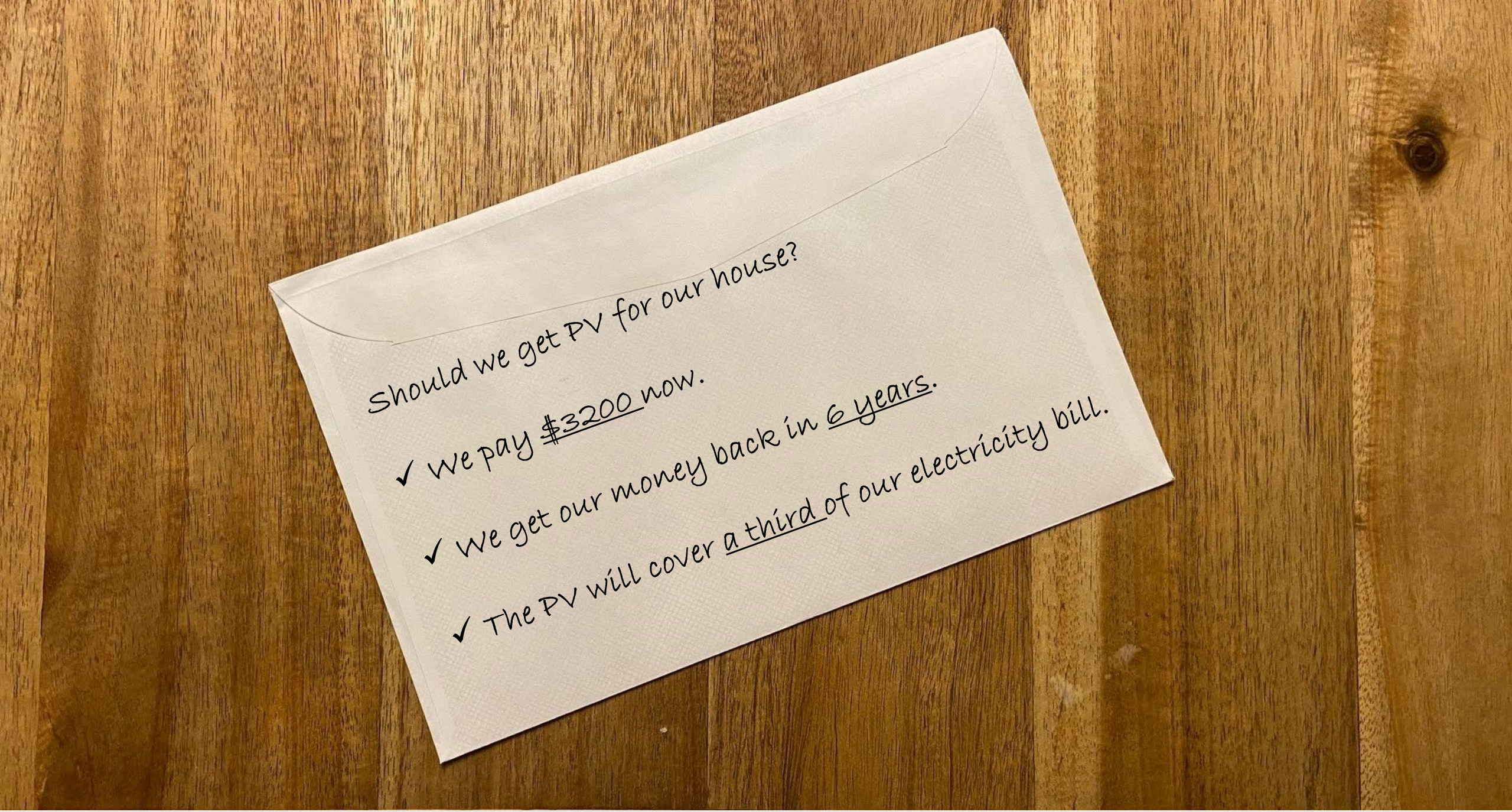


- Generation of a 3D model through surface triangulation

Solar Radiation Map



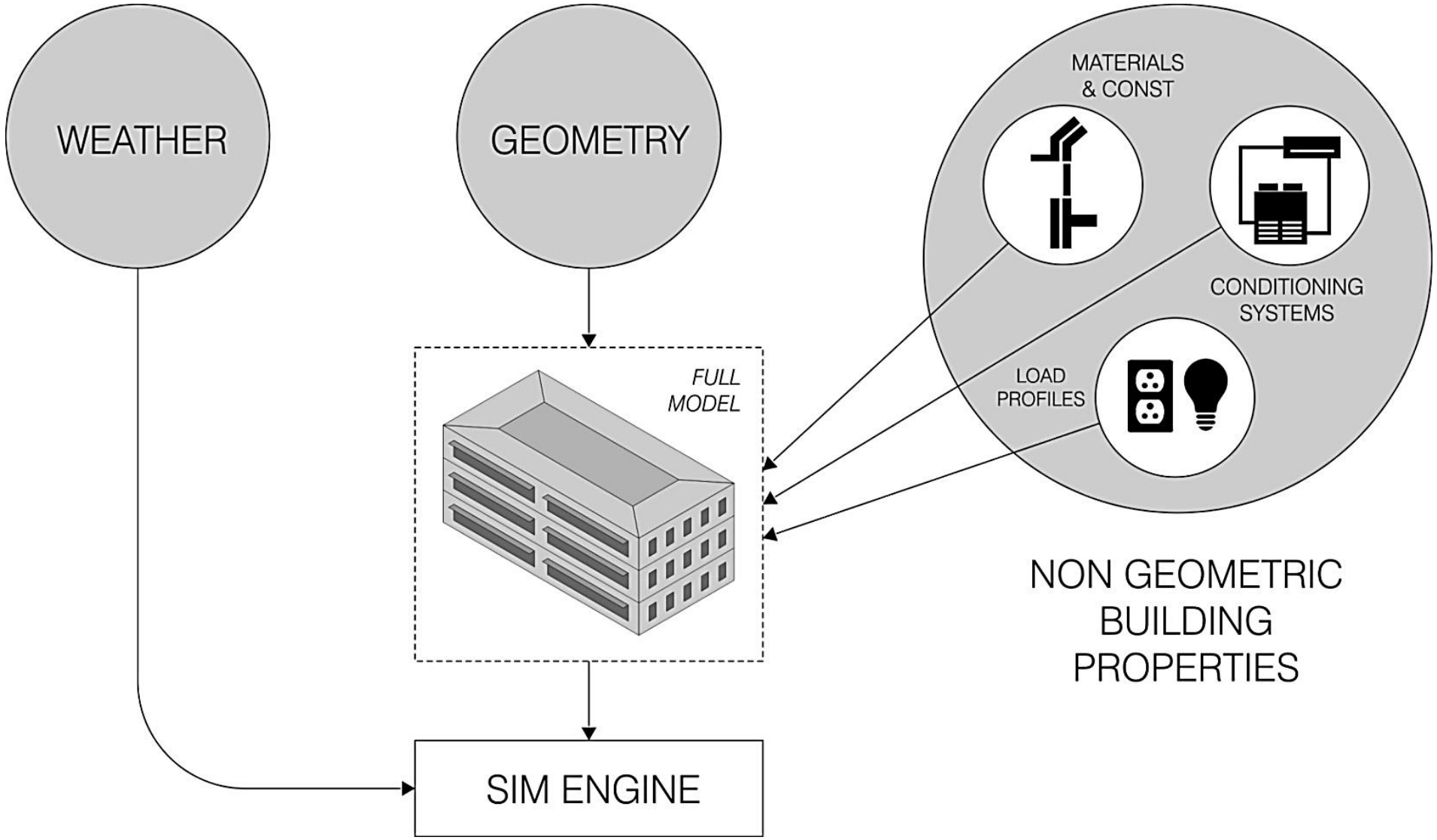
- In 2013 we formed an MIT spinoff called mapdwell that develops interactive maps to predict the potential to install PV on urban rooftops.
- In 2021 mapdwell merged with Palmetto and now covers over +119 million US homes (84% coverage)


Should we get PV for our house?
✓ We pay $3200 now.
✓ We get our money back in 6 years.
✓ The PV will cover a third of our electricity bill.

Case Study Wellfleet, MA

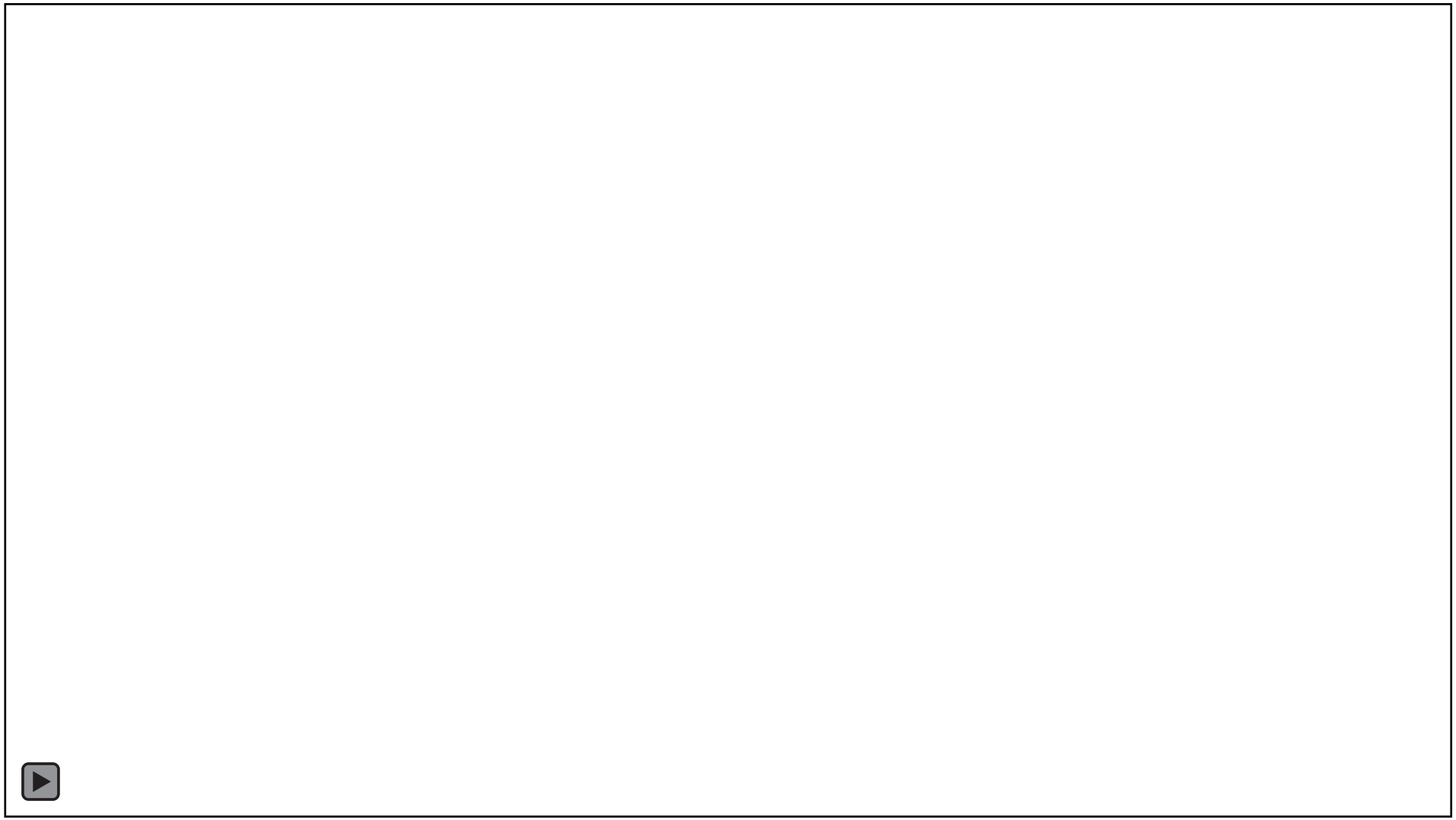
- In 2014 the mapdwell map of Wellfleet, MA, successfully supported a community-driven solarize program: Within 4 months 10% of all households went solar.

Urban Building Energy Modeling



C F Reinhart and Cerezo, 2016, "Urban Building Energy Modeling – A Review of a Nascent Field," Building and Environment, 97:196–202

UBEM Boston



Link: https://www.youtube.com/watch?v=O46GkHSYvYE

- Massing models can be generated from city-wide GIS files

Paper: C Davila Cerezo, J Bemis and F Reinhart, “Modeling Boston: A workflow for the efficient generation and maintenance of urban building energy demand models from existing geospatial datasets,” Energy, 117, pp. 237-250, 2016

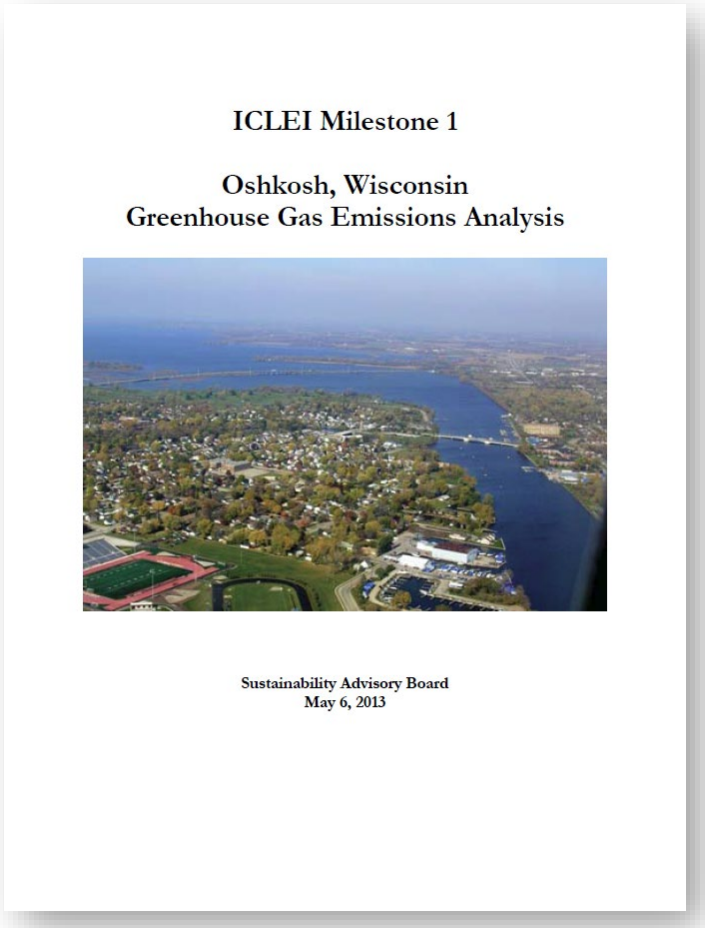
2016 - Boston Building Energy Study

- In collaboration with the Boston Redevelopment Authority with support from the Massachusetts Clean Energy Center we created an UBEM with has over 80,000 buildings.
- Together with Lincoln Laboratory we applied the model to explored new energy supply technologies such a micro-grids and district heating/cooling.

2020 - Oshkosh, WI

https://marinas.com/view/harbor/znt85_Oshkosh_Harbor_Oshkosh_WI_United_States

Path to Carbon Emissions Reduction

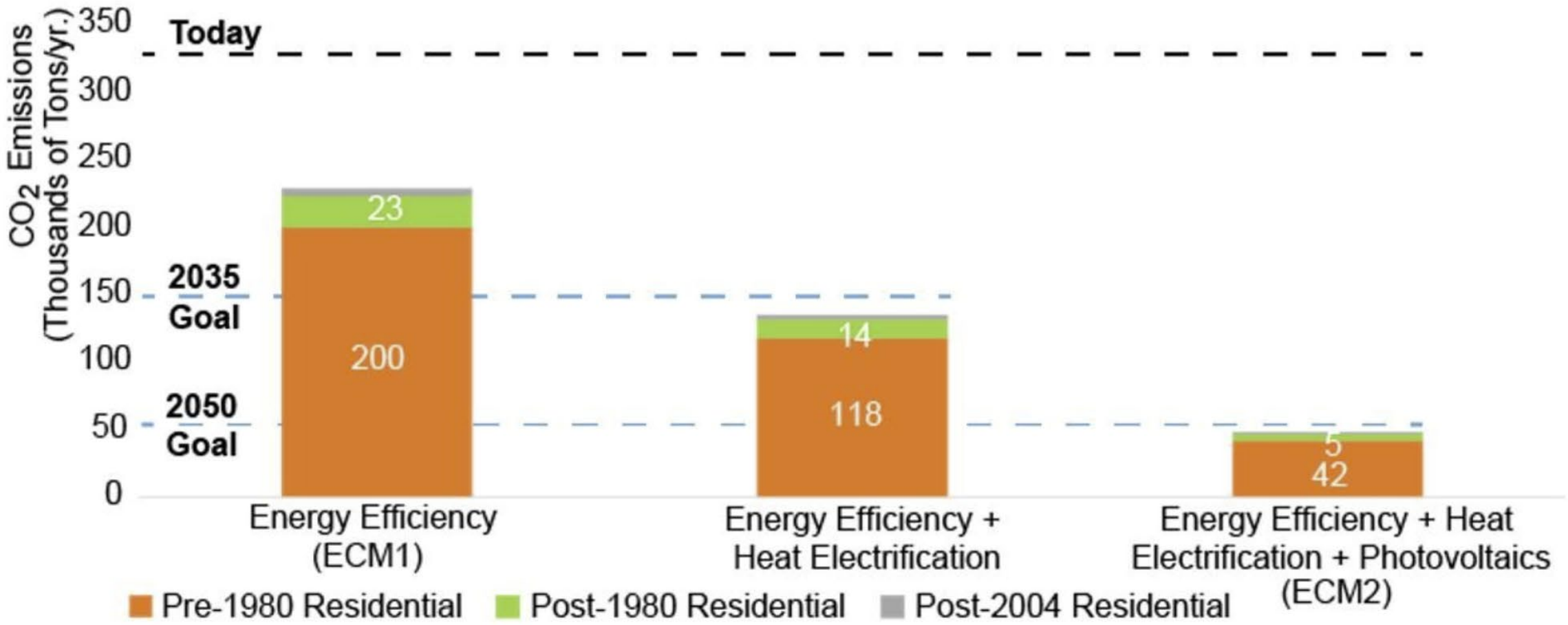


Milestone 3

Carbon reduction pathways

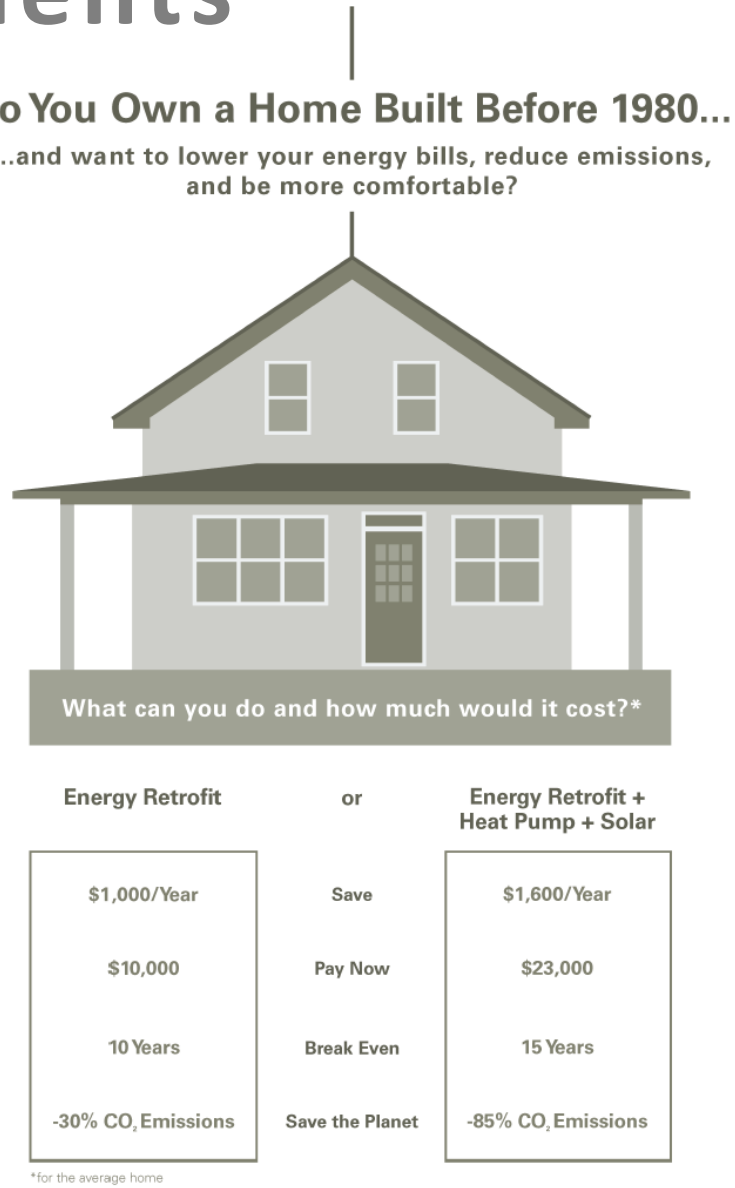
?

Comparison of 3 upgrade strategies



Z M Berzolla. "Meeting A Community's Emissions Reduction Targets Using Urban Building Energy Modeling." Masters thesis, Cambridge, MA: Massachusetts Institute of Technology

Outreach to residents

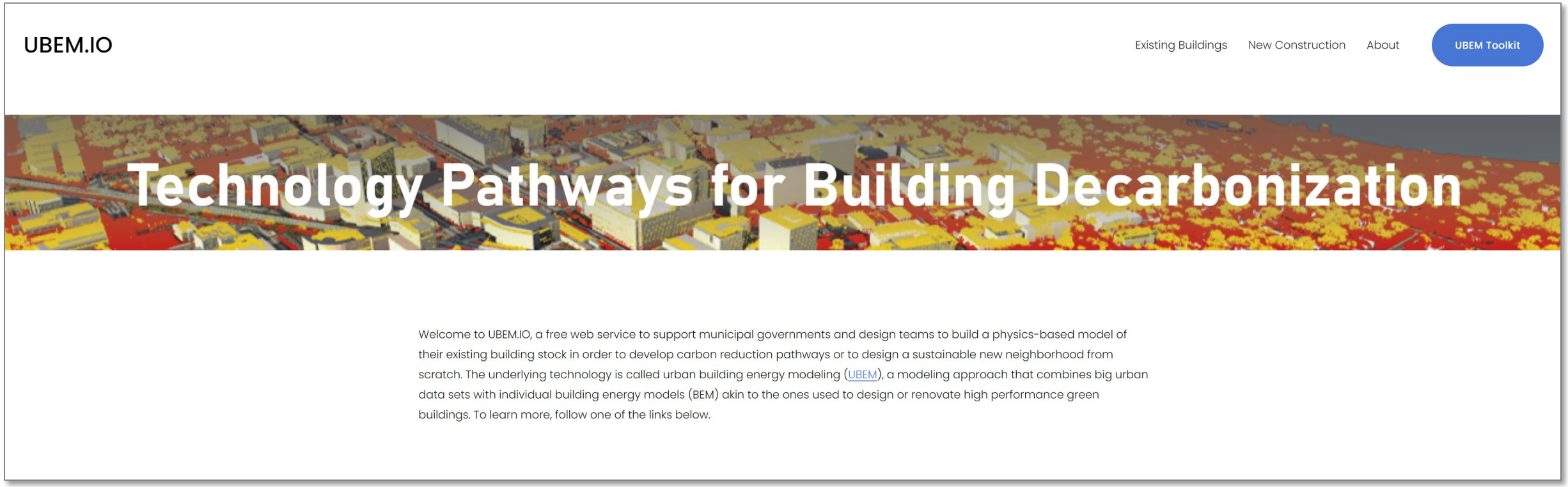


Z M Berzolla. “Meeting A Community’s Emissions Reduction Targets Using Urban Building Energy Modeling.” Masters thesis, Cambridge, MA: Massachusetts Institute of Technology

Our goal

Help cities anywhere to conduct a carbon reduction pathway analysis of their building stock

UBEM.IO



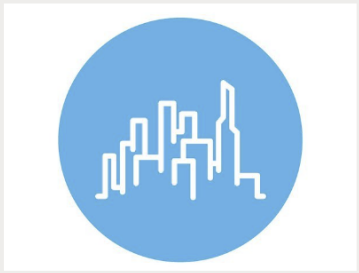
Y Q Ang, Z Berzolla, S Letellier-Duchesne, V Jusiega and C Reinhart, 2021, “UBEM.io: A web-based Framework to Rapidly Generate Urban Building Energy Models for Carbon Reduction Technology Pathways” Sustainable Cities and Society

Eligibility Criteria – Three roles

Sustainability Champion

As with any policy-related task, the process requires a champion whose mandate is to promote/implement a municipality's carbon emissions reduction goals. In many cases, this individual will be a generalist with responsibilities expanding beyond buildings to transportation and other sustainability-related municipal concerns.

Learn more



GIS Manager

The GIS manager has access to and is familiar with a jurisdiction's urban datasets such as shapefiles, tax accessor data, LiDAR etc. The role is key to the project since shapefiles often have to undergo some cleanup before the data can be successfully converted into an UBEM. Having the GIS manager onboard ensures that this data cleanup is applied consistently.

Learn more

Energy Modeler

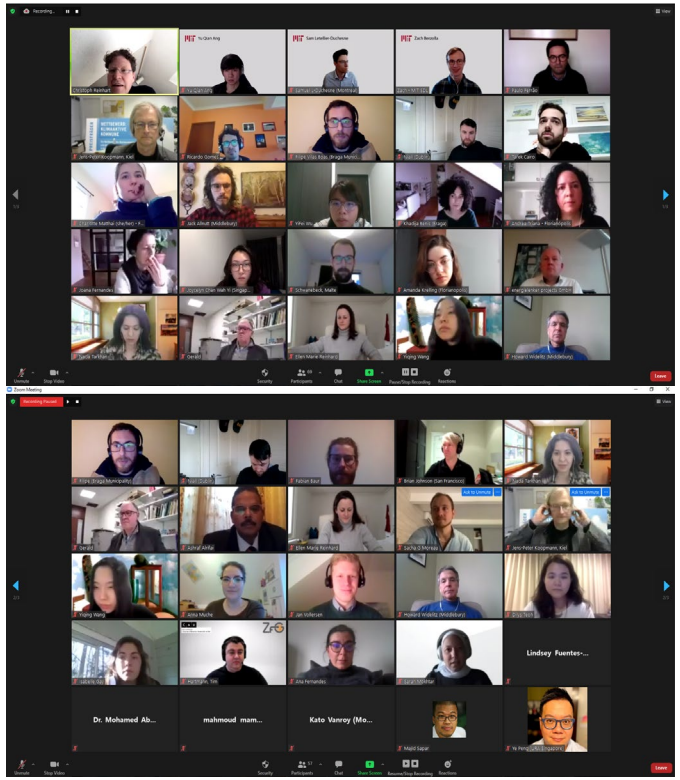
The energy modeler has a background in green building consulting and individual building energy modeling (BEM) . The energy modeler will work with the Sustainability Champion to define shallow and deep energy retrofitting upgrades for the local building stock and work with the GIS manager to build an UBEM to calculate the resulting stock-level carbon dioxide reductions.

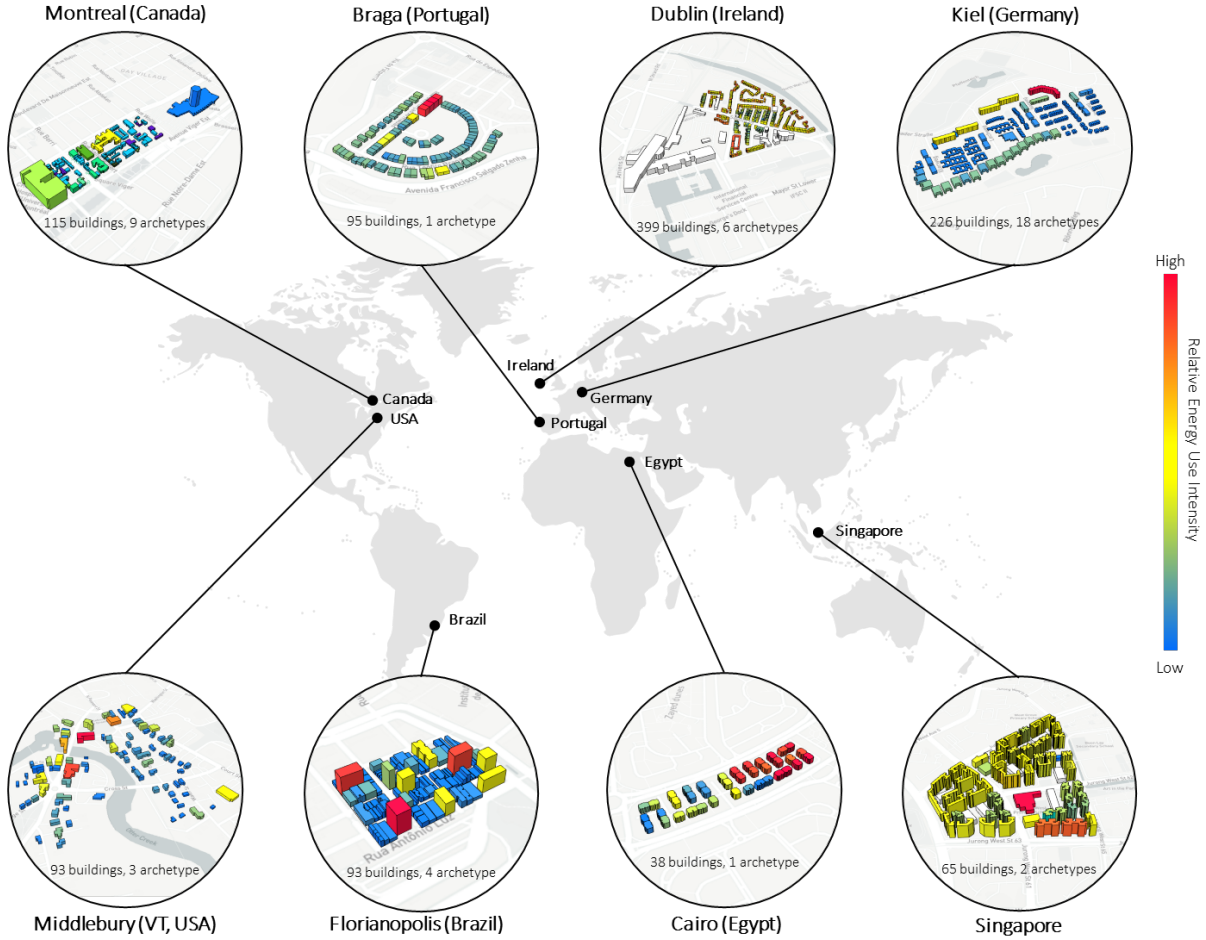
Learn more

Y Q Ang, Z Berzolla, S Letellier-Duchesne, V Jusiega and C Reinhart, 2021, "UBEM.io: A web-based Framework to Rapidly Generate Urban Building Energy Models for Carbon Reduction Technology Pathways" Sustainable Cities and Society

January 2021 – Model Cities Anywhere

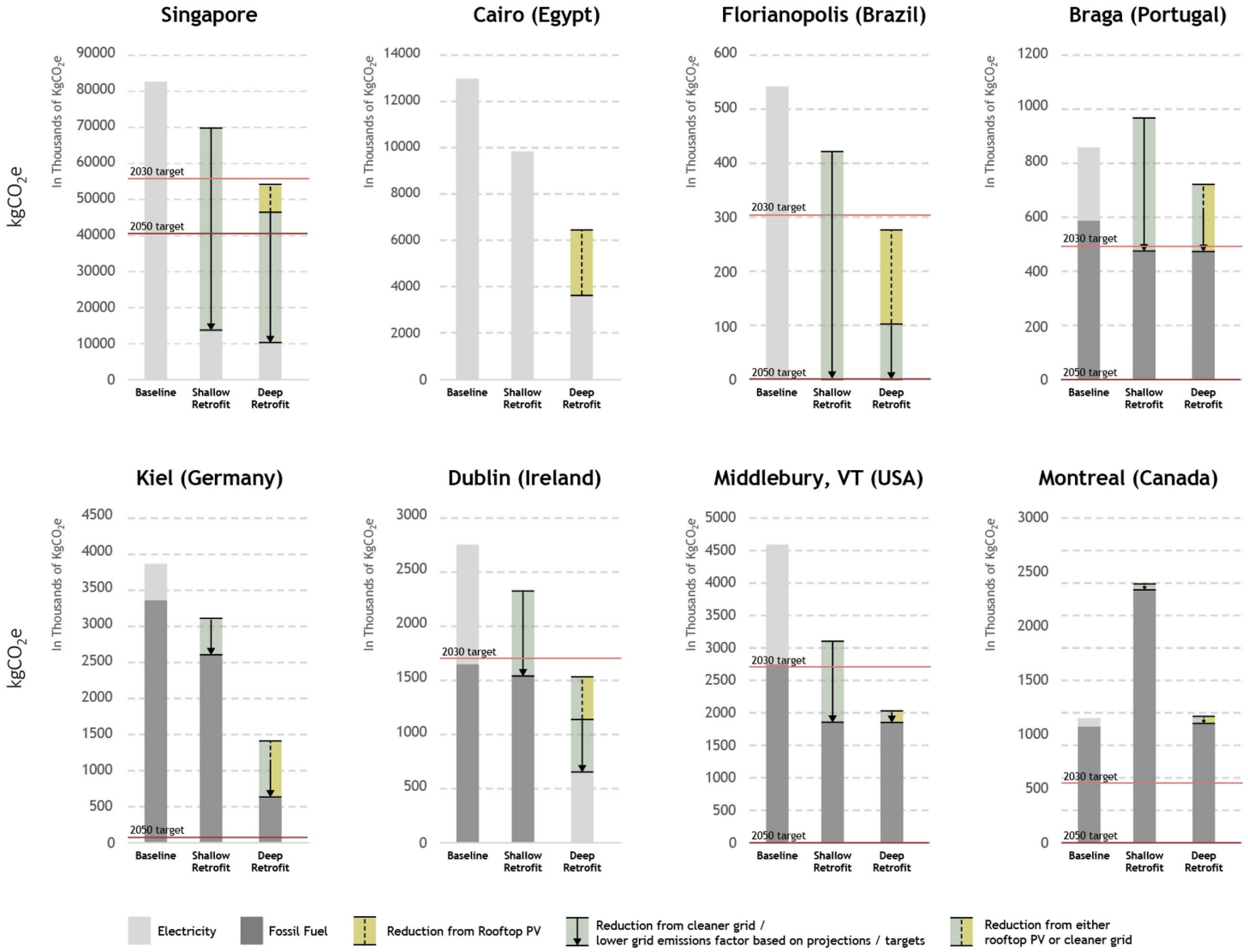
Representatives & Policymakers





Y Q Ang, Z M Berzolla, S Letellier-Duchesne and C F Reinhart, Carbon reduction pathways for buildings in eight cities, Nature Communications, 14, 1689, 2023

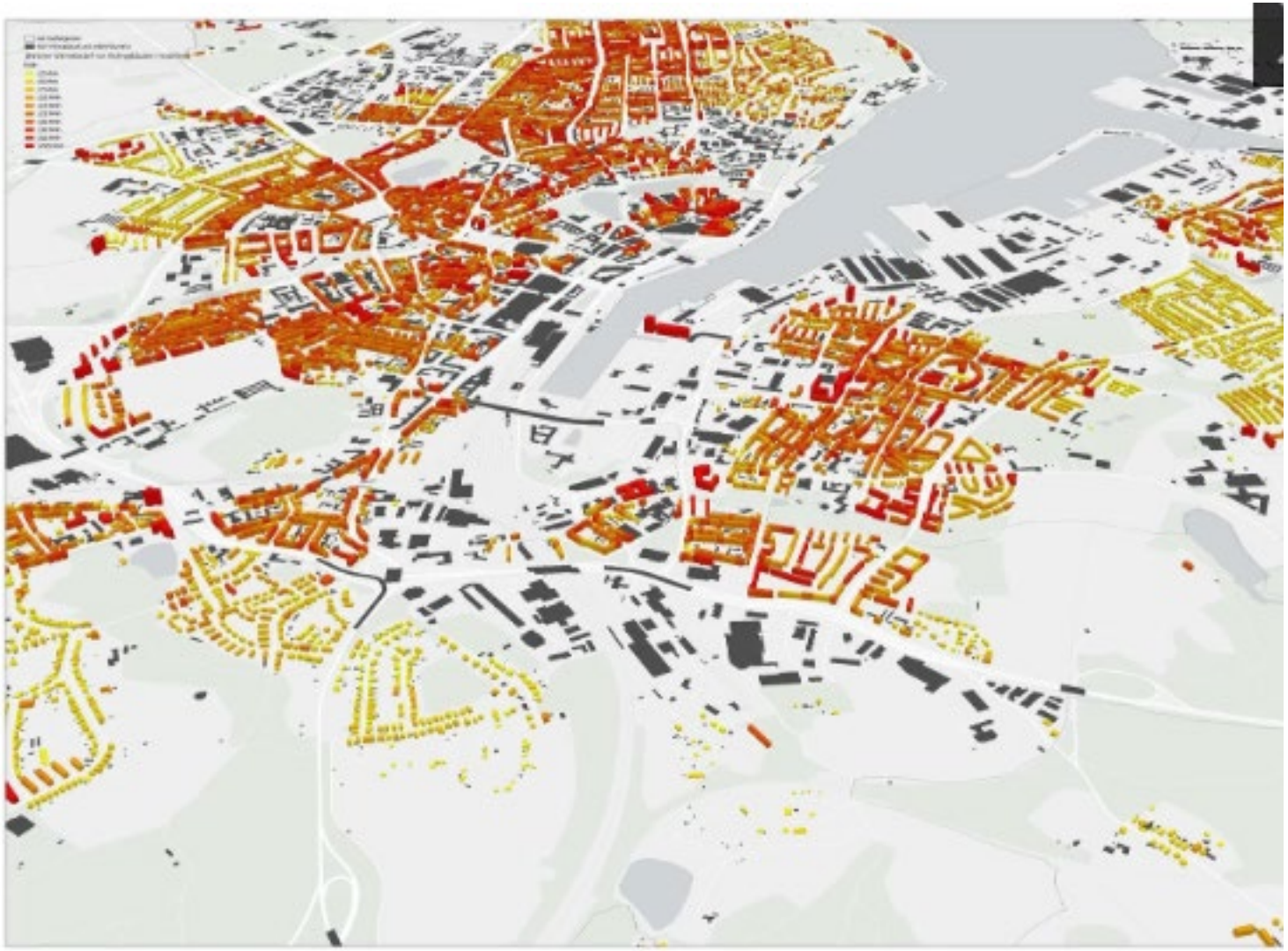
Carbon emissions for shallow, and deep retrofits



- Every city is different. Justifiable effort.

Y Q Ang, Z M Berzolla, S Letellier-Duchesne and C F Reinhart, Carbon reduction pathways for buildings in eight cities, Nature Communications, 14, 1689, 2023

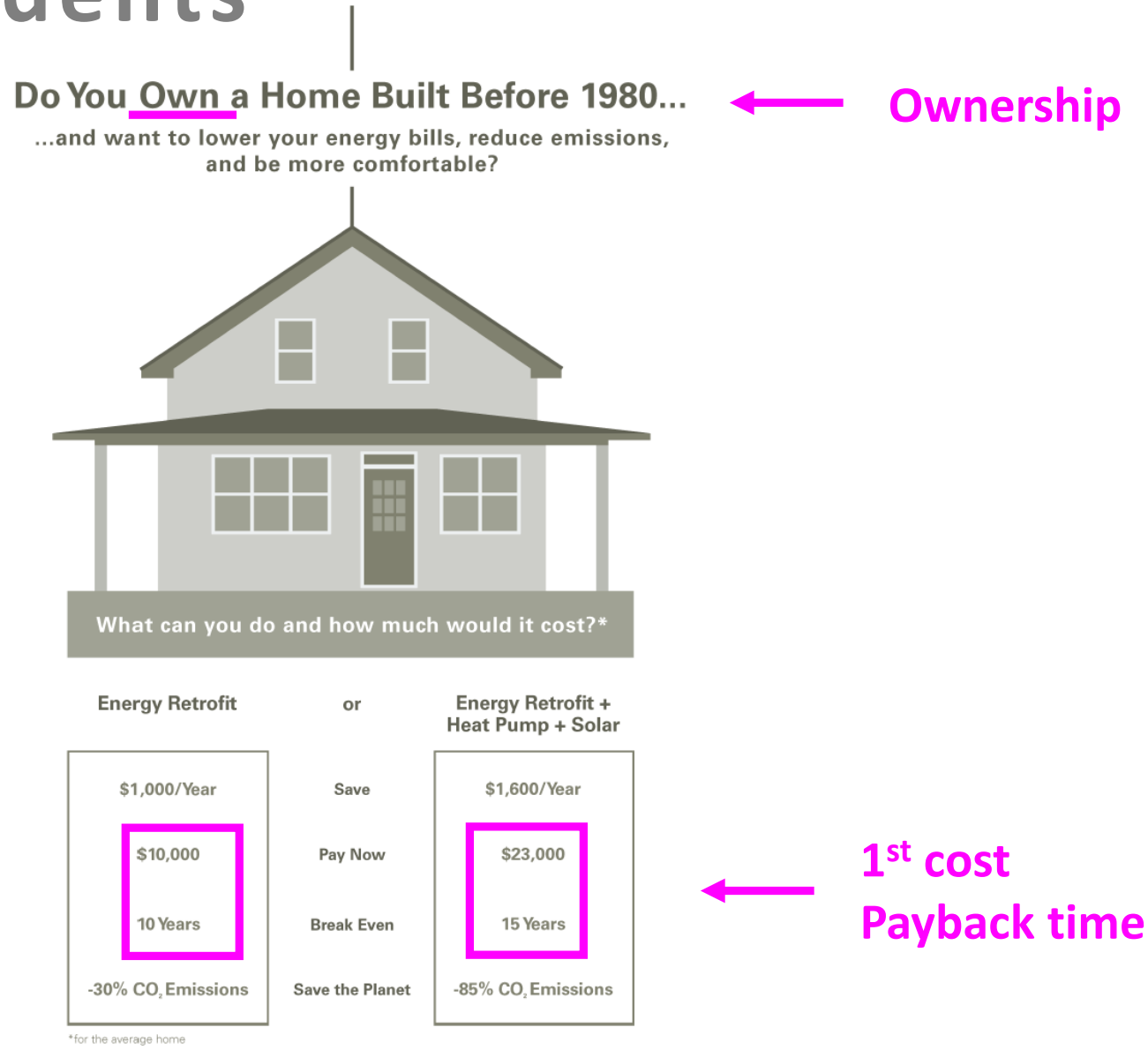
UBEM - Kiel



https://idw-online.de/de/news806351 View of the Hörn area of Kiel and the 3D building model of the city. The areas shown in red have particularly high energy requirements.

Who within a community is most likely to upgrade their home?

Outreach to residents



Ownership

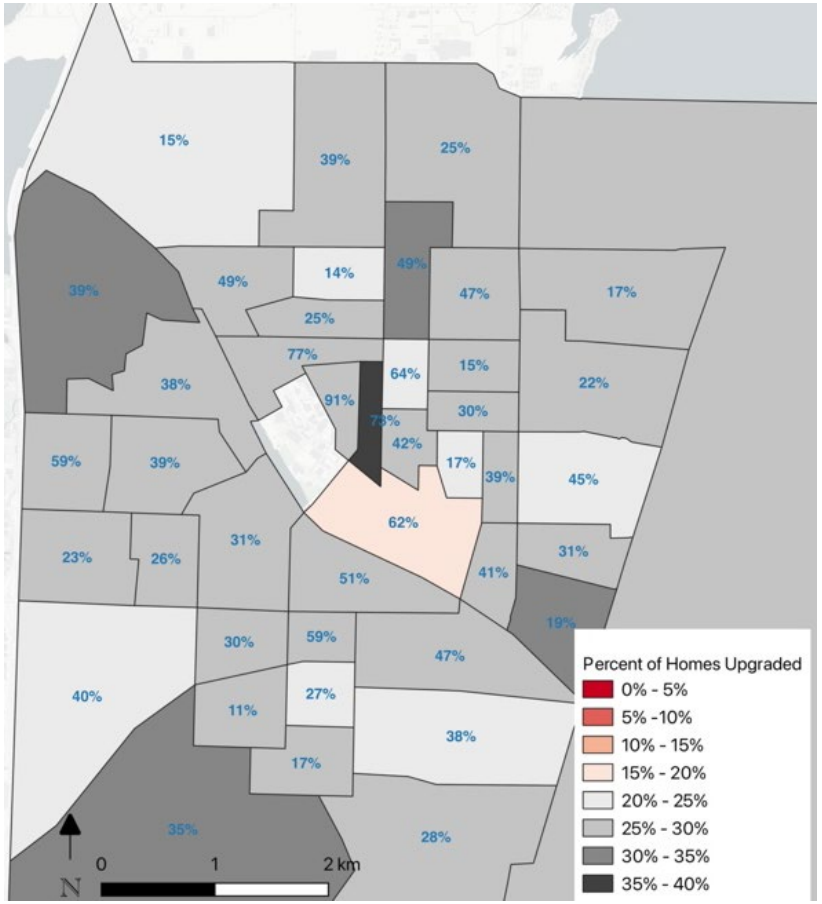
1st cost

Payback time

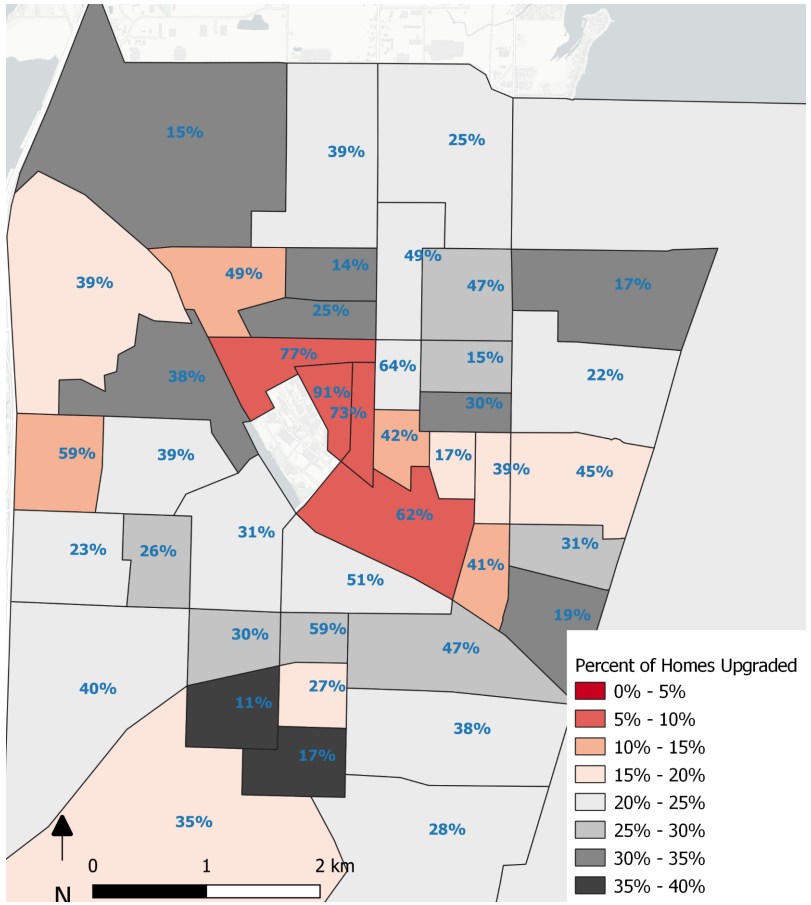
Z Berzolla, YQ Ang, C Reinhart, 2022, "Combining Urban Building Energy Models with Retrofit Adoption Models for Time-Dependent Carbon Emission Projections," 2022 ACEEE Summer Study on Energy Efficiency in Buildings, Asilomar, CA, August 20

Technology Adoption Model

Uniform distribution



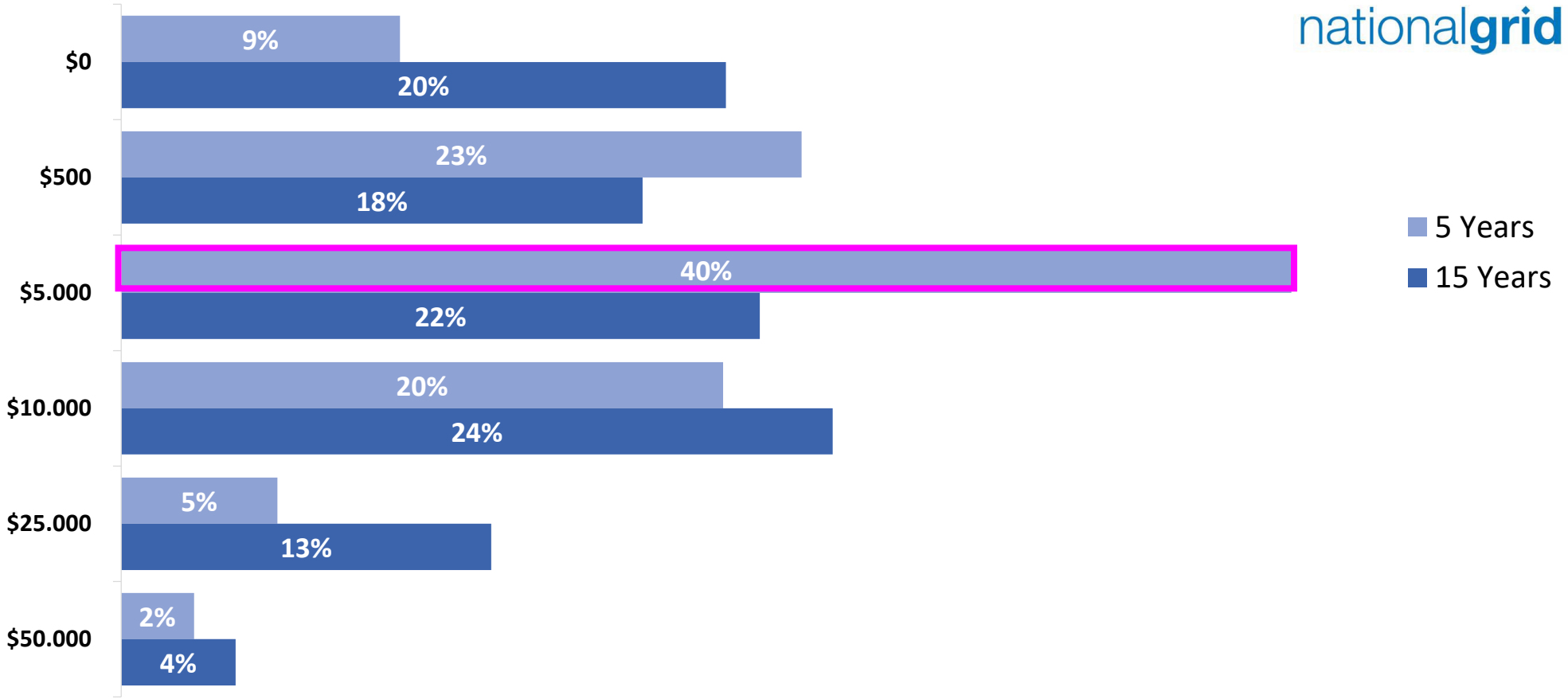
Adoption model prediction



- ❑ High uptake in affluent neighborhoods with high building ownership rates
- ❑ Tale of two Americas; tradeoff carbon emission savings versus equity

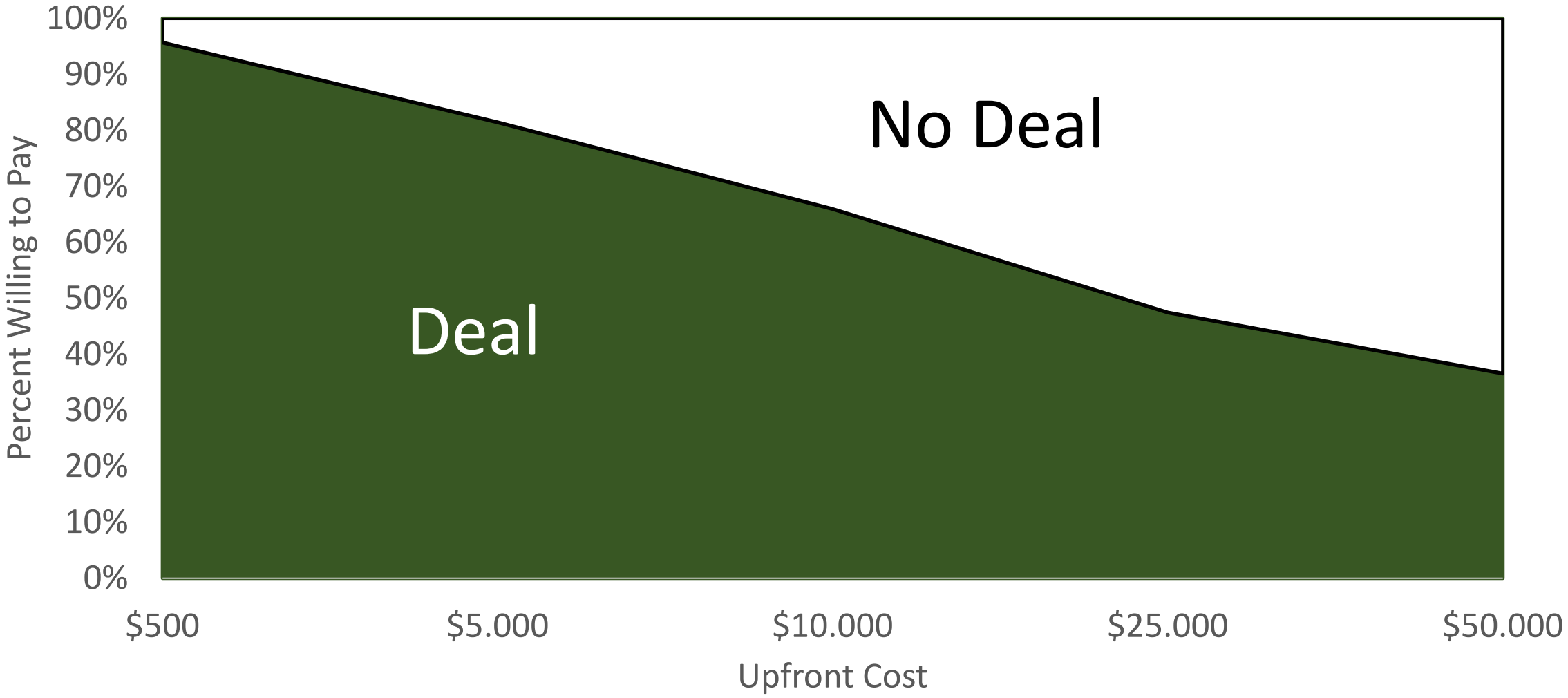
Z Berzolla, YQ Ang, C Reinhart, 2022, "Combining Urban Building Energy Models with Retrofit Adoption Models for Time-Dependent Carbon Emission Projections," 2022 ACEEE Summer Study on Energy Efficiency in Buildings, Asilomar, CA, August 2022

Preliminary Results for National Grid Survey



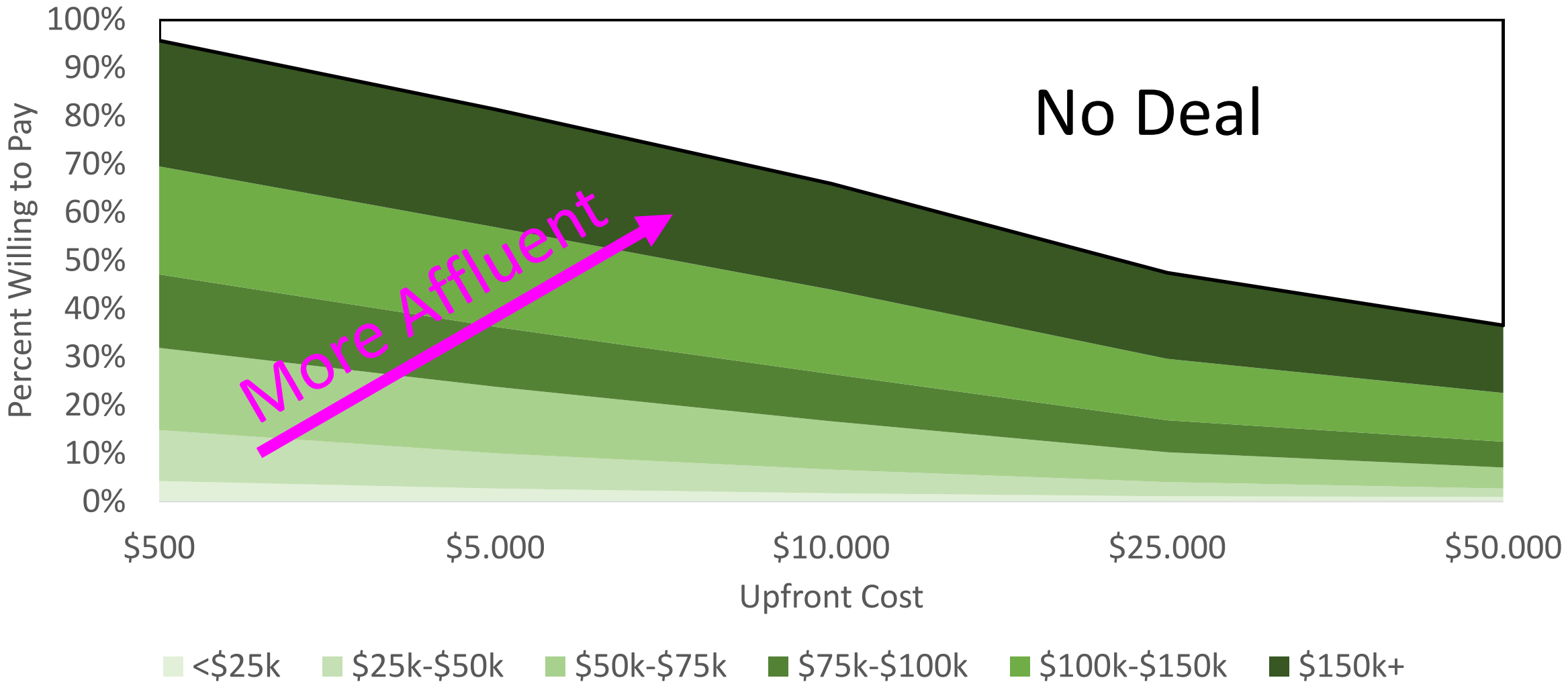
- For energy efficiency upgrades with a 5-year payback period, many are willing to invest up to $5,000

Percent Willing to Pay



ZB

Percent Willing to Pay by Income



ZB

Closing Thoughts

- We need to help city governments and policymakers to better understand the opportunities of existing buildings in their carbon reduction strategies.
- Society expects the building sector to deliver carbon neutral new construction for all building typologies by 2030.
- Heat pumps, PV and (increasingly) batteries are the new default. Added insulation is need to ensure rid stability.
- Embodied energy analysis is rapidly becoming an integral component of high-performance building design.

Questions?

MIT Building Technology Program, Fall 2022
email: creinhart@mit.edu