Modeling a Renovation Wave at sub-national resolution for the EU building stock

Enrico Cofler, Francesco Colelli, Giacomo Falchetta, Massimo Tavoni

June 2026

Read the full paper here

cmcc Centro Euro-Mediterraneo sui Cambiamenti Climatici

POLITECNICO MILANO 1863

RFF CMCC European Institute on Economics and the Environment

EDITS Energy Demand changes Induced by Technological and Social innovations

Motivation

- How can energy demand projections and policies for the **building sector decarbonization** be modeled at sub-national resolution for the EU?

- How will the **spatial distribution of energy demand and investments** evolve in the **future** across EU regions?

- What are the levels of **investments and public support** required to pursue ambitious **EU-wide renovation strategies** over the coming decades?

Methodology & Scenarios

Model

EDGE-EU: bottom-up model to describe projections of buildings' energy demand up to year 2050, at **0.5° x 0.5° spatial resolution** for EU-27

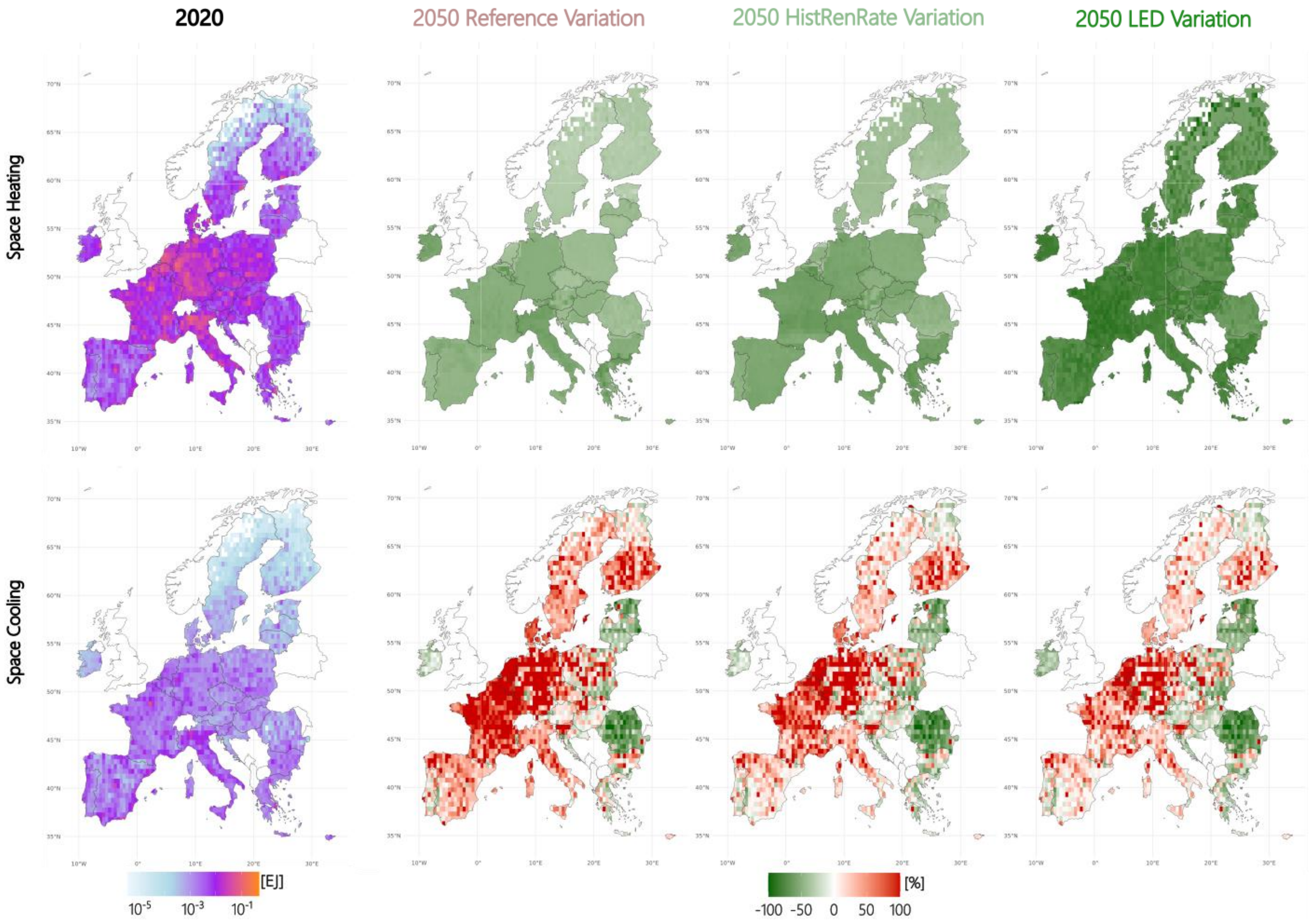
Dynamics:

1. Given current building conditions and expected future energy expenditures across the national building stock, **what are the optimal insulation levels to invest in**?
2. Given a target renovation rate, **where should each country allocate the investments to minimize costs**?

Scenarios

	Insulation renovation	Electrification & Efficiencies	Floorspace
Reference	**No subsidies** on renovation	Mild growth	No cap
Historical Renovation Rate (HistRenRate)	**Subsidies** to reach historical renovation rates	Mild growth	No cap
Low Energy Demand (LED)	**Subsidies** to reach 2% renovation rate in all countries	Strong growth	40 m²pc cap

Results: Energy



2020-2050 Total Energy Decrease	-29%	-36%	-51%

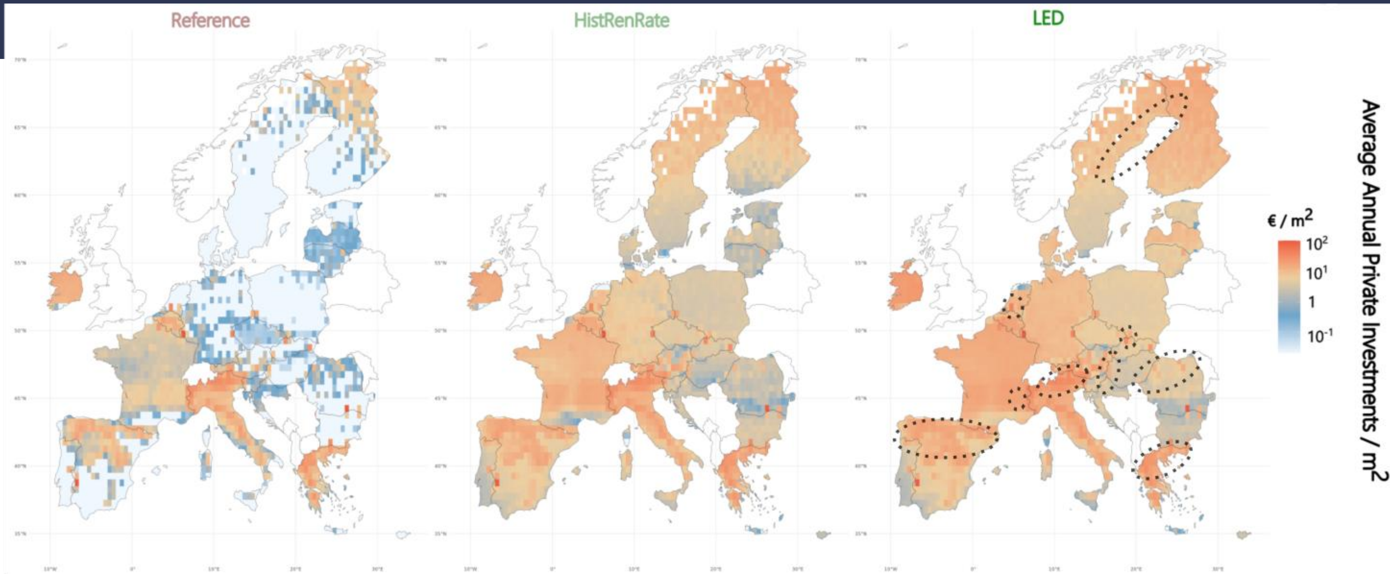
- Relatively **homogeneous** decrease
- **Moderate growth** in Southern Europe
- **Strong growth** France, Germany and Benelux
- **Decrease** in part of Central and Eastern Europe *(secondary effect of insulation investments targeting heating)*

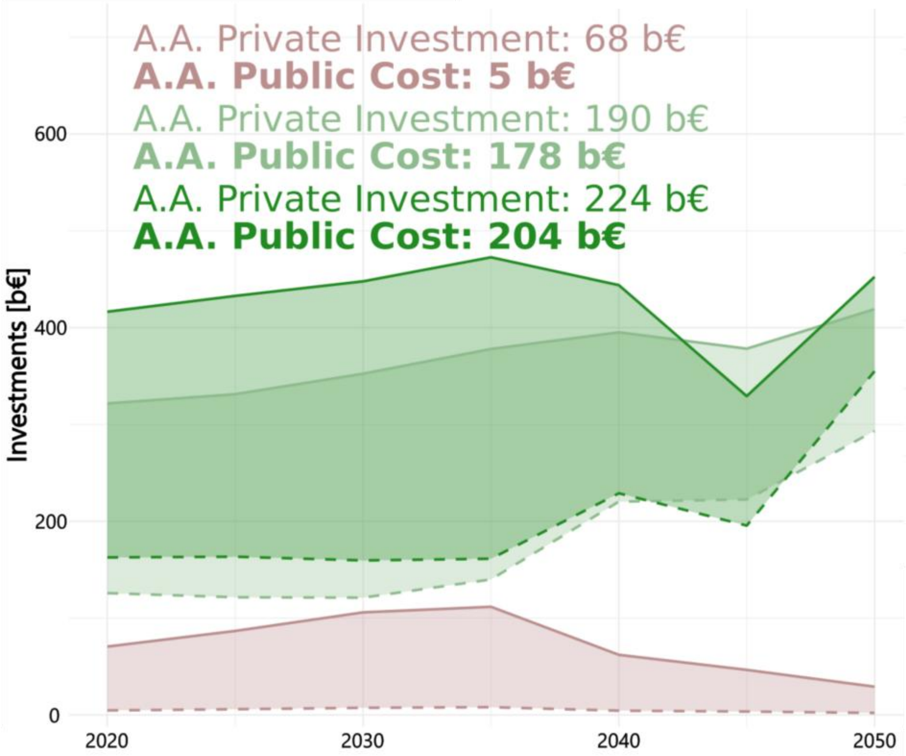
Results: Investments

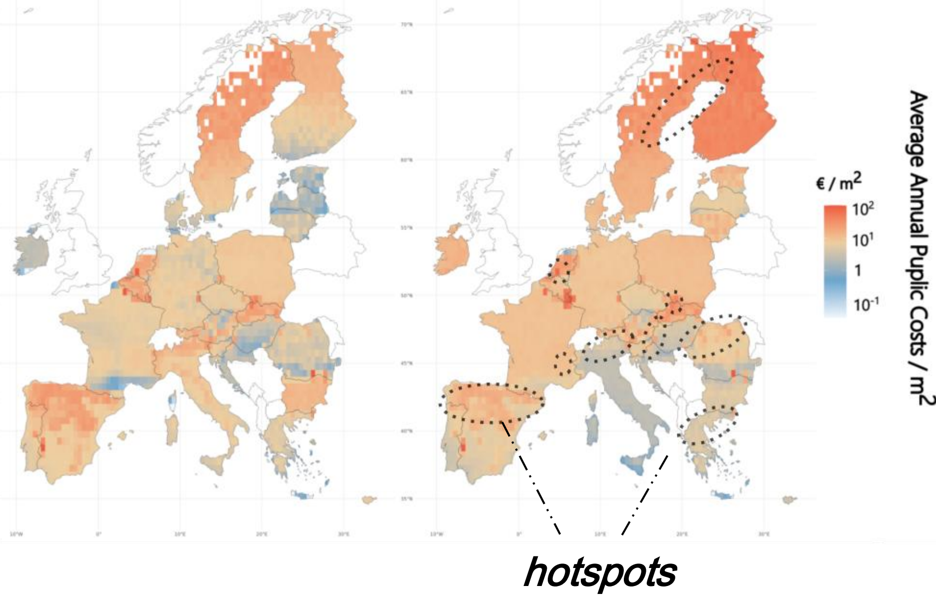
Public support is substantial, also because the model can use only the most expensive policy (subsidies).

LED scenario (2%) can be a good targets (substantial energy and emissions reduction),
BUT it requires an **increase of 18% w.r.t current energy-related renovation investments in the EU.**

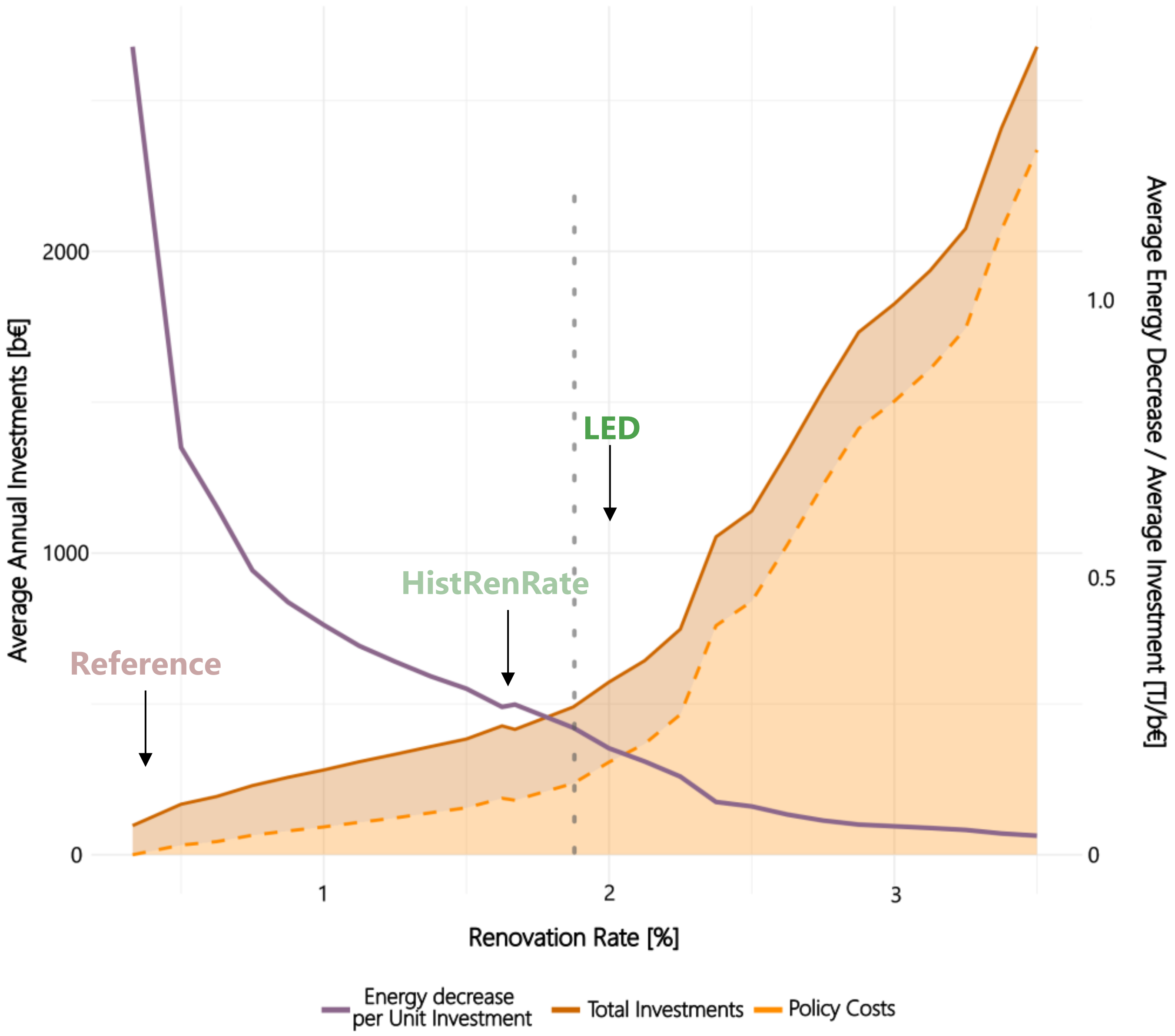
If total investment/m² and total investment/GDP are significantly larger than the country average = ***hotspot***







Results: Exploring the investment–energy efficiency tradeoff



Sweep of runs between 0.3% and 3.5% renovation rate to look at:

- Average Annual Cost
- Average Energy Decrease per Unit Investment

After 1.875%, for each unit of investment, the marginal energy efficiency gains decrease much faster than before.

From a techno-economic point of view, 2% might be a good point to stop.

Conclusions

- Energy efficiency and total investment **trends** are well reproduced, and with the **LED** scenario **substantial decreases in emissions (-74%) and energy (-51%)** can be achieved for an **increase in investments** of **18%**

- Spatial trends in EU are quite different, especially for space cooling *and* its interaction with renovations

- Investment hotspots should be anticipated, if the optimal allocation approach is considered

Open questions:

- What are the **distributional effects** of these simulated policies?
  How does the optimal spatial allocation interact with socioeconomic heterogeneity?

- In a world of growing efficiency and decreasing demand with clear **spatial differences**, how can the **supply-side** of the energy system react?

Thanks!

Read the full paper here

Conclusions

Key takeaways

- Renovation efforts can differ considerably within single countries. A general improvement of buildings condition and energy efficiency is to be expected in all EU27, but **building stock and energy consumption differences will be relevant in 2050** at the subnational scale mainly due to energy prices, building age and local climatic conditions.

- Ambitious renovation targets can limit strongly space heating demand, but we should expect a **mild growth in space cooling** even in the most ambitious policy scenarios

- **Renovation costs** might weight more on households or on the public budget depending on the location. In some countries, **hotspots** are to be expected.

- Ambitious scenarios (LED, HistRenRate) require **up to more than 2 times the current spending on energy-related renovations** in the EU, and half of this could be paid by households

- **After a 2% renovation rate**, the marginal costs starts to increase and the energy efficiency gains per unit cost decrease faster than before

Limitations

- High costs are probably driven by the **restricted portfolio of renovation options** (opaque surfaces instead of walls, floors, roofs separately)
- **Only renovation are priced**, lack of cost representation for HVAC systems
- **No initial U-values within-country downscaling based on climate** – example: in 2020, 90ies buildings in Palermo and Aosta have the same U-value

Bibliography

G. Falchetta, E. D. Cian, F. Pavanello, and I. S. Wing, 'Inequalities in global residential cooling energy use to 2050', *Nat Commun*, vol. 15, no. 1, p. 7874, Sep. 2024, doi: 10.1038/s41467-024-52028-8.

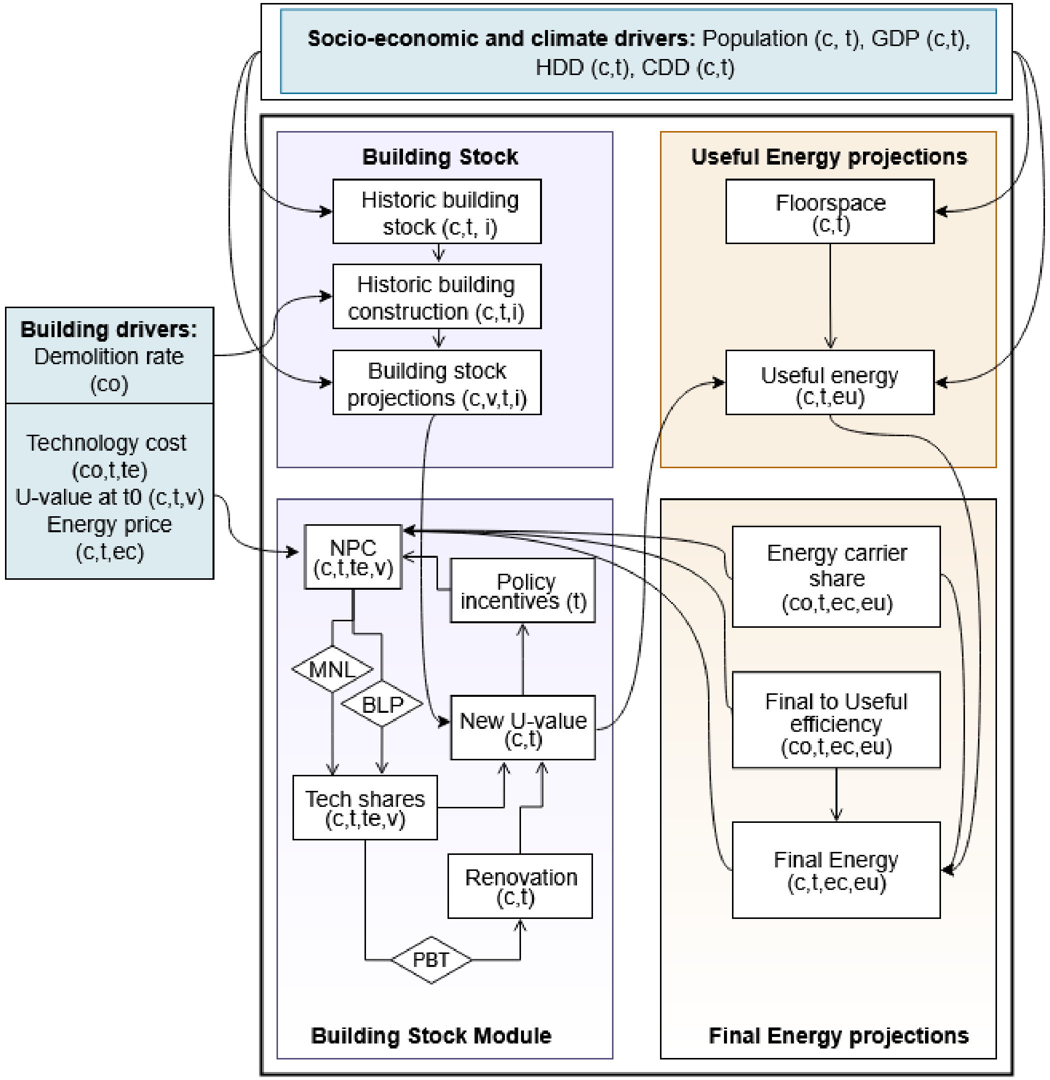
Martinez, G. Kakoulaki, P. Florio, and P. Politis, 'DBSM R2025: EU Digital Building Stock Model update including satellite-based attributes', May 2025, doi: 10.2905/a601a4a8-9289-4fc4-983a-25d54f957f3a.

European Commission: Directorate-General for Energy, IPSOS and Navigant, 'Comprehensive Study of Building Energy Renovation Activities and the Uptake of Nearly Zero-energy Buildings in the EU: Final Report.', 2019. [Online]. Available: https://energy.ec.europa.eu/publications/comprehensive-study-building-energy-renovation-activities-and-uptake-nearly-zero-energy-buildings-eu_en

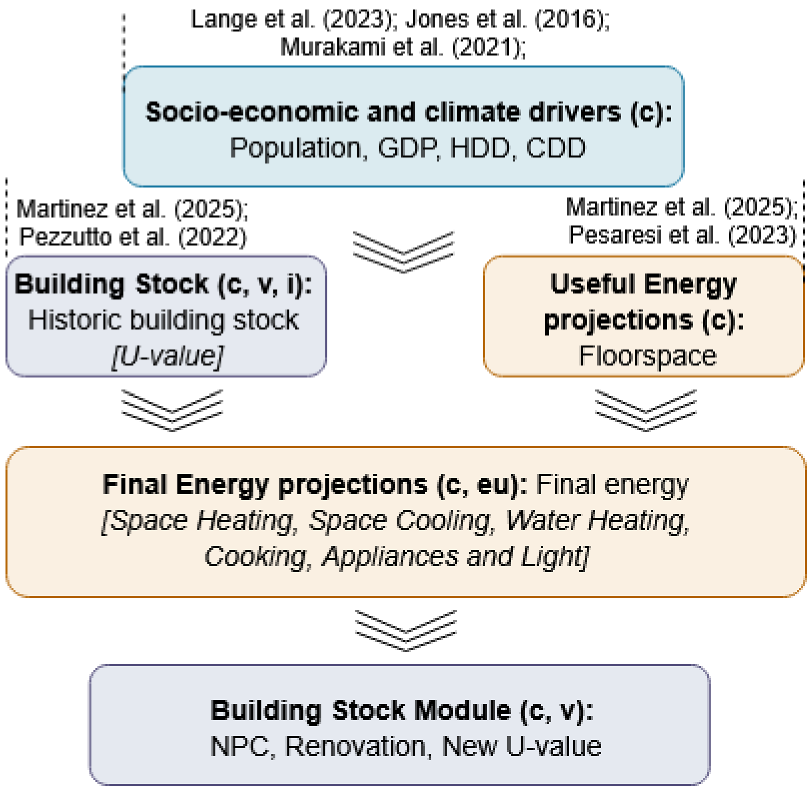
L. Vivier, A. Mastrucci, and B. van Ruijven, 'Meeting climate target with realistic demand-side policies in the residential sector', *Nat. Clim. Chang.*, vol. 15, no. 7, pp. 744–751, Jul. 2025, doi: 10.1038/s41558-025-02348-4.

T. Mandel, L. Kranzl, E. Popovski, F. Sensfuß, A. Müller, and W. Eichhammer, 'Investigating pathways to a net-zero emissions building sector in the European Union: what role for the energy efficiency first principle?', *Energy Efficiency*, vol. 16, no. 4, p. 22, Mar. 2023, doi: 10.1007/s12053-023-10100-0.

Methodology – Supplementary Information

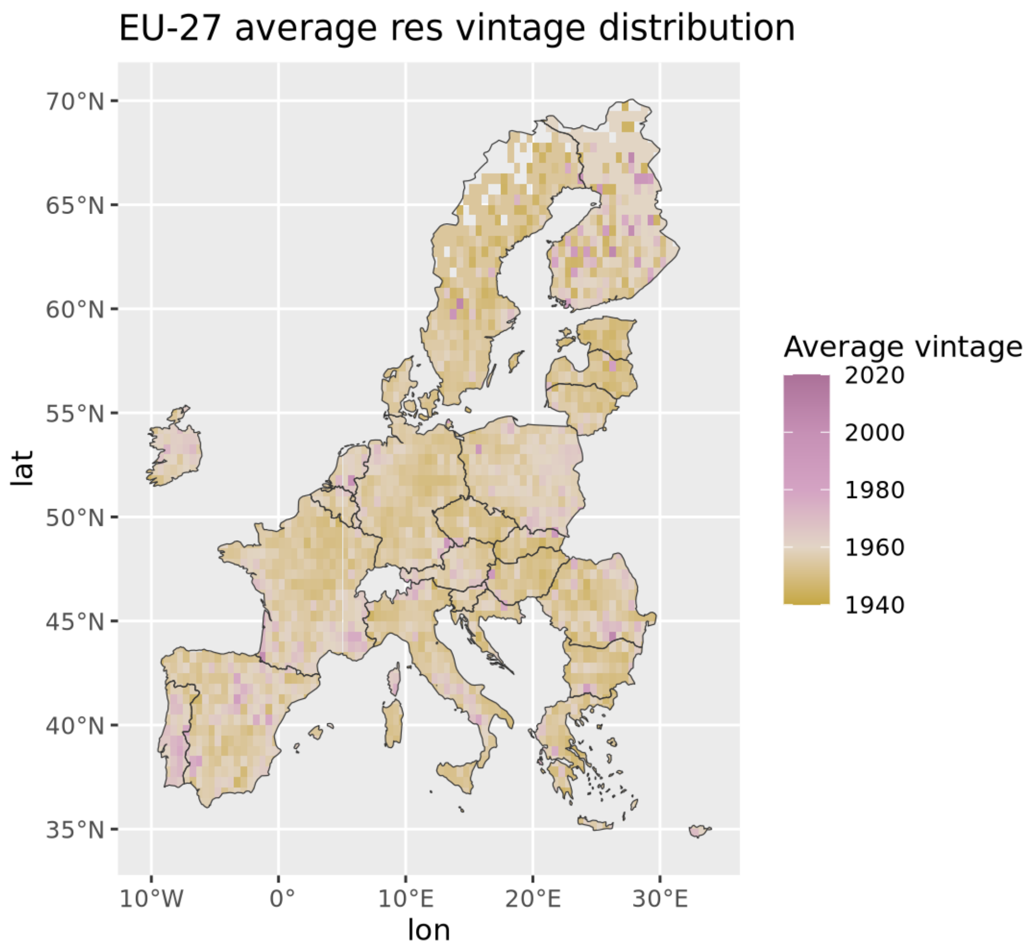


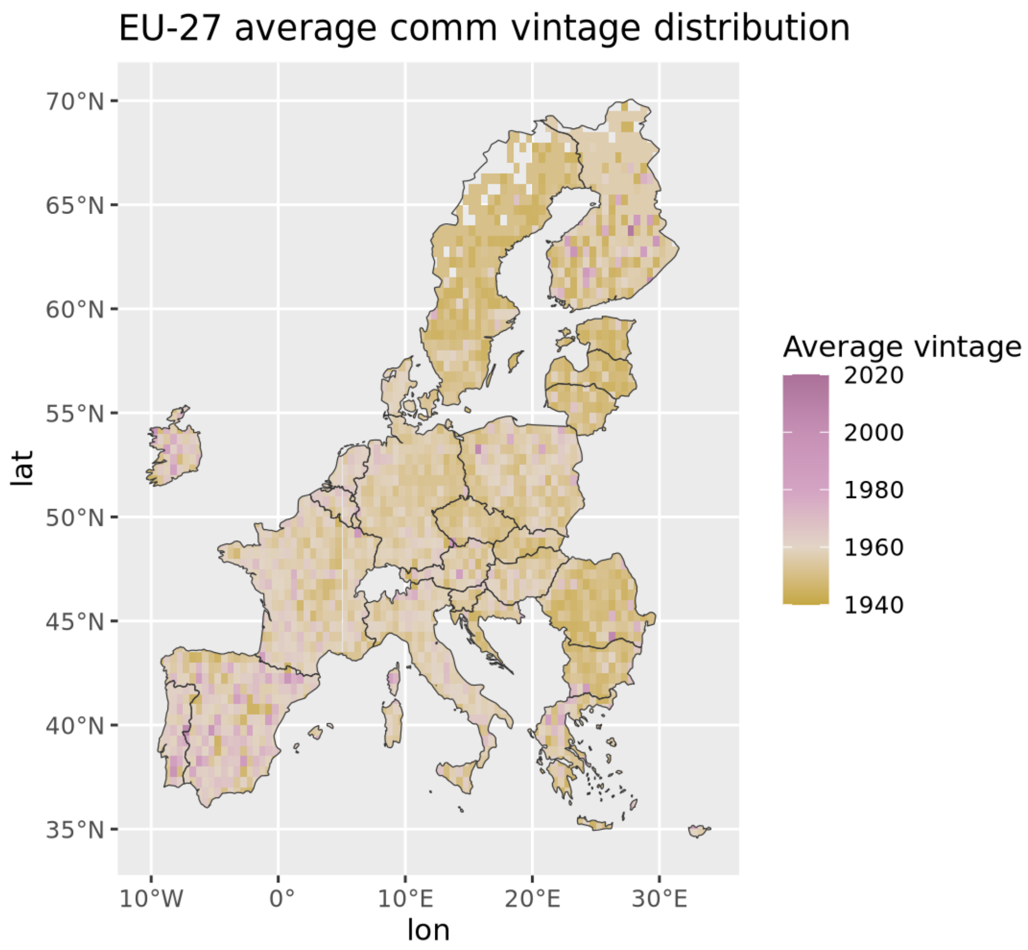
The indices **c, co, t, te, v, i, ec, eu**, respectively, denote **cell, country, time, technology, vintage, type of building** (residential or commercial), **energy carrier** and **end use**. Blue boxes represent the inputs, purple boxes the modules for the building stock, the orange boxed the modules for energy.



Downscaling pipeline applied to EDGE-EU. Socio-economic and climate drivers, Building stock and Useful Energy projections downscaling has been performed independently from one another, using the sources cited above the corresponding modules, and just for the variables mentioned. The dimensions that have been downscaled are indicated by the letters.

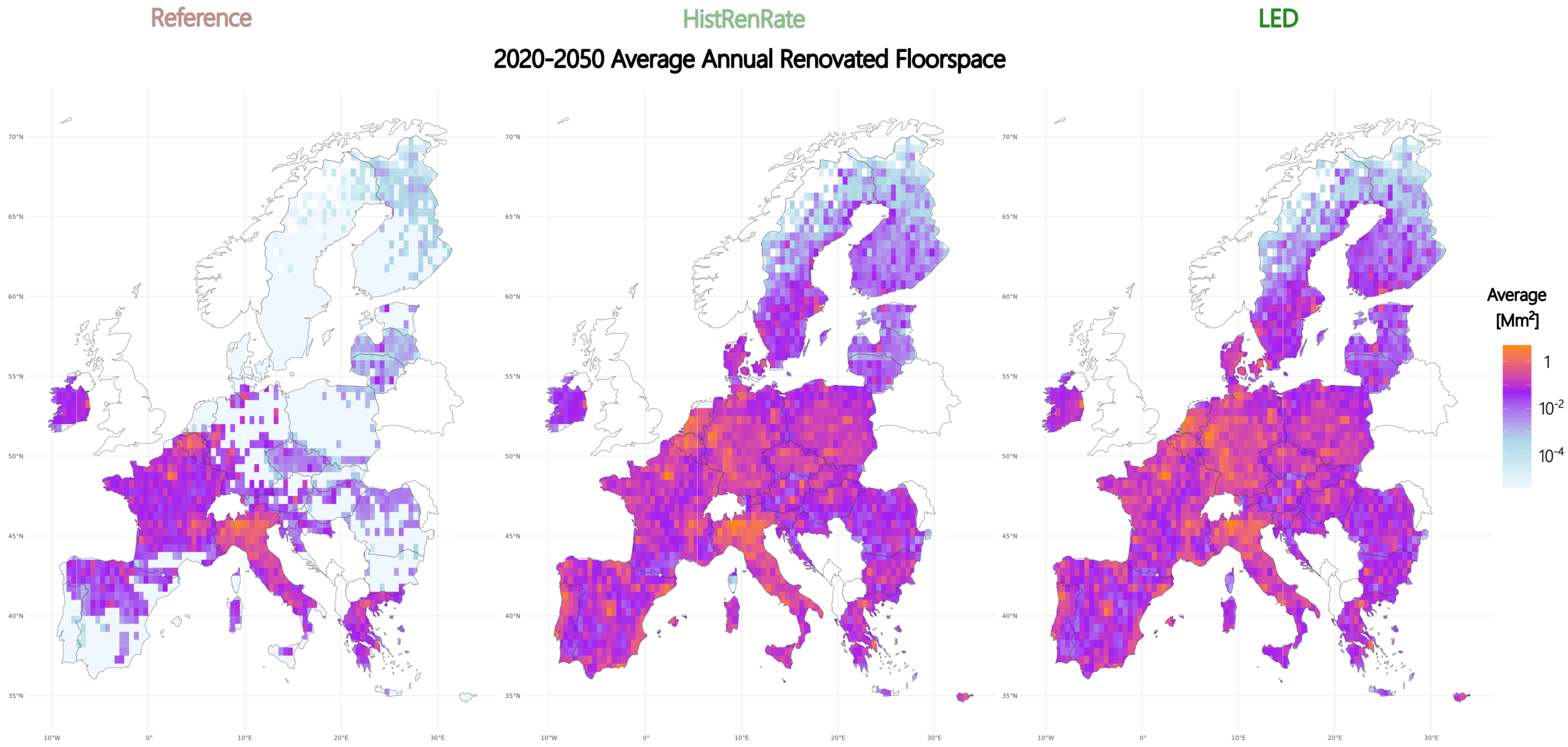
Methodology – Supplementary Information



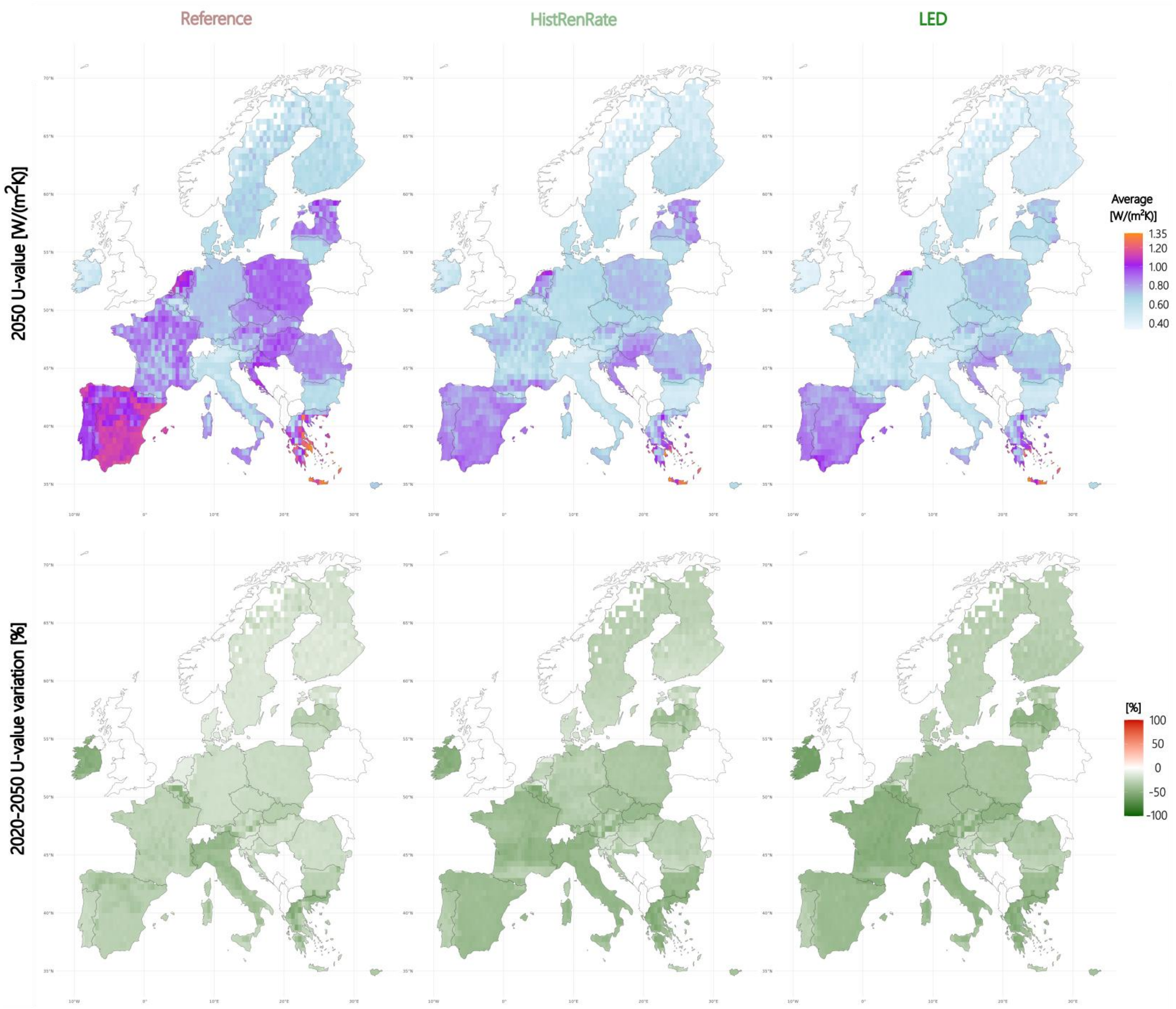


Results – Supplementary Information

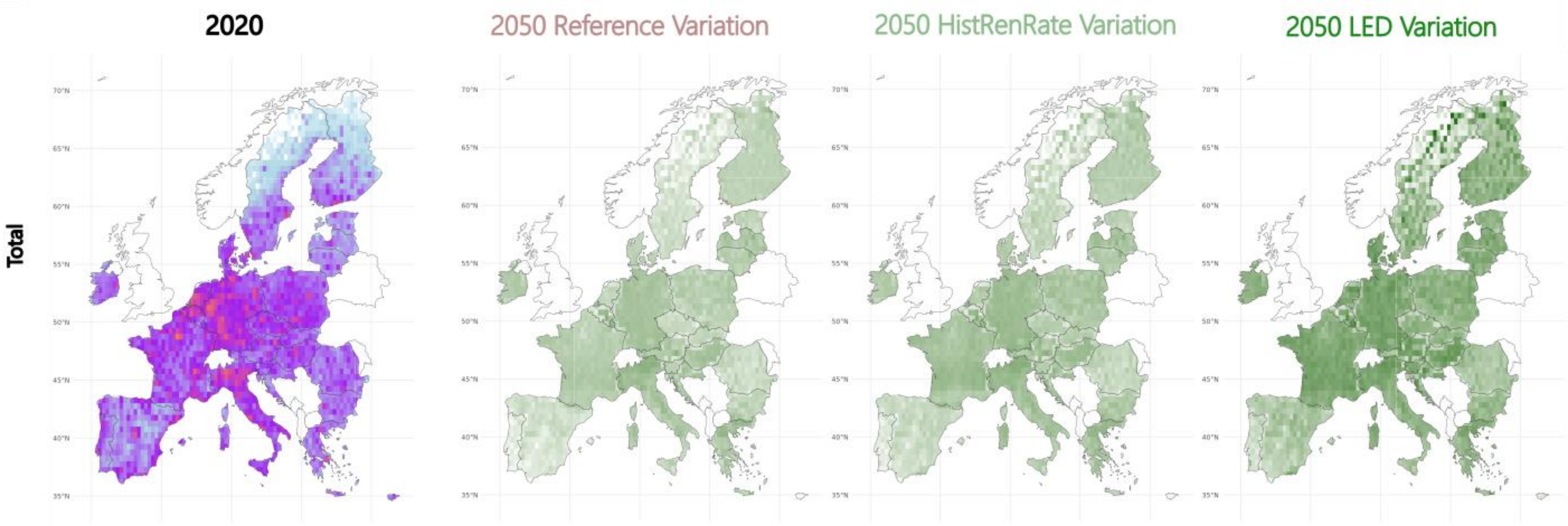
Results – Supplementary Information



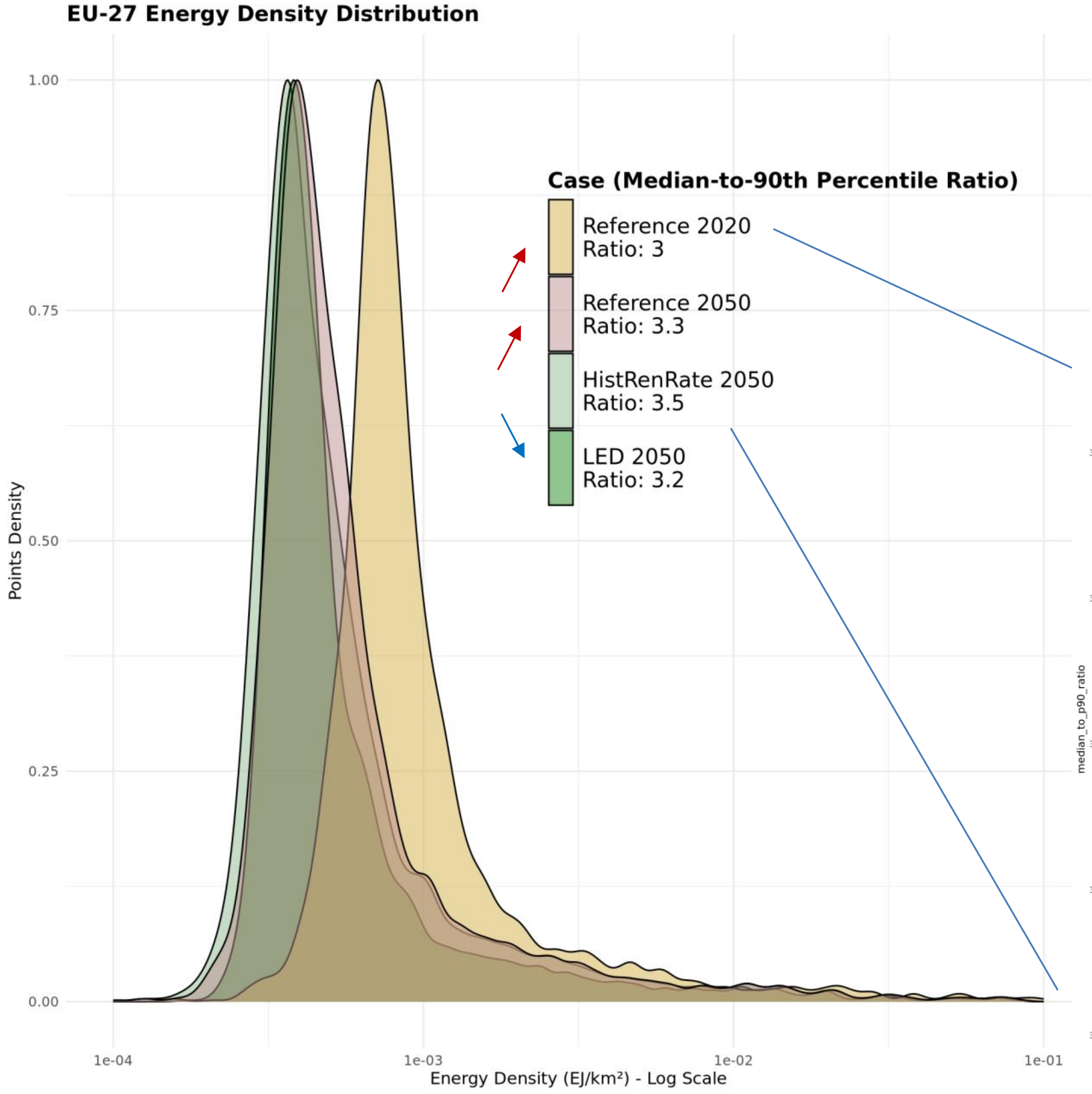
Results – Supplementary Information



Results – Supplementary Information

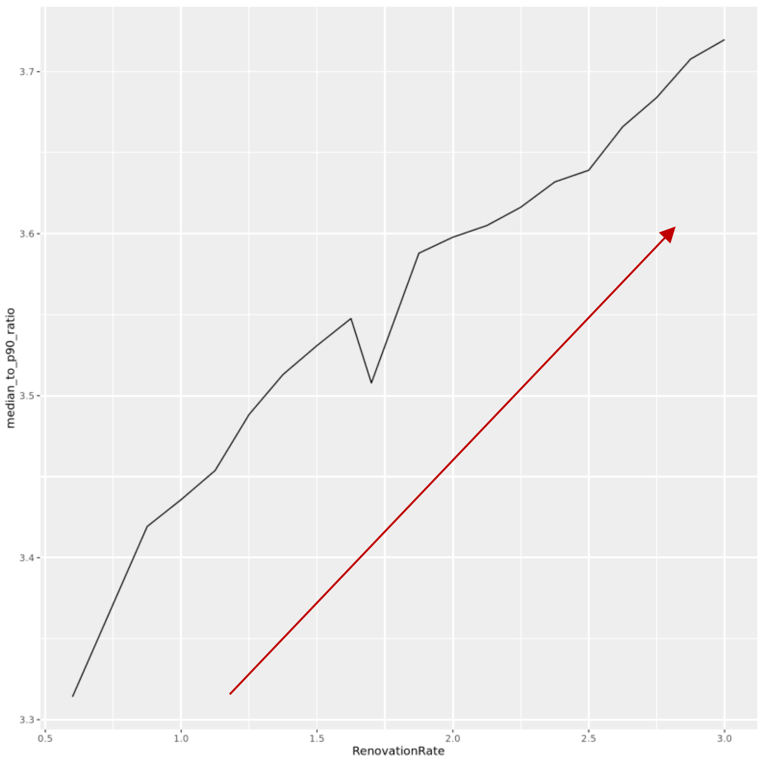


Results - Energy



How will energy demand be spatially distributed in the future?
Consider the distribution of **energy density [EJ/km²]** for the EU27 cells.
Polarization can be understood from the **90th percentile / median ratio** of the distribution.

- Optimally-distributed renovations alone increase energy density polarization
- In the LED scenario, all the other non-renovation measures partially compensate this effect

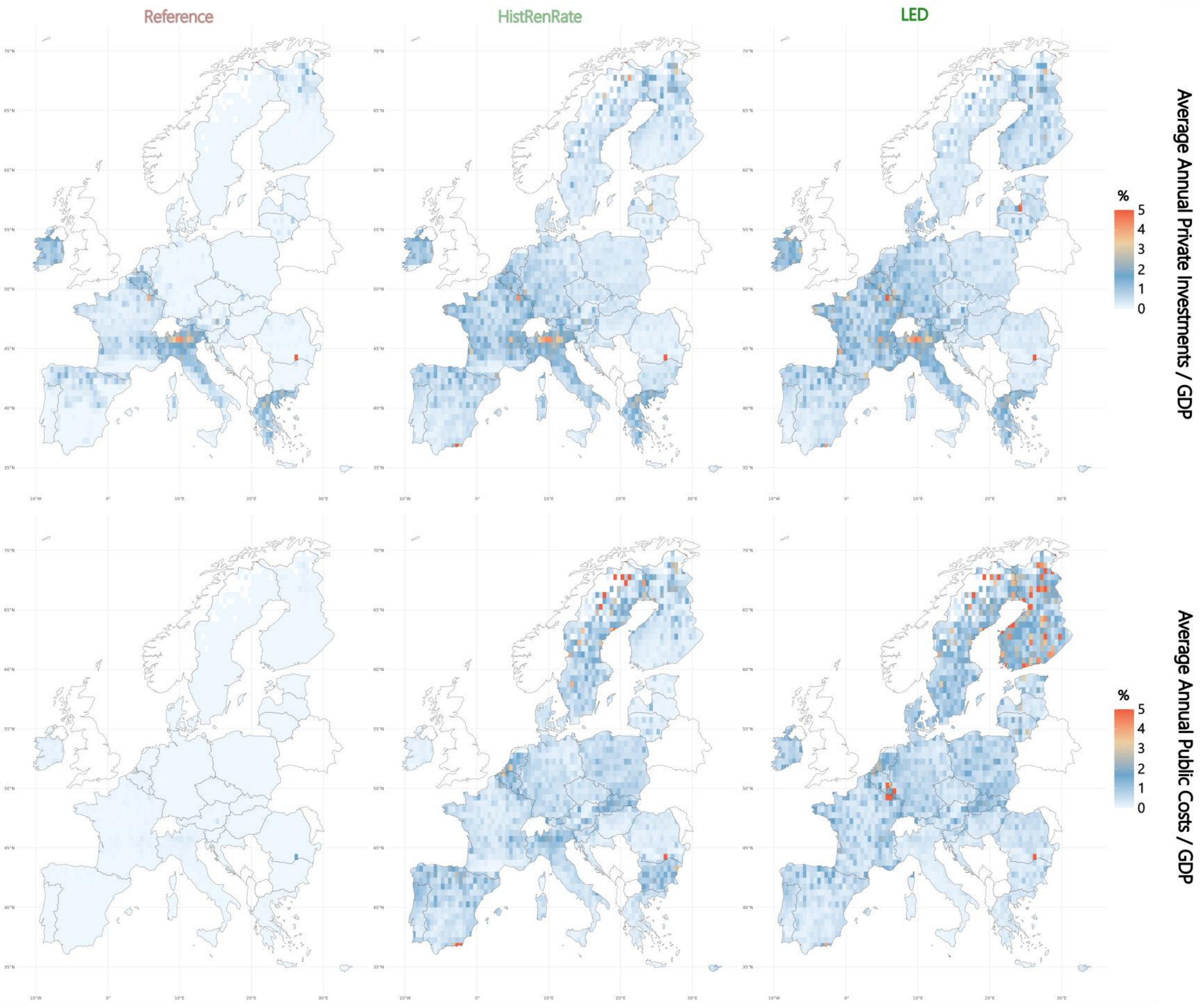


Why?
In most countries, there is a **mismatch** between high energy intensity areas, aged-building areas, and colder areas

Reference		HistRenRate		LED	
Private Investments	Public Costs	Private Investments	Public Costs	Private Investments	Public Costs
Annual Average Absolute values [b€]					
ITA (38.4)	ITA (2.2)	FRA (50.9)	DEU (36.1)	FRA (63.3)	DEU (47.6)
FRA (19.8)	FRA (2.2)	ITA (47.3)	ITA (25.4)	DEU (56.2)	FRA (40.4)
BEL (11.2)	BEL (1.1)	DEU (41.7)	FRA (24.5)	ITA (49.2)	NLD (22.0)
IRL (5.1)	IRL (0.6)	ESP (16.2)	ESP (23.3)	ESP (15.9)	POL (19.3)
GRC (5.1)	DEU (0.4)	BEL(12.0)	BEL (20.6)	BEL (11.8)	ESP (15.9)
Annual Average Percentage values over country GDP [%]					
BEL (1.45)	IRL (0.15)	ITA (1.57)	BEL (2.09)	IRL (1.85)	LUX (4.44)
ITA (1.25)	BEL (0.14)	BEL (1.56)	SVK (1.93)	ITA (1.61)	FIN (3.20)
IRL (1.24)	ITA (0.07)	IRL (1.26)	BGR (1.38)	BEL (1.55)	SVK (2.07)
GRC (0.96)	LUX (0.07)	FRA (1.18)	NLD (1.38)	AUT (1.21)	MLT (1.93)
LUX (0.90)	FRA (0.05)	GRC (1.15)	SWE (1.04)	LVA (1.24)	NLD (1.71)

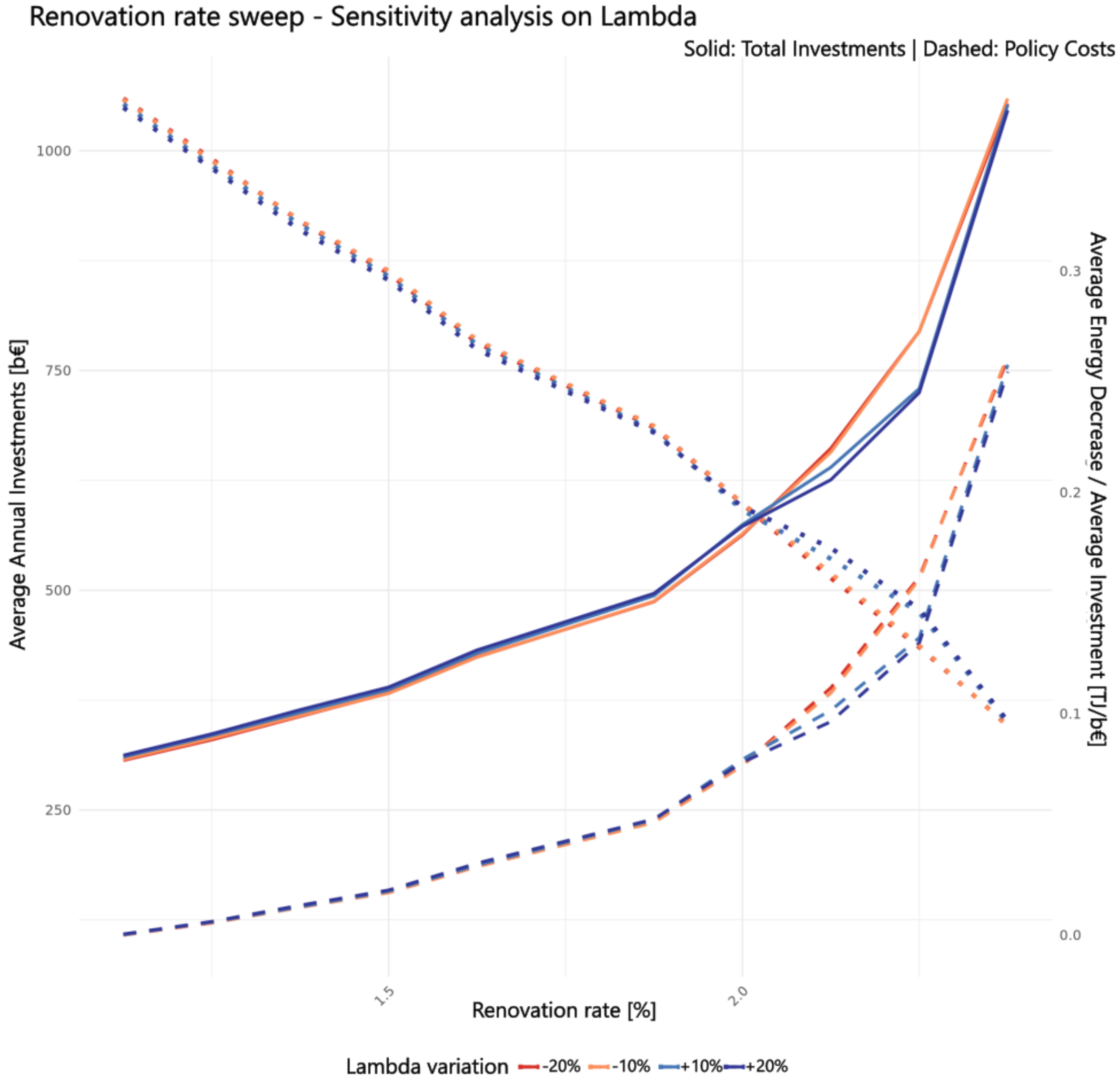
Table SM11: Top 5 countries by annual average private investments and public costs by absolute value b_{2025} (on top), and by percentage over GDP (at the bottom) for Reference, HistRenRate and LED scenario between 2020 and 2050.

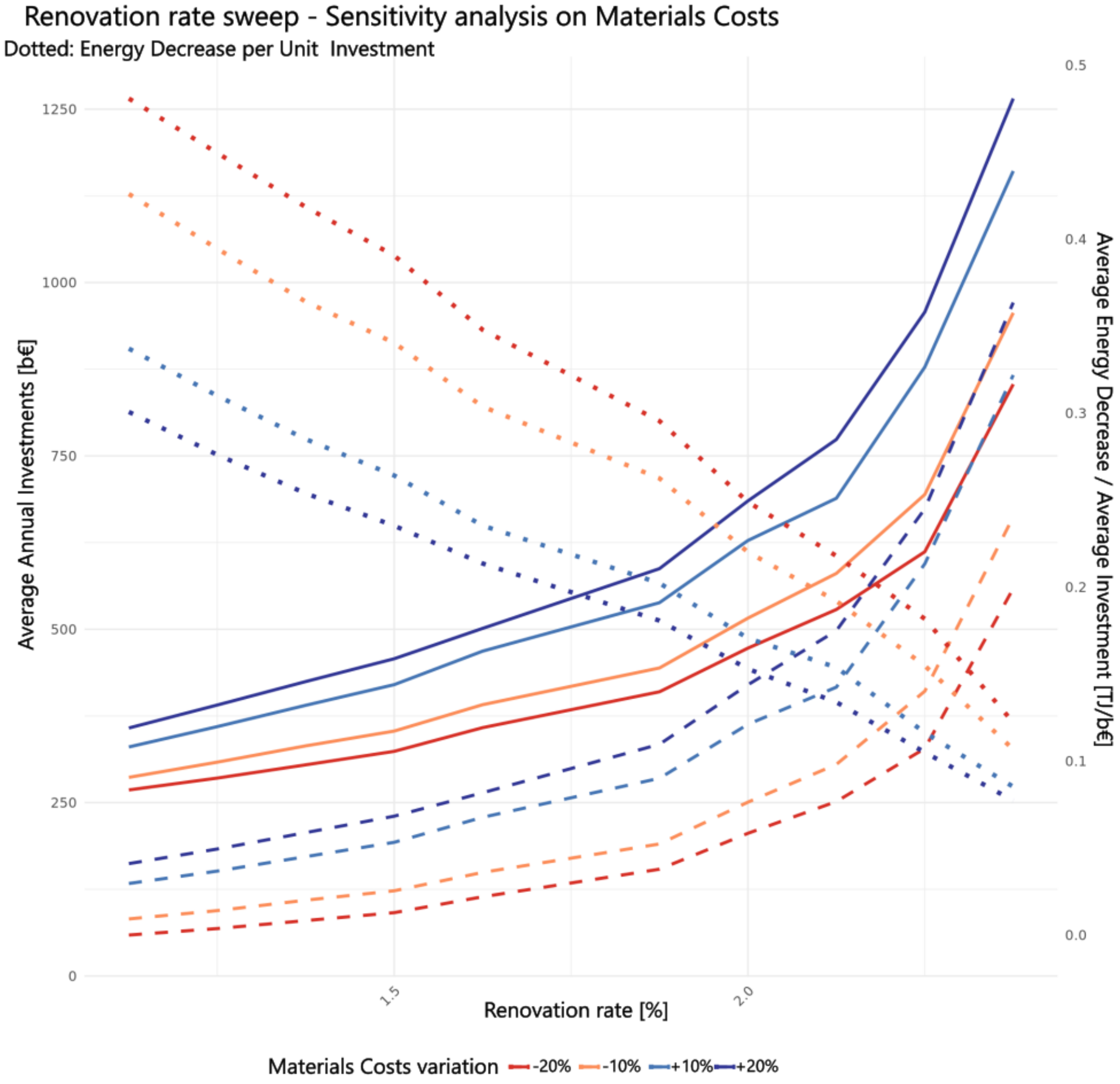
Results – Supplementary Information



Results – Supplementary Information

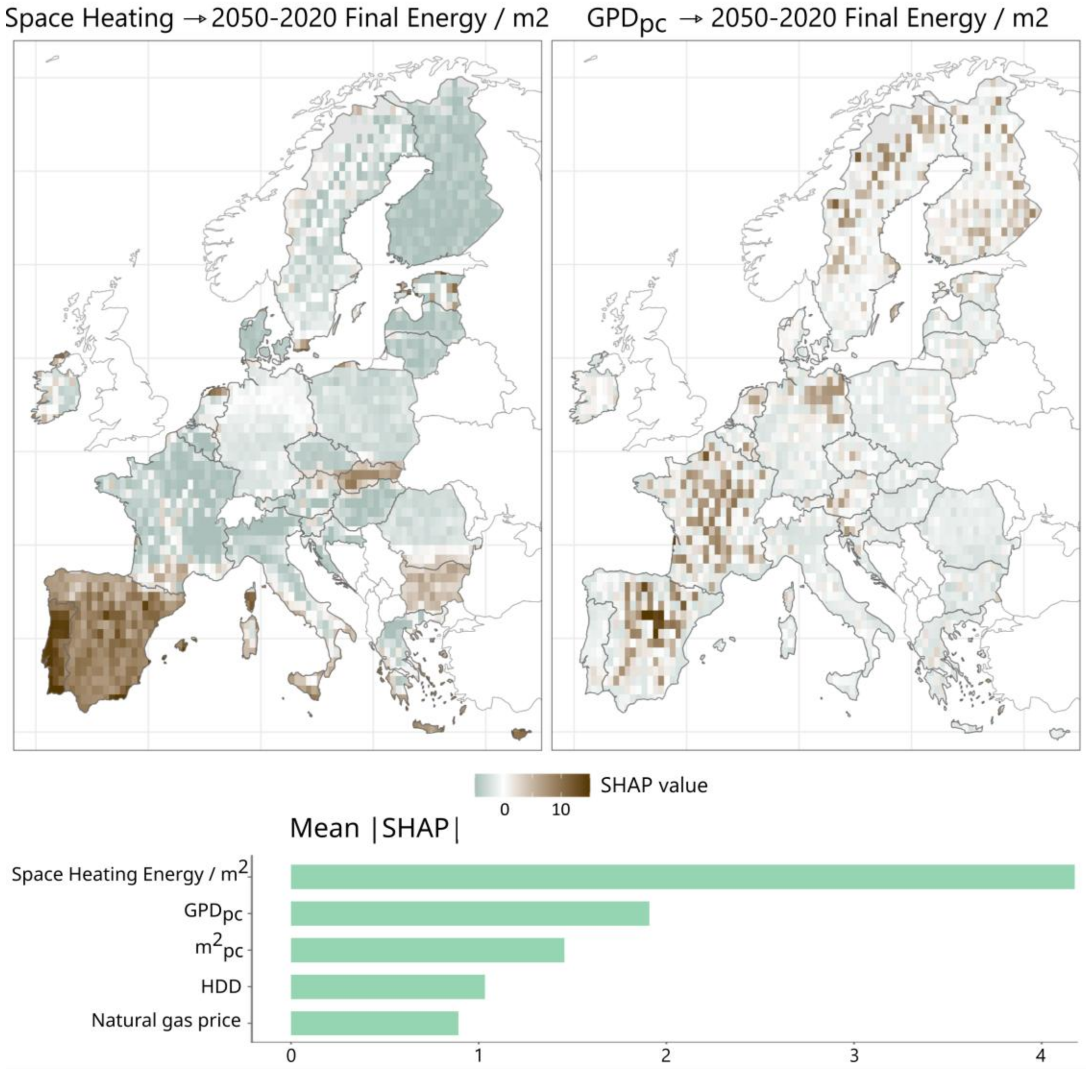
Solid: Total Investments | Dashed: Policy Costs | Dotted: Energy Decrease per Unit Investment





Results – Supplementary Information

SHAP contributions on 2050-2020 Final Energy / m2



SHAP contributions on Total Investments / m2