TECHNISCHE UNIVERSITÄT WIEN

Identifying relevant parameters to replicate a step-by-step retrofitting optimisation model in a building stock level

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IAEE - Online, 2021

07.06.2021

Energy Economics Group

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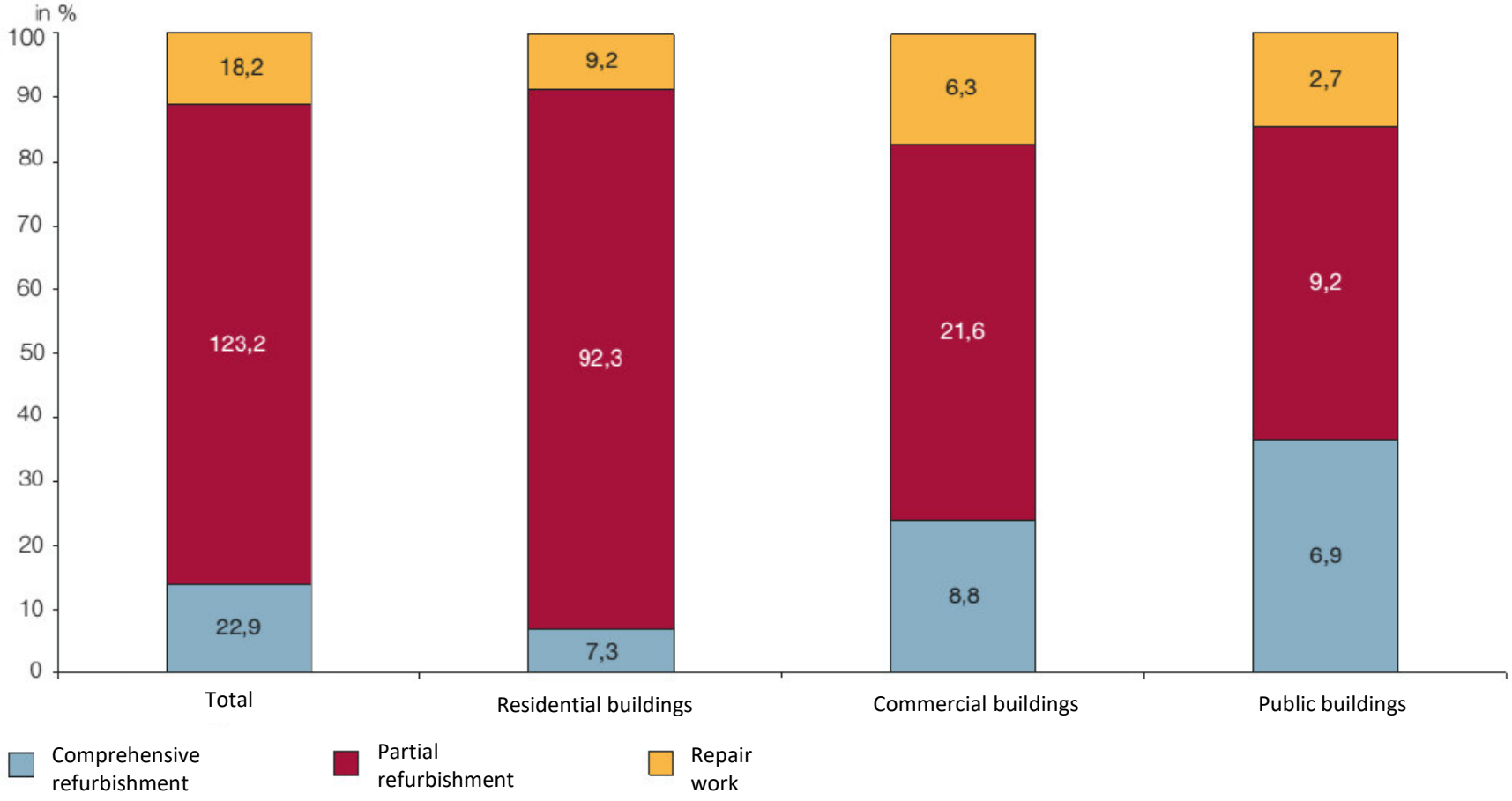
Introduction: empirical evidences

Existing building stock volume of comprehensive / partial refurbishment and repair work (in Mio. Euro)
Stand: Germany, 2010



Source: adapted from Fehlhaber, 2017 – PhD Dissertation – Bewertung von Kosten und Risiken bei Sanierungsprojekten

Introduction: political context

- Building renovation passports:

  - Energy Performance of Buildings Directive (EPBD) 2018/844/EU introduced in Article 19a:

  "complementary document providing a **long-term** and **step-by-step** renovation roadmap for a specific building"

  - **Step-by-step roadmap**:
    - can have various steps, normally 2-5 steps (1 step = single step approach)
    - defines renovation measure or package of measures per step
    - provides techno-economic specifications of each renovation step, including energy savings, investment costs etc.
    - should guide and help building owners through the renovation process

Overall objective and research question

- Objective:
  - Develop a step-by-step retrofitting optimisation model to deliver the optimum timing, when each step should be performed
  - Test the model using roadmaps developed during the iBRoad project
  - Understand how to replicate the approach to a building stock level

- Research questions:

Which results were obtained from a first analysis of the model?

based on the learnings from this analysis:

How to deliver plausible **budget restrictions for the retrofitting,**

representative to the building stock?

Method: model objective function

- Objective function: **maximising net present value**

$$\max NPV = \sum_t^T \frac{CF_t}{(1+r)^t} + \frac{L_T}{(1+r)^T}$$

$$CF_t = INC_t * s - IC_{er,t} - EC_t - OMC_t$$

$$L_T = \sum_i \sum_t IC_{er,t,i} * \frac{(T-t)}{t_{L,i}}$$

- Restrictions:
  - Material's aging process
  - Budget restriction

NPV, energy related net present value [EUR];

CF, cash-flow of energy related expenses [EUR];

L, residual value of the retrofitting measures in year T [EUR];

r, interest rate [%];

t, time [a];

T, period of economic consideration [a];

INC, household income [EUR/a];

s, expenditure share of annual income [%/a];

IC_{er}, energy related investment cost of retrofitting measures [EUR];

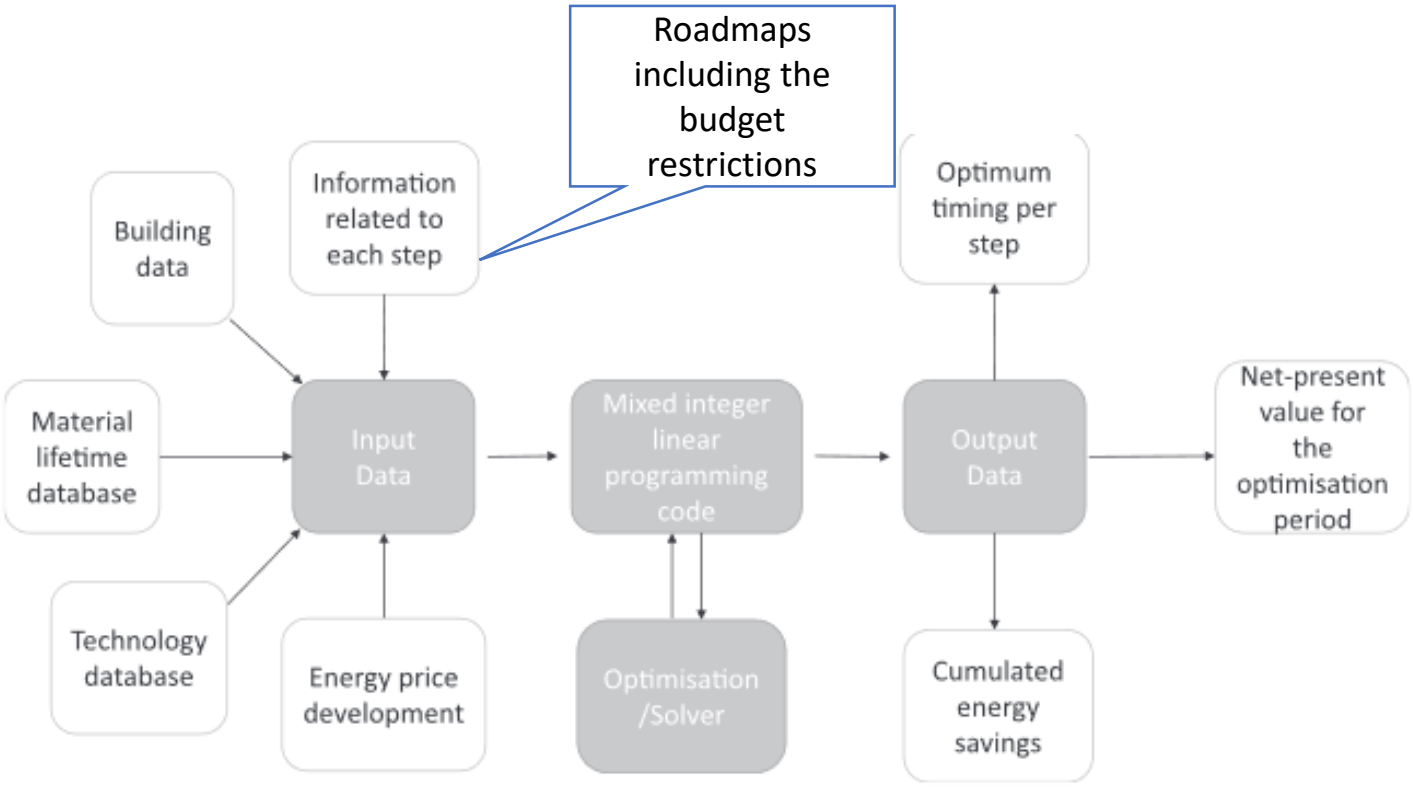
EC, annual running energy costs [EUR/a];

OMC, operation and maintenance costs [EUR/a];

t_L, technical lifetime [a];

T, optimisation period time [a];

Method: model architecture



Source: Maia et al , 2021

- Optimisation period: 2020-2050
- Interest rate: 3%

Case study: 5 buildings

- Buildings selected and roadmaps developed during the H2020 iBRoad project

ID	Country	Year of construction	Net floor area [m^2]	Year of heating system replacement	Heating System
1	PT	1937	74	1937	Electric heater
2	PL	1975	218	1975	Gas boiler
3	PL	1975	368	2004	Gas boiler
4	PL	1981	285	1981	Coal boiler
5	BG	1994	160	1999	Air heat pump

Fixed budget restriction: 3,000 Euro

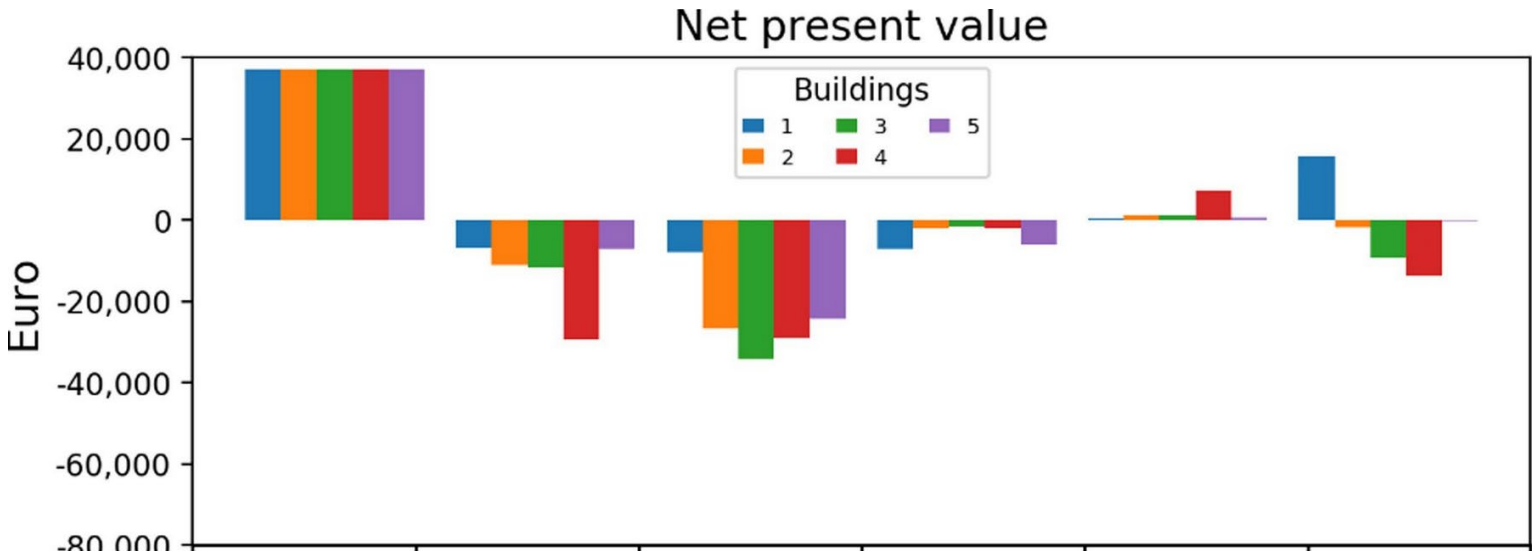
Source: Maia et al , 2021

Case study: exemplary step-by-step roadmap (ID =1)

ID	Step	Measure/Package of measures	Primary energy demand [kWh/m²]	Useful energy demand [kWh/m²]	Carbon emission [kg/m²a]	Investment cost [Euro]	Main energy source
1	**0**	**Status quo**	**600**	**327**	**100**		**electricity**
1	1	Thermal insulation on exterior walls - application on the inside with light coating; thermal insulation with sloped roof - application on the slopes on the resistant structure of the sloped roof; Replacement of existing frames with energy class A windows	249	99	36	14,500	electricity
1	2	Add a biomass boiler	51	112	7	3,000	wood
1	3	Installation of individual inclined solar thermal system	27	87	4	2,000	wood

Source: Maia et al , 2021

Result: model analysis



	cumulated asset	total investment	energy expediture	maintenance expenditure	residual value	net
ID 1	37079	-6820	-7989	-7088	394	15576
ID 2	37079	-11087	-26780	-2245	1123	-1909
ID 3	37079	-11768	-34120	-1566	1034	-9341
ID 4	37079	-29519	-29268	-2065	7094	-13679
ID 5	37079	-7233	-24256	-6179	436	-153

Source: Maia et al , 2021

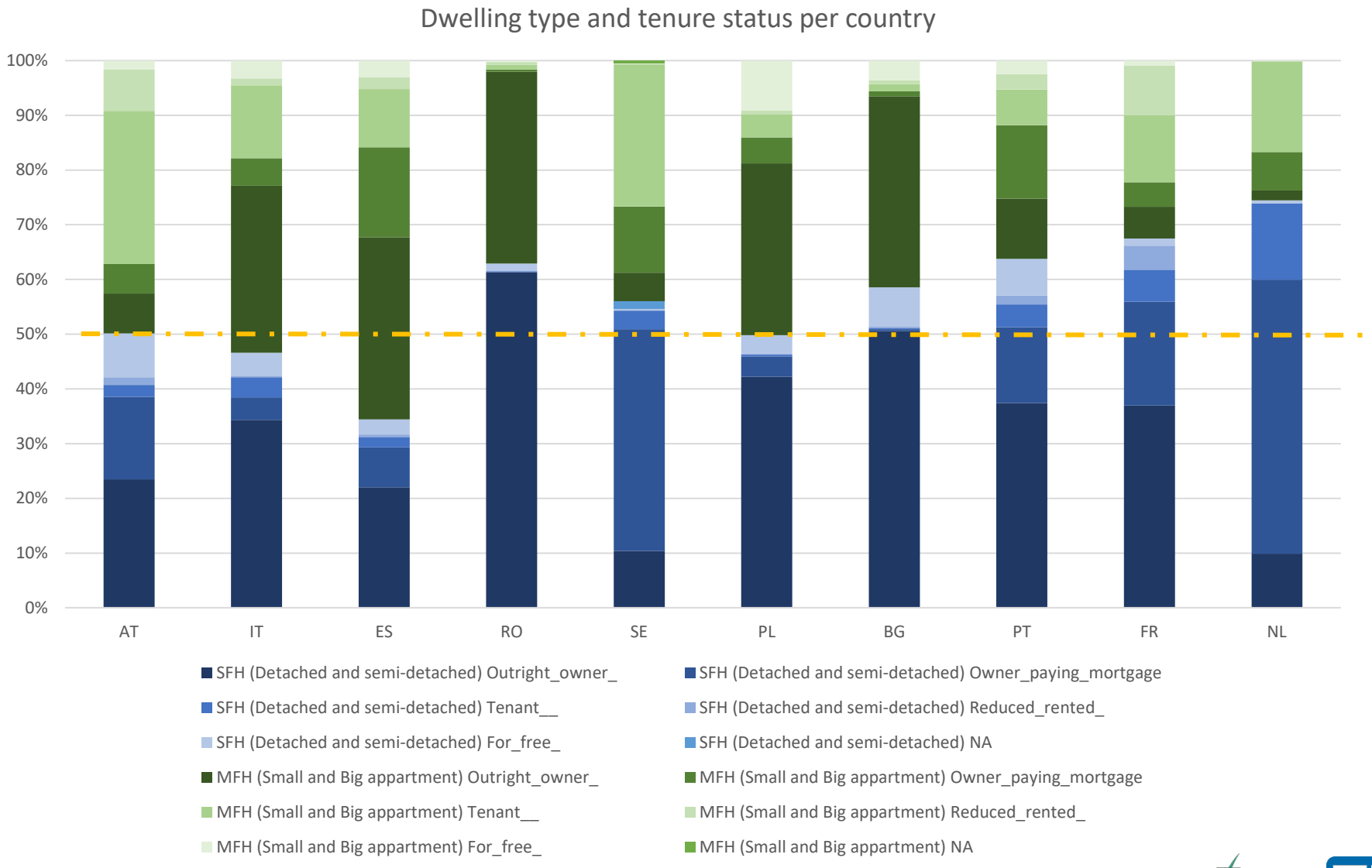
Result: sensitivity analysis

- Model is sensitivity to the budget restrictions
- There is a need to define the budget restrictions more accurately

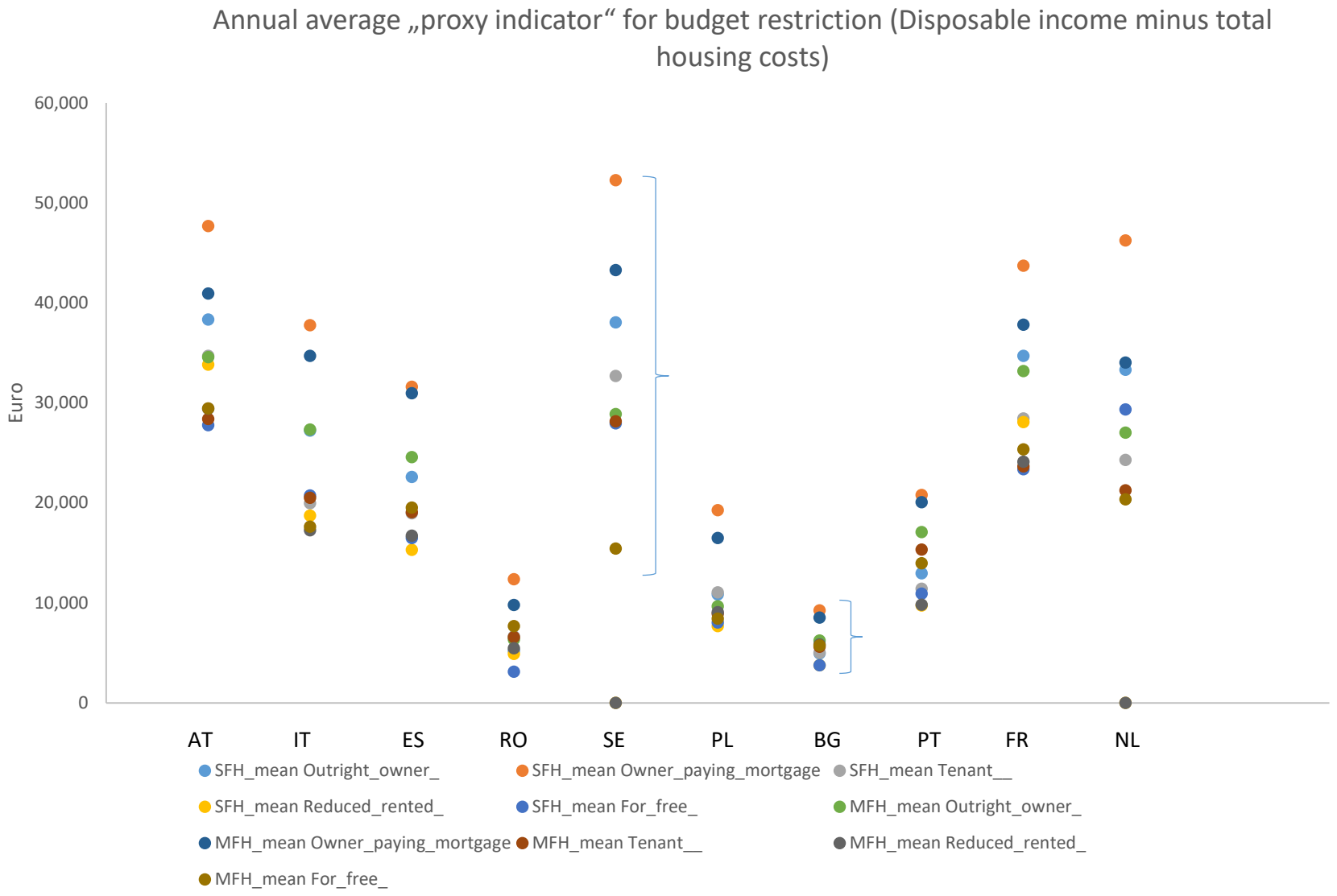
	Budget: 900			Budget: 3,000			Budget: 6,000		
ID	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
1	2034	2036	2023	2025	2025	2021	2023	2024	2021
2	2023	2050	2032	2021	2032	2024	2021	2027	2023
3	2038	2041	2037	2022	2028	2027	2022	2026	2025
4	2023	–	–	2031	2047	2030	2021	2037	2027
5	2031	2034	2027	2024	2024	2022	2024	2024	2022

Source: Maia et al , 2021

Result: SILC statistical analysis



Result: SILC statistical analysis



Conclusions

1) Which results were obtained from a **first analysis of the model**?

- Step-by-step retrofitting model delivered plausible optimum timing when each step should be performed
- Cash-flow net present value: varied between 15.576 and -13.679 € (due to individual technical characteristics of each building and the individual roadmaps)
- Total period of a renovation roadmap (the period between the first and the last step): between 1 and 14 years and 2 to 11 years (according to the different constraints compared) – fixed budget restrictions of 3,000 €
- More details about the model and the analysis: Maia et al, 2021 - Paper „New step-by-step retrofitting model for delivering optimum timing" provides more details about the model and the analysis *https://www.sciencedirect.com/science/article/pii/S0306261921002348#f0010*
- Sensitivity analysis showed the need to define more accurate budget restrictions, as the model is very sensitivy to this parameter

2) How to deliver plausible **budget restrictions for the retrofitting** representative to the building stock?

- Country specific budget restrictions defined according to the building type and tenure status
- EU SILC and HBS datasets are important sources of this information
- Merging SILC and HBS is the ideal approach

Thank you for your attention!

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Orig. Photo: Patrick Stargardt