Demand-side modelling insights to alleviate rural energy poverty in the EU

Akis Apostoliotis, Dimitris Papantonis, Prof. Dr. Alexandros Flamos

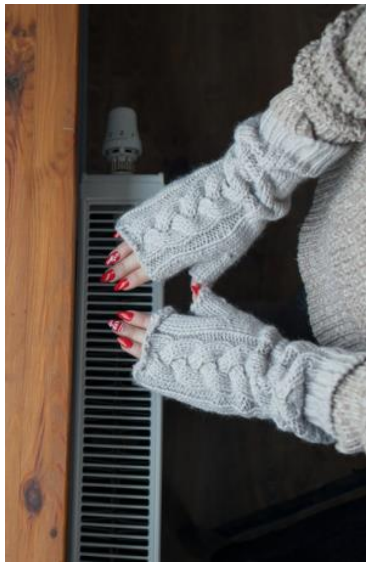
Technoeconomics of Energy Systems laboratory (TEESlab)
University of Piraeus Research Center (UPRC)

World Sustainable Energy Days Young Energy Researchers Conference
4 March 2025

This work is based on research conducted within the co-funded by the European Union LIFE Programme project RENOVERTY: ID101077272. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

Introduction & problem statement

- Causes of energy poverty at the local, regional, national, and European scales have recently become clearer, yet an **absence of practical and theoretical understanding** of how to address the issue in rural areas exists.
- **Rural areas** across Central Eastern (CEE), Southern Eastern (SEE), and Southern Europe (SE) are traditionally much poorer, and more vulnerable to energy poverty.
- Despite their need for support, they are left behind in the energy transition, and **practices to reduce energy poverty are lacking**.



In this context, it's necessary to..

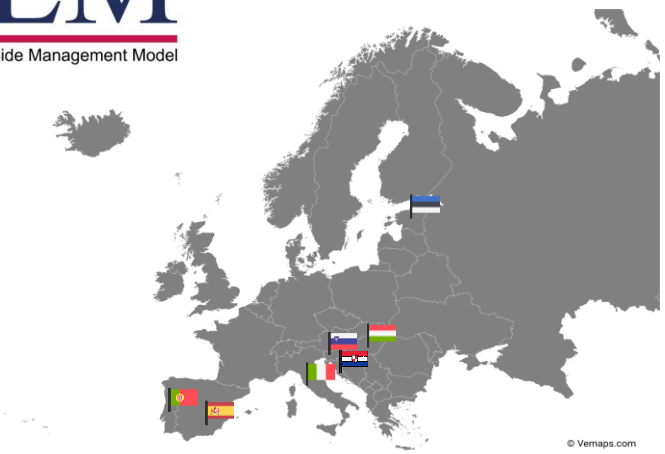
- ✓ **Analyse** the **cost-effectiveness** of **different portfolios** of **measures** and **financing schemes in the real-life pilots** under study.
- ✓ **Evaluate** the **performance** of **different conventional measures** in terms of their **long-term savings.**
- ✓ **Focus** on aspects of **energy poverty** and **assessment** of the **economic benefits** of each measure at a **disaggregated** level.

Main evaluation **criteria:**

- The **energy-saving potential** of the energy efficiency measures
- The energy efficiency measures **cost-effectiveness**

DREEM
Dynamic High-Resolution Demand-Side Management Model

Energy efficiency measures were evaluated in seven pilots for 13 distinct **building typologies**:



DREEM

Dynamic High-Resolution Demand-Side Management Model

ELSEVIER

Energy Conversion and Management

Volume 205, 1 February 2020, 112339

A modular high-resolution demand-side management model to quantify benefits of demand-flexibility in the residential sector

Vassilis Stavrakas, Alexandros Flamos

ELSEVIER

Energy Conversion and Management

Volume 324, 15 January 2025, 119235

Research Paper

Towards decarbonisation or lock-in to natural gas? A bottom-up modelling analysis of the energy transition ambiguity in the residential sector by 2050

Dimitris Papantonis, Vassilis Stavrakas, Dimitra Tzani, Alexandros Flamos

RENOVERTY

Currently applied and further developed in multiple **EC-funded H2020**, **HE**, and **LIFE** projects

HORIZON 2020

Life

HORIZON EUROPE

DigiBUILD

IAM COMPACT

ENSMOV PLUS

ENCLUDE

Energy Citizens for Inclusive Decarbonization

LOCATEE

FORTESIE

Inherit

Building sector

Energy demand simulation model

Benefits & **limitations** of demand-flexibility primarily for **consumers** & other **power actors** involved

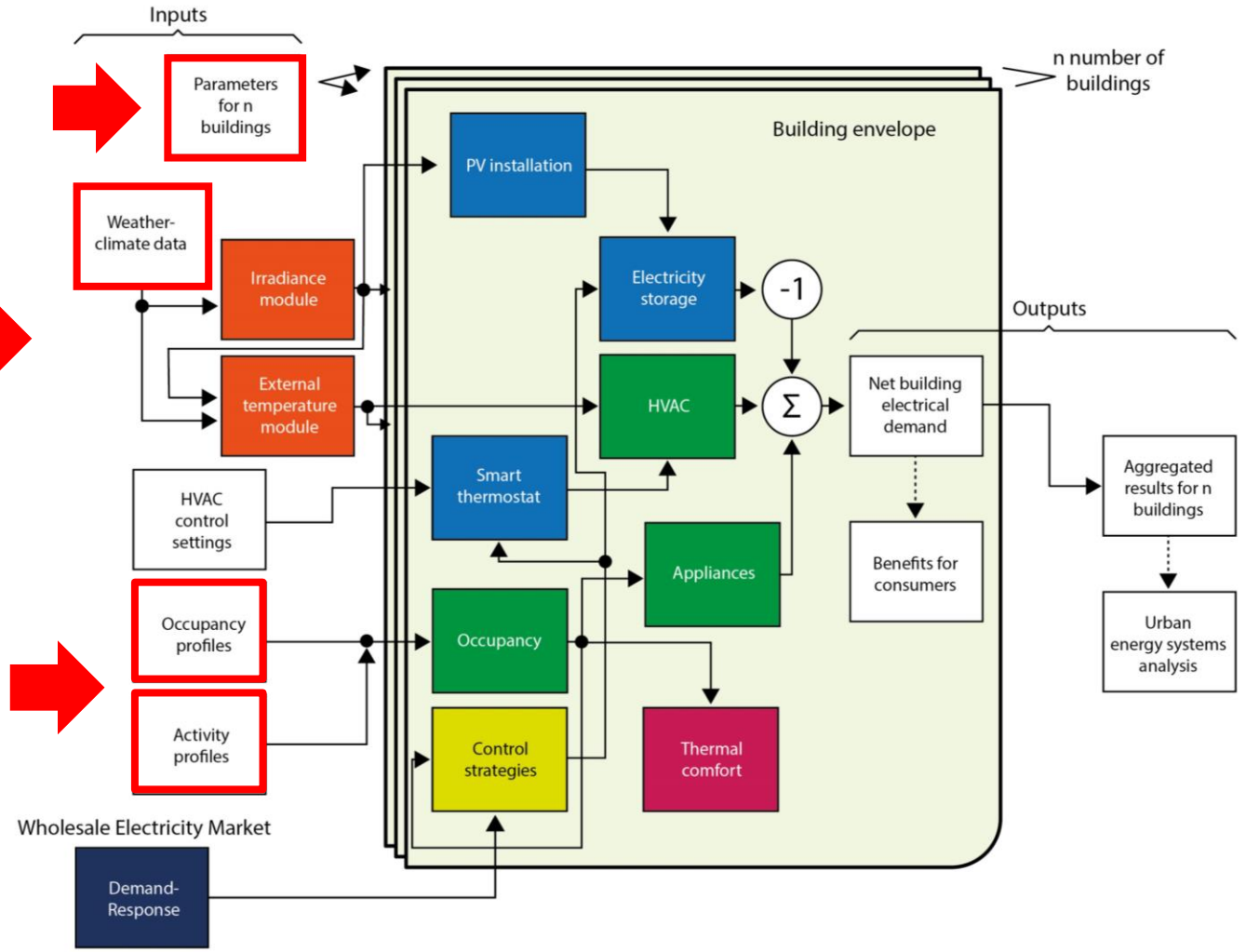
Existing Situation – Baseline Scenarios

Energy Audits & Certificates

Weather-Climate data

Climate.OneBuilding.Org

Building composition, **occupancy** & **activity** patterns from **energy audits**



Future situation – Energy efficiency scenarios

Evaluated the **performance** & **replicability** potential of **Energy Efficiency Measures (EEMs)**

- ✓ Long-term energy savings
- ✓ Sustainability
- ✓ Risk
- ✓ Return of investment

Cost-effectiveness

$$LCSE = \frac{(CRF * \text{Cost}_{investment}) + \text{Cost}_{O\&M}}{Energy\ Savings\ (kWh)}$$

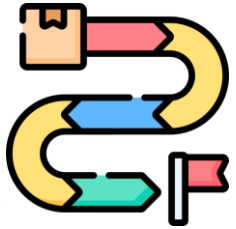
Heating technology change:

Substitution of fossil fuel boilers with efficient **technologies** (e.g., **heat pumps**, etc.)

★ Assessing **benefits** of each **measure** at a **disaggregated** (households-neighbourhood) level

particularities of households experiencing energy poverty in rural pilot regions

★ providing **policymakers**, **consumers** & other potential **end-users** with useful insights



Indicative results: Pilot region of **Osona**, Spain

Country: Spain
Region: Osona

Type of building/usage: Single Family House

Year of Construction: 1960-1980

Total floor area: 140 m^2

Osona, Spain (SFH)	
Building characteristics	
Year of construction	1960-1980
Total floor area of the building	140 m^2
Total area of exterior walls of the buildings	72 m^2
Total roof area of the building	58 m^2
Total area of windows	11 m^2
Building envelope/construction features	
U_{wall}	2.40 $W/m^2/K$
U_{floor}	2.20 $W/m^2/K$
U_{roof}	2.60 $W/m^2/K$
U_{window}	3.60 $W/m^2/K$
HVAC and lighting systems	
Heating system	Oil boiler
Nominal capacity	24 kW
COP	0.85

Indicative results: Baseline scenario

Total energy consumption:

- 31,194.6 kWh/year

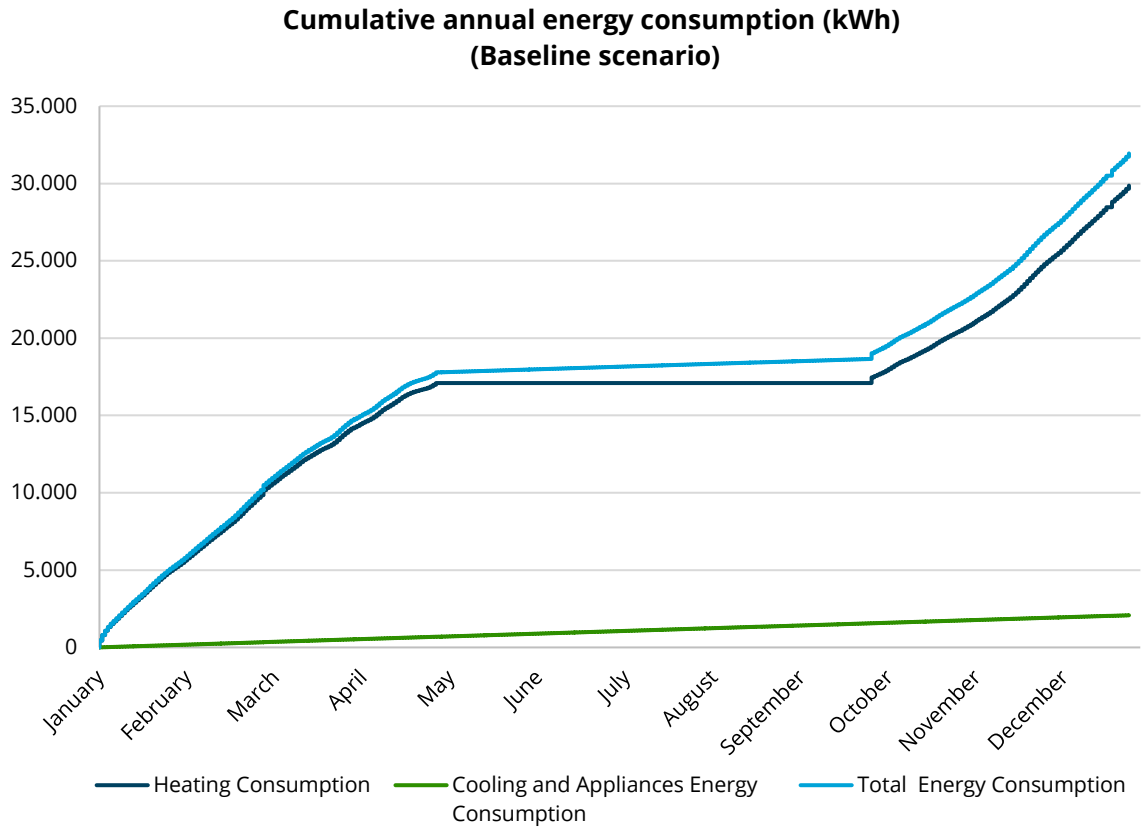
Heating energy consumption:

- 29,867.0 kWh/year

Energy for **cooling** and **appliances**:

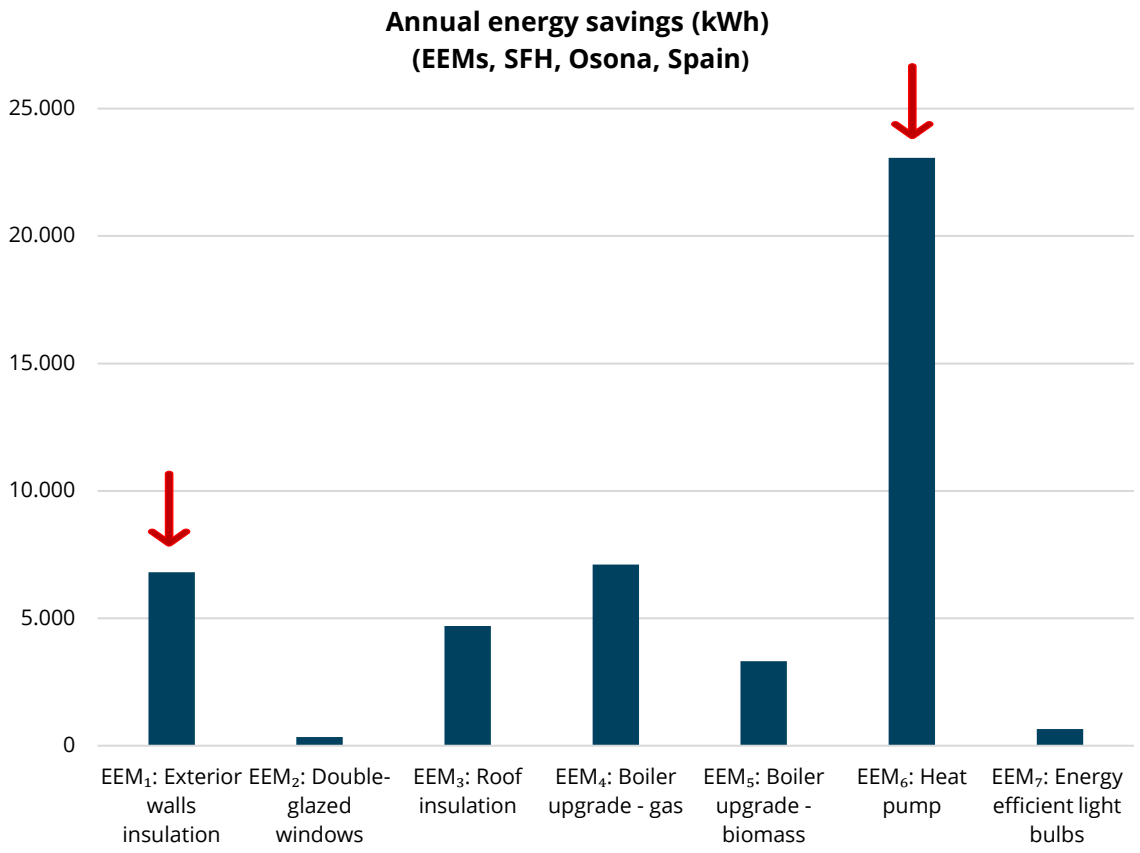
- 2,079.6 kWh/year

- 8,631.8 kg of CO_2 **emitted** per year



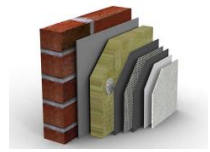
Heating Needs → >90% of total energy consumption

Indicative results: Energy performance



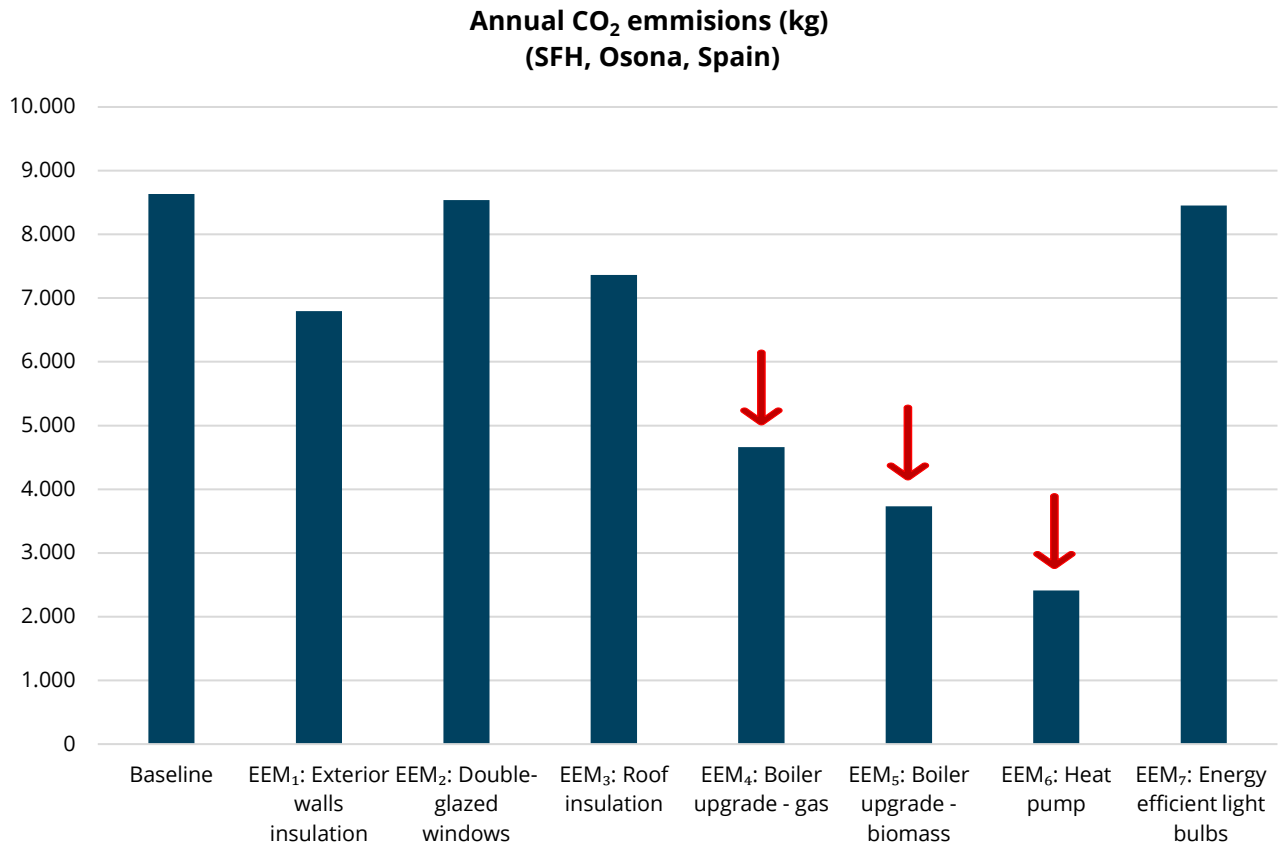
Annual energy savings (in kWh) for the different EEMs (SFH, Osona, Spain)		
	Energy savings (kWh)	Reduction (%)
EEM_1: Exterior wall insulation	6,806.0	21.3
EEM_2: Double-glazed windows	340.8	1.1
EEM_3: Roof insulation	4,694.6	14.7
EEM_4: Boiler upgrade - gas	7,111.6	22.3
EEM_5: Boiler upgrade - biomass	3,318.6	10.4
EEM_6: Heat pump	23,072.2	72.2
EEM_7: Energy efficient light bulbs	658.2	2.1

- *Envelope upgrade*
  - *6,806.0 kWh/year / 21.3%*



- *Heating system change*
  - *23,072.2 kWh/year / 72.2%*

Indicative results: Emissions reduction



Annual energy savings (in kWh) for the different EEMs (SFH, Osona, Spain)		
	Emissions avoided (kg CO_2)	Reduction (%)
EEM_1: Exterior wall insulation	1,837.6	21.3
EEM_2: Double-glazed windows	92.0	1.1
EEM_3: Roof insulation	1,267.5	14.7
EEM_4: Boiler upgrade - gas	3,968.1	46.0
EEM_5: Boiler upgrade - biomass	4,898.2	56.7
EEM_6: Heat pump	6,221.5	72.1
EEM_7: Energy efficient light bulbs	177.7	2.1

- *Heating system changes leads to superior performances*

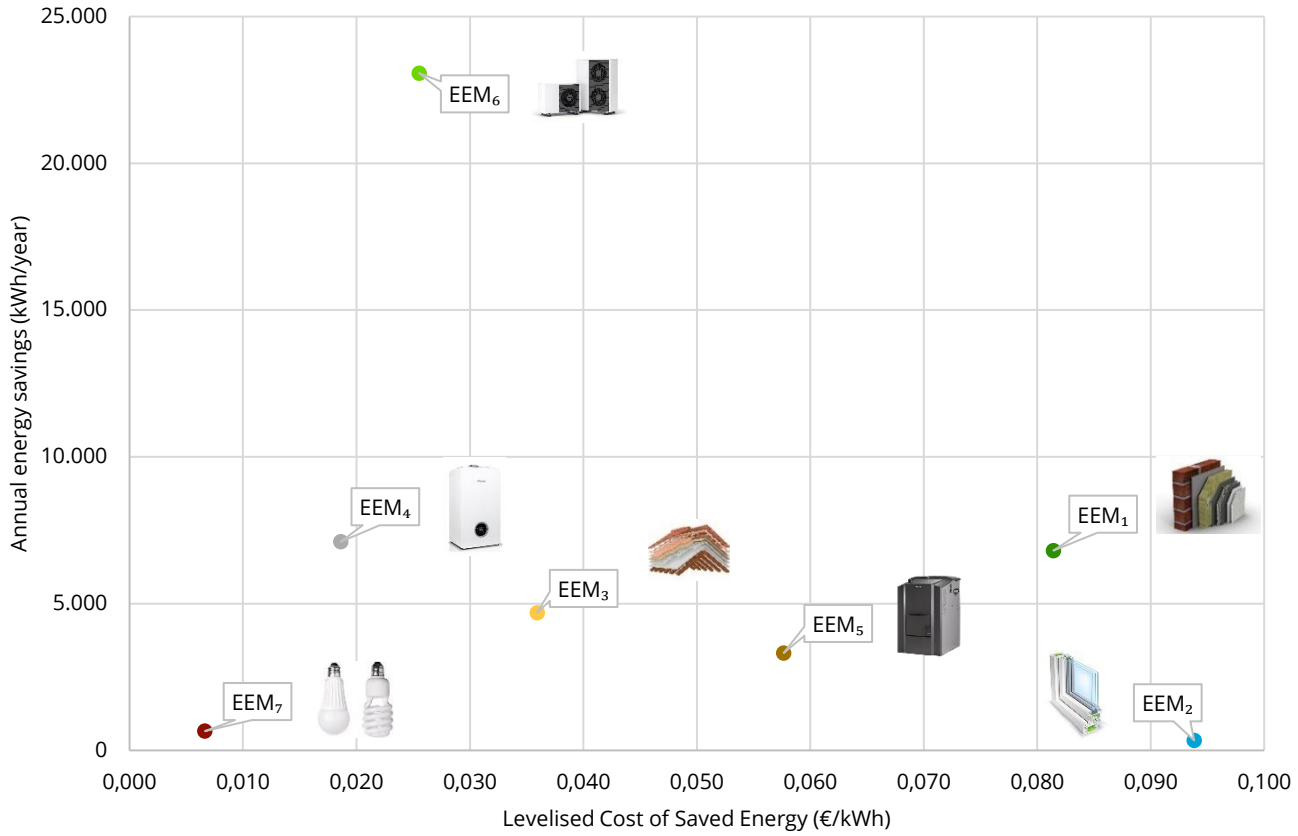
Indicative results: Technoeconomic assesement

	Investment Costs (€)	Lifetime (years)	Discount Rate (%)	NPV (€)	PP (years)	LCSE (€/kWh)
EEM_1	9,583	30	4.00%	6,705.8	13.3	0.081
EEM_2	553	30	4.00%	262.7	16.1	0.094
EEM_3	2,917	30	4.00%	8,318.8	5.0	0.036
EEM_4	1,800	20	4.00%	24,997.8	0.9	0.019
EEM_5	2,600	20	4.00%	42,646.2	0.8	0.058
EEM_6	8,000	20	4.00%	28,600.1	3.2	0.026
EEM_7	65	23	4.00%	2,008.1	0.5	0.007

- *EEM_7 and EEM_4 have the **best levelised cost of saved energy** and the **shorter payback periods**.*

- *Heating system changes have higher **profitability (NPV)***

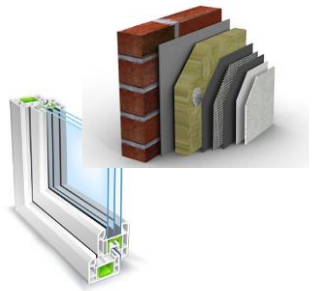
Indicative results: Cost effectiveness



- *Comparison of the annual energy savings with **LCSE**.*
- *Impact of EEMs in terms of **energy saving** coupled with **initial cost of the interventions**.*

***Significant** energy savings + **Low** LCSE*

***Mediocre** energy savings + **High** LCSE*



Indicative results: Financial support

	Subsidy level	NPV (€)	PP (years)	LCSE (€/kWh)
EEM_1	25%	9,101.4	9.3	0.061
EEM_2		400.9	11.1	0.070
EEM_3		9,047.9	3.7	0.027
EEM_4		25,447.8	0.7	0.014
EEM_5		43,114.2	0.6	0.043
EEM_6		30,600.1	2.4	0.019
EEM_7		2,024.4	0.4	0.005

- *Profitability*

36%

71%

	Subsidy level	NPV (€)	PP (years)	LCSE (€/kWh)
EEM_1	50%	11,497.1	5.8	0.041
EEM_2		539.2	6.8	0.047
EEM_3		9,777.0	2.4	0.018
EEM_4		25,597.9	0.5	0.009
EEM_5		43,764.2	0.4	0.029
EEM_6		32,600.1	1.6	0.013
EEM_7		2,040.6	0.2	0.003

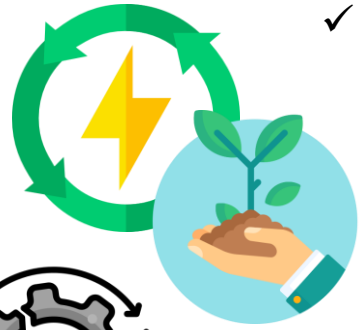
- *Payback Periods*

4 yrs

7,5 yrs

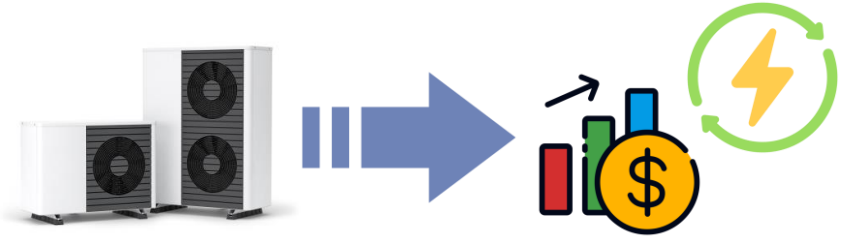
Concluding remarks: Cross-country insights

- Importance of **baseline conditions** in determining the **effectiveness** of **interventions** aimed at reducing energy consumption and environmental footprint.
- Prioritisation of areas with **greater inefficiencies**.
- Need for **financial support** to achieve higher household profitability.



- ✓ Energy efficiency measures focusing on **envelope upgrades** are strongly influenced:
  - **Building** characteristics
  - Renovation **costs**
  - **Baseline** heating technology

- ✓ Installation of heat pumps **consistently** leads to **significant energy savings**, but **local energy prices** strongly impact its **economic** performance.



Akis Apostoliotis
Graduate of National Technical University of Athens, Research Associ...

SCAN ME

Dimitris Papantonis
Research Associate at TEESlab, PhD Candidate at University of Piraeus

SCAN ME

Thank you.

For more info, follow our hashtag, visit our website or contact us:

#RENOVERTY @TEES_Lab

RENOVERTY

apostoliotis@unipi.gr
papantonis@unipi.gr
aflamos@unipi.gr

This work is based on research conducted within the co-funded by the European Union LIFE Programme project RENOVERTY: ID101077272. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.