10th International Conference on Smart Energy Systems
10-11 September 2024
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ADVANCING INTEGRATED AND SMART RENOVATION PACKAGES FOR EFFICIENT, SUSTAINABLE, AND INCLUSIVE ENERGY USE: A MODELLING ANALYSIS OF REAL-LIFE RESIDENTIAL PILOTS ACROSS THE EUROPEAN UNION

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Introduction & Problem statement (1/3)

Buildings are accounting for nearly **40%** of final **energy consumption** in the EU.

50 million consumers struggle to keep their homes **adequately** warm.

Annual renovation rate of the building stock varying from **0.4** to **1.2%**.

More than **220 million building units**, representing **85%** of the EU's building stock, were built **before 2001**.

85-95% of the buildings that exist today will still be standing in 2050.

The building sector has significant room for decarbonisation.

Need for increased energy efficiency renovation efforts

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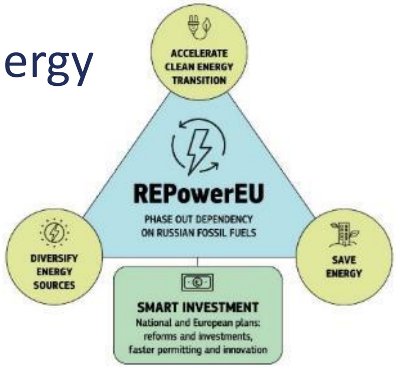
Introduction & Problem statement (2/3)

Towards the uptake of energy efficiency in the building sector



- **Renovation Wave,** as part of the **EU Green Deal,** aims to **double** the annual energy **renovation rate** by 2030.
  - Aim to renovate **35 million inefficient buildings** by **2030**.
- **Fit For 55** sets a target of **reducing emissions** by at least 55% by **2030.**
- **REPowerEU** changes the future of **fossil fuel** use in buildings radically aiming to enhance efforts on **saving energy**, **diversifying energy supplies** and **producing clean energy.**

Introduction & Problem statement (3/3)

EU lags behind the ambitious decarbonisation goals set by 2050, due to various barriers:

- Financial Constraints, Split incentives
- Fragmented decision-making processes
- Uncertainty of long-term benefits of renovation investments

Need to design, demonstrate, validate, and replicate integrated renovation packages for the efficient, sustainable and inclusive energy use. !

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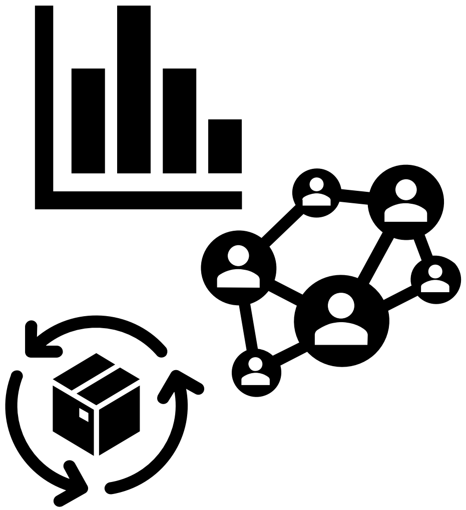
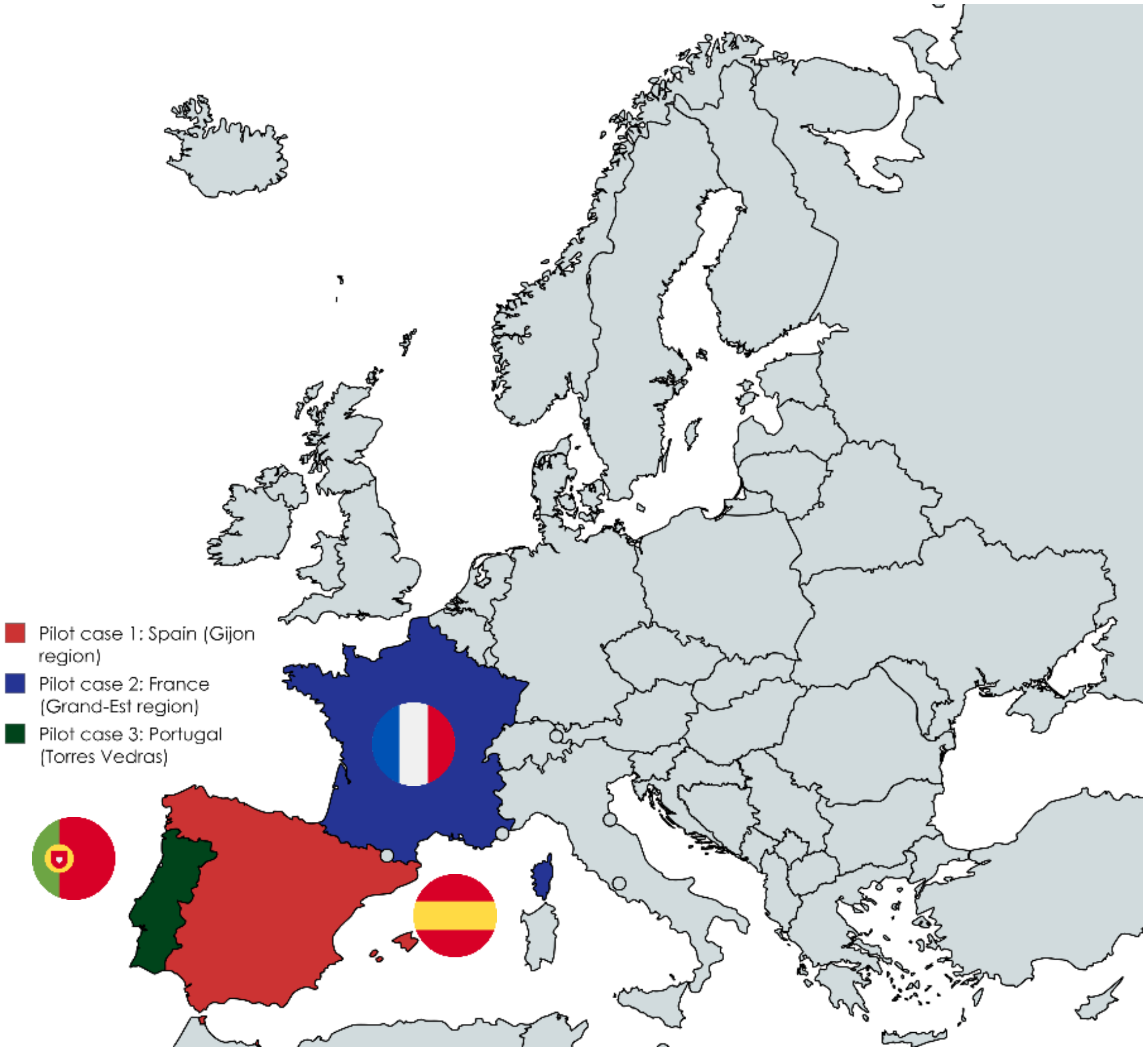
Research Objectives

- ✓ Provide robust **data-driven insights** and **quantifications** on the impacts of different **renovation packages**.
- ✓ Identify **solutions** adaptable to **diverse contexts** and expedite their **replication** across the **EU**.
- ✓ **Enable** relevant stakeholders to assess the **economic viability, energy savings potential** and **environmental impact** of different renovation packages.
- ✓ Outcomes that facilitate **well-informed policy and decision-making.**
- ✓ Overcome **barriers** to the acceleration of the **Renovation Wave** and the achievement of **EU decarbonisation goals**.



Pilot Cases



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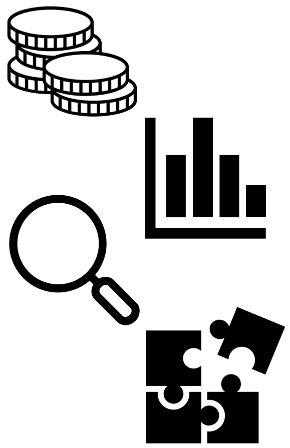
- ✓ **3 neighbouring countries are selected (France, Portugal, Spain)**
- ✓ **Meaningful to compare**

How are the Research Objectives Met?

TL DREEM
Dynamic High-Resolution Demand-Side Management Model

Integrated renovation packages

- ✓ **Analyse** the **cost-effectiveness** of **different portfolios** of **measures** and **financing schemes** per **building typology** 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.
- ✓ **Inclusion** of measures that **improve demand-side management** and optimal control of **heating, ventilation, and air-conditioning systems**.



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The Model

TL DREEM
Dynamic High-Resolution Demand-Side Management Model

Building sector

Energy demand *simulation model*

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

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

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

DigiBUILD
ENSMOV PLUS
OBSERVE
NATIONAL BUILDING STOCK OBSERVATORIES
ENCLUDE
Energy Citizens for Inclusive Decarbonization
LOCATEE
IAM COMPACT
inherit
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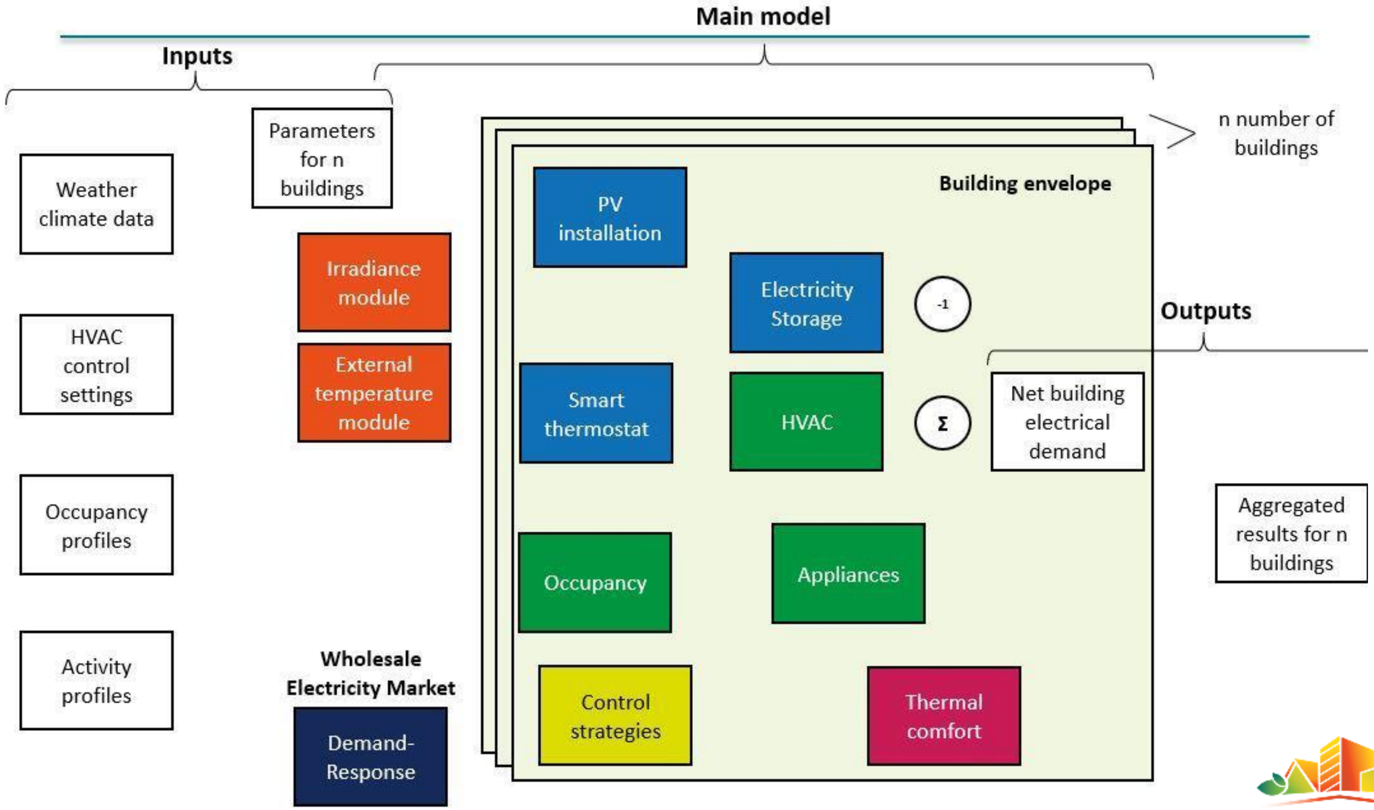
MODEL CHARACTERISTICS (1/2)

Main **principles** of **component-** & **modular-**based system modelling approach.

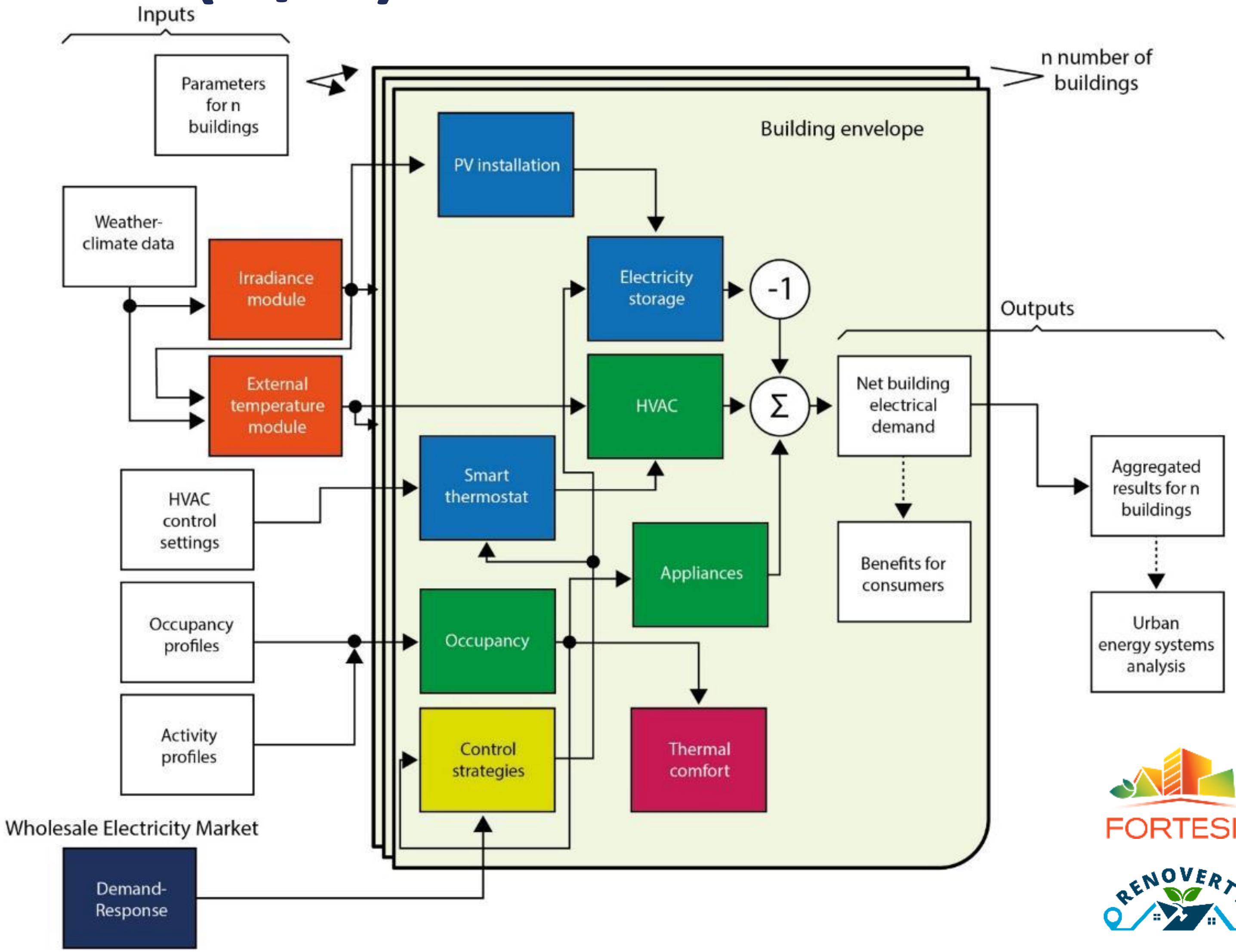
- **Interdependence** of decisions **within** modules.
- **Independence** of decisions **between** modules.
- **Hierarchical dependence** of modules on components embodying **standards & design rules**.



Modular *structure*

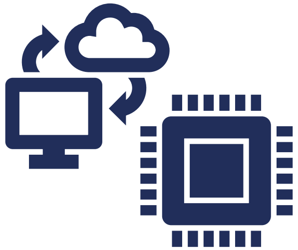
MODEL CHARACTERISTICS (2/2)

- **Incremental** modeling: **sub-models** in multiple levels.
- **Control** capabilities: **managing** the **complexity** of large systems.
- **Realistic representations** of dynamic systems.
- Fast development & simulations: **computational efficiency.**



How is the model employed in this application?

(e.g., necessary inputs, incorporation to the model and interaction between them)



Prior Situation – Baseline Scenario (1/4)

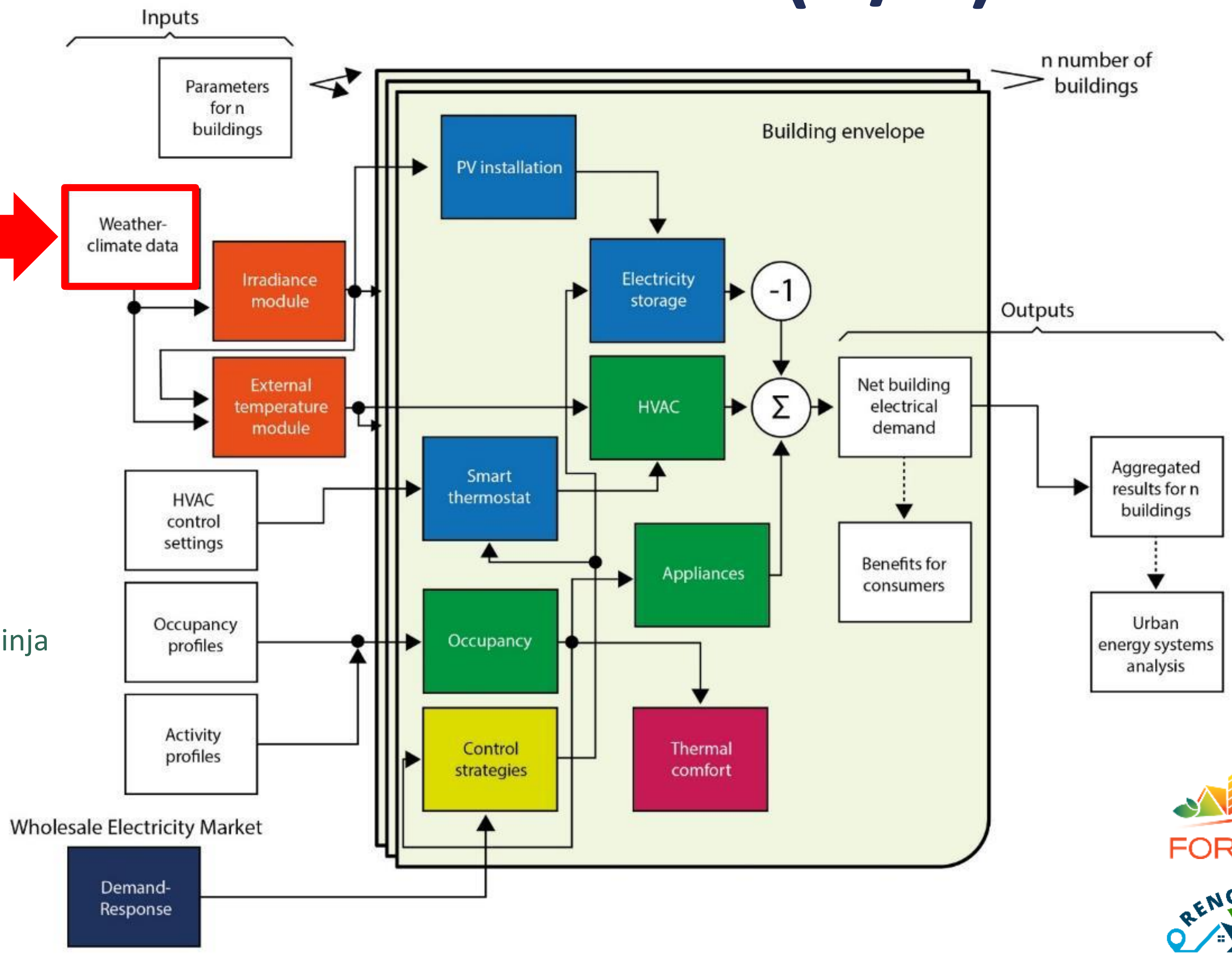
Weather-Climate data

Climate.OneBuilding.Org

WMO

Renewables.ninja

Typical Meteorological Years (**TMY**) for **several regions** in the **pilot** countries.



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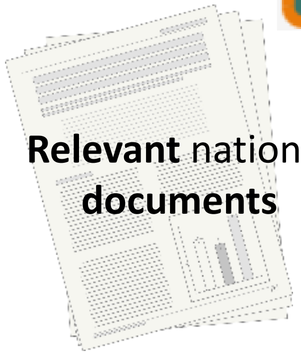
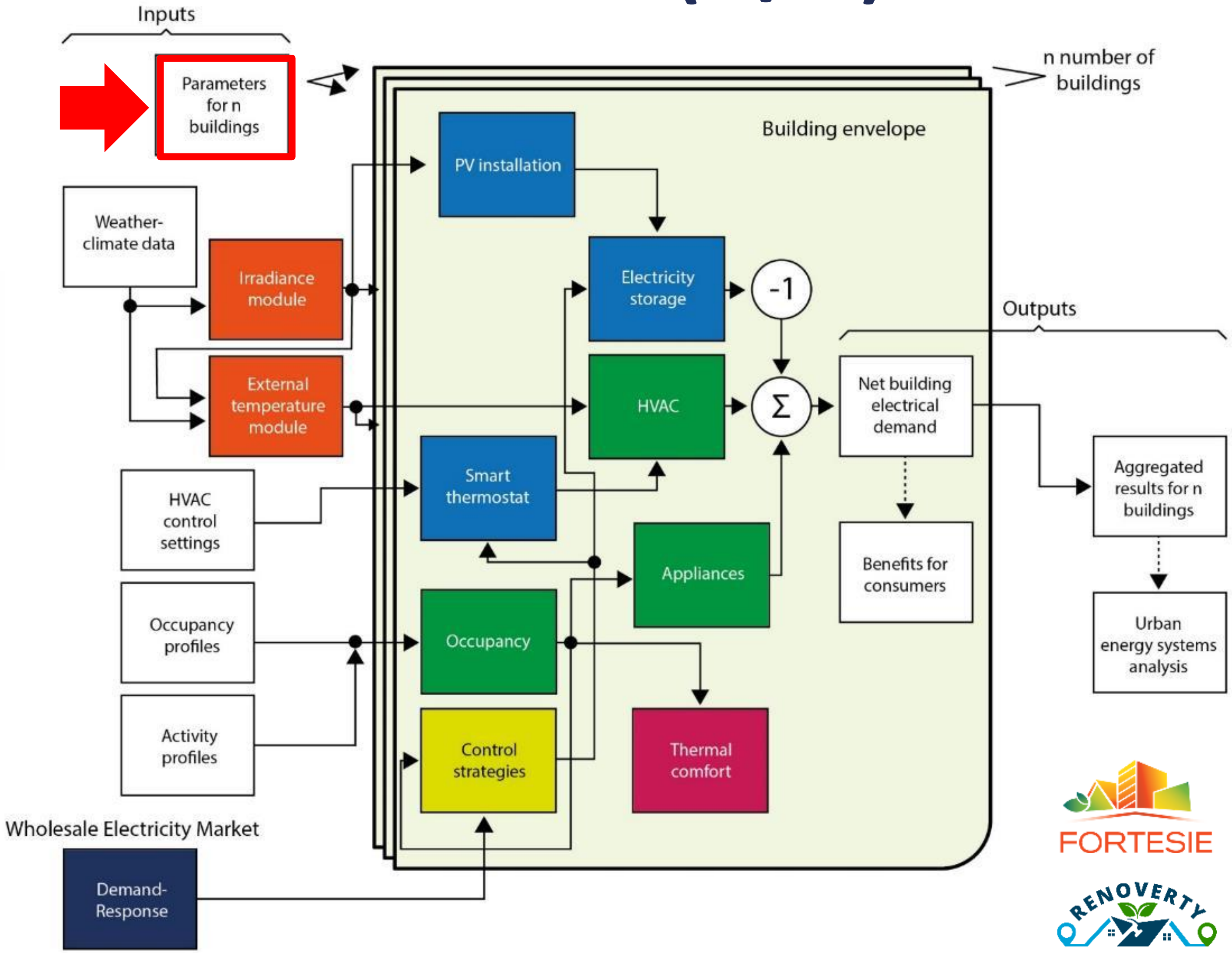
PRIOR SITUATION – BASELINE SCENARIO (2/4)

Building parameters



Relevant national **documents**



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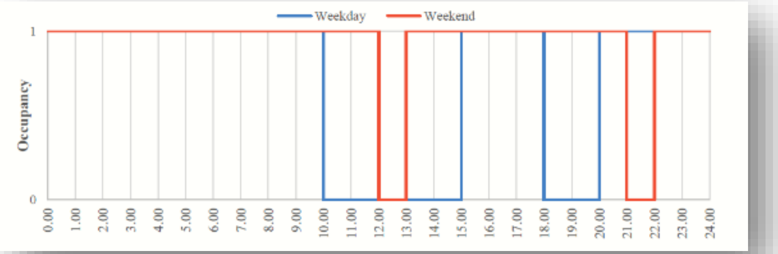
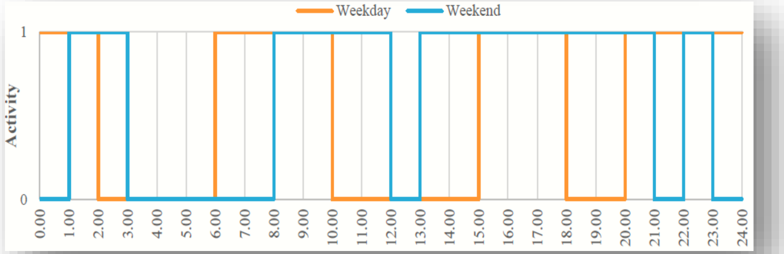
Prior Situation – Baseline Scenario (3/4)

Occupancy & activity profiles

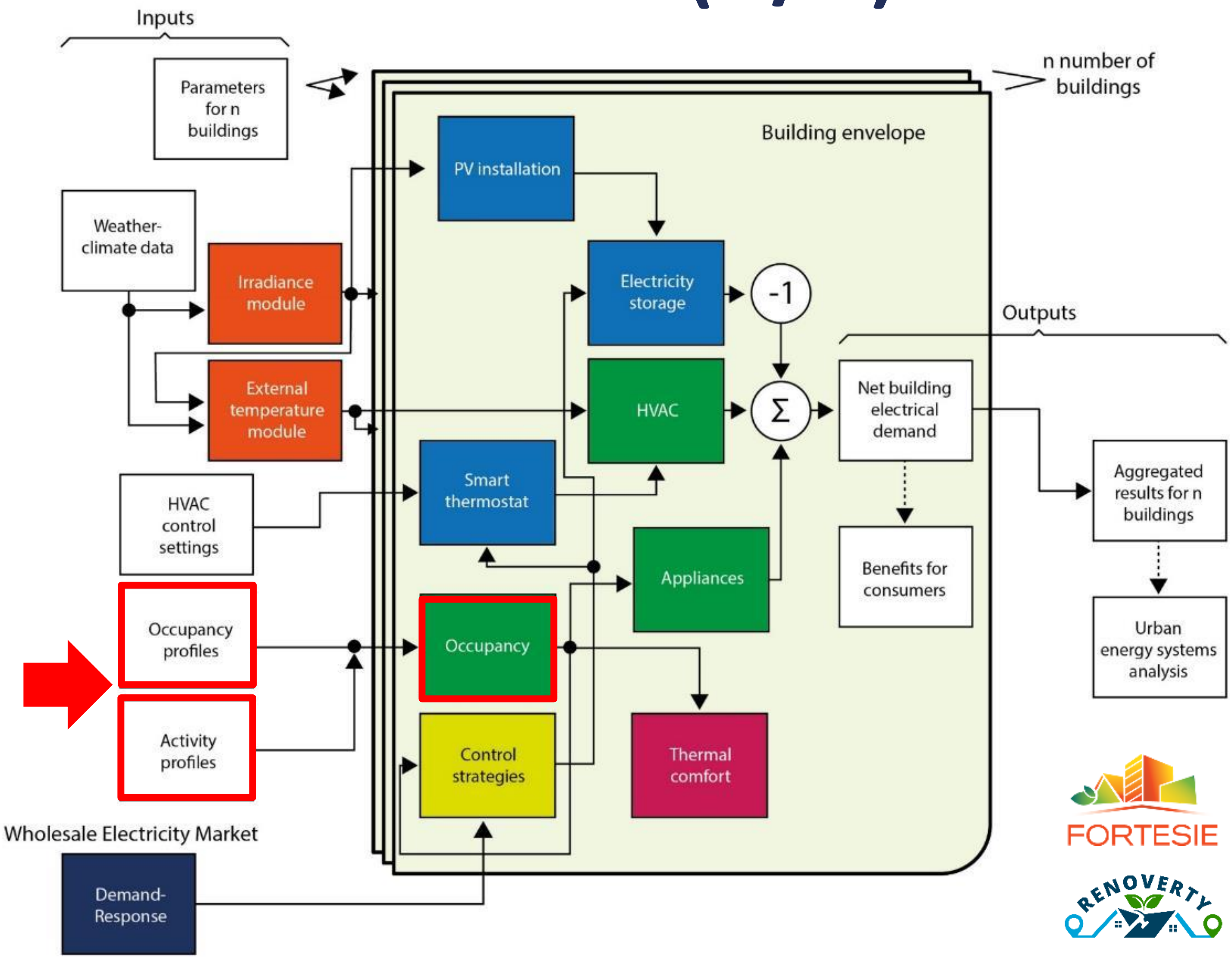
Building composition, occupancy & activity patterns



1= "at home", 0= "not at home"



1= "active", 0= "not active"



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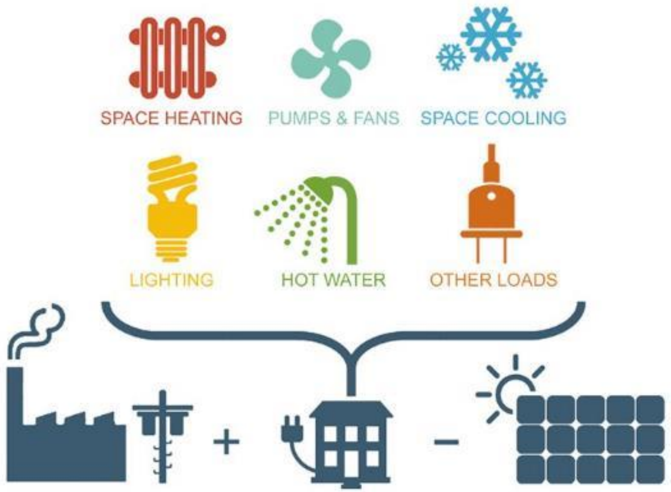
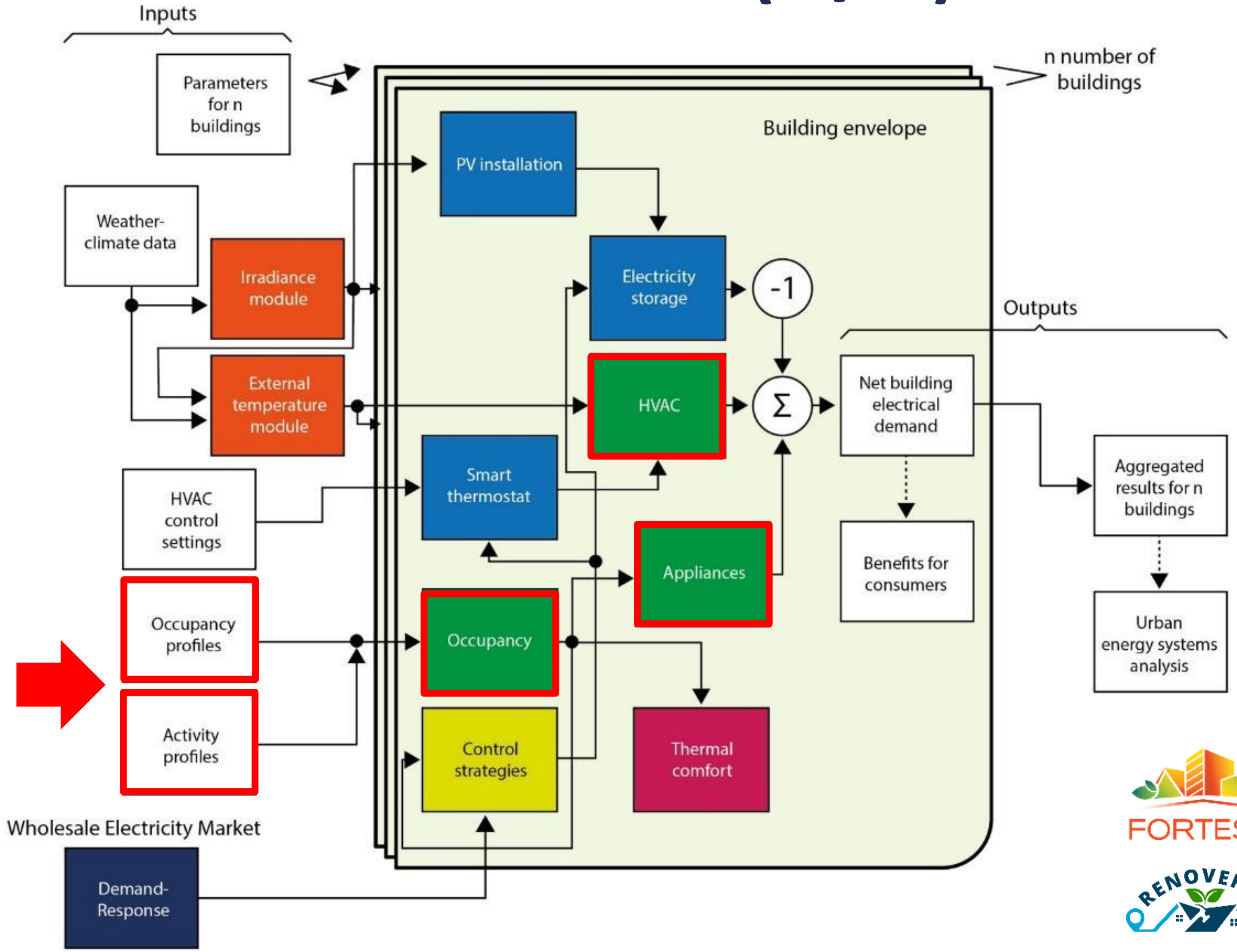
Prior Situation – Baseline Scenario (4/4)

Occupancy & Activity profiles

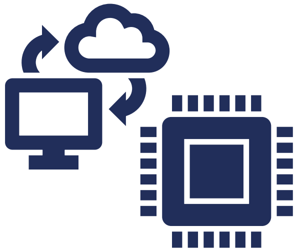
HVAC & Appliance ownership/use

Survey on energy consumption in households (SECH) data





What about the parameterisation process?



Prior Situation: Model Parameterisation

→ **Tailor-made** **approach to capture pilot specificities**

Data acquisition template for the experts working/ following each pilot case.

Pilot **weather/ climate** data

Building characteristics

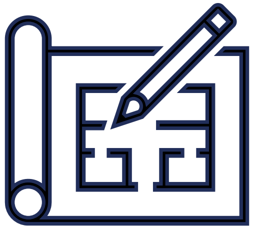
Occupancy/activity profiles

HVAC and **appliance** ownership/ use

Weather/ Climate characteristics	
Country:	Portugal
Region :	Torres Vedras
Building characteristics	
Type of building/ usage:	Single Family House
Year of Construction or Renovation:	1955
Building size:	1 Basement Level
Total Floor area of the building	30
Total area of external walls of the buildings :	51
Total area of Wall1:	7
Total area of Wall2:	14
Total Roof area of the building:	2 si
Windows system:	
Total windows area:	
Total area of Window1:	
Total area of Window2:	
Total area of Window3:	
Total area of Window4:	
Prior Situation: (	
Uwall:	
Ufloor:	
Uroof:	
Uwindow:	

Prior Situation: Existing Building systems	
Heating system:	non existent
Nominal capacity:	non existent
COP (if available):	non existent
Cooling system:	non existent
Nominal capacity:	non existent
EER (if available):	non existent
Lighting equipment:	4 simple ceiling lamps and 3 table lamps
Lighting equipment capacity:	traditional 50W lamps
Future "to-be" Situation: Convetional and Smart Energy Efficiency Measures to be modelled (please write down the preferred	
Heating system change/upgrade	Heat Pump to provide hotwater and Hvac to heat the air
Cooling system change/upgrade	Hvac
Building envelope upgrades	Thermal Insulation with na ETICs, Insulation in roof area, replacing windows for double glazed with thermal break
Upgrade of lighting system	Replacing all the bulbs with LED lightning
Smart systems	Solar panel instalation
Thermal comfort according to standards	Yes
Other parameters	
Occupancy:	2 people
Occupants' indicative working schedule:	Unemployed
Actual energy consumption (kWh/m^2 or kWh)	1300kWh

How are future situation scenarios formulated and evaluated?



FUTURE SITUATION SCENARIOS

Evaluate the **performance** & **replicability** potential of **different energy efficiency measures**

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

Technoeconomic assessment

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

Future situation scenarios formulated according to each pilot's needs!

Future "to-be" Situation: Convetional and Smart Energy Efficiency Measures to be modelled (please write down the preferred	
Heating system change/upgrade	Heat Pump to provide hotwater and Hvac to heat the air
Cooling system change/upgrade	Hvac
Building envelope upgrades	Thermal Insulation with na ETICs, Insulation in roof area, replacing windows for double glazed with thermal break
Upgrade of lighting system	Replacing all the bulbs with LED lightning
Smart systems	Solar panel instalation
Thermal comfort according to standards	Yes

Future "to-be" Situation: Convetional and Smart Energy Efficiency Measures to be modelled (please write down the preferred ones)	
Heating system change/upgrade	replacement of oil boilers with heat pumps
Cooling system change/upgrade	no
Building envelope upgrades	thermal insulation, double-glazed windows, ventilation
Upgrade of lighting system	replacement of traditional bulbs with LEDs
Smart systems	smart meters
Thermal comfort according to standards	yes

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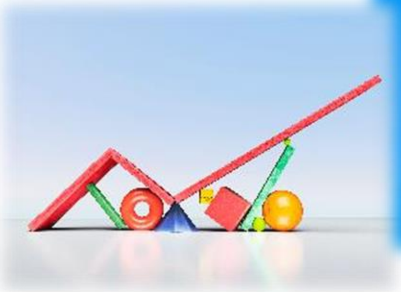


and finally….
What about the simulation process and results?

Pilot case 3- Portugal: Specifications

Country: **Portugal**
Region: Torres Vedras

Type of building/usage: Single Family House

Year of Construction: 1955

Building size: 1 Basement Level

Total floor area: 30m^2

Prior Situation: Construction features (U-values)(W/m²/K)	
Uwall:	1.80
Ufloor:	1.00
Uroof:	0.99
Uwindow:	4.33

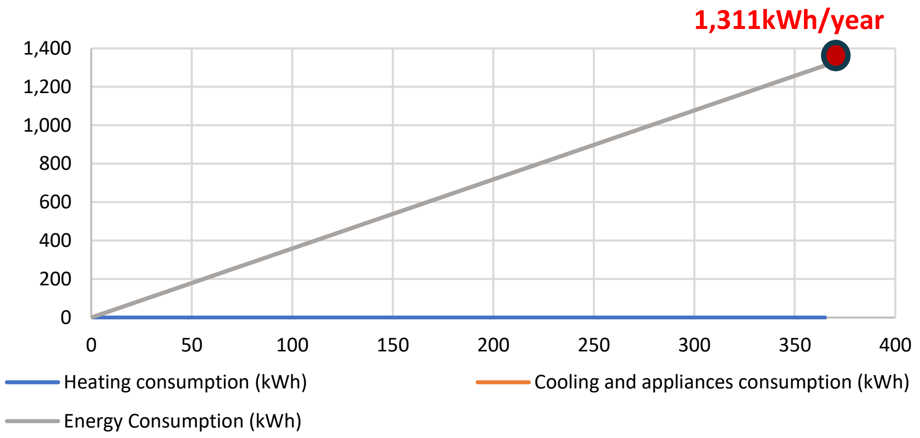
Prior Situation: Existing Building systems	
Heating system:	non existent
Nominal capacity:	non existent
COP (if available):	non existent
Cooling system:	non existent
Nominal capacity:	non existent
EER (if available):	non existent
Lighting equipment:	4 simple ceiling lamps and 3 table lamps
Lighting equipment capacity:	traditional 50W lamps

Future situation scenarios: Measures to be modelled	
Heating system change/upgrade	Heat Pump to provide hotwater and Hvac to heat the air
Cooling system change/upgrade	Hvac
Building envelope upgrades	Thermal Insulation with ETICs, Insulation in roof area, replacing windows for double glazed with thermal break
Upgrade of lighting system	Replacing all the bulbs with LED lightning
Smart systems	Solar panel installation
Thermal comfort according to standards	Yes

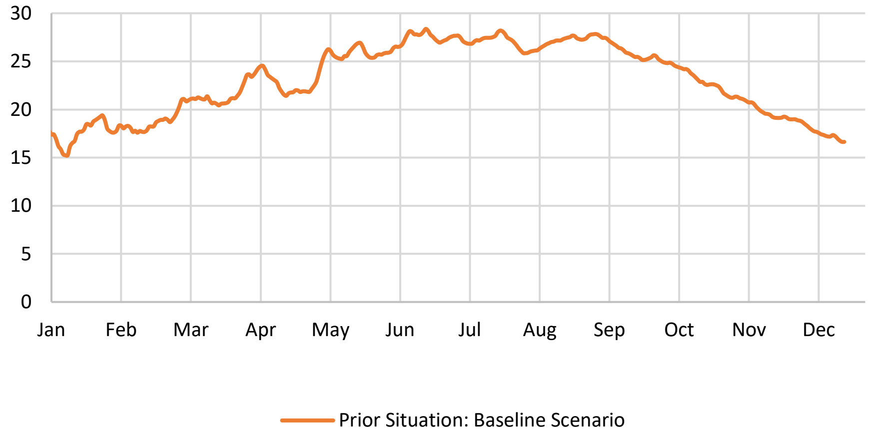
Simulation Results: Baseline Scenario

Prior Situation:
Baseline scenario

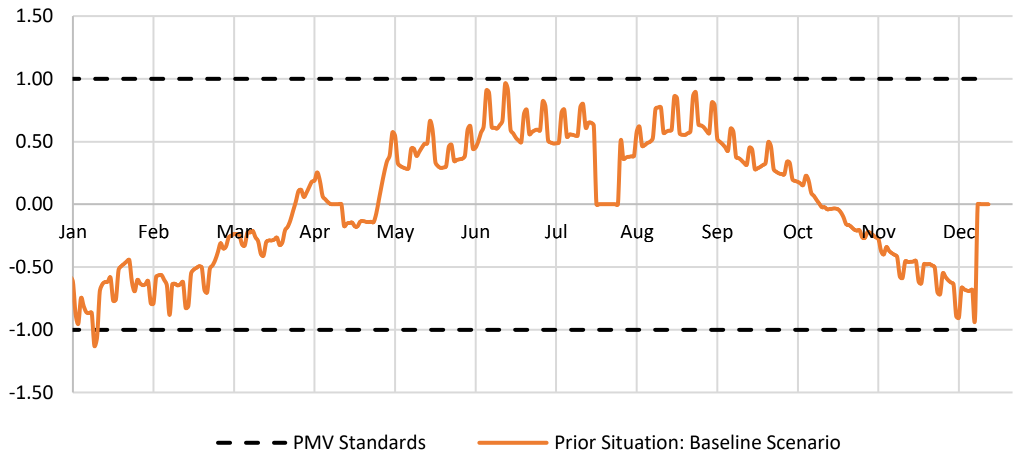
Prior Situation: Baseline Scenario



"Prior Situation": Indoor air temperature (°C)



Thermal Comfort Indicator: PMV* (%)



*Acceptable ranges of the Predicted Mean Vote (PMV): -1<PMV<1

Thermal comfort indicator close to the marginal prices!

Future Situation Scenarios

Pilot Case 3: Portugal

Scenario	Measures
1	Oil boiler & A/C
2	Oil boiler, A/C, Renovation (thermal insulation & windows upgrade)
3	Oil boiler, A/C, Renovation (thermal insulation & windows upgrade), LED lighting
4	Heat pump
5	Heat Pump, Renovation (thermal insulation & windows upgrade), LED lighting
6	Heat Pump, Renovation (thermal insulation & windows upgrade), LED lighting, PV installation

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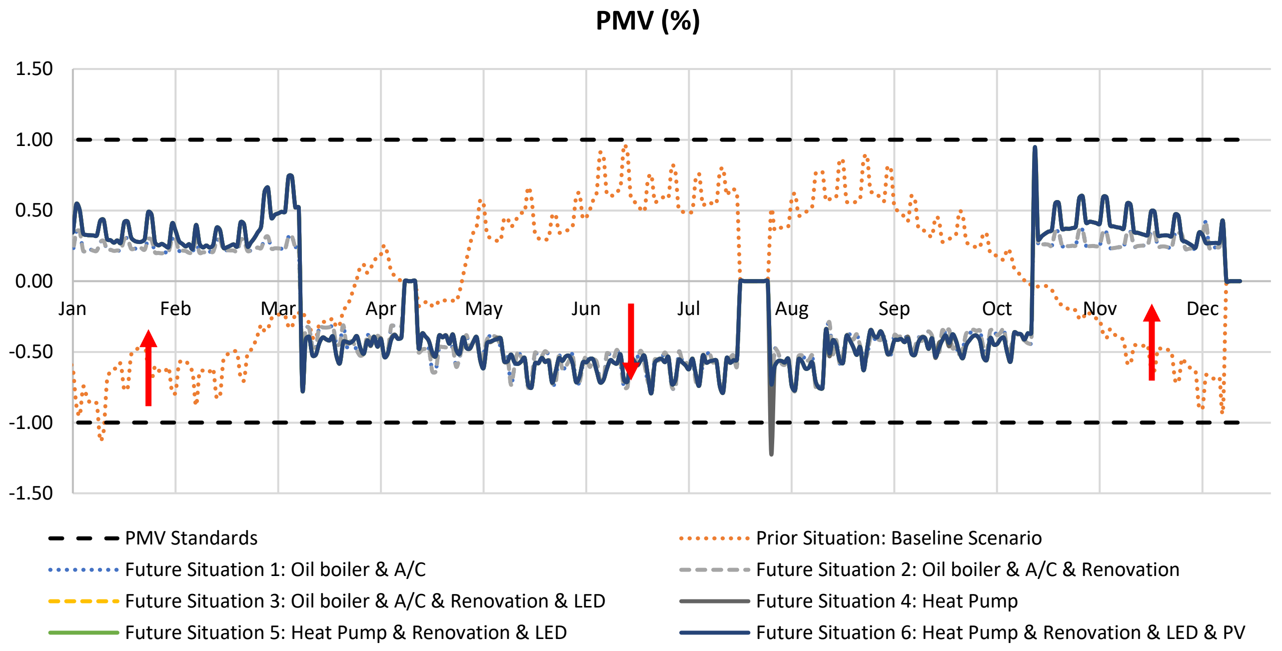
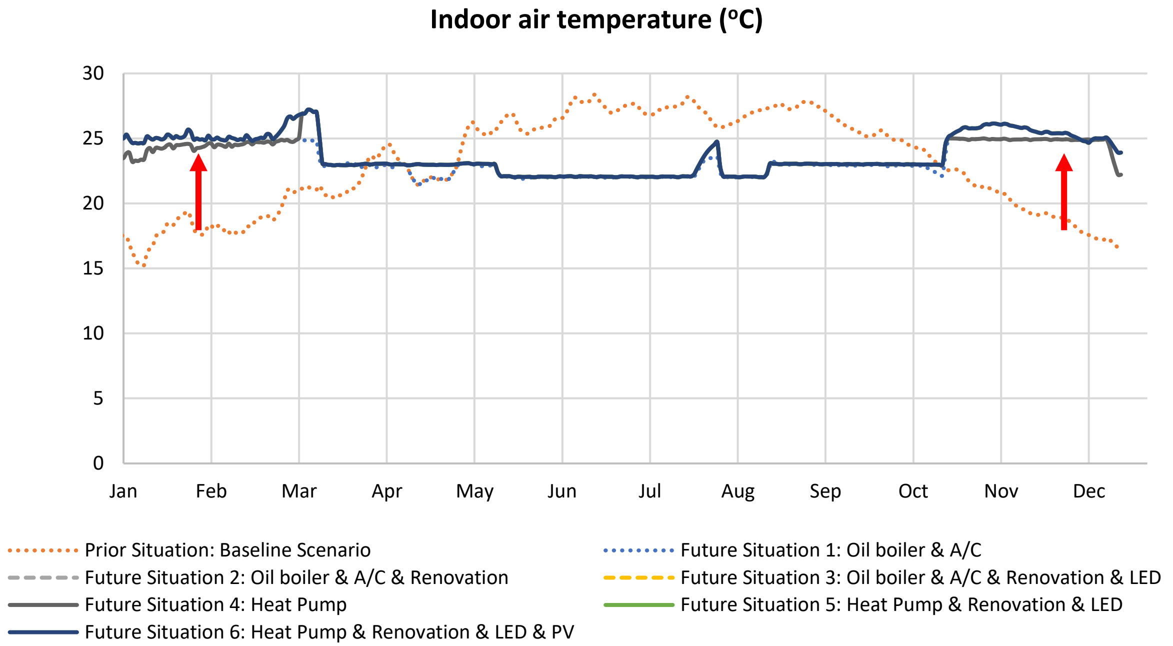
Simulation Results: Future Scenarios (1/6)

Cooler internal conditions in the summer!

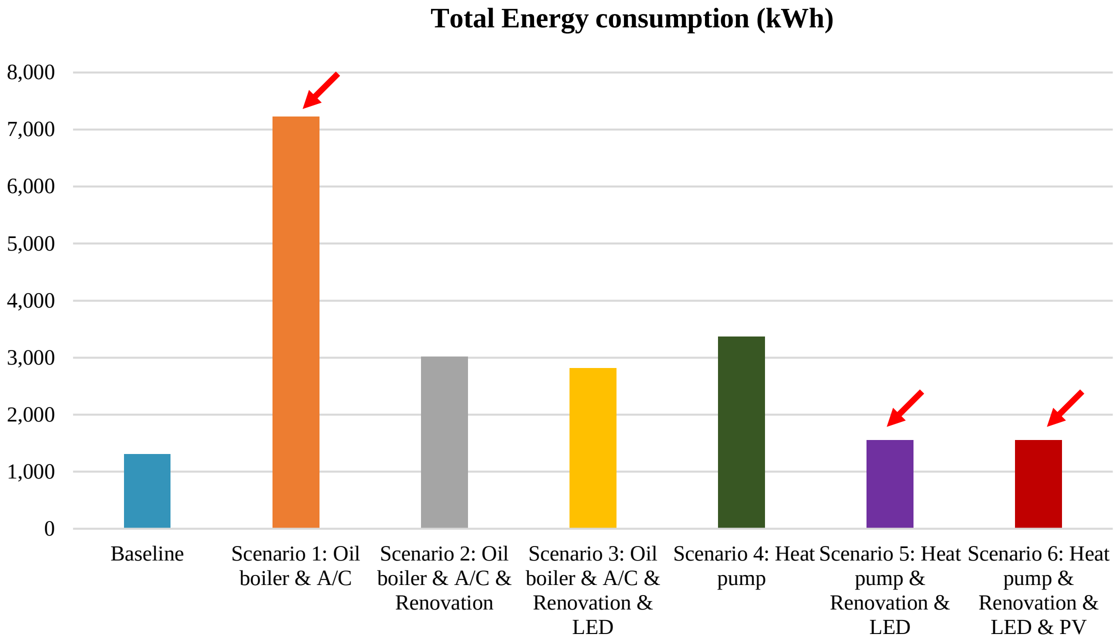


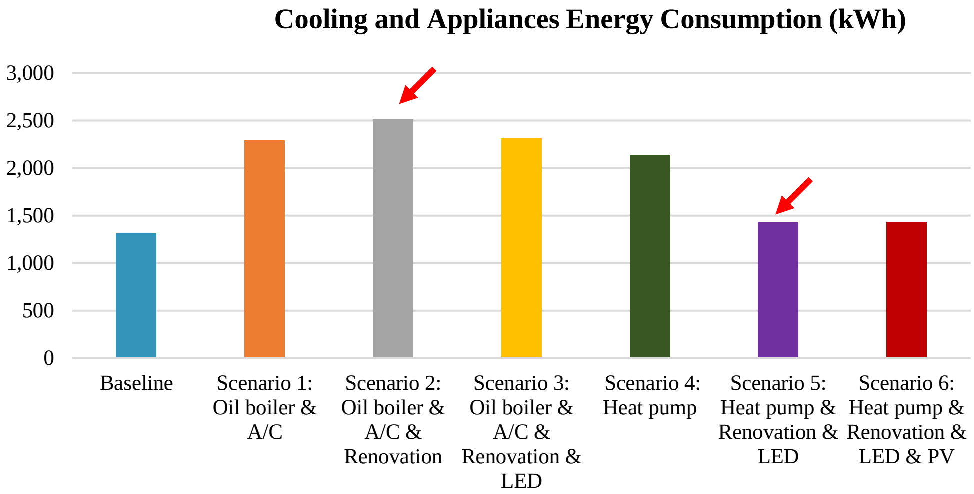


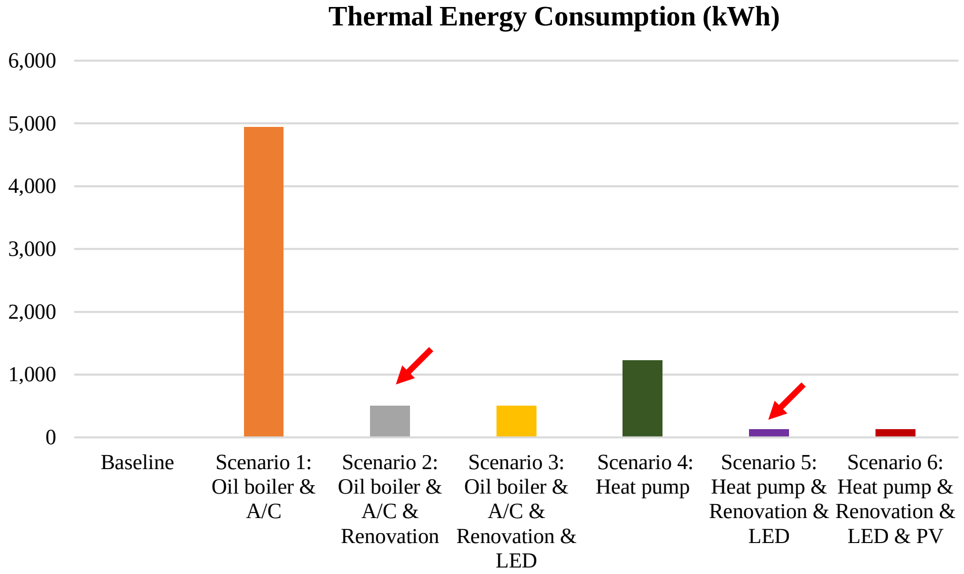
Warmer internal conditions in the winter!

Simulation Results: Future Scenarios (2/6)

Final Energy, Cooling and appliances, and Thermal energy consumption





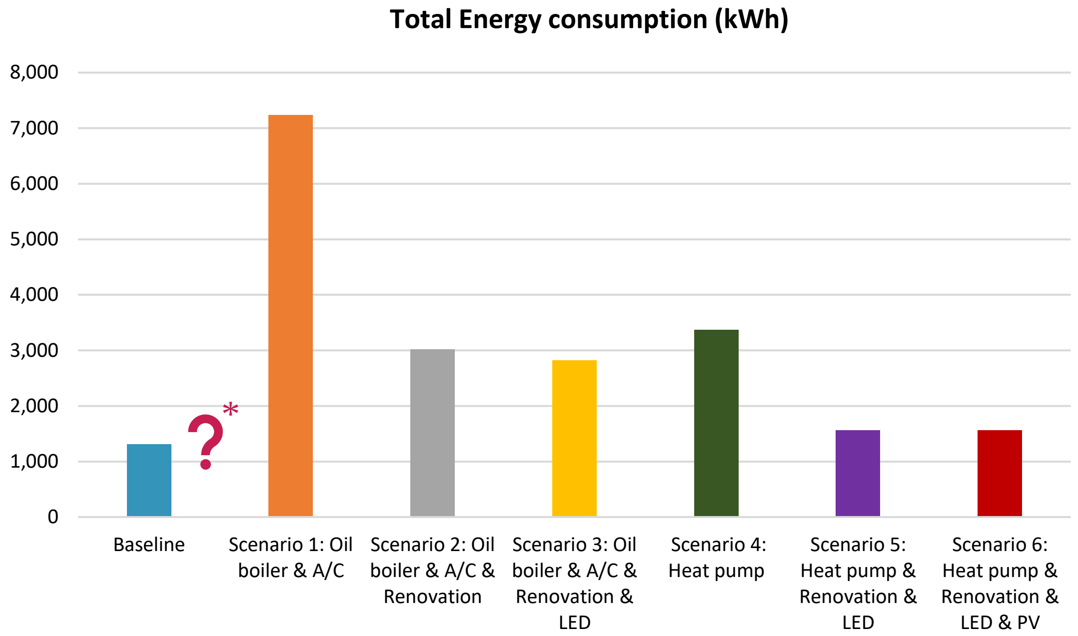


Simulation Results: Future Scenarios (3/6)

Total annual energy consumption and energy savings

	Total energy consumption (kWh)	Total energy savings (kWh)
Prior Situation: Baseline Scenario	1,311. 1	
Scenario 1: Oil boiler & A/C	7,231.4	
Scenario 2: Oil boiler & A/C & Renovation	3,017.5	4,213.8
Scenario 3: Oil boiler & A/C & Renovation & LED	2,816.8	4,414.5
Scenario 4: Heat Pump	3,369.7	3,861.7
Scenario 5: Heat Pump & Renovation & LED	1,559.2	5,672.1
Scenario 6: Heat Pump & Renovation & LED & PV	1,559.2	7,997.0

Energy savings are calculated compared to Scenario 1!



?* Increased energy consumption in future situation scenarios?

No heating system in the baseline scenario!

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Simulation Results: Future Scenarios (4/6)

Thermal, Cooling & Appliances, and overall annual energy consumption & energy savings

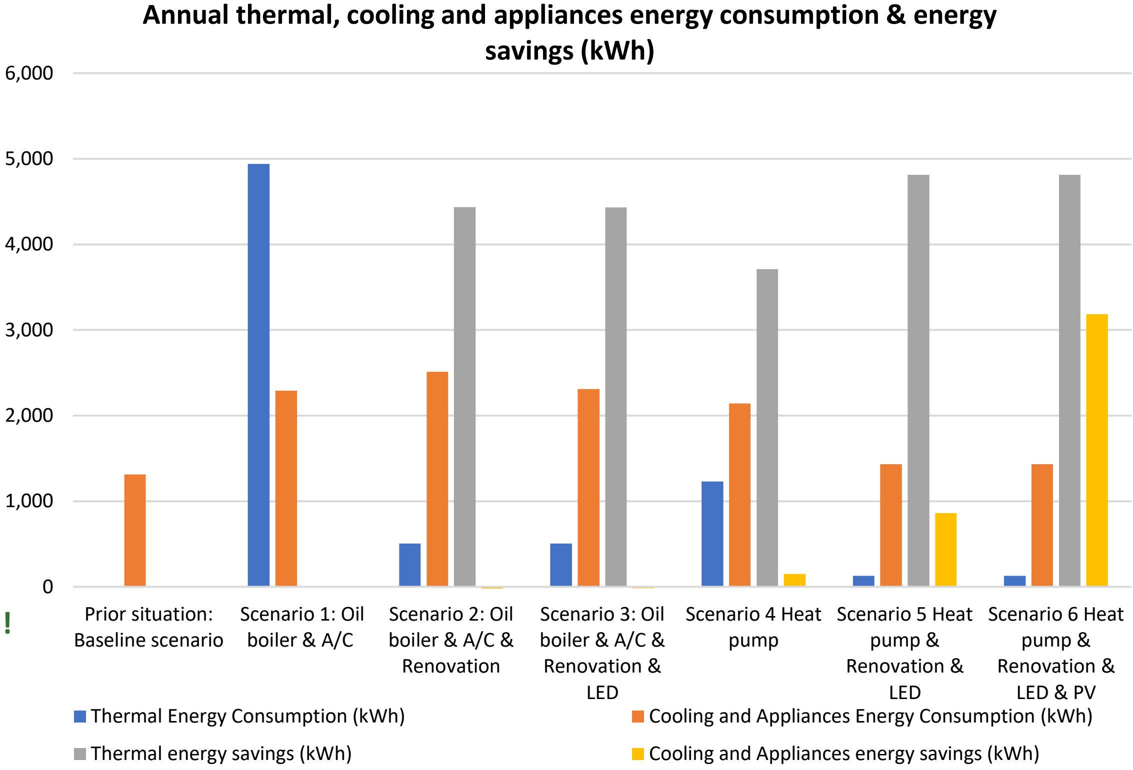
	Energy savings Thermal (kWh)	Energy savings cooling and appliances (kWh)
Scenario 2: Oil boiler & A/C & Renovation	4,433.6	-219.7
Scenario 3: Oil boiler & A/C & Renovation & LED	4,433.4	-18.9
Scenario 4: Heat Pump	3,710.9	150.8
Scenario 5: Heat Pump & Renovation & LED	4,812.2	859.9
Scenario 6: Heat Pump & Renovation & LED & PV	4,812.2	3184.7

Impact of LED lighting (~200 kWh annually)

Effects of building envelope upgrades!

Impact of the PV installation!

Energy savings are calculated compared to Scenario 1!



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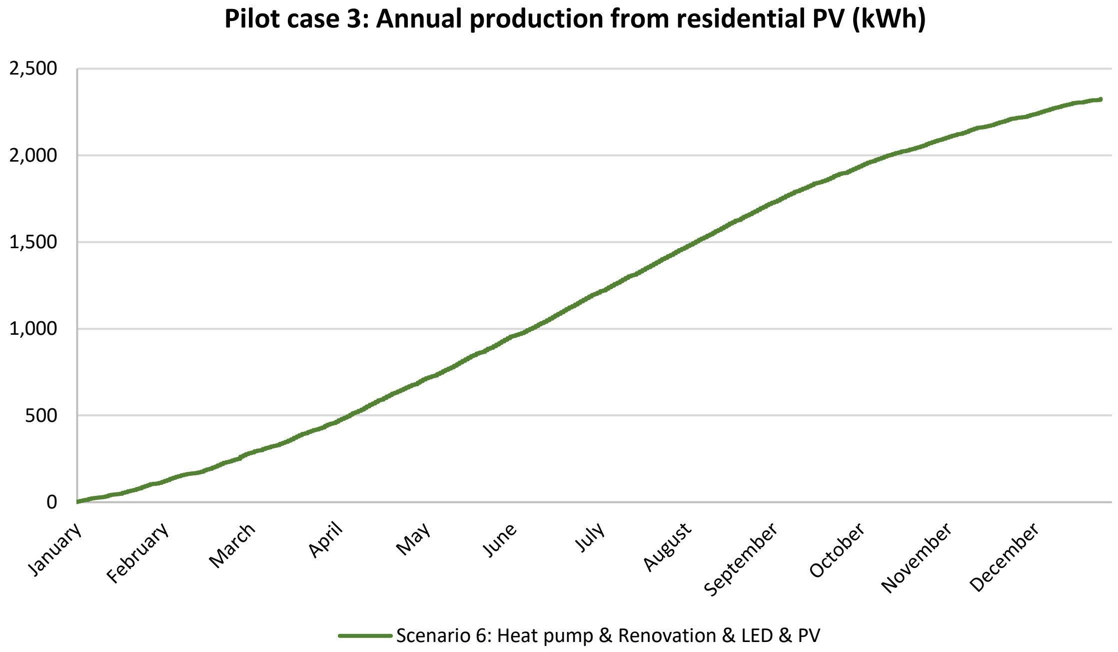
SIMULATION RESULTS: FUTURE SCENARIOS (5/6)

Scenario 6 → PV Installation

Small-scale residential PV (nominal power: 2kW, surface: 11m²)



Production of **2324.8 kWh** per year!

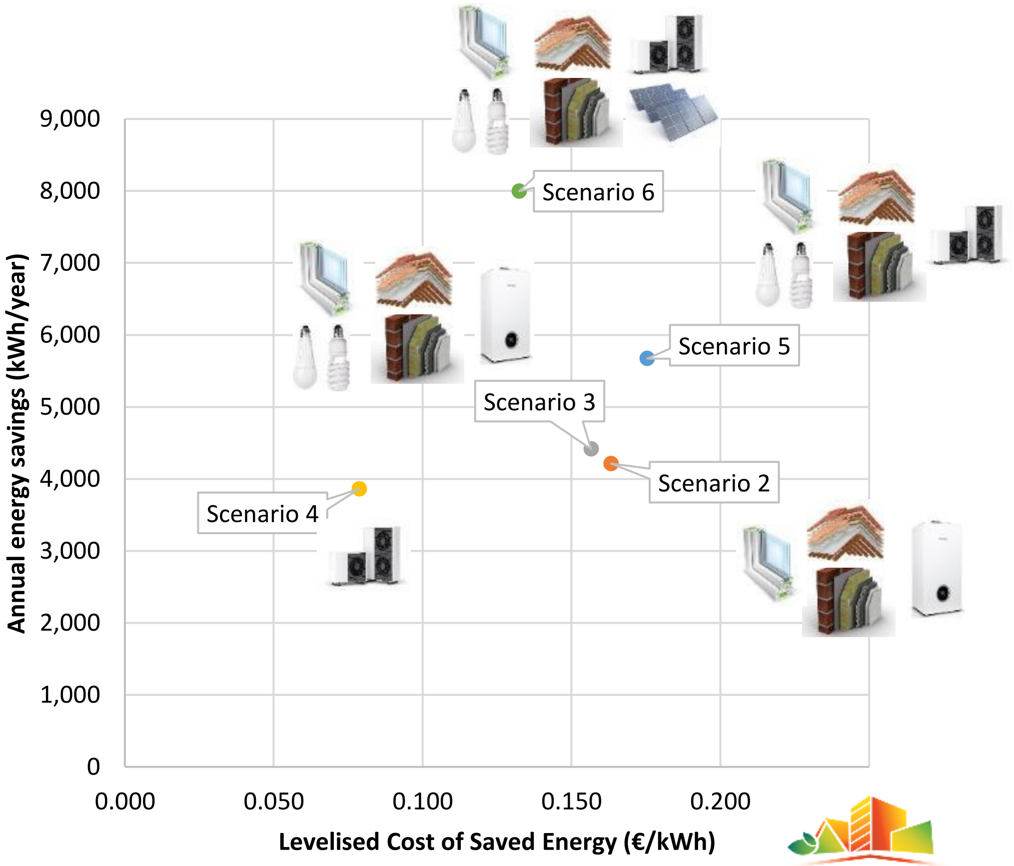
	Annual electricity consumption (kWh)	Coverage of electricity from the produced solar energy
Scenario 1: Oil boiler & A/C	2,291.0	**101.5%**
Scenario 2: Oil boiler & A/C & Renovation	2,510.7	**92.6%**
Scenario 3: Oil boiler & A/C & Renovation & LED	2,309.9	**100.6%**
Scenario 4: Heat Pump	3,369.6	**69.0%**
Scenario 5: Heat Pump & Renovation & LED	1,559.2	**149.1%**
Scenario 6: Heat Pump & Renovation & LED & PV	1,559.2	**149.1%**

SIMULATION RESULTS: FUTURE SCENARIOS (6/6)

	Total energy savings (kWh)	Net Present Value (NPV) (€)	Payback Period (PP) (years)	Levelised Cost of Saved Energy (LCSE) (€/kWh)
Prior Situation: Baseline Scenario	0	0		
Scenario 1: Oil boiler & A/C	0	0		
Scenario 2: Oil boiler & A/C & Renovation	4,213.8	-1267.02	31.4	0.163
Scenario 3: Oil boiler & A/C & Renovation & LED	4,414.5	-381.37	26.6	0.157
Scenario 4: Heat Pump	3,861.7	1931.18	15.0	0.079
Scenario 5: Heat Pump & Renovation & LED	5,672.1	-431.93	26.2	0.175
Scenario 6: Heat Pump & Renovation & LED & PV	7,997.0	9401.98	13.0	0.132

Scenario 6 offers the highest NPV for the household

Scenario 4 is the most cost-efficient in terms of LCSE.



SIMULATION RESULTS: CROSS-PILOT COMPARISON (1/5)

Pilot case 1

Country: **Spain**
Region: **Gijon region**

Type of building/usage: Multi Family House

Year of Construction: 1958

Building size: Ground floor + 2 floors

Total floor area: 80m^2 per apartment

Heating system: Electric heaters

Pilot case 2

Country: **France**
Region: **Grand Est region**

Type of building/usage: Single Family House

Year of Construction: 1950 to 1980

Building size: Basement level + 2 ground floors

Total floor area: 82m^2

Heating system: Oil boiler

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Simulation Results: Cross-Pilot Comparison (2/5)

Pilot case 1: (Gijon region - **Spain**)

Scenario	Measures Implemented
1	Renovation
2	Renovation & PV
3	Heat pump
4	Heat pump & Renovation
5	Heat pump & Renovation & LED & PV

Pilot case 2: (Grand-Est region - **France**)

Scenario	Measures Implemented
1	Heat pump
2	Renovation
3	Heat pump & Renovation
4	Heat pump & Renovation & LED
5	Heat pump & Renovation & LED & PV

! Let's remember Pilot case 3 scenarios

Scenario	Measures Implemented
1	Oil boiler & A/C
2	Oil boiler, A/C, Renovation (thermal insulation & windows upgrade)
3	Oil boiler, A/C, Renovation (thermal insulation & windows upgrade), LED lighting
4	Heat pump
5	Heat Pump, Renovation (thermal insulation & windows upgrade), LED lighting
6	Heat Pump, Renovation (thermal insulation & windows upgrade), LED lighting, PV installation

Common future scenarios **across** the three pilot cases:

- **Renovation** (e.g., building envelope upgrades)
- **Heat Pump**
- **Heat pump** & **Renovation** & **LED** & **PV**

Simulation Results: Cross-Pilot Comparison (3/5)

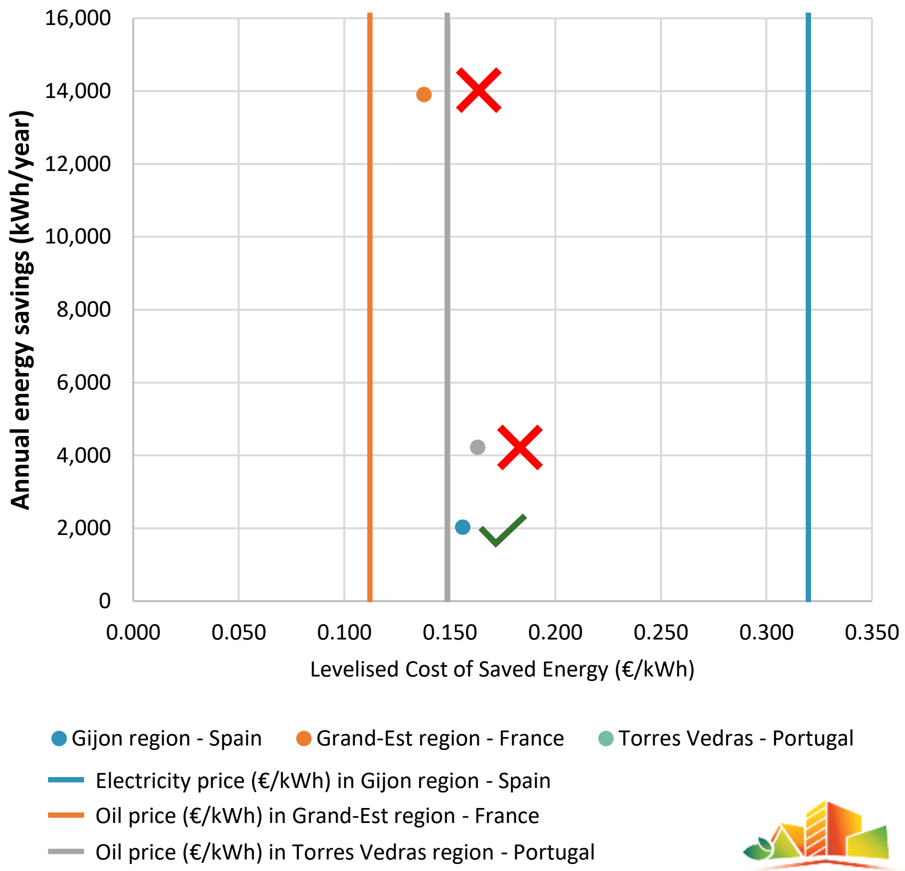
Common scenario 1: Renovation

Pilot case	Total energy savings (kWh)	Total energy savings (%)	LCSE (€/kWh)
1. Spain	2,022.93	21.2%	0.156
2. France	13,905.12	43.4%	0.138
3. Portugal	4,213.84	58.3%	0.163

The **LCSE** for each **future scenario** is compared with the **energy price** of the baseline scenario's energy carrier.

Spain ✓

France, Portugal ✗



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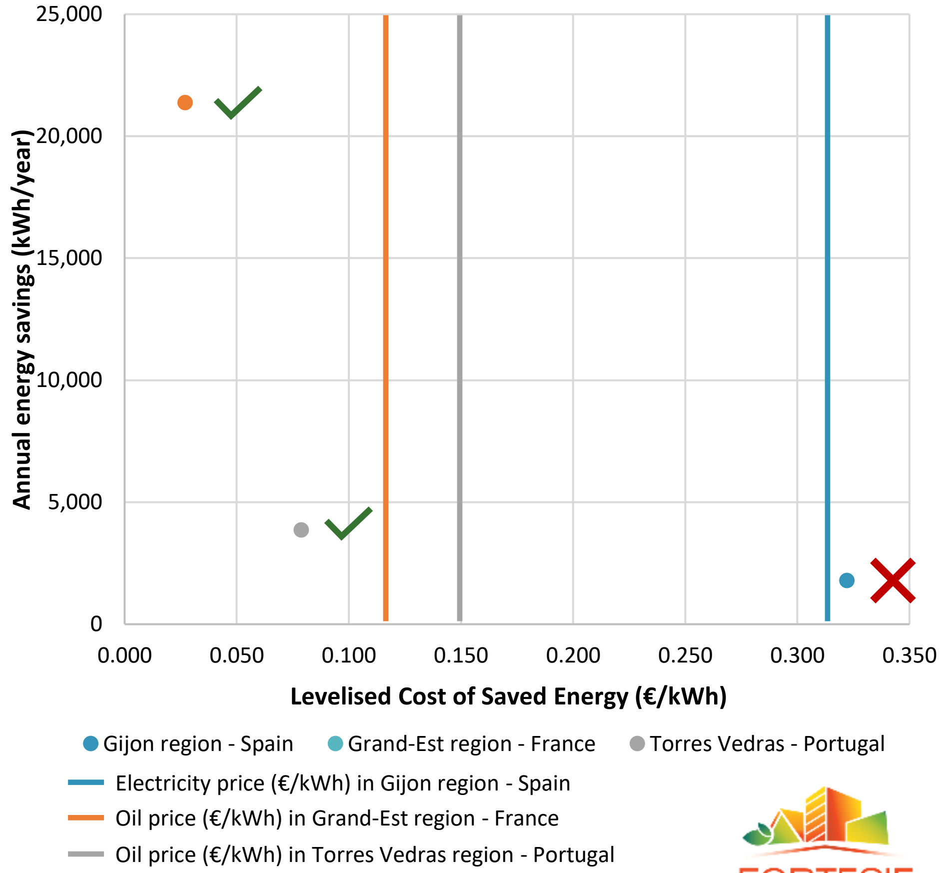
Simulation Results: Cross-Pilot Comparison (4/5)

Common scenario 2: Heat Pump

Pilot case	Total energy savings (kWh)	Total energy savings (%)	LCSE (€/kWh)
1. Spain	1,788.0	18.7%	0.322
2. France	21,372.7	66.7%	0.027
3. Portugal	3,861.7	53.4%	0.079

The **LCSE** for each **future scenario** is compared with the **energy price** of the baseline scenario's energy carrier.

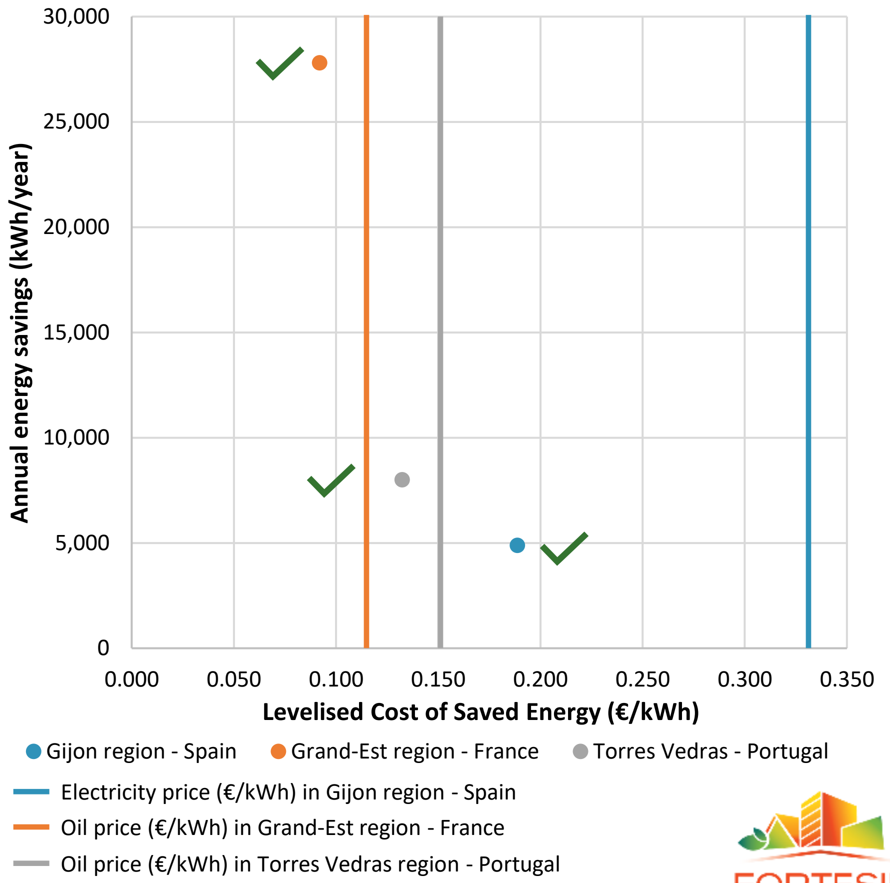
France, Portugal ✓
Spain ✗



Simulation Results: Cross-Pilot Comparison (5/5)

Common scenario 3: Heat pump & Renovation & LED & PV

Pilot case	Total energy savings (kWh)	Total energy savings (%)	LCSE (€/kWh)
1. Spain	4,894.03	51.2%	0.189
2. France	27,804.08	86.8%	0.092
3. Portugal	7,996.98	110.6%	0.132



The **LCSE** for each **future scenario** is compared with the **energy price** of the baseline scenario's energy carrier.

France, Portugal, Spain ✓

CONCLUSIONS AND NEXT STEPS

Useful findings and remarks

- ✓ **Prioritise** the **substitution** of fossil fuel boilers with **heat pumps** is deemed to be the most beneficial in terms of **energy savings** and **economic viability**, followed by **building envelope** upgrades.
- ✓ **Differentiate** the renovation packages according to the **typology**. In **single family houses** **building envelope upgrades** are identified as the most **beneficial**, while in **multi family houses** the installation of **heat pumps**.
- ✓ **Coupling energy efficiency** actions with **renewable generation** can offer **significant** benefits for households, while ensuring the **economic viability** of **measures** with **higher upfront costs** and enhance their attractiveness.
- ✓ **Evaluate** the **performance** of **different energy efficiency scenarios with** the relevant **socio-economic context. Compare** the result with the **local/national energy prices** and **investment costs** to effectively **identify their economic viability.**

Next research steps:

- ❑ Extend the analysis in more countries/ regions across the EU.
- ❑ Focus on more residential **typologies**.
- ❑ Expedite **renovation packages** for upscale across EU.

For More Information

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THANK YOU FOR YOUR ATTENTION!
ANY QUESTIONS?

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