Assessing energy efficiency policies with multiple market and behavioral frictions

PhD Defense - Lucas Vivier

Centre International de Recherche sur l'Environnement et le Développement (CIRED)

Ecole Nationale des Ponts et Chaussées (ENPC)

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PhD Direction:
Louis-Gaëtan Giraudet (main)
Laurent Lamy

Reviewers:
Dorothée Charlier
Joachim Schleich

Jury members:
Peter Berill
Chiara Delmastro
Ken Gillingham

École des Ponts
ParisTech

CIRED

Space heating residential sector

- 20% of total EU energy consumption, with a large share of fossil fuels (Eurostat) → 20% of GHG emission in all EU (Eurostat)

- Objective to meet carbon neutrality by 2050

- Current dynamics are not consistent with climate targets
  - Slow turnover: 75% of the existing EU building stock is expected to remain in 2050

How to accelerate emission reduction in the <u>existing</u> residential space heating sector?
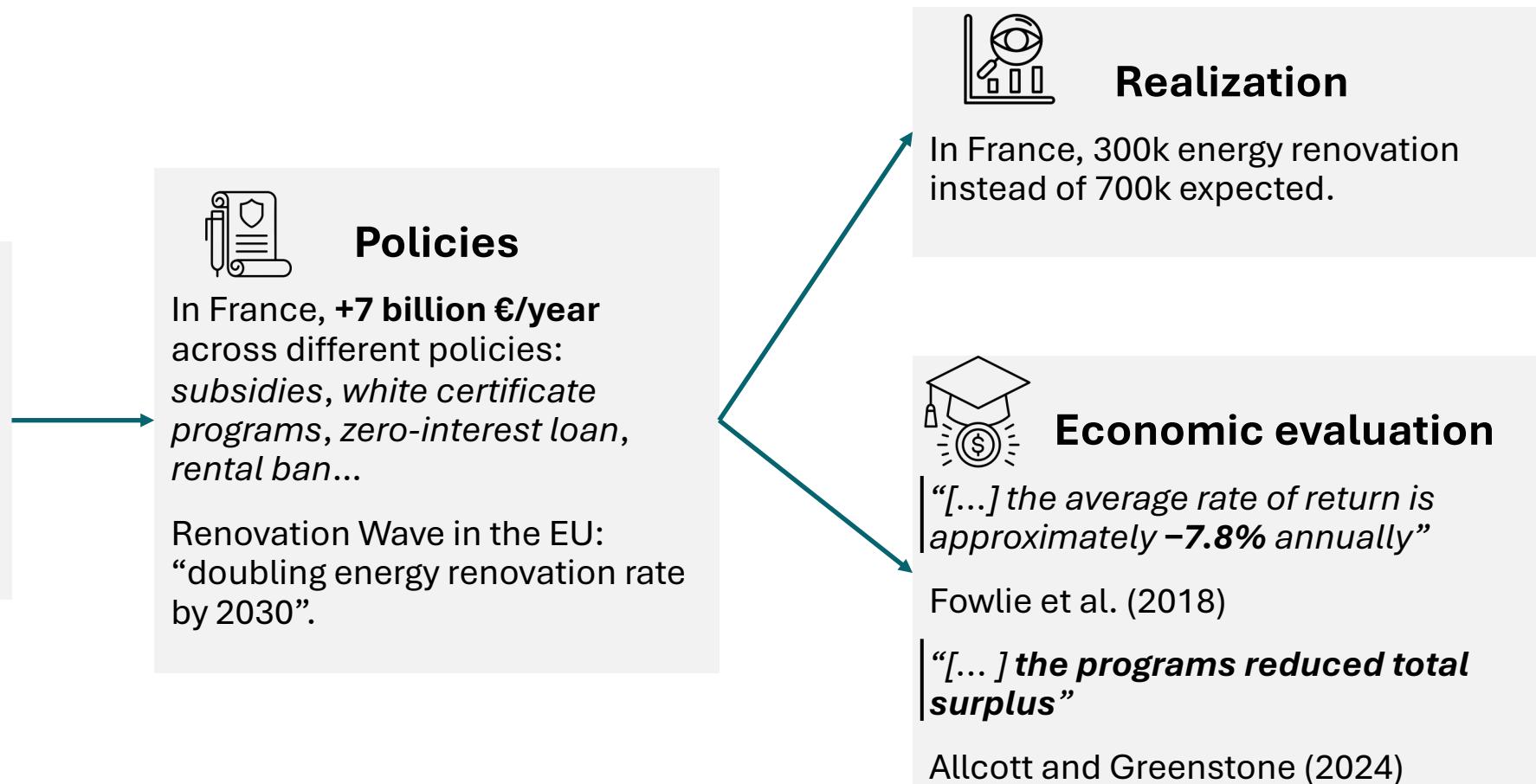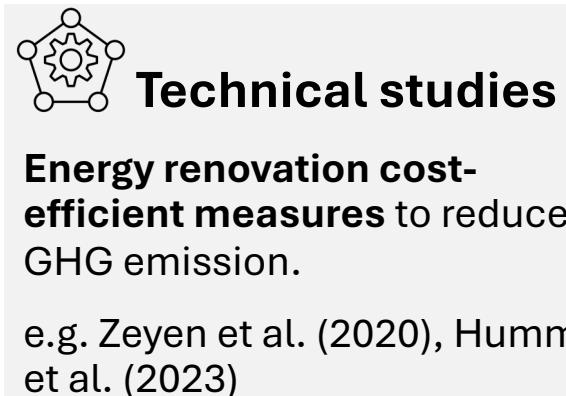
Mitigation channels in the residential stock

29°C

1. Decarbonizing fuel

Energy renovation

2. Switching to low carbon heating system (heat pumps)

3. Home insulation

4. Sufficiency measures

How to allocate efforts between these mitigation channels ?

Energy renovation policy context

Technical studies

Energy renovation cost-efficient measures to reduce GHG emission.

e.g. Zeyen et al. (2020), Hummel et al. (2023)

Policies

In France, **+7 billion €/year** across different policies: *subsidies*, *white certificate programs*, *zero-interest loan*, *rental ban*...

Renovation Wave in the EU: "doubling energy renovation rate by 2030".

Realization

In France, 300k energy renovation instead of 700k expected.

Economic evaluation

"[...] the average rate of return is approximately –7.8% annually"

Fowlie et al. (2018)

"[…] the programs reduced total surplus"

Allcott and Greenstone (2024)

Research questions

New insights into an old question: **How to reconcile optimistic technical assessment with skeptical policy evaluation results?**
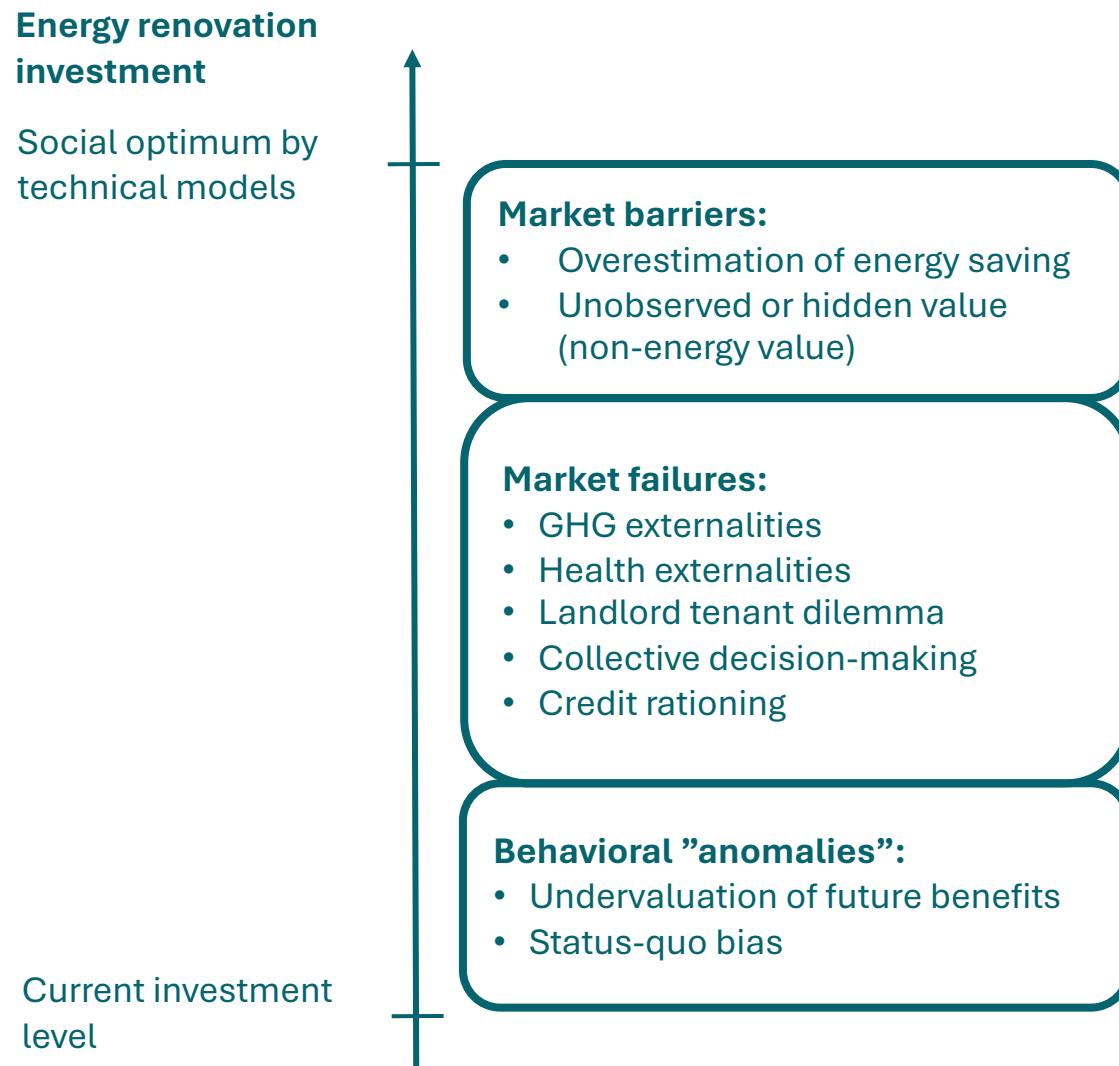
Objective:

→ Develop an investment model including key investment frictions *at the source of the gap*

→ Carefully disentangle and quantify the costs and benefits of energy renovation policies
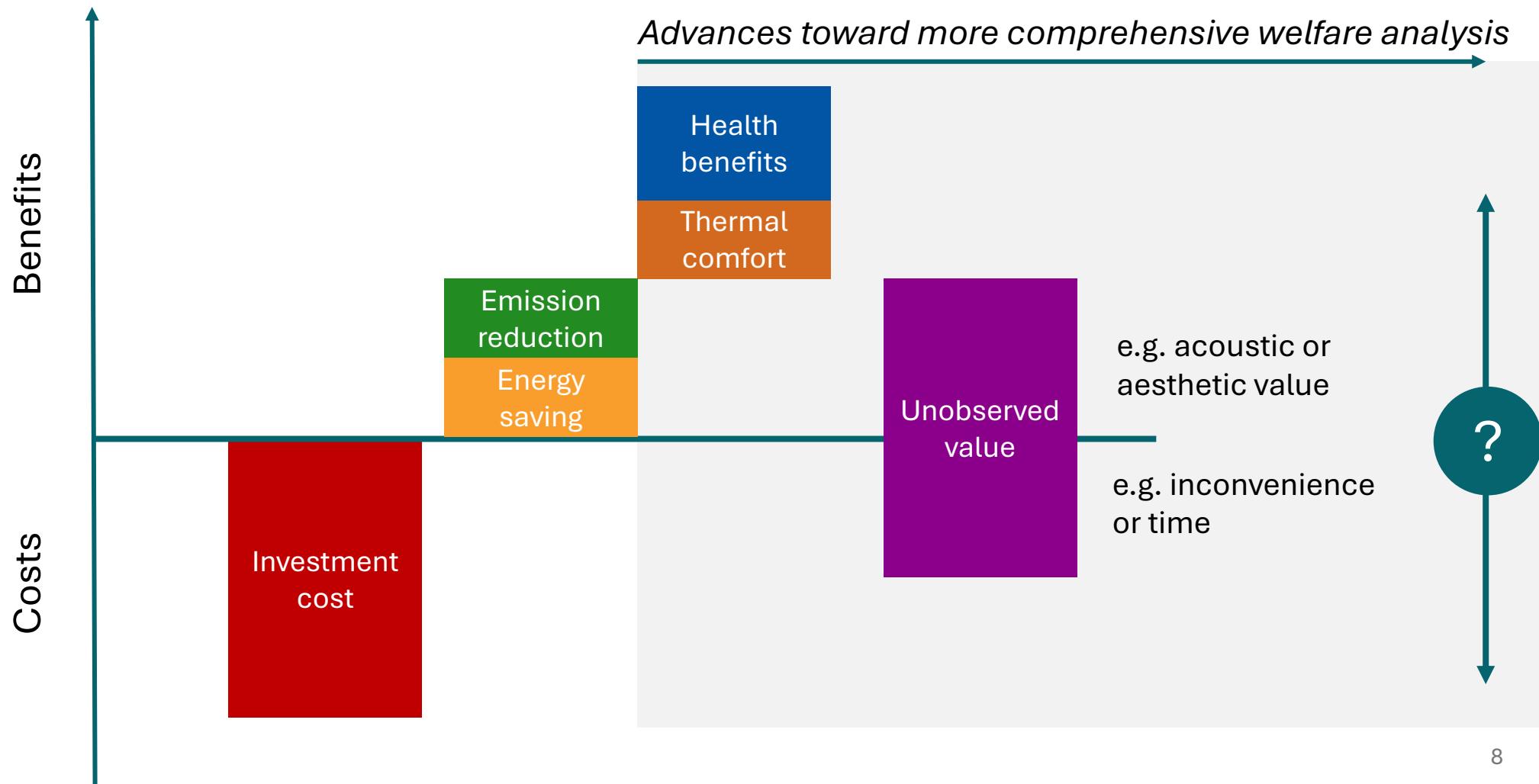
Method: microsimulation framework
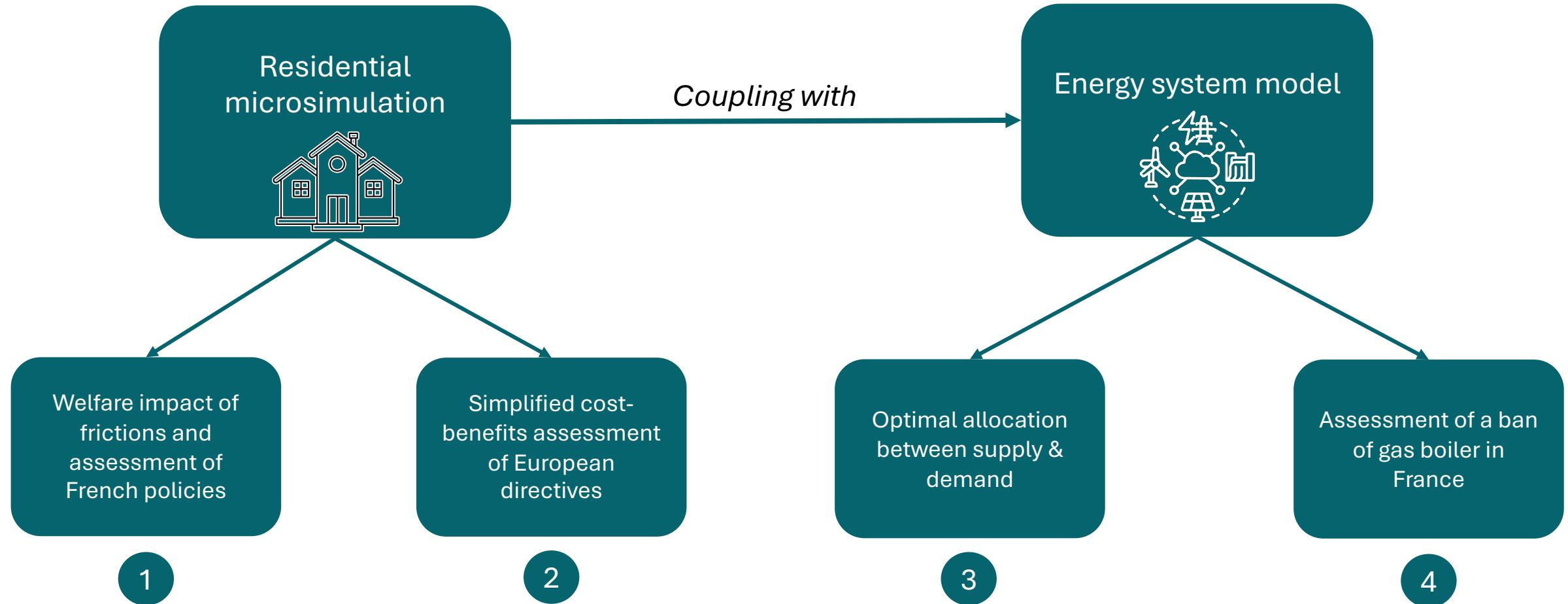
Key ingredient: investment frictions

Energy renovation investment

Social optimum by technical models

Market barriers:
- Overestimation of energy saving
- Unobserved or hidden value (non-energy value)

Market failures:
- GHG externalities
- Health externalities
- Landlord tenant dilemma
- Collective decision-making
- Credit rationing

Behavioral "anomalies":
- Undervaluation of future benefits
- Status-quo bias

Current investment level

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Disentangling and quantifying cost and benefits

Advances toward more comprehensive welfare analysis

Benefits

Health benefits

Thermal comfort

Emission reduction

Energy saving

Unobserved value

e.g. acoustic or aesthetic value

e.g. inconvenience or time

?

Costs

Investment cost

PhD Overview

Residential microsimulation

Coupling with →

Energy system model

Welfare impact of frictions and assessment of French policies

Simplified cost-benefits assessment of European directives

Optimal allocation between supply & demand

Assessment of a ban of gas boiler in France

1

2

3

4

Energy efficiency policy in an n-th best world: Assessing the implementation gap

1

L. Vivier, and L.-G Giraudet. *Energy efficiency policy in an n-th best world: Assessing the implementation gap.* Working paper

Welfare impacts if frictions were corrected
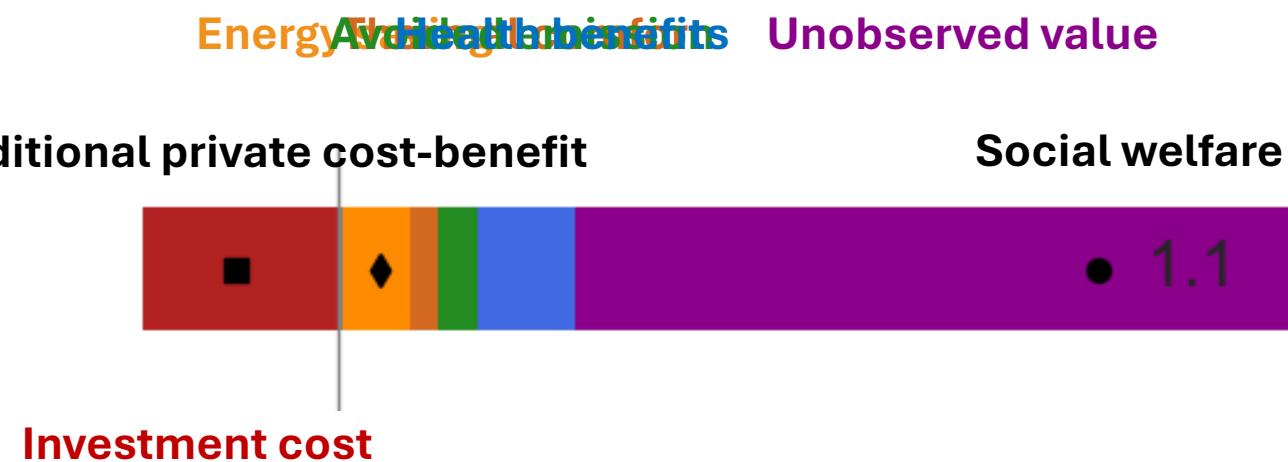
Social welfare
Billion euro per year

Welfare impacts if frictions were corrected

Energy cost savings **Avoided abatement** **Health benefits** **Unobserved value**

Traditional private cost-benefit **Social welfare**

Landlord-tenant dilemma   1.1

Investment cost
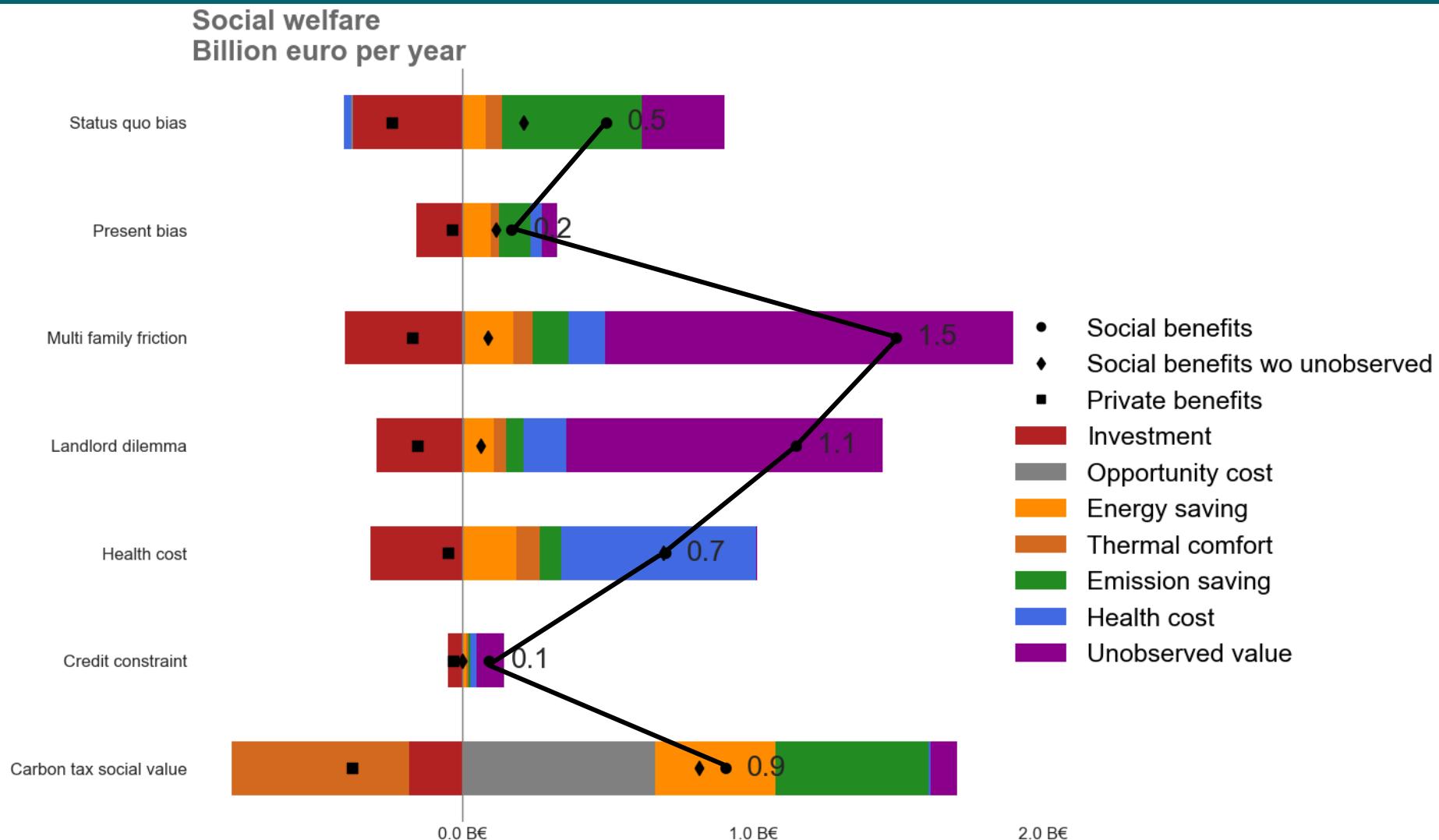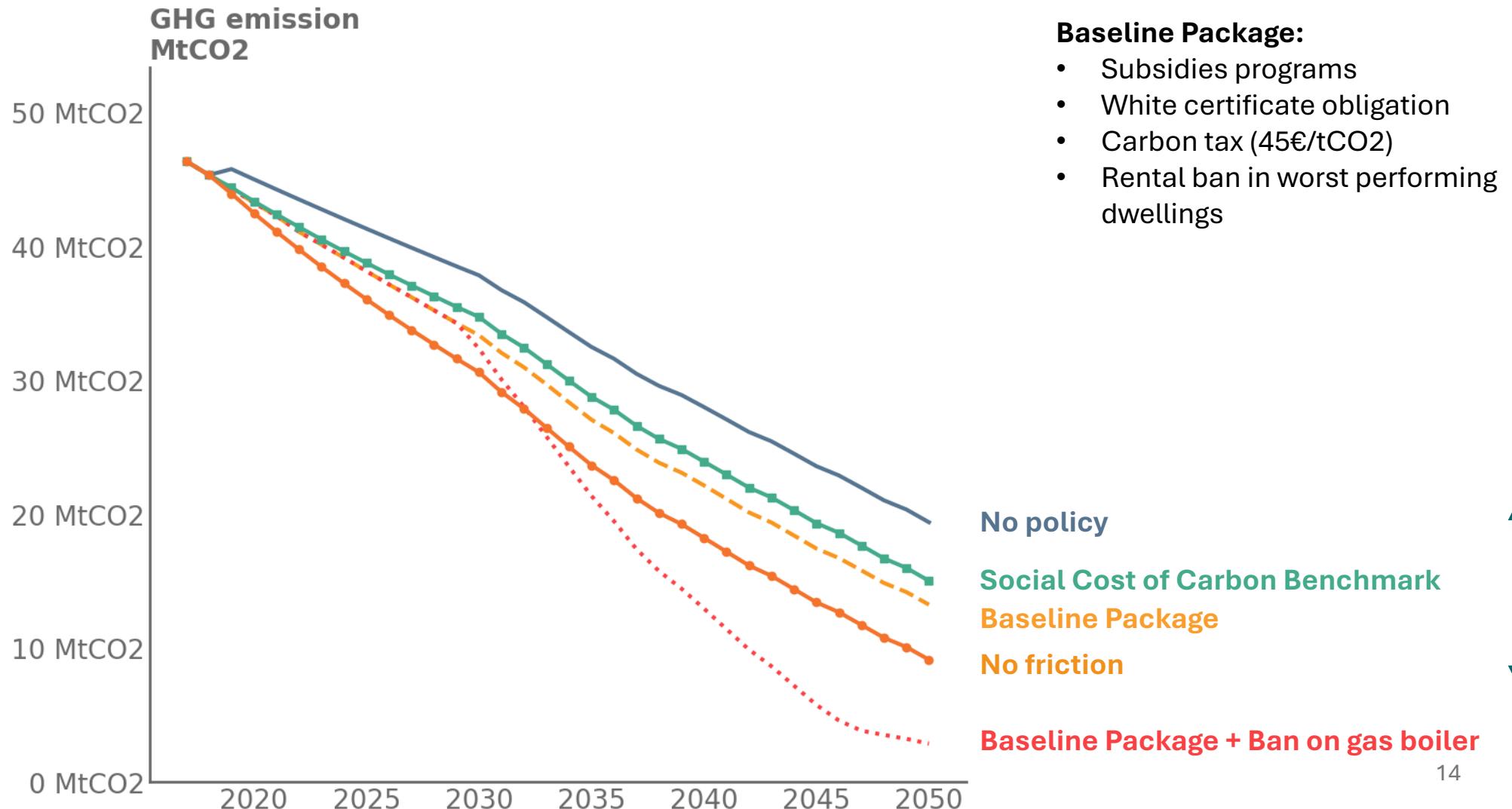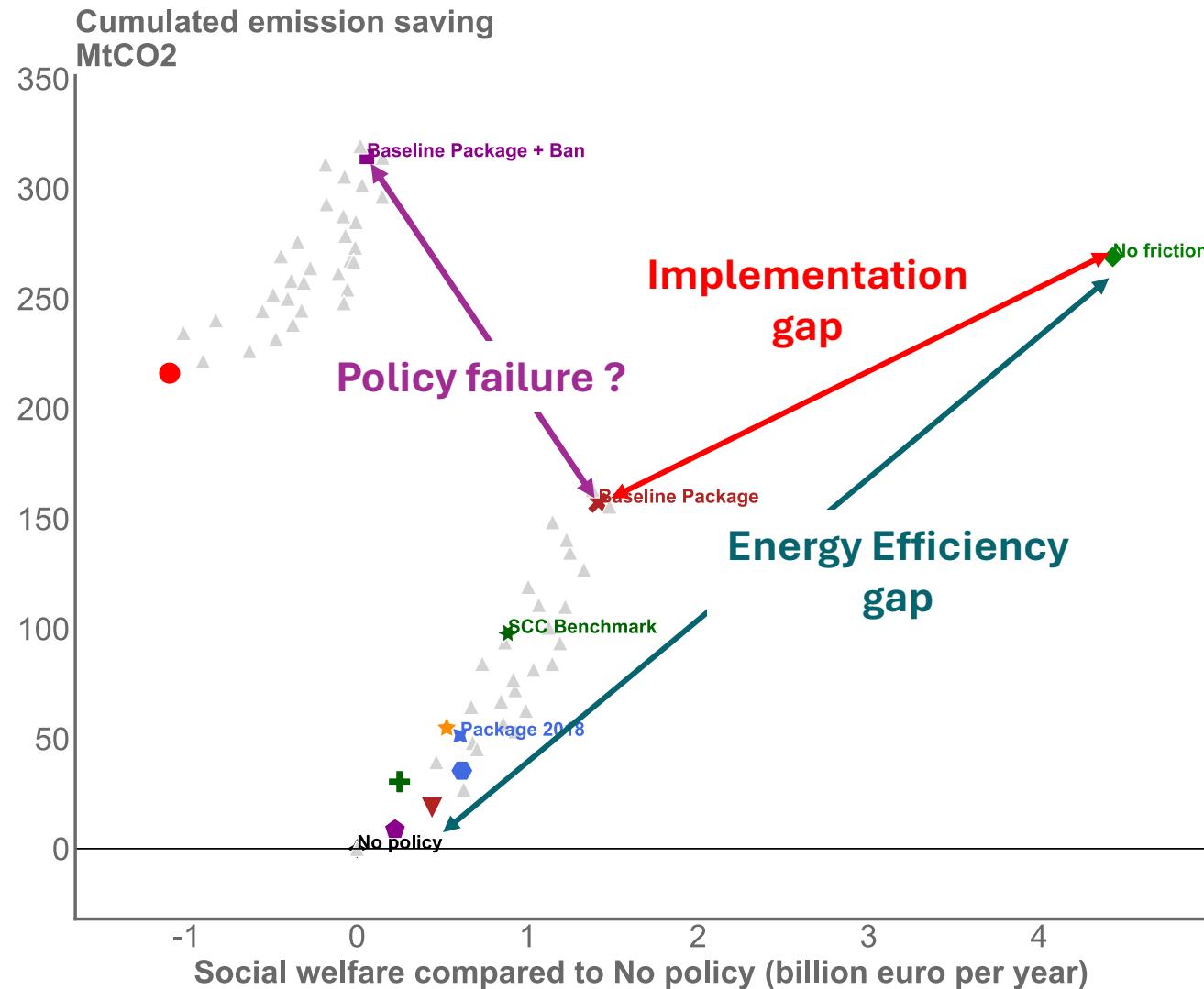
Assessing policy packages in France

Baseline Package:
- Subsidies programs
- White certificate obligation
- Carbon tax (45€/tCO2)
- Rental ban in worst performing dwellings

No policy

Social Cost of Carbon Benchmark

Baseline Package

No friction

Baseline Package + Ban on gas boiler

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Contributions

- Highlight the importance of **unobserved value** in energy renovation decision and welfare assessment

- Show that GHG externality is dominated by **health, rental and multi-family frictions** in the ranking of justifications for energy renovation policies

- Estimate that Baseline package in France close about **half of the Energy Efficiency Gap**

Meeting climate target with realistic demand-side policies in the residential sector in the EU-27

2

L. Vivier and A. Mastrucci. *Meeting climate target with realistic demand-side policies in the residential sector in the EU-27.* Submitted to Nature Climate Change
Preliminary report received the Lewin Award part of the YSSP at IIASA

European residential model

Bottom-up technical model of residential sector MESSAGEix-Buildings

- Detailed representation of the building stock
- Main data source: Building stock libraries, EUROSTAT data

Households' energy renovation decision model
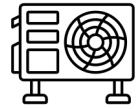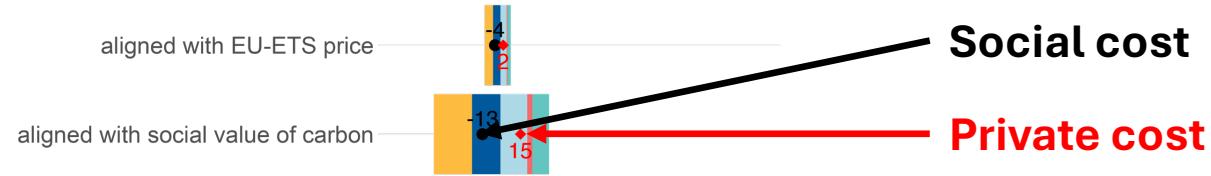
Calibrated on current renovation rate and heating system installation for each EU-27 member states.

International Institute for Applied Systems Analysis

IIASA

Assessing European mitigation policies
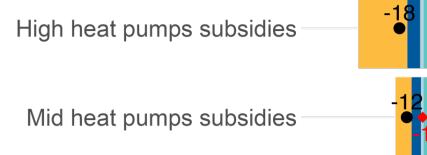
Carbon tax

Promoting heat pumps

Promoting home insulation

aligned with EU-ETS price — Social cost

aligned with social value of carbon — Private cost

| | -4 |
| | 2 |

aligned with social value of carbon: -13 / 15

High heat pumps subsidies: -18 / 18

Mid heat pumps subsidies: -12 / -1

High renovation subsidies: 89 / 96

Mid renovation subsidies: 53 / 57

High Deep renovation subsidies: 116 / 128

Mid Deep renovation subsidies: 75 / 83
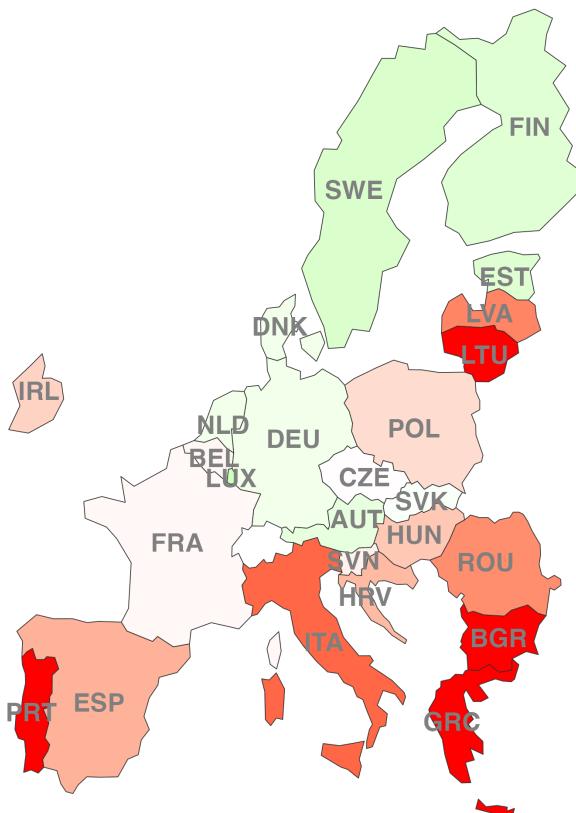
Cost-benefits decomposition:
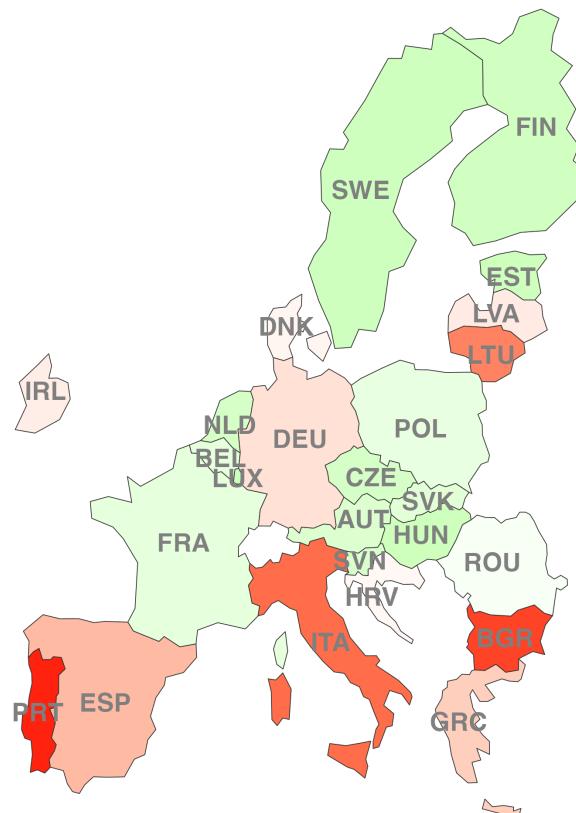
- Cost emission
- Cost fuel
- Cost heating system
- Cost renovation
- Cost thermal comfort

… but home insulation alleviate energy poverty
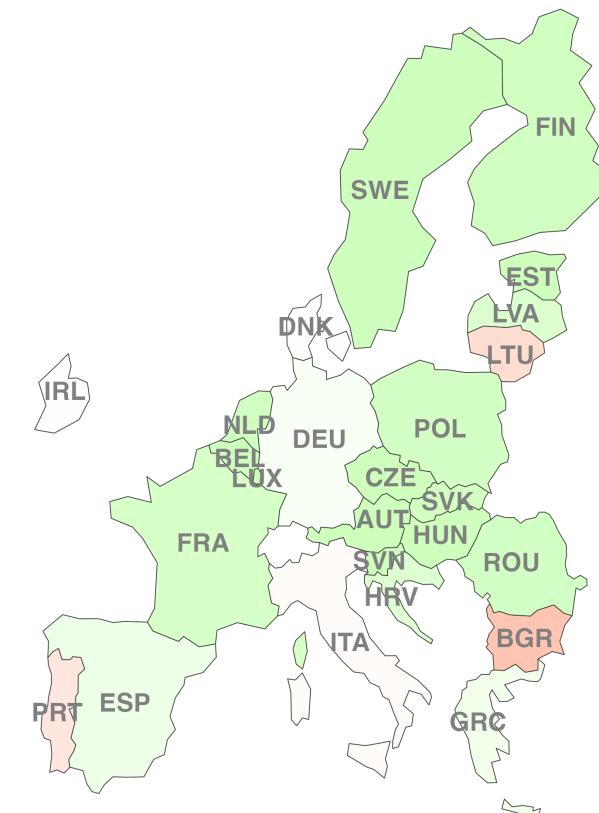
2015

+ heat pump subsidies

+ home insulation subsidies

Share of the population suffering from energy poverty (%)

- 0
- 5
- 10
- 15
- 20

2. Contributions

- Build a **high-resolution bottom-up model** of the European residential sector that includes endogenous investment decision

- **Cost-benefit analysis** of 384 realistic policy packages

- Confirm need of **nationally-determined** policies with a carbon tax and additional **subsidies for heat pumps**

- Nuance the need of doubling the home insulation rate to carefully **calibrated incentives for home insulation**
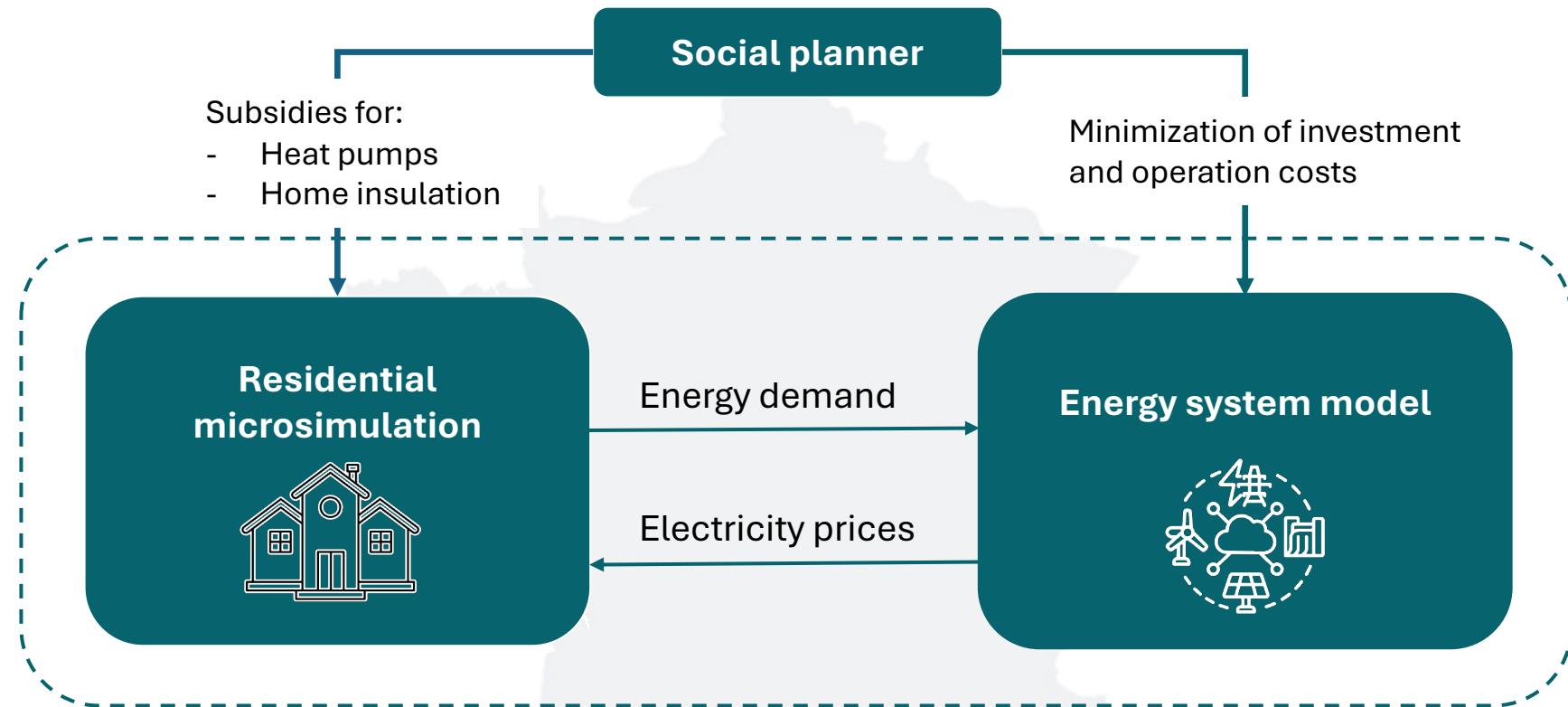
How to allocate mitigation efforts between home insulation, fuel switch and fuel decarbonization?

3

C. Escribe*, **L. Vivier***, L.-G Giraudet, and P. Quirion. *How to allocate mitigation efforts between home insulation, fuel switch and fuel decarbonization? Insights from the French residential sector*. Environmental Research Letters, 2024.

* Equal contribution as co-first author

Integrated demand-supply framework
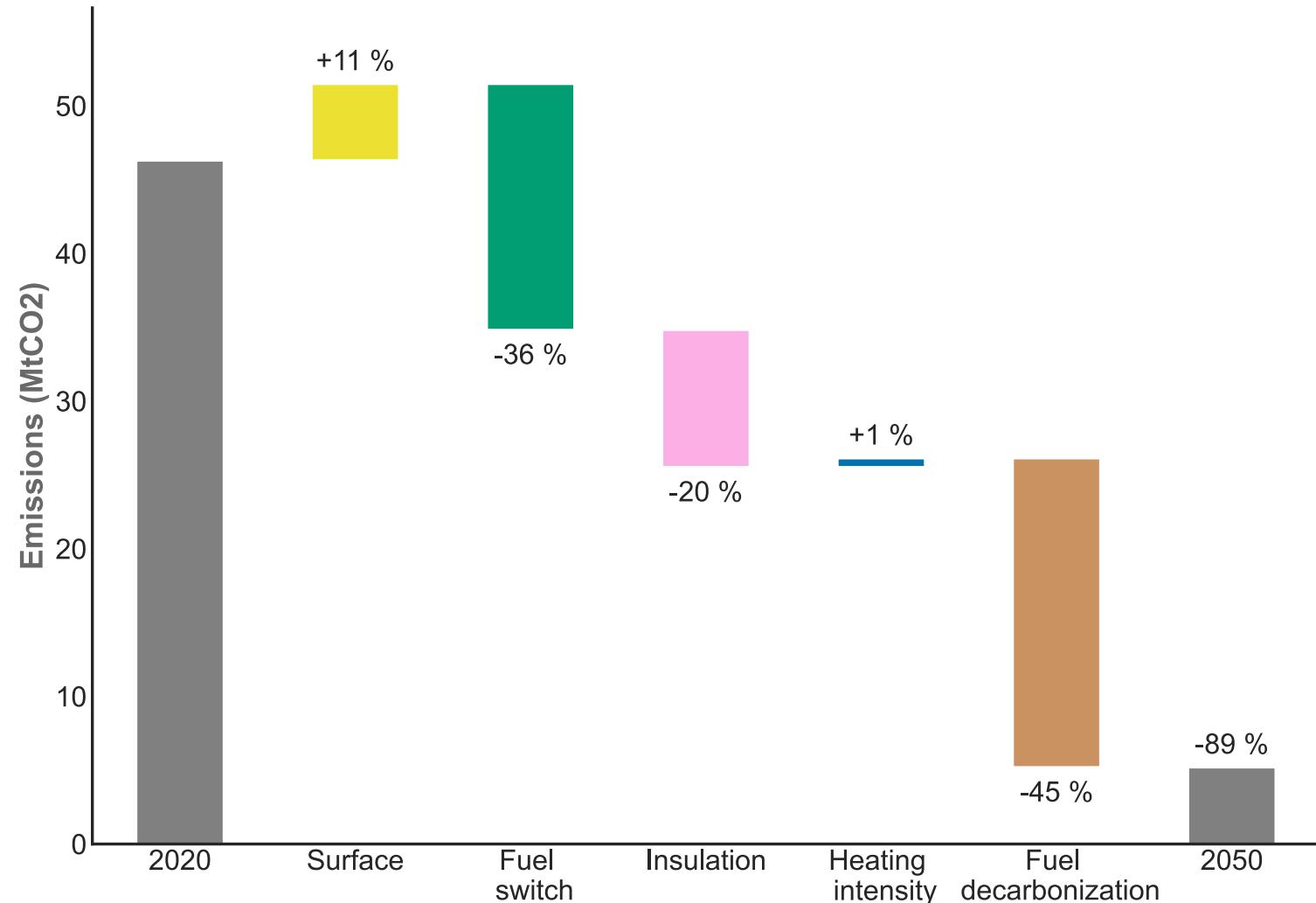
→ Study the impact of subsidy design for home insulation
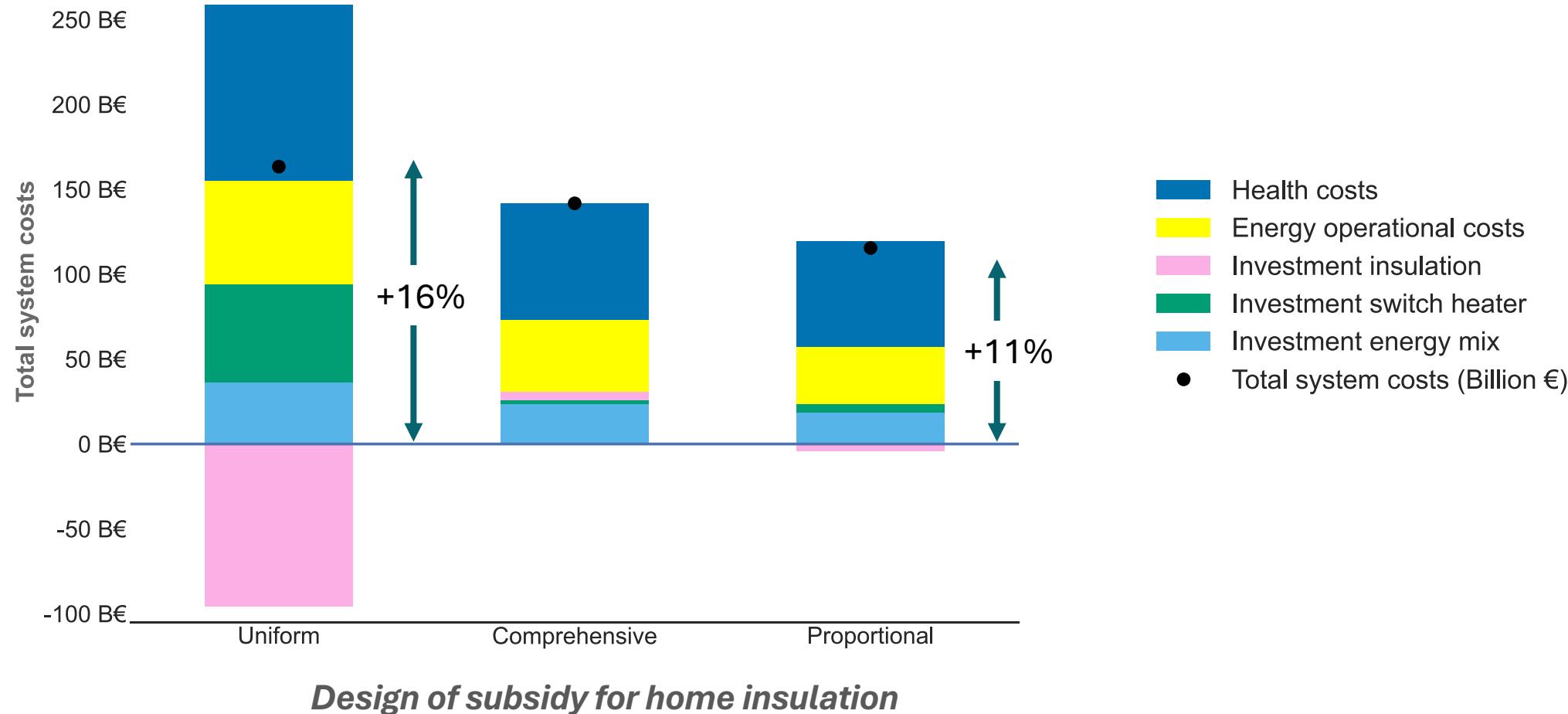
... but total system cost increases by 11 to 16% when accounting for realistic subsidies.

Design of subsidy for home insulation

Legend:
- Health costs
- Energy operational costs
- Investment insulation
- Investment switch heater
- Investment energy mix
- Total system costs (Billion €)

Contributions

- **Couple** high-resolution bottom-up models to endogenize demand-side and supply-side option

- Build an innovative framework with **social planner choose subsidies** (and not energy renovation directly) to account for decentralized investment decision

Banning new gas boilers as a no-regret mitigation option

4
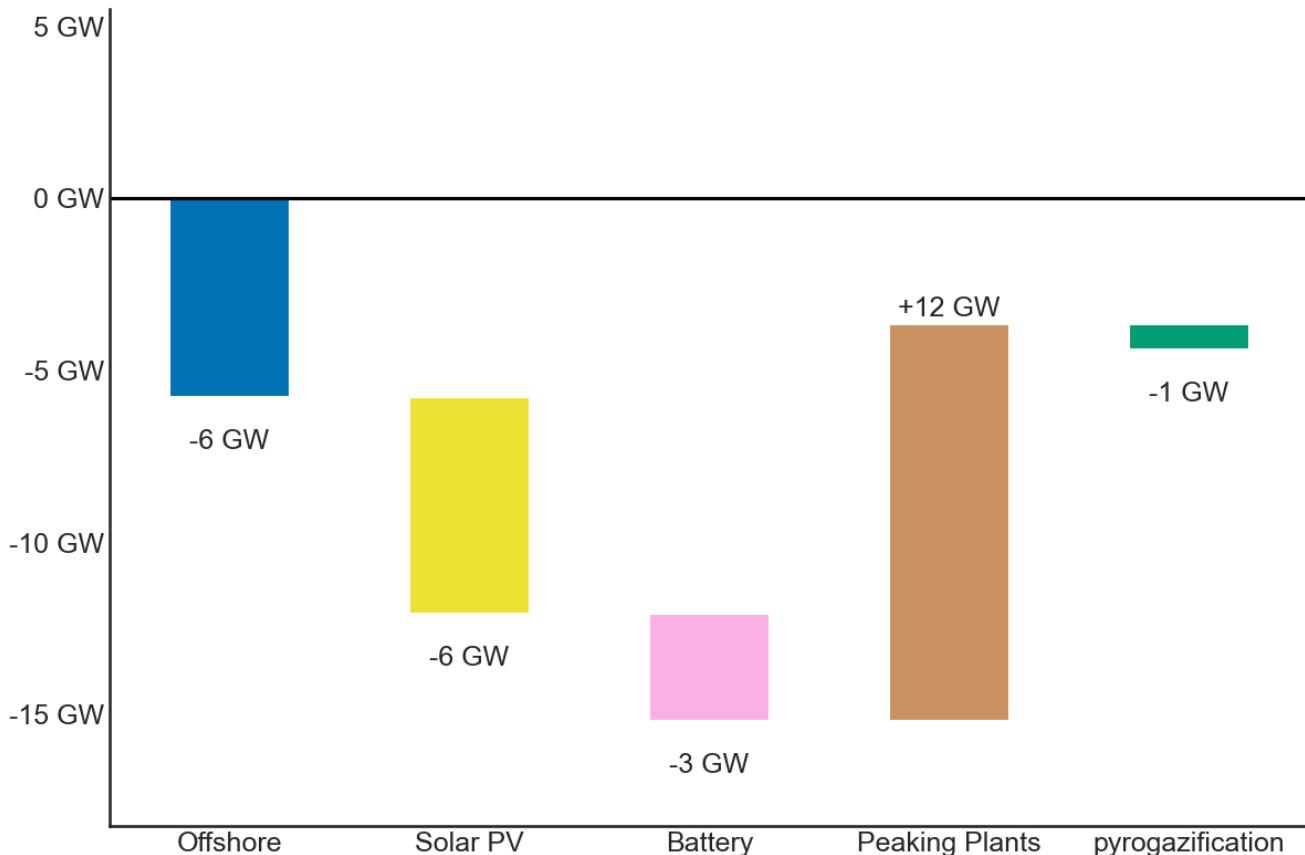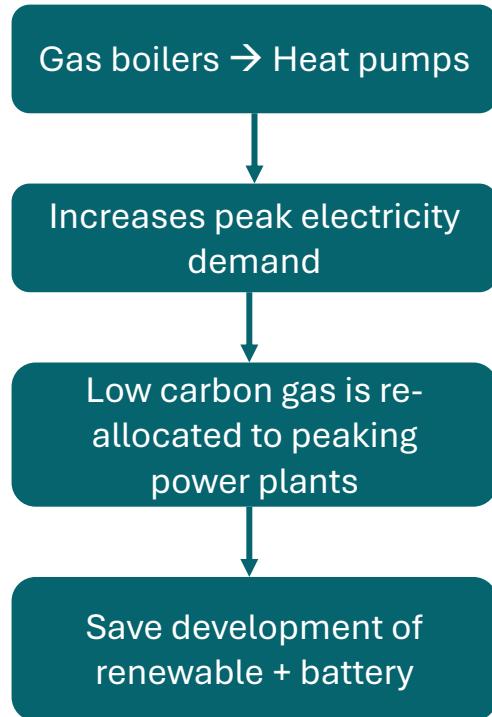
C. Escribe* and **L. Vivier***. *Banning new gas boilers as a no-regret mitigation option*. Revise & Resubmit in Nature Communications.
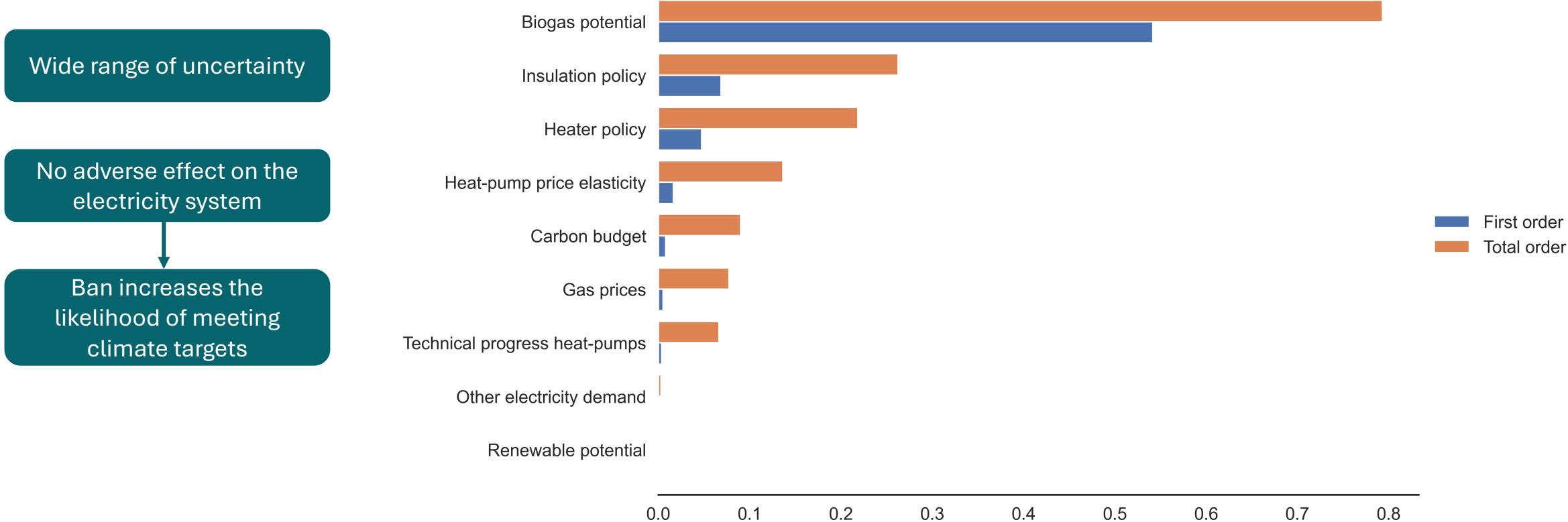
* Equal contribution as co-first author

Banning new gas boilers lead to a more efficient energy system from a whole-system perspective

Gas boilers → Heat pumps

↓

Increases peak electricity demand

↓

Low carbon gas is re-allocated to peaking power plants

↓

Save development of renewable + battery

Additional capacity in 2050 when the ban on gas boilers is implemented
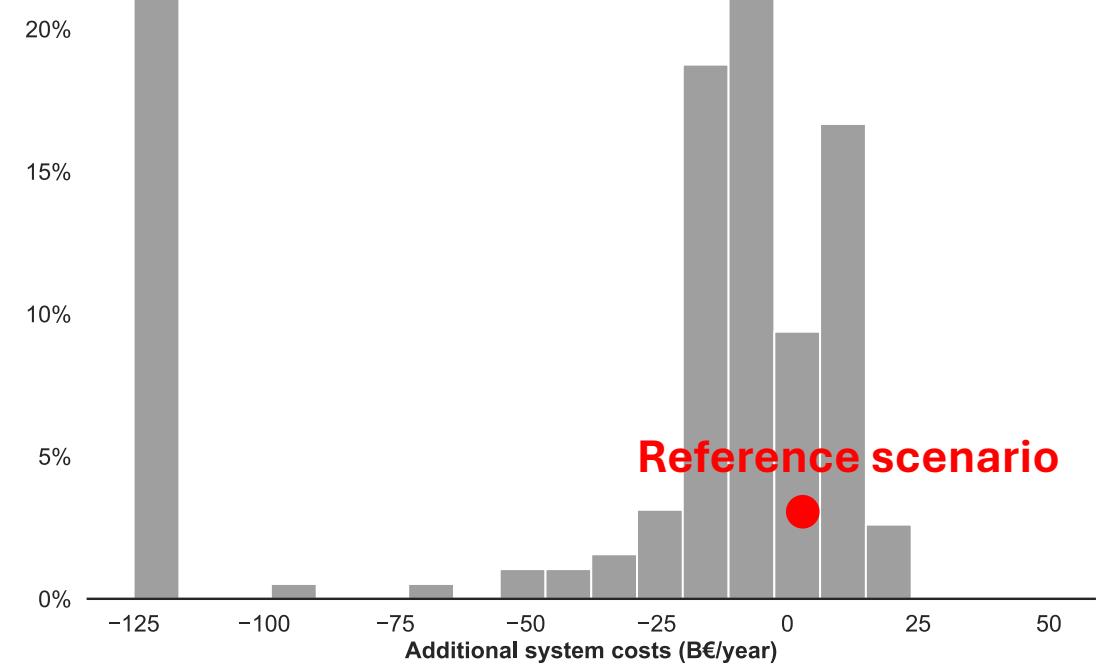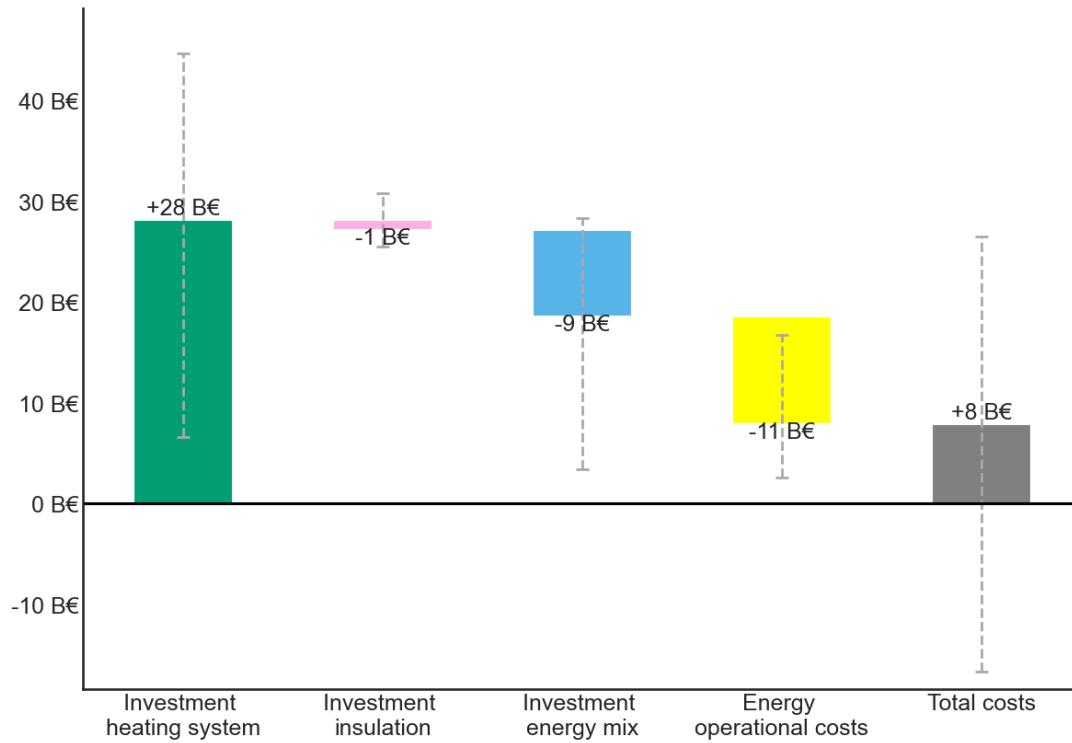
Banning new gas boilers as a hedge against the limited availability of renewable gas supply

Wide range of uncertainty

No adverse effect on the electricity system

Ban increases the likelihood of meeting climate targets

First order
Total order

Main uncertainties that impair the achievement of climate targets without the ban. Sobol analysis.

Ambiguous impact on total system costs

Breakdown and distribution of additional cost when implementing the ban of gas boilers compared to the counterfactual scenario

Contributions

- Highlight the **impact on the energy system** of a demand-side policy, here the ban on gas boiler

- Assess cost impact under **uncertainty** across large set of scenarios (approx. 12,000)

- This ban appears as a **no-regret** mitigation option

Conclusion

General policies takeaway
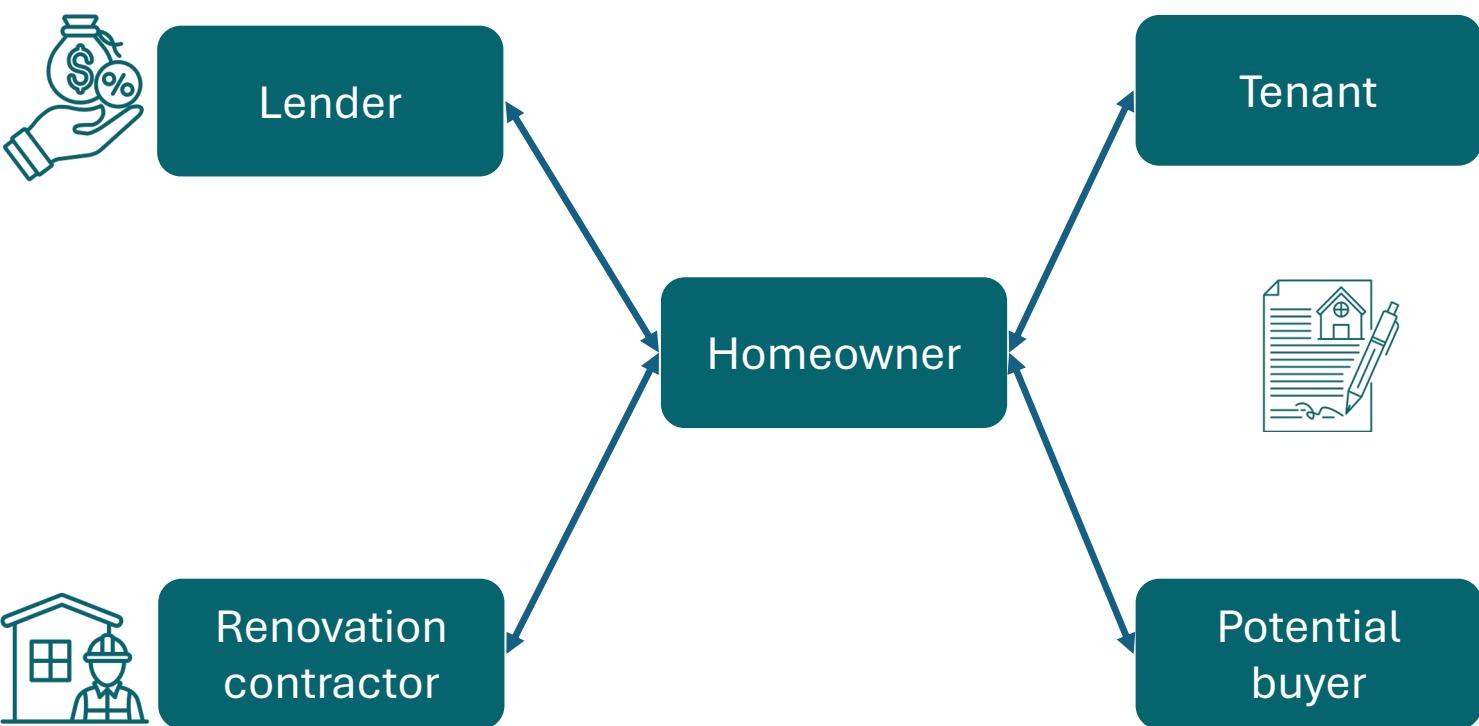
Achieving climate goals:

- Achieving carbon neutrality require ambitious policies to **promote heat pumps** alongside full decarbonization of the electricity system (Chap. 1,2,3,4).

- Adopting heat pumps **shift gas use from heating to electricity generation**, which is a more efficient use of low-carbon biogas (Chap. 4).

- While **regulatory** measures underperform incentive-based instruments from a simple microeconomic perspective, they are crucial for meeting carbon neutrality, especially **under uncertainty** (Chap. 1, 4).

Energy efficiency policies:

- CO2 externality is dominated by **health, rental and multi-family frictions** in the ranking of justification for home insulation policies (Chap. 1,2).

- Overall, for the case of France, current policies only close about **half of the energy efficiency gap** in space heating (Chap. 1).

- Aligning policies on frictions (landlord, multi-family, worst-performing) significantly increase cost-efficiency (Chap. 1, 2, 3).

Further work – Market Interactions

Summary of contribution

Academic contribution

- **L. Vivier,** and L.-G Giraudet. *Energy efficiency policy in an n-th best world: Assessing the implementation gap.* Working paper

- **L. Vivier** and A. Mastrucci. *Meeting climate target with realistic demand- side policies in the residential sector in the EU-27.* Submitted in Nature Climate Change.

- C. Escribe*, **L. Vivier***, L.-G Giraudet, and P. Quirion. *How to allocate mitigation efforts between home insulation, fuel switch and fuel decarbonization? Insights from the French residential sector*. Environmental Research Letters, 2024.

- C. Escribe* and **L. Vivier***. *Banning new gas boilers as a no-regret mitigation option.* Revised & Resubmit in Nature Communications.
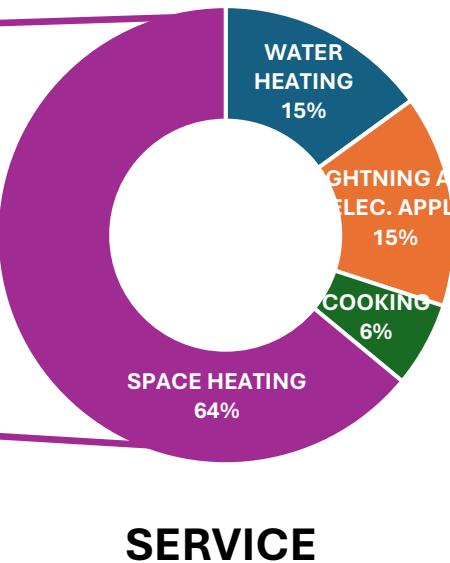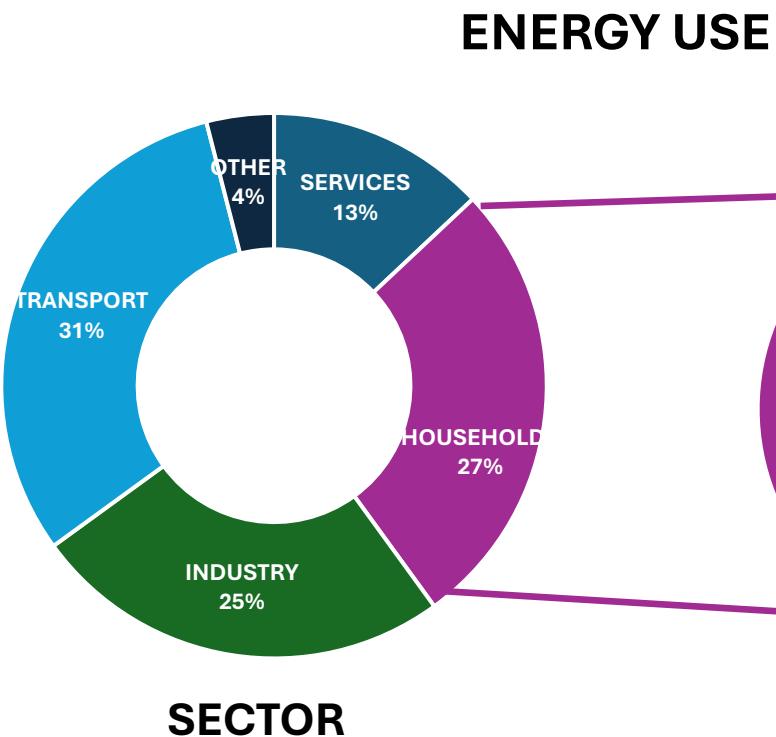
*Equal contribution as co-first author

Research report
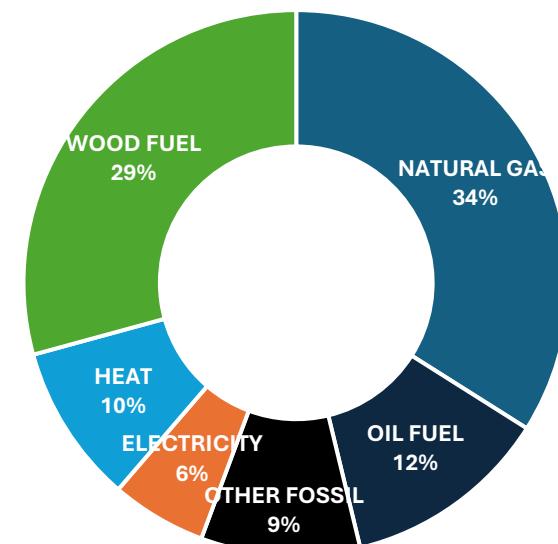
- **L. Vivier** et L.-G. Giraudet, 2024. *Analyse socio-économique de la rénovation énergétique des logements.* Focus Conseil d'Analyse Économique.

- L.-G. Giraud et **L. Vivier**, 2022. *La difficile quantification de la place du bâtiment dans la décarbonation.* Transitions. Les nouvelles Annales des Ponts et Chaussées, Ecole des Ponts ParisTech et Presses des Ponts.

- V. Aussilloux, F. Chabrol, L.-G. Giraudet, **L. Vivier**, 2021. *Quelle rentabilité économique pour les rénovations énergétiques des logements ?* France Stratégie, Note d'analyse, n°104

Supplementary Information

Space heating residential sector

ENERGY USE

DISTRIBUTION BY FUEL TYPE OF SPACE HEATING

SECTOR chart:
- OTHER 4%
- SERVICES 13%
- TRANSPORT 31%
- INDUSTRY 25%
- HOUSEHOLD 27%

SERVICE chart:
- WATER HEATING 15%
- LIGHTNING AND ELEC. APPL. 15%
- COOKING 6%
- SPACE HEATING 64%

Distribution by fuel type chart:
- NATURAL GAS 34%
- OIL FUEL 12%
- OTHER FOSSIL 9%
- ELECTRICITY 6%
- HEAT 10%
- WOOD FUEL 29%

SECTOR

SERVICE

Source: Eurostat 2024

Literature review - Energy Efficiency Gap

Energy efficiency investment

Social optimum by engineering models

Social optimum

→ **Policies to bridge the investment gap ?**

Private optimum in rational model

Realized

Modelling error

Modelling error engineering models:
- Overestimation of energy saving
- Dwellings heterogeneity
- Unobserved or hidden costs (non-energy cost)

→ **Do not justify policies**

Market failures

Energy market failures
- GHG externalities
- Retail price does not reflect real cost

Retrofitting market failures
- Landlord tenant dilemma
- Collective decision-making
- Credit rationing

Social Energy Efficiency Gap
→ **Motivate policies**

Behavior

Behavioral "anomalies"
- Undervaluation of future benefits
- Status-quo bias

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Accounting model
National scale
Detailed representation of the building stock. Exogenous scenarios energy renovation diffusion.

Agent Based Model
National scale
Explicit modelling interaction of agents. Based on psychological and social factors.

Multi-agent model
National or regional scale
Detailed description of the building stock. Heterogenous investment decision relying ad hoc decision function. Do not assess welfare impact of policy mix.

Our work: Microsimulation modelling structural model
National scale
Detailed description of the building stock. Heterogenous investment decision and explicit representation of market barriers and failures. Utility consistent framework which enable welfare assessment.

System dynamics
Multi-regional scale
Intermediate complexity. Heterogeneity can be captured though distribution of parameters. Investment barriers are represented through implicit discount rate.

Structural model
Program based
Grounded in microeconomic consumer theory. Utility consistent framework which enable welfare assessment. Usually used to assess individual energy efficiency program.

Detail representation of building stock and energy efficiency technology characteristics

Economic modelling of households investment behavior

Illustration of impact of investment frictions

- We will do it dynamically
- And how to tackle this potential with policies

L. Vivier and L.-G Giraudet. *Analyse socio-économique de la rénovation énergétique des logements.* Focus CAE n° 106, 2024.

| Category	Barrier	Specification	Source
Market failures	CO2 externality	€150/tCO2 in 2024, increasing to €250 in 2030 and €775 in 2050	Quinet (2019)'s official value
	Health externality	€7,500 to low-income families living in G+ dwellings	Dervaux and Rochaix (2022)'s official value
	Credit rationing	Credit denied if debt repayment exceeds 5% of household income	Dolques et al. (2022)
	Landlord-tenant dilemma	**Penalty of €20,639 per rented house**	**Own calibration**
	Free-riding in MFH	**Penalty of €15,961 per MFH in the private sector**	**Own calibration**
Behavioral anomaly	Present bias	Discount rate increasing from 3% to top 20% to 19% to bottom 20%	Stolyarova (2016)
	Status quo bias	€4,300	Stolyarova (2016)
Market barriers	**Non-energy costs of renovation**	**Calibrated as reduced-form value distributed across households to match price elasticity of -1.**	**Own calibration**
	Performance gap	61% performance gap and a 26% rebound effect based on short-term energy price elasticity of -0.2	Douenne (2020)
	Opportunity cost of public funds	20%	France Stratégie (2017)
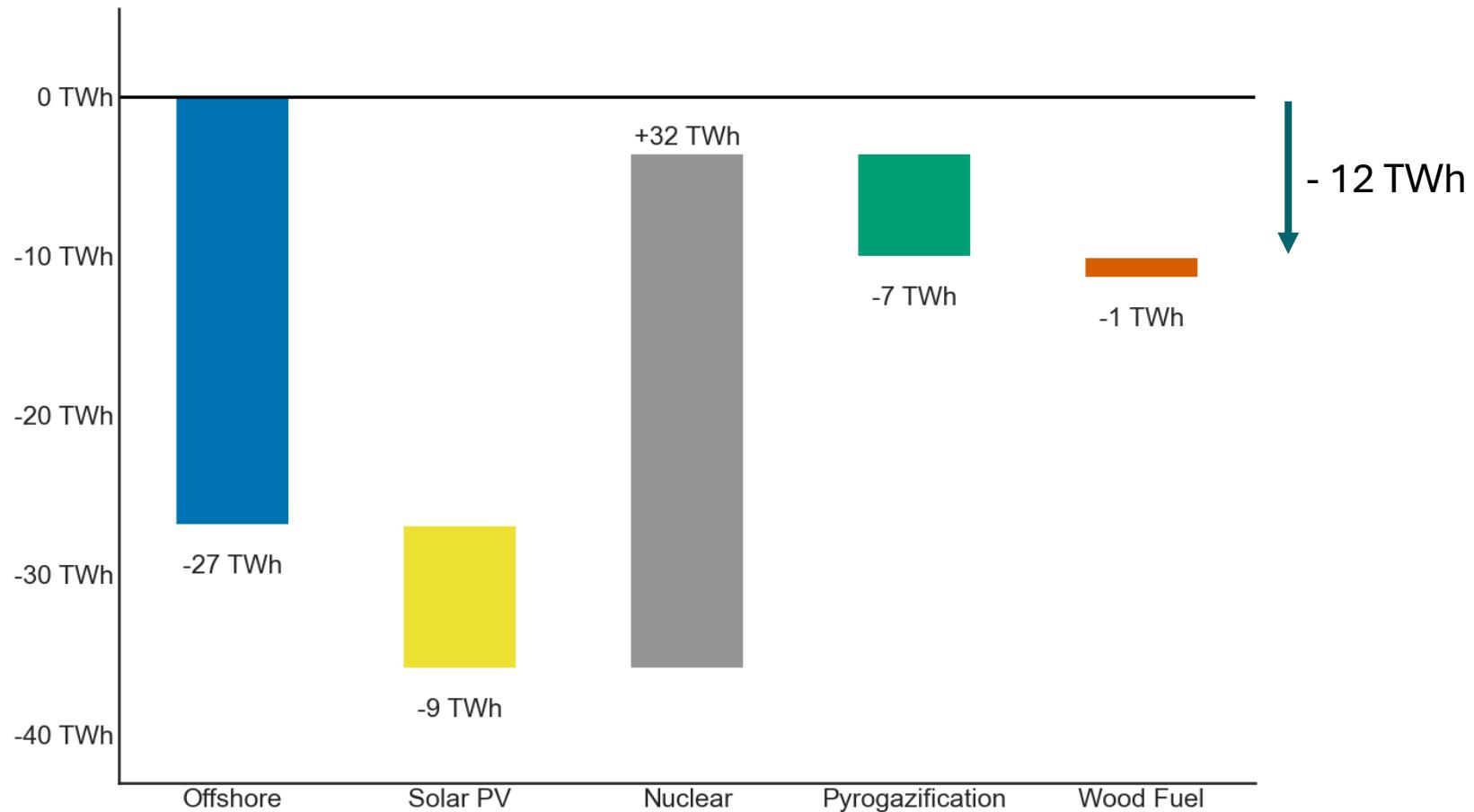
Social welfare
Billion euro per year

- ● Social benefits
- ◆ Social benefits wo unobserved
- ■ Private benefits
- Investment
- Opportunity cost
- Energy saving
- Thermal comfort
- Emission saving
- Health cost
- Unobserved value

BaselinePackage · BaselinePackage + Ban · NoFriction · SCCBenchmark

Banning new gas boilers lead to a more efficient energy system from a whole-system perspective
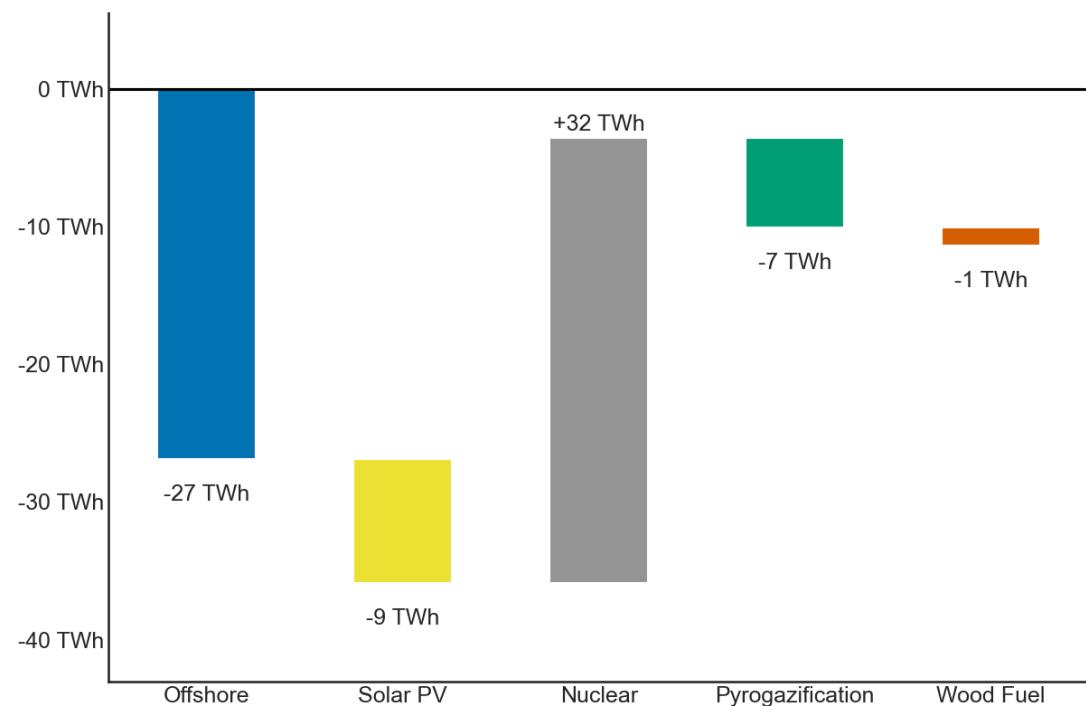

*Additional generation in 2050 when the ban on gas boilers is implemented*
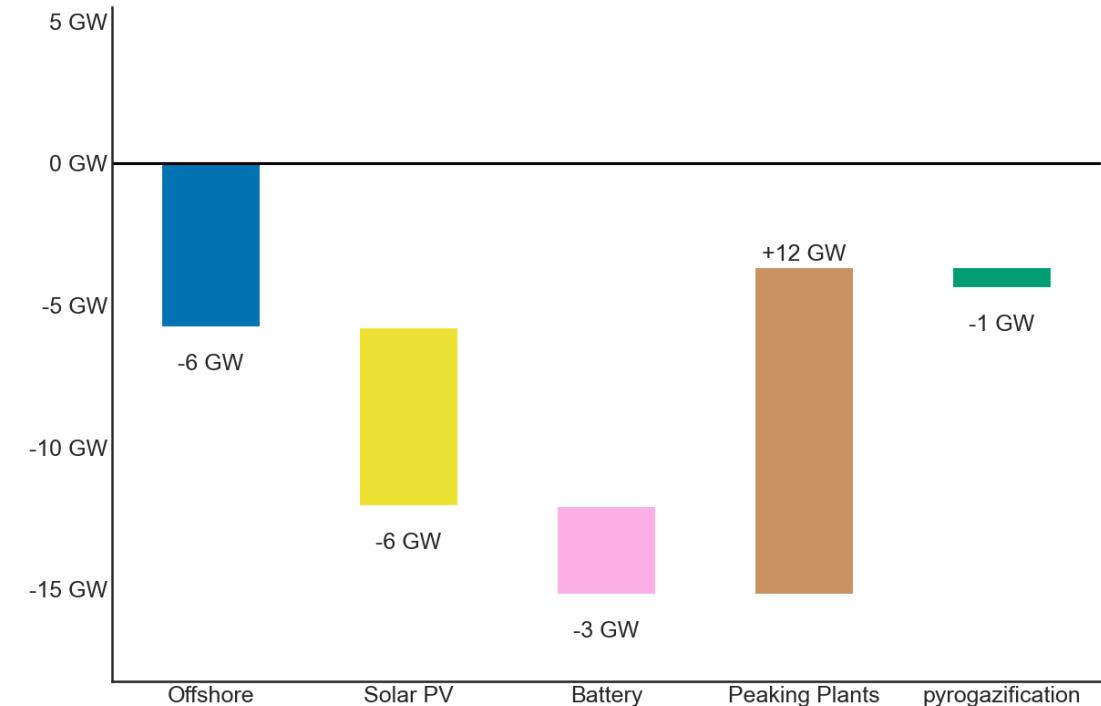
Banning new gas boilers lead to a more efficient energy system from a whole-system perspective

ENERGY GENERATION

ENERGY CAPACITY

Additional installed capacity and generation in 2050 when the ban on gas boilers is implemented