Integrating demand-supply decarbonization efforts in the residential sector: a modeling assessment for France

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Outline

1. **Motivation**
2. Related literature
3. Methods
4. Results
5. Conclusion

Building sector needs to be decarbonized

- Building sector: **second largest contributor** to greenhouse gas emissions in high-income countries.
  - High stakes in decarbonizing residential sector !
- National and European strategies: strong emphasis on insulation and heat pumps adoption.

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Motivation: what is the optimal decarbonization strategy in the residential sector ?

How to decarbonize building sector ?

3 main options to decarbonization:

Improving buildings energy performance — Switch to low-carbon heating system — Reduce energy carbon content

Demand-side options: Improving buildings energy performance; Switch to low-carbon heating system

Supply-side option: Reduce energy carbon content

Decentralized decision-making under market failures

Building sector is characterized by **decentralized** energy efficiency investment decisions by **heterogenous** agents.

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- **Energy market failures**
  - Environmental externality
  - Price divergence from energy marginal cost
- **Energy-efficient durables failures**
  - Landlord-tenant dilemma
  - Public good issues
  - Credit constraints
  - Myopic estimation of energy prices
  - Health benefits not included in investment decisions

A need for public intervention

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  - Not always a politically viable option !

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- **Additional market failures** in the residential sector would require **perfectly targeted subsidies** for each individual agent.

$\Longrightarrow$ First-best cannot be implemented, and **second-best policy designs** need to be explored.

Research questions

- Decarbonizing building sector requires a **comprehensive demand-supply approach**.

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What is the optimal trade-off between the 3 decarbonization options for the residential sector ?

How should energy efficiency subsidies be optimally determined to decarbonize the residential sector ?

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Related literature

Theoretical work on optimal energy efficiency policy instruments (Chan & Globus-Harris, 2023; Allcott *et al.*, 2014; Allcott *et al.*, 2015)

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Dynamic building stock models (Camarasa *et al.*, 2022; Giraudet *et al.*, 2021)

- Limitations: exogenous assumptions regarding energy supply
- **Our contributions**:
  - Explicitly account for the interaction between demand and supply.
  - Endogenize optimal choice for policy instrument.

Related literature

Energy system models

- Brown *et al.*, 2018; Zeyen *et al.*, 2021; Mandel *et al.*, 2023
- Limitations: exogenous assumptions on demand, focus on first-best solutions by disregarding the decentralized investment decisions.

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- Limitations: exogenous assumptions on demand, focus on first-best solutions by disregarding the decentralized investment decisions.
- **Our contributions**
  - Provide a framework to quantify variations in total costs between first-best setting and second-best settings.

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Building stock model: Res-IRF

Dynamic microsimulation model of the energy performance of the building stock and space heating consumption in France.

- Extensive description of **heterogeneity of the dwelling stock**
- Investment decisions (insulation and heating system switch) result from **discrete choice models**.

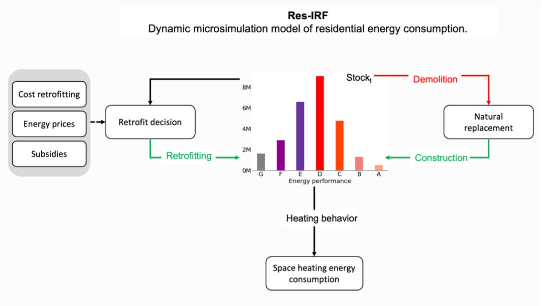


Figure: Res-IRF model

Energy system model: EOLES

Optimization of **investment and operation** by minimizing total costs while satisfying energy demand.

- **Hourly** temporal resolution
- Vector-coupling: electricity, methane, hydrogen
- Economic parameters and demand projections: RTE, 2022

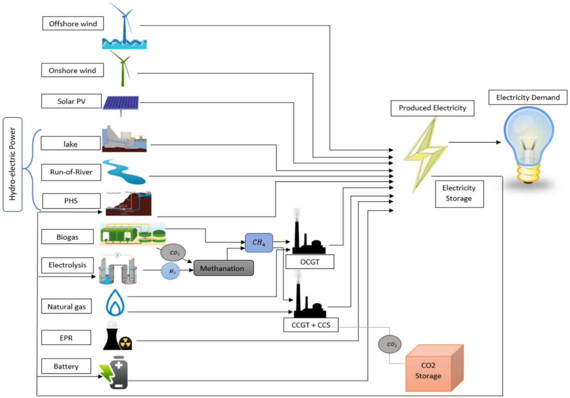


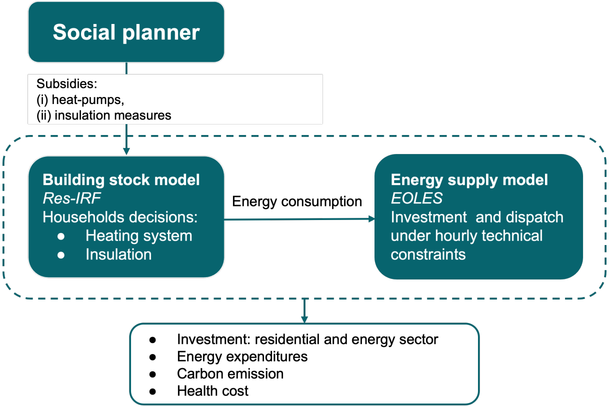
Figure: EOLES model. Source: Shirizadeh & Quirion, 2021

Integrated demand-supply framework

Social planner **minimizes total costs**:

- energy system costs
- heater and insulation investment costs
- operational costs
- health costs

Complex optimization problem: solved through **bayesian optimization** framework.



Subsidy design scenarios

We simulate an ad valorem subsidy targeting heat pumps in all scenarios, while we consider **different ad valorem subsidy designs for insulation.**

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Second-best scenarios

- *Uniform*: **all insulation measures** are eligible for the rebate.

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Second-best scenarios

- *Uniform*: **all insulation measures** are eligible for the rebate.
- *Deep renovation*: only **deep insulation measures** (i.e., an upgrade of at least two energy performance certificates levels) are eligible for the rebate.

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The first-best scenario

- Energy efficiency **reduces by 38 % the residential space heating consumption** in 2050 compared to 2020
  - 25 % coming from investments in insulation
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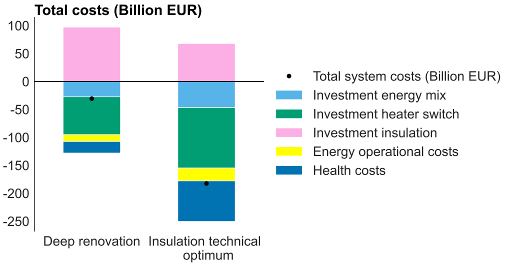
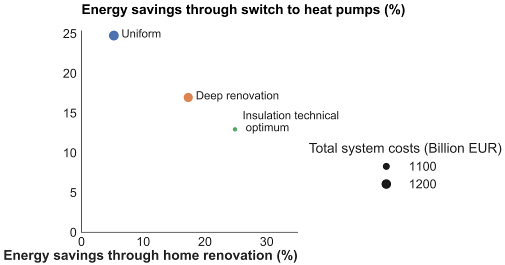
- Energy efficiency investment are prioritized in the **least energy-efficient buildings**.
- Important investment in **energy mix decarbonization**:
  - 84 % of electricity production generated with renewable sources

Second-best subsidy designs



(a)



(b)

Figure: Comparison of subsidy designs. a) Difference of total annualized system costs over period 2025-2050 compared to the uniform subsidy scenario. b) Savings from insulation and heat pumps in 2050.

Comparison with single sector modelling framework

- Exogenous assumptions on **carbon content and energy costs**.
- Single sector approaches yield **higher total system costs**.
- With assumption of higher carbon content: no solution
  - **Inconsistent** solution !

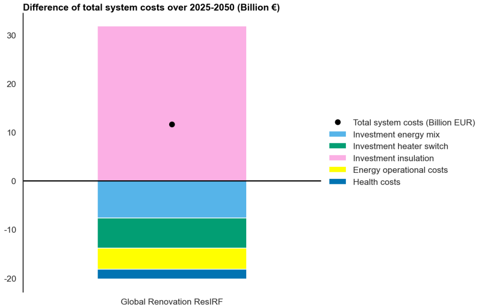


Figure: Difference of total system costs compared to the scenario in the coupling approach.

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  - Explore **distributional impacts**.

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Thank you !

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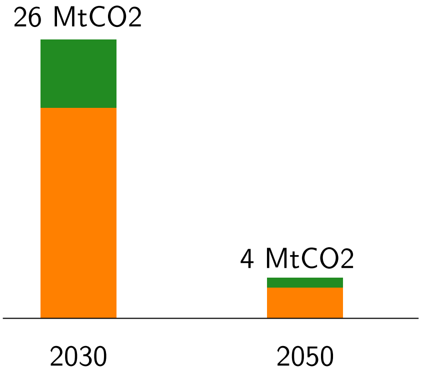
The specific case of France

- **Carbon tax** not politically feasible (Douenne & Fabre, 2022)
- Unparalleled diversity of **energy-efficiency subsidy programs** (Giraudet *et al.*, 2021)
  - MaPrimeRenov', income tax credit, ...
- **A peculiar energy system**
  - Low-carbon electricity, but **important investment needs** in the future
  - High prevalence of electricity to satisfy heating demand

Integrated demand-supply framework

- Optimization under **global carbon budget** constraint
  - Residential + energy mix emissions
- **Myopic framework**: iterative 5-year time steps.



Evolution of carbon budget.
Orange: residential. Green: energy mix.

Conservative assumptions on energy mix

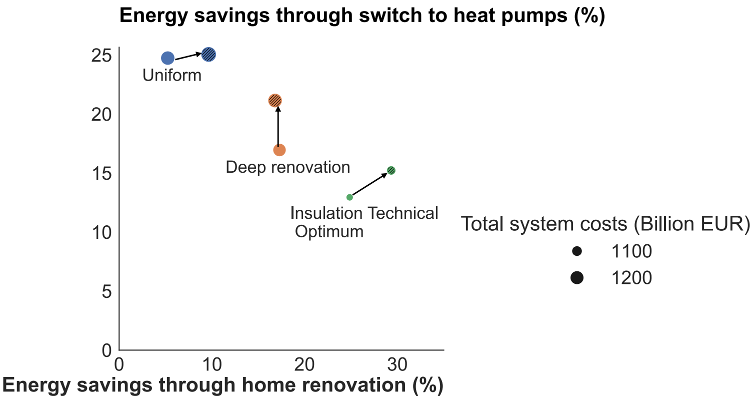


Figure: Comparison of savings from insulation and fuel switch across different subsidy scenarios and across two variants of the potential for renewable gas. Dashed points: scenario with decreased biogas potential.

Limitations

- Focus on portfolio of two subsidies

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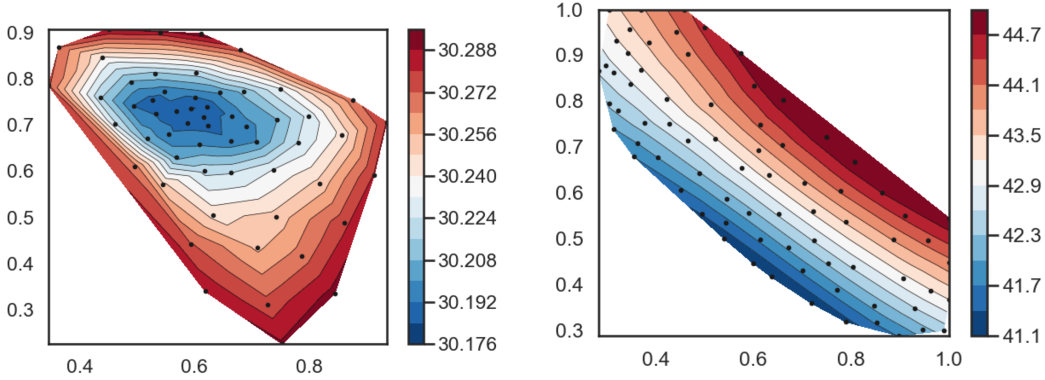
- **Constant household energy price** approach to mitigate the influence of political decisions

Summary of subsidy designs

	Unit	Uniform	Global Renovation	Proportional	Insulation Technical Optimum
Investments heat pumps	Billion EUR	277	188	192	143
Subsidies heat pumps	Billion EUR	268	138	142	114
Investments insulation	Billion EUR	92	200	169	111
Subsidies insulation	Billion EUR	27	125	105	NA
Savings heater	TWh	69	47	48	37
Savings insulation	TWh	15	48	48	70
Renewable capacity	GW	246	222	228	226
Peaking plants capacity	GW	51	48	48	45
Onshore/offshore production	TWh (%)	386 (51)	386 (54)	386 (53)	386 (54)
PV production	TWh (%)	198 (26)	163 (22)	172 (24)	170 (24)
Peaking plants production	TWh (%)	18 (2.4)	15 (2.0)	15 (2.1)	13 (1.7)
Nuclear production	TWh (%)	98 (13)	102 (14)	100 (14)	99 (14)
Total system costs	B EUR per year	48.5	47.3	46.4	41.2

Table: Summary of comparison of subsidy scenarios. In the table, values in billion euros are actual invested values. On the other hand, the metric Total system costs refers to the average of annualized costs over time period 2025-2050.

Bayesian Optimization

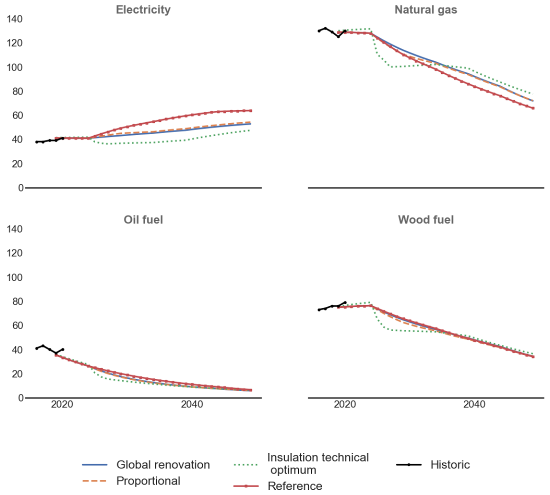


(a) Integrated approach.

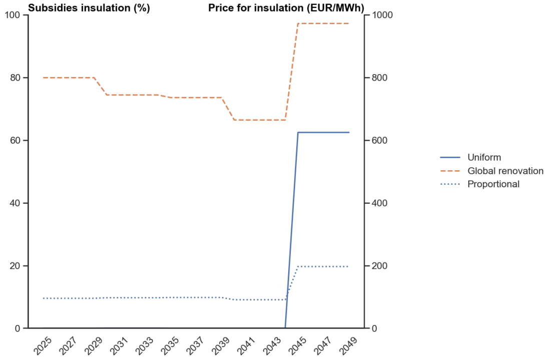
(b) Single sector approach

Figure: Black dots correspond to the sampling points used in the bayesian optimization framework.

Evolution of space heating consumption



Evolution of subsidies



(a) Evolution of insulation subsidies.

(b) Evolution of ad valorem heater subsidies.

Figure: Evolution of subsidies for the scenarios *Uniform*, *Global Renovation* and *Proportional*.

Evolution of heat pump stock

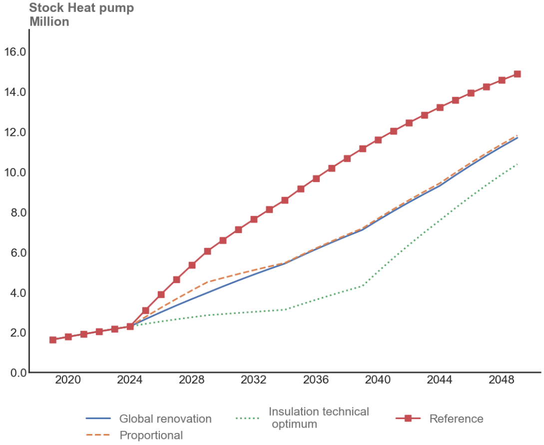
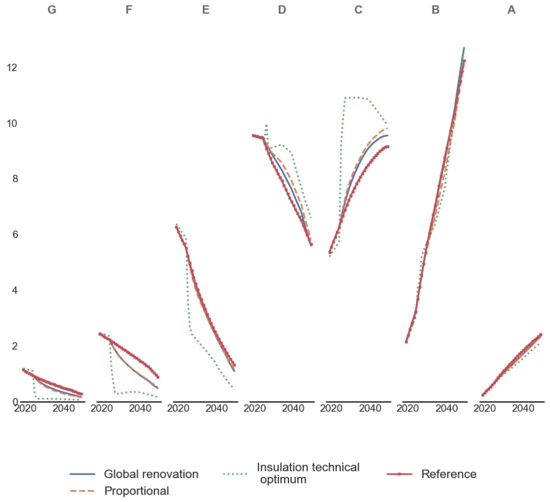
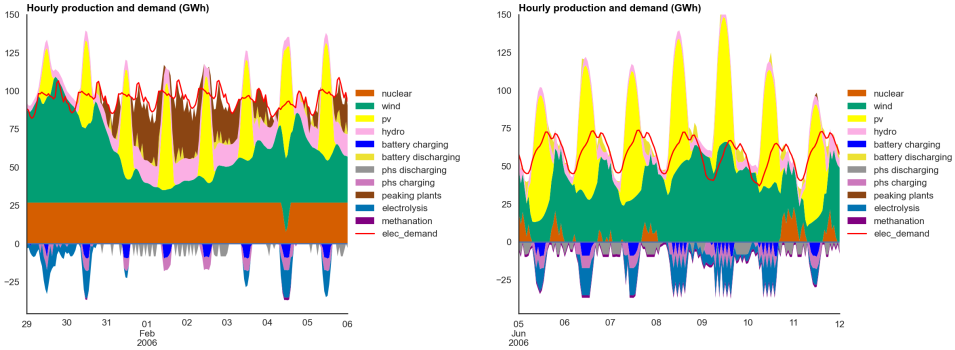


Figure: Development of the stock of heat pumps in all scenarios.

Evolution of housing stock



Hourly generation



(a) Representative week of February

(b) Representative week of June

Figure: Hourly generation for two representative weeks in winter and summer, for the *Global Renovation* scenario. The hourly demand profile is different in February and June due to the strong seasonality of heating demand.

Implicit carbon value

Year	Uniform	Global Renovation	Proportional	Insulation Technical Optimum
2030	586	430	390	151
2035	520	493	486	349
2040	511	520	515	588
2045	513	600	587	715
2050	1230	1080	1154	1337

Table: Evolution of implicit carbon value in €/tCO_2 for each subsidy scenario.