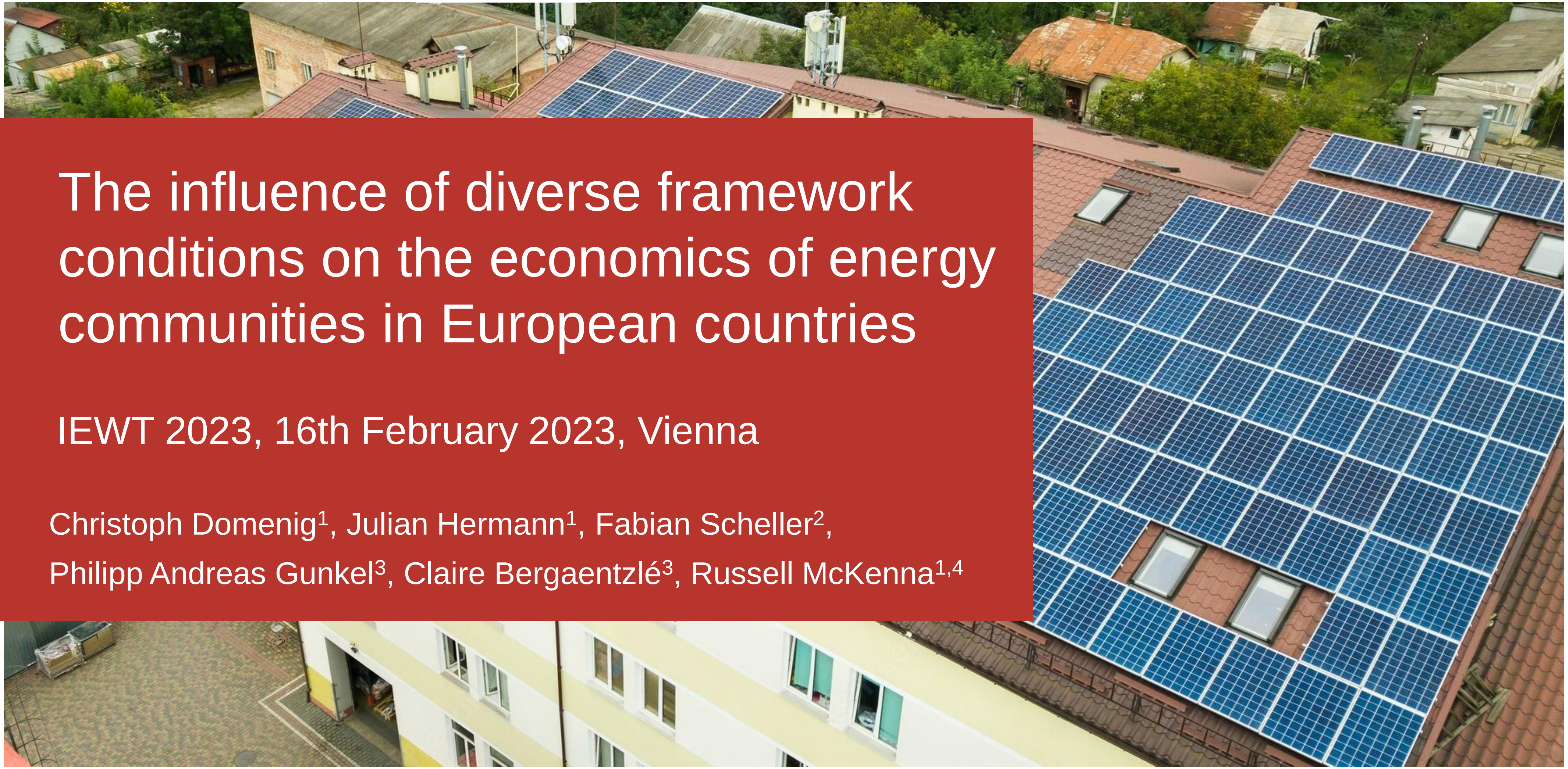

The influence of diverse framework conditions on the economics of energy communities in European countries

IEWT 2023, 16th February 2023, Vienna

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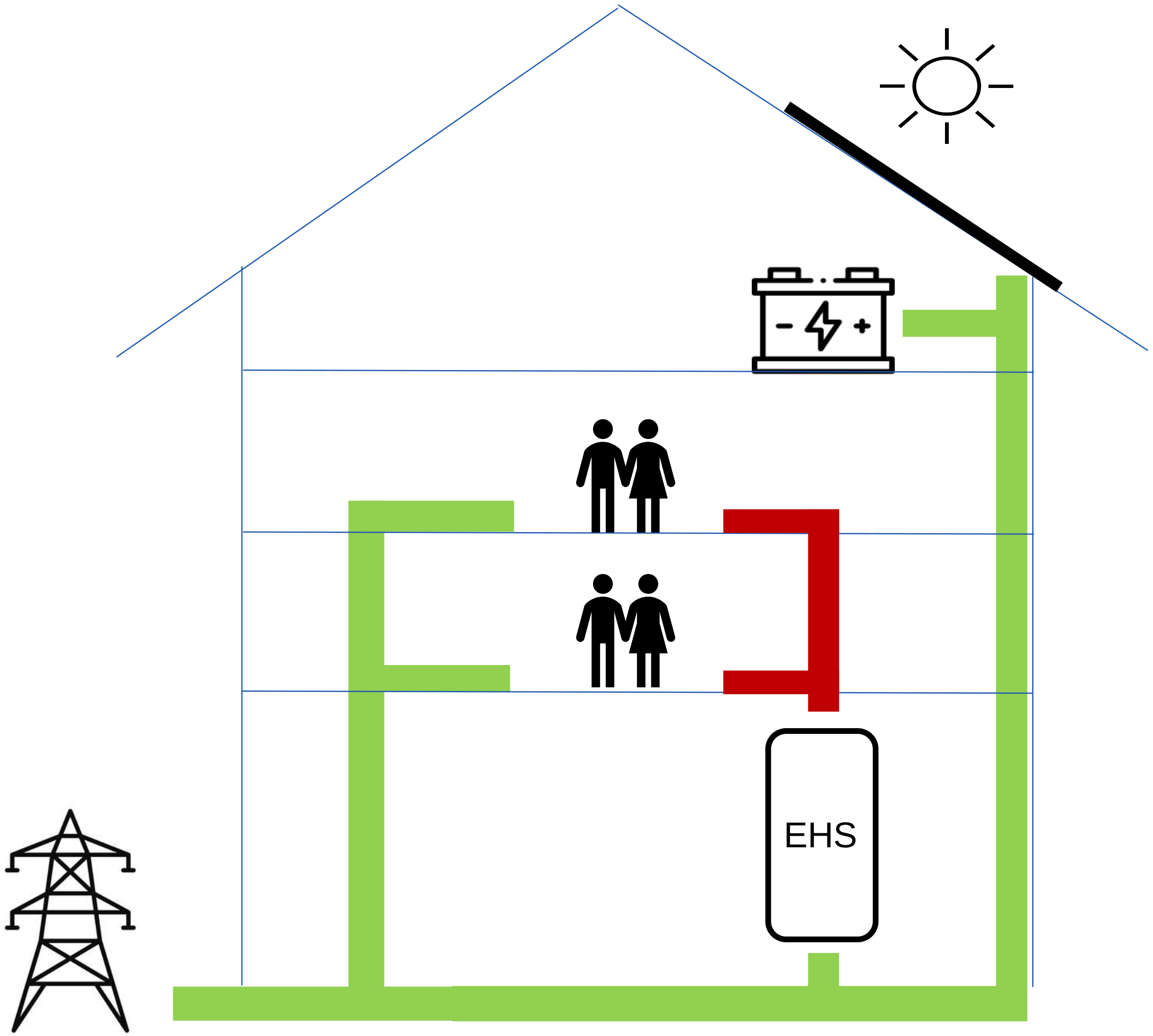
Split incentives in multi-family buildings (MFBs) represent a problem for both climate change and energy poverty

MFBs (~ 50% of EU residential buildings) show large potential for energy efficient renovation and low-carbon building energy systems (BES)

Split incentives in renter-occupied MFB represent a significant obstacle

Leaving renters potentially traped in energy poverty

Forming collective self-consumption (CSC) communities in MFBs could represent a promising solution



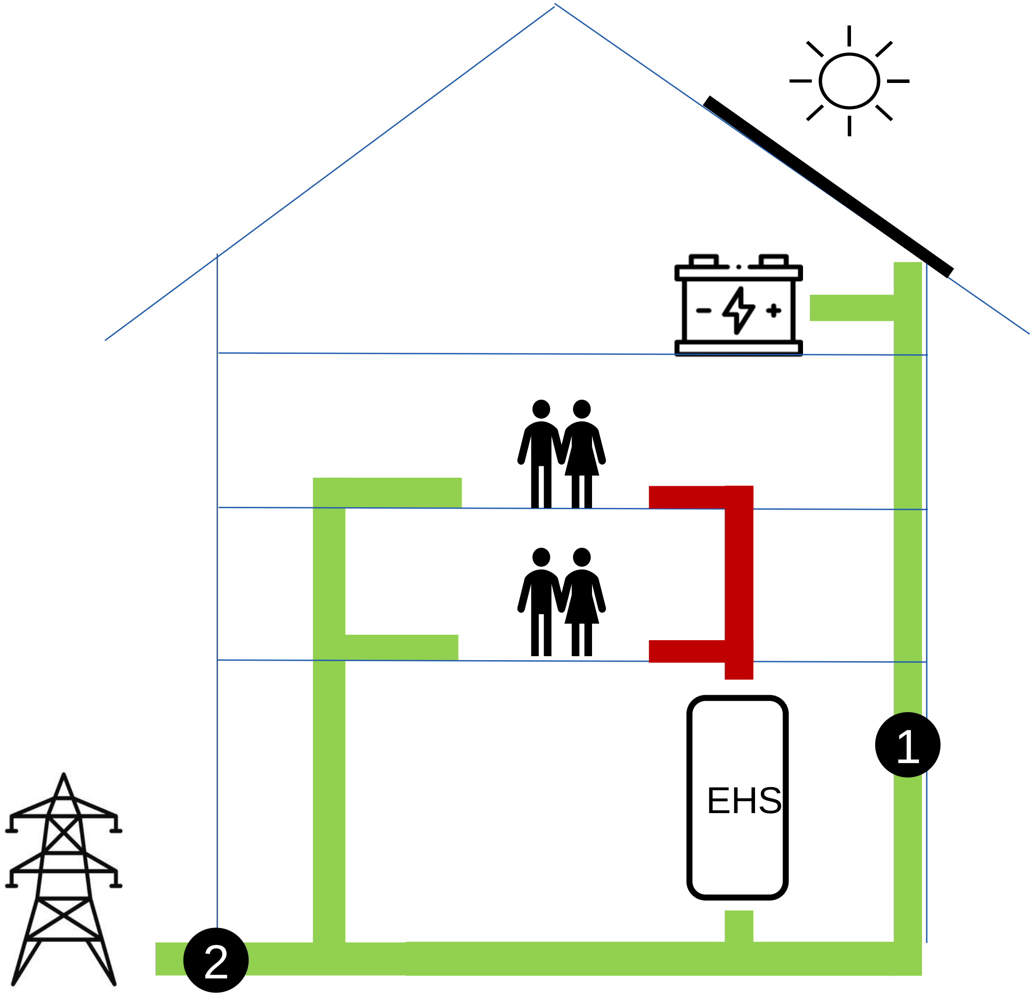
EHS = Electric Heating System

Research Question

1. Can CSC communities support the diffusion of low-carbon BES* in MFBs while helping to alleviate energy poverty?

*BES=Building Energy Sytems

CSC policy frameworks show large differences in European countries



1	full grid tariff + e-taxes	only VAT, max. 50% of cost benefit to owner	only VAT + subsidy, max. 90% of CoE
2	BAU price, paid to utility	reduced price, paid to owner	reduced price, paid to owner

EHS = Electric Heating System, BAU = Business As Usual

Research Question

1. Can CSC communities support the diffusion of low-carbon BES* in MFBs while helping to alleviate energy poverty?

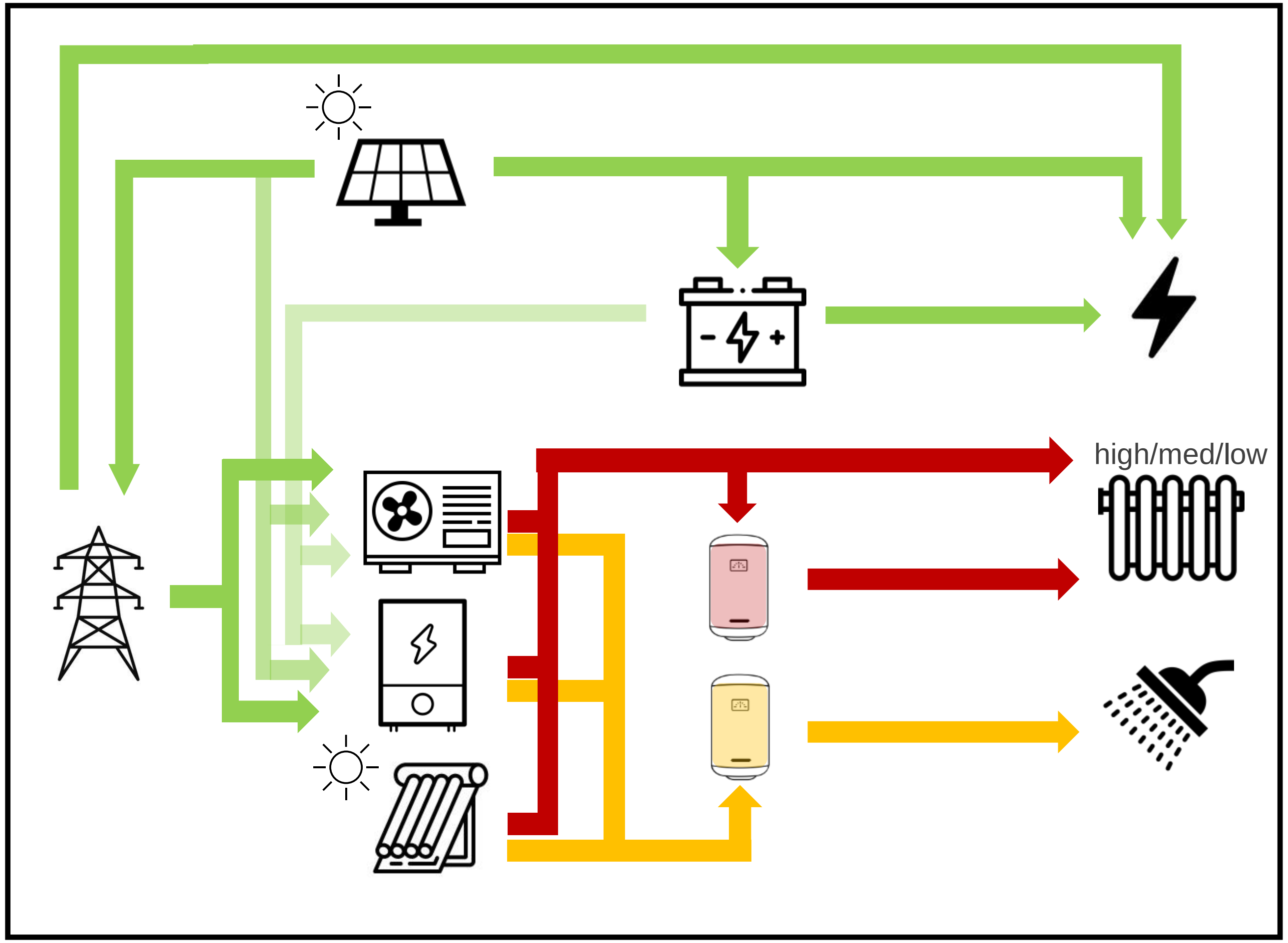
2. What impact do different European CSC policies have on these goals?

*BES=Building Energy Sytems

The policy frameworks are integrated into a MILP model that optimizes the design and operation of a CSC community in an MFB for one year

Input

- Technology Data
- Passive Retrofit Costs
- Market Data
- CSC Price Matrix
- Demand Data
- Weather Data
- Building Data



Output

- Technology Capacities
- Energy Flows
- Passive Retrofit Level
- Owner Income
- Renter Savings
- Other Stakeholder Costs/Benefits

The model maximizes the annual income of the building owner

Maximize:

Total Annual Income of Owner =

- Annualized Active Retrofit Costs
- Annualized Passive Retrofit Costs
- PV and Battery O&M Costs

+ Increased Rental Income
+ PV Cashflows*

PV Renters, PV Heating, PV Export

Subject to:

Binary Technology and Storage Investment

Binary Passive Retrofit Investment

Minimum HP Retrofit Constraint

Technology and Storage Models

Demand Node Balance

Max/Min Capacity and Flow Constraints

Hot Water Tank Constraints

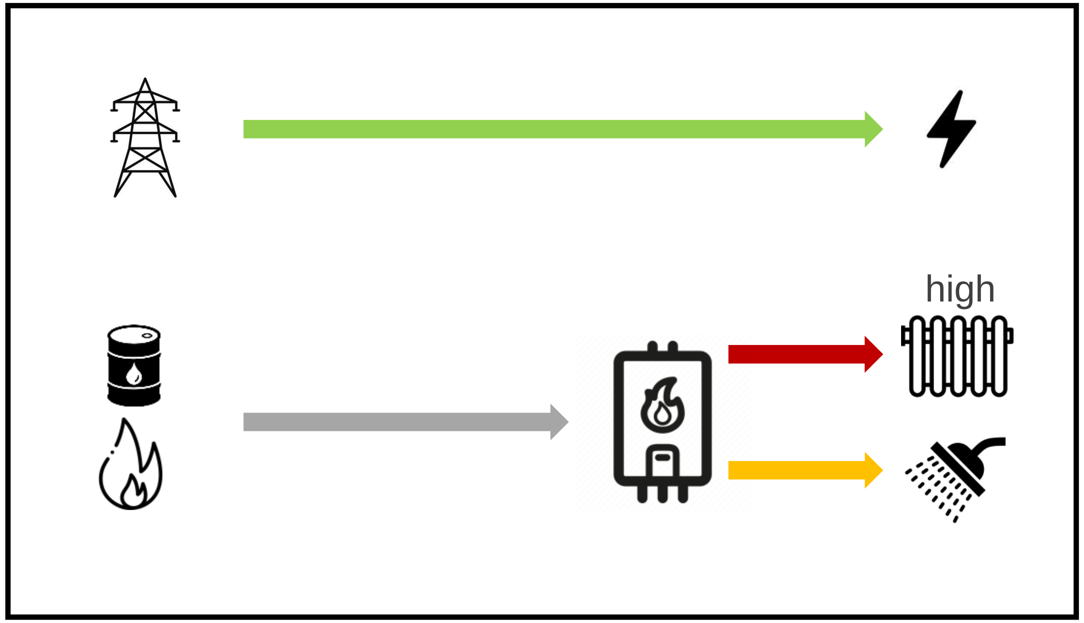
Rent Increase Constraints

*No income taxes, metering and administrative costs considered

The BAU case comprises the operation of the unrenovated MFB without forming an energy community

Rent increase <= 8% of value active/passive heating upgrades

Rent increase + new heating costs <= 90% of BAU heating costs



The three different CSC policies are tested on a level playing field under varying electricity tax scenarios

Category	Input Parameter	Value
Building	Space Heating Demand	high
	Heating System	low efficiency boiler
	Size	8 apartments
	Location/Climate	CH
Financial	Investment	DE
	Discount Rate	4 %
Cost of Electricity	Wholesale Energy Price	Ø 10.6 ct/kWh
	Grid Tariff	10.1* and 5.0* ct/kWh

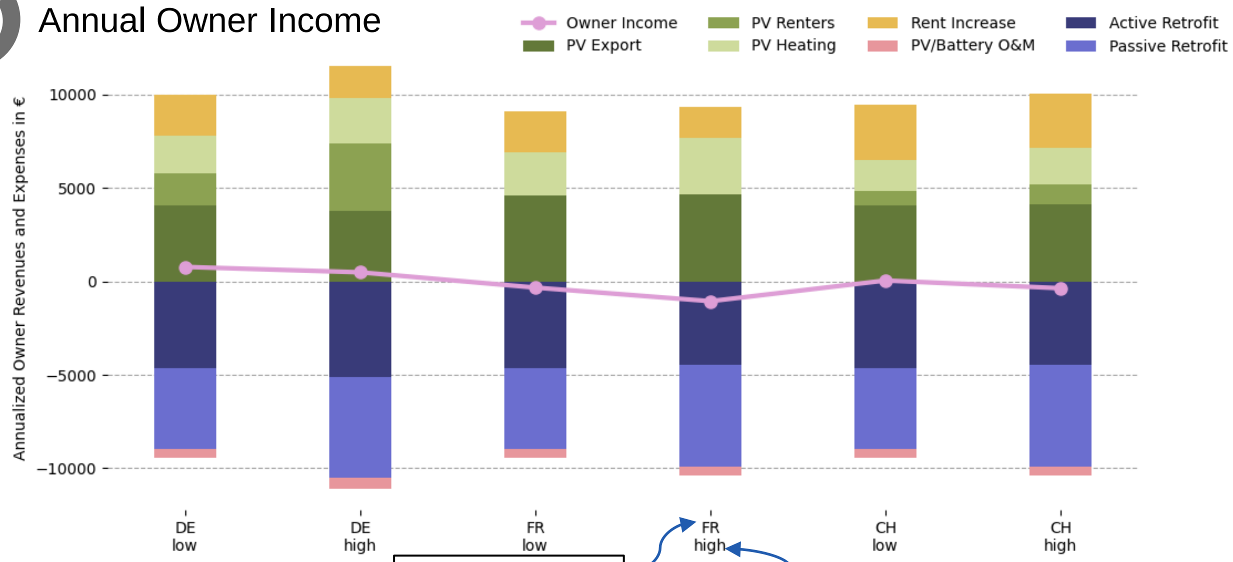
+ Level playing field to isolate policy effects

- Level playing field does not reflect the specific boundary conditions in every country

Results

High passive retrofitting costs limit owner value in all scenarios

Annual Owner Income



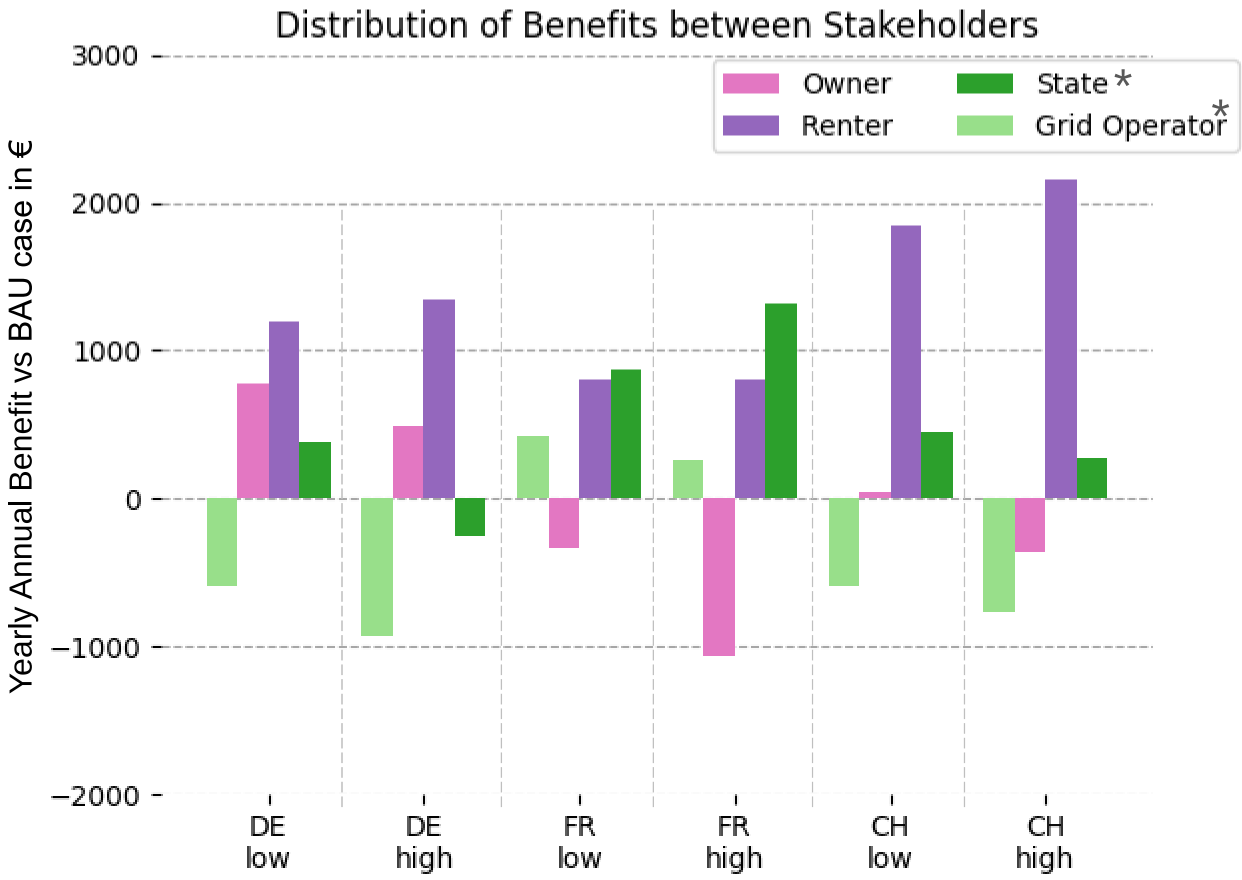
Policy Framework

Electricity Tax Level

Policy Framework

Electricity Tax Level

Larger CSC community benefits lead to lost electricity grid tariff revenue



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Take-home messages

a) CSC communities in MFBs can …

1 ... support the diffusion of low-carbon BES
policy levers: e-grid tariff / e-tax exemptions and subsidies

2 … help alleviate energy poverty by reducing renters utility expenses
policy levers: lower grid e-costs and 50/50 CSC electricity profit

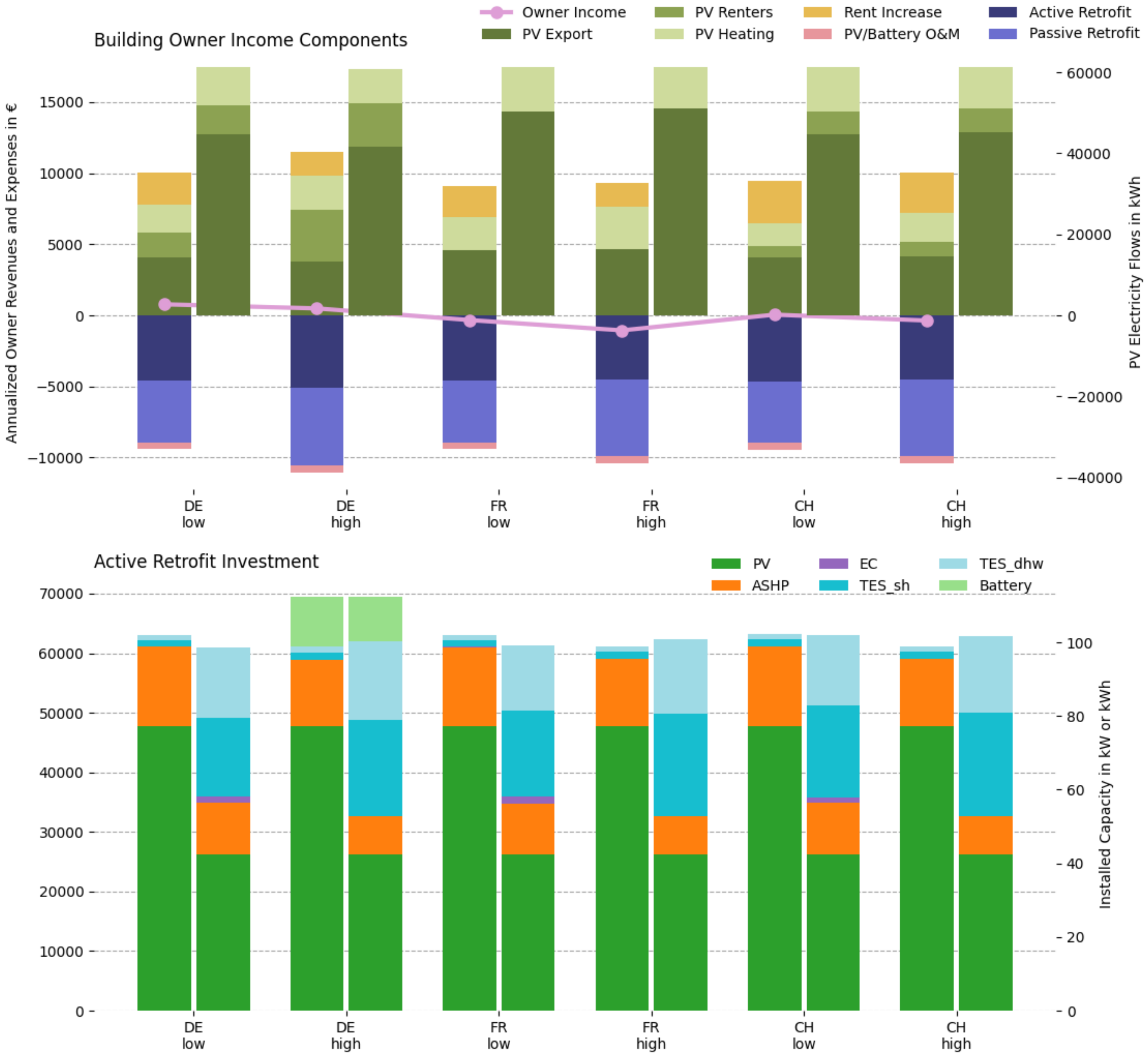
b) Renovation costs pose a significant barrier to 1 + 2

c) Impact of different CSC policies on 1 + 2 ?

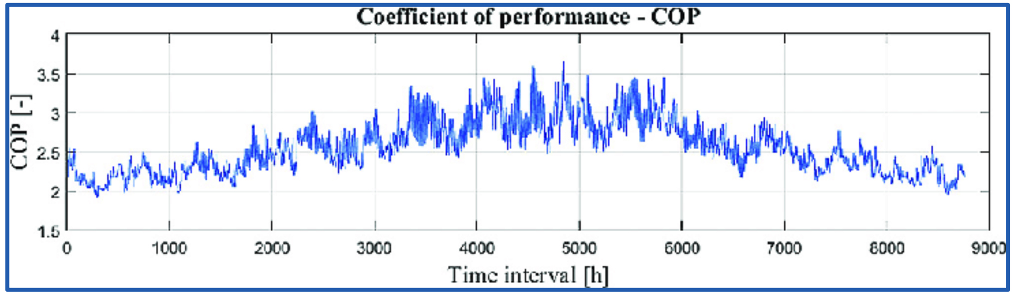
‘There is no free lunch’: Larger benefit for renter and owners -> higher burden for e-tax and e-grid tariff budgets

Appendix

Electricity Tax Scenarios



Modelling Complexity Analysis



Example of hourly COP taken from Pavičević et al. 2017

Input
- Temperature Profile
- Comfort Limit
- Building Data
- Solar Irradiance

→ **Flexible Heating Model** →

Output
- Flexible Heat Demand
- Retrofit Investment Decision

The three different CSC policies are tested on a level playing field under varying electricity tax scenarios

Category	Input Parameter	Value
Building	Space Heating Demand	high
	Heating System	low efficiency boiler
	Building Size	8 apartments
Financial	Investment Costs	DE
	Discount Rate	4 %
Cost of Electricity	Wholesale Energy Price	Ø 10.6 ct/kWh
	Grid Tariff	10.1* and 5.0* ct/kWh
	Electricity Tax Scenario	low-high
Other	CSC Policy	DE-FR-CH
	Climate Data	CH

*Values for 2 different electricity consumption bands — Fixed (light blue) / Scenario-specific (light green)

Goals

1. Asses whether CSC communities can support the diffusion of low-carbon BES in MFBs while helping to alleviate energy poverty
2. Identify efficiency of different European CSC policies at achieving 1

Two research fields looking at BES investment in MFBs from a different perspective

EC

- Individual actors
- Detailed policy frameworks
- Distributional Aspects

BEP

- Building perspective
- Detailed thermal models
- Renovation

\+ Country comparison

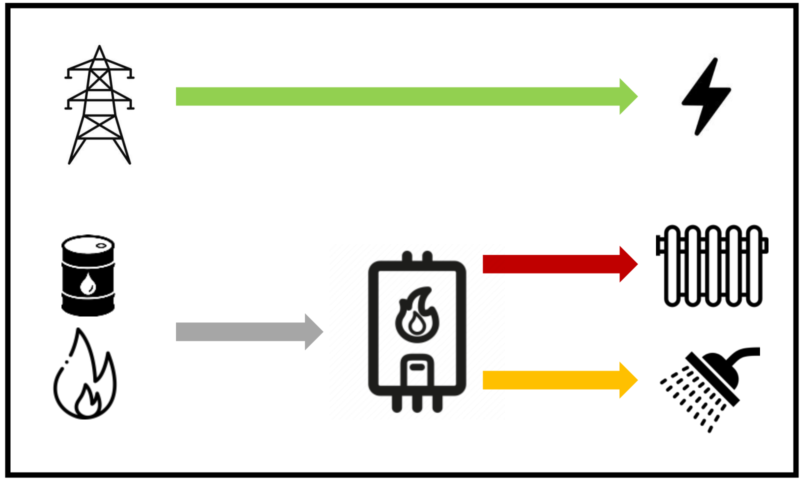
The BAU case comprises the operation of the unrenovated building without forming an energy community

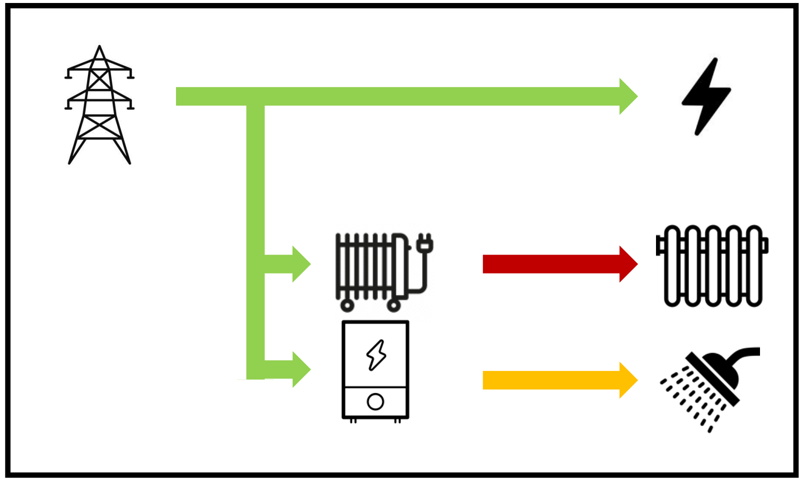
Rent increase <= 8% of value active/passive heating upgrades

Rent increase + new heating costs <= 90% of BAU heating costs

BAU Assumptions

Cost of Fossil Fuel:	7 ct/kWh
Cost of Electricity:	country-specific
Annual SH Demand:	unrenovated case
Owner Income:	(rent)
Renter Expenses:	(rent) + utilities





Energy Policy Framework Comparison

	France	Switzerland	Germany
Participation	max. 2km* radius; public grid usage allowed	same building or connected properties	same building or apartment block
Governance	definition of legal person required	part of rental law	landlord is energy supplier
Capacity Constraints	< 3MW	> 10% grid connection power	< 100 kW*
Price PV electricity	-	Owner's profit max. 50% between original CoE and solar energy price	max. 90% of original CoE
Price grid electricity	payed directly to utility (H4)	payed to landlord, no markup (H6)	payed to landlord, with markup (H6)
Taxes	full grid tariffs and taxes	no grid tariffs and taxes except VAT	no grid tariffs and taxes except VAT + subsidy

Cost of Elecitricity Components 2021

Country	Consumption Band (kWh)	Wholesale Energy Price	Grid Tariffs	Taxes (incl. VAT)	Total
Germany	1.000 - 2.500	9.6	9.4	17.1	36.0
	2.500 - 5.000	9.6	7.8	16.6	34.0
	>15.000	9.6	4.9	15.3	29.8
France	1.000 - 2.500	10.9	8.0	7.3	26.2
	2.500 - 5.000	10.9	5.9	7.2	24.0
	>15.000	10.9	4.3	6.8	21.9
Switzerland	1.800	11.4	13.0	5.1	29.7
	4.500	11.4	9.5	5.0	25.9
	25.000	11.4	6.0	4.6	22.0

Technology and Retrofit Costs

Technologies	Fixed Costs (€)	Variable Costs	OPEX	Efficiency	Self-Discharge Losses	Max Charge	Max Size	Lifetime (years)
Solar PV	1000	190 €/m2	0.01	0.17	-	-	250 m2	20
Solar Thermal	4000	350 €/m2	0.01	0.7	-	-	250 m2	20
ASHP	5000	600 €/kWth	0.02	3.2/2.1	-	-	30 kW	20
GSHP	-	-	-	-	-	-	-	-
Pellet Boiler	10000	300 €/kWth	0.03	0.9	-	-	30 kW	20
Electric Coil	0	60 €/kWth	0.01	1	-	-	30 kW	30
Buffer Tank	0	45 €/kWh	0.01	0.99*	0.006	200 kW	200 kWh	25
Battery	1000	250 €/kWh	0.01	0.95*	0.0001	100 kW	200 kWh	20

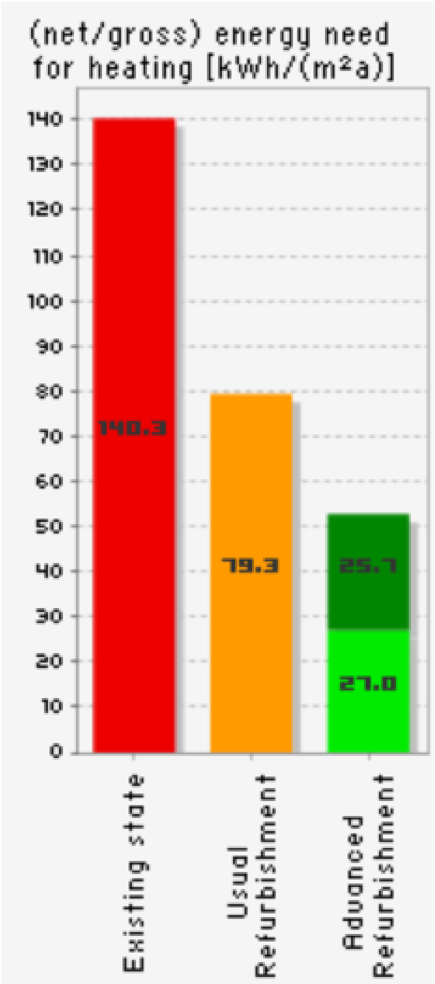
*charge/discharge efficiency

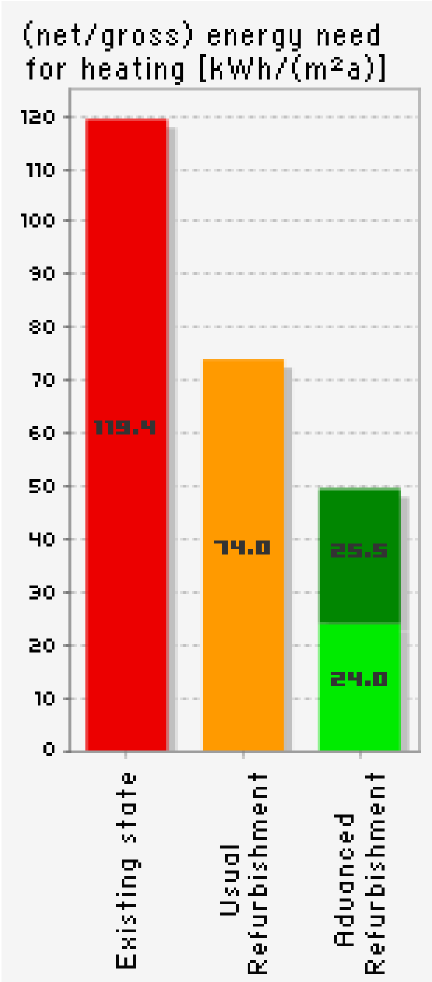
Reference Floor Area	Usual Refurbishment	Advanced Refurbishment
469 m2	93.000 €	117.000 €

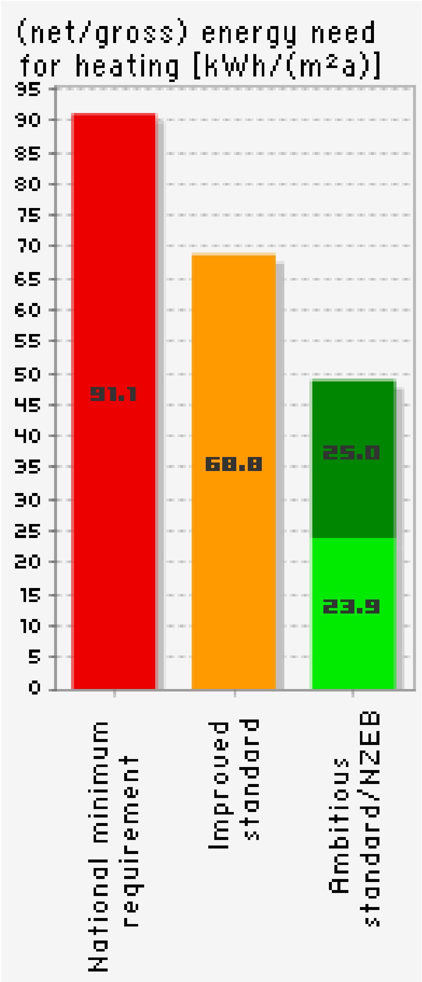
Input Data Sources

Input	Sources
Technology Data	PV: Brauer et al. 2022, Other: Kotzur 2018
Retrofit Costs	Based on Tabula and IWU Report
Electricity Prices	Eurostat, ElCom, ENTSOE
Electricity Demand	Gunkel et al. 2023
Temperature Data	PVGIS
Building Data	Tabula
Hot Water Demand	Based on HotMaps D2.3 WP2 Report
Solar Irradiation	PVGIS

Heat Demand for Building Scenarios

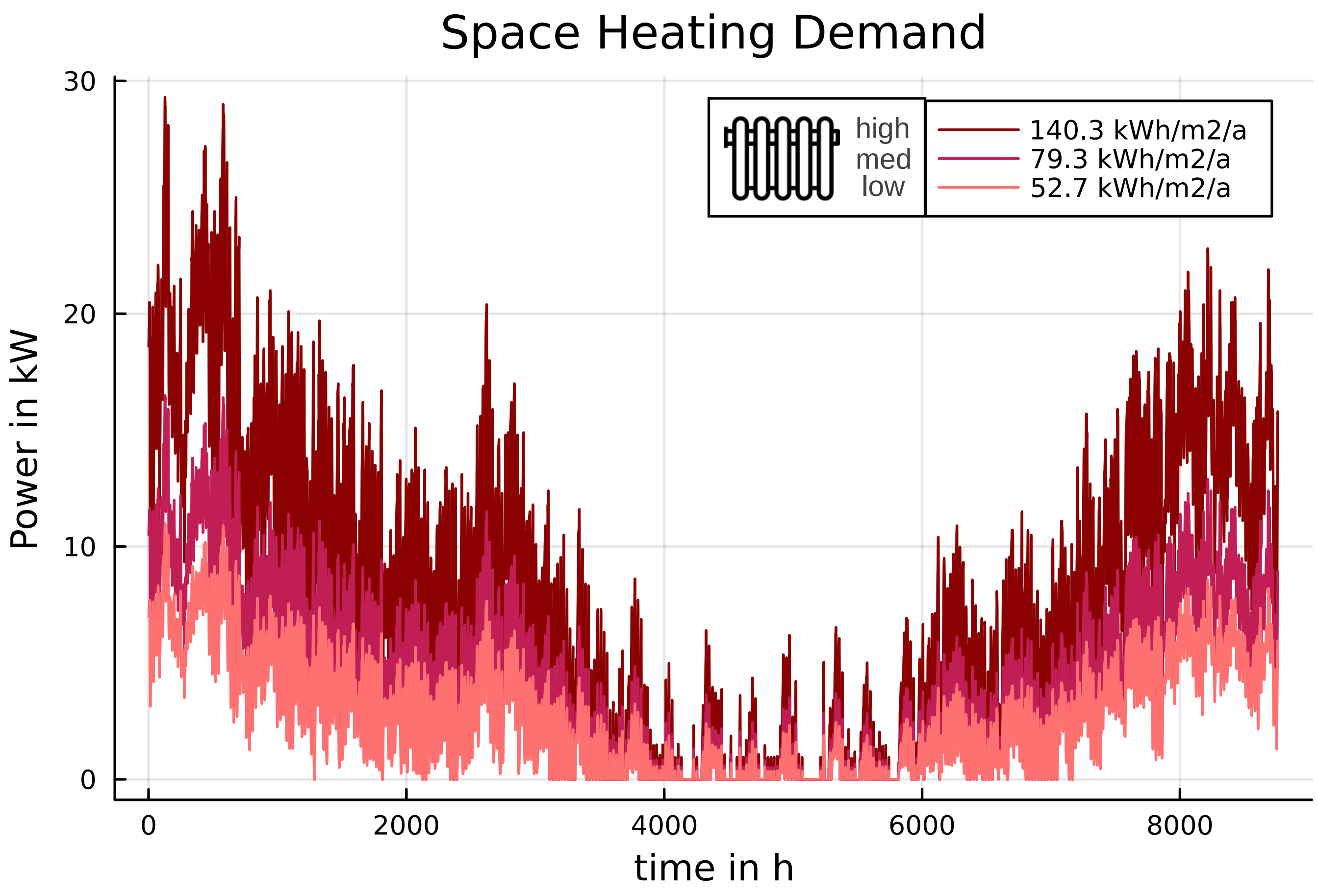


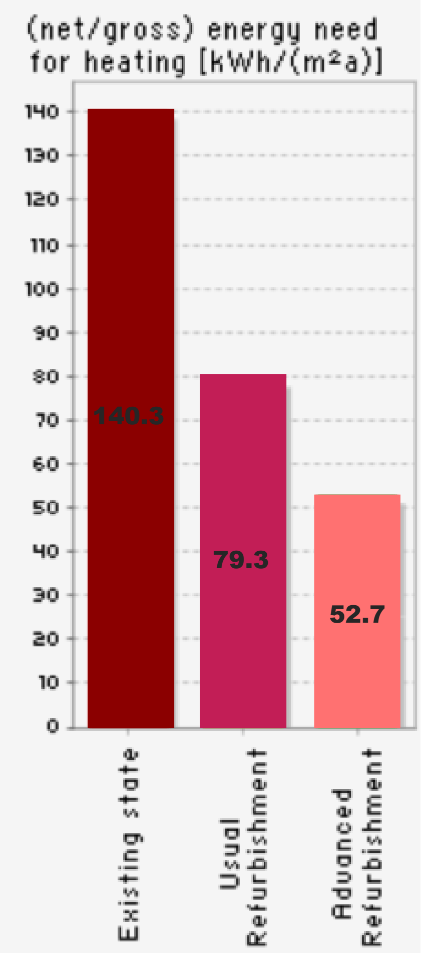




Source: Tabula Webtool

Three passive retrofit levels are considered simultaneously in the model

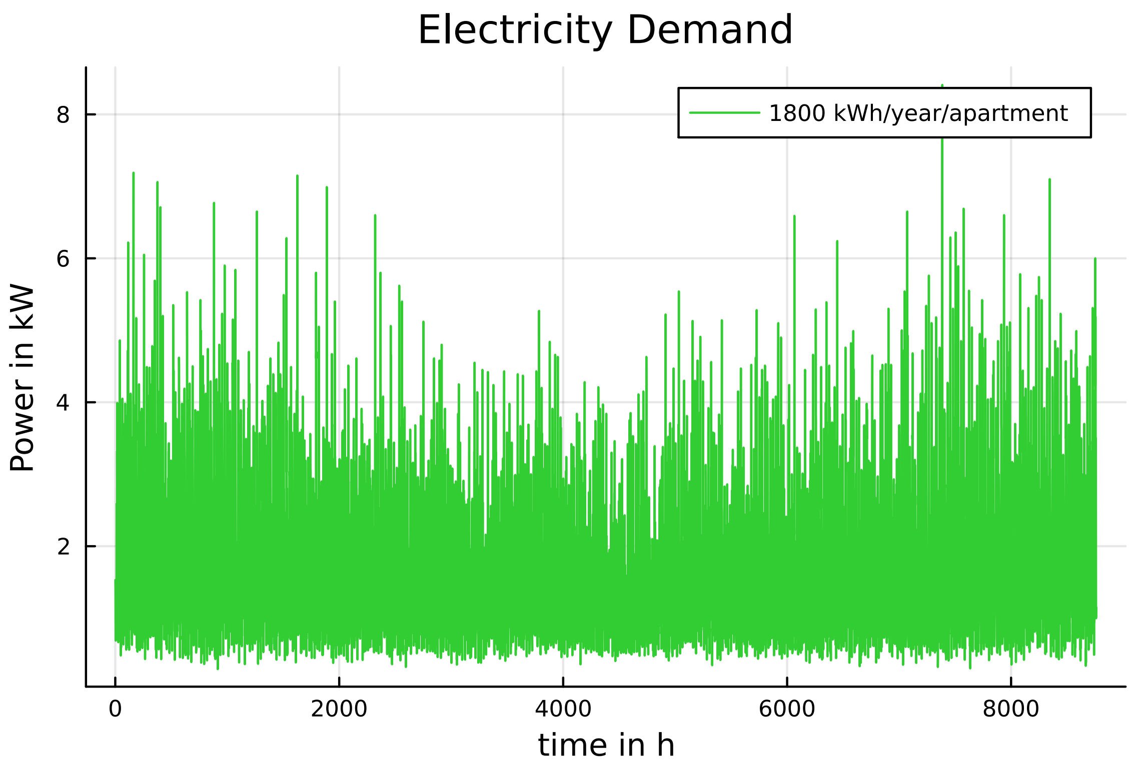


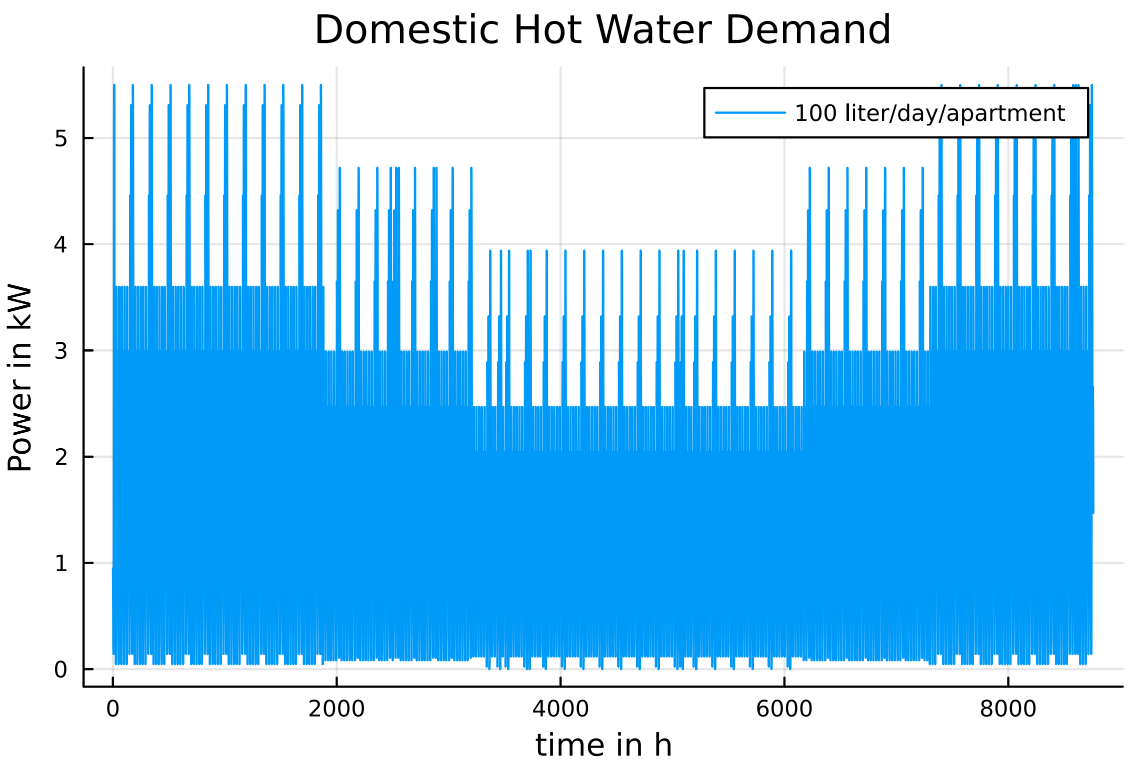


Building Size Class:
MFH
Construction Period:
1949...1957
Reference Floor Area:
486 m^2
Heat Supply System:
gas central heating, poor efficiency (multi-unit housing)
Climate Region
Default (National (EnEV 2009))

Adapted from Tabula Webtool

Demand Profiles





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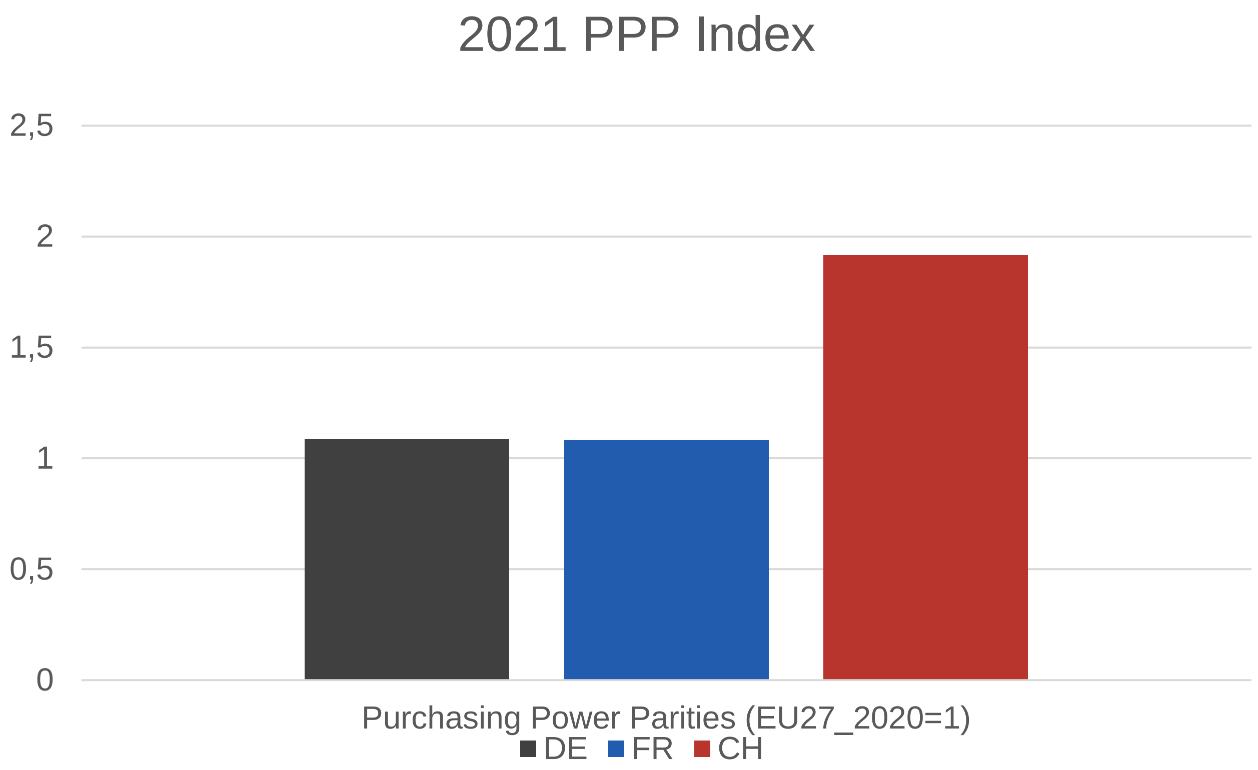
PPP Index Accross Case Study Countries



Source: Purchasing power parities (PPPs), price level indices and real expenditures for ESA 2010 aggregates, Eurostat, 2023.

Objective Function

$$
\begin{aligned}
max.\ TAI_{owner} = \\
& - \sum_{g = i \cup k} (\mathbf{Cap}_g * c_g^{var} + \mathbf{X}_g * c_g^{fix}) * a_g \\
& - \sum_{y = PV,BAT} (\mathbf{Cap}_y * c_y^{var} + \mathbf{X}_y * c_y^{fix}) * c_y^{opex} \\
& - \sum_{r} \mathbf{X}_r * c_r^{retro} * a_r \\
& + \sum_{i,j,t} \mathbf{E}_{i,j,t}^{tech} * C_{i,j,t}^{tech,own} + \sum_{k,l,t} \mathbf{E}_{k,l,t}^{sto} * C_{k,l,t}^{sto,own} + \sum_{m,n,t} \mathbf{E}_{m,n,t}^{imprt} * C_{m,n,t}^{imprt,own} \\
& + \mathbf{R}
\end{aligned}
$$

$i =$[Technologies] , $j =$[Technologies, Storages, Demand Types, Electricity Export]
$k =$[Storages] , $l =$[Technologies, Demand Types]
$m =$[Energy Carriers] , $n =$[Technologies, Demand Types]
$r =$ [Retrofit Scenarios]
$d =$ [Demand Types]

Various Constraints

Design Variable Constraints

$$\mathbf{X}_g \in \{0,1\} \quad \forall\, g = i \cup k$$

$$\mathbf{X}_{TES_{dhw}} = 1$$

$$\mathbf{X}_r \in \{0,1\} \quad \forall\, r$$

$$\sum_r \mathbf{X}_r = 1$$

$$X_{HP} >= X_{usual} + X_{advanced}$$

$$0 \leq \mathbf{Cap}_g \leq \mathbf{X}_g * Cap_g^{max} \quad \forall\, g = i \cup k$$

Min and Max Energy Flow Constraints:

$$0 \leq \mathbf{E}_{i,j,t}^{tech}\,,\ \mathbf{E}_{k,l,t}^{sto}\,,\ \mathbf{E}_{m,n,t}^{imprt} \quad \forall\, i,j,k,l,m,n,t$$

$$\sum_j \mathbf{E}_{i,j,t}^{tech} \leq \mathbf{Cap}_i * \Delta\tau \quad \forall\, t, \{i \mid i_{in} \neq \text{sun}\}$$

$$\sum_i \mathbf{E}_{i,k,t}^{tech} \leq \mathbf{Cap}_k * \delta_k^c \quad \forall\, k,t$$

$$\sum_l \mathbf{E}_{k,l,t}^{sto} \leq \mathbf{Cap}_k * \delta_k^d \quad \forall\, k,t$$

$$\sum_n \mathbf{E}_{m,n,t}^{imprt} \leq Cap_m^{max} * \Delta\tau \quad \forall\, m,t$$

$$\mathbf{E}_{i,elxp,t}^{tech} \leq Cap_{elxp}^{max} * \Delta\tau \quad \forall i,t$$

Initiliaze Zeros in Energy Flow Matrix

<u>Setting Nonphysical Energy Flows to Zero:</u>

$$\mathbf{E}^{tech}_{i,j,t} = 0 \quad \forall t\ , \{i, j/\{elxp\} \mid\ i_{out} \cap j_{in} = 0\}$$

$$\mathbf{E}^{tech}_{i,elxp,t} = 0 \quad \forall t\ , \{i \mid i_{out} \cap elxp = 0\}$$

$$\mathbf{E}^{tech}_{i,dhw,t} = 0 \quad \forall i, t$$

$$\mathbf{E}^{sto}_{k,l,t} = 0 \quad \forall t\ , \{k, l \mid\ k_{out} \cap l_{in} = 0\}$$

$$\mathbf{E}^{imprt}_{m,n,t} = 0 \quad \forall t\ , \{m, n \mid\ m_{out} \cap n_{in} = 0\}$$

Technology Models

Technology Node Balance:

$$W_{i,t} = \sum_j \left(\frac{1}{\eta_{i,d}} * \mathbf{E}^{tech}_{i,j,t} \text{ if } i_{out} \cap j_{in} \neq 0\right) \quad \forall i, t$$

$$I_t^{DNI} * \Delta\tau * \mathbf{Cap}_i = W_{i,t} \quad \forall t \text{ , } \{i \mid i_{in} = \text{sun}\}$$

$$\sum_m \mathbf{E}^{imprt}_{m,i,t} + \sum_k \mathbf{E}^{sto}_{k,i,t} + \sum_{v=\forall i} \mathbf{E}^{tech}_{v,i,t} = W_{i,t} \quad \forall t \text{ , } \{i \mid i_{in} \neq \text{sun}\}$$

Storage Model
and Demand = Supply

$$0 \leq \mathbf{S}_{k,t} \leq \mathbf{Cap}_k \quad \forall k, t$$

$$\mathbf{S}_{k,1} = (\mathbf{X}_k * S_k^0) * (1 - \lambda_k) + \eta_k^c * \sum_i \mathbf{E}_{i,k,t}^{tech} + \frac{1}{\eta_k^d} * \sum_l \mathbf{E}_{k,l,t}^{sto} \quad \forall k$$

$$\mathbf{S}_{k,t} = \mathbf{S}_{k,t-1} * (1 - \lambda_k) + \eta_k^c * \sum_i \mathbf{E}_{i,k,t}^{tech} + \frac{1}{\eta_k^d} * \sum_l \mathbf{E}_{k,l,t}^{sto} \quad \forall k, \{t \mid 1 < t \leq T\}$$

$$\mathbf{S}_{k,T} = \mathbf{X}_k * S_k^0 \quad \forall k$$

Demand Node Balance:

$$\sum_m \mathbf{E}_{m,d,t}^{imprt} + \sum_k \mathbf{E}_{k,d,t}^{sto} + \sum_i \mathbf{E}_{i,d,t}^{tech} = \sum_r \mathbf{X}_r * \dot{Q}_{r,t}^d * \Delta\tau \quad \forall d, t$$

Rent Increase Constraints

Rent Increase Constraint:

$$\mathbf{R} <= 0.08 * (\sum_h \mathbf{Cap}_h * c_h^{var} + \mathbf{X}_h * c_h^{fix} + \sum_r \mathbf{X}_r * c_r^{retro})$$

$$\mathbf{R} <= 0.9 * \Big((\dot{Q}^{sh}_{bau,t} + \dot{Q}^{dhw}_{bau,t}) * \Delta\tau * \frac{c^{sh}_{bau}}{\eta^{sh}_{bau}} + (Cap_{bau} * c^{var}_{bau} + X_{bau} * c^{fix}_{bau}) * c^{opex}_{bau} \Big)$$
$$- \sum_{h,t} \Big(\sum_i \mathbf{E}^{tech}_{i,h,t} * C^{tech,rent}_{i,h,t} + \sum_k \mathbf{E}^{sto}_{k,h,t} * C^{sto,rent}_{k,h,t} + \sum_m \mathbf{E}^{imprt}_{m,h,t} * C^{imprt,rent}_{m,h,t} \Big)$$
$$- \sum_h (\mathbf{Cap}_h * c_h^{var} + \mathbf{X}_h * c_h^{fix}) * c_h^{opex}$$

EU Renovation Wave Goals