Justice in decarbonizing heating systems consistent with the Paris Climate Agreement: subsidy balance between landlords and tenants at the multi-apartment building level

Sebastian Zwickl-Bernhard[a,*], Hans Auer[a], Antonia Golab[a]

[a] *Energy Economics Group (EEG), Technische Universität Wien, Gusshausstrasse 25-29/E370-3, 1040 Wien, Austria*

Abstract

Keywords:

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*Corresponding author
Email address: `zwickl@eeg.tuwien.ac.at` (Sebastian Zwickl-Bernhard)

Nomenclature

Type	Description	Unit
Set and index		
$y \in \mathcal{Y} = \{1, \ldots, Y\}$	Years, index by y	
$m \in \mathcal{M} = \{1, \ldots, M\}$	Months, index by m	
Decision variables		
inv_{grant}	Landlord's investment grants	EUR
$sub_{heat,y,m}$	Tenant's heating costs subsidy in y and m	EUR
$q_{init,y,m}$	Heat demand supplied by the initial heating system	kWh
$q_{alt,y,m}$	Heat demand supplied by the heating system alternative	kWh
Π_{alt}	Newly installed heating system alternative capacity	kW
$r_{y,m}$	Rent charge adjustment in y and m	EUR/m^2
Parameters		
n_{ten}	Number of tenants	1
i	Interest rate	%
$q_{load,y,m}$	Total heat demand in y and m	kWh
α_m	Ratio between total heat demand and peak load in m	1
$c_{alt,hs}$	Specific heating system alternative investment costs	EUR/kW
$c_{alt,con}$	Heating system alternative construction costs	EUR
$\bar{r}$	Initial rent price	EUR/m^2
a	Rented area per tenant	m^2
$p_{init,y}$	Energy price fueling the initial heating system	EUR/kWh
$p_{alt,y,m}$	Energy price fueling the heating system alternative	EUR/kWh

1. Introduction

- Green deal: climate neutrality in Europe until 2050
- Fit for 55: measures until 2030 ensuring a CO_2 reduction of at least 55 %
- Fair and sustainable future for all citizens (leaving no one left behind)
- Special initial conditions in the heating sector: (i) high shares of fossil fuels, and (ii) ownership structure in urban areas
- Natural gas face out

- Renewable energy: historical development of PV systems: investment grants and feed-in tariffs

Against this background · · ·

2. State-of-the-art and progress beyond

Focus here on renewable technologies in the heating sector; without energy communities; sharing renewable energy generation

2.1. Local renewable heating and cooling systems

- options for the sustainable provision of heating and cooling demand: [1], [2]
- using network infrastructure (district heating and cooling) $\longrightarrow$ fueling energy mix: [3]: primary energy sources
- local on-site generation

2.2. Justice in energy systems: fair and socially balanced sustainable energy transition

the three energy justice tenets (distributive, recognitional and procedural)
A review Energy justice - equality [4] Sehr schwer aber zu generalisieren weil geopgraphische und lokale Apsekte berücksichtigt werden sollten Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research: non-western Westliche Welt nicht auf die ganze Welt schließen (inklusive nicht entwickelte Länder) [5] case study von Mozambik
Harnessing social innovation for energy justice: A business model perspective: Energy justice may be operationalised through market principles but not through the market alone [6]
We examine two local energy transitions from an energy justice perspective [7] show that energy justice and transitions frameworks can be combined [8]
Recently 2021, do renewable energy communities deliver energy justice? Exploring insights from 71 European cases [9]

- "We aim to show how when low-carbon transitions unfold, deeper injustices related to equity, distribution, and fairness invariably arise" [10]
- energy justice in household low carbon innovations; low carbon heating; collection of opportunities but also threats; who wins and who loses; difficulties to people without the capital, or who do not own their own home. ([11])

Wir müssen speziell auf low-income households und renters schauen: Energy efficiency and energy justice for U.S. low-income households: An analysis of multifaceted challenges and potential: Low-income households and renters have fewer energy efficiency appliances; need tailored assistance [12]
low-income haben auch höheren residential heating energy use intensity, an energy efficiency proxy [13]
"They are grinding us into the ground" – The lived experience of (in)energy justice amongst low-income older households: Energy justice was experienced

on four separately distinguishable levels of social relationships: intra-households, household-energy retailer relations, immediate social networks and wider social relations. simple retrofits improved householder heating capabilities [14]

2.3. Trade-offs between overnight investments and net present value decisions

2.4. Progress beyond state-of-the-art

- heating system change and sustainable heat supply takes place
- analytical and modeling framework; justice; qualitative analysis
- Trade-off analysis between governance, landlords, and tenants $\longrightarrow$ required incentives
- Sensitivity analysis helps us to bettter understand the different ownership structure and its influence on the sustainable energy transition

3. Materials and methods

This section explains the methodology and the optimization model developed in this work. The section starts with an introduction and overview of the model in Section 3.1, followed by a detailed description of the mathematical formulation in Section 3.2. The case study and scenario description is given in Section 3.3. The model validation is described in Section 3.4 and the open-source programming environment in Section 3.5

3.1. Introduction and model overview

This section provides an comprehensive overview of the proposed model. In general, three agents with the following characteristics are considered:

Governance. The governance's main objective is to decarbonizing the residential heating sector. Therefore, the intention is to trigger a heating system change to a sustainable alternative on the multi-apartment building level by financial support for both landlord and tenants. The avowed aim is to find a cost-minimal and socially balanced solution. The financial support can be realized by an investment grant (paid directly from the governance) or rent-charge-related revenues (from the tenants and refunded by the governance) for the landlord and heating costs subsidy payments for the tenants.

Landlord. is the owner of the multi-apartment building and provides the heating system for the tenants, and is profit-oriented. Thus, a heating system change toward a sustainable alternative only is realized in case of the economic viability of the investment. In this context, the landlord can achieve profitability of the alternative heating system by receiving an investment grant (to reduce the overnight investment costs from the governance) and a rent-charge-related revenue cash flow (from the tenants).

Tenant. rents a dwelling within the multi-apartment building from the landlord and has rent-related and energy-related spendings. He cannot change the heating system on his authority but depends on the landlord's willingness to realize a low-emission sustainable alternative. Especially in the case of the existing heating system, its costs are directly subject to a higher pricing of CO_2 emissions. Nevertheless, the tenant aims to limit total costs in case of a heating system change at the level of the initial condition.

Figure 1 shows a sketch illustrating the interrelations between the governance, the landlord, and the tenants. The governance can support the landlord financially by investment grants and by the allowance of rent charge adjustments. At the same time, tenants are supported by a heating costs subsidy payment. The gray bar in the middle indicates that these financial benefits need to be socially balanced and overcome the differences in ownership within the multi-apartment building. The rent or rent charge adjustment is the direct financial exchange between the landlord and the tenant.

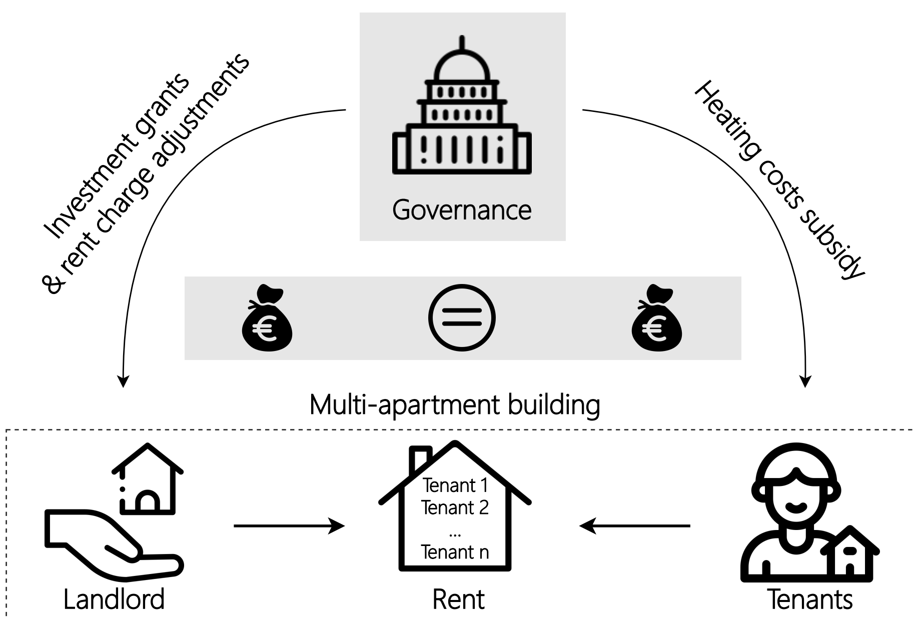


Figure 1: Sketch of the model illustrating the iterrelations between the governance, landlord, and tenants. Financial support from the governance is socially balanced at the multi-apartment building.

Objective function. The objective function of the model is to minimize the governance's total costs for investment grants and subsidies. Therefore, the objective function can be written as follows:

$$\min_{x} \underbrace{inv_{grant}}_{\text{landlord}} + \sum_{y}\sum_{m} n_{ten} \cdot \frac{1}{(1+i_g)^y} \cdot \underbrace{sub_{heat,y,m}}_{\text{tenant}} \tag{1}$$

where inv_{grant} is the investment grant for the landlord and $sub_{heat,y,m}$ the tenant's subsidy for the heating costs in year y and month m. In addition, n_{ten} is the number of tenants[1] and i_g the governance's interest rate. The model's decision variables are included in the decision variable vector x.

Decision variables. In order to improve the readability of the section, we explicitly list all the decision variables of the model using x

$$\underline{x} = [inv_{grant}, sub_{heat,y,m}, q_{init,y,m}, q_{alt,y,m}, \Pi_{alt}, r_{y,m}] \tag{2}$$

where $q_{init,y,m}$ is the quantity of heat demand supplied by the initial heating system using conventional fuels and $q_{alt,y,m}$ using the sustainable heating system alternative in y and m. Π_{alt} is the capacity of the newly installed heating system alternative and $r_{y,m}$ the rent charge in y and m.

Constraints. Equation 3 describes the load satisfaction in each time steps (year and month)

$$q_{load,y,m} \leq q_{init,y,m} + q_{alt,y,m} \quad : \forall y, m \tag{3}$$

where $q_{load,y,m}$ is the total heat demand of the multi-apartment building. Equation 4 defines the minimum required newly installed capacity of the heating

[1] It is assumed that the multi-apartment building consists of n_{ten} equal tenants. This is a simplification, however, in this paper we do not focus on the socially balanced between tenants, but on that between the landlord and the tenants.

system alternative

$$\alpha_m \cdot q_{alt,y,m} \leq \Pi_{alt} \quad : \forall y, m \tag{4}$$

where α_m is a factor that transforms the amount of monthly heat demand to the corresponding peak demand (i.e., monthly heating system load factor). Equation 5 defines the landlord's investment costs ($costs_{inv}$)

$$costs_{inv} = \Pi_{alt} \cdot (c_{alt,hs} + n_{ten} \cdot c_{alt,con}) - inv_{grant} \tag{5}$$

where $c_{alt,hs}$ is the specific investment costs of the heating system alternative and $c_{alt,con}$ the related construction costs associated with the heating system change. Equation 6 sets the rent-related revenues of the landlord ($rev_{rent,y,m}$)

$$rev_{rent,y,m} = (\bar{r} + r_{y,m}) \cdot a \cdot n_{ten} \quad : \forall y, m \tag{6}$$

where $\bar{r}$ is the initial rent price, $r_{y,m}$ the additional rent charge resulting from the heating system change in y and m and a the area of a tenant's dwelling. Equation 7 defines the landlord's net present value constraint and ensures economic viability of the heating system change

$$-costs_{inv} + \sum_y \sum_m \frac{1}{(1+i_l)^y} \cdot rev_{rent,y,m} \geq 0 \tag{7}$$

where i_l is the landlord's interest rate. Equation 8 describes the initial annual spendings of all tenants (s_y)

$$s_y = n_{ten} \cdot (\bar{r} \cdot a + \sum_m q_{load,y,m} \cdot p_{init,y}) \quad : y = y_0 \tag{8}$$

where $p_{init,y}$ is the price of the conventional fuel initially supplying the heat demand. Building on this, Equation 9 sets the tenants' total spendings (s_{total})

$$s_{total} = -\sum_{y} \frac{1}{(1+i)^y} \cdot s_{y_0} \tag{9}$$

where s_{y_0} represents the initial spendings from Equation 8 above. Equation 10 defines the total spendings of all tenants using the sustainable heating system alternative (s_{alt})

$$s_{alt} = -\sum_{y} \frac{n_{ten}}{(1+i)^y} \sum_{m} (\bar{r} + r_{y,m}) \cdot a + q_{alt,y,m} \cdot p_{alt,y,m} + sub_{heat,y,m} \tag{10}$$

and Equation 11 ensures economic viability of the tenants (i.e., greater net present value than in the initial case) in case of the heating system change

$$s_{total} \leq s_{alt} \tag{11}$$

Equation 12 defines the parity of the landlord's investment grant and rent charge as well as the tenants' heating costs subsidy and ensures socially balanced parity from an economic perspective at the multi-apartment building.

$$sub_{inv} = n_{ten} \left(\sum_{y} \sum_{m} \frac{1}{(1+i)^y} \cdot (sub_{heat,y,m} - r_{y,m}) \right) \tag{12}$$

3.3. Empirical settings and case study description

18.10.2021

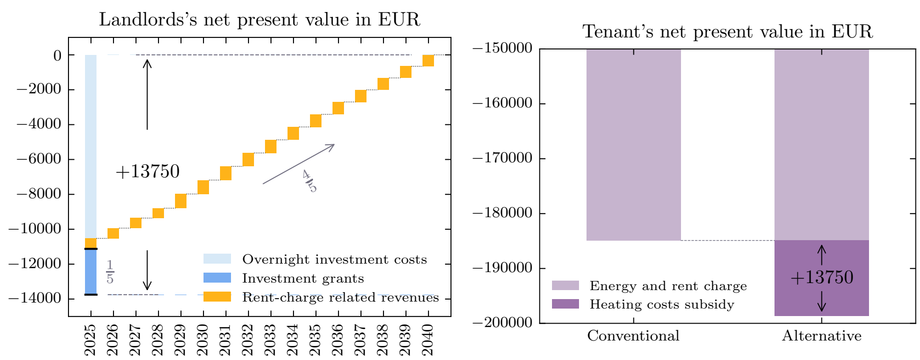
Scenario	Climat target	Heat pump	District heating
Low CO_2 price development (LD)	none	✓	✓
Gradual Development (GD)	2.0 C	✓	✓
Societal Commitment (SC)	1.5 C	✓	-
Directed Transition (DT)	1.5 C	-	✓

Table 1

Interest rate: 3 (governance),5 (tenants), 7 (landlord) percentage; inflation

3.4. Validation of the model

This section aims to test the presented model and its functionalities. However, a model validation using existing empirical data can not be applied in this case. There is simply a lack of comparable data from real cases. Therefore, a small illustrative case study is chosen to demonstrate the main functionalities and to verify the model. We assume a single landlord and tenant in a representative single-family household implementing a heat pump. It is assumed that the landlord's and tenant's interest rate is equal (3 %). A detailed description of the empirical settings can be found in Appendix A. Figure 2 shows the landlord's (a) and tenant's (b) net present value.



(a) Development of landlord's net present value

(b) Comparison of tenant's net present value

Figure 2: Landlord's and tenant's net present value and equal financial support. The landlord reaches a net present value equal to zero in 2040 resulting from an investment grant and rent-charge related revenues. The tenant's net present value remains constant compared to the conventional heating system resulting from heating costs subsidy payments.

Both agents receive equal financial support with a total of 13 750 EUR. One finfth of the landlord's support is paid as an investment grant and four-fifths as rent-charge related revenues. The tenant receives a heating costs subsidy. The level of financial support results exactly in (i) a landlord's net present value equal to zero within the time horizon of 15 years (see Figure 2a) and (ii) a constant remaining net present value of tenant compared to the conventional (existing) heating system (including the initial rent charge) (see Figure 2b).

3.5. Open-source programming environment and data format

The developed optimization model is implemented in Python using the modeling framework Pyomo [15]. It is solved with the solver Gurobi version 9.0.3. We use for data analysis the common data format template developed by the Integrated Assessment Modeling Consortium (IAMC) using the open-source Python package pyam [16]. Note that all materials used in this study are disclosed as part of the publication at GitHub [2]. We refer to the repository for the codebase, data collection, and further information.

4. Results and discussion

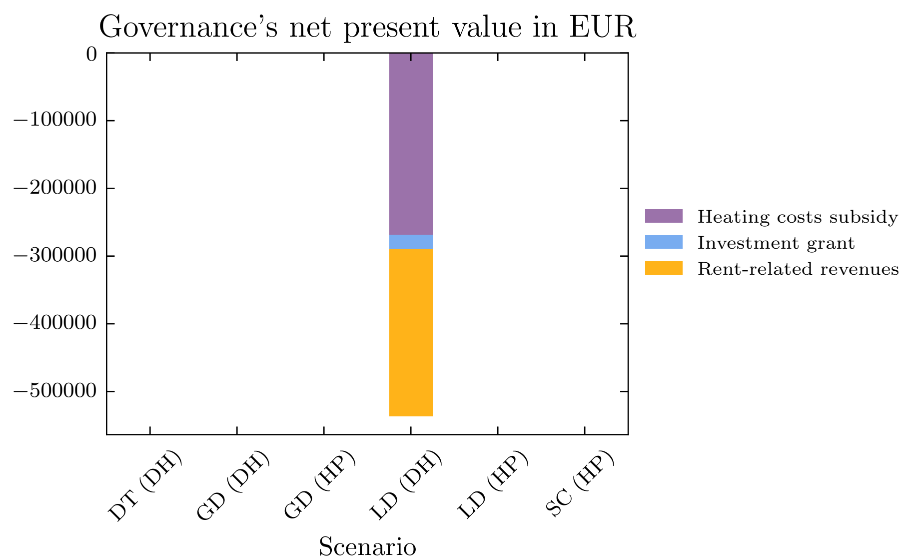


Figure 3

[2]https://github.com/sebastianzwickl

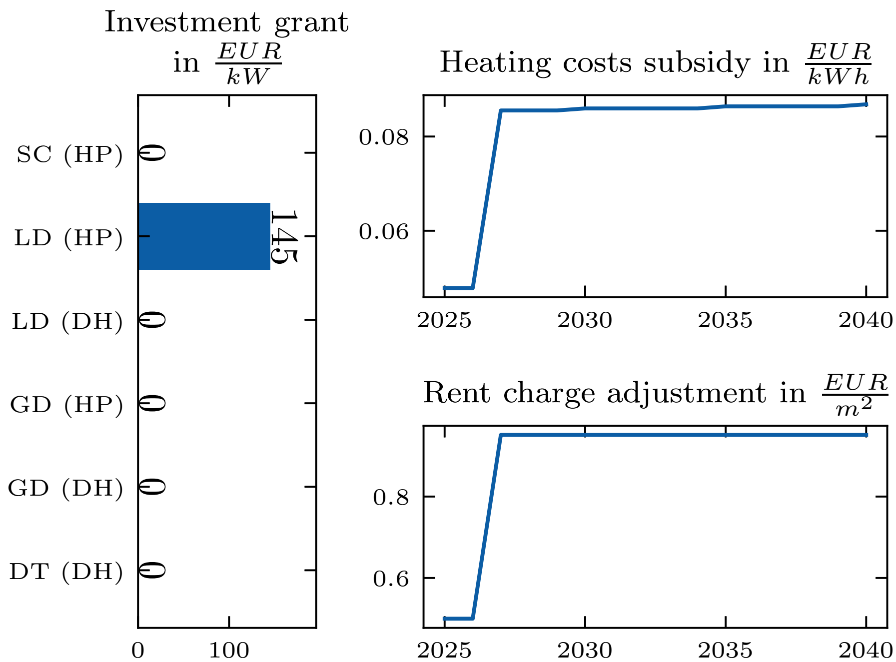


Figure 4

5. Sensitivity analysis

6. Conclusions and recommendations

sozial ausgewogenen bedeutet hier, dass kosten für den mieter dürfen nicht stark ansteigen investitionsförderung und dem mieter erlauben höhere mieten zu verlangen aufgrund von renewable enery systems

viel mehr muss der staat hier geld in die hand nehmen um profitability sicherzustellen

Socially-balanced heating system transition in urban areas (landlords and tenants) hilft uns CO2 nicht als Trigger anders als in übrigen analysen

co2 nur als trigger wenn man die kosten auf des co2 preises auf beide akteure aufteilt und nicht nur auf den mieter packt, dann kann co2 preis trigger sein, dass hat die sensitivität analyse gezeigt

zeigt, dass wir uns nicht nur alleine auf den co2 verlassen dürfen, im wärmesektor muss geld in die hand genommen werden.

Future work: investment grants depend on buidling renovation

Declaration of interests

None.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Empirical settings of the small case example

Variable	Unit	Value
Heat pump investment costs	EUR/kW	1000
Construction costs	EUR	1000
Initial rent price	EUR/m^2	10
Rented area	m^2	100
Total heat demand	kWh	22 000
Peak heat demand	kW	13
CO_2 price (2025-2034)	EUR/tCO_2	50
CO_2 price (2035-2040)	EUR/tCO_2	100
Natural gas price	EUR/kWh	0.05
Electricty price	EUR/kWh	0.2
Specific emissions of electricity	kgCO_2/kWh	0.130

Table A.1: Data assumptions of the small case example