Residential Rent Externalities of Photovoltaic Systems: The Relevance of View

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Motivation: View Matters

Motivation: View at PV Systems Potentially Matters Too

Research Question

Does the view at PV systems affect residential rental prices in Switzerland?

- Public concern:
  - **mandatory PV installation** on new and pot. existing (residential) property [Blick, 2022; Watson, 2022]
  - facilitates sustainable energy production & **subsidization** in alignment with Energy Strategy 2050 [SFOE, 2018, 2021]

$\Rightarrow$ Relevant for **energy infrastructure planning** policies

- Growing body of literature on PV & real estate prices:
  - internal effects (mostly +) [e.g. Brinkley and Leach, 2019]
  - external effects of large-scale PV (mostly −) [e.g. Dröes and Koster, 2021; Elmallah et al., 2023]

$\Rightarrow$ **External effects of (small-scale) PV systems** in Switzerland

$\Rightarrow$ Novel measurement: **3D-view-modeling** & **rooftop sun exposure**

$\Rightarrow$ Additional explorations (potential **causal pathways**):

- different view (e.g. single vs. multiple PV) & housing (e.g. with own PV) types
- municipality-level preferences for sustainability

Data: Sources (1/2)

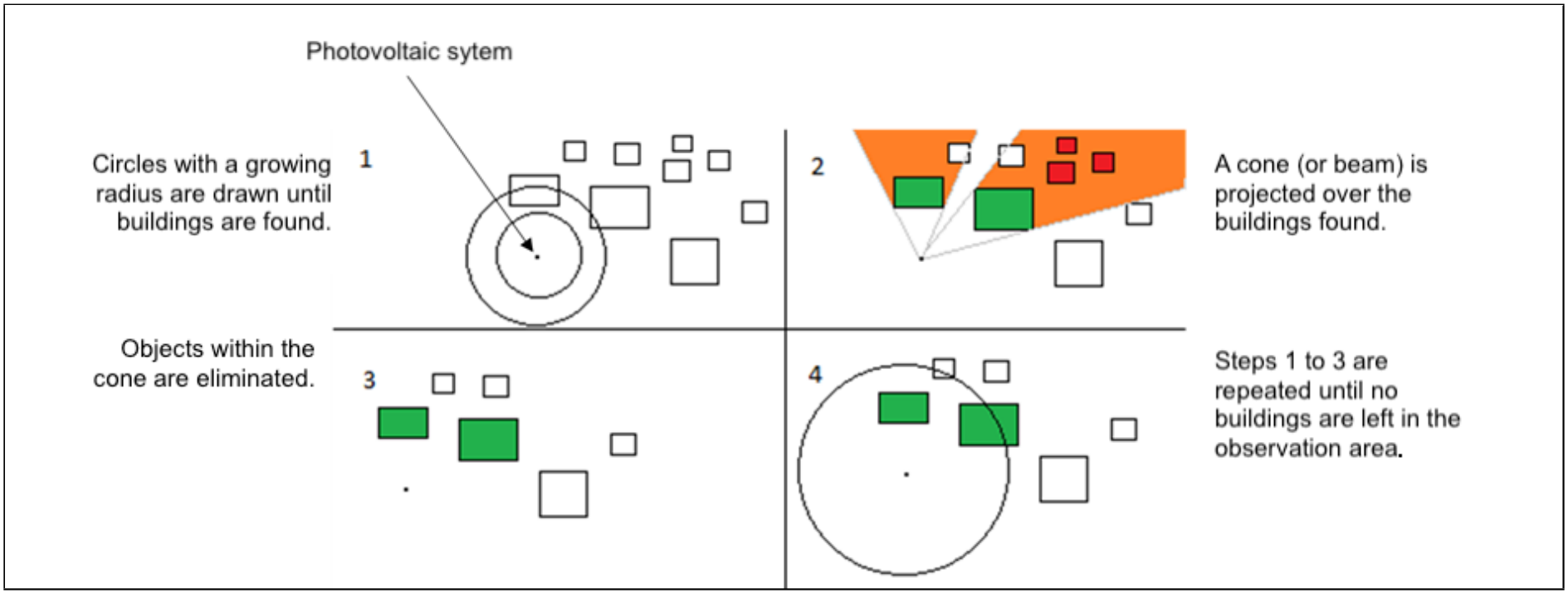
- **Rental Prices:** 621,010 residential housing rents are given for our study areas in Switzerland from 2004 until 2021 (real estate advertisements from *Immoscout24.ch* or *Homegate.ch*).
  ▸ Data: Housing Rents (Descriptives) ▸ Data: Study Areas
  - Geo-referenced location
  - Listing date
  - Dwelling type and characteristics
  - Number of rooms and scenic view
- **Photovoltaic Systems:** Information on individual PV systems stems from a geo-database on electricity production facilities provided by the Swiss Federal Office of Energy. ▸ Data: Mapping PV Systems
  - Geo-referenced location
  - Date of commissioning
  - Output/size
  - Placement (*Sonnendach.ch*)

Data: Sources (2/2)

- **3D Topographical Information:** To create a 3D model of our study areas in Switzerland, we collect and combine three datasets from the Swiss Federal Office of Topography. ▸ Data: Topographical Model in 3D
  - *swissAlti3D*: digital elevation model (xyz-file in regular grids)
  - *swissBuildings3D 2.0*: shapes and overhangs of dwellings
  - *swissTLM3D*: landscape model including natural/artificial objects
- **Municipal Data:** To explore preferences for sustainability we collect recent voting results of two referendums in Switzerland as well as other municipal attributes from the Swiss Federal Statistical Office.
  - Revised Federal Energy Act 2017
  - Federal CO_2 Act 2021
  - Number and share of electric vehicles
  - Solar energy potential (roofs and facades)

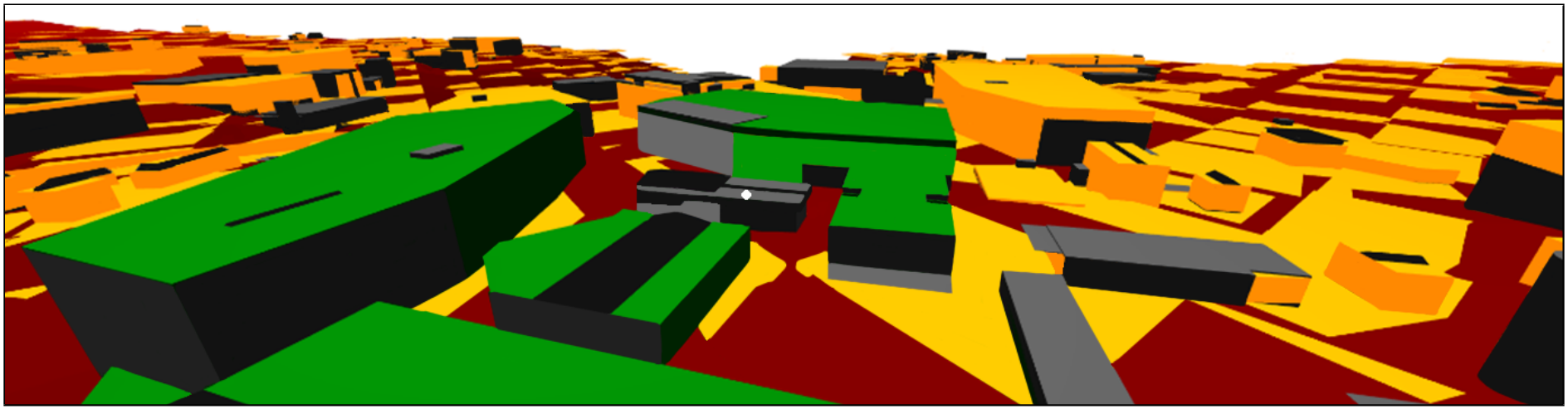
View Modeling: Ray Tracing

We use the **ray tracing** method to model the visibility of all PV installations in our Swiss study areas.



View Modeling: 3D Model

The ray tracing method is applied in the **3D model of our study areas in Switzerland**. Green buildings have a view at the PV system (white dot).



▸ Data: Topographical Model in 3D

Methodology: Difference-in-Differences Estimation

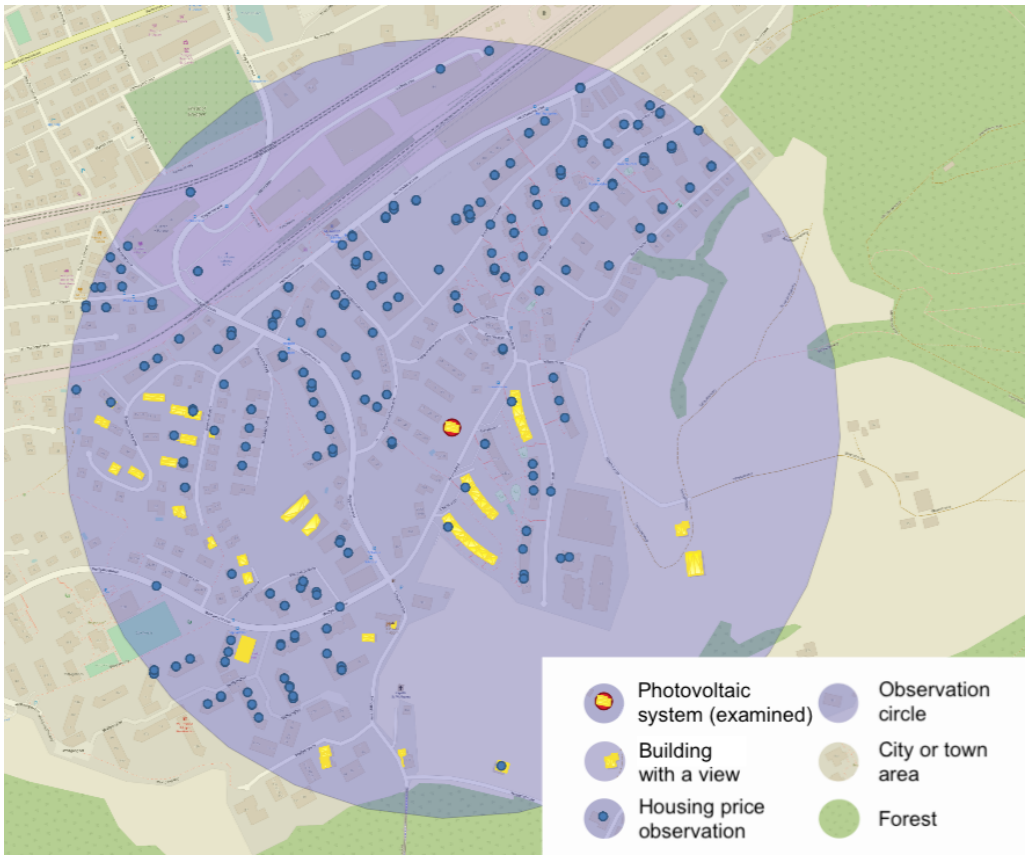
We specify a staggered DiD model following the inference procedure of *Callaway and Sant'Anna (2021)* with multiple time periods and variation in treatment timing:

$$ln\left(r_{ibt}\right) = \boldsymbol{X_{it}}\beta + \gamma PV_{it} + \eta_b + \lambda_t + \epsilon_{ibt}, \tag{1}$$

where:

i, b, t :	indices: property, building, year
r_{ibt} :	residential rents
η_b	building fe
λ_t :	time fe (yearly dummies)
X_{it} :	hedonic characteristics
PV_{it} :	DV for view at PV installation (after the treatment date)
ϵ_{ibt}	error term

▸ View Modeling: Unimpaired View



Results: Baseline

Having a view at a PV systems lowers residential rents by -1.3% on average.

	Residential Rents
View at PV System	-0.013*** (0.002)
Scenic view	0.020*** (0.001)
Dwelling characteristics	Yes
Year fixed effect	Yes
Building fixed effect	Yes
Observations	621,010
Adjusted within R^2	0.352

Note: ***p < 0.01

▸ Results: Cohort Aggregated Biennial ATET (Rents)

▸ Results: Time Aggregated Biennial ATET (Rents)

Results: View & Building Types

Distinguishing between various view types at PV systems and building types from which PV systems can be seen yields insights into drivers of our baseline result. ▸ Summary: View & Building Types

	Residential Rents
Likely view	-0.015*** (0.003)
Less likely view	-0.012*** (0.002)
Single PV system	-0.010*** (0.003)
Multiple PV systems	-0.013*** (0.002)
Small PV system	-0.014*** (0.002)
Large and close PV system Δ	0.017*** (0.005)
View w/o own PV	-0.013*** (0.002)
View with own PV Δ	0.067** (0.028)
View w/o scenic view	-0.011*** (0.002)
View with scenic view Δ	–0.008*** (0.001)
View from apartment	-0.013*** (0.002)
View from house Δ	-0.003 (0.004)

Note: Δ differential, **p < 0.05, ***p < 0.01

Results: Political Perception (Stated Preferences)

Splitting housing rent observations across municipality quartiles (lowest to highest share of yes-votes) shows a causal pathway of the external effect.

	Residential Rents	
Panel A: Revised Federal Energy Act 2017		
View (Yes-votes Q1)	-0.059***	(0.004)
View (Yes-votes Q2) Δ	0.016***	(0.004)
View (Yes-votes Q3) Δ	0.028***	(0.004)
View (Yes-votes Q4) Δ	0.064***	(0.004)
Panel B: Federal CO_2 Act 2021		
View (Yes-votes Q1)	-0.055***	(0.008)
View (Yes-votes Q2) Δ	0.000	(0.009)
View (Yes-votes Q3) Δ	0.015*	(0.009)
View (Yes-votes Q4) Δ	0.051***	(0.008)

Note: Δ differential, *p $<$ 0.10, ***p $<$ 0.01

Results: Electric Vehicles (Lived Preferences)

Splitting observations across municipality quartiles (lowest to highest number and growth in electric vehicles) shows a similar path of the effect.

	Residential Rents
Panel A: # Registered electric vehicles 2015	
View (# EV (Q1))	-0.083*** (0.012)
View (# EV (Q2): Δ)	0.042*** (0.013)
View (# EV (Q3): Δ)	0.039*** (0.012)
View (# EV (Q4): Δ)	0.074*** (0.012)
Panel B: Change (%) in registered electric vehicles 2015-2021	
View (Change in EVs (Q1))	-0.050*** (0.010)
View (Change in EVs (Q2): Δ)	0.015 (0.015)
View (Change in EVs (Q3): Δ)	0.004 (0.010)
View (Change in EVs (Q4): Δ)	0.040*** (0.010)

Note: Δ differential, ***p < 0.01

▸ Results: Solar Energy Potential

Conclusions

- Results demonstrate that the **view at a PV system leads to a depreciation of residential rents**.
- **Negative impact varies** across different view & housing types:
  - Absolutely **larger effect** if view **multiple PVs** (rather than a single one) & viewed from **dwelling that also offers a scenic view**.
  - An **internal PV system offsets the negative externalities** of having a view at a PV system.
  - A **view at large PV systems increases rents** (potential benefit to surrounding tenants in terms of electricity provision).
- Lower **preferences for sustainability** (stated and lived) **are a potential driver** of negative externality effects of PV installations.
- **Formulation of policies to address** not only PV electricity production factors (e.g. placement/exposition) of PV systems but also its **visibility & distribution of benefits.**

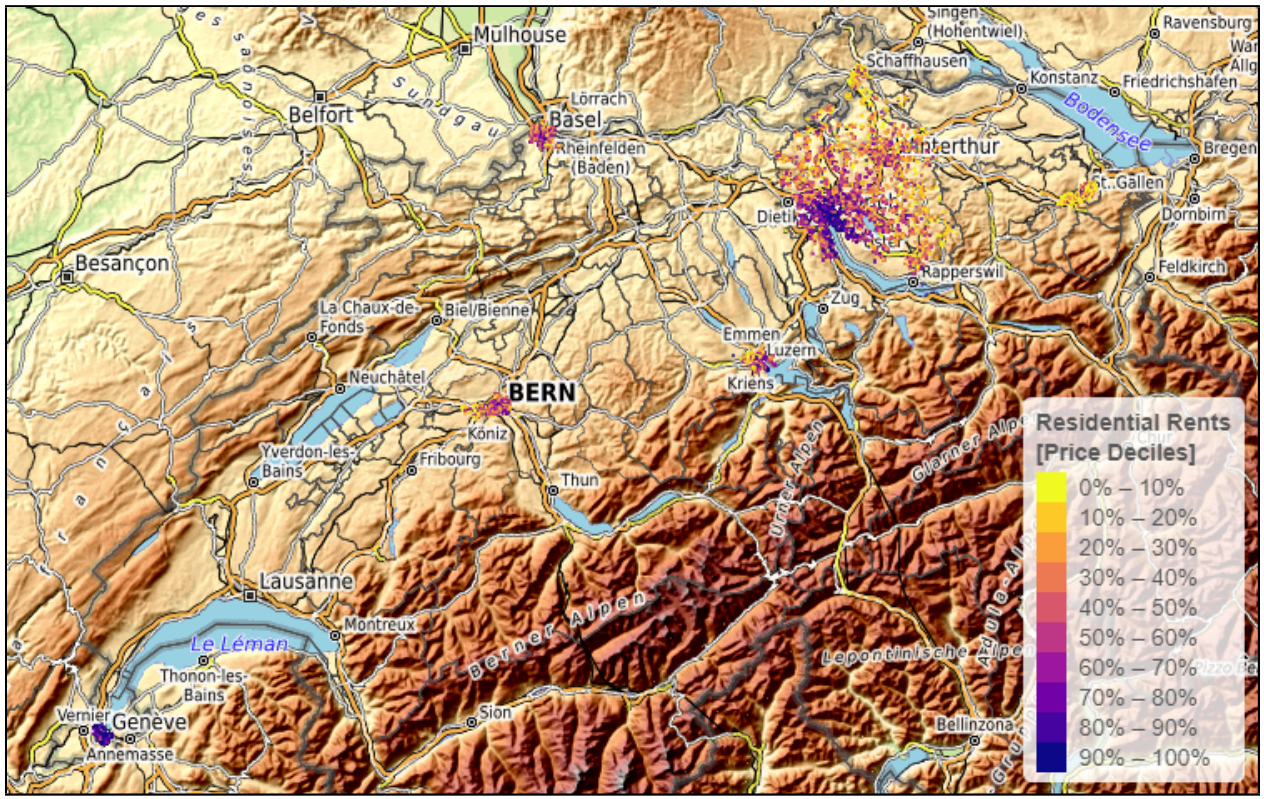
Appendix 1 - Data: Residential Rental Prices (Descriptives)

	Mean	S.D.	Min	Max
Rent (CHF/m^2/month)	21.266	6.145	9.00	45.70
log(Rent)	3.019	0.271	2.197	3.822

▸ Data: Sources (1/2)

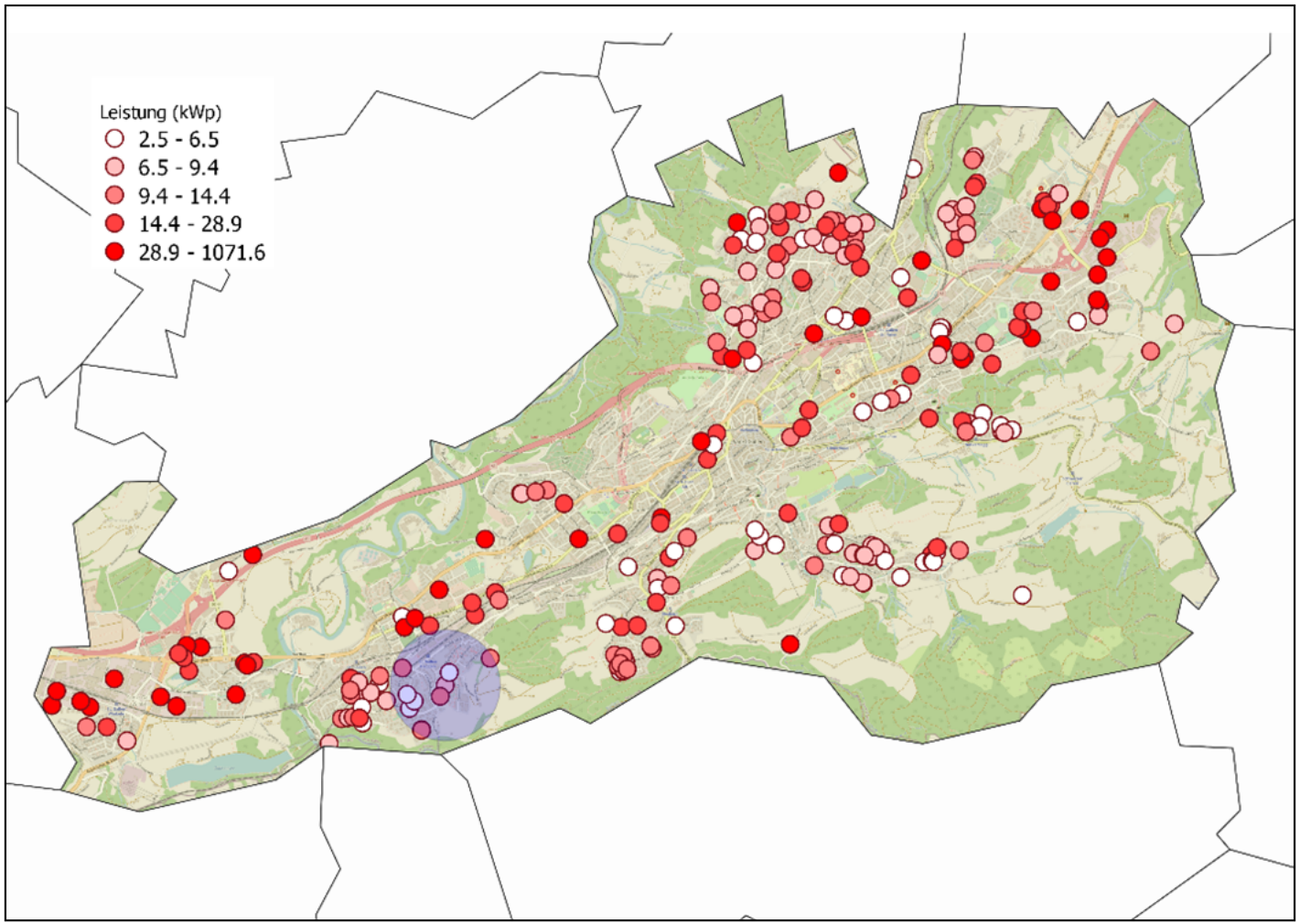
Appendix 2 - Data: Study Areas

The study areas comprise the metropolitan areas of Basel, Bern, Geneva, Lucerne, Schaffhausen, and St.Gallen. In addition, we include the whole canton of Zurich in our analysis (exemplary map of rental observations).



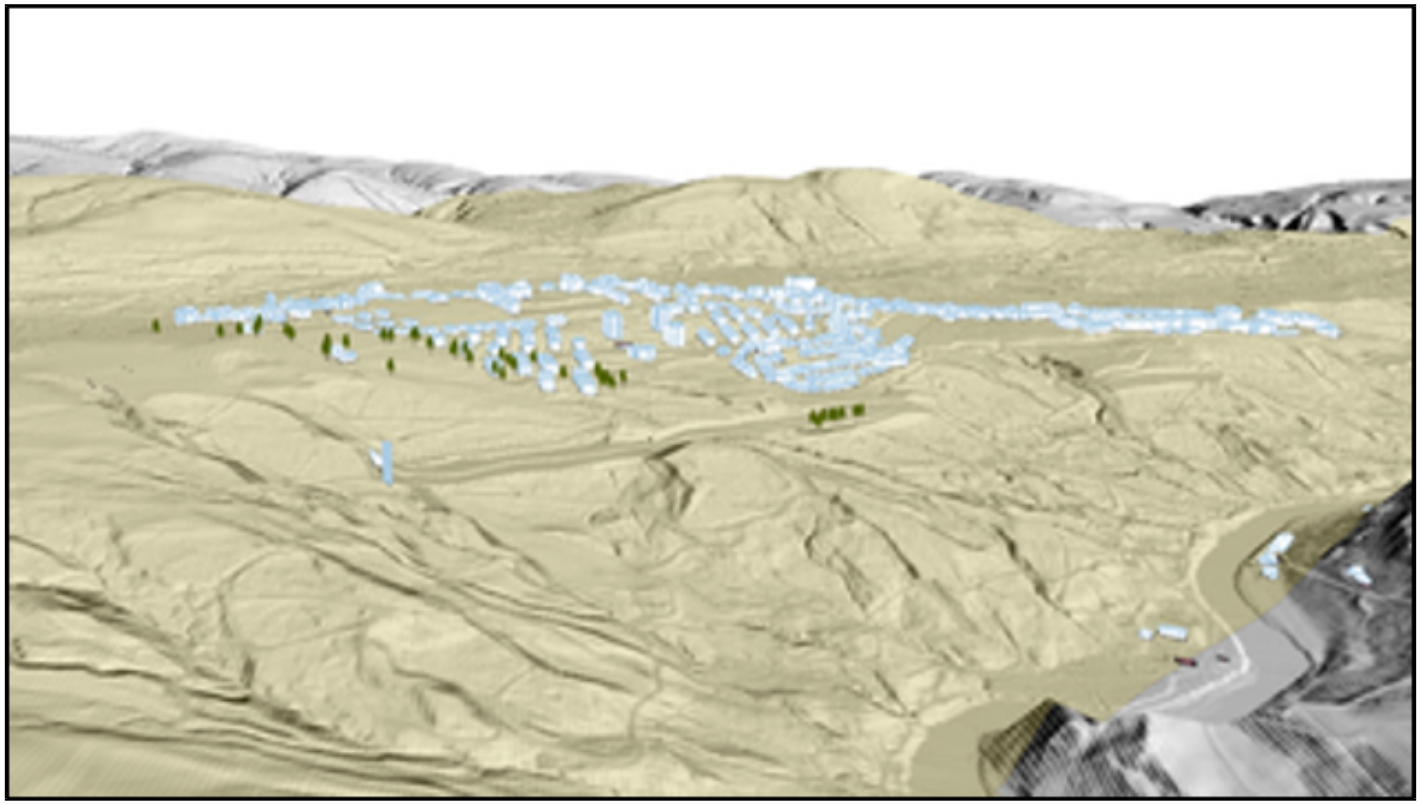
▸ Data: Sources (1/2)

Appendix 3 - Data: Mapping PV Systems



▸ Data: Sources (1/2)

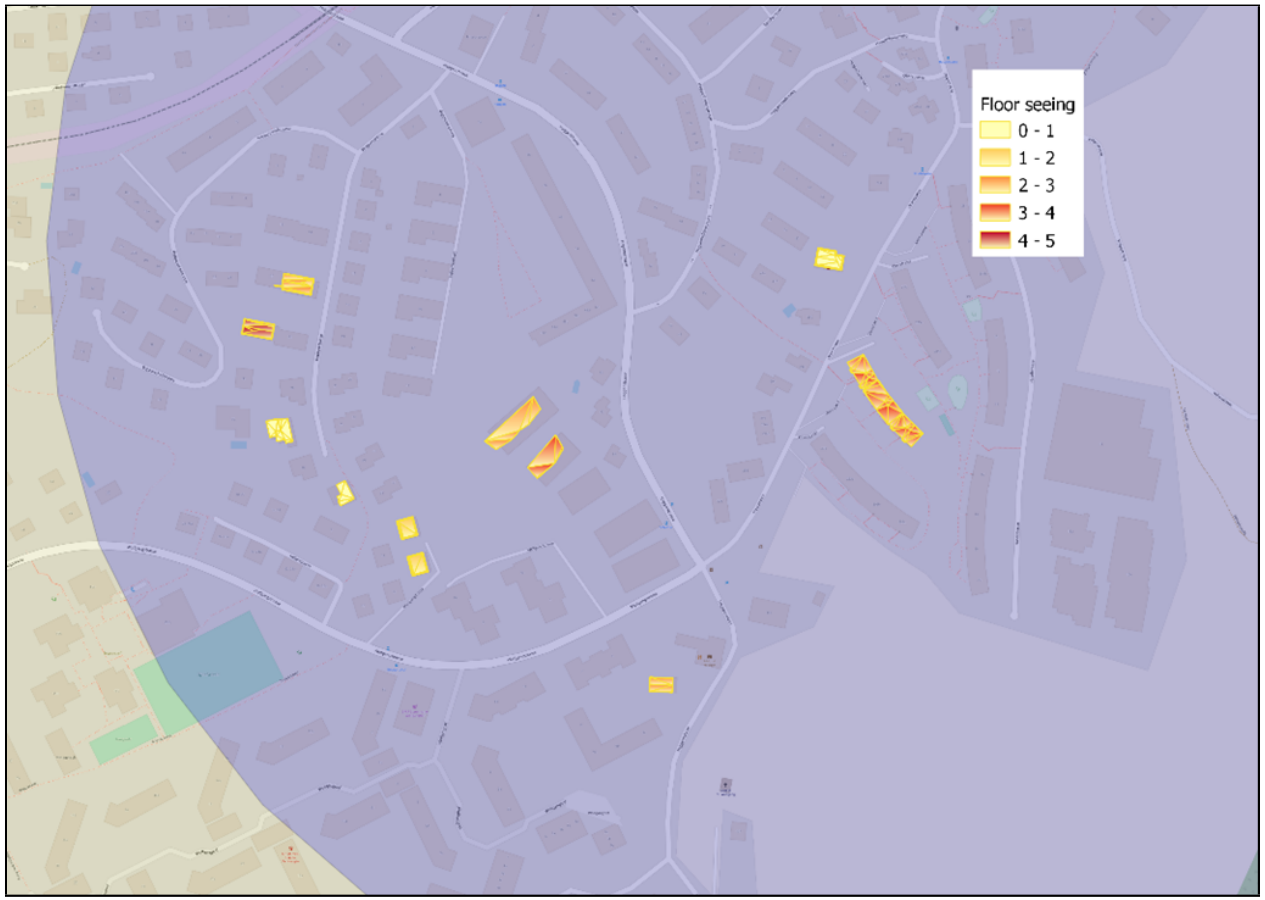
Appendix 4 - Data: Topographical Model in 3D



▸ Data: Sources (2/2) ▸ View Modeling: 3D Model

Appendix 5 - View Modeling: Unimpaired View

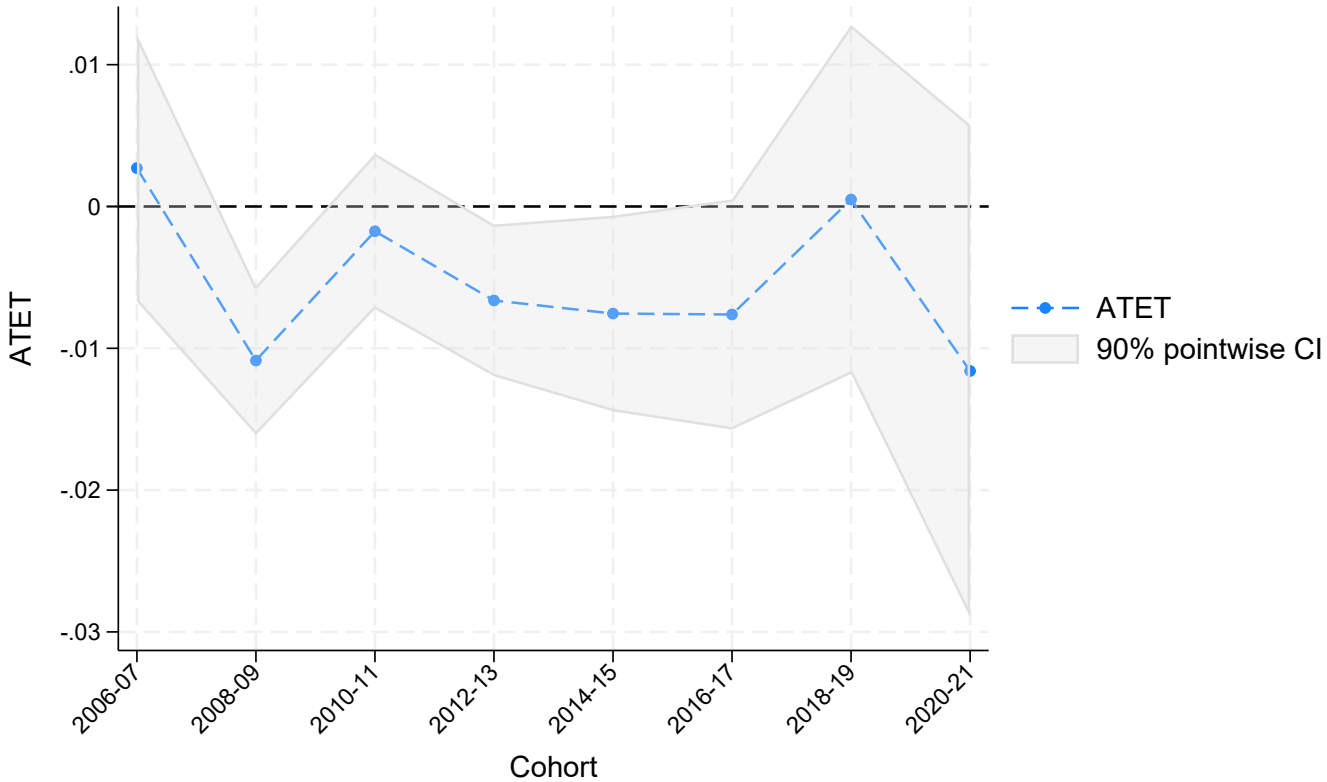
The number of dwellings with a view is reduced if only buildings with an **unimpaired view** are considered.



▸ View Modeling: Treatment Group (Baseline)

Appendix 6 - Results: Cohort Aggreg. Biennial ATET

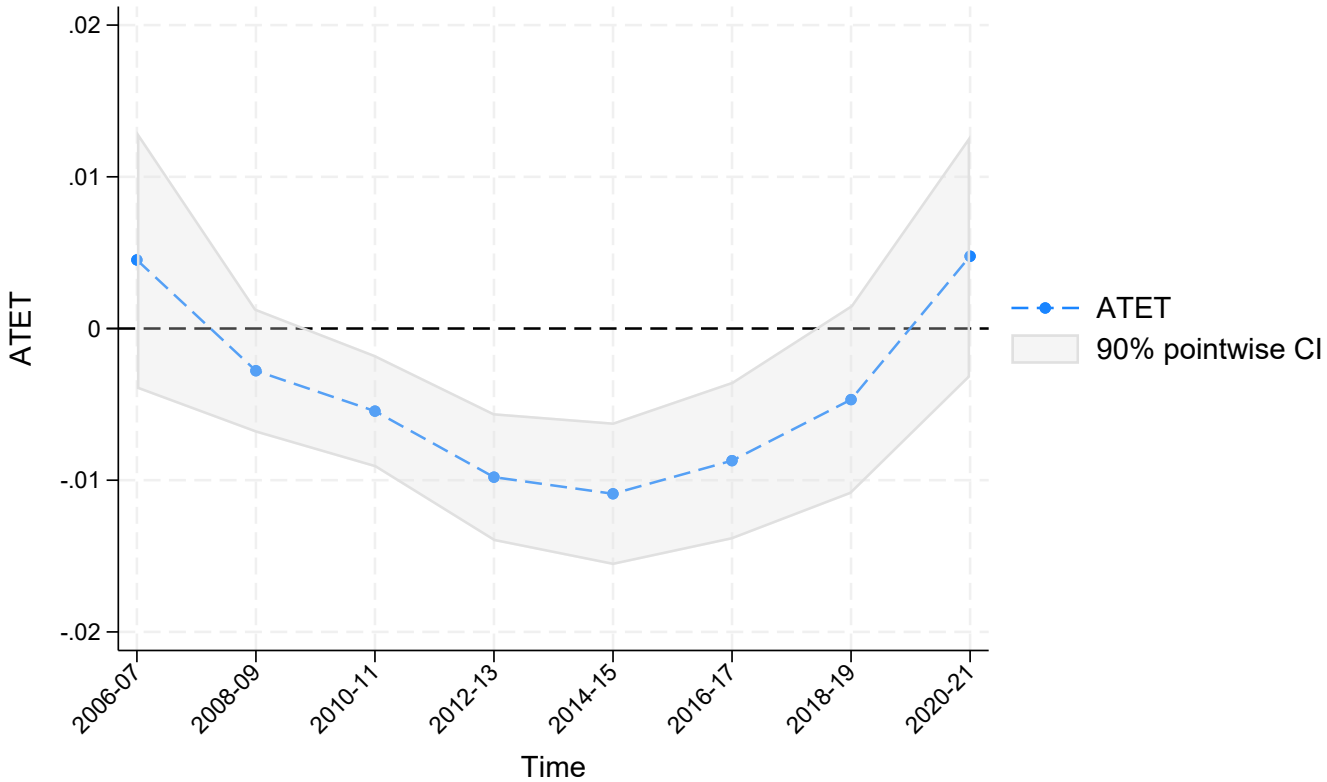
We compute **aggregated ATET** biennially to highlight different sources of treatment effect heterogeneity on residential rents **across cohorts**.



▸ Results: Baseline

Appendix 7 - Results: Time Aggreg. Biennial ATET

We compute **aggregated ATET** biennially to highlight different sources of treatment effect heterogeneity on residential rents **across time**.



▸ Results: Baseline

Appendix 8 - View Modeling: View & Building Types

	Residential Rents
View (unimpaired and impaired)	0.589
Likely view	0.157
Unlikely view	0.432
Single PV system	0.103
Multiple PV system	0.486
Small PV system	0.535
Large and close PV system	0.054
View w/o own PV	0.584
View with own PV	0.005
View w/o scenic view	0.419
View with scenic view	0.170
View from an apartment	0.574
View from a house	0.015

▸ Results: View & Building Types

Appendix 9 - Results: Solar Energy Production Potential

Splitting observations across municipalities (lowest to highest solar energy production potential on roofs and facades) shows another causal pathway of the external effect.

	Residential Rents
Panel A: Solar energy production potential (roofs and facades)	
View (Potential (Q1))	-0.082*** (0.014)
View (Potential (Q2): Δ)	0.006 (0.014)
View (Potential (Q3): Δ)	0.037*** (0.014)
View (Potential (Q4): Δ)	0.074*** (0.014)

Note: Δ differential, ***p $<$ 0.01

▸ Results: Electric Vehicles (Lived Preferences)