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The Impact of Selected Small- and Large-Scale Energy Infrastructures on Real Estate Prices

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Zusammenfassung

Die vorliegende Studie untersucht den Einfluss ausgewählter kleiner und grosser Energieinfrastrukturen auf Immobilienpreise und -mieten in der Schweiz – sowohl in Bezug auf interne als auch auf externe Effekte (Sicht).

Bezüglich der Heizsysteme finden wir signifikante und positive Effekte einer Wärmepumpe und einer Holzheizung auf die Preise von Wohneigentum. Ausserdem erhöht eine Wärmepumpe die Nettomieten auf den Wohnungsmärkten. Im Gegensatz dazu werden die Mieten im gewerblichen Immobiliensektor von keiner der kleinen Energieinfrastrukturen beeinflusst – mit Ausnahme eines Abschlags für Ölheizungen gegenüber Gasheizungen auf gewerbliche Immobilienmieten. Objekte mit einer Photovoltaikanlage erhöhen die Immobilienpreise im Segment für selbstgenutztes Wohnen, nicht aber die Nettomieten von Renditeobjekten.

Zur Beurteilung externer Effekte wurde eine aufwändige Sichtmodellierung unter Berücksichtigung von Topografie, Überbauung und Vegetation vorgenommen, wobei der Fokus auf der Photovoltaik lag. Mit dem "difference-in-differences" Ansatz wurde ein Modell gewählt, das den Einfluss der Infrastruktur möglichst gut von anderen Effekten isoliert. Der Preis dieser aufwändigen Sichtmodellierung ist, dass (noch) nicht die ganze Schweiz berechnet werden konnte. Dies führt dazu, dass die präzisesten Resultate für Mietwohnungen vorliegen. Die Sicht auf eine Photovoltaikanlage führt zu einem Abschlag bei den Wohnungsmieten. Dieser Effekt ist umso stärker, je grösser und dichter die Photovoltaikanlagen auf Nachbarsgrundstücken sind. Diese negativen Auswirkungen auf die Wohnungsmieten werden jedoch hauptsächlich durch die Betrachtung mehrerer Photovoltaikanlagen und nicht einer einzelnen getrieben. Zudem ist ein Mietpreisrückgang aufgrund einer Photovoltaikanlage nur bei Objekten zu beobachten, die keine eigene Photovoltaikanlage installiert haben. Für Wohneigentum lässt sich kein signifikanter Effekt nachweisen.

In Bezug auf grosse Energieinfrastrukturen liefert die Studie erste Resultate, die durch eine Ausweitung der Stichproben zur Vollerhebung weiter erhärtet werden könnten. Die kleineren Stichproben ergeben sich aus der äusserst zeitaufwändigen Berechnung von Sicht auf Infrastrukturen über grössere Perimeter. Eindeutig scheinen die Resultate in Bezug auf das (oberirdische) Übertragungsnetz. Die Sicht auf Hochspannungsleitungen hat erhebliche Externalitäten, also negative Auswirkungen auf Wohneigentumspreise und Mieten von Anlageimmobilien. Die übrigen Resultate geben nur erste Hinweise auf die Stossrichtung der Effekte, da bei grossen Energieinfrastrukturen auch die Region der Stichprobe eine Rolle spielen kann (also evtl. auch nur lokale Effekte gemessen werden). Die Sicht auf Kernkraftwerke wirkt sich im Erhebungszeitraum nicht auf die Immobilienpreise aus; der angekündigte schrittweise Ausstieg aus der Kernenergie im Nachgang zu Fukushima scheint aber einen positiven Effekt zu haben. Eine tatsächliche Sicht auf ein Laufwasserkraftwerk wirkt sich negativ auf die Wohnungsmieten aus. Dagegen liefert die reale Betrachtung einer Kehrrichtverbrennungsanlage keine statistisch signifikanten Ergebnisse. Schliesslich bewirken Windenergieanlagen nur einen Abschlag für Wohnungsmieten, Effekte auf Wohneigentum sind nicht belegbar (die Ergebnisse stammen ausschliesslich von zwei Windparks und sind möglicherweise nicht repräsentativ für die gesamte Schweiz).

Résumé

La présente étude examine l'influence d'une sélection de petites et grandes infrastructures énergétiques sur les prix et les loyers de l'immobilier en Suisse - tant en termes d'effets internes qu'externes (vue).

En ce qui concerne les systèmes de chauffage, nous trouvons des effets significatifs et positifs d'une pompe à chaleur et d'un chauffage au bois sur les prix des logements en propriété. En outre, une pompe à chaleur augmente les loyers nets sur les marchés du logement. En revanche, les loyers dans

le secteur de l'immobilier commercial ne sont influencés par aucune des petites infrastructures énergétiques, à l'exception d'un rabais pour le chauffage au mazout par rapport au chauffage au gaz sur les loyers de l'immobilier commercial. Les objets équipés d'une installation photovoltaïque augmentent les prix de l'immobilier dans le segment du logement à usage personnel, mais pas les loyers nets des objets de rendement.

Pour évaluer les effets externes, une modélisation visuelle complexe a été effectuée en tenant compte de la topographie, des constructions et de la végétation, l'accent étant mis sur le photovoltaïque. L'approche "difference-in-differences" a permis de choisir un modèle qui isole le mieux possible l'influence de l'infrastructure des autres effets. Le prix de cette modélisation visuelle complexe est qu'il n'a pas (encore) été possible de calculer toute la Suisse. Il en résulte que les résultats les plus précis sont disponibles pour les logements locatifs. La vue d'une installation photovoltaïque entraîne une réduction des loyers des logements. Cet effet est d'autant plus fort que les installations photovoltaïques sont grandes et denses sur les terrains voisins. Toutefois, ces effets négatifs sur les loyers des logements sont principalement induits par la vision de plusieurs installations photovoltaïques et non d'une seule. De plus, une baisse des loyers due à une installation photovoltaïque ne s'observe que pour les biens qui n'ont pas installé leur propre installation photovoltaïque. Aucun effet significatif ne peut être mis en évidence pour les logements en propriété.

En ce qui concerne les grandes infrastructures énergétiques, l'étude fournit des premiers résultats qui pourraient être confirmés par un élargissement des échantillons en vue d'un recensement complet. Les échantillons plus petits résultent du calcul extrêmement long de la vue des infrastructures sur des périmètres plus grands. Les résultats semblent clairs en ce qui concerne le réseau de transport (en surface). La vue sur les lignes à haute tension a des externalités importantes, c'est-à-dire des effets négatifs sur les prix de l'immobilier et les loyers des immeubles de placement. Les autres résultats ne donnent que de premières indications sur l'orientation des effets, car pour les grandes infrastructures énergétiques, la région de l'échantillon peut également jouer un rôle, et donc éventuellement mesurer des effets locaux. La vue sur les centrales nucléaires n'a pas d'effet sur les prix de l'immobilier pendant la période d'enquête ; l'annonce de l'abandon progressif de l'énergie nucléaire à la suite de Fukushima semble toutefois avoir un effet positif. Une vue réelle d'une centrale au fil de l'eau a un effet négatif sur les loyers des logements. En revanche, l'observation réelle d'une usine d'incinération des ordures ménagères ne donne pas de résultats significatifs sur le plan statistique. Enfin, les installations éoliennes n'entraînent qu'un rabais sur les loyers d'habitation, les effets sur la propriété du logement ne peuvent pas être prouvés (les résultats proviennent de deux parcs éoliens et peuvent ne pas être représentatifs de toute la Suisse).

Summary

This study investigates the impact of selected small- and large-scale energy infrastructures on real estate prices and rents in Switzerland – both in terms of internal and external effects (visibility).

Regarding heating systems, we find significant and positive effects of a heat pump and wood heating on residential property prices. Furthermore, a heat pump increases net rents in the housing markets. In contrast, rents in the commercial real estate sector are not affected by any of the small-scale energy infrastructures – with the exception of a discount for oil-heating versus gas-heating on commercial real estate rents. Properties with a photovoltaic system are characterized by higher prices in the owner-occupied housing segment, but do not increase net rents of income-producing properties.

To assess externalities, extensive view modeling was performed, taking into account topography, building coverage, and vegetation, with a focus on photovoltaics. With the "difference-in-differences" approach, a model was chosen that isolates the influence of an infrastructure as good as possible from other effects. The price of this complex view modeling is that the whole of Switzerland could not

(yet) be calculated. This leads to the fact that the most precise results are available for rented apartments. The view of a photovoltaic system leads to a reduction in residential rents. This effect is stronger the larger and denser the photovoltaic systems are on neighboring properties. However, this negative impact on residential rents is mainly driven by the view of multiple photovoltaic systems rather than a single one. Moreover, a decrease in rents due to a photovoltaic system is only observed for properties that do not have their own photovoltaic system installed. No significant effect can be demonstrated for residential property.

With regard to large-scale energy infrastructures, the study provides initial results that could be further corroborated by expanding the samples to a full survey. The smaller samples result from the extremely time-consuming calculation of views on infrastructures over larger perimeters. The results seem clear with regard to the (above-ground) transmission grid. The visibility of power lines has significant externalities, i.e., negative effects on residential property prices and rents of investment properties. The other results only give a first indication of the direction of the effects, since for large-scale energy infrastructures the region of the sample can also play a role (i.e., possibly only local effects are measured). The view of nuclear power plants does not affect real estate prices in the survey period; however, the announced gradual phasing out of nuclear energy in the aftermath of Fukushima seems to have a positive effect. An actual view of a run-of-river power plant has a negative effect on residential rents. In contrast, an actual view of a waste incineration plant does not yield statistically significant results. Finally, wind turbines only cause a discount for residential rents (the results are obtained from two windfarms and may not be representative for entire Switzerland).

Main findings

- Carbon-neutral heating systems increase the price and rents of residential properties compared to objects with conventional oil/gas heating.
- Negative external effects of a photovoltaic system seem to exist only for multi-family rental homes without an own photovoltaic system. Having a photovoltaic system compensates the effect. Hence, it is possible that any negative externalities on tenants diminish with increasing efforts to expand the adoption of photovoltaic systems on residential and commercial real estate.
- While an acceptance problem may naturally disappear with increasing propagation of this renewable infrastructure (photovoltaic system), the formulation of appropriate policies to address the significant, negative externalities of transmission grids on real estate prices and rents in Switzerland are required.

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Abbreviations

DiD	difference-in-differences
FOEN	Federal Office for the Environment
GEPA	Geodatabase on Electricity Production Facilities
GRID	transmission grid
GWR	Federal Building and Housing Registry
NPP	nuclear power plant
PV	photovoltaic
REIDA	Real Estate Investment Data Association
RPP	run-of-river power plant
SFOE	Swiss Federal Office of Energy
WIP	waste incineration plant
WPP	wind power plant

1 Introduction

1.1 Background information and current situation

The Swiss electorate adopted the Energy Strategy 2050 in 2017 and the Federal Council committed to net-zero greenhouse gas emissions in 2019. These initiatives are triggering a fundamental transformation of the Swiss energy system. Central developments to induce this change are the gradual phasing out of nuclear energy and the expansion of renewable energies along with an increase in energy efficiency (Schweizerische Eidgenossenschaft, 2021). Therefore, the Swiss Federal Office of Energy, in their publication “Energy Perspectives 2050+”, assumes a ninefold increase in electricity production from new renewable energies within the next 30 years in its projections.[1] In order to achieve the goal of complete decarbonization of the energy system by 2050, the housing stock plays a key role. In 2019, real estate accounted for about 24 % of greenhouse gas emissions and 42 % of final domestic energy consumption in Switzerland (FOEN, 2021). Space heating required almost three quarters of this power usage, from which a significant proportion of 66 % is consumed by fossil fueled heating systems like oil- and gas-fired heating (Prognos, Infras, & TEP Energy, 2021).

In Switzerland, the political system requires that the majority of the population approves a future transformation of the energy landscape. Recent examples of rejected bills in the energy and climate sector are the votes on a (partial) adoption of the model cantonal energy regulations (so-called MuKEn 2014) in the energy legislation of the cantons of Solothurn (2018), Bern (2019), and Aargau (2020), as well as on the total reform of the CO2 Act (2021). In all of these referendums, the additional financial burden on the real estate sector was one of the opponents’ main arguments for their vote against these initiatives (gfs.Bern, 2018; HEV Aargau, 2018; HEV Schweiz, 2021). Given the ambitious energy and climate policy objectives described above, the impact that such a transformation of the current energy infrastructure has on real estate prices and rents is, therefore, of great socio-political relevance.

1.2 Purpose of the project

Previous literature mainly focuses on the impact of energy efficiency measures in terms of aggregated energy certificates on house as well as commercial real estate prices and rents. Most of the studies confirm the existence of a green building premium in commercial real estate, in particular, the office market (see, e.g., Eichholtz, Kok, & Quigley, 2010; Brounen & Kok, 2011; Fuerst & McAllister, 2011; Reichardt, Fuerst, Rottke, & Zietz, 2012). More granular studies deal with the question of how such certificates affect buildings’ energy consumption (see, e.g., Jakob, 2006; Brounen, Kok, & Quigley, 2012; Fuerst & Szumilo, 2013). In the housing market, studies analyze behavioral aspects of private households when they make investment decisions in renewable energy projects (see, e.g., Kempton & Layne, 1994; Greene, 2011; Bull, 2012; Brounen, Kok, & Quigley, 2013; Wiencke, 2013; Kahn, Kok, & Quigley, 2014; Ramos, Gago, Labandeira, & Linares, 2015).

The main idea of this study is to identify the impact of selected types of energy infrastructure on real estate prices, i.e., potential positive or negative externalities as well as internal effects. In this context, we differentiate between house prices (single-family homes and owner-occupied apartments) as well as residential (single- and multi-family homes) and commercial real estate (office, retail, and industrial) rents. To the best of our knowledge, we are the first to provide an isolated valuation of the impact of small- and large-scale energy infrastructure investments on residential and commercial real estate prices and rents. The results could even allow for an estimation of their impact on the overall (real es-

[1] Photovoltaics (from 2.2 TWh/2019 to 33.6 TWh/2050), wind power (from 0.1 TWh to 4.3 TWh) and geothermal energy (up to 2.0 TWh) are expected to make a significant contribution (Prognos, TEP Energy, Infras, & Ecoplan, 2020, p. 60).

tate) capital stock. The results provide important insights into how a specific type of energy infrastructure affects real estate prices and rents, and if creating added-value, can promote acceptance among the population.

1.3 Objectives

This study aims to determine the potential effect of selected small- and large-scale energy infrastructures on Swiss residential and commercial real estate prices. Different types of energy infrastructures are categorized into small-and large-scale as follows: Small-scale infrastructures are mainly internal, i.e., they are either installed within a building such as various types of heating systems or on the building's exterior such as part of a heating pump or a photovoltaic installation. Large-scale infrastructures are, in general, comparably big energy plants of various types. Furthermore, we distinguish between direct (internal) and/or neighborhood-related (external) price effects. Table 1 provides an overview of the energy infrastructures considered in the study and the nature of the effects examined in each case.

Table 1: Internal and external effects of large- and small-scale energy infrastructures

<table>
<tr><th colspan="2" rowspan="2">Effect</th><th colspan="2">Energy infrastructures</th></tr>
<tr><th>Large-scale</th><th>Small-scale</th></tr>
<tr><td rowspan="2">Internal</td><td></td><td></td><td>District heating
Gas heating
Oil heating
Storage heating
Wood heating (boiler)
Wood heating (furnace)
Heating pump (various technologies)</td></tr>
<tr><td rowspan="2">External</td><td></td><td>Photovoltaic</td></tr>
<tr><td></td><td>Nuclear power
Run-of-river power
Transmission grid
Waste incineration
Wind power</td><td></td></tr>
</table>

Notes: This table shows the different types of infrastructure that might directly (i.e., internal infrastructure as part of a building) or indirectly (i.e., externalities such as the view of an external infrastructure) affect real estate prices. The type of infrastructure is categorized into two dimensions: large/small and internal/external infrastructure. The various types of photovoltaic systems overlap the dimension internal/external as they can be part of a building (within the building or on its roof) but may also cause externalities in terms of view and noise. Characteristically, small-scale infrastructures are internal, whereas large-scale infrastructure are external.

1.4 Structure

The remainder of this study is organized as follows: The next section discusses related literature. Section 3 describes the data of energy infrastructures and of real estate prices and rents and introduces the methodology. Section 4 presents our results on potential internal as well as on external effects of small- and large-scale energy infrastructures on real estate prices and rents. Robustness checks are presented in section 5. In section 6, we summarize the results and conclude the study. Section 7 outlines further research needs and policy implications of our findings. Section 8 concludes with an overview of the organizations we cooperated with regarding data procurement for small-scale energy infrastructures.

2 Literature Review

The location of energy infrastructure is of essential interest to both local communities and policymakers (Clark & Allison, 1999). Thereby, changes in property prices as a consequence of infrastructure policies are a crucial aspect to consider during the respective decision-making process of new energy projects. Hence, research interest on the impact of energy infrastructure on property values has been vibrant. A vast body of literature has focused on the housing price impact of energy infrastructures[2] as this field has gained momentum in the wake of the current challenges of climate change and the promotion of renewable energy (Fuerst & McAllister, 2011). Brinkley and Leach (2019)'s meta-analysis documents that nowadays, more than half of the empirical studies in this domain are concerned with renewable energy infrastructure while before the 21st century the major focus was on transmission lines.

2.1 The impact of large-scale energy infrastructures on real estate prices

A conceptual dichotomy between public perception and cost-savings can be useful in distinguishing the underlying mechanism that drives the price changes upon the siting of energy infrastructure. We stress that in practice they could and probably should interact.

Public perception of energy infrastructure can be a first-order effect. Two examples provide highly illustrative evidence: one on nuclear power plants as in the study of Bauer, Braun, and Kvasnicka (2017) and another one on wind turbines as in the study of Clark, Michelbrink, Allison, and Metz (1997). Brinkley and Leach (2019) find that before the 21st century most studies on house price impacts of nuclear power plants report no or even slightly positive effects (see, e.g., Clark et al., 1997; Clark & Allison, 1999; Bezdek & Wendling, 2006). These authors attribute the positive price impacts of nuclear power plants to job growth in affiliated businesses. However, in the 21st century more studies now document statistically significant negative impacts of nuclear reactors and other energy infrastructures on house prices (Bauer et al., 2017).

In March 2011, the Fukushima accident in Japan led to an immediate shutdown of nearly half of Germany's nuclear power plants. Considering the German data used, property prices near nuclear sites that had been in operation before Fukushima have been reduced by 4.9 % because of Fukushima. Property prices near sites that had to shut down have even decreased by 9.8 %. The regression estimate shows that Fukushima caused a decrease of housing prices near nuclear plants by 3.2 % relative to housing prices further away from these sites (Bauer et al., 2017). The study of Breidenbach and Schaffner (2020) also suggests that policy interventions such as the closing of nuclear plants can have a significant effect on the real estate market in Germany. Another study uses the coefficient for distance to a nuclear site in its spatial model. It shows a negative sign but not significant. Hence, the authors argue that the negative perceptions of nuclear plants do not translate into market behavior (Munro & Tolley, 2018). Already earlier research by Clark and Allison (1999) confirms that proximity and visual reminders of energy infrastructure have an impact on property values.

In recent years, wind turbines and their impact on property values have gained importance in research. The growing interest mainly stems from wind turbines' environmental advantages, their economic development, and their energy independence. Expanding wind farms in countries like Sweden can be crucial in substituting nuclear power and thereby achieving a climate-neutral energy production (Westlund & Wilhelmsson, 2021). Their paper analyzes the capitalization of wind farms on property

[2] Another large stream of literature studies how transportation infrastructure impacts property values. In this literature stream most results point to positive externalities. That is the increased connectivity brought by the transport facility such as bus or train lines leading to higher property prices in the surrounding area. A further consequence of such as policy implication is the concept of value capture. This is represented by the areas that benefit from such infrastructure and should be subject to special tax treatment. Such tax treatment is typically higher to compensate and encourage the development of such infrastructure.

values in Sweden and concludes a significant capitalization which is relatively local in a radius of eight kilometers of the wind turbines. Dröes and Koster (2016) further document negative impacts from wind turbine on property prices in the Netherlands and find that there are negative anticipation effects before the installation. Such barriers have also been identified by the nationwide survey sponsored by the U.S. Department of Energy mainly because of its noise (Hoen, Firestone, Rand, Elliot, Hübner, Pohl, Wiser, Lantz, Haac, & Kaliski, 2019). Based on the regression model it has been identified that higher background sound levels significantly lower the probability of hearing wind turbines on one's property. Further it has established the argument that an increase of wind turbine sound level results in distinctive higher noise annoyance; however, it is considered as an expression of personal perception rather than an objective response to sound level. Another study applying a calculus method by Wen et al. (2018) confirms this and finds that residents prefer to have wind farms further away from their properties. However, respondents have divergent preferences for the size of wind farms and turbine height. A study of Haase, Schweizer, and Wider (2019) in which the impact of 216 wind projects (37 realized and 179 planned) on dwellings in Switzerland has been analyzed, suggests that there are tendencies to price-reducing effects related to wind projects. However, according to the authors, those results are not empirically proven. Due to Switzerland's regulatory framework, wind projects are mostly realized in rural, less densely populated areas which results in a smaller probability of observing significant price effects. The authors propose to implement variables such as noise, shadow casting or the public perception to improve their model. The research paper of Firestone, Hoen, Rand, Elliott, Hübner, and Pohl (2018) focuses on local public attitudes towards planning wind power plants as public perception, developer transparency as well as aesthetics might influence the success of energy transformation. They find that neither place attachment, appearance nor turbine view are significant determinants. However, it has been found that an engaged citizen is more likely to have a positive attitude towards the corresponding wind turbine project. The findings of Hoen et al. (2019) agree with this analysis and have a closer look at influencing factors for nearby-living neighbors' attitudes towards local wind projects. Overall, the study concludes a positive-leaning sentiment towards wind projects partly also because of its environmental friendliness. This attitude further improves over years as citizens decide for communities near existing wind plants, which means they incorporate those into their neighborhood.[3] Furthermore, the visual influence of wind farms on landscape heavily depends on environmental externalities. Results from a hedonic price model composed for two Greek islands suggest that on the relatively isolated and hardly populated island, the distance to a wind turbine has no statistically significant impact on property prices. However, on the second island (Evia) the wind turbines are distributed in a large area and installed at close distances to residences. There it is estimated that properties within a 2 km distance of wind turbines have a reduced price by about 14.4 %. This demonstrates that environmental externalities indeed have an impact on the effect of wind farm distance on house prices (Skenteris, Mirasgedis, & Tourkolias, 2019).

There is a large amount of literature dealing with the question whether traditional (high voltage) power lines (transmission grids) affect house prices. In general, the studies find either negative (see, e.g., Hamilton & Schwann (1995), Sims & Dent (2005)) or no statistically significant relationships (see, e.g., Rigdon (1991), Wolverton & Bottemiller (2003)) between house prices and distance to or view of transmission lines. Zhao, Simons, and Fen (2016) analyze the impact of incineration facilities (biomass) on house values and find a large negative effect of 25.9 %, which diminishes by 7.3 percentage points for each km distance. In a more detailed study, Kiel and McClain (1995) study the effect during five stages (pre-rumor, rumor, construction, early operation, and ongoing operations) with statistically significant negative coefficients during construction, early operation and during ongoing operation. For

[3] Using survey data, Hoen et al. (2019) document significant effects of residents' attitudes on noise annoyance levels caused by nearby turbines. Their empirical results show that none of the individuals who reported "very annoyed" could be predicted by sound levels alone. Further, whether they like the look of a wind project, the community's noise sensitivity and prior attitude towards the energy project are the top three variables that had an impact on an individuals' noise annoyance.

hydropower, Bohlen and Lewis (2009) demonstrate a small but significant positive influence of proximity to hydropower systems on sales prices of single-family homes. In contrast, single-family home prices increase by USD 2.43 per meter distance from a dam according to Lewis, Bohlen, and Wilson (2008).

2.2 The impact of small-scale energy infrastructures on real estate prices

A growing body of literature attempts to understand the parameters that drive the public acceptance of renewable energy infrastructure projects (Hoen et al., 2019). Among various parameters, the impact of the energy plant siting on housing values is of particular interest to the local communities and has resulted in many studies. Brinkley and Leach (2019) review 54 studies and conclude that the literature consistently finds positive value impacts from solar rooftops. Contrastingly, cost-savings attributed to low-cost energy projects can be essential drivers of price impacts according to Fuerst and McAllister (2011). They argue that cheap energy provided by a facility or energy efficiency within a property drives attractiveness up, especially for tenants with net rental contracts. Further, increases in rents and asset values in green buildings can be traced to other attributes associated with greater thermal efficiency and sustainability (Eichholtz, Kok, & Quigley, 2013).

With respect to small-scale, internal energy infrastructures, Brändle, Füss, Schläpfer, and Weigand (2022) study how a property's CO_2 emissions affect net rental values and capitalization rates. Their results suggest that apartments in carbon-neutral buildings, i.e., with a heating pump, have higher net rents compared to dwellings with oil or gas-fired heating systems. They also show that low-carbon buildings have lower capitalization rates to offset higher investment costs in sustainable heating systems. Existing studies on rooftop solar installations consistently show statistically significant premiums between 3 and 7 % of sale prices (Dastrup, Zivin, Costa, and Kahn (2012) as well as Coffman, Allen, and Wee (2018)) and between USD 4 and 6 % per watt premium (Hoen, Wiser, Thayer, & Cappers (2013) after the installation of a photovoltaic system.

The impact of installing renewable energy plants on commercial property values has also generated an ongoing research interest. Most of these studies focus on how improvements with environmentally sustainable building practices affect property values, while studies about how nearby energy infrastructure can impact commercial properties are relatively scarce. Fuerst and McAllister (2011) document premiums on such green buildings in terms of both rents and prices. Brounen and Kok (2011) also find positive price premiums on houses labelled "green". Eichholtz, Kok, and Quigley (2013) find that the gains from energy efficiency are fully capitalized into the rents and prices of green buildings.

Overall, the findings on different types of energy infrastructures are mixed, apart from the installation of solar rooftops that consistently lead to statistically significant property price premiums (D'Alpaos & Moretto, 2019). However, various important and insightful patterns can be identified that partly explain the mixed results. Brinkley and Leach (2019) point out both lessons learned and limitations from previous studies. First, they find that visual attributes, including distance to the energy supply, are important factors, which may be attributable to the conflicting results of these studies. Second, they propose that further studies should be conducted on various types of housing and properties since the prior focus had been largely confined to residential single-family homes. Third, taking pre- and post-tests into account is important to fully understand the price impacts. Fourth, newer energy plants are less represented in the literature and thus should be more closely examined to compare them with old plants. Fifth, they doubt the generalizability of the empirical results from such studies due to cultural and regional differences in communities' perception, planning processes and land-use values. The fifth lesson is particularly important in the Swiss context because of the vibrant differences across cantons. One way to learn about the community perception could be to look at the voting tendency on related energy projects. In our study, we address most of these shortcomings in the previous literature by focusing on a broad spectrum of small- and large-scale energy infrastructures in Switzerland. We take into account not only the distance but also introduce a novel approach to capture the influence of the view of an infrastructure. In our empirical analyses, we specify traditional and spatial hedonic regressions, as well as a “difference-in-differences” methodology.

3 Data and Methodology

There are two main sources of data for this study: Data on small- and large-scale energy infrastructures and data on real-estate prices as well as rents. This section describes these two datasets and how they are combined.

3.1 Data of energy infrastructures

Considerable effort was put into the collection and preparation of the dataset on energy infrastructures. In addition to data on large-scale energy infrastructures (transmission grid, nuclear power, wind power, run-of-river power and waste incineration), data on photovoltaic systems and heating solutions were obtained for six of the most populated cities of Switzerland. As there was no central database on the small-scale energy infrastructures, the project actively approached around 25 contact persons in the municipal administrations. In summary, approximately 250 correspondences took place with the municipal representatives alone via e-mail, telephone, and physical or virtual meetings. As a result, a total of seven confidentiality agreements with around 35 signatures were initiated.

At the start of the project, it was not apparent that the Swiss Federal Office of Energy (based on the revised Energy Ordinance and Geoinformation Ordinance as of 01.01.2021) would publish a new geo database on over 110,000 electricity production plants in Switzerland available for free use as Open Government Data on 08 April 2021. This dataset, as well as the access to the dataset of the Federal Building and Housing Registry, which was not expected at the time of the project application, made the laborious compilation of numerous datasets on small- and large-scale energy infrastructures, which had already been completed up to that point, obsolete.

The following is a brief description of the two latter datasets mentioned. In addition, reference is made to other datasets that were used with regard to identify the location of and the view of energy infrastructures.

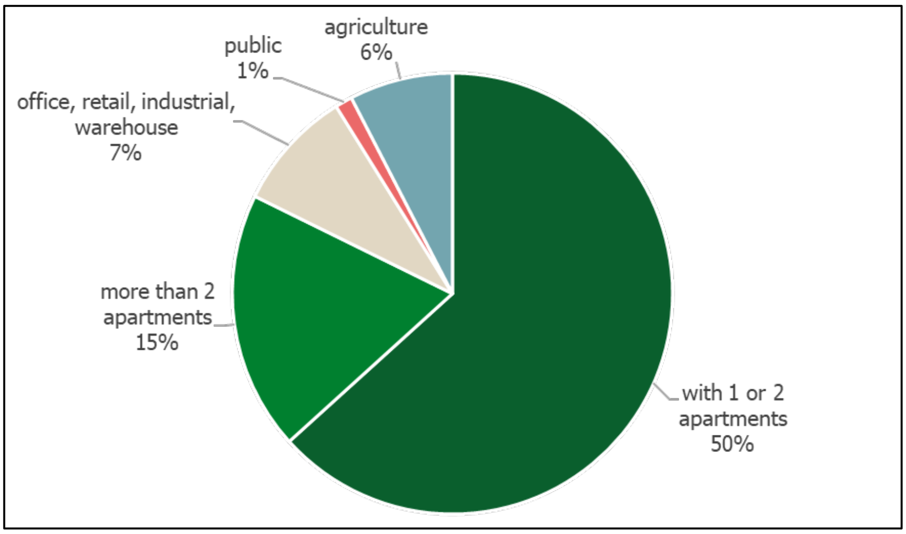
Federal building and housing registry

The Federal Building and Housing Registry (GWR) (Gebäude- und Wohnungsregister | Bundesamt für Statistik (admin.ch)) was used as the data source for heating solutions, with data recorded until 18 February 2021. It contains data on a total of 2.576 million buildings in Switzerland (see Figure 1).

Originally, the database was created using data from the 2000 census; since then, it has been continuously updated by the Federal Statistical Office in cooperation with the specialized agencies of the confederation, the cantons, and the municipalities. It is mainly used for statistical, research and planning purposes.[4]

[4] The GWR contains information on construction projects, buildings, apartments, building entrances and streets. A catalogue of features provides information on structure, definitions and contents: Merkmalskatalog – Eidgenössisches Gebäude- und Wohnungsregister – Version 4.1 | Publikation | Bundesamt für Statistik (admin.ch).

Figure 1: Overview of the buildings recorded in the GWR



For about 2 million of these buildings, the data on the type of heating system or the energy source of the heating system are known (however, for 130,000 buildings, no heating solution data is available).

Table 2: Overview of the heating types recorded in the GWR

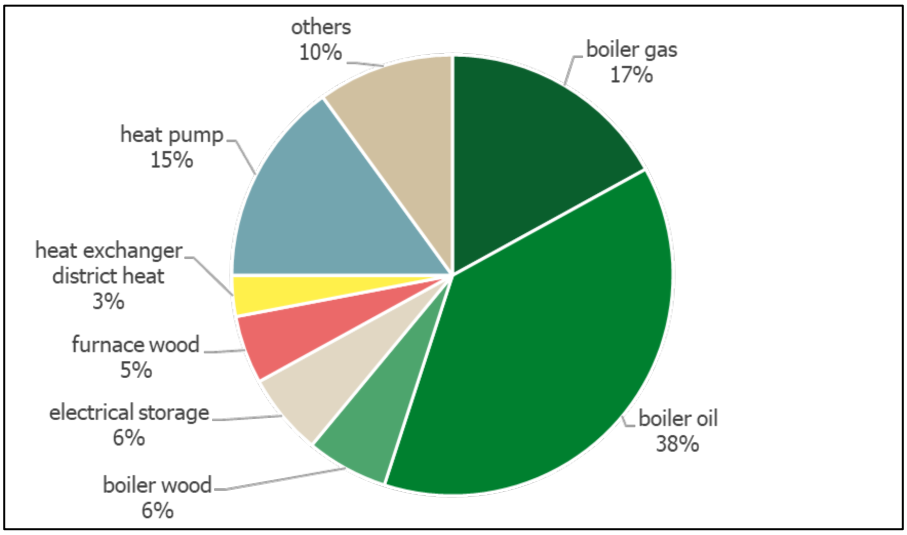
Heating type	#Buildings	Percentage
Boiler	1,179,006	66%
Heating pump	279,451	16%
Furnace	134,783	8%
Storage heating	123,463	7%
Heat exchanger	65,441	4%
Solar heat	5,879	0%
Direct electric heating	2,616	0%
Others	922	0%
Combined heat and power	38	0%
TOTAL	**1,791,599**	**100%**

Table 3: Overview of buildings included in the GWR (by heating energy source)

Heating energy source	#Buildings	Percentage
Oil heating	755,873	42%
Gas heating	326,344	18%
Heating pump (undefined source)	250,621	14%
Wood heating	213,884	12%
Electric (82 % storage heating)	150,761	8%
District heating	67,358	4%
Heating pump (geo/electricity)	17,411	1%
Others	11,163	1%
Heating pump (air/electricity)	8,598	0%
Sun (thermic solar heating)	5,995	0%
Unknown	4,055	0%
Heating pump (water/electricity)	966	0%
TOTAL	**1,813,029**	**100%**

In Table 3, “air/electricity” refers to air-source heat pumps. If the type of heat pump is not known, the energy source “undefined/electricity” is stored in the database. Figure 2 summarizes the heating solutions of the buildings included in the GWR.

Figure 2: Overview of the heating solutions of the buildings included in the GWR



Geodatabase on Electricity Production Facilities

As a data source for the small- and large-scale electricity production plants (photovoltaics, nuclear power, wind power, run-of-river power as well as waste incineration) considered in this study, the Geodatabase on Electricity Production Facilities (GEPA) (Elektrizitätsproduktionsanlagen | opendata.swiss) deposited on the portal opendata.swiss as Open Government Data was used.

It contains approximately 110,000 electricity production plants in operation that are registered in the Swiss guarantee of origin system. This includes all plants with a capacity >30kVA, small plants (>2kVA) with voluntary registration for the issuance of guarantees of origin, and all plants subsidized in the form of feed-in tariffs, one-time payments, additional cost financing, or investment contributions.

The dataset is primarily used for the (spatial) visualization of the addition of plants used for the production of new renewable electricity in Switzerland. In addition to the location of the electricity production plants, the respective output and the date of commissioning can also be gathered from this.[5]

Table 4: Overview of electricity production facilities covered by the GEPA

Main categories	Subcategories	Plant categories	# of plants
water	water	waste-water power plant	13
water	water	parallel hydropower plant	417
water	water	ecological flow hydropower plant	49
water	water	continuous feed power plant	300
water	water	drinking-water power plant	447
water	water	pumped-storage power plant	24
water	water	storage power plant	107
water	water		98
other renewable energy	garbage	waste incineration	33
other renewable energy	photovoltaic	detached	575
other renewable energy	photovoltaic	attached	85,504
other renewable energy	photovoltaic	integrated	19,963
other renewable energy	photovoltaic		3,723
other renewable energy	wind		69
other renewable energy	biomass	biomass utilization	254
other renewable energy	biomass	waste-water treatment	154
atomic power	atomic power		4
fossil fuels	oil		5
fossil fuels	gas		183
TOTAL			111,922

Other energy data sources

Up to now the GEPA has been able to obtain the location of photovoltaic systems, but not their exposure. This information is relevant for determining the visibility of the installation. For this reason, a geodata model developed by Meteotest under the name Sonnendach.ch (Wie viel Strom oder Wärme kann mein Dach produzieren? (admin.ch)) was used to determine the solar potential of all roof surfaces and fronts of buildings in Switzerland.[6] It is important to note that in this study, it is assumed that

[5] Further details can be found in the documentation of the geodata model: Elektrizitätsproduktionsanlagen (admin.ch)
[6] Details can be found in the documentation of the geo data model: Solarenergie: Eignung Hausdach (admin.ch)

the existing photovoltaic systems are located at the optimal location on the roofs according to Sonnendach.ch.

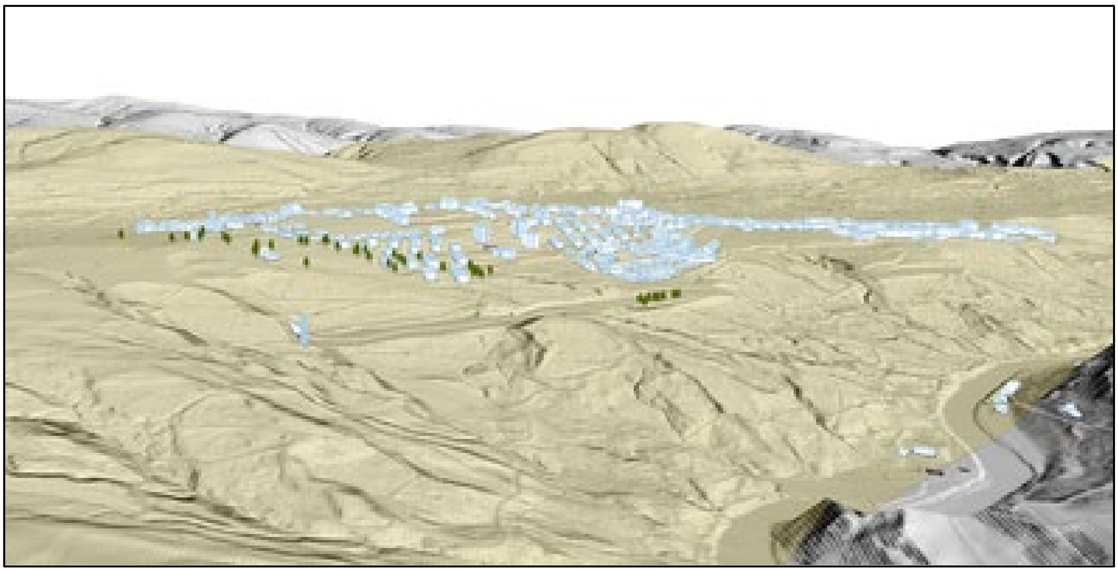
Admittedly, data on five selected grid projects were promised by the transmission system operator Swissgrid to determine the influence of the transmission grid on real-estate prices. However, much more comprehensive data on the existing routes of the transmission grid could be obtained from the publicly available database OpenStreetMap (OpenStreetMap) operated by the OpenStreetMap Foundation. While this is not officially published data by Swissgrid, this study assumes that these datasets match.

3D-data of buildings, trees and forests, and topographical data

For this information, three datasets from the Federal Office of Topography are used. These three datasets are listed below and visualized in Figure 3:

- swissBuildings3D 2.0 (buildings) (swissBUILDINGS3D 2.0 (admin.ch)): vector dataset representing buildings as 3D-models with roof shapes and overhangs; each object is assigned various attributes (e.g., object type, usage or name); updated every six years.
- swissTLM3D (trees, forests) (swissTLM3D (admin.ch)): large-scale topographic landscape model of Switzerland; it includes the natural and artificial objects as well as the name data in vector form; individual subsections of the dataset have been continuously updated since 2011.
- swissAlti3d (topography) (swissALTI3D (admin.ch)): precise digital elevation model describing the surface of Switzerland without vegetation and buildings; digital terrain model is represented as a raster dataset or as an xyz-file in regular grids, where each cell of a grid or each point of the xyz-file contains an elevation value; updated every six years.

Figure 3: Visualization of the used datasets at the example of a part of St.Gallen



Whereas buildings have exact so-called polyhedral surfaces and the topography is modelled at a detail of 5 meters, trees and forests are positioned in swissTLM3D, but without exact description. Therefore, we assume 5 meters of height for trees and forests.

3.2 Real estate price data

AdScan

The main data source used is “AdScan” from Meta-Sys AG, the database of all Swiss Real Estate advertisements since 2004. The variables of this dataset are listed in Table 5:

Table 5: Variables of the data source AdScan

	House price (owner-occupied)	Residential real estate rent	Commercial real estate rent
gross / net rent		monthly/m²	monthly/m²
sales price	X		
year of (intended) transaction	X	X	X
object type	X	X	X
surface usable	X	X	X
surface property	X		
number of rooms	X	X	
floor	(apartments, houses, missing = 0)	(apartments, houses, missing = 0)	(missing = 0)
year of construction	(missing = 0)	(missing = 0)	(missing = 0)
first use	X	X	X
elevator	X	X	X
view	X	X	X
MINERGIE	X	X	X
wheelchair access	X	X	X

As many ads are published on several platforms, duplicates had to be removed from the dataset. This is done by a specific double filtering process, comparing all major variables of each listing. Not all observations (especially owner-occupied property in the western part of Switzerland) have exact addresses. Therefore, only listings with precise geo-coding (so-called “rooftop”) are considered. Records with missing price or surface information are excluded from the dataset as well. Missing years of construction or missing floors are set to 0.

Possible bias of advertisement data

Advertized property prices can slightly differ from contractual prices. However, these differences are mostly negligible as several studies show. Firstly, in the case of rental housing, a study for the Swiss Real Estate Institute (Swiss Real Estate Institute – Institut der Schweizer Immobilienwirtschaft (swissrei.ch)) showed, that advertized and contractual rents are in most cases the same. Secondly, in the case of owner-occupied housing, Haurin (1988) argues that asking and transaction prices should be similar, especially, in cases where standard houses are considered. Moreover, Han and Strange (2016) state that asking prices can be a fairly accurate estimator for the actual transaction prices of houses in the residential property market. Their paper argues that asking prices are relevant and that a valuable share of housing transactions have been closed with a price equal to the initial asking price. Ardila, Ahmed, and Sornette (2021) provide strong evidence that asking and transaction prices are comoving across different market segments and hence, asking prices can be a suitable estimate for the developments in the Swiss real estate market. Thirdly, the co-integration of asking and transaction prices has not been investigated by the literature and, hence, we cannot necessarily assume that asking and transaction prices are the same in our setting. Therefore, we also include commercial contract data from the Real Estate Investment Data Association (REIDA) in our analysis. To further eliminate any possible bias in the case of owner-occupied housing, we stress our result by using a detailed dataset on owner-occupied housing transaction in the Canton of Zurich.

Summary Statistics on Real Estate Prices

In our empirical study, we consider three different types of real estate markets: (1) owner-occupied housing, which includes *asking prices* for single-family homes as well as apartments, (2) residential *asking rents* for predominantly apartments in multi-family homes and but few single-family homes, and (3) *asking rents* for commercial real estate including office and retail, as well as mixed use properties. Table 6 shows the prices and rents per square meter. The number of observations vary between the sectors with residential real estate being the largest sample of approximately 1.8 million observations, followed by house prices (267,269 observations, while commercial real estate rents comprise only 67,985 observations.

Table 6: Summary statistics on real estate prices (estimation sample: Switzerland)

Variable	Mean	Std.dev.	Min	Max
Panel A: House Prices (Owner-occupied) (number of observations is 267,269)				
Price/m^2 [CHF]	5,523.47	2,012.06	1,603.77	11,933.33
log(Price)	8.553	0.359	7.38	9.387
Panel B: Residential Real Estate Rent (number of observations is 1,825,019)				
Rent/m^2/month [CHF]	18.99	5.696	9	45.7
log(Rent/m^2/month)	2.904	0.278	2.197	3.822
Panel C: Commercial Real Estate Rent (number of observations is 67,985)				
Rent/m^2/month [CHF]	235.375	118.593	74	655
log(Rent/m^2/month)	5.348	0.47	4.304	6.485

Note: This table shows the descriptive statistics on the three different real estate segments. Owner-occupied house prices and residential rents commercial real estate are asking prices. Residential and commercial rental values are given in m^2 per month.

The average price per m2 of housing is CHF 5,523 with a large variation between CHF 1,600 and 12,000 per m^2 living space (Panel A of Table 6). The rents for residential apartments and commercial real estate are given in m^2 per year. The average residential rent is CHF 19 with a range between CHF 9 and CHF 46 (Panel B). Commercial real estate is rented out with an average price of CHF 235 per m^2 and year. The lowest rent is at CHF 74 while the prime rent reaches CHF 655 (Panel C). In the Appendix, the descriptive statistics on the residential and commercial real estate are provided.

3.3 Methodology

We use different approaches to estimate the relationship between energy infrastructure and real estate prices and rents. First, we use a hedonic model specified as a panel regression with zip-code and year fixed-effects of the following formula:

$$lnp_{it} = X_{it}\beta + \gamma IFS + \eta_i + \lambda_t + \varepsilon_{it} \quad (1)$$

In order to control for housing characteristics as well as the micro and macro locational factors, we implement linear hedonic regressions. This approach follows Fahrländer, Gerfin, and Lehner (2015) who estimate the influence of noise on net rental values and prices of commercial real estate. The house as well as the rental prices are in natural logarithm. The main variable is *IFS* which includes the infrastructure and/or the view of a specific infrastructure such as a photovoltaic system or a large-scale energy infrastructure. X_{it} consists of the property attributes: Object type (apartment, attic, detached house, etc.), number of rooms (categorized 1 to 7 (> 6.5)), number of floors (1 to 10 and more), building period (categorized between early 1919 and later 2015), first use (either newly built or fully renovated), view on amenities (such as on mountains, lakes, river), neighborhood type (from low density, pure housing to high density, mixed use neighborhood type), and usable for commercial real estate (see also the Appendix for the scaling of the control variables). In order to give the estimates a causal interpretation, we implement a “difference-in-differences” approach in extension to the fixed effects model specified in equation (1). We specify the following linear “difference-in-differences” model, including a full set of time and zip-code fixed effects:

$$lnp_{it} = X_{it}\theta + \kappa_i + \tau_t + \varphi D_{IFS} + \delta(D_{Install} \times D_{IFS}) + \varepsilon_{it} \quad (2)$$

with:
- p_{it} = change in house prices,
- X_{it} = housing characteristics,
- $D_{Install}$ = dummy variable before and after installation of photovoltaic,
- D_{IFS} = dummy variable with and without photovoltaic,
- ε_{it} = normally distributed error term.

The aim of the econometric models is to measure price or rent effects on three categories of real estate: owner-occupied housing, rental housing, rented commercial real estate. For owner-occupied housing, we estimate offer sales prices per m^2 and for the latter two categories net offer rents per m^2, respectively. We use cluster-robust standard errors at the level of zip codes.[7] Because energy infrastructure investments have a local component, i.e., they affect surrounding houses or commercial properties, we extend the classical hedonic models by a spatial error model in the robustness test section.

[7] In robustness tests we control for spatial autocorrelation in the residuals to address potential remaining concerns about biased estimates and/or wrong inference about significance.

4 Results and discussion

4.1 Internal effects of small-scale energy infrastructures

4.1.1 Internal effects of heating systems

In this section, we estimate the effect of the heating system together with the energy source on real estate prices. We consider the following heating systems/energy sources:

- Gas heating (boiler)
- Oil heating (boiler)
- Electrical storage heating
- Heating pump (various technologies)
- Wood heating (furnace)
- Wood heating (boiler)

To analyze the internal effect of heating systems on the owner-occupied house prices, residential rents and commercial real estate rents, we use an unbalanced panel regression with fixed effects for zip codes and cluster robust standard errors. In this model, we control for property types, individual property characteristics as well as location attributes (see section 3) to successfully quantify the internal effect. We exclude heating information, which is based on the census of 2000, as this information is too outdated and, hence, could be unreliable.

Owner-occupied house prices

With 111,831 observations we can estimate the owner-occupied model, which leads to a clear result: Heat-pumps, wood-furnaces and wood boilers have a clear positive effect on house prices at a minimum significance level of 10 %. In contrast, oil-fired heating systems, electricity storage heating as well as district heating do not yield a significant estimate and cannot be differentiated from gas-boilers.

Residential rents

The estimation based on 770,939 residential rental observations shows that oil boilers and wood boilers are penalized on the rental market compared to gas boilers, whereas heat-pumps increase the rental payment. A somewhat confusing but significant result is obtained for district heating, which reduces net rents significantly. This might be due to the high expenses for district heating which leads to substantially higher gross rent, or in other words tenants are only willing to accept lower net rents. All other heating types have no significant effect on net rents. Notably, since our estimation sample does not cover data for the year 2022 it cannot account for the recent increases in gas prices and may therefore not be representative for any recent changes in relative energy prices. These developments potentially exert dampening (accelerating) effects on observed price penalties (premia) relative to gas boilers, however, future research is required to provide statistical evidence on any such potential differential impacts brought about by current developments in energy prices.

Commercial real estate rents

Based on 33,181 observations, commercial real estate rents only show a significant penalization of oil boilers compared to gas-boilers. All estimates for other heating types are not significant but carry plausible signs in the context of commercial real estate.

Table 7: Internal effects of small-scale infrastructures on real estate prices

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
Internal effects of small-scale infrastructure (against base category: gas-heating (boiler)			
Oil heating (boiler)	-0.001 (0.004)	-0.009*** (0.002)	-0.030*** (0.010)
Electrical storage heating	-0.010 (0.011)	0.008 (0.009)	-0.048 (0.042)
District heating	-0.005 (0.008)	-0.008* (0.004)	-0.001 (0.015)
Heating pump	0.035*** (0.004)	0.010*** (0.003)	0.009 (0.016)
Wood heating (furnace)	0.028*** (0.009)	0.007 (0.011)	-0.024 (0.060)
Wood heating (boiler)	0.012* (0.007)	-0.010** (0.004)	-0.007 (0.031)
Residential object types (against base category: house (unspecified type))			
Single-family house	0.016 (0.011)	0.069*** (0.011)	
Single-family house (detached)	0.058*** (0.010)	0.040*** (0.006)	
Single-family house (semi-detached)	-0.044*** (0.010)	0.090*** (0.009)	
Townhouse (corner)	-0.061*** (0.011)	0.091*** (0.013)	
Townhouse (single-family)	-0.115*** (0.011)	0.045*** (0.014)	
Apartment	-0.079*** (0.010)	-0.021*** (0.005)	
Attic	0.078*** (0.011)	0.120*** (0.005)	
Maisonette	-0.089*** (0.011)	0.001 (0.006)	
Loft	-0.007 (0.014)	0.044*** (0.008)	
Penthouse	-0.075*** (0.011)	-0.005 (0.006)	
Studio	-0.084*** (0.032)	0.022 (0.015)	
Commercial object types (against base category: commercial (unspecified))			
Office			0.258*** (0.012)
Retail			0.382*** (0.017)
Arcade			0.241*** (0.021)
Mixed (office/commercial)			0.145*** (0.013)
Mixed (office/commercial/storage)			0.019 (0.016)
Mixed (office/retail)			0.333*** (0.016)
Mixed (office/retail/commercial)			0.223*** (0.018)
Mixed (office/retail/storage/commercial)			0.084*** (0.027)
Mixed (office/retail/storage)			0.351*** (0.023)
Mixed (office/storage)			0.201*** (0.014)
Mixed (office/practice)			0.257*** (0.014)
Mixed (commercial/storage)			-0.185*** (0.019)
Mixed (retail/commercial)			0.273*** (0.027)
Mixed (retail/storage)			0.298*** (0.033)

Table 7 continues on the next page.

Table 7 continued.

Rooms (against base category: unknown)			
1	-0.142*** (0.020)	-0.079*** (0.006)	
2	-0.079*** (0.007)	-0.023*** (0.003)	
3	-0.022*** (0.005)	-0.007*** (0.002)	
4	0.006 (0.005)	0.014*** (0.003)	
5	0.018*** (0.005)	0.052*** (0.004)	
6	0.026*** (0.005)	0.125*** (0.007)	
7 and more	0.034*** (0.006)	0.229*** (0.013)	
log(living space)/log(usable space)	-0.148*** (0.007)	-0.294*** (0.011)	-0.074*** (0.005)
Floors (against base category: unknown)			
1-3	0.012 (0.033)	0.012 (0.019)	-0.021 (0.019)
4-6	-0.026 (0.033)	-0.014 (0.019)	-0.011 (0.018)
7-9	-0.055 (0.034)	-0.013 (0.020)	0.020 (0.022)
10 and more	-0.036 (0.050)	-0.015 (0.021)	0.066** (0.034)
Building period (against base category: < 1919)			
1919-1945	-0.008 (0.008)	-0.028*** (0.006)	-0.042*** (0.015)
1946-1960	-0.029*** (0.009)	-0.057*** (0.006)	-0.060*** (0.011)
1961-1970	-0.046*** (0.008)	-0.049*** (0.006)	-0.101*** (0.015)
1971-1980	-0.047*** (0.008)	-0.039*** (0.007)	-0.097*** (0.016)
1981-1985	-0.016* (0.009)	-0.030*** (0.007)	-0.061*** (0.021)
1986-1990	-0.008 (0.008)	-0.013* (0.007)	-0.091*** (0.017)
1991-1995	0.006 (0.009)	0.006 (0.009)	-0.069*** (0.019)
1996-2000	0.024*** (0.008)	0.009 (0.012)	-0.033 (0.021)
2001-2005	0.058*** (0.007)	0.053*** (0.007)	-0.002 (0.017)
2006-2010	0.073*** (0.008)	0.074*** (0.007)	0.001 (0.017)
2011-2015	0.129*** (0.008)	0.104*** (0.007)	0.019 (0.019)
>2015	0.150*** (0.009)	0.076*** (0.009)	-0.014 (0.020)
First use (new or renovated)	0.009** (0.003)	0.074*** (0.003)	0.089*** (0.011)
Has view on mountain, lake etc.	0.042*** (0.002)	0.036*** (0.002)	0.092*** (0.008)
Neighborhood type (against base category: very low density, housing)			
Low density, housing	0.015* (0.009)	0.006 (0.006)	-0.067 (0.073)
Above average density, housing	-0.011 (0.008)	-0.012** (0.005)	-0.110 (0.071)
High density, housing	-0.025*** (0.010)	-0.015*** (0.006)	-0.062 (0.070)
Very low density, mixed use	0.015 (0.011)	-0.007 (0.006)	-0.091 (0.078)
Low density, mixed use	0.012 (0.009)	0.004 (0.006)	-0.055 (0.071)
Above average density, mixed use	-0.011 (0.009)	-0.004 (0.005)	-0.050 (0.069)
High density, mixed use	-0.018* (0.010)	-0.004 (0.006)	0.001 (0.070)

Table 7 continues on the next page.

Table 7 continued.

Year (against base category: 2004)			
2005	0.025*** (0.007)	0.007** (0.003)	0.034 (0.022)
2006	0.047*** (0.007)	0.014*** (0.003)	0.018 (0.017)
2007	0.056*** (0.007)	0.021*** (0.003)	0.037* (0.021)
2008	0.079*** (0.072)	0.045*** (0.004)	0.033* (0.018)
2009	0.093*** (0.007)	0.061*** (0.004)	0.044** (0.019)
2010	0.127*** (0.008)	0.071*** (0.005)	0.047*** (0.018)
2011	0.169*** (0.009)	0.084*** (0.005)	0.045** (0.018)
2012	0.214*** (0.009)	0.096*** (0.005)	0.040** (0.020)
2013	0.252*** (0.009)	0.107*** (0.005)	0.068*** (0.019)
2014	0.265*** (0.009)	0.113*** (0.005)	0.090*** (0.021)
2015	0.290*** (0.009)	0.121*** (0.005)	0.116*** (0.019)
2016	0.306*** (0.009)	0.122*** (0.006)	0.117*** (0.018)
2017	0.331*** (0.009)	0.130*** (0.006)	0.113*** (0.019)
2018	0.352*** (0.009)	0.129*** (0.006)	0.089*** (0.020)
2019	0.359*** (0.009)	0.130*** (0.007)	0.075*** (0.020)
2020	0.362*** (0.009)	0.106*** (0.007)	0.137*** (0.019)
2021	0.427*** (0.009)	0.119*** (0.007)	0.170*** (0.019)
Constant	9.160*** (0.052)	4.119*** (0.052)	5.499*** (0.078)
Observations	111,831	770,939	33,181
Adjusted within R^2	0.389	0.323	0.184

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 2,581 in column (1), 2,602 in column (2), and 1,242 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

4.1.2 Internal effects of photovoltaic systems

As in the context of internal heating systems, photovoltaic (PV) systems may influence prices as well as rents of residential and commercial real estate. Therefore, we re-estimate our unbalanced panel data regression with fixed-effects at zip-code level for samples of owner-occupied houses (267,269 observations), residential real estate rents (1,825,019 observations) as well as commercial real estate rents (67,985 observations).

In the context of owner-occupied housing, our results suggest a positive impact of a building's internal PV systems. This effect is significant across all conventional significance levels. Owner-occupiers are able to cut down electricity cost by having a PV installation. This reduction in ancillary cost translates into higher house prices. In contrast, there is no significant effect of an internal PV installation on residential rents or commercial real estate rents. Tenants sign market-based electricity contracts and are, hence, not able to benefit from internal PV installations (the market price of electricity is always based on the most expensive power generation method). Preferences for sustainability would be another driver of positive internal effects on rents. However, preferences for greenness seem to not be of particular relevance for this type of real estate.

Table 8: Internal effects of PV systems on real estate prices

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
Internal effects of small-scale infrastructure (against base category: objects without PV)			
Object with PV installation	0.031*** (0.004)	0.007 (0.005)	-0.012 (0.0133)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Post code	X	X	X
Observations	267,269	1,825,019	67,985
Adjusted within R^2	0.383	0.346	0.190

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 3,016 in column (1), 2,946 in column (2), and 1,635 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

4.2 External effects of small-scale energy infrastructures

In this subsection, we estimate the impact of view and noise of external energy infrastructure on real estate prices. One might expect that these externalities emerge mainly from large-scale energy infrastructures like nuclear power, run-of-river power, transmission grids, waste incineration, and wind power. However, the view of a technical installation such as a PV system and/or a heating pump might affect real estate prices as well. Therefore, we first describe our novel approach to model the view of an energy infrastructures in subsection 4.2.1. Secondly, in subsection 4.2.2 we estimate externalities of a PV system (as small-scale energy infrastructure) on real estate prices for buildings which do not have a PV system.

4.2.1 View modeling of energy infrastructures

Step 1: Linking prices and energy infrastructures with buildings' dimensions

In order to model the view of a PV system, real estate prices and the specific energy infrastructure have to be matched with the three-dimensional shape of a building. When merging polyhedral building information with other data sources, one crucial question is how the coordinates of these other sources relate to the surface of buildings. The following map illustrates this matching process graphically for a neighborhood in Bubikon, Switzerland.

Figure 4: Linking prices and energy infrastructures with buildings (example of Bubikon)

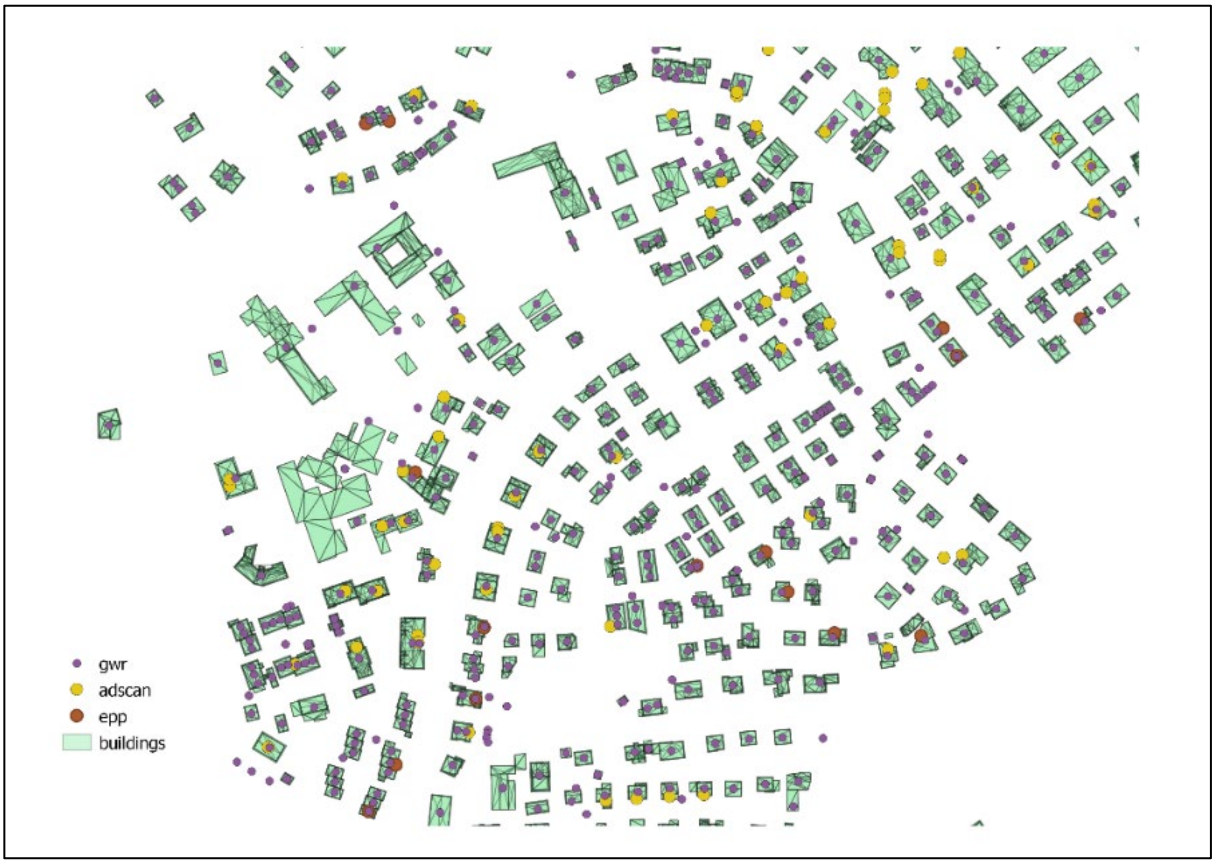
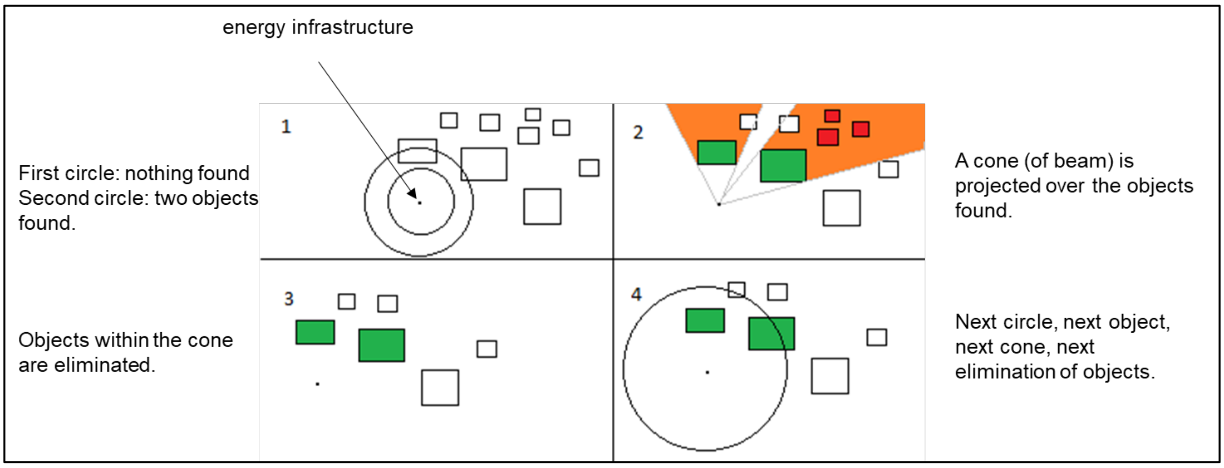


Figure 4 illustrates that GWR and GEPA coordinates mostly overlap with polygons of Swiss buildings, i.e., only a small amount of GWR points are not mapped within buildings. In other words, the matching of GWR and GEPA to Swiss buildings is only successful when the GWR points lie strictly inside the buildings' edges. Consequently, all other mappings are omitted. In contrast, AdScan observations may lie outside (but close) to a building. For these objects, a distance of up to 10 meters from a building is allowed. If several buildings are found, then the closest dwelling is selected.[8]

Step 2: Ray tracing

To successfully model the view of each building of an energy infrastructure, we use a method called "ray tracing". The approach is illustrated in Figure 5.

Figure 5: Illustration of the method "ray tracing"



The starting point of the "ray tracing" approach is a circle around a given energy infrastructure. Objects intersecting the circle are identified (if no object intersects, a larger circle is drawn). In the next step, identified objects are used to draw a cone. All other objects within the cone cannot be seen from (or see) the infrastructure. These objects are removed. Finally, this procedure is repeated until the radius of the circle reaches the pre-defined cut-off distance of the infrastructure type (see Table 9).

Objects only partly in a cone can see the infrastructure in part. View of an infrastructure from a building is therefore classified: the entire building has a view of the infrastructure or only part of it. Most buildings only have a partial view of it, as only direct neighbors could see it in full. However, even for those direct neighbors a tree is sufficient to make these objects "partially seeing" a PV installation. For the underlying analysis, we count the number of intersections a building has with the different cones. As can be seen from Figure 5, the further away a building is from the infrastructure, the higher this number can be. It then becomes more likely that these buildings do not see much if anything. As explained in the methodology part, we use all buildings with an unimpaired as well as with a partial view in our regressions. However, we distinguish among properties from which a view of an installation is relatively likely or unlikely by using the "partially seeing" (or "partially hidden") score. The higher the score, the less likely a PV installation can be seen from a building. The search is not only done for buildings, but also for the individual floors in a building. A property located on a lower floor can be eliminated from the group of property viewing, whereas an object on a higher floor is more likely to have a view of the energy infrastructure.

[8] Not all GEPA infrastructures are located within buildings. Wind power plants, for example, do not have a representation in Swiss buildings.

Figure 6: Illustration of the energy infrastructure to be considered for an area in St.Gallen

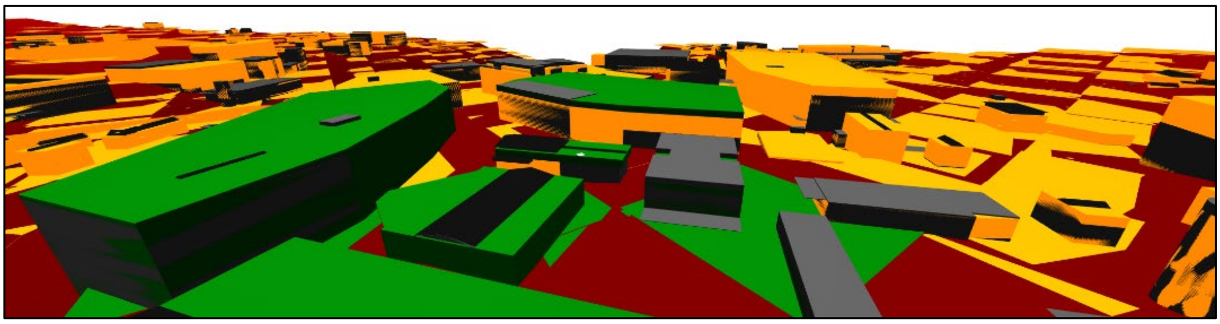


Figure 6 shows a neighborhood in St.Gallen and the view modelling on a PV installation. The PV installation is the white point in the center of the image. The green buildings have (at least in part) a view of the PV installation. The building behind does so only from the top floor (black). If several energy infrastructures are in the same area, a building might have a view of several of them. These multiple relations need to be aggregated in the econometric model to avoid double counting of objects. In addition, Table 9 lists distance criteria for each type of infrastructure:

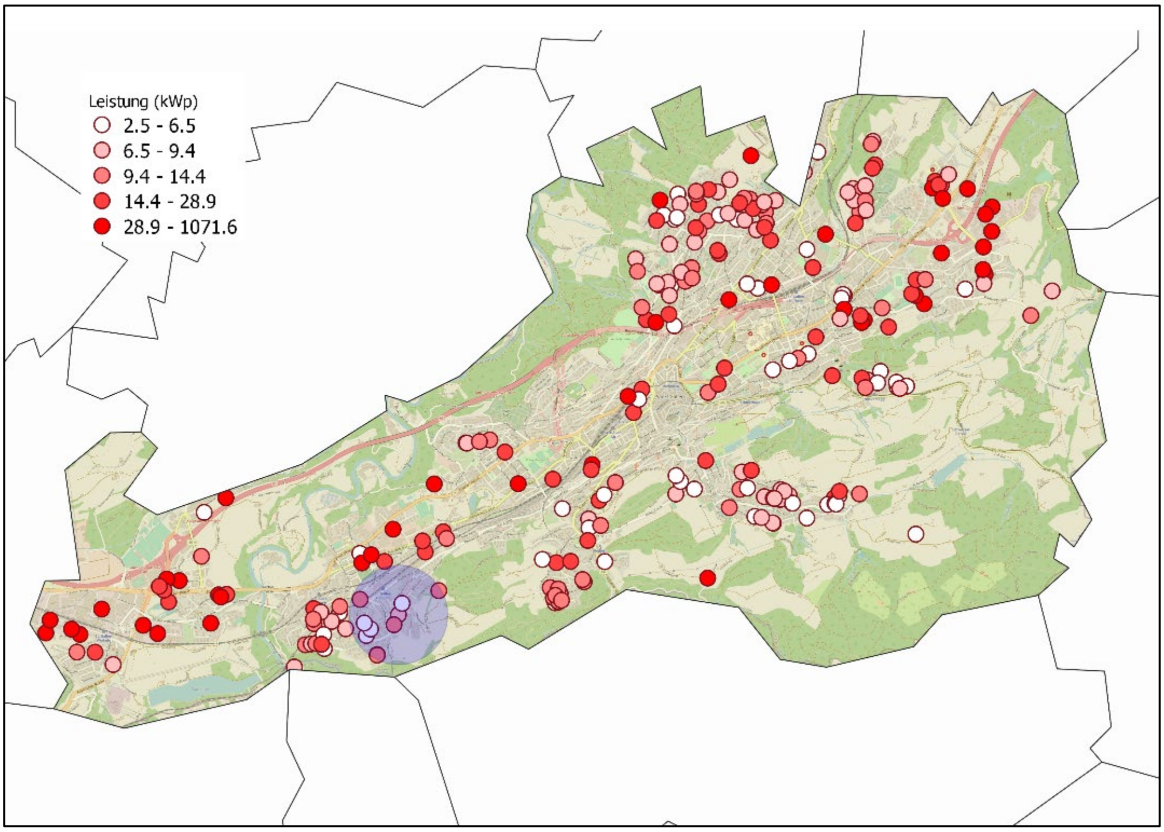
Table 9: Considered criteria for each type of infrastructure

Type of infrastructure	Size of infrastructure (l, w, h)	View	Noise	Smelling
water, ejection power plant	5*5*3	2 km		
water, continuous flow power plant	10*20*3	3 km		
waste incineration	100*100*10	5 km		5 km
PV not integrated	25*25*0	2 km		
PV integrated	on best location	1 km in villages 500 m in cities		
wind	44*44*77	10 km	2 km	
nuclear	120*120*140	10 km		
transmission grid		10 km		

Step 3: Creating view data

Let us describe the final data of the view of external energy infrastructure by illustrating a map of St.Gallen with its PV installations:

Figure 7: Map of PV systems with different energy production (city of St.Gallen)

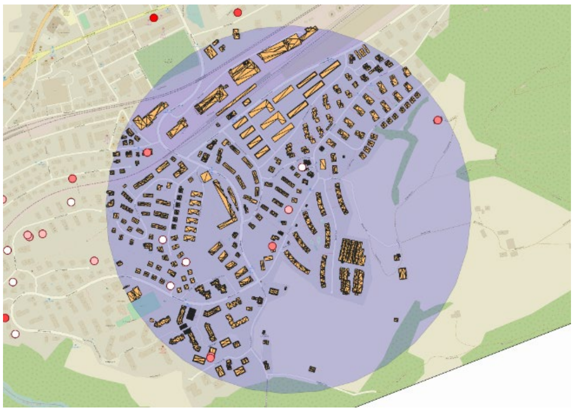
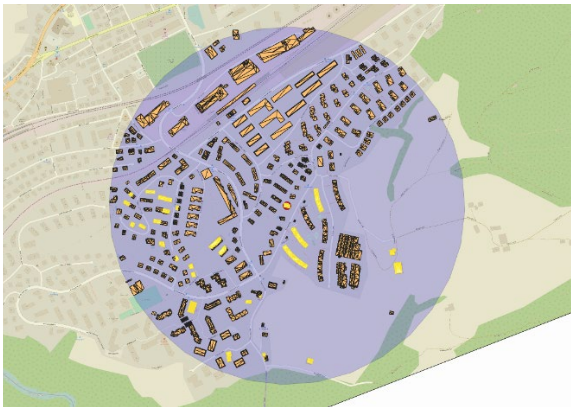


Since it is possible that a building has a view of several installations, we summarize these cases for individual buildings in the following way:

- seeing large and close PV: within 100 m and total power >10kW(p)
- number of PV installations seen

Furthermore, in the “difference-in-differences” model we take the earliest beginning of operation for each infrastructure as starting observation. To get a more detailed idea of the construction of our view variable, we zoom into the area of the blue circle (bottom left from center) in Figure 8.

Figure 8: Buildings with a view of a PV installation (area of St.Gallen)

Panel A: Buildings within a 500m radius of a *specific* PV installation (located in center)	Panel B: Buildings with a view of the *specific* PV installation
	

In Panel A of Figure 8, the circle with a radius of 500 m is drawn around its center. If we calculate the view for all the buildings with regard to the center, several buildings are likely to have a view of other PV installations as well. Panel B of Figure 8 shows which buildings have a view of the roof of the building in the center from a given floor or part of the building (marked yellow).

The PV installation is oriented south-west on a pitched roof, i.e., only buildings to the south-west have a view of the installation. However, the question is, why the neighboring buildings do not have a view. Let us consider the satellite image (Figure 9):

Figure 9: Buildings with or without a view of a specific PV installation (area of St.Gallen)

The building with the PV installation is surrounded by trees and the direct neighbors can hardly see the installation. The higher buildings to the south, however, have a partial view. Considering exclusively buildings and floors that have an unimpaired view, the number of buildings with a view of a PV installation is strongly reduced.

Figure 10: Buildings and floors that can fully see a specific PV installation (area of St.Gallen)

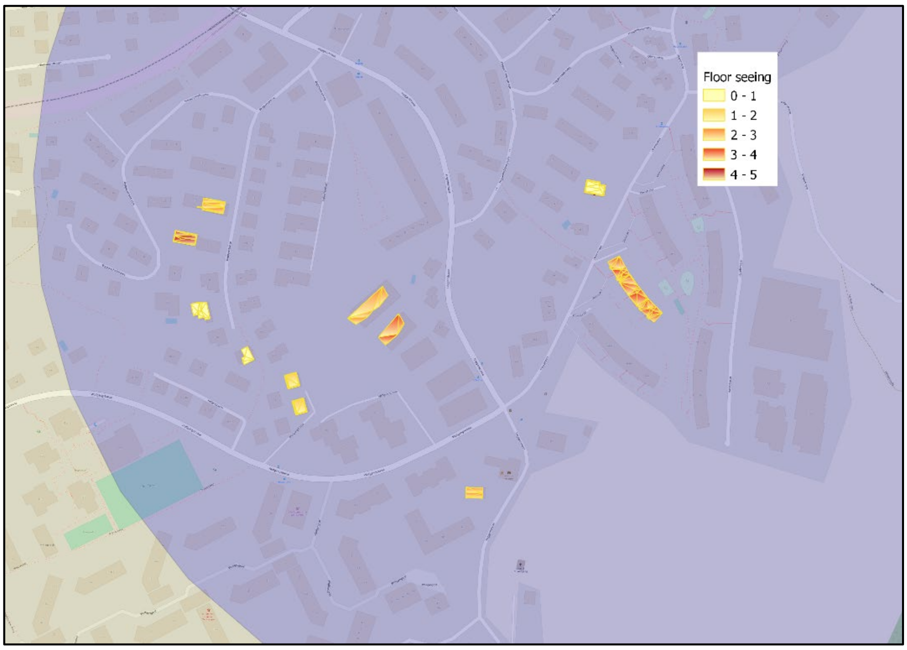
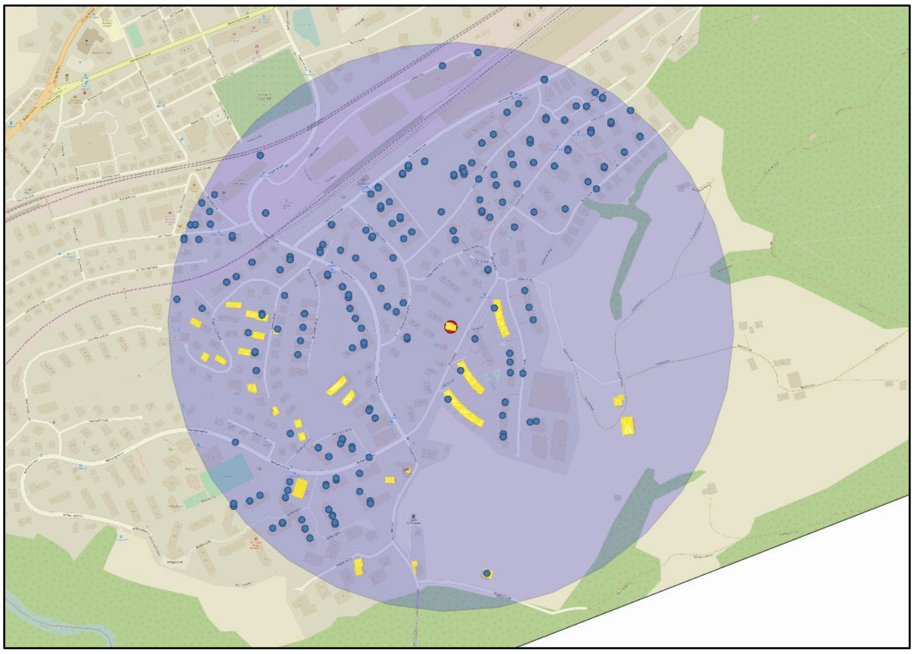


Figure 10 shows only buildings that have an unimpaired view of the PV installation from a certain floor. Red roofs illustrate higher up floors that have a view of the PV installation. Finally, we can take a look at the price/rent data that are used for the model in this case:

Figure 11: Price/rent data regarding buildings/floors that can fully see a specific PV installation (area of St.Gallen)



In Figure 11, the blue dots mark geo-referenced price data for the buildings in this circle. The model-ling approach described above and the corresponding selection and grouping of data into treatment and control units is crucial for the ensuing analyses. After careful consideration of several approaches, we opted to treat all buildings that have a view the PV installation, marked by yellow shading, as "viewing" and inquire into potential differential treatment effects among partially hidden and fully viewing objects in additional explorations. The remaining buildings in the circle are treated as not having a view of a PV installation.

4.2.2 External effects of photovoltaic systems

As outlined, we analyze the effects of energy infrastructures on owner-occupied housing, rental housing as well as rented commercial real estate. Therefore, the price effect of external PV systems on the respective real estate prices is estimated in an unbalanced panel regression with fixed effects for zip codes and robust standard errors, the results of which are reported in Table 10. To present these estimations in a clear way, estimated coefficients of controls are not listed in detail anymore. However, we comment on anomalies where applicable.

In general, the majority of observations in each subsample is classified as having a view of a PV system. This is related to our data selection process. We classify each building that is characterized by a partial or unimpaired view of the installation as having a "view of a PV system". As not having a view, we consider the buildings in the exact same perimeter, which do not have a view of an installation at all. Therefore, areas where there are no installations at all are excluded from our estimation sample. This explains the large weight of buildings with a view of a PV system and ensures that we only compare similar properties to each other, i.e., within a small (500 meter) perimeter around PV installations. The thought experiment goes as follows: we compare two properties of same type and other observable characteristics (i.e., property-specific controls) that are both observed in the same year and located in the same neighborhood (i.e., year and zip code fixed effects), and both lie within 500 meters of a PV installation. The difference is that one property does have a view of a PV and the other one does not. Properties are classified as viewing even if only a small part of the building has a view of the infrastructure.

In the context of residential rents, model (2) explains 30.4 % of the variance in the data, neglecting the variation explained by the full set of regional fixed effects at the level of zip codes (i.e., the within R-squared). Having a view of a PV installation would lower net rents by an expected 1.4 % on average, with the negative effect on rents being highly significant. Applied to owner-occupied housing with 45,767 observations, the same model gives mostly similar results in terms of direction, but not to the same extent. The overall effect of having a view of a PV system is slightly negative, but not significantly different from zero. In the sub-sample of commercial real estate rents of 28,019 observations, we cannot document a significant effect either. Although, the estimate also carries a negative sign.

Table 10: External effects of PV systems on real estate prices

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
View of PV system	-0.003 (0.005)	-0.014*** (0.003)	-0.015 (0.010)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	45,767	622,660	28,019
Adjusted within R^2	0.461	0.304	0.168

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 336 in column (1), 475 in column (2), and 254 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

Omitted Variable Bias

As already mentioned, the next consideration is the omitted variable bias, which in the case of our estimation could be any variable that correlates with both seeing a PV installation and property prices or rents but is not part of our model. An appropriate way to deal with this problem is a “difference-in-differences” (DiD) model. For this approach an additional variable is generated, which groups buildings that actually have a view or will have a view of an installation at some point during the observation period (i.e., years 2004 to 2021). The two variables created are:

Table 11: Classification of treatment and control group as well as treatment status

Variable	**Description**
“potential view of a PV system”	binary variable, which equals 1 if the price/rent is observed for property that will ever have view of a PV installation during the observation period (2004-2021), and 0 otherwise (i.e., the treatment group)
“actual view of a PV system”	binary variable, which equals 1 if the price/rent is observed for a property that actually has a view of an installed PV installation (i.e., after its beginning of operation), and 0 otherwise (i.e., interaction term of the binary indicator for the treatment group, “potential view of a PV system”, and an indicator, which equals 1 if a PV system is installed/operating at the time the property price/rent is observed, and 0 otherwise)

Figure 12 illustrates the construction of these variables. All the orange buildings are part of the control group (“potential view of a PV system” = 0). The yellow buildings are part of the treatment group (“potential view of a PV system” = 1). The month of the beginning of operation of the PV installation is the point in time when an observation is considered as treated. If the property or rental price is observed in the month of or after the beginning of PVs' operation, the binary indicator "actual view of a PV system" is assigned the value 1, otherwise 0.

Figure 12: Buildings (partially) seeing (yellow) or not seeing (orange) a PV installation (red circle in the center)

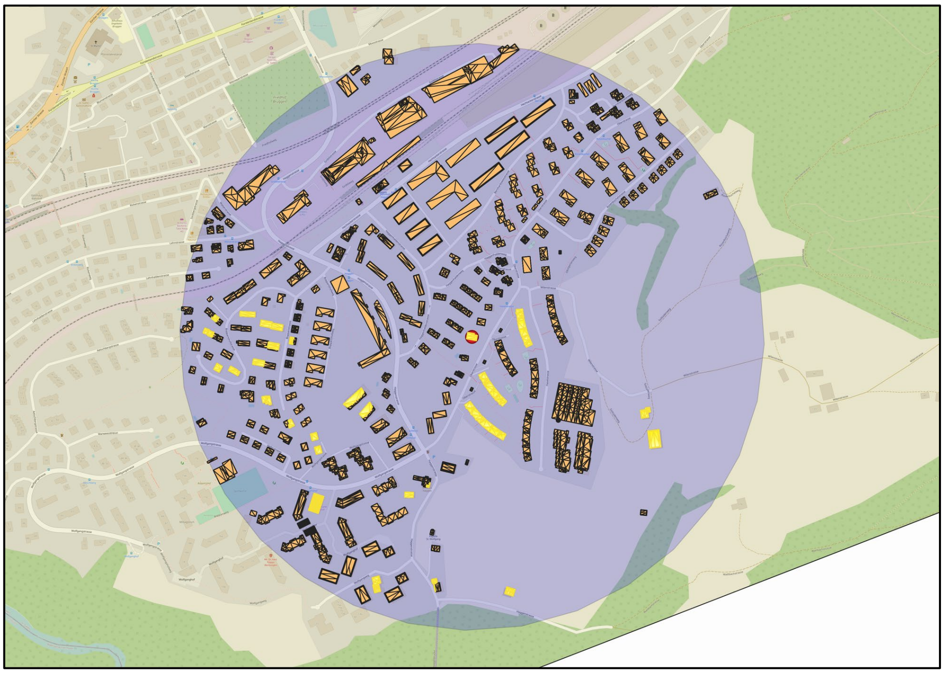


Table 12 shows the results of the unbalanced panel estimation including time and zip code fixed effects with cluster robust standard errors and a "difference-in-differences" specification. The parameter estimate on variable "actual view of a PV" is the one, which we interpret for the measurement of the differential effect of the energy infrastructure on property prices/rents (i.e., coefficient of main interest). The variable "potential view of a PV" measures whether property prices/rents in the treatment group differ upon exposure to PV installations from those that never have a view of such systems. In the context of residential real estate rents, both estimates (potential and actual view) carry an expected negative sign and are highly significant, which is in line with the baseline fixed-effects panel model. Although, estimates for subsamples of owner-occupied housing and commercial real estate show negative signs as well, these results are not different from zero at common statistical significance levels.

Table 12: External effects of PV systems on real estate prices: DiD

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
Potential view of a PV system	0.000 (0.007)	-0.010** (0.004)	-0.014 (0.010)
Actual view of a PV system	-0.004 (0.005)	-0.009*** (0.003)	-0.008 (0.011)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	45,767	622,660	28,019
Adjusted within R^2	0.461	0.305	0.169

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 336 in column (1), 475 in column (2), and 254 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

The advantage of dealing with omitted variables using a “difference-in-differences” specification outweighs the handling of possible spatial autocorrelation among zip codes with the spatial error model by far. The panel specification also handles heteroscedasticity and serial autocorrelation. Throughout the study we will therefore work with this approach.

Concerning potential problems of measurement error in the dependent variables, which are based on ads, we estimate subsamples with transaction-based or contractual data where possible (see section 5.2). Likewise, our main explanatory variables may be subject to measurement error. The discussion in this section indicated, that the handling of the external viewing information is not as straightforward as it seems, because we do not know where exactly in terms of exposition and floor level an apartment or a commercial surface is located in a building. Therefore, we only know that a floor in a building has a partial or complete view of a PV installation. Aggregating over floors and PV installations in buildings’ vicinity (see view modelling described above), we thus measure whether a building has an unimpaired or partial view of a PV installation.

Hence, in this study we do not measure something like “the PV installation can be seen from the window of the living room”. Rather we measure “the PV installation can be seen from the building”. As an indication of how well the PV installation is seen, we count the number of situations, where the building only has a partial view of the PV, because another building, tree etc. may impair the view. Over all the cones that are analyzed for an infrastructure, partial view can occur very often. The number of partial intersections can reach over 100. If the number of partial intersections from a building to a given PV grows large, the installation is less likely to be clearly visible from that building.

In the main results, we summarize all seeing situations, because we do not know the precise seeing situation of an object. Therefore, some measurement error is included in our regressor of main interest. As an additional exploration, we estimate a variant of the DiD regression model, in which we split buildings into two groups according to their likelihood of having a view of a PV installation. More precisely, the first group considers buildings, respectively, observations on property ads located in these, that are likely to have a view of a PV, comprising buildings with unimpaired view as well as buildings in the bottom quartile of the distribution of buildings with partial intersections (i.e., among those partially viewing PVs, the quartile most likely to actually have a view of them). The second group comprises buildings in the second, third and fourth quartiles of the distribution of buildings with partial intersections, which are less likely to have a view of a PV installation. The first 25 % have few intersections with cones and might see the installation quite well. The last 75 % on the other hand have many intersections and might not see the installation well. For our model above, these results are:

Table 13: External effects of PV systems on real estate prices: DiD (likely vs. less likely view)

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
Potential view of a PV system (likely)	-0.001 (0.011)	-0.013*** (0.005)	-0.014 (0.015)
Potential view of a PV system (less likely)	0.001 (0.007)	-0.009** (0.004)	-0.014 (0.011)
Actual view of a PV system (likely)	-0.002 (0.011)	-0.006* (0.003)	-0.016 (0.017)
Actual view of a PV system (less likely)	-0.004 (0.005)	-0.010*** (0.003)	-0.005 (0.012)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	45,767	622,660	28,019
Adjusted within R^2	0.461	0.305	0.169

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 336 in column (1), 475 in column (2), and 254 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

These estimations of the “difference-in-differences” setting underline previous results on the relationship of residential rents and the view of PV installations. Potential view and actual view variables show a similar negative coefficient which is statistically significant at least at a 10 % level. This holds for both potential and actual view variables.

Single vs. Multiple Views

Other than large infrastructures, which are seen from afar, PV installations are built in the middle of the built environment. Therefore, besides the aspect of "viewing" or not, their effect might also depend on other aspects, as for example the number of visible PV installations. Therefore, we re-estimate the "difference-in-differences" model again and allow for the potential and actual view on single vs. multiple installations. These results are listed in Table 14.

As in previous analyses, estimated external effects on residential rents tend to be more significant compared to estimates on owner-occupied house prices and commercial real estate rents, which do not yield any significant results at all. Potential and actual view estimates are not significant for residential real estate either. However, potential and actual view variables yield a highly significant estimate of -0.005 and -0.008, respectively. These results indicate that the view on multiple PV installations matters.

Table 14: External effects of PV systems on real estate prices: DiD (single vs. multiple PVs)

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
Potential view of a single PV system	0.008 (0.009)	-0.005 (0.004)	-0.023* (0.014)
Potential view of multiple PV systems	-0.003 (0.008)	-0.013*** (0.005)	-0.008 (0.011)
Actual view of a single PV system	-0.005 (0.009)	-0.005 (0.005)	0.008 (0.017)
Actual view of multiple PV systems	-0.002 (0.005)	-0.008*** (0.003)	-0.014 (0.012)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	45,767	622,660	28,019
Adjusted within R^2	0.461	0.305	0.169

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 336 in column (1), 475 in column (2), and 254 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

Large vs. Small and Close vs. Far

Additionally, we adapt our "difference-in-differences" setting to whether a PV installation is large or close. Two potential scenarios are likely to prevail: Either residents do not like it, because of its size or the contrary, i.e., people prefer a clear structural accent in the neighborhood rather than smaller (scattered) installations, which they less clearly see. Furthermore, it is possible, that they use electricity from this installation and therefore directly benefit themselves.

Residential rents are significantly impacted by small PV installations in a negative way, whereas large and close PVs have a positive impact, which would be in line with our previous argumentation. Large and close PV installations are similar to internal PV installations as people often use the electricity from these installations themselves. Owner-occupied housing and commercial real estate do not yield robust or significant results.

Table 15: External effects of PV systems on real estate prices: DiD
(heterogenous treatment effects: large and close PV installation)

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
Potential view of a PV system	-0.001 (0.007)	-0.008** (0.004)	-0.013 (0.010)
Potential view of a large and close PV system (differential)	0.019* (0.011)	-0.017*** (0.006)	-0.012 (0.014)
Actual view of a PV system	-0.003 (0.005)	-0.011*** (0.003)	-0.007 (0.011)
Actual view of a large and close PV system (differential)	-0.012 (0.014)	0.019*** (0.006)	-0.001 (0.023)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	45,767	622,660	28,019
Adjusted within R^2	0.461	0.305	0.169

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 336 in column (1), 475 in column (2), and 254 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

Internal vs. External

In this paragraph we test whether the effect changes if a “viewing” building has a PV installation itself, because the inhabitants could then be more inclined towards these installations. In contrast to owner-occupied house prices and commercial real estate rents, residential rents show again more reliable results due to the large sample size available.

As similarly estimated in previous models, there is a significant effect of -0.9 percentage points (compared to property without a view and without an own PV installation). for seeing a PV installation on residential rents. Having a PV on the building which actually has a view of another PV installation compensates this negative effect by far (i.e., a positive rental price differential of 3.2 percentage points compared to property without a view and without an own PV installation). Hence, apartments in buildings with PV installations still document a rent increase when seeing a PV installation.

Table 16: External effects of PV systems on real estate prices: DiD
(heterogenous treatment effects: buildings with own PV installation)

	(1)	**(2)**	**(3)**
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
No view of a PV system (with own PV)	0.004 (0.026)	0.011 (0.027)	-0.036 (0.036)
Potential view of a PV system (w/o own PV)	-0.000 (0.007)	-0.010** (0.004)	-0.014 (0.010)
Potential view of a PV system (differential: with own PV)	0.029 (0.036)	0.016 (0.029)	0.058 (0.056)
Actual view of a PV system (w/o own PV)	-0.004 (0.005)	-0.009*** (0.003)	-0.008 (0.011)
Actual view of a PV system (differential: with own PV)	0.003 (0.031)	0.032** (0.015)	0.022 (0.046)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	45,767	622,660	28,019
Adjusted within R^2	0.461	0.305	0.169

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 336 in column (1), 475 in column (2), and 254 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

4.3 External effects of large-scale energy infrastructures

4.3.1 Nuclear power

For nuclear power plants (NPP) our “difference-in-differences” specification cannot be applied as these plants were built before the starting point of our database. Hence, we can only investigate whether having a view of a NPP within a 10 km radius (see Table 9) is correlated with real estate rents or prices.

Based on 7,312 observations, no statistically significant coefficient can be estimated for rental housing. The same observation can be made for owner-occupied housing (2,607 observations) and commercial real estate rents (181). These insignificant results are probably due to very small sample sizes. Hence, view exposures of residential property for sale to NPP or rental dwellings are not expressed in statistically significant real estate price penalties when compared to buildings in the same area which do not have a view of such a large-scale infrastructure.

Table 17: Potential externality effects of NPPs on real estate prices

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
View of an NPP	0.025 (0.041)	0.010 (0.013)	0.195 (0.163)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	2,607	7,312	181
Adjusted within R^2	0.432	0.559	0.582

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 39 in column (1), 41 in column (2), and 18 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

To better investigate a potential effect of having a view of a NPP, we establish a “difference-in-differences” specification, which uses the Fukushima incident on 11th March 2011 as the treatment date. Observations with a view of a NPP before the event date are considered as non-treated, while observation with a view thereafter are treated. However, this analysis suffers from the small number of observations in each dataset which complicates the exploitation of such arguably exogenous variation in the perception of NPPs among the local Swiss population. Nevertheless, we report these “difference-in-differences” results in Table 18 which need to be interpreted with caution.

Table 18: External effects of NPPs after the Fukushima Daiichi incident on real estate prices: DiD

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
View of an NPP	-0.016 (0.053)	- 0.018 (0.011)	-0.089 (0.360)
View of a NPP after Fukushima	0.063** (0.029)	0.036** (0.014)	0.291 (0.339)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	2,607	7,312	181
Adjusted within R^2	0.434	0.560	0.587

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 39 in column (1), 41 in column (2), and 18 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

Keeping previous studies in our literature review in mind, Table 18 presents counterintuitive results. In the context of owner-occupied house prices and residential real estate rents, we find positive treatment estimates which are statistically significant at a 5 % level. This signals a positive price or rent growth differential for buildings with a view of NPPs after the Fukushima incident. This effect may be distorted due to the small sample sizes or due to a composition effect in observations after the event. However, it may also be the case that the local Swiss population had a different perception of the incident.

4.3.2 Run-of-river power

Firstly, the effect of run-of-river power plants (RPP) on rental housing is based on 89,244 observations. Having an actual view of a RPP within 3 km (see Table 9) has a negative effect on residential rents, which is statistically significant at a 5 % level. In this case, it cannot be excluded, that omitted variables concerning the micro-location could affect the result, because having a view of a RPP could also imply benefitting from an amenable view of the river and surrounding landscape, which may outweigh any potential average negative externality effect that may arise from the view of RPPs (likewise noise externalities in their immediate vicinity). The estimate for having a potential view of a RPP is insignificant. Secondly, the results for owner-occupied house prices are based on 7,486 observations and show no significant effects for a potential and actual view of a RPP. Thirdly, 4,848 commercial real estate rental observations, show slightly negative estimates for a potential as well as actual view. However, only the estimated coefficient for a potential view of a RPP is significant at a 10 % level.

Table 19: External effects of RPPs on real estate prices: DiD

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
Potential view of a RPP	-0.012 (0.009)	0.005 (0.009)	-0.061* (0.031)
Actual view of a RPP	0.021 (0.016)	-0.031** (0.014)	-0.025 (0.029)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	7,486	89,244	4,848
Adjusted within R^2	0.508	0.364	0.205

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 69 in column (1), 110 in column (2), and 45 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

4.3.3 Transmission grid

As in the case of nuclear power plants, a “difference-in-differences” model cannot be estimated for transmission grids (GRID) as their beginning of operation is not available in our database. Although, we are able to measure a potential externality effect on property prices, arising from a view of the GRID within 10 km of the infrastructure (see Table 9) conditional on the vast set of controls included in our regressions. Table 20 summarizes the result for unbalanced panel regressions with fixed-effects at zip-code level for owner-occupied house prices, residential real estate rents as well as commercial real estate rents.

Table 20: Potential externality effects of GRID on real estate prices

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
View of the GRID	-0.035** (0.017)	-0.023*** (0.008)	-0.053** (0.025)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	7,074	71,050	3,501
Adjusted within R^2	0.191	0.387	0.196

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 273 in column (1), 306 in column (2), and 133 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

In all three real estate categories, evidence for a negative external effect of having a view of the GRID is provided. In the sample of 7,074 observations of owner-occupied house prices, this estimate amounts to -0.035 and is statistically significant of a 5 % level. With the sample of 71,050 residential real estate rents, an effect of -0.023 can be estimated at a significance level of 1 %. By using the sample of commercial real estate rents, the estimate is given by -0.0053 which is significant at a 5 % level.

4.3.4 Waste incineration

Neither the models for rental housing, based on 59,850 observations, nor the ones for owner-occupied housing (4,374 observations) or rented commercial real estate (1,724 observations) yield any statistically significant estimates of having an actual view of a waste incineration plant (WIP) within 5 km (see Table 21). In contrast, a potential view of a WIP has a negative effect of -0.009 on residential real estate rents and a positive effect on of 0.070 on commercial real estate rents. Although these estimates are significant at least at a 10 % level, these results are counterintuitive and may be due to smaller sample sizes.

Table 21: External effects of WIPs on real estate prices: DiD

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
Potential view of a WIP	0.014 (0.015)	-0.009* (0.005)	0.070** (0.031)
Actual view of a WIP	0.015 (0.019)	0.002 (0.005)	-0.080 (0.052)
Control Variables			
Object types	X	X	X
Rooms	X	X	X
Space	X	X	X
Floors	X	X	X
Building period	X	X	X
First use	X	X	X
View	X	X	X
Neighborhood type	X	X	X
Year	X	X	X
Zip code	X	X	X
Observations	4,374	59,850	1,724
Adjusted within R^2	0.420	0.355	0.208

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 59 in column (1), 89 in column (2), and 43 in column (3). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

4.3.5 Wind power

As opposed to PV installations, wind turbines are not found in densely populated, but in rather remote areas. Because of this, proper view modeling is extremely time consuming and we had to limit ourselves to two very different locations in Andermatt and Schaffhausen.[9] The below results are therefore explorative in nature, but could be extended with sufficient computing time at our disposal. Furthermore, with regards to effects measured, it needs to be emphasized that of all objects within the perimeter of the installations only approximately 2 % have a view of a wind farm. Even if significant effects do exist, they are unlikely to affect many buildings. We estimate our model with 21,480 observations for rental housing and 4,477 for owner-occupied housing. We do not report results for the category of commercial real estate rents as the number of observations drops to 114, which does not allow an estimation of our unbalanced panel regression with fixed-effects at zip-code level.

[9] The wind park Andermatt consists of four installations: one of 46 meters height with a rotor diameter of 40 meters, and three of 55 meters height with a rotor diameter of 44 meters each (EWU, 2022). The wind park near Schaffhausen houses three installations, each of 134 meters height with a rotor diameter of 131 meters (Hegau-wind, 2022).

Table 22: Potential externality effects of WPPs on real estate prices

	(1)	**(2)**
Variable	**House price (owner-occupied)**	**Residential real estate rent**
View of a WPP	0.015 (0.016)	-0.048*** (0.013)
Control Variables		
Object types	X	X
Rooms	X	X
Space	X	X
Floors	X	X
Building period	X	X
First use	X	X
View	X	X
Neighborhood type	X	X
Year	X	X
Zip code	X	X
Observations	4,477	21,480
Adjusted within R^2	0.394	0.389

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 80 in column (1), and 98 in column (2). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

Wind power has no statistically significant effect on owner-occupied house prices, as it is shown in Table 22. In contrast, the average effect of wind power is negative on rental housing rents in buildings which have a view of a wind power plant (WPP). The corresponding estimated coefficient amounts to -0.048. It is probable, that two effects are measured conjointly in this analysis, potential view and noise (for property located in wind farms' immediate vicinity) externalities. In theory, noise should be a minor issue as strict noise regulations are in place. Nevertheless, we include the distance to the next wind turbine as well as its interaction with our view indicator in the estimations of Table 23.

Table 23: Potential externality effects of WPPs on real estate prices:
effect heterogeneity by distance to WPP

	(1)	(2)
Variable	**House price (owner-occupied)**	**Residential real estate rent**
View of a WPP	0.034 (0.038)	-0.075** (0.029)
Distance from WPP	-0.010 (0.010)	-0.023 (0.015)
Interaction term: View×Distance	-0.018 (0.037)	0.025 (0.026)
Control Variables		
Object types	X	X
Rooms	X	X
Space	X	X
Floors	X	X
Building period	X	X
First use	X	X
View	X	X
Neighborhood type	X	X
Year	X	X
Zip code	X	X
Observations	4,477	21,480
Adjusted within R^2	0.394	0.392

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 80 in column (1), and 98 in column (2). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

If noise emissions of wind turbines are the driver of our result, we should obtain significant slope coefficients for the distance variable as well as the interaction of distance and view (noise diminishes with distance). However, in both cases, owner-occupied house prices and residential rents, corresponding estimates remain insignificant in our model. Contrastingly, the view variable shows a negative estimate of -0.075 which is significant at a 5 % level in the case of residential rents. Therefore, we conclude that view and not noise is the driver of this effect. However, this result must again be interpreted with caution. Due to the small number of wind turbines which can be seen by houses or residential buildings, these results are not generalizable for entire Switzerland.

5 Robustness tests

In this section, we apply two robustness tests. The first test addresses the problem of inconsistent and inefficient estimates in case of spatial autocorrelation. To still allow the coefficients as marginal effects, we opt for the spatial error model. Hence, we are not interested in specifically deriving spillover and feedback effects as in the spatial autoregressive model (LeSage and Pace (2009)). The second robustness test refers to the bias in asking prices, in particular in (owner occupied) house prices.

5.1 Spatial error model

We expand the classical hedonic approach by estimating location-specific, heterogeneous coefficients based on quasi-maximum likelihood estimation, see Aquaro, Bailey, and Pesaran (2015), or LeSage and Chih (2016):

$$ln\, p_{it} = X_{it}\beta + \gamma IFS + \eta_i + \lambda_t + \varepsilon_{it}, \qquad \text{where } \varepsilon_{it} = \omega W \varepsilon_{it} + v_{it} \tag{3}$$

with: $ln\, p_{it}$ = log house and rental price,

X_{it} = housing characteristics including small or large-scale infrastructure variables (sight),

W = pre-specified weighting matrix,

ω = spatial lag, which measures the degree of cross-sectional dependence,

η_i = individual fixed effects,

ε_{it} = normally distributed error term.

Neighborhoods

For the spatial error model, we construct detailed neighborhoods because the use of individual properties is not appropriate for the view modeling. The neighborhood definition is based on the age structure, the usages and the density of areas. This base information is taken from the GWR.

Detailed Neighborhoods

Each hectare of Switzerland is categorized according to its structures with a 3-digit code: NNN.

First digit: main building period (more than 50 % of buildings are from this period)

< 1919

>= 1919 and < 1960

>= 1961 and < 1985

>= 1986 and < 2005

>= 2005

no main building period

Second digit: usage-ratio (counted with buildings)

0-30 % housing

30 %-90 % housing

> 90 % housing

Third digit: density (floor space in relation to ground space)

<= 0.077 (“low”)

> 0.077 and <= 0.3 (“single family”)

> 0.3 and <= 0.77 (“middle density”)

> 0.77 (“high”)

Neighboring hectares of each category are then combined to larger areas, the “neighborhoods”.

Larger Neighborhoods

The larger neighborhoods do not consider age as relevant. Therefore, they only have a 2-digit code, with:

First digit: usage

>= 80% housing

< 80%

Second digit: density

<= 0.077 (“low”)

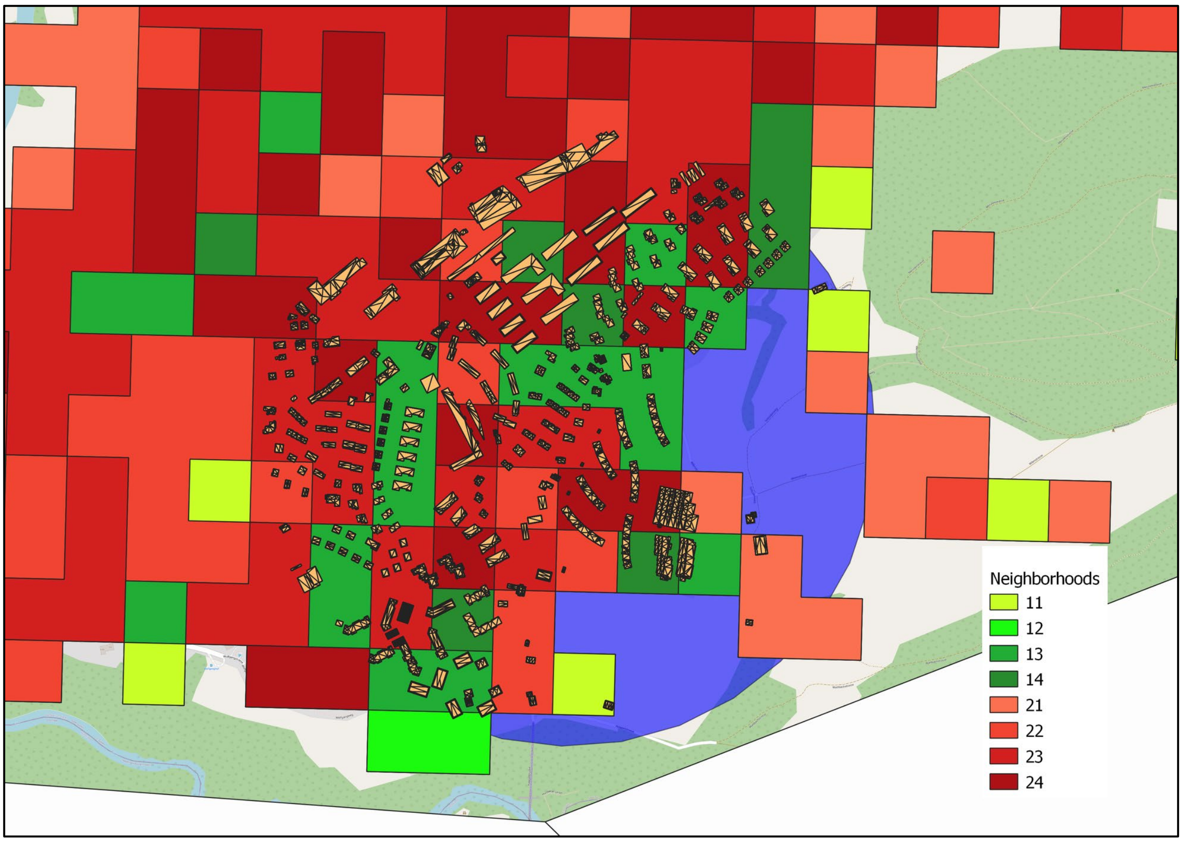
> 0.077 and <= 0.3 (“single family”)

> 0.3 and <= 0.77 (“middle density”)

> 0.77 (“high”)

As it is likely, that there is some spatial autocorrelation between regional units (e.g., neighborhoods) a spatial error model on individual or grouped data could address this issue. The estimation of such a model with this large dataset of individual data is difficult. Therefore, we estimate a model for the neighborhoods specified in equation (3). Figure 13 shows these exemplary square neighborhoods in St.Gallen. To successfully estimate a spatial model, we have to calculate averages of our explanatory variables across these squares. This requires some simplifications. The type of objects is simplified to the quota of houses and the building period to the average age of the buildings.

Figure 13: Example of neighborhood classification in eight categories



The results of the spatial error models for the neighborhoods suggest a non-significant negative effect of having a view of a PV installation for residential real estate and commercial real estate rents. Prices for owner-occupied housing are not affected with an estimated coefficient of zero. The exact results for these spatial error models across neighborhoods are listed in Table 24.

Table 24: External effects of PV systems on real estate prices: spatial error model for neighborhoods

	(1)	(2)	(3)
Variable	**House price (owner-occupied)**	**Residential real estate rent**	**Commercial real estate rent**
Share property with view of a PV system	0.000 (0.011)	-0.004 (0.007)	-0.012 (0.026)
Control Variables			
Property type: houses [%]	X	X	X
Rooms [log average]	X	X	X
Space [log average]	X	X	X
Building age [log average]	X	X	X
First use [%]	X	X	X
View [%]	X	X	X
Neighborhood type [average]	X	X	X
Year [log average]	X	X	X
Neighborhoods	5,048	7,225	2,045

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for residential property, in column (2), and commercial property, in column (3). The unit of observation is a neighborhood at the level of one-hectare grids. Asymptotic standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

The spatial error model for neighborhoods slightly confirms the result of the viewing effect in our fixed-effects panel model, but it suffers from the aggregation. The negative effect of having a view of a PV installation can be found (although insignificant). It seems safe to conclude that, although spatial auto-correlation can affect our panel specification it does not seem a reason to contest its results.

5.2 Transaction versus Asking Prices

In order to increase the number of observations in our database, we use data on real estate listings gathered from various internet portals. This approach raises concerns of a possible bias regarding differences between asking and transaction prices.

According to Han and Strange (2016) asking prices can be an accurate estimate for the actual transaction prices of houses in the residential property market. The authors' argue that asking prices are relevant and that a valuable share of housing transactions have been closed with a price equal to the initial asking price. Haurin (1988) argues that asking and transaction prices should be similar especially in cases where standard houses are considered. In these cases, selling prices are usually known and there is no benefit of setting a higher asking price and leaving room for negotiation or bidding wars. Furthermore, a study by Ardila, Ahmed, and Sornette (2021) has likewise analyzed the relationship between asking and transaction prices for the Swiss residential real estate market using data from 2005 to 2015. There is strong evidence that asking and transaction prices are co-moving across different market segments and hence, asking prices may be a suitable proxy for the developments in the Swiss real estate market, especially given the sparsity of available transaction data. In contrast, Fleury (2018) documents that in the case of residential rents in Switzerland, a very high proportion of advertized rents correspond to contracted rents.

Despite these insights from previous studies, it is difficult to assess the complicated relationship between transaction and asking prices. Firstly, the housing market in Switzerland is highly illiquid and secondly, Switzerland does not have one particular comprehensive database including all real estate transactions. Furthermore, no analysis exists for commercial rents. Therefore, we estimate our "difference-in-differences" model with two additional datasets in order to compare the results to those obtained and reported for asking prices in Section 4.2.2.

The dataset for owner-occupied prices contains 62,386 transactions in the canton of Zurich from the beginning of 2008 until the middle of 2021. In the case of commercial rents, we use a dataset on 13,036 contractual rents for newly concluded contracts, which were obtained from the REIDA. Although, this database is not a random sample, it covers institutional as well as private owners. Control variables in both datasets differ slightly from controls in our advertisement data. The results from the corresponding unbalanced panel regressions with zip-code level fixed-effects are listed in Table 25.

Table 25: Potential external effects of PV systems on real estate prices: DiD

	(1)	(3)
Variable	**House price (owner-occupied)**	**Commercial real estate rent**
Potential view of a PV system	0.002 (0.010)	0.031 (0.053)
Actual view of a PV system	-0.013 (0.009)	0.011 (0.043)
Object types	X	X
Rooms	X	
Space (usable) (land area for houses)	X	X
Floors	X	X
Building period	X	X
First use		
View		
Neighborhood type	X	X
Year	X	X
Zip code	X	X
Observations	62,386[10]	13,036
Adjusted within R^2	0.590	0.212

Notes: The dependent variable is the natural logarithm of the nominal house price, in column (1), respectively, the natural logarithm of the rental price per square meter for commercial property, in column (2). Cluster-robust standard errors (at the level of zip codes) are reported in parenthesis. The number of zip code fixed effects is 204 in column (1) and 141 in column (2). ***, **, and * denote statistical significance at the 1 %, 5 %, and 10 % level.

[10] As the view on PV systems is mainly modelled in the canton of Zurich and in cities (where home-ownership is low), the sample size of owner-occupied transactions is larger than for advertisement observations. More specifically, this dataset covers the universe of all transactions conducted in Zurich, whereas not all of them have necessarily been advertized.

In comparison to advertisement data, the negative externality effect of PV systems on owner-occupied prices is larger in size, yet still not statistically significant at the 10 % level. For commercial real estate, even less significant results are obtained than in the main analysis of advertized rents. Therefore, the opposite signs of the effects do not have an economic meaning or interpretation. However, as previously mentioned, non-significant results do not imply no potential effect. The lack of significance may also be attributable to measurement inaccuracies.

6 Conclusions

The purpose of this study is to identify potential effects of selected types of energy infrastructure on real estate prices, i.e., potential positive or negative externalities as well as internal effects, with a particular focus on the view of external infrastructures. In our analysis, we distinguish between owner-occupied house prices, residential rents as well as commercial real estate rents. The internal infrastructure covers mainly the heating system within a building.

Our results suggest that heat pumps and wood heating not only increase house prices of owner-occupied dwellings but the former also does so for net rents of multi-family homes, whereas rental price penalties are attached to wood-, oil boiler and district heating. In contrast, offer (as well as transaction) rents in the commercial real estate sector are not affected by any of the small-scale energy infrastructures but oil heating boilers, which indicate rental price penalties. Notably, since our estimation sample cannot account for the current increases in gas prices, fueled by recent events such as the war in Ukraine. The above findings may thus not be representative for any recent changes in relative energy prices. The value of buildings with a PV installation only increases in the segment for owner-occupied housing. Our main findings remain robust when we specify a spatial error model and when we use transaction instead of asking prices.

Our analysis on potential external effects includes both small- as well as large-scale energy infrastructures. The view of a PV system leads only to a depreciation in residential rental prices independent of whether we consider potential or actual views. This effect is stronger the larger and closer the PV systems on neighboring properties are. However, this negative impact on residential rents is mainly driven by the view of multiple PV installations rather than a single one. In addition, a decrease in rents due to a view of a PV system can only be observed for objects which do not have an own PV system installed.

Nuclear power plants do not affect real estate prices. However, when we control for the exogenous shock of Fukushima, we surprisingly find a positive effect on residential prices and rents. An actual view of a run-of-river power plant has a negative effect on residential rents, while commercial real estate rental observations show slightly negative estimates for a potential as well as actual view. The view of a transmission grid has significant externality, i.e., negative effects on all types of property prices. In contrast, the actual view of a waste incineration plant does not yield any statistically significant estimates. Finally, wind turbines only include a discount for residential rents without an additional impact arising from the distance. Due to the small number of wind turbines that can be viewed from residential property, these findings may, however, not be generalizable for all of Switzerland and should thus be interpreted with caution.

It must be noted that the majority of conclusions derived from large-scale energy infrastructures are limited by smaller sample sizes and potential omitted variable biases. Table 26 summarizes the extensive results on external effects of real estate prices and rents.

7 Outlook and policy implications

Unfortunately, the use and availability of different datasets for energy infrastructures as well as housing and commercial real estate do not allow us to estimate a meta model by combining several small- and large-scale energy infrastructure effects. Future research might also take into account cultural biases with respect to energy infrastructures and attitudes towards sustainable housing. Moreover, future research is required to provide statistical evidence on potential differential impacts brought about by current developments in energy prices after 2021.

Our results have important implications for policy makers and real estate investors. Carbon-neutral heating systems increase the price and rents of residential properties compared to objects with conventional gas-heating. Negative external effects of a PV system seem to exist only for multi-family homes without an own PV system. Hence, it is possible that any negative externalities on tenants diminish with increasing efforts to expand the adoption of PV systems on residential and commercial real estate. While an acceptance problem may naturally disappear with increasing propagation of this renewable infrastructure, the formulation of appropriate policies to address the significant, negative externalities of transmission grids on real estate prices and rents in Switzerland are required.

Table 26: Summary of potential external effects on real estate rents and prices of energy infrastructures

Infrastructure	**Category**	**Effect**	**Exp. effect over all seeing**	**Comments**
PV	rental housing	yes	-1.4 %	Stronger effect for larger and closer PV systems. Moreover, effect is mainly driven by the view on multiple installations. Actual and potential view on PVs matter.
	owner occupied	no	not significant	
	rented commercial	no	not significant	
Nuclear power	rental housing	no	not significant	
	owner occupied	no	not significant	
	rented commercial	no	not significant	
Run-of-river	rental housing	yes	-3.1 %	Actual view on a run-of-river power plant drives this result.
	owner occupied	no	not significant	
	rented commercial	yes	-6.1 %	Potential view on a run-of-river power plant drives this result.

Table 26 continues on the next page.

Table 26 continued.

Trans-mission grids	rental housing	yes	-3.5 %	Consistent negative external effects on real estate prices and rents.
	owner occupied	yes	-2.3 %	
	rented commercial	yes	-5.3 %	
Waste incineration	rental housing	yes	-0.9 %	Potential view on waste incineration plants drives the result.
	owner occupied	no	not significant	
	rented commercial	no	not significant	
Wind power	rental housing	yes	-4.8 %	View on wind power plant drives this result and not noise. Results are obtained from two windfarms and may not be representative for entire Switzerland.
	owner occupied	no	not significant	
	rented commercial	Insufficient number of observations.			

8 National cooperation

At the start of the project, it was not apparent that the GEPA and the GWR would be accessible. Therefore, as described in subchapter 3.1, considerable effort was put into the collection and preparation especially of the dataset on small-scale energy infrastructures.

For the preparation of the research proposal, we received a so-called Letter-of-Intent from the (politically) responsible persons of 6 of the most populated cities of Switzerland to confirm a general support of our research project. After approval of the project by the SFOE, the first step was to identify and contact the respective persons that were responsible for the operative data-handling in the municipal administrations. After the identification of the responsible contact persons for the topics of PV and heating solutions, an individually customized confidentiality agreement was drawn up and signed for each of these cities. In addition, a confidentiality agreement was signed with the SFOE to provide an overview of federally funded PV installations and with Swissgrid to provide the exact routing for selected transmission grid projects (large-scale energy infrastructure).

Table 27 summarizes the 15 organizations we cooperated with in regard to data procurement for small-scale energy infrastructures:

Table 27: National cooperations with regard to data procurement for small-scale energy infrastructures

City	Organization
Basel	Environment Office
	Statistical Office
Bern	Energie Wasser Bern
	Environmental Protection Office
Geneva	Services Industriels de Genève
Lucerne	Energie Wasser Luzern
	Municipality of Lucerne
St.Gallen	St.Galler Stadtwerke
	Office for Environment and Energy
	Directorate of Planning and Construction
	City Presidium
Zurich	Department of Industrial Operations
	Environmental and Health Protection
	Elektrizitätswerk der Stadt Zürich
	Entsorgung + Recycling Zürich

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10 Appendix: Descriptive Statistics on Real Estate Markets

Table A.1: Summary Statistics – Residential House Price (estimation sample: Switzerland)

Variable	mean	std. dev.	min	max
Price (CHF)	5,523.47	2,012.06	1,603.77	11,933.33
log(Price)	8.553	0.359	7.38	9.387
Object types				
House (unspecified)	0.007	0.085	0	1
Single-family house	0.018	0.131	0	1
Single-family house (detached)	0.27	0.444	0	1
Single-family house (semi-detached)	0.073	0.26	0	1
Townhouse (corner)	0.028	0.166	0	1
Townhouse (single-family)	0.053	0.224	0	1
Apartment	0.407	0.491	0	1
Attic	0.048	0.213	0	1
Maisonette	0.056	0.23	0	1
Loft	0.01	0.098	0	1
Penthouse	0.029	0.167	0	1
Studio	0.002	0.046	0	1
Rooms				
Unknown	0.034	0.181	0	1
1	0.008	0.09	0	1
2	0.052	0.222	0	1
3	0.153	0.36	0	1
4	0.291	0.454	0	1
5	0.252	0.434	0	1
6	0.124	0.329	0	1
7 and more	0.087	0.281	0	1
Living space [m^2]	138.705	56.974	16	1,415
log(living space)	4.855	0.397	2.773	7.255
Floors				
Unknown	0.012	0.107	0	1
1-3	0.63	0.483	0	1
4-6	0.335	0.472	0	1
7-9	0.014	0.118	0	1
10 and more	0.009	0.094	0	1

Table A.1 continues on the next page.

Table A.1 continued.

Building Period				
<1919	0.086	0.28	0	1
1919-1945	0.052	0.221	0	1
1946-1960	0.064	0.245	0	1
1961-1970	0.083	0.276	0	1
1971-1980	0.146	0.353	0	1
1981-1985	0.057	0.232	0	1
1986-1990	0.089	0.285	0	1
1991-1995	0.094	0.291	0	1
1996-2000	0.087	0.283	0	1
2001-2005	0.076	0.265	0	1
2006-2010	0.089	0.284	0	1
2011-2015	0.048	0.214	0	1
>2015	0.03	0.17	0	1
First use (new or renovated)	0.175	0.38	0	1
Has view on mountain, lake etc.	0.436	0.496	0	1
Neighborhood type				
Very low density, housing	0.043	0.204	0	1
Low density, housing	0.136	0.342	0	1
Above average density, housing	0.245	0.43	0	1
High density, housing	0.088	0.283	0	1
Very low density, mixed use	0.062	0.242	0	1
Low density, mixed use	0.119	0.324	0	1
Above average density, mixed use	0.218	0.413	0	1
High density, mixed use	0.088	0.284	0	1
Year				
2004	0.033	0.178	0	1
2005	0.043	0.203	0	1
2006	0.053	0.224	0	1
2007	0.059	0.235	0	1
2008	0.071	0.256	0	1
2009	0.067	0.25	0	1
2010	0.059	0.235	0	1
2011	0.063	0.242	0	1
2012	0.056	0.231	0	1
2013	0.053	0.223	0	1
2014	0.053	0.225	0	1
2015	0.052	0.223	0	1
2016	0.055	0.227	0	1
2017	0.059	0.237	0	1
2018	0.052	0.222	0	1
2019	0.057	0.231	0	1
2020	0.066	0.248	0	1
2021	0.05	0.219	0	1

Note: The number of observations is 267,269.

Table A.2: Summary Statistics – Residential Real Estate Rent (estimation sample: Switzerland)

Variable	mean	std. dev.	min	max
Rent/m^2 [CHF]	18.99	5.696	9	45.7
log(Rent/m^2)	2.904	0.278	2.197	3.822
Object types				
House (unspecified)	0.002	0.04	0	1
Single-family house	0.001	0.036	0	1
Single-family house (detached)	0.027	0.162	0	1
Single-family house (semi-detached)	0.004	0.064	0	1
Townhouse (corner)	0.002	0.039	0	1
Townhouse (single-family)	0.005	0.071	0	1
Apartment	0.826	0.379	0	1
Attic	0.032	0.175	0	1
Maisonette	0.042	0.201	0	1
Loft	0.01	0.101	0	1
Penthouse	0.039	0.193	0	1
Studio	0.01	0.101	0	1
Rooms				
Unknown	0.026	0.16	0	1
1	0.081	0.272	0	1
2	0.189	0.392	0	1
3	0.343	0.475	0	1
4	0.272	0.445	0	1
5	0.068	0.252	0	1
6	0.014	0.119	0	1
7 and more	0.006	0.077	0	1
Living space [m^2]	84.893	35.075	1	817
log(living space)	4.356	0.428	0	6.706
Floors				
Unknown	0.011	0.103	0	1
1-3	0.283	0.45	0	1
4-6	0.631	0.482	0	1
7-9	0.052	0.222	0	1
10 and more	0.023	0.15	0	1

Table A.2 continues on the next page.

Table A.2 continued.

Building Period				
<1919	0.114	0.318	0	1
1919-1945	0.067	0.25	0	1
1946-1960	0.123	0.328	0	1
1961-1970	0.168	0.374	0	1
1971-1980	0.129	0.335	0	1
1981-1985	0.058	0.234	0	1
1986-1990	0.059	0.236	0	1
1991-1995	0.059	0.236	0	1
1996-2000	0.045	0.207	0	1
2001-2005	0.041	0.197	0	1
2006-2010	0.063	0.244	0	1
2011-2015	0.05	0.218	0	1
>2015	0.024	0.154	0	1
First use (new or renovated)	0.085	0.279	0	1
Has view on mountain, lake etc.	0.299	0.458	0	1
Neighborhood type				
Very low density, housing	0.02	0.141	0	1
Low density, housing	0.046	0.21	0	1
Above average density, housing	0.203	0.402	0	1
High density, housing	0.213	0.41	0	1
Very low density, mixed use	0.038	0.191	0	1
Low density, mixed use	0.056	0.229	0	1
Above average density, mixed use	0.199	0.399	0	1
High density, mixed use	0.224	0.417	0	1
Year				
2004	0.025	0.155	0	1
2005	0.034	0.182	0	1
2006	0.042	0.201	0	1
2007	0.047	0.212	0	1
2008	0.048	0.214	0	1
2009	0.048	0.214	0	1
2010	0.051	0.221	0	1
2011	0.056	0.23	0	1
2012	0.058	0.233	0	1
2013	0.051	0.22	0	1
2014	0.057	0.232	0	1
2015	0.055	0.229	0	1
2016	0.062	0.242	0	1
2017	0.072	0.258	0	1
2018	0.068	0.251	0	1
2019	0.072	0.259	0	1
2020	0.076	0.265	0	1
2021	0.077	0.267	0	1

Note: The number of observations is 1,825,019.

Table A.3: Summary Statistics – Commercial Real Estate Rent (estimation sample: Switzerland)

Variable	**mean**	**std. dev.**	**min**	**max**
Rent/m^2 [CHF]	235.375	118.593	74	655
log(Rent/m^2)	5.348	0.47	4.304	6.485
Object types				
Commercial (Unspecified)	0.061	0.239	0	1
Office	0.345	0.475	0	1
Retail	0.060	0.239	0	1
Arcade	0.013	0.113	0	1
Mixed (office/commercial)	0.131	0.338	0	1
Mixed (office/commercial/storage)	0.049	0.216	0	1
Mixed (office/retail)	0.056	0.230	0	1
Mixed (office/retail/commercial)	0.019	0.137	0	1
Mixed (office/retail/storage/commercial)	0.012	0.109	0	1
Mixed (office/retail/storage)	0.024	0.154	0	1
Mixed (office/storage)	0.108	0.311	0	1
Mixed (office/practice)	0.067	0.250	0	1
Mixed (commercial/storage)	0.030	0.171	0	1
Mixed (retail/commercial)	0.008	0.089	0	1
Mixed (retail/storage)	0.017	0.127	0	1
Usable space [m^2]	227.135	594.497	1	30,300
log(usable space)	4.807	0.971	0	10.319
Floors				
Unknown	0.095	0.293	0	1
1-3	0.253	0.435	0	1
4-6	0.552	0.497	0	1
7-9	0.087	0.281	0	1
10 and more	0.014	0.118	0	1

Table A.3 continues on the next page.

Table A.3 continued.

Building Period				
<1919	0.208	0.406	0	1
1919-1945	0.086	0.281	0	1
1946-1960	0.098	0.297	0	1
1961-1970	0.120	0.325	0	1
1971-1980	0.108	0.310	0	1
1981-1985	0.053	0.224	0	1
1986-1990	0.101	0.301	0	1
1991-1995	0.073	0.260	0	1
1996-2000	0.031	0.173	0	1
2001-2005	0.035	0.184	0	1
2006-2010	0.040	0.196	0	1
2011-2015	0.029	0.167	0	1
>2015	0.019	0.136	0	1
First use (new or renovated)	0.070	0.256	0	1
Has view on mountain, lake etc.	0.166	0.372	0	1
Neighborhood type				
Very low density, housing	0.004	0.067	0	1
Low density, housing	0.012	0.109	0	1
Above average density, housing	0.051	0.220	0	1
High density, housing	0.139	0.346	0	1
Very low density, mixed use	0.038	0.191	0	1
Low density, mixed use	0.070	0.256	0	1
Above average density, mixed use	0.196	0.397	0	1
High density, mixed use	0.489	0.500	0	1
Year				
2004	0.020	0.141	0	1
2005	0.030	0.169	0	1
2006	0.038	0.192	0	1
2007	0.043	0.202	0	1
2008	0.051	0.221	0	1
2009	0.047	0.213	0	1
2010	0.056	0.230	0	1
2011	0.051	0.221	0	1
2012	0.051	0.220	0	1
2013	0.058	0.233	0	1
2014	0.072	0.258	0	1
2015	0.062	0.241	0	1
2016	0.072	0.258	0	1
2017	0.079	0.270	0	1
2018	0.057	0.232	0	1
2019	0.066	0.248	0	1
2020	0.079	0.269	0	1
2021	0.068	0.252	0	1

Note: The number of observations is 67,985.