Journal of Real Estate Research

ISSN: 0896-5803 (Print) 2691-1175 (Online) Journal homepage: www.tandfonline.com/journals/rjer20

The Low-Carbon Rent Premium of Residential Buildings

Angelika Brändle, Roland Füss, Jörg Schläpfer & Alois Weigand

To cite this article: Angelika Brändle, Roland Füss, Jörg Schläpfer & Alois Weigand (2026) The Low-Carbon Rent Premium of Residential Buildings, Journal of Real Estate Research, 48:2, 172-200, DOI: 10.1080/08965803.2025.2496023

To link to this article: https://doi.org/10.1080/08965803.2025.2496023

JOURNAL OF REAL ESTATE RESEARCH
2026, VOL. 48, NO. 2, 172–200
https://doi.org/10.1080/08965803.2025.2496023

The Low-Carbon Rent Premium of Residential Buildings

Angelika Brändle[a], Roland Füss[b,c,d], Jörg Schläpfer[a] and Alois Weigand[b]

[a]Wüest Partner AG, Zurich, Switzerland; [b]Swiss Institute of Banking and Finance (s/bf), University of St.Gallen (HSG), St.Gallen, Switzerland; [c]Swiss Finance Institute (SFI), Geneva, Switzerland; [d]Center for Real Estate and Environmental Economics, NTNU Business School, Trondheim, Norway

ABSTRACT

Based on 92,600 rental contracts in the Swiss real estate market, we study how a property's CO_2 emissions are related to net rental values (gross rent without ancillary costs). We use a novel measure of operational carbon emissions that relies on various parameters that capture the sustainability and energy efficiency of a building as well as the climate conditions of its location. In an extensive hedonic framework, our results suggest that apartments in low-carbon buildings have higher net rents. A sub-analysis of urban and rural areas, as well as warm and cold locations, shows that lower ancillary costs of sustainable apartments are correlated with this low-carbon rent premium. Tenants' higher preferences for environmentally friendly living do so as well, as shown by sample splits across regions with high and low support of the Swiss Federal Act for the Reduction of Greenhouse Gas Emissions. We further document that Europe's energy crisis causally increases our main effect. Shifting the focus to 611 residential building transactions reveals that low-carbon buildings have lower capitalization rates due to lower risk premiums. Together with higher rental income, these lower capitalization rates translate into higher market values of residential buildings.

KEYWORDS

Apartment Net Rents; Capitalization Rates; CO_2 Emissions; Energy Efficiency; Residential Buildings; Sustainable Real Estate

JEL CLASSIFICATION

Q40; R11; R32

1. Introduction

In Switzerland, the operation of the residential building stock accounts for 15.4% of the country's overall CO_2 emissions in 2022 (Federal Ministry for the Environment, 2024). Therefore, real estate must make a significant effort to achieve the net-zero target and to operate carbon-neutrally in the future.[1] These sustainability pursuits and the increasing energy costs of recent years incentivize landlords to make investments in a building's energy efficiency. In the context of residential buildings, these developments may create a negative correlation between apartment net rents (gross rents without ancillary costs[2]) and the property's operational carbon emissions. Figure 1 illustrates this relationship by showing average net rents in Switzerland, which tend to be higher in cantons where residential buildings emit less CO_2 on average.

CONTACT Alois Weigand alois.weigand@unisg.ch

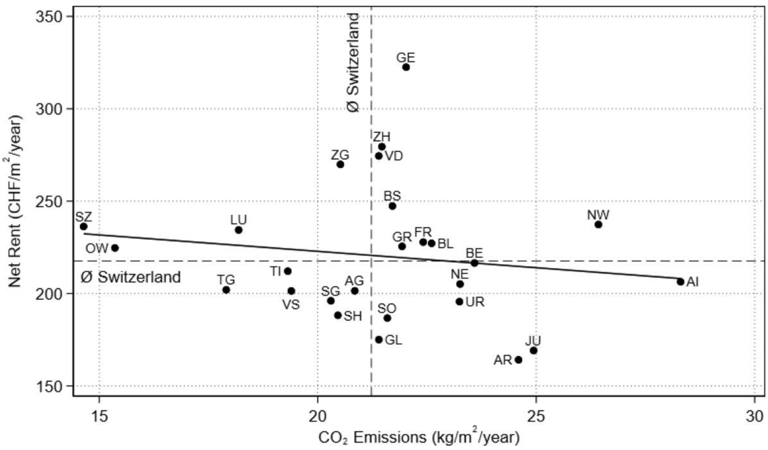


Figure 1. An apartment's average net rent and carbon emissions in Switzerland. This figure depicts the relationship between an apartment's average net rent and its carbon emissions across all 26 Swiss cantons. Net rents are expressed in CHF/m^2/year, and CO_2 emissions are quantified in kg/m^2/year. A solid line illustrates a negative correlation of −0.15 between both characteristics on the cantonal level. Equally weighted averages across Switzerland (all cantons) are shown by dashed lines.

In this Swiss context, we investigate two main hypotheses in this research paper. Firstly, we assume that net rents in low-carbon properties are higher due to tenants' higher willingness-to-pay. Secondly, we hypothesize that this willingness-to-pay for sustainable apartments is associated with savings in ancillary costs and preferences for environmentally friendly living. In addition to our two main research questions, we analyze whether and how the low-carbon rent premium is causally affected by Europe's energy crisis in 2021/22. Thereby, we assume that due to the spike in fossil fuel prices and due to the fear of oil and gas shortages, the low-carbon rent premium will increase significantly in the Swiss rental market. We also take a look at the transaction market, where we test whether residential buildings that can be operated with lower CO_2 emissions have lower capitalization rates and, thus, higher market values.

To test our hypotheses empirically, we use a novel operational CO_2 indicator on the property level developed by the independent real estate consultancy Wüest Partner AG. More specifically, this estimation refers to carbon emissions caused by the operation of real estate, i.e., during heat generation and by its electricity consumption. We merge this information on CO_2 emissions with an extensive dataset of 92,600 rental contracts in Switzerland. In doing so, we also obtain a very detailed set of control variables on the apartment, property, and municipal level for our hedonic framework. Most importantly, we account for the possibility that properties with higher net rents and low CO_2 emissions have a better building quality by including controls for a building's age, annualized future renovation costs, as well as an appraiser's assessment of the building's condition. Sustainable properties may also be located in specific locations or neighborhoods, which significantly impact market rents. Therefore, we add controls for the quality of the building's macro and micro location, as well as local rental market elasticities. In addition, we control for a dwelling's green building certificate to disentangle its signaling effects from the relationship between a property's carbon emission and its net rents.

Our results suggest that apartment net rents in residential buildings are, on average, 0.19% higher if operational carbon emissions are 1 kg/m^2/year lower. In the context of an average-sized residential building installing a low-carbon heat pump instead of a fossil heating system, this effect accumulates to 4.18% or an absolute increase in apartment net rents of CHF 45,240 on property level per year, while 114 tons of CO_2 emissions are saved. From the tenants' point of view, this higher willingness-to-pay, firstly, is correlated with ancillary cost savings when living in a low-carbon property. More specifically, a large part of the above difference is offset by the ancillary cost savings, which amount to CHF 29 per apartment and per month in buildings with a heat pump. Secondly, we point out that a higher willingness-to-pay for low-carbon housing also goes in hand with a tenant's higher preference for living in an environmentally friendly apartment. Sample splits across urban and rural regions, warm and cold locations, as well as areas with a high or low share of people supporting a Federal Act for the Reduction of Greenhouse Gas Emissions confirm these results. In light of Europe's energy crisis in 2021/22, we further document a causal increase in our low-carbon rent premium by carrying out simple difference-in-difference regressions that stress our results in times of increasing fossil fuel prices and rising concerns about resource scarcity. Moreover, based on capitalization rates from 611 residential building transactions, we suggest that replacing a fossil heating system with a heat pump decreases a building's capitalization rate by −0.0594 percentage points, which reflects a lower risk premium. In this example, the market value of a residential building increases by 2.10%. An intuitively small effect, however, as the low-carbon cap rate and rent premium go hand in hand, both effects are additive and result in an overall increase in the market value of 6.28% when a residential building becomes virtually carbon-neutral.

Our findings have interesting implications for policymakers, real estate professionals, and the academic debate on sustainable real estate. For policymakers, relying on people's sustainable behavior is not a stand-alone mechanism to achieve climate goals. Market intervention mechanisms like CO_2 taxes are one key instrument to induce the transition toward a more sustainable residential real estate market. In this regard, policies must carefully consider the potential impact on low-income households and the need to avoid the low-carbon rent premium disproportionately affecting those in affordable rental apartments. Policymakers must also evaluate incentives for sustainable housing, considering that higher market values of low-carbon buildings compensate investors for reducing carbon emissions. For real estate professionals, our results on the low-carbon cap rate premium signalize that valuation models need to account for the lower risk premium associated with lower-carbon residential properties. In addition, our results may give an indication that acquiring brown residential buildings and reducing their carbon emissions can generate a significant investment impact. In the academic debate, our approach provides a more accurate and nuanced understanding of the relationship between CO_2 emissions and residential rents as well as prices compared to binary variables like green certificates.

To the best of our knowledge, this is one of the first studies that analyzes how lower operational CO_2 emissions affect net rental values. In doing so, we provide a precise quantification of the low-carbon rent premium in the Swiss context, allowing for comparisons with other markets. We also show further evidence of carbon emissions on residential building capitalization rates and, thus, transaction prices. In this context, McCord et al. (2024) take a similar direction and provide evidence of a rental premium of 0.2% for a one-point improvement in energy efficiency measured in European

Energy Performance Certification scores. Cajias and Piazolo (2013) use detailed data on the energy consumption of residential buildings to document a premium in rental prices as well as market values for energy-efficient buildings in Germany. More specifically, the authors show that one percent energy conservation boosts rent prices by 0.08% and market values by 0.45%. Other studies on the residential real estate market mainly focus on the impact of energy labels or certificates[3] on rental as well as transaction prices. Among others, Hyland et al. (2013) find that A-rated properties experience rental rates (sales prices) that are 1.8% (9%) higher in comparison to D-rated properties. However, most of these studies only document premiums in transaction prices as a consequence of unavailable data on rental contracts (Brounen & Kok, 2011; Fuerst et al., 2015; Jensen et al., 2016; Kahn & Kok, 2014; Yoshida & Sugiura, 2015; Zheng et al., 2012). In contrast, rent premiums of certified properties are widely documented in the commercial real estate market. For example, Brolinson et al. (2023) find 3.6% higher rents for commercial office buildings associated with an energy efficiency certification. Eichholtz et al. (2010, 2013) document that certified green office buildings in the U.S. command 3% higher rents and 16% higher selling prices compared to otherwise identical buildings. Reichardt et al. (2012) show a rent premium of 2.5–2.9% for energy-efficient commercial buildings in the U.S. as well. Similar findings on green-labeled commercial properties for the Netherlands and the U.K. are mentioned in the work of Kok et al. (2011) and Chegut et al. (2014), respectively. Further studies on energy-efficient buildings in the U.S. include Wiley et al. (2010), Fuerst and McAllister (2011) and Das et al. (2011). Additionally and similarly to Kempf and Syz (2022), our study is among the first to analyze drivers of a tenant's willingness-to-pay for low-carbon apartments by looking into incentives for saving ancillary costs and preferences for sustainable living.

The remainder of the paper is organized as follows: The next section derives our hypotheses based on a theoretical model and the existing literature. Section 3 describes the institutional setting as well as the data, in particular the measure of operational CO_2 emissions. Section 4 introduces the methodology before discussing our empirical results step-by-step. Section 5 concludes.

2. Theoretical Foundation and Hypotheses

By adapting the theoretical model of Whitehead (1995) and extending the variation function of McConnell (1990), let us assume that tenants spend their expected income I over their lifetime on housing services z_i in terms of rents and the consumption of a bundle of other consumer goods c_i. The set of housing attributes includes common property characteristics z_i, such as age, size, micro and macro location, and environmental attributes z_e, such as a heating pump or building insulation, which lower an apartment's operational CO_2 emissions. We normalize the price of other consumption goods to 1 to treat it as a numeraire good c. The hedonic rental price function consists of housing and sustainable attributes $p_i * z_i + p_e * z_e$, where $p_e > p_i$. Thus, a tenant's budget constraint is given by the following equation:

$$I = c + p_i * z_i + p_e * z_e. \tag{1}$$

Given this budget constraint, a tenant maximizes the utility function $u(c, z_i, z_e)$. The expenditure function $m(p, z_i, z_e, u)$ is determined by the tenant's consumption problem:

$$\begin{aligned} &\min c + p_i' * z_i + p_e' * z_e \\ &\text{s.t. } u = u(c, z_i, z_e). \end{aligned} \tag{2}$$

Based on the expenditure function, we derive the minimum amount of rent that a tenant must spend to remain on a pre-defined utility level. This function increases in p and u but decreases in z (decreasing marginal utility). The willingness-to-pay for a low-carbon apartment is the maximum amount of money a tenant would give up in order to live in an environmentally friendly apartment, i.e., going from z_e to z_{e^*}:

$$WTP_e = m(p_i, p_e, z_i, z_e, u) - m(p_i, p_e, z_i, z_{e^*}, u). \tag{3}$$

$WTP_e\ (\cdot)$ indicates the willingness-to-pay valuation function and z_{e^*} stands for a CO_2 low-carbon apartment. The tenant's expenditure on a fixed level of utility decreases with an increasing energy efficiency of a building (z_e to z_{e^*}) and, thus, the $WTP_e \geq 0$. This leads us to our first and key testable hypothesis:

Hypothesis 1: Low-carbon rent premium:

Net rents in low-carbon properties are higher due to tenants' higher willingness-to-pay.

Tenant's higher willingness-to-pay for low-carbon housing can be driven by ancillary cost savings and preferences for sustainable living. In this context, previous studies on properties with energy-efficiency certificates provide first insights into what is really driving the willingness-to-pay for lower carbon emissions. Eichholtz et al. (2010, 2013) document that premiums in rents and asset values of sustainable buildings mainly stem from efficient energy use. These findings indicate that the increment to market value is more than a "green" labeling effect but provides additional occupier benefits, lower holding costs, and a lower risk premium (Fuerst & McAllister, 2011). Furthermore, the rental choice between green and conventional floor space affects firms' sustainability, which is particularly important for companies in specific sectors like the oil or banking industry (Eichholtz et al., 2016). The results emphasize the economic benefits and institutional pressure as the "ecological" responsiveness of firms. Similarly, households might be willing to pay a higher net rent to signal environmental responsibility. For instance, Kahn and Vaughn (2009) argue that environmental ideology leads to a higher willingness-to-pay to reduce carbon emissions in the Californian housing market.[4] In contrast, Brounen et al. (2012) show low "energy literacy" and energy consumption awareness among Dutch households, which is reflected in low adaption rates for semi-mandatory energy certificates (Brounen & Kok, 2011).[5]

Despite the evidence being rare, we follow the findings of Kempf and Syz (2022) who decompose the willingness-to-pay for sustainable housing in Switzerland into multiple components (energy savings, increased comfort, and enhanced conservation of value). We do the same and hypothesize that higher willingness-to-pay for low-carbon housing is not defined by a single driver but rather by a mix of ancillary cost savings and preferences for sustainability. Hence, our second hypothesis is the following:

Hypothesis 2: Ancillary cost savings and preferences for sustainability.

Tenants' willingness-to-pay for sustainable apartments is simultaneously driven by savings in ancillary costs and by preferences for environmentally friendly housing.

3. Institutional Setting and Data

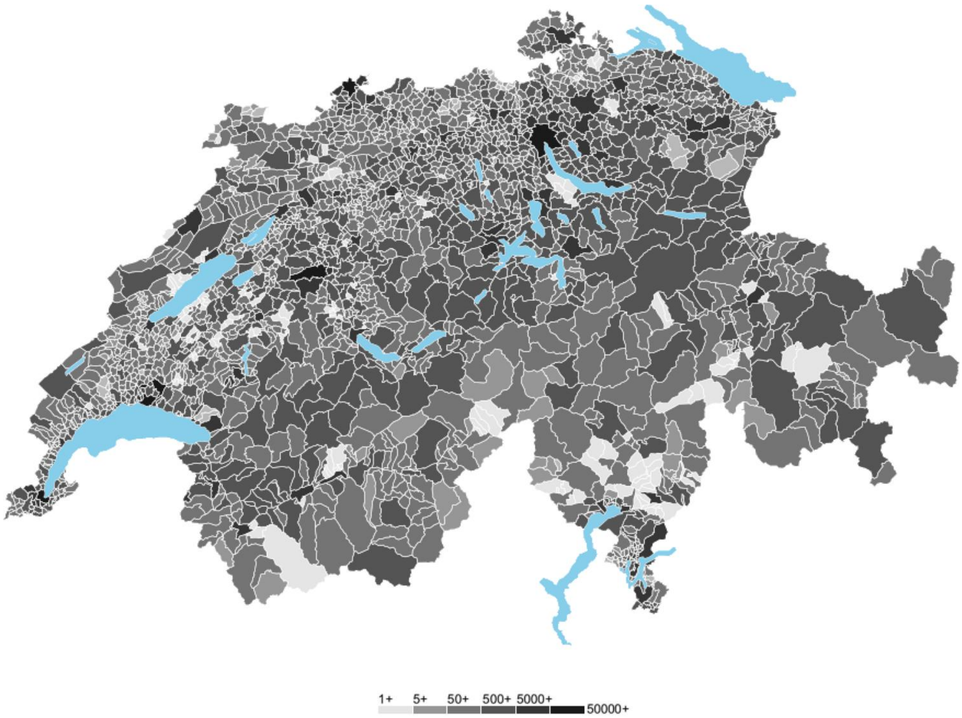
3.1. Swiss Residential Rental Market

Switzerland's housing stock comprised approximately 4.5 million dwellings (apartments or houses), with about 2.6 million of these being rental units (roughly 60%). The Swiss rental market is dominated by private landlords, who own about 57% of rental properties. Institutional investors own roughly 22% of rental properties, while housing cooperatives and public entities account for the remaining 21% (Swiss Federal Statistical Office, 2024).

With its rental rate being one of the highest in Europe,[6] the Swiss rental market is heavily regulated, with strong tenant protection laws in place that govern the relationship between landlords and tenants. This highly regulated nature of the market also has an increasing focus on sustainability. In recent years, the introduction of non-mandatory building energy certificates has provided a standardized way to assess and communicate a building's energy performance. At the same time, the Swiss Federal Council increased its efforts to quantify and reduce the carbon emissions of the residential housing stock. In this regard, tenants became more aware of housing-related carbon footprints.

While federal laws provide an overarching framework, the Swiss rental market can have significant regional differences. Cantons may have additional regulations, and market conditions can vary considerably between urban, suburban, and rural areas as well as tourist regions. Economic factors and population density primarily drive these regional variations, which follow the country's topography. Dense municipalities with a large housing stock can usually be found in the North and West, while mountainous and large municipalities in the South and East exhibit fewer rental dwellings. Figure 2 shows the distribution of the rental housing stock (Panel A) and compares it to the number of observations in our dataset of Swiss rental contracts (Panel B, described in Section 3.2).

The strict tenancy law also provides a clear framework for rental contracts in the Swiss residential market. On a monthly basis, a Swiss tenant pays the gross monthly rent to the landlord, which may be decomposed into the apartment's net rent and ancillary costs. Net rent has to be paid for the direct use of rental property, while ancillary costs in Swiss rental properties are additional or indirect charges related to this usage. Ancillary costs encompass various utilities and services, including heating and hot water consumption,[7] water usage, common area electricity, waste disposal fees, and building maintenance services. The charges also cover common area maintenance such as caretaker services, garden maintenance, elevator maintenance, stairwell cleaning, snow removal, and security services. These costs are typically distributed among tenants using a predetermined allocation key based on factors like apartment size or number of occupants. In most cases, ancillary costs also include a 3–5% administrative fee. Under Swiss law, all ancillary costs must be explicitly listed in the rental agreement, and certain expenses cannot be charged as ancillary costs (i.e., renovation costs, property taxes, insurance premiums, or general administrative costs). Tenants have legal rights regarding



Panel B: Swiss Rental Contract Dataset

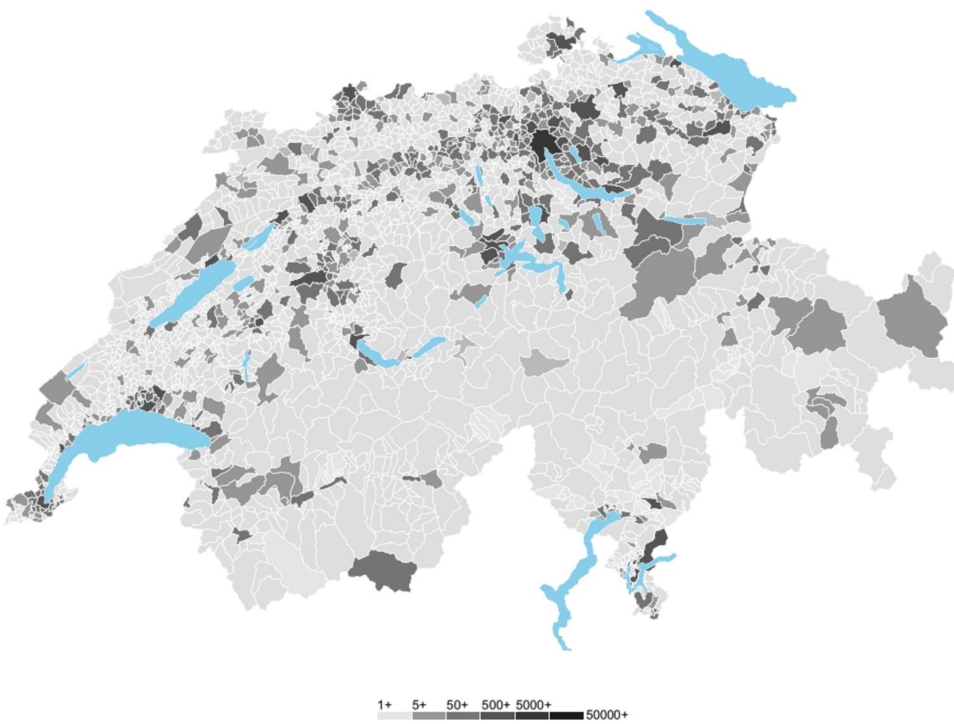


Figure 2. Dispersion in the Swiss Rental Housing Stock. This map depicts the regional dispersion of the rental housing stock in Switzerland (Panel A) and our dataset on Swiss rental contracts (Panel B) across municipalities. The solid shapes indicate 2,172 communes within Switzerland. The degree of coloring depends on the number of observations in each municipality. Blue shades indicate lakes and rivers. Panel A: Swiss Rental Housing Stock. Panel B: Swiss Rental Contract Dataset.

these charges, including a five-year period to dispute charges and the ability to claim overcharged amounts for up to ten years. Apartment-level electricity costs or TV/internet fees are billed to the tenants by the respective providers individually and not by the landlord.

Overall, the high rental rate, the strong tenancy law, high market regulation, the regional variation, as well as the ambitious climate goals make the Swiss rental market an excellent laboratory for analyzing the impact of CO_2 emissions on rental prices.

3.2. Data

To conduct our analysis, we use an extensive dataset of 92,600 Swiss rental contracts in 2,653 residential buildings owned by 111 institutional investors, including pension funds, insurance companies, banks, family offices, and real estate funds, among others.[8] Overall, our sample includes 16.2% of all rental dwellings held by institutional investors in Switzerland and 3.6% of all rental dwellings in the country. Hence, we consider our dataset to be representative of the investment activity of institutional investors, who tend to invest more in urban and suburban areas, but also own a small share of buildings in rural regions. This is visible in Panel B of Figure 2, where we observe rental contracts across the whole of Switzerland but concentrated in specific municipalities. These communities are more likely to be found in more densely populated areas and not in rural regions in which private landlords dominate.

Table 1 presents the list of main variables and essential controls in the dataset on Swiss rental contracts as well as their descriptive statistics for the sample period April 2015 to October 2023. This list includes each variable’s unit and its granularity (apartment level, property level, or municipality level). In Table 2, we provide the main variables’ pairwise correlation coefficients to indicate the strength of their linear relationship.

3.2.1. Apartment Net Rents

All Swiss properties or Swiss rental agreements in this sample for which we observe apartment net rents meet the following criteria: (1) A dwelling has at least two residential units. (2) The property is equipped with gas or oil-fired heating or with a heat pump (shares of 92.5 and 7.5%, respectively).[9] (3) The apartment size is between 20 and 340 m^2 with a monthly net rent of at least CHF 500 and at most CHF 5,000. (4) The apartment is unfurnished. (5) A rental contract needs to be signed between January 2015 and October 2023 and has to be valid at the end of the sample period.[10] Hence, these selection rules for residential buildings and rental agreements ensure that only real and current leases are included in the final dataset. All agreements are close to current market rents and reflect tenants’ willingness to pay. Older rental contracts would distort the

Table 1. Descriptive statistics –rental contracts.

	Granularity	Mean	S.D.	Min	Max
Monthly net rent (CHF)	AL	1399.8215	344.2316	500.0000	5000.0000
Size (m^2)	AL	77.1910	26.5967	20.0000	340.0000
Rooms (#)	AL	3.2529	1.0875	1.0000	13.0000
Floor	AL	2.3332	2.4624	−2.0000	17.0000
CO_2 emissions ($kg/m^2/year$)	PL	21.2290	11.1185	2.3940	76.1900
Standard (score)	PL	3.3370	0.4593	1.5000	5.0000
Usability (score)	PL	3.3839	0.4530	1.7000	5.0000
Units (#)	PL	65.3380	71.5342	2.0000	529.0000
Condition (score)	PL	3.6158	0.8126	1.2000	5.0000
Building age (in years)	PL	42.5920	33.2369	0.0000	403.0000
Renovation costs (per m^2)	PL	48.4050	20.5451	0.0000	166.4470
Quality index (score)	PL	3.9207	0.8125	1.7946	5.6058
Macro location (score)	ML	0.8079	0.6614	0.0000	4.0000
Micro location (score)	PL	3.5190	0.5754	1.0000	5.0000
Minergie certificate (score)	PL	0.9255	0.9559	0.0000	2.0000
Rental offer rate (%)	ML	6.5748	2.9659	0.3266	38.3571
Yes-votes CO_2 Act (%)	ML	54.9280	11.3951	21.9050	77.4830
Heating degree days (#)	ML	3377.7000	279.0839	2373.1000	6756.0000

This table shows descriptive statistics for the dataset on Swiss rental contracts (sample period: April 2015 to October 2023). The mean, standard deviation (S.D.), as well as minimum and maximum values are listed. Each rental contract can be linked to one of 2,172 Swiss municipalities and one of 26 Swiss Cantons, as well as to one of 9 postal regions. Furthermore, communes can be categorized as urban, sub-urban, or rural municipalities. Time stamps of rental contracts are available as well. The granularity of data is either apartment level (AL), property level (PL), or municipality level (ML).

results in our study as these agreements are strongly influenced by the Swiss tenancy law and, thus, deviate more from current rents over time. Furthermore, our cleaning criteria ensure that each apartment is only observed once.

3.2.2. CO_2 Emissions

Our analysis focuses on CO_2 emissions caused by operating residential real estate, i.e. when a dwelling is heated, and by its electricity consumption (in accordance with the Greenhouse Gas Protocol (Scope 2) and the Carbon Risk Real Estate Monitor's whole-building approach).[11] The carbon emissions of our dataset's properties are estimated by the CO_2 calculator of the independent real estate consultancy Wüest Partner AG. This calculation defines CO_2 emissions as the product of a building's final energy consumption and the emission factor (see description in Appendix A). In short, the CO_2 modeling is calibrated against a dataset on 50,000 energy performance certifications and determines the dwelling's CO_2 emissions based on mandatory parameters and optional inputs. The mandatory variables include a property's exact geo-coordinates (to model climate conditions), year of construction of the property, number of heated floors, utilization schedules with floor space details, the energy reference area, and energy sources of heat generation. Optional inputs include the year and type of energy renovations (such as heat generation, external walls, windows, roof, and basement ceiling), window properties, shading factors, ventilation types, and heat recovery efficiency, among others. Regarding precision in comparison with actual carbon emissions based on actual energy demand for heating, hot water, and electricity (Scope 2), the CO_2 modeling has a mean relative deviation of 18% (40%) in the calibration sample of 148 buildings if all mandatory and optional (only mandatory) input variables are available. Based on the availability

Table 2. Correlation matrix – rental contracts.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
(1) Monthly net rent	1																	
(2) Size	0.67	1																
(3) Rooms	0.56	0.86	1															
(4) Floor	0.05	−0.03	−0.05	1														
(5) CO_2 emissions	−0.30	−0.30	−0.05	−0.09	1													
(6) Standard	0.39	0.39	0.11	0.04	−0.50	1												
(7) Usability	0.37	0.30	0.17	0.01	−0.43	0.64	1											
(8) Units	0.02	0.01	0.03	0.21	−0.12	0.03	0.10	1										
(9) Condition	0.33	0.12	0.05	0.03	−0.63	0.65	0.50	0.14	1									
(10) Building age	−0.15	−0.22	−0.18	0.03	0.43	−0.31	−0.40	−0.12	−0.37	1								
(11) Renovation costs	−0.17	−0.18	−0.14	−0.03	0.50	−0.46	−0.37	−0.09	−0.68	0.35	1							
(12) Quality index	0.31	0.20	0.10	0.01	−0.69	0.65	0.55	0.12	0.89	−0.58	−0.77	1						
(13) Macro location	−0.35	0.08	0.13	−0.08	0.01	−0.01	0.02	−0.06	−0.05	0.20	−0.27	0.18	1					
(14) Micro location	0.12	−0.04	−0.09	0.06	−0.02	0.15	0.11	0.02	0.09	0.08	0.02	0.05	−0.09	1				
(15) Minergie certificate	0.05	0.03	0.02	0.01	−0.07	0.09	0.14	0.01	0.11	−0.07	−0.05	0.09	−0.03	0.02	1			
(16) Rental offer rate	−0.26	0.26	0.12	−0.07	−0.03	0.02	0.04	−0.09	0.05	−0.18	−0.22	0.17	0.64	−0.04	−0.10	1		
(17) Yes-votes CO_2 Act	0.17	−0.17	−0.21	0.13	0.01	−0.00	−0.06	−0.02	−0.09	0.31	0.21	−0.20	−0.59	−0.02	0.09	−0.43	1	
(18) Heating degree days	−0.09	0.09	0.09	−0.09	−0.10	0.03	0.05	−0.09	0.03	−0.03	−0.07	0.05	−0.21	−0.02	−0.05	0.17	−0.17	1

This table reports the pairwise correlation coefficient (Bravais-Pearson) of all main variables in the dataset on Swiss rental contracts. Dummy variables or location identifiers are not included. All reported correlation coefficients are at least significant at a 10% level.

of input variables in our dataset on Swiss rental contracts, we expect a maximum mean relative deviation of 25% in the CO_2 modeling for our 2,653 residential buildings.

In our dataset on Swiss rental contracts, an average dwelling emits CO_2 of 21 $kg/m^2/year$. This number is mainly driven by buildings with oil and gas-fired heating systems that emit 25 $kg/m^2/year$ of CO_2 on average, while dwellings with a heat pump have an average of 3 $kg/m^2/year$ of CO_2.[12] Hence, in contrast to the Paris Climate Agreement, we do not consider dwellings with a heat pump to be carbon-neutral. Heat pumps generate a higher electricity demand, which is taken into account when calculating a dwelling's carbon emissions.[13]

3.2.3. Building Quality

To isolate the effect of CO_2 emissions on apartment net rents, a variety of controls for a building's quality are essential. Therefore, our dataset includes three indicators. (1) Condition: During the appraisal process, a property's condition is assessed on a discrete scale from 1.0 (in need of renewal) to 5.0 (as new) in tenths of a point. Based on a standardized assessment process and an on-site inspection, this measure facilitates the comparison of buildings in terms of materialization and condition. (2) Age of a Dwelling: A building's age serves as another control for a building's quality due to obsolescence and depreciation over time. (3) Renovation Costs: This variable refers to the renovation schedule considered in the appraisal process and is given by the annualized cash flow of the future repair costs per square meter.[14]

Obviously, all three indicators of a property's quality show significant correlations with a building's CO_2 emissions (Table 2). These relationships may bias the results of the effect of carbon emissions on apartment rents. Therefore, in one of our estimation models, we take all three controls as sub-indicators and aggregate them into a quality index. More specifically, this new index captures the quality of a building without taking sustainability into account. The challenge of constructing the index using three sub-indicators is that their means and variances are not identical. Sub-indicators with a high mean value and high variance characterize the overall index more than sub-indicators with a low mean value and a small variance. Accordingly, we standardize the distributions of all sub-indicators to a range of 1.0 (poor) to 6.0 (very good). Computing an unweighted average of all three adjusted sub-indicators yields the quality index in a final step.[15]

3.2.4. Property and Apartment Characteristics

To further control for a variety of property and apartment attributes, we account for a property's standard, usability, and number of rental units. The discrete score for the standard and the usability of a dwelling are assessed by an appraiser. Both variables' scales start at 1.0 (very bad) and end at 5.0 (excellent). Additional hedonics in our dataset are an apartment's size, number of rooms, as well as the floor on which the apartment is located. With respect to the apartment size, we also control for nonlinearity by adding a quadratic term for the size variable.

3.2.5. Macro and Micro Location

To describe the location quality of rental contracts, we distinguish between the macro and micro location of individual properties. The micro location is based on a model-based proposal, which can be overruled based on an appraiser's subjective assessment on a discrete scale from 1.0 (very bad) to 5.0 (excellent) in tenths of a point. The rating takes a dwelling's immediate surroundings or neighborhood into account, which are graded on its terrain, infrastructure, recreational opportunities, noise emissions, and population density. A building's macro location reflects a building's geographical location within the country. Based on economic and socio-demographic data as well as information on connectivity and infrastructure, a model-based score is given from 0.0 (D-location) to 4.0 (A-location) at the municipality level. Together with cantonal indicators, the variables on a property's macro and micro location can also capture spatial differences in the adoption of heating systems, which mainly persist in the comparison of urban/suburban versus rural municipalities.

3.2.6. Green Building Certificates

To account for the signaling effect of green building certificates, i.e., energy certificates signal lower energy costs and, thus, lower ancillary costs, we use the information on Swiss Minergie labels on the property level.[16] Based on this sustainable building standard, rental observations are grouped into three categories: Firstly, buildings without certification or missing information have a score of 0 (reference category). Secondly, buildings with a basic certification (Minergie) score 1. Thirdly, properties with a higher level certificate (Minergie-P and Minergie-A) score 2 in our dataset.

3.2.7. Local Rental Elasticities

The effect of operational CO_2 emissions on apartment net rents must be separated from the influence of "loose" and "tight" rental market conditions. To proxy for local rental (in-)elasticities, our dataset includes rental offer rates as an additional control. Rental offer rates in each municipality or city district are the percentage ratio of apartments on offer in relation to the existing apartment stock.

3.2.8. Municipal Characteristics

Municipal attributes are the final component of the dataset on Swiss rental contracts. Each rental contract can be linked to one of 2,172 Swiss municipalities and one of 26 Swiss Cantons. Moreover, urban, sub-urban, as well as rural classifiers are available in each commune. Most importantly, we collect voting results on the revised Federal Act on the Reduction of Greenhouse Gas Emissions (CO_2 Act) on the municipality level. In this nationwide referendum on June 13th, 2021, Swiss citizens said no to a law to curb the nation's greenhouse gas emission even further by 2030 (59.70% voter turnout).[17] Lastly, the average amount of yearly heating degree days (between 1981 and 2010) is available for each municipality and serves as an indicator of local climate conditions. To obtain this measure, on each heating day (average outside temperature of less than 12 °C), it is recorded by how much the outside air temperature deviates from the targeted inside air temperature of 20 °C. The yearly heating degree days are the sum of the differences between the outside air temperature and the targeted inside air temperature for all heating days.

4. Methodology and Results

4.1. The Low-Carbon Rent Premium

We test our main hypotheses in a low-carbon rent premium model, which is based on the concept of hedonic regressions developed by Rosen (1974). In line with Malpezzi (2002), this log-linear regression model with heteroskedastic disturbances is specified as follows:

$$ln(R_i) = \beta_0 + \beta_1 CO_2 \text{ Emissions} + \Psi_i X_i + \epsilon \quad \text{with } \epsilon \sim \mathcal{N}\left(0, \sigma^2\right). \tag{4}$$

The model aims to estimate the effect of CO_2 emissions on apartments' net rents R_i while controlling for differences in building quality, location attributes, local rental market conditions, as well as property and apartment characteristics. In Equation (4), the set of control variables is denoted by the vector X_i and allows the comparison of two identical properties, which only differ in terms of their carbon emissions. β_0, β_1, and Ψ pick up (vectors of) coefficients. Consequently, CO_2 emissions are not a direct function of some control variables in the low-carbon rent premium model. ϵ denotes the error term.

Table 3 presents linear regression results from estimating different versions of Equation (4). These different specifications confirm our first hypothesis, i.e., lower CO_2 emissions have a positive effect on rental income: the lower carbon emissions, the higher net rents. This is shown by carefully isolating the effect of CO_2 emissions on net rental values from the influence of a building's quality. To do so, we alternately include a property's condition, age, or future renovation costs in Models (1) to (3), include all three measures in Model (4), and use these variables' aggregated index in Model (5).

As apartment net rents are log-transformed, the estimated coefficients of CO_2 emissions varying from −0.0011 to −0.0033 indicate that if carbon emissions are 1 $kg/m^2/year$ lower, the net rent is 0.11–0.33% higher. [18] All effects are statistically significant at common significance levels (10, 5, and 1%). However, Models (2) and (3) show relatively high estimates as these specifications fail to account for a building's quality by only including one control variable (age or renovation costs). A building's condition seems to be the key variable in controlling for a building's quality in Model (1). Models (4) and (5) are even more successful in doing so and yield coefficients of similar as well as smaller sizes. Furthermore, the models' adjusted R^2 shows that Model (4) has a slightly higher explanatory power than Model (5), as during the aggregation process of the quality index, variation is lost. Therefore, we consider Model (4) as our reference specification.[19]

On an apartment level, the result of Model (4) is economically significant. If a heat pump is installed instead of oil or gas-fired heating, CO_2 emissions are cut by 22 $kg/m^2/year$ on average. At the same time, rents are around 4.18% higher (0.19% * 22). The average net rent in the dataset on Swiss rental contracts is CHF 1,400 per month. Hence, with a heat pump, the monthly net rent would be, on average, CHF 58 higher than with a fossil heating system. Taking this interpretation to a property level, investors generate a CHF 3,770 higher monthly rental income per average-sized low-carbon building (with 65 apartments) compared to an identical building with oil or gas-fired heating. Aggregated to a yearly level, the low-carbon rental premium accumulates to CHF 45,240

Table 3. Regression results – low-carbon rent premium model.

	(1) Condition	(2) Age	(3) Costs	(4) All	(5) Index
Constant	5.8588***	5.9419***	6.0301***	5.7733***	5.8229***
	(0.0113)	(0.0120)	(0.0135)	(0.0130)	(0.0123)
CO_2 emissions	−0.0015***	−0.0041***	−0.0033***	−0.0019***	−0.0011***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Size	0.0135***	0.0132***	0.0136***	0.0136***	0.0134***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Size2	−0.0001***	−0.0001***	−0.0001***	−0.0001***	−0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Rooms	0.0300***	0.0332***	0.0289***	0.0308***	0.0332***
	(0.0014)	(0.0014)	(0.0015)	(0.0014)	(0.0015)
Floor	0.0050***	0.0042***	0.0041***	0.0050***	0.0051***
	(0.0004)	(0.0004)	(0.0004)	(0.0005)	(0.0005)
Standard	0.0526***	0.1120***	0.0977***	0.0510***	0.0610***
	(0.0023)	(0.0019)	(0.0022)	(0.0020)	(0.0022)
Usability	0.0251***	0.0366***	0.0289***	0.0319***	0.0123***
	(0.0020)	(0.0019)	(0.0020)	(0.0019)	(0.0020)
Units	−0.0004***	−0.0003***	−0.0003***	−0.0004***	−0.0003***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Condition	0.0812***	–	–	0.0913***	–
	(0.0011)	–	–	(0.0014)	–
Building age	–	0.0002***	–	0.0003***	–
	–	(0.0000)	–	(0.0000)	–
Renovation costs	–	–	−0.0009***	−0.0005***	–
	–	–	(0.0000)	(0.0001)	–
Quality index	–	–	–	–	0.0824***
	–	–	–	–	(0.0014)
Macro location	−0.1293***	−0.1194***	−0.1278***	−0.1221***	−0.1396***
	(0.0014)	(0.0015)	(0.0017)	(0.0014)	(0.0016)
Micro location	0.0448***	0.0466***	0.0501***	0.0422***	0.0487***
	(0.0010)	(0.0011)	(0.0012)	(0.0010)	(0.0011)
Rental offer rate	−0.0083***	−0.0073***	−0.0067***	−0.0081***	−0.0082***
	(0.0003)	(0.0004)	(0.0004)	(0.0003)	(0.0004)
Minergie dummies	Yes	Yes	Yes	Yes	Yes
Cantonal dummies	Yes	Yes	Yes	Yes	Yes
Quarterly dummies	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.7585	0.7440	0.7477	0.7610	0.7581
# Obs.	92,600	92,600	92,600	92,600	92,600

This table shows linear regression results for five different specifications of the low-carbon rent premium model. Model specifications differ in terms of measures of a building's state. Model (1) includes a score for the building's condition. Model (2) considers a dwelling's age. Model (3) includes the annuity of a property's future renovation costs. Model (4) includes all three different measures individually, while Model (5) combines these three controls in a quality index. The dependent variable is the natural logarithm of the monthly net rent. HAC-robust standard errors are reported in parentheses. *** denotes statistical significance at the 1% level.

for an investor of a low-carbon residential dwelling while saving 114 tons of CO_2 (22 $kg/m^2/year$ * 65 apartments * 80 m^2).

One strong assumption in our low-carbon rent premium model is the linearity of the negative relationship between apartment net rents and carbon emissions. To investigate this further, we categorize apartments according to their CO_2 emissions and re-estimate our low-carbon rent premium model.[20] Figure 3 illustrates these estimated coefficients, which must be compared to the base category of virtually carbon-neutral apartments (CO_2 emissions ≤ 5 $kg/m^2/year$). The figure shows that the negative effect of carbon emissions on net rents increases linearly until the fifth category (CO_2 emissions $> 25 kg/m^2/year$) and remains the same in the last category. This may indicate a diminishing linear effect once a residential building exceeds a certain threshold of carbon emissions.

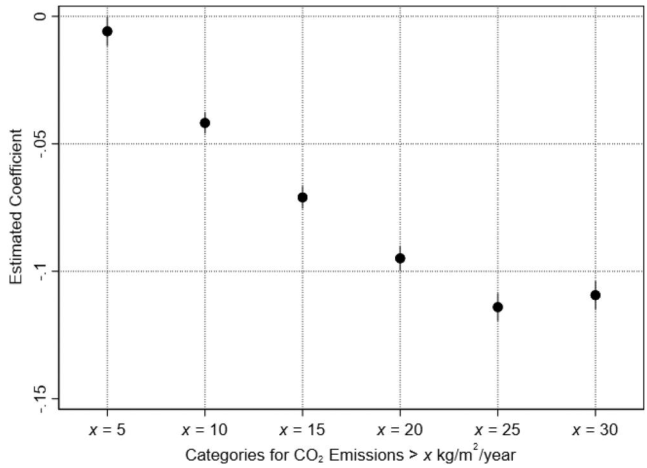


Figure 3. CO_2 categories - low-carbon rent premium model. This figure shows estimated regression coefficients for six categories of rental apartments' CO_2 emissions compared to the base category of virtually carbon-neutral apartments ($x < 5kg/m^2/year$). Coefficients are estimated in an adapted version of the low-carbon rent premium model, where categories are included as binary variables and replace the main explanatory variable CO_2 emissions. The number of observations in this regression is again 92,600 with an adjusted R^2 of 0.7836. Spikes indicate 90% confidence intervals around the estimated coefficients, which are indicated by black dots.

The low-carbon premium in net rents and the corresponding higher willingness-to-pay may be traced back to two possible reasons.[21] Firstly, residential buildings with a heat pump have lower ancillary costs than dwellings with oil or gas-fired heating systems. More precisely, heating costs amount to CHF 29 per m^2/year on average, while the average costs of fossil heating are CHF 34 per m^2/year. This difference of CHF 5 translates to CHF 33 higher ancillary costs per month for an average-sized 80 m^2 apartment. As a consequence, higher net rents do not necessarily lead to higher housing costs for tenants as the CHF 58 per month higher rent for a low-carbon apartment is partially offset by the average savings in ancillary costs (ancillary cost savings are passed through to tenants). Secondly, higher net rents of apartments with lower CO_2 emissions may go in hand with preferences for environmentally friendly apartments.

4.2. Ancillary Cost Savings vs. Preferences for Sustainability

To disentangle both potential reasons of the low-carbon rent premium, we perform three different sample split regressions for our low-carbon rent premium model in Equation (4). Firstly, we divide our sample into an urban and rural sub-sample (neglecting sub-urban observations). This sample split allows for the assessment of the influence of ancillary costs as buildings in more densely populated locations are heated in a more efficient and cost-saving way due to a denser building structure than in rural areas. Secondly, we divide our rental contracts based on climate conditions to account for different levels of heating costs. To do so, we sort rental contracts based on municipalities' heating degree days and consider values larger (smaller) than the upper (lower) quartile as our Cold (Warm) sub-sample. Thirdly, we perform a similar sample split based on municipal voting results on the revised Federal Act on the Reduction of Greenhouse Gas

Table 4. Sample split regression results – low-carbon rent premium model.

	(1) Urban	(2) Rural	(3) Warm	(4) Cold	(5) High Yes–%	(6) Low Yes–%
Constant	5.8057***	6.0803***	5.5476***	5.9135***	5.7889***	6.1215***
	(0.0139)	(0.0804)	(0.0266)	(0.0214)	(0.0267)	(0.0221)
CO_2 emissions	−0.0020***	−0.0042***	−0.0005**	−0.0033***	−0.0022***	−0.0009***
	(0.0001)	(0.0004)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
Size	0.0136***	0.0087***	0.0134***	0.0148***	0.0140***	0.0116***
	(0.0002)	(0.0011)	(0.0002)	(0.0002)	(0.0003)	(0.0002)
Size2	−0.0001***	−0.0001***	−0.0001***	−0.0001***	−0.0001***	−0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Rooms	0.0295***	0.0732***	0.0522***	0.0388***	0.0336***	0.0434***
	(0.0015)	(0.0085)	(0.0028)	(0.0031)	(0.0026)	(0.0021)
Floor	0.0051***	−0.0024	0.0093***	0.0017***	0.0143***	0.0017**
	(0.0004)	(0.0031)	(0.0006)	(0.0004)	(0.0004)	(0.0006)
Standard	0.0556***	0.0635***	0.0574***	0.0015	0.0636***	0.0139***
	(0.0021)	(0.0147)	(0.0041)	(0.0030)	(0.0040)	(0.0032)
Usability	0.0304***	0.0614**	0.0392***	0.0338	0.0369**	−0.0156
	(0.0019)	(0.0115)	(0.0042)	(0.0027)	(0.0037)	(0.0032)
Units	−0.0004***	−0.0007***	−0.0006***	−0.0002***	−0.0008***	−0.0001***
	(0.0000)	(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Condition	0.0878***	0.0768***	0.0642***	0.0960***	0.0751***	0.0999***
	(0.0014)	(0.0093)	(0.0025)	(0.0023)	(0.0029)	(0.0021)
Building age	0.0003***	−0.0002**	0.0003***	−0.0001	−0.0004***	−0.0011***
	(0.0001)	(0.0001)	(0.0001)	(0.0000)	(0.0001)	(0.0000)
Renovation costs	−0.0004***	−0.0003	0.0000	0.0001	0.0004***	−0.0003***
	(0.0001)	(0.0004)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Macro location	−0.1453***	−0.0562***	−0.0973***	0.1022	0.0020	−0.0792***
	(0.0000)	(0.0077)	(0.0038)	(0.0021)	(0.0200)	(0.0028)
Micro location	0.0384***	0.0472***	0.0387***	0.0266***	0.0508***	0.0171***
	(0.0011)	(0.0070)	(0.0023)	(0.0018)	(0.0021)	(0.0015)
Rental offer rate	−0.0119***	−0.0006**	−0.0048***	−0.0085***	−0.0179***	−0.0018***
	(0.0004)	(0.0007)	(0.0006)	(0.0005)	(0.0025)	(0.0003)
Minergie dummies	Yes	Yes	Yes	Yes	Yes	Yes
Cantonal dummies	Yes	Yes	Yes	Yes	Yes	Yes
Quarterly dummies	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.7589	0.8490	0.74201	0.8515	0.7797	0.7964
# Obs.	81,941	1,724	22,987	23,339	22,783	22,803

This table shows linear regression results for three different sample splits in the estimation process of the low-carbon rent premium model. Firstly, Model (1) only includes observations in urban areas, while Model (2) is solely based on rental contracts in rural municipalities. Secondly, based on a location's heating degree days, Models (3) and (4) are estimated with observations in municipalities with warm and cold temperatures, respectively. Thirdly, Models (5) and (6) include rental contracts in municipalities with a high- and low share of Yes-votes for the Swiss CO_2 Act, respectively. The dependent variable is the natural logarithm of the monthly net rent. HAC-robust standard errors are reported in parentheses. *** and ** denote statistical significance at the 1 and 5% level, respectively.

Emissions (CO_2 Act) to account for varying preferences for sustainable housing within the population. Table 4 lists all sample-split regression results.[22] In all sample-split regressions, we control for quality by including all three measures of a building's quality individually according to Model (4) of Table 3 in Section 4.1.

Firstly, the estimated coefficients of CO_2 emissions in Models (1) and (2) indicate that the rural low-carbon rent premium of −0.0042 is significantly higher than in urban areas at a 1% level (Table B.1 of the Appendix for equality tests of coefficients). Based on the urban sub-sample, this main coefficient of interest amounts to −0.0020. Secondly, in cold regions (Model (4)), the significant coefficient of CO_2 emissions on net rental values is equal to −0.0033, while in warm regions (Model (3)), the estimate is just slightly negative with −0.0005.[23] This difference between warm and cold municipalities is significant at a 1% level. Thirdly, sample split regressions of Models (5) and (6) show a higher low-carbon rent premium in municipalities with a higher share of supporters of the Swiss CO_2 Act, implying that these environmentally friendly communities penalize CO_2 emissions more.[24] This difference in coefficients for the effect of carbon emissions on net rents is again significant at all common significance levels (10, 5, and 1%). Consequently, we argue that the low-carbon rent premium is significantly correlated with ancillary cost savings of sustainable buildings and tenants' preferences for sustainability.

4.3. Europe's Energy Crisis and the Low-Carbon Rent Premium

Despite including several hedonic variables in our analysis, estimating Equation (4) in a simple hedonic framework does not allow for causal inference. Therefore, we conduct an event study by specifying a simple difference-in-difference model in light of Europe's Energy Crisis that started in October 2021. This crisis could have strengthened the negative relationship between a building's carbon emissions and net rental values.

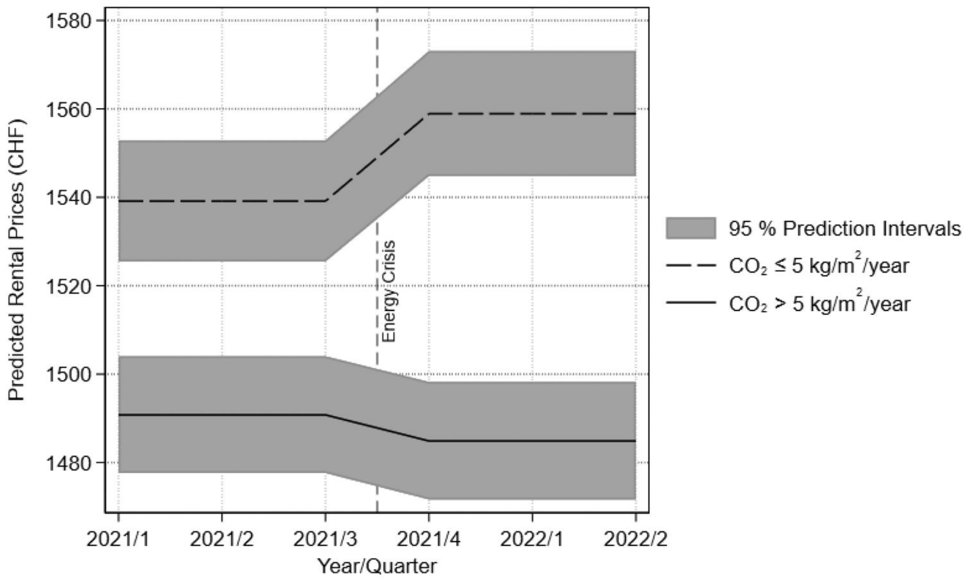
$$ln(R_i) = \beta_0 + \beta_1 \text{High } CO_2 \text{ Emissions} + \beta_2 \text{Crisis} + \beta_3 (\text{High } CO_2 \times \text{Crisis}) + \Psi_i X_i + \epsilon \quad \text{with } \epsilon \sim \mathcal{N}(0, \sigma^2). \tag{5}$$

$ln(R_i)$ again denotes the natural logarithm of rental prices observed in a symmetrical time window around the crisis' start date (9 months before and after). We define CO_2 emitting rental apartments as the treatment group (High CO_2), whereas virtually carbon-neutral apartments (CO_2 emissions ≤ 5 kg/m^2/year) form our control group (mostly heat pumps). In this regard, two possible channels might have affected our treatment and control group differently. Firstly, CO_2 emitting rental apartments were affected by the increase of ancillary cost as prices of fossil fuels rose due to the economic upturn after the COVID-19 pandemic and skyrocketed after the start of the Ukrainian/Russian conflict in February 2022.[25] In contrast, carbon-neutral apartments remained unaffected by rising fossil fuel prices due to their exclusive reliance on electricity for heat generation. For renters or households, electricity prices did not increase significantly in Switzerland until 2023 due to contractually based price mechanisms. Secondly, our treatment group might have been affected negatively by a growing preference for environmentally friendly living due to the fear of oil and gas shortages.

Two underlying requirements that have to be fulfilled to estimate this proposed difference-in-difference model validly are the parallel trends assumption and the no-anticipation effect. Our pre-trend analysis suggests that both the treatment and control groups follow a similar trend despite being on different levels in terms of rental prices, as shown in Figure 4. In this regard, we do not reject the null hypothesis of equal trends in the pre-treatment period with a *t*-statistic of −1.22 or an empirical significance level of 22.01%. In addition, we argue that Europe's energy crisis was not anticipated as it represents an exogenous shock.

Table 5 reports the results of our simple difference-in-difference specification in Equation (5). Independent of how we control for a building's quality, the estimated coefficients show meaningful and highly significant results with intuitive signs. We estimate a price difference between the treatment group and the control group of −2.83% and −8.58% before the crisis. After the crisis, these negative differences between both groups increase to the range of −4.47% and −10.17%, which is the result of a treatment effect ranging between −1.50% and −1.65%. Hence, Europe's energy crisis in 2021/2022

Panel A: Rental Predictions with Constant Inputs



Panel B: Rent Predictions with Quarterly Varying Inputs

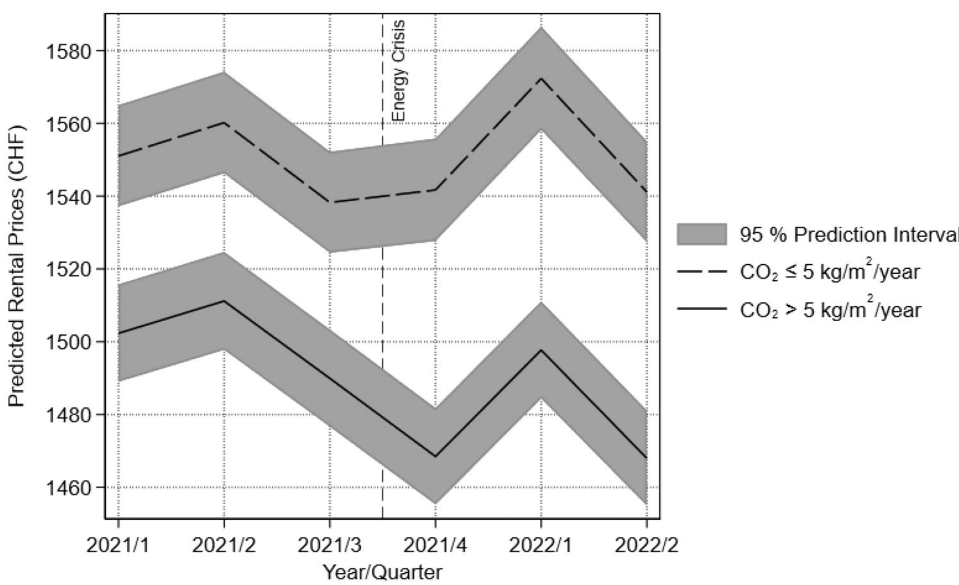


Figure 4. Difference-in-difference regression results – trend analysis of predicted rents. These graphs show predicted rental prices for an average virtually carbon-neutral apartment (CO_2 emissions ≤ 5 kg/m^2/year) and for CO_2 emitting rental apartments in light of Europe's Energy Crisis starting in October 2021. More specifically, the figures show rent predictions according to our reference specification Model (4) in a symmetrical time window around the crisis's start date (9 months before and after, quarterly level). Panel (A) keeps prediction inputs constant across all periods, whereas Panel (B) allows for varying prediction inputs over time. Panel A: Rental predictions with constant inputs. Panel B: Rent predictions with quarterly varying inputs.

Table 5. Difference-in-difference regression results – low-carbon rent premium model.

	(1) Condition	(2) Age	(3) Costs	(4) All	(5) Index
Constant	5.9063***	5.9644***	6.0919***	5.8709***	5.8711***
	(0.0135)	(0.0147)	(0.0151)	(0.0143)	(0.0144)
High CO_2	−0.0283***	−0.0858***	−0.0676***	−0.0326***	−0.0352***
	(0.0031)	(0.0031)	(0.0031)	(0.0031)	(0.0031)
Crisis	0.0124***	0.0142***	0.0132***	0.0122***	−0.0123***
	(0.0026)	(0.0027)	(0.0027)	(0.0026)	(0.0026)
Crisis*High CO_2	−0.0164***	−0.0159***	−0.0150***	−0.0163**	−0.0164
	(0.0037)	(0.0038)	(0.0038)	(0.0037)	(0.0038)
Size	0.0137***	0.0134***	0.0134***	0.0138***	0.0137***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Size2	−0.0001***	−0.0001***	−0.0001***	−0.0001***	−0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Rooms	0.0313***	0.0340***	0.0329***	0.0311***	0.0312***
	(0.0021)	(0.0021)	(0.0021)	(0.0021)	(0.0021)
Floor	0.0059***	0.0053***	0.0053***	0.0058***	0.0057***
	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)
Standard	0.0523***	0.1153***	0.1013***	0.0513***	0.0516***
	(0.0033)	(0.0031)	(0.0033)	(0.0033)	(0.0032)
Usability	0.0298***	0.0474***	0.0413***	0.0358***	0.0381***
	(0.0029)	(0.0032)	(0.0030)	(0.0030)	(0.0031)
Units	−0.0005***	−0.0004***	−0.0004***	−0.0004***	−0.0004***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Condition	0.0822***	–	–	0.0839***	–
	(0.0018)	–	–	(0.0018)	–
Building age	–	0.0001***	–	0.0003***	–
	–	(0.0000)	–	(0.0000)	–
Renovation costs	–	–	−0.0011***	−0.0010***	–
	–	–	(0.0001)	(0.0001)	–
Quality index	–	–	–	–	0.0907***
	–	–	–	–	(0.0022)
Macro location	−0.1340***	−0.1220***	−0.1306***	−0.1297***	−0.1299***
	(0.0022)	(0.0024)	(0.0023)	(0.0023)	(0.0022)
Micro location	0.0423***	0.0432***	0.0456***	0.0408***	0.0418***
	(0.0017)	(0.0017)	(0.0017)	(0.0017)	(0.0017)
Rental offer rate	−0.0133***	−0.0124***	−0.0132**	−0.0132***	−0.0131***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Minergie dummies	Yes	Yes	Yes	Yes	Yes
Cantonal dummies	Yes	Yes	Yes	Yes	Yes
Quarterly dummies	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.7874	0.7708	0.7454	0.7980	0.7880
# Obs.	29,658	29,658	29,658	29,658	29,658

This table shows regression results of simple difference-in-difference versions of our low-carbon rent premium model. Rental price observations are considered if they are signed in a symmetrical time window around the start of Europe's Energy Crisis in October 2021 (9 months before and after). Virtually carbon-neutral rental contracts (CO_2 emissions ≤ 5 kg/m^2/year) form the control group, and CO_2 emitting rental apartments are the treatment group. Model specifications differ in terms of measures of a building's quality. Model (1) includes a score for the building's condition. Model (2) considers a dwelling's age. Model (3) includes the annuity of a property's future renovation costs. Model (4) includes all three different measures individually, while Model (5) combines these three controls in a quality index. The dependent variable is the natural logarithm of the monthly net rent. HAC-robust standard errors are reported in parentheses. *** and ** denote statistical significance at the 1 and 5% level, respectively.

causally increased the low-carbon rent premium of residential buildings through the channels of increased ancillary costs and/or an aversion toward fossil heating systems.

4.4. Further Evidence from Residential Building Transactions

Shifting the focus of our analysis from rental contracts to transaction prices reveals several possible channels of how sustainability affects a residential capitalization rate, which is given by $C = r_f + r_p - g$. For a low-carbon property, the risk premium (r_p) is smaller because, e.g., regulatory and financing risks are lower, and the building's market liquidity and the preference of investors are higher.[26] The risk premium is also reduced by a lower vacancy rate which, implies a higher stability of monthly cash flows (low-carbon residential buildings attract more potential tenants). Furthermore, investors can expect a higher rent growth (g) for sustainable residential buildings due to tenants' higher willingness-to-pay.

As a consequence, we expect residential buildings with lower CO_2 emissions to have lower capitalization rates. Therefore, we replace the natural logarithm of monthly net rents in Equation (4) with transactions' capitalization rates C_i and obtain a low-carbon cap rate premium model:

$$ln(C_i) = \beta_0 + \beta_1 CO_2 \text{ Emissions} + \Psi_i X_i + \epsilon \quad \text{with } \epsilon \sim \mathcal{N}\left(0, \sigma^2\right). \tag{6}$$

To estimate the low-carbon cap rate premium according to Equation (6), we collect a detailed transaction dataset on Swiss residential buildings and investigate capitalization rates of 611 transactions.[27] These Swiss investment properties with a residential income share of at least 60% have been traded between the beginning of 2017 and 2023. Only transactions of apartment buildings that changed hands in a private transaction are considered. Portfolio transfers are excluded. CO_2 emissions on the property level are again quantified by the CO_2 calculator of Wüest Partner AG. Due to differences in data availability, the set of control variables is smaller.[28] In Appendix B, Table B.2 presents descriptive statistics on our dataset on Swiss capitalization rates, while Table B.3 lists pairwise correlation coefficients.

Consequently, estimating this model in various specifications to differently control for a building's quality results in mostly statistically significant coefficients of CO_2 emissions, which are summarized in Table 6. Full regression results can be found in Table B.4 of the Appendix. A decrease of 1 kg/m^2/year of dwelling's CO_2 emissions yields an average decrease of −0.0025 to −0.0033 percentage points of a property's capitalization rate. This effect accumulates to −0.0550 to −0.0726 percentage points if an average fossil-fueled residential building with 27 kg/m^2/year of CO_2 emissions (in our dataset on Swiss capitalization rates) goes low-carbon by installing a heat pump and cutting emission by 22 kg/m^2/year. Since the average capitalization rate in our dataset is 2.82%, the low-carbon cap rate premium alone increases market prices by 1.94–2.56% in the case of a building that installs a heat pump.[29]

Regarding economic significance, the low-carbon cap rate premium seems small. However, when a residential building goes green, not only will associated risks change (reflected by the capitalization rate) but also its rental income will increase due to the low-carbon rent premium. Combining these two effects for our reference specification in Model (4) results in an overall increase in the market value of a typical residential building of 6.28% if it replaces a fossil heating system with a heat pump. 4.18 percentage points are due to the low-carbon rent premium (Section 4.1), and 2.10 percentage points are due to the low-carbon cap rate premium. Consequently, residential properties whose operation emits less CO_2 emissions due to a heat pump installation are, on average, more valuable than identical properties heated with fossil fuel.

Table 6. Coefficients of CO_2 emissions – low-carbon cap rate premium model.

	(1) Condition	(2) Age	(3) Costs	(4) All	(5) Index
CO_2 emissions	0.0025**	0.0025*	0.0032***	0.0027**	0.0033***
	(0.0012)	(0.0013)	(0.0013)	(0.0012)	(0.0012)
Control variables	Yes	Yes	Yes	Yes	Yes
Cantonal dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.5654	0.5651	0.5867	0.5889	0.5680
# Obs.	611	611	611	611	611

This table shows estimated coefficients of a property's CO_2 emissions for five different specifications of the low-carbon cap rate premium model. These specifications differ in terms of measures of a building's state. Model (1) includes a score for the building's condition. Model (2) considers a dwelling's age. Model (3) includes the annuity of a property's future renovation costs. Model (4) includes all three different measures individually, while Model (5) combines these three controls in a quality index. The dependent variable is the properties' capitalization rate in %. HAC-robust standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10% levels.

This appreciation of a building's market value, caused by higher rents and lower capitalization rates, offsets, on average, the higher investment costs associated with adopting low-carbon solutions. For example, the installation of new oil and gas heating systems incurs average costs of CHF 1,300 and CHF 1,200 per apartment, respectively. In contrast, switching to a heat pump generates higher investment costs. Costs for a heat pump with an air-water heat exchanger amount to around CHF 9,300, and a brine-water heat pump with a geothermal probe costs approximately CHF 14,300 per apartment in an average residential building.[30]

5. Conclusion

The operation of residential real estate accounts for a large part of worldwide greenhouse gas emissions and has to become more sustainable to contribute to countries' net-zero targets in the future. To measure the effect of going green, we analyze 96,200 rental contracts from 2,653 residential properties in Switzerland and study how a property's CO_2 emissions are related to apartment net rents. More specifically, we use a novel measure to quantify operational carbon emissions by utilizing various parameters on the sustainability and energy efficiency of a building as well as the climate conditions of its location.

After controlling for a building's quality, its macro and micro location, local rental market conditions, green building certification, and various property or apartment characteristics in an extensive hedonic framework, our results suggest that apartments in low-carbon buildings have higher net rents compared to identical dwellings that emit more carbon emissions. From the tenants' point of view, this higher willingness-to-pay is correlated with ancillary cost savings when living in a sustainable property. Moreover, we point out that the low-carbon rent premium is also related to a tenant's higher preference for living in an environmentally friendly apartment. Sample splits across urban and rural regions, warm and cold locations, as well as areas with a high or low share of people supporting a Federal Act for the Reduction of Greenhouse Gas Emissions, confirm these results. In light of Europe's energy crisis, we further document a causal increase in our main effect by carrying out simple difference-in-difference regressions. Additionally, based on capitalization rates from 611 transactions, we suggest that the market value is, on average, higher for low-carbon residential properties due to lower expected risk premiums, but also due to higher rental income.

Our findings have interesting implications for policymakers, real estate professionals, and the academic debate on sustainable real estate. Firstly, while relying on individuals' sustainable behavior can contribute to achieving climate goals, policymakers must recognize that it is not a standalone solution. Market intervention mechanisms, such as CO_2 taxes, are crucial instruments for inducing a transition toward a more sustainable residential real estate market. However, policies shall consider potential adverse impacts on low-income households and prevent the low-carbon rent premium from disproportionately affecting those in affordable rental apartments. Additionally, policymakers should carefully evaluate incentives for sustainable housing, acknowledging that higher market values of low-carbon buildings compensate investors for reducing carbon emissions. Secondly, for real estate professionals, our findings highlight the importance of incorporating the lower-risk premium associated with lower-carbon residential properties into valuation models. Furthermore, our results suggest that acquiring brown residential buildings and investing in reducing their carbon emissions can generate significant investment returns. Thirdly, in the academic debate, our approach provides a more accurate and nuanced understanding of the relationship between CO_2 emissions and residential rents as well as prices compared to binary variables like green certificates.

Notes

1. The Swiss Federal Council decided that Switzerland should become climate neutral by 2050. Hence, by 2050, Switzerland should not emit more greenhouse gases than natural and technical storage can absorb.
2. Ancillary costs in Swiss rental properties are additional charges that tenants must pay on top of their net rent, covering expenses such as heating, water consumption, and others (see Section 3.1).
3. During the last decades, mandatory government regulation and voluntary industry standards have emerged with its main objective to reduce information asymmetries on building's degree of energy efficiency and sustainability between landlords (investors) and tenants (occupiers) or sellers and buyers, respectively. Mandatory approaches include the European Union's Directive on the Energy Performance of Buildings in 2003 while market-based approaches and certificates are the Leadership in Energy and Environmental Design (USA), Energy Star (USA), Green Globes (USA) as well as the Building Research Establishment Environmental Assessment Method (UK).
4. Salvi et al. (2010) find the willingness to bear the extra costs in terms of energy-efficient homes is mainly related to income levels in Switzerland.
5. Survey-based studies of Amecke (2012) and Murphy (2014) support these empirical findings. Both authors state that only a small number of households consider energy labels when buying a home and that certificates are not helpful in understanding the implications of energy efficiency.
6. This high proportion of renters is partly due to strict mortgage lending criteria and high property prices, making homeownership challenging for many Swiss residents, especially in urban or touristic areas where property prices are the highest.
7. In Switzerland, the costs of fossil heating are mostly based on current market prices. In contrast, electricity prices are contractually binding for each calendar year. The costs of fossil heating include a CO_2 tax of CHF 120 per ton CO_2.
8. All buildings in our dataset are valuation mandates of Wüest Partner AG that are either appraised on a quarterly, semi-annual, or yearly level based on the size and type of the

institutional investor. Wüest Partner AG is one of the largest real estate consultancies in Switzerland, which serves a broad spectrum of institutional clients.

9. Residential buildings with both fossil heating and a heat pump are not included in the dataset. Buildings with other types of heat generators (wood, coal, district heating, etc.) are not included. For example, it is difficult to model the CO_2 emissions of buildings heated with district heating as carbon emissions depend highly on the type of energy source used to feed the district heating network (some include fossil fuels during peak times).
10. The dataset spans the COVID-19 pandemic due to the special nature of the rental market during the pandemic. Balemi et al. (2021) summarize multiple studies and highlight that the residential rental market was relatively unaffected by the pandemic due to economic support measures for individuals or households. Dubler et al. (2021) shift their focus to Switzerland and highlight stable rental income for investors in residential real estate during the pandemic. Nevertheless, we include quarterly dummies in our model specifications to control for macroeconomic effects and shocks such as the COVID-19 pandemic.
11. We do not include gray energy due to two reasons. Firstly, the CO_2 emissions caused by the operation of real estate are mainly considered by investors and tenants, while a property's embodied energy is currently less present. Secondly, there is still hardly any comprehensive data on gray energy.
12. In general and also in Switzerland, heat pumps are more likely to be installed in newer properties. However, improved heat pump technology also allows for installation in older buildings with sufficient insulation, likely increasing the number of older buildings with heat pumps over our sample period. To address the concern about the correlation between building age, heat pump installation, and CO_2 emissions, we emphasize that buildings with heat pumps are not considered carbon-neutral per se (Appendix A). By including building age as a control variable in our regression analysis, we can also more confidently attribute the low-carbon rent premium to the energy efficiency and sustainability of the properties rather than solely to the presence of heat pumps in newer buildings.
13. Electricity production in Switzerland is mostly based on hydro and nuclear power. However, due to international electricity trade, 2% of the electricity consumption in Switzerland is based on fossil fuels (Swiss Federal Office of Energy (2023).
14. A high annualized cash flow of future repairs signals that a lot of repairs have to be made in the future and that the actual quality of the property is probably bad.
15. Other variables providing information about the quality of a property (e.g., the renovation year of individual components such as facades, windows, or basement ceilings) are not included in this index as these characteristics are already incorporated in the modeling of a building's carbon emissions.
16. Swiss Minergie labels have three categories. Minergie is the basic certification for energy-efficient buildings, requiring 20-25% better performance than conventional properties. Minergie-P represents the highest energy efficiency standard, requiring superior insulation and a maximum heating demand of 15 $kWh/m^2/year$. Minergie-A labels are awarded to buildings that achieve net-zero energy balance, producing as much energy as they consume through renewable sources like solar panels and heat pumps.
17. As highlighted by Stutzer and Lalive (2004), Swiss citizens are used to expressing their opinions at the poll. The direct democratic decision-making process is very common in Switzerland at municipal, cantonal, as well as national levels. The voter turnout in these votes and elections typically varies strongly across cantons. Urban municipalities usually exhibit lower voter turnouts.
18. In a previous version of this paper, we estimate the low-carbon rent premium without dummies for green building certificates (Minergie). In the estimation with dummies for green building certificates, we receive lower absolute coefficients for CO_2 emissions than in the estimation without these dummies, which indicates that by controlling for green building certificates, we can assume that our main estimate is not diluted by a green building signaling effect. The correlation between CO_2 emissions and the Minergie certificate is -0.07 according to Table 2.

19. As outlined in Appendix A, the building age, overall number of units, building standard, and heating degree days are also included in the calculation of a building's CO_2 emissions. These carbon emissions are defined as the product of final energy consumption and the emission factor in a physics-based rather than a model-based (such as regression analysis) approach. Hence, to calculate the first term (final energy consumption), we use physical attributes to determine a physical outcome, considering factors such as heat losses and solar and internal heat gains. The final energy consumption is then translated into CO_2 emissions by multiplication with the regional emission factor.
20. Other non-linear specifications of our low-carbon rent premium model did not yield significant and/or meaningful results. More specifically, fitting a negative root function or polynomial regression up to the 4th degree significantly underperformed our linear version of Equation (4).
21. Although the exact quantity of an apartment's operational CO_2 emissions is unknown, tenants are able to make assumptions about the apartment's operational carbon emissions by the property's heating system, condition, and green building certificate. In general, this information is provided by the real estate agent or given in the apartment advertisement.
22. To better understand these independent sample splits: 70.5% in the High Yes-% sub-sample can also be found in the urban sub-sample, whereas 68.7% of the Cold sub-sample are urban observations. Furthermore, 34.1% of cold observations can be found in the High Yes-% sub-sample.
23. We document a lower proportion (4.7%) of properties with heat pumps in our Warm sub-sample. In contrast, 10.7% of residential properties in our Cold sub-sample are equipped with a heat pump. This difference underlines the lower potential of ancillary cost savings in warmer regions.
24. These findings are in line with Füss et al. (2023), who use a similar differential based on municipal voting results in Switzerland to analyze externalities of going green (installing photovoltaic systems) on apartment net rents.
25. According to the Swiss Federal Statistical Office (2023), average gas prices (per month) in Switzerland peaked at CHF 0.1382 per kWh in June 2022 (43% price increase compared to pre-crisis levels) during the crisis. Furthermore, average monthly oil prices reached an all-time high of CHF 169.81 per 100 liters in June 2022 (72% price increase compared to pre-crisis levels).
26. In Switzerland, for example, investors are reluctant to invest in fossil-fuel-heated properties as the environmental taxonomy is steadily gaining importance. Low-carbon residential buildings may have better prospects for cheap financing with Swiss commercial banks.
27. By using effectively applied discount rates from real transactions, we avoid an appraiser's subjective assessment falsifying our results.
28. In particular, information on green building certificates (Minergie) is not available.
29. The market value increase of a property with a new heat pump is calculated by dividing the accumulated low-carbon cap premium of 0.0550 or 0.0726 percentage points by the average capitalization rate.
30. We do not consider public subsidies or funding for going green and installing a heat pump. Additional costs that may arise when installing a heat pump, for example, by switching from radiators to underfloor heating or any costs for additional insulation measures, are also not included.

Acknowledgments

The authors are grateful to the editor, Michael Seiler, and the two anonymous referees for valuable suggestions that have significantly improved the article. We are also indebted to Jon Olaf Olaussen, Are Oust, Ole Jakob Sønstebø, and participants at the 2023 NTNU Business School Conference, the 2023 GPEF Poster Seminar at the University of St.Gallen, as well as the 2022 AsRES-AREUEA Joint Conference. Furthermore, we thank Wüest Partner AG for providing us with data on CO_2 emissions as well as detailed data on rental contracts and real estate transactions.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

ORCID

Angelika Brändle http://orcid.org/0000-0002-9085-6560
Roland Füss http://orcid.org/0000-0002-3050-2621
Alois Weigand http://orcid.org/0000-0003-4679-3619

References

Amecke, H. (2012). The impact of energy performance certificates: A survey of German home owners. *Energy Policy*, *46*, 4–14. https://doi.org/10.1016/j.enpol.2012.01.064

Balemi, N., Füss, R., & Weigand, A. (2021). COVID-19's impact on real estate markets: Review and outlook. *Financial Markets and Portfolio Management*, *35*(4), 495–513. https://doi.org/10.1007/s11408-021-00384-6

Brolinson, B., Palmer, K., & Walls, M. (2023). Does energy star certification reduce energy use in commercial buildings? *Journal of the Association of Environmental and Resource Economists*, *10*(1), 55–93. https://doi.org/10.1086/720952

Brounen, D., & Kok, N. (2011). On the economics of energy labels in the housing market. *Journal of Environmental Economics and Management*, *62*(2), 166–179. https://doi.org/10.1016/j.jeem.2010.11.006

Brounen, D., Kok, N., & Quigley, J. (2012). Residential energy use and conservation: Economics and demographics. *European Economic Review*, *56*(5), 931–945. https://doi.org/10.1016/j.euroecorev.2012.02.007

Cajias, M., & Piazolo, D. (2013). Green performs better: Energy efficiency and financial return on buildings. *Journal of Corporate Real Estate*, *15*(1), 53–72. https://doi.org/10.1108/JCRE-12-2012-0031

Chegut, A., Eichholtz, P., & Kok, N. (2014). Supply, demand and the value of green buildings. *Urban Studies*, *51*(1), 22–43. https://doi.org/10.1177/0042098013484526

Das, P., Tidwell, A., & Ziobrowski, A. (2011). Dynamics of green rentals over market cycles: Evidence from commercial office properties in San Francisco and Washington DC. *Journal of Sustainable Real Estate*, *3*(1), 1–22. https://doi.org/10.1080/10835547.2011.12091814

Dubler, G., Füss, R., & Weigand, A. (2021). *Corona lässt Schweizer Betongold bröckeln* (pp. 14–16). Schweizer Monat.

Eichholtz, P., Kok, N., & Quigley, J. (2010). Doing well by doing good? Green Office Buildings. American Economic Review, 100(5), 2492–2509.

Eichholtz, P., Kok, N., & Quigley, J. (2013). The economics of green building. *Review of Economics and Statistics*, *95*(1), 50–63. https://doi.org/10.1162/REST_a_00291

Eichholtz, P., Kok, N., & Quigley, J. (2016). Ecological responsiveness and corporate real estate. *Business & Society*, *55*(3), 330–360. https://doi.org/10.1177/0007650315575118

Federal Ministry for the Environment. (2024). *Kenngrössen zur Entwicklung der Treibhausgasemissionen in der Schweiz 1990–2022*. Schweizerische Eidgenossenschaft.

Fuerst, F., & McAllister, P. (2011). Green Noise or Green Value? Measuring the Effects of Environmental Certification on Office Values. *Real Estate Economics*, *39*(1), 45–69. https://doi.org/10.1111/j.1540-6229.2010.00286.x

Fuerst, F., McAllister, P., Nanda, A., & Wyatt, P. (2015). Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England. *Energy Economics*, *48*, 145–156. https://doi.org/10.1016/j.eneco.2014.12.012

Füss, R., Kürschner Rauck, K., & Weigand, A. (2023). *Housing price externalities of photovoltaic systems: The relevance of view* (Discussion Paper 23-100). Swiss Finance Institute Research Paper.

Galimshina, A., Moustapha, M., Hollberg, A., Padey, P., Lasvaux, S., Sudret, B., & Habert, G. (2020). Statistical method to identify robust building renovation choices for environmental and economic performance. *Building and Environment*, *183*, 107143. https://doi.org/10.1016/j.buildenv.2020.107143

Hyland, M., Lyons, R., & Lyons, S. (2013). The value of domestic building energy efficiency-evidence from Ireland. *Energy Economics*, *40*, 943–952. https://doi.org/10.1016/j.eneco.2013.07.020

Jensen, O., Hansen, A. R., & Kragh, J. (2016). Market response to the public display of energy performance rating at property sales. *Energy Policy*, *93*, 229–235. https://doi.org/10.1016/j.enpol.2016.02.029

Kahn, M., & Kok, N. (2014). The capitalization of green labels in the California housing market. *Regional Science and Urban Economics*, *47*, 25–34. https://doi.org/10.1016/j.regsciurbeco.2013.07.001

Kahn, M., & Vaughn, R. (2009). Green market geography: The spatial clustering of hybrid vehicles and LEED registered buildings. *BE Journal of Economic Analysis & Policy*, *9*(2), 1–22.

Kempf, C., & Syz, J. (2022). Why pay for sustainable housing? Decomposing the green premium of the residential property market in the Canton of Zurich, Switzerland. *SN Business & Economics*, *2*(11), 170. https://doi.org/10.1007/s43546-022-00346-8

Kok, N., McGraw, M., & Quigley, J. (2011). The diffusion of energy efficiency in building. *American Economic Review*, *101*(3), 77–82. https://doi.org/10.1257/aer.101.3.77

Malpezzi, S. (2002). Hedonic pricing models: A selective and applied review. In T. O'Sullivan & K. Gibb (Eds.), *Housing economics and public policy: Essays in honor of Duncan Maclennan* (pp. 67–89). Blackwell Science.

McConnell, K. (1990). Models for referendum data: The structure of discrete choice models for contingent valuation. *Journal of Environmental Economics and Management*, *18*(1), 19–34. https://doi.org/10.1016/0095-0696(90)90049-5

McCord, M., McCord, J., Davis, P., Haran, M., & Squires, G. (2024). Do private rental tenants pay for energy efficiency?: The dynamics of green premiums and brown discounts. *Journal of Property Research*, *41*(3), 251–275. https://doi.org/10.1080/09599916.2024.2349293

Murphy, L. (2014). The influence of the energy performance certificate: The Dutch case. *Energy Policy*, *67*, 664–672. https://doi.org/10.1016/j.enpol.2013.11.054

Reichardt, A., Fuerst, F., Rottke, N., & Zietz, J. (2012). Sustainable building certification and the rent premium: A panel data approach. *Journal of Real Estate Research*, *34*(1), 99–126. https://doi.org/10.1080/10835547.2012.12091325

Rosen, S. (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. *Journal of Political Economy*, *82*(1), 34–55. https://doi.org/10.1086/260169

Salvi, M., Horehájová, A., & Syz, J. (2010). *Are households willing-to-pay for green buildings? An empirical study of the Swiss Minergie Label* (working paper). European Real Estate Society.

Stutzer, A., & Lalive, R. (2004). The role of social work norms in job searching and subjective well-being. *Journal of the European Economic Association*, *2*(4), 696–719. https://doi.org/10.1162/1542476041423331

Swiss Federal Office of Energy. (2023). *Cockpit Stromkennzeichnung 2022 - Elektrizitätsstatistik*. Schweizerische Eidgenossenschaft.

Swiss Federal Statistical Office. (2023). *Landesindex der Konsumentenpreise - Durschnittspreise der Energie*. Schweizerische Eidgenossenschaft.

Swiss Federal Statistical Office. (2024). *Wohnungen - Mietwohnungen. Schweizerische Eidgenossenschaft*.

Walker, L., Hischier, I., & Schlueter, A. (2022). The impact of modeling assumptions on retrofit decision-making for low-carbon buildings. *Building and Environment*, *226*, 109683. https://doi.org/10.1016/j.buildenv.2022.109683

Whitehead, J. (1995). Willingness to pay for quality improvements: Comparative statics and interpretation of contingent valuation results. *Land Economics*, *71*(2), 207–215. https://doi.org/10.2307/3146501

Wiley, J., Benefield, J., & Johnson, K. (2010). Green design and the market for commercial office space. *Journal of Real Estate Finance and Economics*, *41*(2), 228–243. https://doi.org/10.1007/s11146-008-9142-2

Yoshida, J., & Sugiura, A. (2015). The effects of multiple green factors on condominium prices. *Journal of Real Estate Finance and Economics*, *50*(3), 412–437. https://doi.org/10.1007/s11146-014-9462-3

Zheng, S., Wu, J., Kahn, M. E., & Deng, Y. (2012). The nascent market for "green" real estate in Beijing. *European Economic Review*, *56*(5), 974–984. https://doi.org/10.1016/j.euroecorev.2012.02.012

Appendix A
Modeling CO_2 emissions

To quantify a residential building's CO_2 emissions, our analysis relies on the CO_2 calculator of independent real estate consultancy Wüest Partner AG.* This estimation procedure is designed to provide reliable estimates of operational greenhouse gas emissions for commercial or residential buildings, even with limited input data. At its core, the calculator uses a physics-based model enriched with empirical factors to simulate a building's energy demand and subsequent emissions. The fundamental approach of modeling a building's CO_2 emissions can summarized as:

$$CO_2 \text{ Emissions} = \text{Final Energy Consumption} * \text{Emission Factor}$$

In the first step, the calculator estimates the building's energy demand, which will be converted to the final energy consumption by accounting for the efficiency of the building's energy systems. The process requires the following set of mandatory input parameters to start the simulation:

- Year of construction
- Building location (exact geo-coordinates)
- Building area and area type (Energy Reference Area)
- Number of heated floors
- Use type(s) of the building (including area shares if multiple types)
- Heating system(s) and energy carrier(s) with their respective shares

For space heating, the energy simulation follows the Swiss Heating Demand Standard (SIA 380/1:2016), employing a quasi-static single-zone approach, which is evaluated monthly. This procedure considers heat losses through transmission and ventilation, as well as solar and internal heat gains.† The domestic hot water consumption is estimated using benchmarks from the Swiss Thermal Energy In Building Construction Standard (SIA 380/1:2009), while electricity demand for appliances, lighting, and other systems is based on the Swiss Standard of Space Usage Data for Energy and Building Technology (SIA 2024:2021). To enhance the estimation accuracy, additional optional inputs can be included in the CO_2 modeling:

- Refurbishment year and details
- Specific U-values for building elements
- Window properties (g-value, frame fraction)
- Shading factors
- Ventilation type and heat recovery efficiency
- Building system efficiencies

In the second step, emission factors are applied to the final energy consumption to determine the building's CO_2 emissions. Emission factors vary based on regional specifics, particularly for electricity, which depends on the local energy mix. Hence, the carbon emissions used in our analysis are reported according to the Greenhouse Gas Protocol (Scope 2) and the Carbon Risk Real Estate Monitor whole-building approach.

A key strength of the calculator is the ability to work with limited data. When specific building parameters are not provided, benchmark values based on the building's construction period and region are used. This allows for quick assessments of large portfolios or buildings with incomplete data. However, naturally, more detailed inputs lead to more accurate results. In this regard, a full set of input variables (mandatory and optional) leads to an estimation with a mean relative deviation of 18% regarding carbon emissions based on actual energy demand (Scope 2) tested on a sample with complete data for 148 buildings, 108 residential and 40 office buildings. If only mandatory inputs are considered, the mean relative deviation increases to 40% in this testing sample.

Moreover, the simulation of carbon emissions has been checked against benchmarks and official energy performance certificates in Switzerland.

*The basic foundation of the CO_2 calculator was laid during the Swiss Greenhouse Gas Inventory as well as the Paris Agreement Capital Transition Assessment in 2020.

†In previous research, similar model configurations are applied (for example, in Walker et al. (2022) or in Galimshina et al. (2020)).

Appendix B
Additional analysis

Table B.1. Equality tests of sample split results - low-carbon rent premium model.

	(1) Urban	(2) Rural	(3) Warm	(4) Cold	(5) High Yes-%	(6) Low Yes-%
Constant	5.8057***	6.0803***	5.5476***	5.9135***	5.7889***	6.1215***
	(0.0139)	(0.0804)	(0.0266)	(0.0214)	(0.0267)	(0.0221)
|△|	0.2746***		0.3659**		0.3326***	
	[3.3649]		[10.6860]		[9.5703]	
CO_2 emissions	−0.0020***	−0.0042***	−0.0005**	−0.0033***	−0.0022***	−0.0009***
	(0.0001)	(0.0004)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
|△|	0.0022***		0.0028***		0.0013***	
	[5.2175]		[12.9139]		[5.6626]	

This table tests differences in estimated constants and slope coefficient for CO_2 emissions in our low-carbon rent premium model across different sample splits (Table 4). |△| denotes the absolute difference between respective estimates. HAC-robust standard errors are reported in parentheses. *t*-Statistics are reported in square brackets. ***, **, and * denote statistical significance at the 1, 5, and 10% levels.

Table B.2. Descriptive statistics – capitalization rates.

	Granularity	Mean	S.D.	Min	Max
Capitalization rate (%)	PL	2.8221	0.4943	1.4887	4.6708
CO_2 emissions (kg/m^2/year)	PL	26.6531	13.6225	3.4353	84.5061
Rentable area (m^2)	PL	1546.7330	546.2631	247.0061	19285.3303
⌀ term rental contracts	PL	6.3047	5.8000	0.0000	28.5187
Standard (score)	PL	3.2093	0.4339	1.5000	4.7000
Usability (score)	PL	3.3236	0.4043	1.8000	4.8000
Condition (score)	PL	3.4584	0.7712	1.5000	5.0000
Building age (in years)	PL	46.4860	21.9723	0.0000	70.0000
Renovation costs (per m^2)	PL	44.5790	19.6569	13.4760	118.0470
Quality index (score)	PL	3.8133	0.7423	2.3488	5.6110
Macro location (score)	ML	1.9149	0.7738	1.0000	4.7000
Micro location (score)	PL	3.5471	0.5525	1.7000	5.0000

This table shows descriptive statistics for the dataset on Swiss capitalization rates (sample period: April 2015 to October 2023). The mean, standard deviation (S.D.), as well as minimum and maximum values are listed. Each transaction can be linked to one of 2,172 Swiss municipalities and one of 26 Swiss Cantons, as well as to one of 9 postal regions. Furthermore, communes can be categorized as urban, sub-urban, or rural municipalities. Transaction dates are available. All variables are available at the property level (PL) or municipality level (ML).

Table B.3. Correlation matrix – capitalization rates.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) Capitalization rate	1											
(2) CO_2 emissions	0.02	1										
(3) Rentable area	0.00	−0.33	1									
(4) ⊘ term rental contracts	−0.14	0.18	0.14	1								
(5) Standard	−0.07	−0.48	0.13	−0.19	1							
(6) Usability	−0.06	−0.38	0.15	−0.09	0.62	1						
(7) Condition	0.08	−0.52	0.01	−0.40	0.65	0.41	1					
(8) Building age	−0.19	0.53	−0.24	0.25	−0.41	−0.43	−0.47	1				
(9) Renovation costs	−0.31	0.37	−0.07	0.40	−0.40	−0.22	−0.67	0.41	1			
(10) Quality index	0.18	−0.60	0.08	−0.44	0.62	0.43	0.90	−0.72	−0.77	1		
(11) Macro location	0.50	−0.17	0.08	−0.15	0.06	0.03	0.20	−0.41	−0.29	0.33	1	
(12) Micro location	−0.20	−0.04	−0.04	−0.04	0.18	0.14	0.03	0.13	0.05	−0.04	−0.25	1

This table reports the pairwise correlation coefficient (Bravais-Pearson) of all main variables in the dataset on Swiss capitalization rates. Dummy variables or location identifiers are not included. All reported correlation coefficients are at least significant at a 10% level.

Table B.4. Regression results – low-carbon cap rate premium model.

	(1)	(2)	(3)	(4)	(5)
	Condition	Age	Costs	All	Index
Constant	2.5991***	2.7115***	2.9544***	3.1034***	2.4752***
	(0.2547)	(0.2844)	(0.2481)	(0.2790)	(0.2551)
CO_2 emissions	0.0025**	0.0025*	0.0032***	0.0027**	0.0033***
	(0.0012)	(0.0013)	(0.0013)	(0.0012)	(0.0012)
Rentable area (*ln*)	−0.0015	−0.0060	−0.0020	−0.0121	−0.0010
	(0.0232)	(0.0233)	(0.0221)	(0.0232)	(0.0227)
⊘ term rental contracts	−0.0059*	−0.0063**	−0.0025	−0.0035	0.0046*
	(0.0027)	(0.0026)	(0.0026)	(0.0027)	(0.0028)
Standard	−0.0532	−0.0350	−0.0994**	0.0544	−0.0739
	(0.0534)	(0.0470)	(0.0466)	(0.0732)	(0.0514)
Usability	−0.0120	−0.0185	0.0012	0.0264	−0.0182
	(0.0419)	(0.0442)	(0.0414)	(0.0597)	(0.0420)
Condition	0.0233	–	–	−0.0844***	–
	(0.0274)	–	–	(0.0291)	–
Building age	–	−0.0005	–	−0.0001	–
	–	(0.0010)	–	(0.0009)	–
Renovation costs	–	–	−0.0046***	−0.0057***	–
	–	–	(0.0007)	(0.0009)	–
Quality index	–	–	–	–	0.0636**
	–	–	–	–	(0.0294)
Macro location	0.2319***	0.2276***	0.2193***	0.2192***	0.2212***
	(0.0291)	(0.0318)	(0.0287)	(0.0309)	(0.0301)
Micro location	−0.0316	−0.0313	−0.0197	−0.0266	−0.0268
	(0.0251)	(0.0254)	(0.0247)	(0.0246)	(0.0249)
Cantonal dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.5654	0.5651	0.5867	0.5889	0.5680
# obs.	611	611	611	611	611

This table shows linear regression results for five different specifications of the low-carbon cap rate premium model. These specifications differ in terms of measures of a building's state. Model (1) includes a score for the building's condition. Model (2) considers a dwelling's age. Model (3) includes the annuity of a property's future renovation costs. Model (4) includes all three different measures individually, while Model (5) combines these three controls in a quality index. The dependent variable is the property's capitalization rate in %. HAC-robust standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10% levels.