Does energy retrofitting pay off? An analysis of German multifamily building data

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Abstract. Several studies have investigated the relationship between the energy performance of buildings and housing prices. First, this paper identifies a price premium for energy efficiency within the German rental market. Then, the generated price differences and associated marginal benefits are compared to the marginal costs of energy retrofits. An extensive database of Germany's largest online platform for housing over a time span from 2016 to 2020 is used in a hedonic regression approach. Additionally, to extract the marginal costs of energy consumption abatement, a dataset of 1,048 rental units regarding green-retrofit measures is utilized. While a significant green premium is identified in the rental market, the findings suggest that it is not high enough to compensate landlords for the money they have to spend to retrofit. The marginal costs exceed the marginal benefits by far. Furthermore, it is found that the German government's recent plans to split the CO₂ tax between landlords and tenants does not change this because the price per metric ton of carbon is insufficiently high. The findings can help both tenants and landlords in their decision-making, as well as policy makers in the implementation of decarbonization efforts.

Keywords: Energy Performance Certificates, Hedonic Pricing Model, Generalized Additive Model, Economic viability, Marginal Cost

1. Introduction
For Germany, the rented residential building stock plays an outstandingly important role for climate impact reduction in comparison to other European countries, as the homeownership rate is below 50% and thus the lowest in the Eurozone [1]. In contrast to owner-occupied dwellings, there is a problem with the energy efficient renovation of rented buildings that is frequently mentioned in the literature: The Split Incentive Problem or Landlord-Tenant Dilemma [2]. This dilemma is indeed an obstacle to the renovation of many rented buildings. While one party, the landlord, must invest the costs of a retrofit, he cannot benefit directly from the advantages this investment brings. The tenant, on the other hand, benefits directly from the energy renovation, as he faces lower heating costs and enjoys improved thermal comfort after a retrofit. Consequently, from a landlord’s perspective, there must be another channel to compensate him for the investment or he would not retrofit his property in the first place.

At the beginning of 2021, a uniform CO₂ tax was introduced on fuels for heat generation, which is levied on the heating costs. The costs for the CO₂ tax were intended to be shared equally between tenants and landlords, but this ruling was overturned just before it was passed because one of the governing parties at the time voted against it, so that for the time being, 100% of the tax burden is borne by the tenant. In the near future however, another aspect that could increase the benefit of lower energy consumption of an apartment from the landlord’s perspective are tax savings. This is the case because
the new German government recently announced that the carbon tax burden will be split between landlords and tenants [3].

This paper analyses how energy performance is transferred to the rent of an apartment or a house and tests how and if green premia are present. To do so, an extensive dataset of rental listings in Germany is examined, wherein the energetic conditions from Energy Performance Certificates (EPC) is utilized as central exogenic variables. In addition, a dataset with energy modernization data of multi-family houses in Germany is used to calculate marginal costs for energetic improvements in the context of building renovation. The central research question of the present study is threefold. The first part explores the question of whether, in the German market for rented apartments in multi-family buildings, there is a price premium for energy efficiency (green premium). This evaluation has already been carried out several times, which is reflected in the literature section. Provided that a price premium is indeed found, the subsequent research-focus is on whether the rent increase potential from an improvement in energy efficiency is sufficient to offset the costs of a retrofit, over the expected useful life of the asset. The question of whether retrofit measures pay off from an economic point of view has to the best of our knowledge not yet been investigated regarding new lettings. Therefore, this paper establishes the connection between these two components discussed above. Hence, the costs of retrofit measures are analyzed in relation to the expected higher rent for a new tenancy. If performing retrofits is not beneficial on an aggregate level, it is necessary to investigate whether the current and upcoming regulatory framework in Germany provides sufficient incentives for the implementation of an increased volume energy efficiency measures. As the analyzed regulation has not yet been fully implemented and there is a newly introduced split of the carbon tax between landlord and tenant, this paper provides important policy implications.

The paper is organized as follows. Section 2 introduces the theoretical background and reviews literature on the topic. In Section 3, the two datasets are described, whereas in Section 4, the methodology of both the statistical model estimation and derivation of marginal benefit and marginal cost curves is presented. The results of the hedonic pricing model as well as the derived curves, are placed in relation to each other and supplemented by the influence of the assumed future course of the CO₂ taxation in Section 5. Lastly, Section 6 concludes the paper.

2. Literature Review

Most research concerning the influence of energy efficiency on real estate prices and showing a positive influence of higher EPC ratings is primarily focused on purchase transactions [4-10]. One cannot assume that the energy efficiency effects identified on the residential sales market can be simply transferred to the rental market, as these markets differ both in the degree of formalization of disclosure of rights (e.g. involvement of real estate agents and notaries) and in the prevalence of compliance controls [11]. However, the influence of EPC ratings has also been investigated, albeit to a lesser extent, in the context of rental apartments: Cajas & Piazolo identify a green premium in the German rental market for the energy classes “B”, “C” and “D” of 13.3% (which is on average €0.47/m²), 13.5% (€0.59/m²) and 16.3% (€0.74/m²) higher rent as the reference class, the lowest energy efficiency [5]. Hyland et al. find a significant lower premium for rental apartments than for property sales [12]. Their research, for which they used rental advertisement data from Ireland, also suggests a significantly lower premium than that found by Cajas & Piazolo. For A-rated dwellings, Hyland et al. find a gain of 1.8% green premium relative to otherwise similar D rated dwellings. Dressler & Cornago find, with data for rentals in the city of Brussels, that highly energy-efficient dwellings are associated with a 4.8% rent premium when compared to low-energy-efficient dwellings, which amounts to €50 per month for the average apartment in their dataset, which has 107 m² of living space [11]. Additionally, they point out that disclosing energy-efficiency information for dwellings with intermediate energy-efficiency results in a discount, which they interpret as a strategic motivation not to disclose a dwelling’s energy performance when it is not in the top classes. Cajas et al. with a big dataset of nearly 760 thousand observations across over 400 local markets in Germany, estimated that rents for A+, A, B and C-rated rental apartments are on average 0.9%, 1.4%, 0.1% and 0.2% higher than the reference category D, whereas dwellings in the
categories below E, F, G and H are subject to rent discounts of up to -0.5% [13]. By analyzing different subsamples, Cajas et al. also demonstrate that the Top 7 real estate markets show less sensitivity to energy-efficiency, while in secondary markets, the premium is enhanced by up to 1.4% points (for A+), while discounts are also increased by up to 1.8% points. Additionally, the premiums for the A category increased over time from 0% in 2013 to 1.4% in 2017 and the brown discounts for G and H-rated apartments decreased over time. Furthermore, and in line with Fuerst et al., evidence for a negative coherence of time on the market and energy-efficiency of rental units is provided [14].

Overall, the majority of studies suggest that a green premium exists in the rental market, but that the level of this premium differs according to various factors. This present paper is part of the existing debate and aims to broaden it by comparing the efficiency gains from a retrofit with the associated marginal costs, and analyzing whether the monetary benefits justify the implementation of retrofit measures from the landlord’s perspective.

3. Data

3.1. Data on asking rents

The original unadjusted dataset comprises more than 5 million observations of rental listings from the leading online platform in Germany for housing, ImmobilienScout24, for the time span 2016 to year 2020. Data access was provided by the Research Data Centre Ruhr at the RWI – Leibniz-Institute for Economic Research (FDZ Ruhr). The dataset is identified at DOI: “10.7807/immo:red:hm:suf:v3”.

We cleared the data of implausible values such as zero or negative area, and of missing values that are required for the estimation such as energy demand per square meter. Additionally, we chose to focus our analysis on big cities with a population of more than 100 thousand in which most multifamily buildings are located. After data-clearing processes, we are left with 533,780 observations with full hedonic characteristics. The dataset contains information on rent, apartment size, energy demand per square meter, number of rooms, quality and if the features Elevator, Balcony, Guest WC, Built-in Kitchen, Garden and Cellar are applicable. The categorial variable for quality has the classifications simple, normal, sophisticated and luxury, which we include as binary variables as well as for the aforementioned equipment features. We also add two socioeconomic variables to the dataset by including the number of households in a city and the average household income. The socioeconomic data was retrieved from GfK (http://www.gfk.com). The average rent for a unit is at €751.86, the average rent per square meter is €10.89 and the average energy demand per square meter is at 118 kWh/m²a, which equals EPC D. The average apartment age is 45 years, whereby the age of the building is calculated as the difference between the year of construction and the year in which the rental listing was placed. About 1.6% of the properties are classified as simple, 49.6% as normal, 43.4% as sophisticated, and only 0.5% as luxury.

As indicated by Pearson correlation coefficients, the energy consumption and age have a clearly positive correlation, which has resulted from the tightening of energy consumption regulations for new construction over the course of time [7]. One indicator for an expected green premium is that energy consumption and rent per square meter have a negative correlation. In order to examine the relationship between energy demand and rental potential, the energy efficiency ratings, which are also called EPC bands or EPC classes, are used in addition to the absolute value per square meter. The EPC classes are not included in the data from the outset, but are calculated on the basis of the energy demand values according to German legislation. EPC rating bands are defined from class H (the worst) to class A+ (the best) in the German Building Energy Act (GEG). Accordingly, we construct a binary variable for each EPC-rating band. Most apartments in the data set are in EPC class D (24%), followed by E (18%) and C (16%) but only very small proportions of the buildings are assigned to the very upper and very lower rating bands. While the shares of the classes A+ and A are close to the share in the German building stock at 2% (A+) and 5% (A), the very lowest groups G and H are massively underrepresented. In the multi-family housing stock in Germany, their shares are around 7% (H) and 9% (G) [15], while in the data sample, they comprise only 2% (H) or 5% (G). The highest average rent is charged in class A.
(€13.78/m² p.m.), while the lowest is charged in class H (€8.82/m² p.m.). The rent differential is not constant, for example, the average monthly rent per square meter in energy efficiency class E with €9.34/m² is slightly higher than in class D with €9.27/m². Rent and energy consumption show a negative correlation coefficient of -0.26 while the correlation coefficients of the different EPC classes and the rent per square meter have changing signs. For classes A+ to C the sign is positive and from class D downwards it is negative. The range of correlations is between 0.23 and -0.09. Surprisingly, the highest or lowest correlations are not at the extreme points of the energy-efficiency classes, i.e. at A+ and H, but at B with 0.23 and at D with -0.09. Due to the correlations one would expect the presence of a green premium in the classes A+ to C.

3.2. Green Retrofit Data
The data used for this study regarding the cost of green retrofits, meaning measures to increase the energy efficiency of the building and in some cases the use of renewable energy on site and corresponding efficiency gains was collected by the General Association of the German Housing Industry (Bundesverband deutscher Wohnungs- und Immobilienunternehmen e. V.; GdW) from some housing companies and partners and kindly made available to us. The sample comprises exclusively multifamily buildings in Germany and includes observations on 1,048 residential units in 27 properties with a total of 64,519 m² of living space before and after retrofit measures. The data contains a description of the measures carried out, the year of the retrofit, renovation costs, the energy demand before and after refurbishment, and the energy consumption before and after refurbishment, whereas energy demand and consumption are included in relation to the living space. Since the EPC classes according to the GEG do not refer to the living space but to the usable space, the energy consumption and demand must be converted to this. Here, we apply the simplified conversion according to GEG § 82 para. 2, which for this purpose specifies a conversion factor of 1.2 for multi-family houses. Additionally, because the year in which the retrofit measures were carried out varies, we extrapolate costs of the retrofit to 2018, using the construction cost index for Germany provided by the German statistical office “destatis” [16] in order to make them comparable. The descriptive statistics of the data sample show that in terms of energy demand, the average value before retrofit is 236.88 kWh/m²a and 69.97 kWh/m²a afterwards. This corresponds on average to a retrofit starting from EPC class G and resulting in EPC class B. In terms of actual measured consumption, on average a refurbishment performance of 176.28 kWh/m²a to 94.39 kWh/m²a is realized, i.e. EPC band G to D. The average absolute energy saving in the energy demand is 166.91 kWh/m²a, while the actually measured saving is less than half as high at about 81.89 kWh/m²a.

Regarding Pearson correlation coefficients for the retrofit data it can be noted that the cost of retrofit per square meter correlates negatively with both the number of housing units and the total usable space in the building, implying that the average cost of retrofit decreases with the size of the building and that economies of scale may be achieved accordingly. However, positive correlation coefficients of the costs with the initial state before renovation in kWh/m²a and the additional state afterwards are particularly noteworthy. This indicates rising marginal costs of retrofitting with increasing energetic performance.

4. Methods
4.1. Hedonic Pricing and Generalized Additive Model
The econometric approach to examining whether higher or lower energy consumption in rental multifamily housing is associated with a significant price premium involves two steps. Our first step is to estimate a hedonic pricing model (HPM), as empirically justified by Sirmans et al., which is the standard methodology for examining value determinants in housing [17]. The baseline model is specified as follows:

$$Y = X\beta + f(x_t)$$  \hspace{1cm}(1)
With apartment unit factors \((i)\), energy consumption proxies \((j)\), socioeconomic indicators \((k)\), binary locational variables on ZIP code level \((l)\) and binary time dummy controls by listing year \((t)\):

\[
\log(\frac{\text{price}}{\text{m}^2})_i = \beta X_i + \mu E_j + \delta S_k + \theta L_t + \lambda K_i + \epsilon_i \tag{2}
\]

In doing so, we apply the ordinary least squares estimation method on the fully linear form and thus use the log of price per square meter as the response variable, and the log of energy consumption per square meter as the energy proxy. In a second step to apply a GAM approach, we use partial residual plots on our HPM estimates to identify possible nonlinear relationships between predictor and response variables \[18\]. A visual inspection reveals that all non-categorial covariates suggest nonlinear modelling to some degree. Consequently, these are modelled non-linearly within an additive mixed approach with mixed covariates of parametric estimates and nonlinear functions. We estimated four different model specifications of which two are solely linear. Two more are mixed linear and nonlinear covariates, whereas non-linearity is accounted for by modeling the nonlinear covariates with penalized splines. For each HPM and by means of the GAM approach, a further model is estimated in which the energy consumption is represented by the EPC rating bands. Since we are interested in the rent difference of the better classes compared to the worst performing buildings, we set the classes G and H as the reference category.

4.2. Hedonic Pricing and Generalized Additive Model

Following Copiello & Donati, Marginal Benefit (MB) for energetic improvements in buildings can be calculated as follows \[10\]:

\[
MB = \frac{\Delta TB}{\Delta Epi} \tag{3}
\]

where \(\Delta TB\) is the change in total benefit (TB), and hence, the price premium due to an increase in energy efficiency after a green retrofit. And \(\Delta Epi\) is the change in the energy performance index Epi which is measured in kWh/m²a. To apply this calculation procedure to the coefficients resulting from the estimation of the HPM for each energy efficiency class and then estimate a marginal benefit curve (MBC), we use the average savings between two classes resulting from the data set, and the associated rent premium at the point of means for the reference category (EPC G & H).

Analogous to the calculation of the MB, the marginal costs (MC) can be calculated as the quotient of total costs (\(\Delta TC\)) per square meter to undertake the green retrofit measures and the resulting change in the energy performance index (\(\Delta Epi\)):

\[
MC = \frac{\Delta TC}{\Delta Epi} \tag{4}
\]

To derive the appropriate slope of the marginal cost curve, we relate the MC determined for each observation \(i\) to the respective intervention level \((IL_i)\) which is defined as average of energy performance index before \((Epi^b)\) and energy performance index after \((Epi^a)\) retrofit:

\[
IL_i = \frac{Epi^b + Epi^a}{2} \tag{5}
\]

In order to make the curve determined, that is shifted towards a lower degree of energy efficiency comparable with the MBC, it has to be shifted back toward a higher level of energy efficiency by factor \(S\). \(S\) being defined as:

\[
S = \left(\frac{1}{n} \sum_{i=1}^{n} \Delta Epi_i \right)^{\frac{1}{2}} \tag{6}
\]

The two curves derived in this way can be used to graphically analyze the extent to which the implementation of the measures pays off economically in terms of an increase in rents provided there is an intersection of the curves. The intersection of the MBC and MCC indicates the optimal level of energy reduction.
5. Results and Implications

5.1. Hedonic Pricing Model Regression Results
For all estimates, a significant influence of the energy quality of the buildings on the rent was found, confirming the results of previous studies. As expected, the positive impact of really high energy quality is much greater than for slightly better apartments according to the results of the linear regression. Surprisingly, the signs of the small but significant coefficients for EPC classes D, E and F in the standard HPM are negative. However, this result in the linear regression appears plausible when the correlation coefficients of the EPC classes with the rent per square meter are included, because the negative correlation for the classes G and H is weaker than for E, F, and G. This relationship, which is difficult to explain economically, is not found in the analogous GAM model for EPC ratings, which suggests that the non-linear inclusion of several variables has improved the model estimation. From the estimated coefficients of binary variables in a semi-logarithmic regression the percentage effect is calculated by applying the formula $100 \times (e^b - 1)$ as stated explicitly for hedonic pricing models by Halvorsen & Palmquist [19]. Accordingly, in the GAM model with EPC bands as energy proxies, which is the basis for the following analysis, the highest green premium for energy efficiency class A+ is 3.98%, compared to the reference category. The following categories A, B, C, show a green premium of 2.43%, 2.12% and 0.80%, while for D, E and F, only very small differences of 0.3%, 0.1% and 0.2% were identified in comparison with worst performing classes G and H.

5.2. Derivation of Marginal Benefit Curve and Marginal Cost Curve
In order to derive the marginal benefit of avoiding another unit of energy per square meter from the previously identified green premium, we proceed with the average square meter rent within the reference category, which is at €9.09/m². This is increased by the respective percentage of the green premium for the higher energy classes. The resulting increases in future cash flows are discounted to a net present value (NPV) using a yearly discount rate of 3% and assuming a 50-year useful life for the facility components. The discount rate reflects the investor's capital return requirement and would, in practice, vary according to the location or risk profile of the property. The assumption regarding the useful life of the building is based on the legal requirements of German tax law, which provides for straight-line depreciation at 2% per year, corresponding to a period of 50 years until the building is fully depreciated (§ 7 EStG para. 2).

\[ \text{(a)} \quad \text{MB for EPC classes} \quad \text{MBC} \]
\[ \text{(b)} \quad \text{MC on IL} \quad \text{MCC (IL)} \quad \text{MCC} \]

\[ \begin{align*}
\text{Energy Demand (kWh/m²a)} & \quad 200 \quad 175 \quad 150 \quad 125 \quad 100 \quad 75 \quad 50 \quad 25 \quad 0 \\
\text{MB (€/kWh)} & \quad 0.6 \quad 0.5 \quad 0.4 \quad 0.3 \quad 0.2 \quad 0.1 \quad 0 \\
\text{MC (€/kWh)} & \quad 12 \quad 10 \quad 8 \quad 6 \quad 4 \quad 2 \quad 0
\end{align*} \]

\[ \text{Figure 1. Derivation of the Marginal Benefit Curve and Marginal Cost Curve.} \]
This NPV is finally divided by the absolute change in the energy performance index from each EPC class to the reference category, as stated in equation (3). This procedure yields the following plot which is presented in reversal scale in figure 1a.

Following the procedure outlined in Section 4.2 and defined by equations (4) and (5), the marginal costs of energy demand adjustment are plotted against the intervention level (IL), as depicted by the blue circles in figure 1b. The result suggests increasing marginal costs for retrofits on higher levels of energy efficiency, which has also been observed in earlier studies on energetic retrofits for different measures and materials [20, 21]. To adjust the MCC (IL) that was plotted on the intervention level to the target level to obtain the final MCC, it is shifted to the right by $S (=83.46 \text{ kWh/m}^2\text{a})$. The comparison of the value range of the MBC and MCC clearly shows that the costs exceed the expected benefits by far. In the following section, the analysis of the generated curves will be continued and extended by different approaches, in order to economically evaluate relevant interrelationships.

5.3. Synthesis and Economic Evaluation of the CO₂ tax

The joint depiction of MBC and MCC in one plot yields the conclusion that the MB from possible rent increases is not sufficient to offset the retrofit costs from the owner's point of view. The MBC runs under the MCC and does not intersect it. At this point, it should be noted that the preceding cost analysis is based on the full costs of the renovation measures, because only for 12 observations in the data set the costs eligible for subsidies for energy-efficient buildings (“förderfähige Kosten”) are known. For these 12 observations, the average share of energy-related costs is at 45% of full costs. Even assuming this percentage for all retrofits in the dataset and shifting the MCC downward by 55%, the observation of the irretrievability of the measures from the owner perspective does not change. Also, the assumption-based Marginal Cost Curve for energy-related costs (MCCer; grey dotted line in figure 2a) does not intersect the MBC (green dotted line at bottom of figure 2a).

![Figure 2](image-url)

**Figure 2. Marginal Cost Curves, Marginal Benefit Curve and Energy Cost Saving.**

The observation that energy-efficient refurbishment does not pay off in monetary terms applies in particular to rented housing, because of the split incentive problem. This is illustrated with a calculation example: To approximate the NPV of the reduction in energy consumption by one kWh/a, we assume the natural gas price per kWh of the year 2020 of 6.2 Cent/kWh, before the CO₂ tax on fuels was introduced in Germany, and calculate the total cost benefit over a 50-year useful life, applying the discount rate mentioned above and an energy cost progression of 2% which reflects the average annual increase for the years 2005 to 2020 [22]. We assume the price and price progression for natural gas,
because in the private household sector, natural gas is the most important energy source on the heating market, with a current share of around 44% [23]. This results in an NPV of €2.44 in terms of energy cost saving for one kWh/m². The corresponding line (ECS) intersects the MCC at an energy performance of about 185 kWh/m²a, meaning that a retrofit would be expected to be economically advantageous up to this point (figure 2b). This consideration assumes that owner-occupiers can retrofit at the same cost per square meter as the real estate companies that provided the data for the analysis. However this might in many instances not be the case, as these companies are able to benefit from economics of scale and bargaining power. The intersection with the MCCer, is reached at a much higher energetic level at about 60 kWh/m²a, due to the lower marginal costs. The example does not claim to provide an exact estimation regarding the de facto profitability of retrofit measures in practice, as it is based on averaged data and various assumptions. Nevertheless, the insight is quite clear that undertaking modernization efforts to increase building energy efficiency is much more attractive, due to the inclusion of energy cost savings in the owner-occupied sector.

With the potential to solve the landlord-tenant dilemma to some extent, a proposal of splitting the CO₂ tax between tenant and landlord was included as a declaration of intent in the coalition agreement of the newly voted-in German federal government in 2021 [3]. The agreement states that a percentage allocation of the tax will be implemented, that will depend on the EPC class of a building. If this law has not been passed by 1st June 2022, the distribution will be made on a parity basis and regardless of the energy performance. Below, we analyse these two cases and again calculate a marginal benefit for saving one kWh of energy, but with inclusion of the carbon tax. One challenge hereby is that the CO₂ price, which is regulated in the BEHG (“Brennstoffemissionshandelsgesetz”), is only defined until 2026. In 2021, it was introduced at €25 per metric ton (t) of CO₂ and will gradually increase to €30 (2022), €35 (2023), €45 (2024), €55 (2025) and a range from €55 to €65/tCO₂ in 2026. Subsequently, free pricing is to be established on the market, unless it is decided in 2025 that defined price corridors will be continued. The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) uses values from the BMU-funded project "Politik-Szenarien IX" ("Policy Scenarios IX") in its current model calculations [24]. The "Policy Scenarios IX" project assumes a CO₂ price of €65/tCO₂ in 2026 and an annual increase of €15/t to €125/t in 2030, €200/t in 2035 and up to €275/t in 2040. We adopt this assumption and add the expectation that the price will not increase further from 2045, when Germany is expected to have already achieved net carbon neutrality. To calculate this tax on a kWh of energy, we include the CO₂ emission factor for natural gas of 0.20431 kg/kWh [25]. This conversion results in a kWh of natural gas being taxed, for example, with 0.73 Cents in 2022, with 3.0 Cents in 2030 or with 8.5 Cents in 2045 and after. The sum of the tax savings thus achieved for one kWh over a 50-year period results in an NPV of €1.10/kWh. In the case of parity distribution of the tax, simply 50% of the calculated NPV, i.e. 55 Cent, can be added to the MB for each EPC class, which shifts it upwards. Since, at this point in time, no detailed information has been published on the exact percentages of the tax distribution on tenant and landlord for the individual EPC classes, we build further assumptions: For classes A and A+ the tax is payed 100% by the tenant, for class B 20% by the landlord, C 40% by the landlord, D 50%, E 60%, F 80% and for classes G and H 100% by the landlord.

Based on the input parameters just presented, the modified MBCs for the two different cases of imposing the carbon tax on the landlord are derived (figure 3a). The course of the MBC is increased significantly in both cases. However, the taxation is still insufficient to raise the marginal benefit of saving one kWh in the rental sector to such an extent that it offsets the cost of the renovation for any level of energy efficiency. Both MBCs that include CO₂ taxation also run strictly below the MCCer. In making this observation, it is important to note that the tax payments to be made in the future were discounted to 2021. The incentive effect of the tax would therefore also increase in influence, as the price rises over time. However, this is also partly countered by rising construction costs.
In the owner-occupied sector, on the other hand, the tax would be fully added to the energy cost savings and thus further increase the economically reasonable depth of renovation (figure 3b). In general, it is highly questionable whether both investors and private users would apply such assumptions in their decision making. The fact that the tax is only defined until 2026 and, as a consequence it is unclear how high it will be in subsequent years, creates planning uncertainty which limits the incentive effect of the carbon tax.

6. Conclusion
This study empirically investigated whether a green premium is paid for energy efficiency in the German rental market. The results show that this is indeed the case for the very high-performance EPC classes, while there is only a very small, almost negligible premium for mediocre- and lower-performance classes. In addition, a marginal cost curve for the abatement of an additional kilowatt-hour of final energy was derived from a dataset of green retrofits of multi-family homes in Germany.

A comparison of the marginal cost with the marginal benefit derived from the identified green premium shows that the monetary advantage resulting from possible rent increases is far from sufficient to compensate for the costs of retrofit measures (if there are no public subsidies). In this context it is important to state, that the dataset consists only of data on rents up to the year 2020. Recent price increases in the energy market of up to 30% are not reflected in the green premium [26]. These increases might affect the demand for buildings with a better energy performance. In the context of increased energy costs, it is also important to note recent developments in the construction sector in which costs have risen sharply. If the costs in both sectors rise equally (in percent), this has no impact on the key finding that retrofits do not pay off from a landlord’s point of view. However, if energy costs increase more than construction costs, the retrofit measure becomes more attractive. If there is a higher increase in construction costs it gets less attractive to retrofit.

While the finding of a green premium implies that the landlord-tenant dilemma is not absolute, but that landlords can also benefit to some extent from efficiency gains in relation to rent, a comparison shows that the net present value from energy cost savings would be many times larger than that of additional rent. An inclusion of the planned split of the CO₂ tax between both landlord and tenant in the analysis has shown that at the time of the study, this split is not capable of providing a sufficient incentive for the landlord to carry out green retrofits. The price per ton of CO₂ appears to be too low for this purpose. It should be noted that an excessive increase in the tax to correct this and to increase the renovation rate in the short term is not an advisable measure, because this would drive up the housing cost savings.
costs of all households including those of owner-occupiers for which the incentive is already stronger than for owners of rental stock. Over time, as the tax per ton of CO₂ increases, the incentive effect will also increase. However, from today's point of view, the inclusion of the tax in calculations is associated with considerable planning uncertainty, as the price per ton is only defined until 2026. To increase the renovation rate in the short term and to focus on the worst performing buildings where the greatest efficiency gains are achievable, binding minimum standards as already proposed in the last update of the EPBD, appear to be a good alternative.

The study results, even if imperfect and subject to limitations, appear to be valuable not only for tenants and investors in their decision-making, but also for policy makers in the implementation of decarbonization efforts in the residential real estate sector.

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