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# Technical Paper

## German residential real estate valuation under NGFS climate scenarios

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# Non-technical summary

## Research Question

The Financial Stability Review 2021 published by the Deutsche Bundesbank (Deutsche Bundesbank, 2021) features a special chapter dedicated to potential effects of climate change on financial stability. To complement the discussion in this chapter, we investigate by how much residential real estate (RRE) valuation may change depending on expectations of market participants regarding future developments of energy costs. Depending on the future path of energy costs, energy-inefficient buildings could loose in value if policies were to induce strongly rising energy costs. This is a relevant issue, because RRE serves as collateral for the vast majority of loans to households in Germany. As a consequence, this would lead to increased losses given default (LGDs) on the side of lenders. Thus, estimating how RRE valuation may change in response to changing expectations about future energy costs is an important question from a financial stability perspective.

## Contribution

We combine online advertisement data on RRE in Germany with climate scenarios from the Network for Greening the Financial System (NGFS). To this end, we develop a simple theory of how price differentials between buildings of different energy efficiency levels are related to expected energy costs. To arrive at our estimates of price discounts across efficiency levels, we approximate expectations by time series on energy prices and $CO_2$ taxes under different scenarios. These results are then aggregated to the national level using the observed distribution of energy performance certificates (EPCs). We also compare differences in valuation across climate scenarios, thereby providing estimates of potential collateral losses if expectations were to switch across scenarios.

## Results

Our analysis shows that our theory is consistent with prior results concerning energy efficiency and residential real estate prices. Further, we show that climate scenarios featuring prominently rising costs of energy have little impact on valuations for efficient buildings, but imply stark drops in prices of inefficient ones. Scenarios with such cost paths are the ones in which climate targets are met, meaning that from the RRE valuation perspective, successful climate policies could come with significant losses of collateral value. Lastly, we show that the aggregate impacts of the scenarios can potentially also be large, depending on the scenario. Comparing the least and most intrusive policies in terms of $CO_2$ taxation, we find for Germany as a whole potential valuation decreases in the 11-13% range of the underlying value of RRE.

# Nichttechnische Zusammenfassung

## Fragestellung

Der Finanzstabilitätsbericht 2021 der Deutschen Bundesbank (Deutsche Bundesbank, 2021) enthält ein Sonderkapitel, welches sich den möglichen Auswirkungen des Klimawandels auf die Finanzstabilität widmet. Als Beitrag zu diesem Kapitel wird in dieser Arbeit quantifiziert, wie sich Veränderungen in erwarteten Energiekosten auf die Preise für Wohnimmobilien auswirken könnten. Sollten energieineffiziente Immobilien im Zuge eines politikinduzierten deutlichen Anstiegs der Energiekosten an Wert verlieren, könnte diese zu höheren Verlustraten bei Zahlungsausfall auf Seiten der Kreditgeber führen. Dies ist relevant, weil in Deutschland Wohnimmobilien als Sicherheit für den Großteil der Wohnimmobilienkredite an Haushalte dienen. Daher ist eine Abschätzung dieser Effekte aus Sicht der Finanzstabilität relevant.

## Beitrag

Um zu einer solchen Abschätzung zu gelangen werden Daten zu Online-Angeboten für Wohnimmobilien in Deutschland mit Klimaszenarien des Network for Greening the Financial System (NGFS) verknüpft. Der Analyse wird ein theoretischer Zusammenhang zwischen Immobilienpreisen und erwarteten Energiekosten zugrundegelegt. Die relevanten Erwartungen werden mithilfe von Zeitreihen zu Energiepreisen und $CO_2$-Steuern aus verschiedenen Klimaszenarien approximiert, sodass sich Schätzwerte für Preisunterschiede in Abhängigkeit der Energieeffizienz ergeben. Abschließend werden die Ergebnisse mittels der beobachteten Verteilung der Energieeffizienzklassen auf die nationale Ebene aggregiert. Zudem werden potenzielle Wertverluste über Klimaszenarien hinweg verglichen, wodurch sich Einschätzungen zu Verlusten bei Kreditsicherheiten aufgrund sich ändernder Erwartungen ergeben.

## Ergebnisse

Die Ergebnisse zeigen, dass die Theorie bisherige empirische Ergebnisse zu Energieeffizienz von Wohngebäuden und Immobilienpreisen abbilden kann. Während steigende Energiekosten nur geringe Auswirkungen auf die Preise von effizienten Immobilien haben, sind die Preiseffekte für ineffiziente Gebäude potentiell groß. Szenarien, in denen die Klimaziele über stark steigende Energiekosten erreicht werden, haben beträchtliche Auswirkungen auf die Immobilienpreise und damit auf den Wert der Wohnimmobiliensicherheiten. Für Deutschland insgesamt zeigt die Analyse, dass bei einem Vergleich der Szenarien mit der niedrigsten und höchsten $CO_2$-Besteuerung die Wertverluste zwischen 11 und 13% des aggregierten Immobilienwertes betragen könnten.

# German residential real estate valuation under NGFS climate scenarios [*]

Lucas ter Steege [†] Edgar Vogel[‡]

## Abstract

We combine data on real estate online listings and climate scenarios from the Network for Greening the Financial System (NGFS) to estimate changes in real estate valuations due to changing expectations about future energy costs. Using a simple theory of the relation between prices and energy consumption, we find that the most ambitious climate scenarios potentially come with significant impacts on real estate prices and thus the collateral value of inefficient homes. In the aggregate, losses in housing values and thus collateral could lie in the range of 11 to 13% of the aggregate housing value.

Keywords: Residential Real Estate, climate transition risk, climate scenarios, $CO_2$ taxation
JEL Codes: R31, Q41, Q54

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[*] The views expressed are those of the authors and do not necessarily represent the views of Deutsche Bundesbank or the Eurosystem. All errors are our own.

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# 1 Introduction

Climate change has by now been recognized as a major challenge to be solved over the coming decades. Therefore, an important question for central banks and macruprudential bodies is how climate change may affect price and financial stability. An important channel through which the effects of climate change may adversely affect financial stability is the exposure of banks and other financial intermediaries to climate risks through mortgage lending. Large parts of lending to households for house purchase is collateralized by residential real estate (RRE), and changes in real estate valuations directly impact balance sheets via changes in losses given default (LGD). In turn, we argue that an important price determinant of RRE is the energy efficiency of a building coupled with future developments of energy prices, with likely more adverse valuation effects from rising energy costs for high energy consumption buildings. Thus, the connection between energy prices and RRE valuations is one potential channel of climate transition risks, and this paper provides a simple way to approach the question of how climate change may affect real estate valuations which feed into financial stability considerations.

Our analysis has three building blocks. First, we develop a simple theory of the relation between house prices and expected energy costs that results in a monotone relationship between relative house prices and energy efficiency differentials. We motivate this analysis by the fact that (expected) changes in energy costs should be capitalized into prices already today, a common assumption in the asset pricing literature. In our analysis, we therefore model the fact that energy consumption is a potentially important price determinant in its own right as a part of the cost of living. Higher price of energy and of carbon taxes will increase these living costs and thus lower the prices of all buildings but more so in the case of less efficient buildings. We then bring this simple theory to the data using information on house prices and energy performance certificates (EPC) that allow us to approximate the German price and efficiency distribution of the housing stock. Combined with scenario paths for energy costs from the Network for Greening the Financial System (NGFS), we lastly obtain estimates of the price effects of households switching expectations about the future development of energy costs. We find that the decline in aggregate RRE prices (collateral value) in a scenario with an early and gradual change in energy and carbon prices ("orderly transition") are likely to be modest. A more ambitious transition under the "Disorderly" or "Net Zero" scenarios with sharp increases in energy prices may, however, lead to significantly larger reductions of collateral values. Our results suggest that for Germany as a whole, the aggregate valuation effect could be as large as 13% when we compare the "Net Zero" to the "Current Policies" scenario, in which energy costs stay roughly constant.

We have to emphasize that this analysis is limited by the fact that no information is available on the lending standards, e.g. loan-to-value ratios (LTVs).[1] However, such information is needed to compute the loss given default (LGD) and eventually expected losses. There are also other important channels of climate (transition) risk which we leave aside in this analysis. For instance, higher energy costs or the need to improve the energy efficiency of houses may stretch borrowers (owners) and tenant's budgets. This would increase the probability of default (PD). Further, the awareness of climate change and for energy efficiency could increase further and thus lead to a decline in the demand for and the

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[1] This issue is relevant because lenders could already now incorporate such issues into their lending policies and impose stricter lending standards for less efficient buildings. Then, the materialization of risks may be less problematic.

prices of less efficient buildings. Lenders may become less willing to provide financing for inefficient dwellings and thus also contributing to falling prices of such buildings.[2] It is important to note that the negative price effects are "intended" and may also have positive effects by setting incentives to modernize buildings and thus improve the energy efficiency of the building stock. The latter could dampen the effect of the transmission channel assumed in this paper. While we do not model such behavioral responses, they could partly counteract the price effect. Thus, our results are valid only in an "everything else equal" environment. Finally, as increasing the energy efficiency of the housing stock will be a major part of the policy package along the transition path toward a low-carbon economy, further policy measures, such as restrictions to rent out inefficient buildings may considerably affect real estate prices. For instance, in the UK it is illegal to rent out residential or commercial real estate that has an energy performance rating less than F or G since April 2018. Research suggests that the ban had an immediate effect on RRE prices (Ferentinos et al. (2021)). In the Netherlands, as of 2023 office buildings will be required to have an energy label with at least a C-rating. Indeed, the Climate Protection Plan 2050 *(Klimaschutzplan 2050)* passed by the German Government in 2016, entails further development of the Nearly Zero-Energy Buildings-Standard *(Niedrigstenergiegebäudestandard)*, which requires objects build from 2021 to be in line with upper bounds on final energy consumption. In addition, the plan aims to improve existing buildings until 2050 such that these are compatible with a near climate-neutral building standard (Bundesministerium für Umwelt, 2016).

## 2 Related literature

A growing body of research aims to assess the impact of climate change and associated policies on financial markets and the arising financial stability issues. Our paper speaks to the strand of the literature concerned with transition risks associated with climate change. Regarding RRE markets, transition risks stemming from policy interventions to combat climate change are intimately tied to energy efficiency standards. Previous studies for Germany have thus estimated price differentials across different efficiency levels in the housing market. Taruttis and Weber (2020) and Kholodilin et al. (2017) find economically and statistically significant discounts for inefficient buildings in the range of 17-23% for the least efficient labels when compared to the most efficient ones or for the difference of about 300 kWh, the equivalent distance.[3] Despite different approaches, the papers conclude that pricing differences can be interpreted as rough proxies for the net present value of energy savings. Whether these discounts cover required investment costs (to realize energy saving potentials) is much less of a consensus, which can be explained by the fact that cost estimates (e.g. from practitioners, specific examples, etc.) are much more heterogeneous. This is likely the case because such cost estimates tend to be very specific to building types (e.g. detached houses) or cover very specific aspects, such as changing windows or insulating the ceiling of the cellar, and lend themselves much less for generalization purposes. The findings above are in line with Frondel et al. (2020) who show that following the mandatory disclosure of energy efficiency

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[2] The German Federal Financial Supervisory Authority (BaFin) has issued a "Guidance Notice on Dealing with Sustainability Risks" in which it recommends lender to take sustainability risks for RRE into account(BaFin (2019)). This may have repercussions on lenders' willingness to lend for and the pricing of financing of less energy efficient properties, which could affect prices.

[3] Estimates are not always exactly comparable because of different specifications.

standards the price of houses with poor thermal efficiency dropped, with no price change for efficient buildings. For rental markets in Germany, Cajias et al. (2019) find evidence that energy efficient apartments are rented out at a premium. This finding is confirmed for the Berlin rental market by Kholodilin et al. (2017). Below we show that the discounts from the literature are roughly in line with the "Current Policies" scenario in which energy prices rise only modestly.

In terms of policy considerations, perhaps closest to our work are the recent contributions by Ferentinos et al. (2021) and Schütze (2020). Ferentinos et al. (2021) estimate how mandatory minimum energy requirements in England and Wales impacted residential property prices, showing that the policy decreased house prices of affected properties relative to unaffected ones roughly equal to the expected renovation costs of meeting the standards. They further link their findings to financial stability, arguing that impacts of this policy on the banking sector are limited, as only a small fraction of high LTV mortgages are secured by inefficient properties. For Germany, Schütze (2020) performs similar policy scenario simulations and finds that climate change has negative effects on brown portfolios of banks, while green portfolios (label categories $A+$, $A$, $B$) are much less affected. She concludes that lenders actively rebalancing their portfolios towards more efficient mortgages can substantially reduce risks. Her results suggest that expected losses from mortgage defaults under brown portfolios could equal up to 0.6% of banks' mortgage portfolios if heating costs were to suddenly rise by about 40%. The magnitude is similar in size to results from stress tests for the German mortgage market Barasinska et al. (2019).

International evidence on the pricing of climate transition risks is provided by Kaza et al. (2014) who find that mortgages on energy-efficient homes, those with an Energy Star label indicating whether a home is classified as energy-efficient, are associated with 30% lower default risk than buildings without the label in the U.S. For Commercial mortgage-backed security loans for office buildings, An and Pivo (2020) estimate a similar magnitude of 34% lower loan default risk for green buildings. In a study covering several European countries, Bio Intelligence Service et al. (2013) find that sale prices for residential homes in Austria, France and Ireland decrease within the 2-8% range with a one-letter increase in energy consumption of the building. Results for other countries in the study, such as the U.K., are somewhat mixed, possibly due to confounding factors that the respective data do not allow to control for. Nevertheless, the general tendency of higher energy efficiency being associated with higher prices and lower default risk motivates our theory to be developed below, and establishes the ultimate importance of these channels from a financial stability perspective.

## 3 Theoretical background

The point of departure for our thinking about the effect of climate policies on real estate prices is the so-called user-cost approach to real estate valuation. It assumes that households will, everything else equal, pick the cheapest option given their preferences and constraints. Cheapest applies typically to the net present discounted value (NPV) over a certain period, e.g. the life-time of a household or the typical duration of a rental contract or stay in an owner-occupied house. In the simplest version of the theory, the underlying assumption is that households are fully rational and there are no frictions to implement the optimal choice. Then, the net present value of two otherwise identical options should be equal. This type of thinking has typically been applied to the question of renting vs. owning. In such a setting, deviations from the equality described above the can be interpreted as under- or overvaluations of real estate prices. Because of this interpretation, researchers (see Poterba (1984) for an early contribution) and public institutions (Browne et al. (2013), Fox and Tulip (2014), Philiponnet and Turrini (2017)) use this framework in their analyses of risks emanating from price misalignments in real estate markets.

This theory builds the intellectual foundation of hedonic models because those models "adjust" prices of different houses for their different quality. Typical factors include location but also the age or condition of a dwelling. The latter two are directly related to the costs of housing as buildings which are older or in bad condition are likely to need earlier and more costly renovations by the tenant or owner. Also, they may be less energy efficient and have higher heating or cooling costs. Such houses will then, everything else equal, be less expensive. Because of the attractive feature of this class of models, we will apply their key assumption, namely the notion that households compare costs and benefits of different options. We will operationalize this idea below to approximate by how much prices of less efficient houses should drop (relative to more efficient ones), if expectations concerning future energy prices increase. While a number of other factors are likely to impact the prices or real estate, Krause and Bitter (2012) argue that sustainability issues in real estate valuations have become one of the three main themes, at least for the U.S. In Germany, there are numerous subsidised credit facilities offered by the official sector, the probably most prominent programs being offered by the state-owned development bank "Kreditanstalt für Wiederaufbau" (KfW). Because of these programs, banks are highly specialized in advising customers in investing their funds in an efficient way. Thus, it can be assumed that potential buyers in Germany will also consider expected energy costs (and options to reduce them) when making purchasing decisions, and these considerations should show up in market prices.

We formalize this idea by writing the problem in per square meter terms and assuming that all other factors are equal. We further write the problem in terms of energy efficiency labels, i.e. we compare the building with rating $j$ to the building with the highest efficiency rating $A+$ (see Kholodilin et al. (2017) for a similar reasoning). Formally, the price difference per square meter between two properties, one of which with the highest energy efficiency label as the reference point ($A+$), should be solely explained by the sum of the discounted value of (expected) energy cost differences:

$$P_t^j - P_t^{A+} = -\mathbb{E}_t \left[ \sum_{h=1}^{T} \frac{EC_{t+h}^j - EC_{t+h}^{A+}}{(1+r)^h} \right] \tag{1}$$

The term on the right hand side is negative since energy costs ($EC$) per square meter are lower when a dwelling possesses an $A+$ label. The equation takes the perspective of a potential buyer who weighs the options between buying the efficient property at a higher price and enjoying the lower energy costs, and buying the inefficient one at a discount that reflects the expected increased energy costs at time $T$.[4]

It is worth noting that in equation (1) we omitted other factors such as depreciation, maintenance costs, opportunity costs of capital or tax deductibility of interest payments, which are part of the calculus. We argue that the majority of these factors affect all buildings equally and thus cancel each other. Also, we ignore future capital gain differences at period $T$ from the analysis. The reason for doing so is that we do not have a good estimate of these gains across energy efficiency classes. Therefore, if increasing

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[4] Note that we omit idiosyncratic error terms because they should wash out in the aggregate.

energy costs decrease the price of inefficient buildings relative to efficient ones, this should also increase the capital gain differential, in which case we calculate a lower bound on the price effects of energy cost differentials.

To make this setup operational we make two simplifying assumptions. First, we replace expectations over future energy costs in (1) with specific paths for future energy prices from various NGFS scenarios. In this way, we interpret our exercise as measuring house price differentials under different developments of energy costs, depending on specific imposed expectations that households might hold. This also allows us to get a sense of how price discounts change as expectations switch from one potential scenario to another. Second, we assume that energy costs $EC_{t+s}^{(j)}$ are the simple product of the expected energy price ($P_t^E$) and a constant factor measuring energy efficiency ($EE$) conditional on a specific label (in $kWh/m^2$), we write the price differential relative to the price of an $A+$ building, i.e. the respective discount, for a given scenario $S$ as

$$\begin{aligned} D_t^j(S) &\equiv \frac{P_t^j(S) - P_t^{A+}(S)}{P_t^{(A+)}(S)} = -\frac{P_t^E \Delta EE^j}{P_t^{A+}(S)} \sum_{h=1}^{T} \frac{g_{t+h}^E(S)}{(1+r)^h} \\ \Delta EE^j &\equiv EE^j - EE^{A+} \end{aligned} \tag{2}$$

$g_{t+h}^E(S)$ denotes the growth factor of future energy prices for a given scenario, relative to the current price of energy $P_t^E$. The mapping between the energy efficiency class (EE) and energy consumption is standard and shown in Table A1. We discuss in more detail how we set this price and how we calculate the growth factors for different scenarios in Section 4 and Appendix B.

## 4 Data description

In the scenario analysis we feed observed data on house prices, energy efficiency and energy costs into equation (2) to estimate the aggregate impact of changing energy costs on housing values under different climate policy scenarios. Our primary dataset on house prices and energy consumption consists of residential real estate online advertisements from the internet platform ImmobilienScout24, which is provided by the *RWI - Leibniz-Institut für Wirtschaftsforschung*. This dataset contains monthly information on asking prices for houses and apartments posted for sale on the platform between January 2007 and June 2020. Additionally, information on apartments and houses for rent is available, with few observations for the latter category for obvious reasons. Since we aim to link our results to financial stability issues where collateral and debt repayment are critical, we focus on the sales market instead of the rental market. In what follows, we clean the dataset along the lines of Mavropoulos et al. (2021) in that we remove duplicate observations based on dwelling characteristics and implausible values in key variables. Details can be found in Appendix A.

Of particular importance for our purposes is the information related to energy efficiency contained in the dataset. Specifically, there are two types of energy efficiency variables available. The first is a continuous variable measuring energy consumption in kWh per square meter per year (energy consumption hereafter). The second variable is a categorical energy label indicator taking on 9 values, ranging from $A+$ (best) to $H$ (worst). The two variables are intimately linked through a mapping that defines cutoff points to assign energy consumption values to a certain label, presented in Table A1. We make use of this mapping to increase the number of observations in the sample by constructing the labels from the energy consumption data directly. Information on energy consumption and the labels is mandatory only since 2014, and very few observations include any information prior to 2014.

Table 1: *Summary statistics across energy performance certificates*

| | *Houses* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | A+ | A | B | C | D | E | F | G | H |
| Price | 3114.19 | 2685.71 | 2670.49 | 2446.82 | 2294.35 | 2182.29 | 2063.52 | 1884.90 | 1673.55 |
| Discount | . | -13.76 | -14.25 | -21.43 | -26.33 | -29.92 | -33.74 | -39.47 | -46.26 |
| Age | 7.77 | 9.65 | 19.37 | 32.17 | 41.63 | 50.22 | 58.06 | 66.20 | 77.01 |
| Econs. | 15.94 | 40.83 | 63.43 | 88.46 | 115.48 | 145.18 | 179.77 | 224.41 | 320.33 |
| Proportion | 6.24 | 5.97 | 7.91 | 10.09 | 14.18 | 13.40 | 14.46 | 12.29 | 15.45 |
| | *Apartments* | | | | | | | | |
| | A+ | A | B | C | D | E | F | G | H |
| Price | 3791.17 | 3888.09 | 3563.48 | 2807.04 | 2592.29 | 2584.14 | 2584.31 | 2535.39 | 2261.60 |
| Discount | . | 2.56 | -6.01 | -25.96 | -31.62 | -31.84 | -31.83 | -33.12 | -40.35 |
| Age | 7.17 | 8.18 | 20.20 | 38.35 | 46.66 | 50.00 | 52.96 | 58.15 | 64.72 |
| Econs. | 19.96 | 41.43 | 63.78 | 88.79 | 115.40 | 144.03 | 176.87 | 220.27 | 294.48 |
| Proportion | 3.24 | 5.13 | 11.85 | 17.52 | 25.86 | 19.21 | 11.43 | 4.18 | 1.58 |

*Notes:* The table displays averages of each variable for the nine energy efficiency categories, except for *Proportion*. *Price* is measure in $€/m^2$. *Discount* denotes the raw discount in %, calculated as the average price of a dwelling with a given label, relative to the average price of an *A+* dwelling. *Age* is measured in years. *Econs.* denotes average energy consumption, measured in $kWh/m^2a$. Lastly, *Proportion* denotes the fraction of observations of a given label in %. See also the main text and Appendix A for more details.

Table 1 shows summary statistics for relevant variables for the experiment down below. In the table we focus on a consistent sample where information on all variables displayed is available. Starting with houses, prices per square meter start at roughly 3100 $€/m^2$ for the most efficient ones, and decline by about 46% for the least efficient ones on average. This "discount" is not the same as derived in the equations above but simply the percentage difference in average square-meter prices across labels. There is a similar pattern for apartments, where the raw percentage price difference reaches 40% when comparing the most and least efficient apartments. Noteworthy is the prices for $A$ are actually higher than $A+$, perhaps because these apartments are located in better neighborhoods or have other desirable features. Less efficient dwellings tend to be older, as expected. What is perhaps interesting is that apartments are seldom very efficient or very inefficient, but rather the distribution is concentrated around the $C-E$ efficiency range. In contrast, for houses the label distribution features more weight on the $F-H$ range. In light of our theoretical considerations, this would imply that aggregate effects of energy price increases should be stronger for the housing rather than the apartment segment. This distribution should be taken with caution, however. As we show below, it is likely that our sample is somewhat biased towards younger buildings, in which case we might underestimate aggregate price declines as larger discounts arise for less efficient, and typically older, buildings.

For data on future energy prices we make use of time series for scenarios developed by the Network for Greening the Financial System (NGFS). Specifically, we consider paths for energy prices and $CO_2$ taxes from NiGEM, a macroeconomic model that provides us with time series under different NGFS scenarios. We focus on the following scenarios in what follows: (1) *Current Policies* as part of the Hot House World scenarios, (2) *Divergent Net Zero* as a Disorderly scenario, (3) *Below 2°C*, and (4) *Net Zero 2050*. The latter two are orderly scenarios under consideration, meaning that in these scenarios energy targets are met and policies are gradually implemented to meet the targets. For each scenario, we obtain time series for prices for oil and gas (in $ per barrel of oil equivalents) until 2050, which we convert from $ to € using the provided exchange rate for each scenario. We focus on gas and oil as our two energy price variables since these are the most important sources of energy used in German residential housing, accounting for 74% of total energy use for apartments in 2019 according to the *Bundesverband der Energie- und Wasserwirtschaft e.V.* (BDEW, 2019). These estimates further imply that out of this percentage, gas accounts for 65% and oil for 35%. We assume that this split holds across time when calculating the final price of energy under the different scenarios. The assumption should hold especially in the short run because large scale adjustments in the heating technology are likely to take some time. We describe our procedure to arrive at final energy prices in Appendix B.

## 5 Shock to energy price expectations

In this section we quantify the effect of shocks to energy price expectations by parameterizing equations from 3 with price paths for different scenarios from the NGFS. Regarding the theoretical channel, recall that the pricing of houses today depends on *expectations* of energy prices and capital gains. Therefore, the interpretation of the following experiment is that potential buyers have some baseline scenario in mind (see below) but adopt (suddenly) one of the NGFS-scenarios as the new likely outcome. This move in the expected future energy price path should be then capitalized into prices already today. Figure 1 shows the four price paths that we use in this experiment, all standardized to 6 $ct/kWh$ in 2021.[5] Clearly, there is wide disparity among future energy prices across scenarios, with little change under *Current Policies* and a sharp increase to more than 50 $ct/kWh$ by 2040. Note that the increase in prices is primarily driven by changes in $CO_2$ taxation across scenarios, rather than rising oil and gas prices. In fact, all but the *Current Policies* scenario feature declining oil and gas prices, whereas taxes rise considerably faster in the *Net Zero 2050* and *Divergent Net Zero* scenarios, especially in the short term.

With these prices at hand we feed their paths into the theoretical equations, where the term $DF$ is given as the discount sum of future energy prices relative to 2021. To compute the discount factor we follow Kholodilin et al. (2017) and sources cited therein but adjust their calibration to reflect changes in the economic environment. The share of debt financing in computing $r$ is set at 20% at a cost of 1.5% (mortgage with an interest rate fixation period of 10 year; data from the Bundesbank's interest rate

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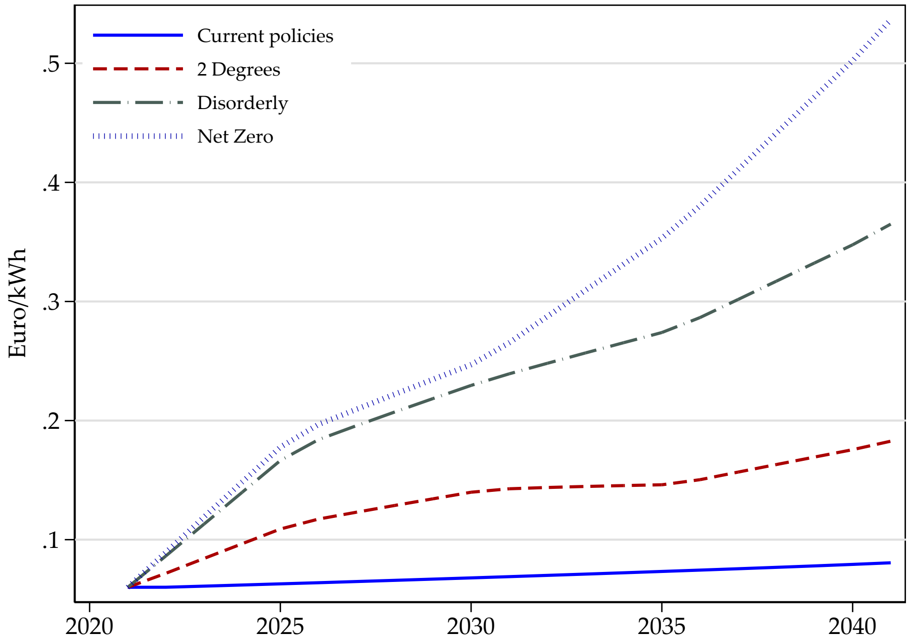
[5] We use the latest available number from Stede et al. (2020).

Figure 1: *Final energy prices implied by NGFS scenarios*



*Notes:* Each line represents the scenario-specific nominal after-tax price path for final energy. All prices are scaled to correspond to 6 $ct/kWh$ in 2021. See the main text and Appendix B for additional details on the calculation.

statistics) and a rate of return on equity $g$ of 6%.[6] and a planing horizon of 20 years (Kholodilin et al. (2017)). To arrive at the policy effect, we standardize the NPV of energy costs with asking prices for $A+$ dwellings in 2019, the latest year with information over the entire year. When standardizing the NPV we subtract 10% of the prices. This adjustment is within the range of reported differences between asking and transaction prices in the literature (Dinkel and Kurzrock, 2012, Henger and Voigtländer, 2014) and makes our estimates more conservative, as the price of comparison is lower and discounts thus larger.[7] Finally, we assume that energy efficiency differentials between labels are constant across time.

Figure 2 shows the results of this exercise, where in the left panel we focus on houses to avoid cluttering the graph. We note at this point that the implied discounts under the *Current Policies* scenario are roughly in the ballpark of other estimates from the literature. The estimates have used data from a period in which climate change and associated energy price increases may have been less of an issue. One interpretation of this fact is that current discounts are not at odds with the assumption that markets currently are pricing an energy path close to the one from the *Current Policies*. This gives us some comfort when mapping expected NPV changes of energy costs into prices (and using *Current Policies* as our "baseline expectations"). Comparing these baseline results to the remaining scenarios, we find that while for efficient buildings the price discounts increase only moderately, at lower efficiency labels the discounts can rise dramatically, up to 45% under the *Net Zero 2050* scenario. The relative ordering of the

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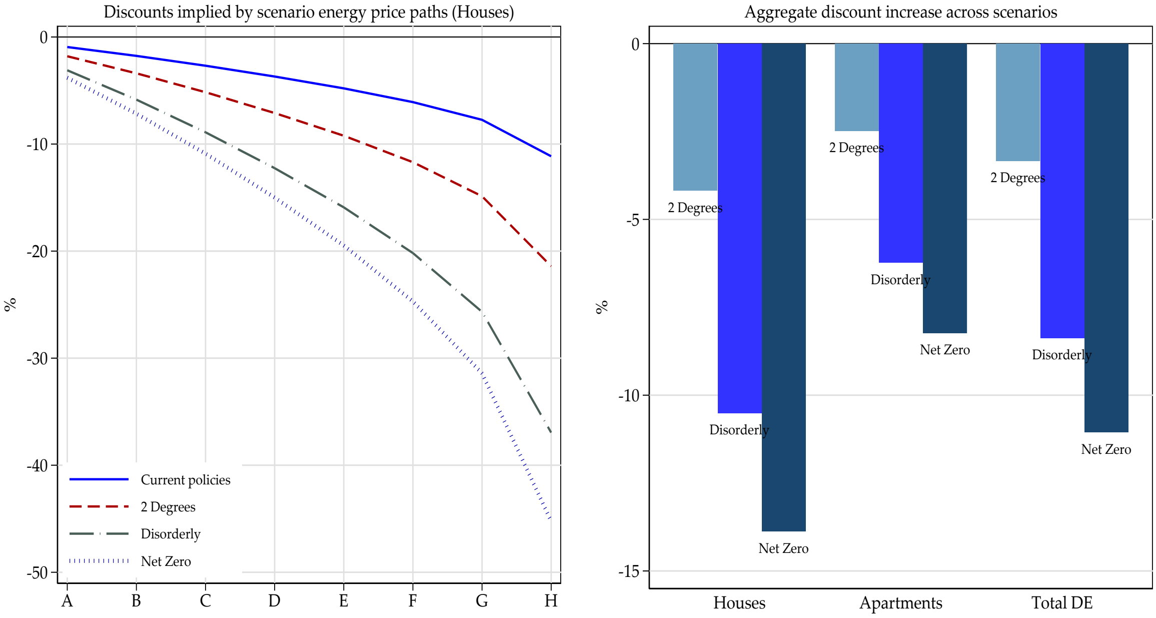
[6] For the risk premium we assume a value of 6% (Jorda et al. (2019) and sources therein) The risk free intersect rate in Germany, e.g. a 10 year German Bund, is slightly below zero. This justifies an overall rate of return of approximately 6%.

[7] Because of the tight real estate markets, this discount could have declined more recently. Assuming a discount of zero would reduce the estimated effect on aggregate collateral values by about 1 percentage point.

Figure 2: *Energy price impacts across NGFS scenarios*



*Notes:* The left panel shows implied discounts given paths for future energy prices in each scenario for houses. The right panel shows the aggregate increase in discounts relative to the (*Current Policies*) scenario, aggregated using volume weights among houses and apartments. Volume weights for each label measure the share of the total value accounted for by a given label, with value approximated by the quoted price. See the main text and Appendix B for more details.

scenarios primarily reflects the differences in underlying changes in taxes, as we noted above. Hence, under these scenarios, the changes in taxes overcompensate the decrease in energy prices, resulting in drastically higher discounts. In the right panel of the figure, we aggregate these values using the empirical observed share of volume (sum of offer prices by label) for each label.[8] These figures represent percent changes in average discounts relative to the baseline scenario. Depending on the scenario, property valuation could decrease considerable reaching by 14% and 8% for houses and apartments under *Net Zero 2050*, respectively, and about 10% for Germany as a whole.

## 5.1 Robustness check

By design, the impact of the energy price expectations will be larger if the fraction of inefficient labels (properties) is higher. Since we base these weights on the online advertisement data, there might be a selection bias if the label distribution does not adequately reflect the true efficiency distribution of the stock of housing. While we cannot check whether or not this is the case directly, we can check whether the age distribution we observe is accurate. We do this because descriptive statistics show that the age of a building is correlated with its energy efficiency. To this end, we use data from the German Statistical Office that groups apartments in each federal state in mutually exclusive age bins based on the year of construction. We then compare this distribution to the corresponding distribution in our data, where we

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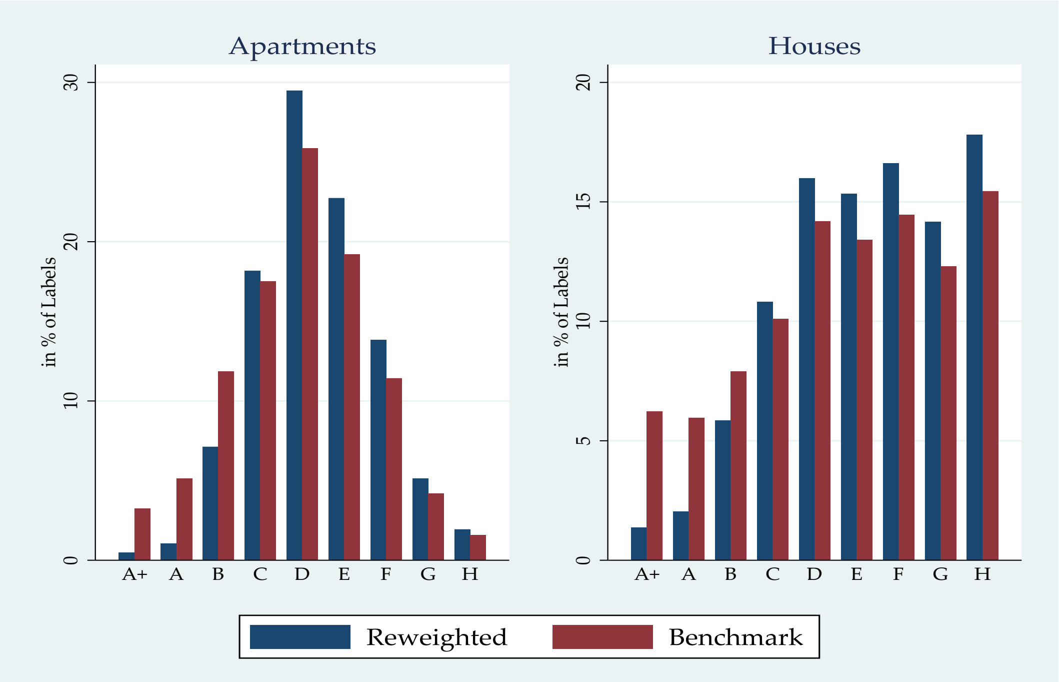
[8] Using the fraction for each label from table 1 leads to similar results. Reporting results by volume-weight seems more appropriate as this also accounts for heterogeneous absolute prices, a proxy for value and loan volumes.

use the same dataset as for the baseline computations.

Figure 3: *Comparison of benchmark and re-weighted label distributions*



*Notes:* Re-weighting in done at the state level but the figure shows only the aggregate distribution for Germany. The "benchmark"-numbers correspond to the numbers reported in table 1.

It turns out that the online advertisement data is in fact skewed towards younger vintages, and we observe fewer old buildings than the official statistics indicate. As a robustness check, we then take account of this by re-weighting the data in such a way that the implied distribution over year-of-construction bins equals the official data and repeat the policy experiment with the minimum energy requirements only. We do this in the following way: For every federal state we calculate the fraction of observations that belong to the official bins. We then calculate, within each state and for each bin, an adjustment factor as the ratio of the official fraction and the observed fraction of observations. Formally, if $N$ denotes the total number of observations, $N_s$ the number of observations in state $s$, $N_s^b$ the number of observations in bin $b$ in state $s$, and $\omega_s^b$ denotes the corresponding fraction in the official data, the new weight for each observation in state $s$ and bin $b$ is

$$\tilde{w}_{i,s}^{b} = \frac{1}{N_s^b} \omega_s^b \frac{N_s}{N} \tag{3}$$

From right to left, of the $N$ total observations, we know that $N_s$ belong to federal state $s$. The official data then tell us that a fraction $\omega_s^b$ falls into bin $b$ in that state. Lastly, this mass is equally distributed among the $N_s^b$ observations in that bin. Note that we take the age-distribution as an exogenous calibration target but the object of interest – the distribution over labels – is endogenous. Alternatively, we can think of this procedure as being able to draw from the bins in each state according to the official distribution, keeping the number of observations the same as we observe them in the data. This means that if in the original data we observe a larger fraction of young buildings than the official data indicate, their weight decreases after re-weighting, and vice-versa. When implementing this correction, we use the same official distribution for houses and apartments as no such distribution is available for houses.[9]

The results of this exercise are show in Figure 3 and reveal that the new distribution over labels puts considerable more mass on less efficient labels, consistent with the observation that our sample is "too young". On average the new distribution over labels becomes by about 1 notch less efficient. As a results, aggregate losses in collateral value amount to about 13%. This suggests that the baseline results might be a lower bound.

## 6 Conclusion

In this paper, we investigate by how much residential real estate (RRE) valuation could change depending on expectations of market participants regarding future developments of energy costs. Our analysis shows that climate scenarios featuring prominently rising costs of energy have little impact on valuations for efficient buildings, but imply stark drops in prices of inefficient ones. Scenarios with such cost paths are the ones in which climate targets are met, meaning that from the RRE valuation perspective, successful climate policies could come with significant losses of collateral value. Lastly, we show that the aggregate impacts of the scenarios can potentially also be large, depending on the scenario. Comparing the least and most intrusive policies in terms of $CO_2$ taxation, we find that for Germany as a whole the valuation decrease reach 11% of the underlying value of RRE in our baseline analysis, and 13% in the robustness exercise.

However, we note that we lack the data to go beyond the price effects and investigate potential impacts of different climate scenarios on the banking sector. For this we would need loan-level data on lending conditions and energy efficiency of buildings serving as loan collateral. Without such data we also cannot assess whether efficiency standards are part of the risk assessment on the side of banks. A crucial aspect of climate policies should therefore be the improvement of data availability, such that the impact of climate change and climate policies on the financial system can be better assessed.

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[9] While this is not optimal, this procedure makes our sample for houses "older" and less efficient when compared to the original data. This is consistent with our aim to generate more conservative results. Note, however, that it could also be the case that older buildings are more often torn down rather than renovated, in which case their age would have no bearing on the energy efficiency of the housing stock. In this case, the official statistics would not be representative for the sales market and the effects from the robustness check would overstate the effects.

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# Appendices

## A Details on data preparation

From the original data provided by the *RWI - Leibniz-Institut für Wirtschaftsforschung*, we keep houses and apartments offered for sale from 2014 onwards since energy information prior to 2014 is very sparse. In the original data, missing information is coded as negative values, which we replace as missing values. Next, we define our own variable indicating the EPC of a building based on the energy consumption variable provided in the dataset. Observations are classified according to Table A1 if energy consumption is strictly positive. The price per square meter is calculated as the asking price divided by living space. Age is simply calculated as the difference between the year the advertisement was placed and the year of construction. For some observations, the year of construction lies after the year of the advertisement. We exclude observations which are not yet constructed.

Next, we drop further observations in two steps. First, we remove duplicate observations based on the following characteristics: *House/Apartment*, *Postcode*, *county*, $1km^2$ *grid cell*, *price*, *plot area*, *living area*, *number of rooms*, *number of bedrooms*, *number of bathrooms*, and *floor*. In a second step, we remove observations which seem to be outliers. For apartments, we keep observations costing between 100€ and 10,000,000€ in total, between 100€ and 20,000€ per square-meter, have a living area between $25m^2$ and $500m^2$, and have no more than 10 rooms. For houses, we additionally require that the underlying plot area is between $50m^2$ and $10{,}000m^2$.

Table A1: *Mapping between energy consumption and labels*

| Energy consumption $\left(\frac{kWh}{m^2a}\right)$ | Energy label |
|---|---|
| $\leq 30$ | $A+$ |
| $\leq 50$ | $A$ |
| $\leq 75$ | $B$ |
| $\leq 100$ | $C$ |
| $\leq 130$ | $D$ |
| $\leq 160$ | $E$ |
| $\leq 200$ | $F$ |
| $\leq 250$ | $G$ |
| $> 250$ | $H$ |

*Notes:* The values displayed in the table are taken from Gebäudeenergiegesetz (2020), Annex 10.

## B Calculating implied discounts for different NGFS scenarios

Here we describe our way to arrive at final energy prices that we feed into our theoretical equations for the price discounts. In what follows, we suppress dependence of variables on the scenario to avoid notational clutter. Let $P_t^O$ and $P_t^G$ denote the Dollar price of oil and gas per barrel of oil equivalent, respectively. Further, let $\kappa^O$ and $\kappa^G$ denote oil and gas specific conversion factors that measure the amount of $CO_2$ per kWh of energy. Another constant needed is the amount of kWh equivalent to one barrel of oil equivalent, denoted $\gamma$. Lastly, define $T_t^{CO2}$ as the tax per tone of $CO_2$, and $\tau_t$ as the value added and energy tax rate. We then calculate the following to arrive at the final energy price:

$$\mathbf{P}_t^O = \kappa^O \frac{T_t^{CO2}}{1000} + \frac{P_t^O \mathscr{E}_t}{\gamma}$$
$$\mathbf{P}_t^G = \kappa^G \frac{T_t^{CO2}}{1000} + \frac{P_t^G \mathscr{E}_t}{\gamma}$$
$$\mathbf{P}_t = (1+\tau_t)\left(\omega^O \mathbf{P}_t^O + (1-\omega^O)\mathbf{P}_t^G\right)$$

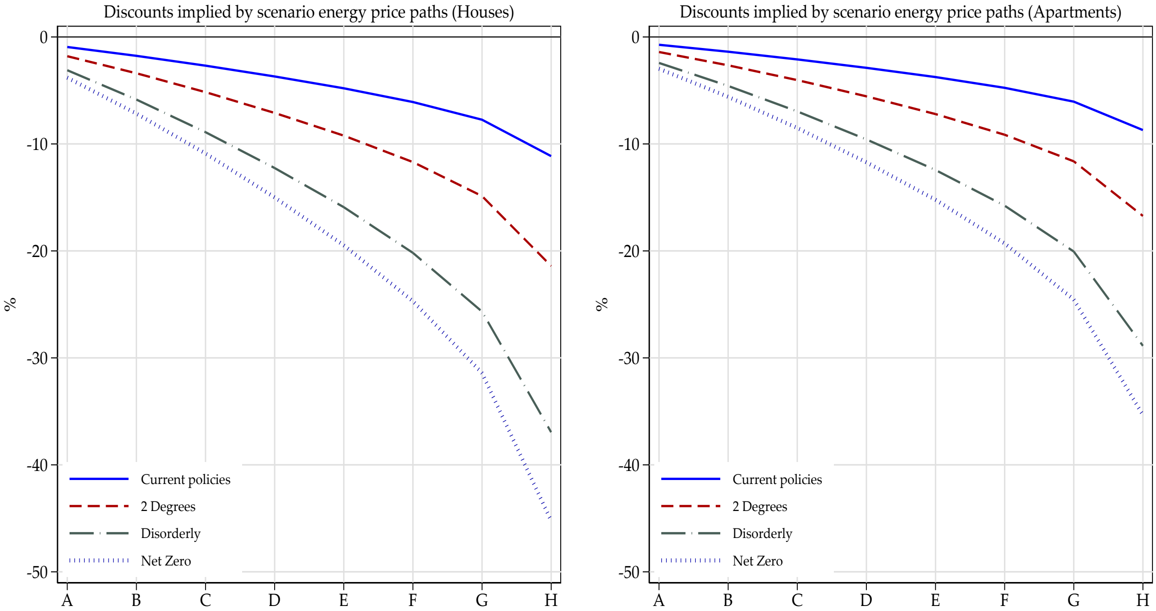
where bold letters denote prices in € per kWh energy. For oil and gas, we convert Dollar prices to Euro using the exchange rate $\mathscr{E}_t$ and scale barrels of oil equivalent to kWh. To this we add the $CO_2$ tax, also measured in Euro per kWh. Lastly, using the weights in heating energy described in the main text, we arrive at the pre-VAT price, to which the VAT and energy tax rate is applied. These are the prices that we use to evaluate the running sum in the theory section of the main text. The following table provides a summary of the parameters, their units, and their values for the calculations above.

Table A2: *Values used to derive final energy prices*

| Parameter | Unit | Value |
|---|---|---|
| $\kappa^O$ | $\frac{kgCO_2}{kWh}$ | 0.287 |
| $\kappa^G$ | $\frac{kgCO_2}{kWh}$ | 0.238 |
| $\gamma$ | $\frac{kWh}{BOE}$ | 1700 |
| $\omega^O$ | % | 35 |

The following figure shows the NGFS scenario analysis for both houses and apartments as a supplement to the results in the main text.

Figure A1: *Energy price impacts across NGFS scenarios*



*Notes:* The left panel shows implied discounts given paths for future energy prices in each scenario for houses. The right panel shows the respective discounts for apartments.