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Carbon Neutrality in the Residential Sector: A General Toolbox and the Case of Germany *

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Abstract

This paper presents a general framework for estimating the renovation and investment requirements associated with a green transformation of the residential sector that effectively reduces the net emissions of the residential sector (close) to zero. The framework takes ecological and distributional considerations into account and aims to provide concrete outcomes suitable to inform policy-making, while being as parsimonious as possible on the side of data requirements. All key steps associated with this framework are compiled in an openly accessible toolbox that can be adapted to different country-specific contexts. This paper takes the German case as an example to illustrate the main assumptions, data requirements, and outcomes that can be derived from this toolbox.

Keywords socio-ecological transformation, residential sector, net zero, just transition, sustainable infrastructure

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Introduction

Attaining carbon neutrality in the residential building sector is essential for successfully transforming modern economies to operate within the limits of planetary boundaries. This overall requirement gives rise to the more specific task of devising programs that facilitate such a transformation on domestic levels. We present a general toolbox that considers several key dimensions of interest suitable to assess, evaluate, or design such domestic programs. These dimensions include (1) the technological requirements for achieving a successful transformation, (2) the scale of effort required for implementing these technologies, (3) the investment costs associated with such an effort, (4) the economic impact of these investments, and (5) the distribution of the investment costs between the private and the public sector as well as within the private sector. The toolbox presented here explicitly incorporates the notion of a 'just transition' in the analysis by considering the impact of domestic action programs on distributional aspects.

The toolbox is available in open-access form and can be adapted to the situation in different countries[1]. Due to its modular structure, different components of the toolbox can be applied in isolation. We keep the data requirements of our framework as parsimonious as possible to ensure broad applicability. In this paper, we apply our toolbox to the case of Germany to illustrate its core functionalities and analytical potential.

The German building sector has, on average, suboptimal isolation standards and still makes heavy use of fossil energy sources. Since Germany committed to achieving climate neutrality by the year 2050, it represents a challenging and important case of application. A key motivation for developing our toolbox is the observation that no standardized procedure for calculating renovation requirements has been developed, although a plethora of studies on the ecological transformation of the German residential sector already exists (BCG, 2021; BMWi, 2015; Bürger *et al.*, 2021; dena and geea, 2017; ifeu *et al.*, 2018; Prognos *et al.*, 2021; Repenning *et al.*, 2018; Thomas *et al.*, 2022, e.g.). Most of these studies lack transparency and replicability regarding the renovation requirements as well as consistent definitions of key concepts like the renovation rate. In this respect, we follow the example of Ermgassen *et al.* (2022) to model domestic transformation pathways for the residential sector in way that is replicable and can potentially be transferred to other countries. In addition, a consistent blind spot of existing studies is that the socio-economic impact of the proposed policy measures is not analyzed. In this paper, we bring more clarity into technical requirements as well as economic consequences associated with a socio-ecological transition of the residential sector in a transparent and reproducible way.

Results

To reach the goal of climate neutrality by the year 2050, Germany set emission targets for all relevant sectors, including the residential sector (Section 4 of the Federal Climate Change Act (Klimaschutzgesetz, KSG)). The direct carbon dioxide (CO_2)-equivalents attributed to the German residential sector are estimated to account for 14% of overall emissions in Germany, while this share increases to at least 25% when also considering indirect emissions (Thomas *et al.*, 2022).[2] The German residential sector consists of 19,4 million buildings. The majority of these are single or two-family houses (83%), while the remaining buildings are apartment buildings containing an average of seven flats (dena, 2021). Information on the quality of insulation and the type of heating system is collected in energy certificates (Sections 79-88 of the Buildings Energy Act (Gebäudeenergiegesetz, GEG)) that contain information on the year of construction, the last renovation, the heating system, and energy requirements. These data indicate that German heating systems are still mostly based on fossil energy sources as nearly 70% of all heating energy is provided by decentralized oil and gas heaters. In contrast, only 17% of all energy devoted to heating draws on renewable energy sources (BMWi, 2022; dena, 2021). Against this backdrop, we first elaborate on the technical requirements before moving on to economic requirements and the consequences of the socio-ecological transition.

[1]The source code of the model is available via GitHub

[2]Direct emissions entail all emissions that are directly *produced* within the residential sector (e.g. through gas-based heating systems), whereas indirect emissions include all emissions that are *consumed* in the residential sector(e.g. electricity-based heating systems).

Technical Requirements: Reduction and Decarbonization of Energy Use

Existing studies on the transformation of the German residential sector show a strong consensus on suitable technical strategies to achieve the climate goals: Reducing carbon emissions can be achieved by a combination of renovations dedicated to improve energy efficiency and the replacement of fossil-based decentralized heating systems. The latter typically relies on heating pumps, that use emission-free ambient heat as well as the expansion of district heating.[3] While following this line of argument, we also take into account that replacing fossil fuels in the residential sector reduces *direct* emissions, but may increase *indirect* emissions as heating pumps require electricity to operate. To capture this potential outsourcing of heating-related emissions from the residential sector to the energy sector, we focus on the *emissions intensity* of the German residential sector. This more inclusive measure also captures all indirect emissions induced by heating and thereby allows for a holistic assessment of how changes in the residential sector impact net emissions created.

Renovation Rate Two different concepts have been dubbed 'renovation rate': First, the share of buildings that are subjected to some form of renovation and, second, the share of square meters that are subjected to a 'full renovation' (where partial renovations are aggregated into full renovations). As these concepts differ substantially, we try to achieve clarity in our analysis by defining the *renovation rate* as the share of buildings that undergo some form of energy-efficient renovation, whereas we will call the share of fully renovated living area the *full renovation equivalent*.

Currently, the full renovation equivalent in Germany is approximately 1.15% (own calculation based on Prognos *et al.*, 2021). Past studies typically recommend increasing the full renovation equivalent to 2%. We show that this will not be sufficient to reach the climate goals. Based on our assumptions, it is necessary to increase the full renovation equivalent to at least 2.4%, which corresponds to a renovation rate of 3% per year. In other words, the analysis facilitated by our toolbox suggests that prior studies have underestimated the necessary renovation rate. To complement and contextualize this main result, we additionally show that an increased renovation rate must be paired with a decarbonization strategy for external energy sources and a prioritization strategy that puts the renovation of badly insulated buildings first. These results are summarized in Figure 1, Panels (A) and (B), which show how different assumptions impact the speed and intensity of emission reductions and plot these reductions relative to the official climate goals.

Prioritization There is a significant difference between renovating buildings in a random order and prioritizing the renovation of the worst-performing buildings. Both renovation strategies can, in the long-run, achieve climate neutrality. However, to achieve conformity with the climate targets over time, a prioritization of the worst-performing buildings is necessary (see Figure 1, Panel (C)).

Decarbonization The need to decarbonize external energy sources applies to the energy sector, which provides the main energy source for heating pumps, as well as to the provision of district heating. In this context, our toolbox allows for mapping the relative contribution achieved by decarbonizing these heterogeneous energy sources as illustrated in Figure 1, Panel (D). For doing so, we employ the notion of *emission intensity* in the residential sector as defined in section . This measure will be closely aligned with conventional estimates based on direct emissions if all external energy sources are truly decarbonized (see Figure 1, Panel (E)), while differences will emerge as soon as outsourcing to other sectors occurs (as already observed in Figure 1, Panels (B) and (D)).

Financial requirements, economic impact and distributional aspects

Financial Requirements Currently, the annual sum of expenditures for energy-efficient renovations in Germany amounts to roughly 58 bn €. According to our calculations, implementing energy-efficient renovations as described above would induce additional costs of about 58 bn € per year. The total investment until 2050 sums up to 3.1 trillion € (in 2023 prices). Prioritizing the renovation of the worst-performing buildings implies that an over-proportional share of total costs occurs in the early years. In the first year of the policy measure, additional costs of 81 bn € are anticipated,

[3] However, at the moment district heating in Germany still relies heavily on fossil fuels as only 12% are provided through renewable sources such as biomass, organic waste, geo- and solar thermal energy and waste incineration (BDEW, 2021).

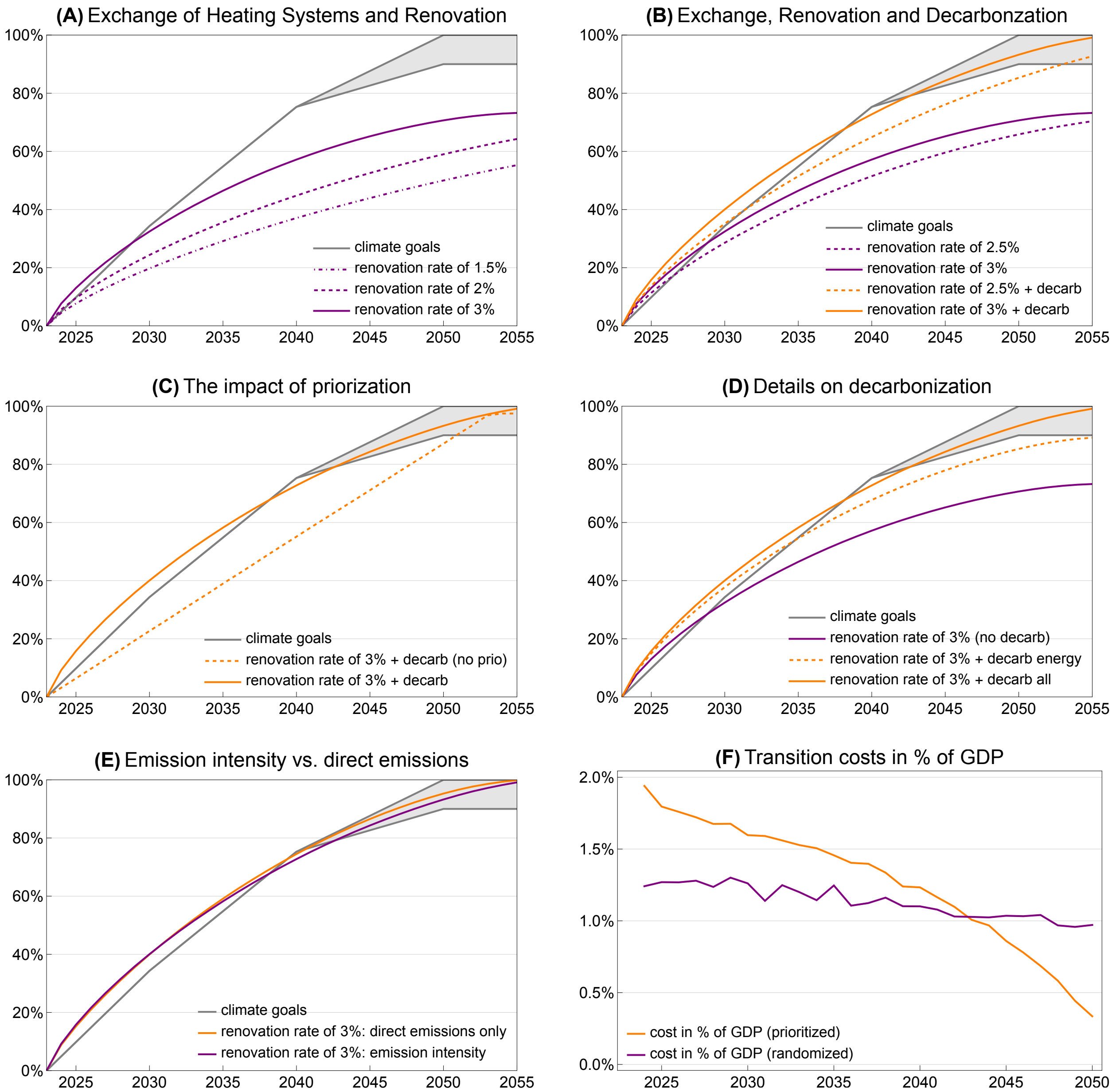

Figure 1: Emission reductions in the residential sector: Panels (A)-(E) show expected emission reductions under different scenarios, while Panel (F) shows expected (additional) costs arising in a full-decarbonization scenario with a 3% renovation rate.

which amounts to about 1.9% of GDP, which over time decreases to 0.3% (Figure 1, Panel (F)).[4] As discussed below, we propose combining targeted public subsidies with regulatory means to meet these requirements. Regulatory means are thereby relevant for an effective prioritization of renovations, i.e. for renovating the worst-performing buildings first, but also to ensure that owners, who do not qualify for a subsidy, cannot delay renovation measures.

Economic Impact These additional investments in the residential sector have direct economic consequences, which are explored by making use of an input-output model. We find a – comparatively low – GDP multiplier of 1.16, which implies that every € invested in transformation measures will increase GDP by 1.16 €. This result is due to the low pre-production intensity of the affected sectors and the fact that many intermediate goods required for such an investment initiative need to be imported from abroad[5].

Our toolbox can be used to assess potential capacity constraints. We find that initiating the suggested transformation will increase employment in the construction sector by approximately 274,000 workers. In the early years, this demand can range up to a maximum of 377,000 workers. Long-term estimates of labor market development in the German construction sector argue that this additional labor demand could be met through a decline in new construction projects (Dorffmeister, 2020). Zika *et al.* (2022) even points to an endogenous decrease in labor demand in the construction industry by 60,000 by 2030 and by 220,000 by 2040 – a trend that could potentially be further intensified by recent ECB interest rate hikes. This leaves a substantial pool of labor in the new construction sector that can be utilized for increased renovations of existing buildings, especially when taking into account the possibility of reallocating the existing workforce from the construction of new buildings toward renovation. Such a reallocation is also advisable when taking into account that the construction of new building contributes significantly to net emission output (see Drewniok *et al.*, 2023a,b).

Distributional aspects The distribution of residential property in most countries is highly uneven as large shares of residential property are held by households at the upper end of the wealth distribution (OECD, 2022). Hence, funding the transformation with a watering-can principle might be effective in technical terms, but it would redistribute taxpayer money from less wealthy individuals toward – already comparably wealthy – residential real estate owners. This would further speed up observed secular trends towards increasing inequality (Frick *et al.*, 2012) and is also likely to reduce public support for such measures (Dabla-Norris *et al.*, 2023). According to HFCS data, the wealthiest 10% of the German population own 48% of residential wealth while the least wealthy 50% only own 3% of real estate property. These observations indicate that possible subsidies should ensure to not intensify wealth concentration.

Energy-efficient renovation measures on residential buildings lead to an increase in the value of the affected properties. If the properties were owned by private individuals, a subsidy would imply subsidizing private wealth. To avoid such a constellation, we assess the economic capacity of subsidized households based on private wealth and suggest to incorporate this into the subsidy decision. We argue that it is reasonable to link the extent of public subsidy to the (net) wealth position of subsidized households to (a) guarantee support to those who cannot afford the necessary renovation efforts, and (b) avoid using general tax revenues to subsidize the wealth of the richest households.

Specifically, we propose that a given segment of the least wealthy households receives funding for the full cost of the necessary renovations, whereas some upper segment of the wealthiest households has to bear the full cost of the renovations – for households falling between these wealth extremes, the subsidy rate can be determined through linear interpolation.[6] According to our calculations, the German government would cover approximately 26% of the financing needs for buildings owned by private households (which corresponds to 21% of total costs when also taking institutional ownerships into account). This amounts to average public costs of around 24 bn € annually.

[4] In this context, we assume a real annual GDP growth rate of 1% and an inflation rate in the construction sector that corresponds to the overall inflation rate.

[5] Most imports are generated in the following sectors: *Specialised construction works*, *Rubber and plastics products*, *Chemicals and chemical products*, *Ceramic products, processed stone and clay*, *Coke and refined petroleum products*, *Machinery*, *Glass and Glassware*, and *Electrical Equipment*.

[6] In our baseline application we employ threshold values of 65% (to demarcate the poorer segment that is fully subsidized) and 90% (to demarcate the richer households, which should receive no public funds), but these numbers could be adapted to local circumstances. The implementation of such a measure could be based on self-declarations of households, subject to random audits, in a rapid, efficient, and data protection-friendly manner.

For institutional owners, we suggest considering discounted costs instead of full costs and restricting the use of subsidies to those renovation costs that cannot be amortized within thirty years. The main reason for this assumption is that institutional owners typically have a longer planning horizon and benefit directly from the impact of renovations on balance sheets, which often leads to an increase in equity that compensates a significant fraction of the investment costs even before cost-reductions are realized.

Discussion

This paper is concerned with the question of how to conceptualize a trajectory towards climate neutrality in the residential sector. Using our toolbox, we find that this trajectory differs significantly from the estimates given in existing studies. The full renovation equivalent necessary to reach German climate goals is at least 2.4% – higher than previously expected. Additionally, we find that, to stay in line with the climate targets, worst-performing buildings need to be renovated first. The required high renovation rate and prioritization imply a need for regulatory measures. A second major finding is related to sector linkages. Typically, the focus on a single sector takes direct emissions as a natural benchmark, which overlooks the potential outsourcing of direct to indirect emissions. By focusing on *emission intensity* as a key concept, we take implications for the energy provision into account to provide an integrated assessment demonstrating the need to decarbonize external energy sources.

Our estimates of the investment required to reach necessary renovation rates are also higher than in previous studies. This is partly due to the higher renovation rate and partly to the fact that existing studies usually employ a net present value method when calculating investment costs.We argue that this approach is not suitable for private owners since, other than institutional owners, they are faced with a more short-term planning horizon. Also, this setup leads to a high variation in existing estimates of the required investment and has contributed to confusion on what costs to expect as well as on what economic impact the investment might have. According to our calculations, an additional yearly investment of 58 bn € is needed (which, on average is below 1.3% of Germany's GDP).

We further study the economic impact of this investment in an input-output framework. Due to a high dependency on imports (30% of initial investments), the multiplier of 1.16 is relatively low. While material bottlenecks are not expected, the investment strategy will generate an average of 274,000 new jobs in the construction sector. A drawback of the input-output method is that it cannot account for possible economies of scale effects arising from such investment. Such effects would reduce overall cost, import-dependency and help to avoid labor shortages. The results of our analysis have two important policy implications. First, creating an innovation-friendly environment in Germany could both help to reduce the import dependency and foster scale effects, thereby reducing costs and the required workforce. Second, measures to avoid short-term labor shortages could support the transformation.

Finally, we provide a financing model that, in the sense of a 'just transition' takes the highly unequal distribution of wealth into account. We propose that the state fully subsidizes renovation measures for the least wealthy households, while the wealthiest should carry the entire costs themselves. Households between these two groups could be subsidized according to a linear function. Providing subsidies conditional on household wealth, (a) can increase support for the necessary renovation efforts, and (b) avoids subsidizing the richest households' wealth. We develop a scenario for illustrative purposes in which the lowest 65% in the wealth distribution are fully subsidized whereas the highest 10% are not subsidized at all.[7] In this scenario, the state would carry 26% of overall renovation costs.

A financing model fit for a socio-ecological transformation has to also take into account the situation of tenants. In Germany, the share of households who live in rental units is above the EU average. It is, therefore, especially important that renovation costs are not passed on by owners (who are already subsidized according to their wealth) to the tenants. According to the 'landlord/tenant dilemma', energy-efficient renovations benefit both parties. While tenants benefit from renovations with lower energy costs and higher living comfort, landlords increase the economic value of their properties. It is therefore not immediately clear who should bear the costs of energy-efficient renovation (Ástmarsson *et al.*, 2013). While it is generally allowed in Germany to pass on renovation costs to tenants via increased rents, it remains controversial whether and to what extent such rent increases can be justified in the long term by lower energy

[7] These thresholds can be adapted to local circumstances.

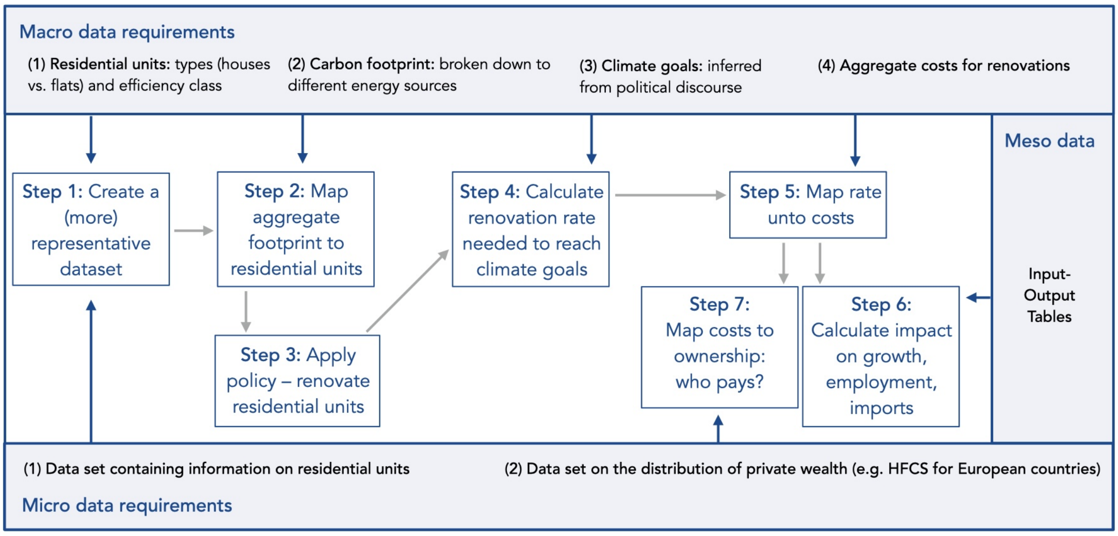

Figure 2: This graph shows the steps necessary to derive reliable results and viable policies on the transformation of the residential sector. All these steps can be also applied in isolation.

costs for tenants (see, e.g. Enseling and Hinz, 2006; Galvin and Sunikka-Blank, 2012). Against this backdrop, additional regulatory measures seem required for the German case to ensure that transition costs are not passed on to renters.

Method

In this section, we present our toolbox that can be used to compute different transformation scenarios for any country of interest. Figure 2 summarizes the main steps of the underlying procedure to derive the necessary renovation rate (steps 1 - 4), associated costs (step 5), the overall economic impact (step 6), and related policy measures that are both considerate of distributional factors and fit to conduct the transformation (step 7). The toolbox makes use of a variety of macro-, meso-, and micro-data. An overview of the data necessary to replicate our study for other countries can be found in Table 1.

Getting the Sample Right

In our toolbox, we assume the availability of microdata on the residential sector. As available data might not be representative of core dimensions of interest, we employ a two-dimensional stratification approach that replicates the known aggregate distribution of (1) housing types and (2) energy efficiency classes. By doing so, we provide a useful starting point to avoid biased results due to selection problems. In addition, the toolbox allows the extraction of aggregate properties from the stratified sample that can be compared with available macro-information, such as the average energy efficiency per square meter and year, to verify the validity of the stratified sample.

For the German case, we use the RWI-GEO-RED Real Estate Data, a dataset that provides information on the German real estate sector. It consists of raw data from the real estate platform *immoscout24.de* on which owners of residential properties provide excessive information to potential tenants and buyers, including data on heating facilities and energy requirements. The RWI dataset is, however, not representative of Germany as older single or two-family houses are less likely to be rented out or sold. Since these buildings tend to have a low energy efficiency class, this leads to an underrepresentation of low energy efficiency buildings in the RWI sample. We counter this shortcoming by applying *step 1* of our procedure as described above.

This method reproduces quite accurately aggregate information on the distribution of efficiency classes dena and Krieger, 2019. Plausibility checks support the thesis that our stratified data is representative of German residential buildings.

Table 1: Data requirements of the toolbox for analyzing transformation requirements in the residential sector

Information	Source
Aggregate Level	
Distribution of energy efficiency classes across residential buildings (ideally including information about the distribution across both single- and two family buildings and apartment buildings)	dena and Krieger (2019)
Distribution of single- and two-family buildings and apartment buildings	dena (2021)
Residential units per efficiency class	dena and Krieger (2019)
Distribution of heating sources	Bundesministerium für Wirtschaft und Klimaschutz (2019)
Aggregate efficiency per square meter per year	dena (2021)
Emission factors for relevant energy sources	Bettgenhäuser and Boermans (2011) and Icha and Lauf (2023)
Total cost of energy-efficient renovations in 2014 (including exchange of heating systems)	Gornig *et al.* (2015)
Full renovation equivalent apartment buildings	Prognos *et al.* (2021)
Full renovation equivalents single and two-family buildings	Prognos *et al.* (2021)
Cost of heating pumps including installation	Thomas *et al.* (2022)
The relative surface area of windows, walls, basement ceilings, and roofs per building	Beuth Hochschule für Technik Berlin and ifeu (2015)
Cost for material and installation of windows, walls, basement ceilings, and roofs per building	Beuth Hochschule für Technik Berlin and ifeu (2015) and Frahm (n.d.)
Sector Level	
Construction cost index	Statistisches Bundesamt (2023)
Input-Output Data	destasis (2023)
Micro Level	
Average size of both single- and two-family buildings and residential buildings	ImmobilienScout24 (2022a,b,c,d)
Type of heating (energy source) for each residential unit	ImmobilienScout24 (2022c,d)
Distribution of net wealth and residential wealth	textitEurosystem Household Finance and Consumption Survey (HFCS)

The Aggregate Footprint

To be able to test different renovation strategies on our dataset, we first need to derive an accurate estimate of the aggregate emission footprint for our dataset. To do so, we combine information on heating systems and the insulation of buildings and link them to their corresponding emission factors to assess the aggregate emission footprint of our adjusted sample. This allows us to calculate the emissions for each building in the sample before and after a renovation is undertaken. When doing so, we use the concept of *emission intensity* to capture the effect of different transformation paths on direct as well as indirect emissions.

The latter aspect is especially relevant as, to this day, electricity supply as well as the provision of district heating in many countries remains strongly dependent on the use of fossil fuels (Statista, 2022), which reduces the positive effects achieved by switching from fossil-based heating to electricity-based or district heating. In this context, our toolbox captures both dimensions – the respective reduction in direct emissions as well as the potential rebound-effect in terms of indirect emissions – and allows for a comparison across different scenarios.

Deriving the Necessary Renovation Rate

A successful transformation will require both a reduction of energy use through improved insulation as well as decarbonization of energy provisioning. As a consequence, our toolbox requires key assumptions on both dimensions. For insulation, we assume that the efficiency level reached by renovated buildings is 60kWh/m^2. Regarding alternative heating systems, we randomly assign all buildings one of the available emission-friendly heating systems. Specifically, we assume that 25% of all buildings are suitable for district heating (mostly in urban areas, see also Fraunhofer IEE, 2021), while the remaining 75% of all buildings will be equipped with a heating pump. The coefficient of performance (COP) for a heating pump is set to 3.1 [8].

Building on these assumptions, we determine the necessary renovation rate within the residential sector by executing our model for different renovation rates and comparing the related emission savings. The relevant climate targets can be extrapolated from policy documents or taken from scientific assessments [9]. As soon as the necessary renovation rate is determined, the full renovation equivalents can be computed by assessing the share of renovated square meters in our sample.

Mapping the Costs

To assess the economic aspect of the transformation process, we extrapolate information on current aggregate costs for energy-efficient renovations to the rate of full renovations required to achieve the necessary renovation rate. Specifically, we take into account information on the total costs of energy-efficient renovations, including the change of heating systems, as well as full renovation equivalents for houses and apartment buildings for a given year to extrapolate current costs to later periods. For doing so we employ a flexible framework, that allows for differentiating between fixed renovation costs per building and size-dependent costs, where the latter reflects differences in average size across both types of buildings.[10]

If the information on renovation costs dates a few years back, costs should be adjusted to match the current price level using a price index π. For extrapolating costs to future periods, we use the number of renovated houses and apartments as produced by our toolbox to calculate expected costs in prices of 2023 – as already indicated, we assume a real annual GDP growth rate of 1% and an inflation rate in the construction sector that corresponds to the overall inflation rate for doing so. As well-insulated buildings that do not yet use a heating pump exist, the number of required heating pumps might exceed the number of renovated buildings, which could lead to a downward bias in estimates of expected costs. To account for these possible additional costs, we use the share of buildings that get a new heating pump as well as available information on the average cost associated with the installation of such a heating pump to employ a correction if required.

Assessing the Economic Impact

We analyze the economic impact of our policy suggestion in an input-output model (Miller and Blair, 2009) that can be calibrated with the latest available data from the respective country to calculate the value added, workforce requirements, and the required domestic and foreign input factors. In addition to direct effects primarily concentrated in the construction and electrical engineering sectors, the proposed input-output analysis considers indirect effects (additional production in supplying industries) and induced effects (additional consumer demand resulting from the income growth associated with increased production). Since input-output modeling is based on linear extrapolations, potential price changes and scale effects are not accounted for in the model. Therefore, the results of the model need to

[8]Heating pumps run on electricity with high efficiency as measured by the coefficient of performance (COP). We set the COP to the average of heating pumps where 1 kWh of electricity can provide 3.1 kWh of heating energy (Fraunhofer ISE, 2013).

[9]For the case of Germany, emissions in the residential building sector need to be lowered to 67 megatons of (CO_2)-equivalents until 2030. By 2040, overall emissions need to be reduced by 88% compared to 1990 (Attachments 2 and 3 to §4 *Klimaschutzgesetz* (Federal Climate Change Act, KSG)). In the residential sector, emissions in 1990 were 210 megatons (Statista, 2024), that is, until 2040, emissions need to be lowered to 25.2 megatons. Until 2050, climate neutrality needs to be reached. We assume that this can be done by lowering emissions to 90% of their current level.

[10]The relation between fixed and size-dependent costs can be determined by the user to explore the impact of different assumptions on cost structures in the construction sector. For the *German case* we assume that a quarter of all costs are fixed costs.

be compared with current assessments of long-term labor market developments and potential scale effects to realistically assess the actual labor demand.

To employ such a model, we need to estimate (1) the amount of investment *additional* to what is already spent on energy-efficient renovations per year as calculated in the preceding section and, (2) the distribution of costs across economic sectors. For the first step, we simply subtract current costs from expected costs (both for insulation measures and heating pumps) to arrive at the effective additional costs.

In the second step, it is required to assign these investments to different economic sectors. While a precise decomposition of costs across sectors is not strictly necessary to arrive at valid estimates, for the *German case* we distribute the costs for different renovation measures as accurately as possible between relevant economic sectors. Specifically, we use data on the relative average size of windows, exterior walls, basement ceilings, and roofs per building (Beuth Hochschule für Technik Berlin and ifeu, 2015), and on corresponding costs for material and installation (Beuth Hochschule für Technik Berlin and ifeu, 2015; Frahm, n.d.) to assign renovation costs according to specific economic sectors[11], which introduces greater precision in the corresponding estimates.[12]

In turn, the input-output model allows for an assessment of input requirements, which helps to identify positive side-effects (e.g. boost on growth and employment) as well as potential constraints (e.g. bottlenecks or import-dependencies) of a socio-economic transformation.

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[11] *Specialised construction works*, *Chemicals and chemical products*, *Ceramic products, processed stone, and clay*, *Glass and Glassware*, and *Rubber and plastics products*

[12] Since we have no information on the share of costs of heating pumps that goes into material and installation, respectively, we split up costs by assuming that 48% are attributable to the sector *Specialised construction works*, 40% to the sector *Machinery*, and the remaining 12% to the sector *Electrical equipment*.

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