

Inaccessibility Calculator: Unveiling Socio-Spatial Inequalities Arising from Barriers to Residential Energy Upgrades in Dortmund.

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Abstract:

Climate change has been the central topic in many policy discourses, with many countries and cities pledging their contribution to curb this issue. Despite successful strides in this direction, a rather complex issue under this umbrella is the issue of residential energy usage. In Germany, a significant portion of the building stock is old and energy inefficient, making renovation eminent for achieving their climate goals.

The paradox in this step is that the decision to renovate is in the hands of the owners. Any attempts to improve renovation rates have to be top down. The cities and administrators can only nudge owners in the right direction with proper incentives. While renovations reduce the city's overall consumption, their primary for individuals lie in improved thermal comfort and financial savings. Despite this prominent reliance on private decision-making, discussions of residential energy upgrades left out the different types of owners for a long time. Given the urgency of meeting climate targets, the increasing fuel vulnerability and growing exposure to thermal discomfort for citizens, it is necessary for city administration to prioritize their efforts in neighborhoods with acute challenges.

The thesis aims to identify such neighborhoods where renovation is inaccessible due to the presence of significant barriers. It does so by constructing a replicable method to study the renovation landscape of the residential buildings through the lens of the owners. Theory of Planned Behavior is used to dissect the decision making patterns of different owners, and the findings are marked spatially. Through this the thesis aims to unveil neighborhoods where socio-spatial inequalities make renovation is inaccessible. The aim to provide significant information to the city administration to focus their action towards creating maximum impact, allowing them to fasten their steps towards climate neutrality.

Index

Acknowledgment	2
Abstract:	3
1. Introduction	6
1.1 Research Problem.....	7
1.2 Objectives of this Research	8
1.3 Expected Outcomes.....	9
2. Methodology	10
2.1 Limitations	12
3. State of The Art	13
3.1 Global and European Level	13
3.2 Policy actions in Germany.....	14
3.3 Policy actions in Dortmund	17
3.4 Reflections	21
4. Conceptual Framework: Inaccessibility	23
The Theory of Planned Behavior.....	24
5. Impact of renovation: The case of Dortmund	29
5.1 Ownership Types	30
5.2 Property Types	39
5.3 Occupancy Types	46
6. Barriers to Energy Renovations	50
6.1 Findings from Individual Barriers.....	53

6.2	Survey Findings Vs Literature	81
6.3	Survey Findings Vs Ownership.....	85
6.4	Inaccessibility of Energy Renovations in Dortmund.....	86
6.5	Policy Implications.....	88
7.	Proposal – Inaccessibility Calculator	90
8.	Conclusions and Recommendations	93
	Appendix	95
9.	Bibliography.....	95
10.	List of Figures	102
11.	List of Tables	105

1. Introduction

Climate change has emerged as one of the most pressing global challenges, demanding urgent and coordinated action from governments, institutions, and individuals. The 2016 Paris Agreement marked a turning point in the international climate agenda, committing nations to limit global temperature rise to well below 2°C above pre-industrial levels (Broer et al., 2022). This agreement spurred a wave of comprehensive policies, plans, and international agreements aimed at reducing greenhouse gas (GHG) emissions and promoting sustainable development. Despite these efforts, public satisfaction with the outcomes of these measures often falls short, highlighting the need for a more people-centered approach to climate mitigation and adaptation.

Germany's Residential Energy Landscape

Within the European Union, Germany plays a pivotal role as both a major consumer and importer of energy. As of 2024, Germany was the third-largest electricity importer in the EU (Fraunhofer ISE, 2024). The country's energy landscape faced significant disruption during the energy crisis triggered by the Russia-Ukraine war, which led to the reactivation of coal plants and a subsequent rise in Green House Gas (GHG) emissions.

Residential households in Germany contributed 212 million tonnes of GHG in 2022, with private households responsible for 25% of these emissions (Destatis, 2022). Key contributors include energy-intensive activities such as heating, hot water production, electricity use, and lighting. Germany's housing stock, which is among the oldest in Europe, offers significant potential for energy savings through renovation.

A large proportion of Germany's buildings were constructed before 1918, during a period of low construction standards, resulting in poor energy efficiency (Aksoezen et al., 2015). Post-war housing construction from 1946 to 1979 further compounded this problem, as the focus was on meeting urgent housing demand rather than adhering to energy efficiency standards (Krapp et al., 2021). While these buildings, particularly those constructed during the post-war period, share uniform designs that make them easier to renovate, the overall renovation rate remains alarmingly low (Brohm, 2014; Galvin, 2023b).

Buildings constructed after 2009 comply with modern energy efficiency standards and typically do not require renovation (Galvin, 2023b). However, a large proportion of Germany's building stock predates these standards, making energy renovations essential for achieving the city's climate targets.

Dortmund's Residential Energy Landscape

In Dortmund, more than 90% of residential buildings were constructed before 2009, resulting in a high average energy consumption rate of approximately 138.2 kWh/m². This figure rises to 147.1 kWh/m² in vulnerable neighborhoods such as Nordstadt, aligning with broader trends in Germany's aging residential building stock (Aksoezen et al., 2015). Additionally, more than 47% of Dortmund's buildings were constructed in the decades following World War II, presenting significant potential for energy-efficient renovations (Galvin, 2023b).

Despite the energy savings potential, North Rhine-Westphalia (NRW)—the state in which Dortmund is located—reports a renovation rate of just 0.7%, equivalent to only 14% of all buildings in Dortmund undergoing energy renovation in the last 2 decades. Meeting Dortmund's emissions reduction target of 651,000 tonnes of CO₂ by 2030 will require at least doubling this renovation rate (Umweltamt, 2021). Given the shortened timeline to meet these climate goals, there is an urgent need to accelerate energy renovations across Dortmund's residential sector.

1.1 Research Problem

The Climate Air Action Plan 2030 (Handlungsprogramm Klima-Luft 2030), which aims to reduce emissions by 65% by 2030 and achieve climate neutrality by 2035, identifies two primary barriers to increasing renovation rates in the city:

- Limited understanding of owner incentives and barriers, leading to poorly designed policy interventions.
- Misallocation of efforts, where projects like 100 Energy Plus Houses for Dortmund succeeded by targeting interventions at specific local audiences, while broader, less targeted initiatives have struggled to achieve similar success.

Numerous studies have explored the barriers to energy renovation, often from the perspective of property owners. For instance, Ambrose, 2015 conducted in-depth interviews with 30 private landlords to understand the challenges they face in undertaking renovations. Aranda et al., 2017 employed complex modeling techniques to identify the most efficient renovation strategies for social housing, addressing key barriers such as high investment costs and long return periods. Taking a different approach, Trotta, 2018 analyzed the socio-demographic characteristics of individuals most likely to invest in renovation, focusing on the motivational factors influencing their decisions.

Several other studies have examined renovation barriers across different ownership and occupancy types. Some research has categorized barriers by ownership structure, such as Blomqvist et al., 2022 who classified obstacles faced by private, public, and cooperative property owners. Others, like Stieß and Dunkelberg, 2013, ranked barriers based on feedback from participants who had completed an energy-focused renovation versus those who had undertaken standard renovations for purposes such as aesthetic improvements or building extensions. These studies provide valuable insights into addressing Dortmund's first major challenge in increasing renovation rates.

However, while existing literature offers important perspectives on renovation barriers, it falls short in identifying where efforts should be concentrated spatially. This thesis aims to bridge that gap by developing an alternative approach to studying renovation barriers—one that enables their spatial mapping to guide targeted interventions.

1.2 Objectives of this Research

The primary objective of this research is to develop a practical and innovative tool that city administrations and stakeholders can use to enhance energy renovation rates in Dortmund's residential buildings. By bridging the gap between identifying renovation barriers and spatially mapping them at the neighborhood level, this tool will empower decision-makers to design and implement targeted, efficient, and impactful strategies.

The specific objectives of the research are as follows:

Identify barriers to energy renovation as perceived by owners: Investigate the perspectives of property owners on the key barriers hindering the adoption of energy renovations in residential buildings.

Determine priority areas for renovation: Develop a methodology to identify neighborhoods where energy renovations are most inaccessible.

Assess the impact of renovations on residents and property: Develop a methodology to identify neighborhoods where energy renovations impact most residents and property.

Enable targeted interventions: Develop a framework to help city administrations design tailored interventions and allocate resources effectively to address neighborhood-specific challenges.

1.3 Expected Outcomes

This research is expected to produce actionable insights and a decision-making tool that supports targeted energy renovation efforts. By focusing on neighborhood-specific barriers and opportunities, the tool will ensure that resources are allocated efficiently and effectively.

The expected outcomes of the research include:

Enhanced Renovation Strategies

A data-driven approach to highlight priority areas and provide insights into neighborhood-specific barriers, helping city administrators focus efforts where they will have the greatest impact and increase energy renovation rates.

Support for Climate Goals

Progress toward Dortmund's emissions reduction target of 65% by 2030 and climate neutrality by 2035, while contributing to Germany's national goal of climate neutrality by 2045.

Scalable and Adaptable Framework

A replicable tool that can be adapted to other cities facing similar challenges, providing broader applications for enhancing residential energy efficiency at a national or international scale.

2. Methodology

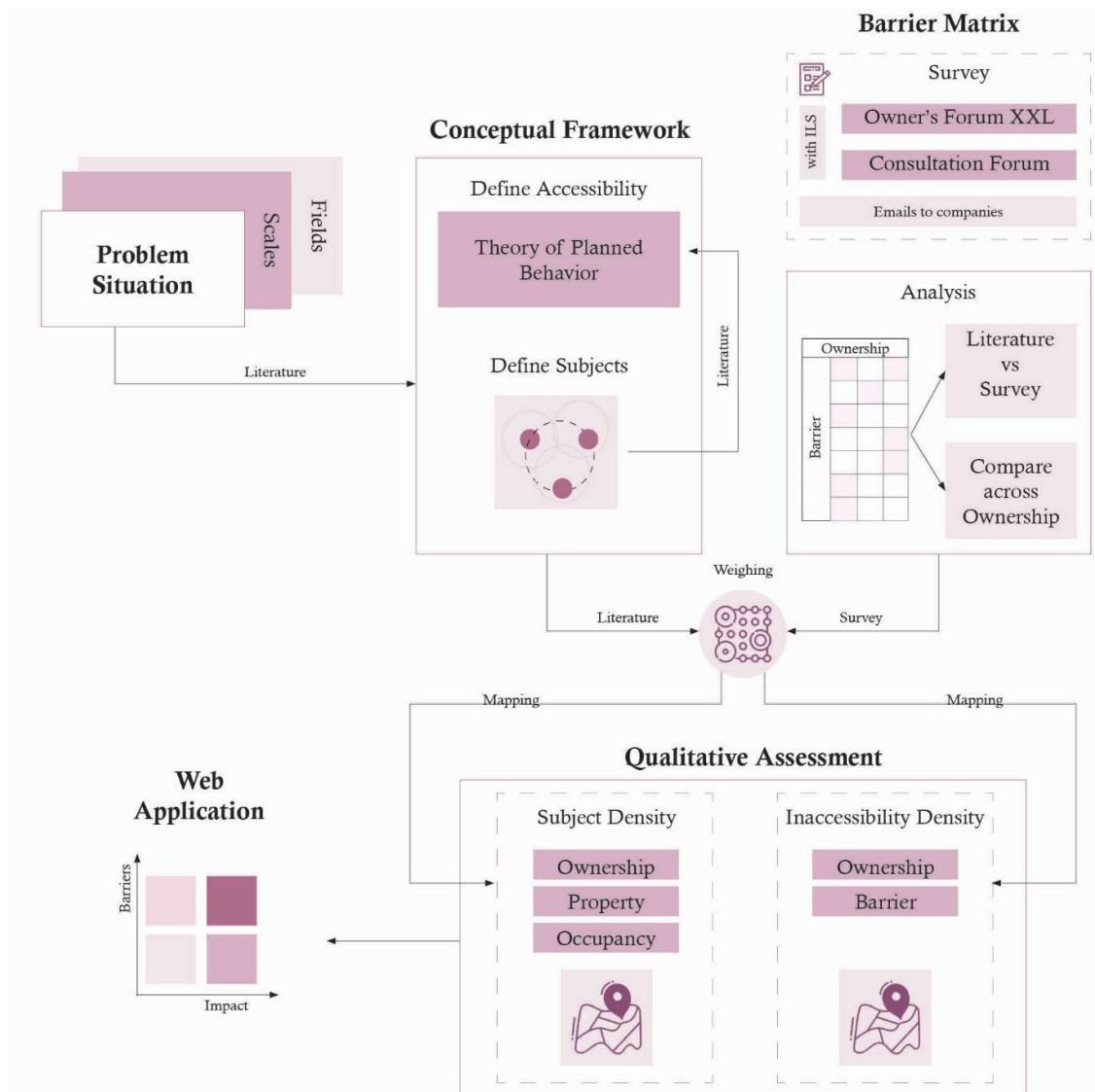


Figure 1 Methodological framework of the research. (Source: Author)

The methodology used in this thesis integrates both theoretical and spatial analyses to comprehensively assess barriers to energy renovation in Dortmund's residential buildings. The research follows a structured approach, using a conceptual framework grounded in the Theory of Planned Behavior to better understand owners' decision-making processes regarding renovations. This framework is coupled with a matrix approach, which was originally developed to assess ecosystem service potential, and is

applied here to spatially locate the intensity of the barriers faced by different ownership types in undertaking energy renovations.

The methodology is organized into the following steps:

Identifying Barriers and Creating the Matrix

The first step involved reviewing the existing literature to identify key barriers to energy renovation. A matrix was developed that outlines barriers faced by different types of ownership (private individuals, commonhold owners, housing cooperatives, private housing companies, public housing companies and NGOs).

Survey:

Using the identified barriers as basis a survey was designed to capture the perspectives of individual owners and companies in Dortmund. Owners were asked to rank the barriers they perceived on a Likert scale ranging from very little to very strong. This ranking provided insights into how significant each barrier is for different types of ownership. The qualitative assessment was converted into numerical values, with higher numbers representing a stronger perception of the barrier (very weak: 1, rather weak: 2, rather strong: 3, very strong: 4). In certain cases, a lack of motivation due to specific reasons was also considered a barrier to renovation.

The survey was originally conducted through the CATCH4D project at ILS, Dortmund, and distributed during the Owners Forum XXL organized by the Urban Renewal Office of Nordstadt. During the event, the survey was made available to the owners both online and as a physical copy.

Since this event is only attended by private owners, another set of online surveys was sent out independently to cooperatives, private housing companies, public housing companies and NGOs.

Spatial Analysis

Two results are generated during this step. First, geographic data- including property type, ownership patterns, and occupation types- were analyzed to identify trends and high-priority areas for intervention in Dortmund. This analysis provides insights that enable the administration to implement renovation strategies that benefit the maximum number of residents and properties.

Second, a matrix approach was applied to map the intensity of barriers across different neighborhoods. This analysis helps identify areas with high and low renovation potential based on the presence and severity of barriers, facilitating targeted policymaking.

These two results are then overlaid to classify neighborhoods into four distinct typologies based on the level of effort required for renovation and the expected outcomes.

Creation of Decision-Making Tool

The result is presented as a practical tool for the city administration, designed for integration into the city's online platform. This tool facilitates a strategic allocation of resources by pinpointing areas where interventions would be most effective, whether by prioritizing high-impact renovations or addressing neighborhoods facing significant barriers to energy efficiency improvements. By making this tool accessible, policymakers can implement more targeted and data-driven renovation strategies.

2.1 Limitations

This thesis relies on survey responses from property owners to build its final analysis. Currently, the findings are based on responses from 32 owners, comprising 17 simple private owners, 11 commonhold owners, 1 cooperative, 2 private housing companies, and 1 non-profit organization. Given the limited sample size, the results cannot be considered conclusive and should be supplemented with additional responses to ensure a more representative understanding of the perspectives of property owners across Dortmund.

Additionally, the ownership, property, and occupancy data used in this study are derived from the 2011 census, making them somewhat outdated. Since these datasets were not updated in the 2022 census, the research relies on older data. However, property ownership and building characteristics tend to change gradually, particularly in cities like Dortmund, where construction rates are relatively low. Therefore, while the study provides valuable insights, it should be updated as and when newer data becomes available to enhance its accuracy and applicability.

3. State of The Art

The thesis begins by establishing the relevance of the study and the urgency of addressing low renovation rates in residential buildings across multiple scales. It does so by analyzing policies and action plans implemented at various levels—global, European, national (Germany), and municipal (Dortmund)—to combat climate change, with a particular focus on their impact on the residential sector.

3.1 Global and European Level

The Paris Agreement

Addressing climate change mitigation and adaptation as a “super wicked” challenge necessitated international agreements, policy transformations, knowledge exchanges, financial mechanisms, and grassroots efforts aimed at reducing emissions and enhancing resilience (Reif, 2009). A pivotal step in this endeavor was the Paris Agreement (United Nations, 2015), a landmark treaty adopted by 196 nations in 2015 with the goal of limiting “the increase in the global average temperature to well below 2°C above pre-industrial levels” (Kinley, 2017; Tobin et al., 2018). Through Nationally Determined Contributions (NDCs), signatories outlined their respective strategies to achieve these targets, supported by frameworks for financial, technical, and capacity-building assistance. The EU established a Strategic Partnership for the Implementation of the Paris Agreement (SPIPA) along with 15 other major economies to promote cooperation in achieving this goal. Their combined efforts have been able to align policy actions on construction material and addressing waste at the other end (Broer et al., 2022).

The European Green Deal (EDG)

Building on the momentum of the Paris Agreement, the European Green Deal (EGD) (European Commission, 2019) represents the EU's strategic roadmap to align with these global commitments, with an interim target of reducing greenhouse gas emissions by at least 55% by 2030. These ambitions are operationalized through the “Fit for 55” legislative package, ensuring that all sectors, from energy and transport to agriculture and construction, align with emissions reduction goals. Progress is monitored and enforced under the European Climate Law (European Union, 2021), which codifies the EU’s climate neutrality targets.

A critical component of the EGD is its focus on decarbonizing the building sector, a significant contributor to energy consumption and emissions. As of 2020, buildings in the EU accounted for 40% of total energy use and 36% of greenhouse gas emissions, considering their entire lifecycle—from construction to use, renovation, and demolition

(European Commission, 2020a). Recognizing this, the European Commission launched the Renovation Wave strategy (European Commission, 2020b), which seeks to double the annual renovation rate for residential and non-residential buildings by 2030.

Energy Performance of Buildings Directive (EPBD)

To achieve these objectives, the Energy Performance of Buildings Directive serves as a cornerstone policy. Originally introduced in 2002 and progressively refined, the EPBD establishes comprehensive measures to accelerate the decarbonization of buildings across the EU. The revised EPBD of 2024 sets ambitious targets, encouraging each member state to reduce energy consumption in residential buildings by 16% by 2030 and 20-22% by 2035, compared to baseline levels (European Commission, 2024). It establishes zero-emission buildings as the new standard for all new constructions, ensuring that future buildings achieve high energy performance and rely on renewable energy sources (European Commission, 2024).

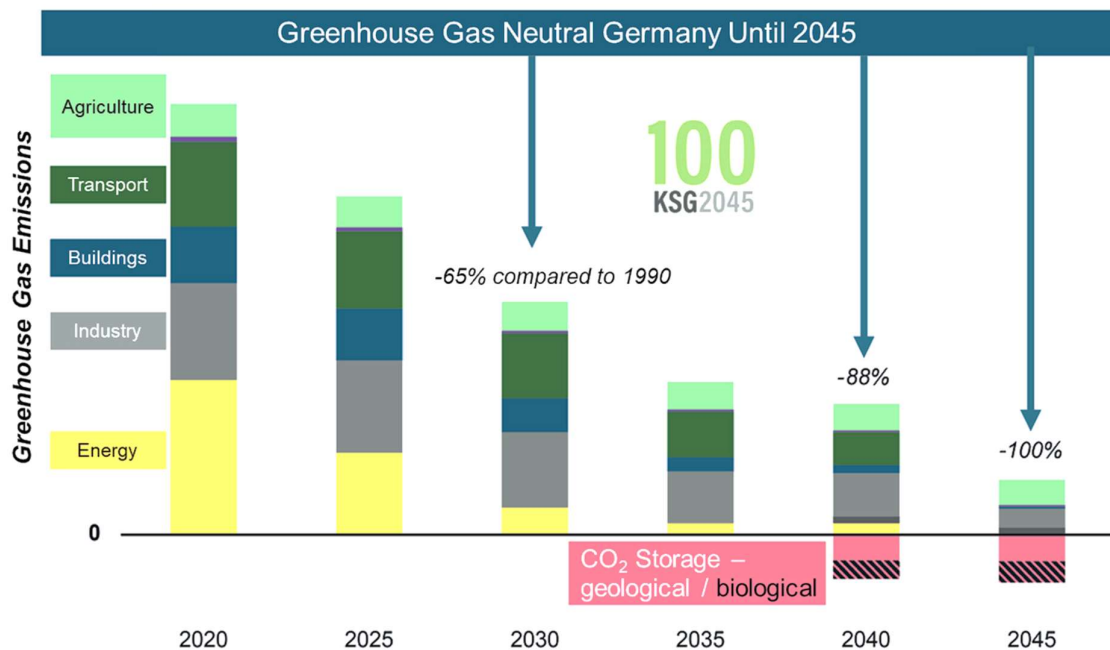
Recognizing the potential social impacts of renovation, the directive includes measures to protect tenants from ‘renovictions’—evictions caused by significant rent increases following energy renovation works. These safeguards aim to ensure that climate actions do not disproportionately burden vulnerable populations (European Commission, 2024).

Member states are also required to develop national Building Renovation Plans, which outline strategies to decarbonize their building stock and achieve the directive’s targets. These plans must detail the steps to overcome barriers such as financing challenges, workforce shortages, and regional disparities in building stock characteristics (European Commission, 2024).

3.2 Policy actions in Germany

Federal Climate Protection Act (KSG)

The Federal Climate Protection Act (Nationales Klimaschutzgesetz – KSG) lies at the core of Germany’s climate legislation. Stemming from the commitments under the Paris Agreement, it outlines Germany’s pathway to achieving climate neutrality by 2045 and becoming a climate-positive nation by 2050 (See **Error! Reference source not found.**). The KSG includes concrete measures and mandates each incoming federal government to submit a Climate Action Program within 12 months of taking office. This ensures the continuity of climate efforts regardless of political changes (*Federal Climate Action Act of 12 December 2019*. Federal Law Gazette I, p. 2513, 2019).



Error! Reference source not found.Germany's sector-wise emissions targeted (Source: Forschungszentrum Jülich, 2024)

The Climate Action Plan 2050 and its intermediate plan, Climate Action Plan 2030 provides the overarching framework and intermediary goals to be achieved respectively. They detail reduction steps across various sectors such as: the energy sector, industry, buildings, transport, agriculture and forestry, land use and waste management (*Climate Action Plan 2050*. Bundesministerium für Umwelt; Naturschutz; Bau und Reaktorsicherheit, 2016). The building sector is a critical focus, contributing up to 30% of Germany's total greenhouse gas emissions. To address this, KSG mandates that all existing building stock must be renovated by 2050 to meet stringent energy efficiency and emissions standards.

Building Energy Act (GEG)

The standards for achieving the required reductions in energy usage are detailed in the Building Energy Act (Gebäudenenergiegesetz – GEG) of 2020. The GEG consolidates three prior ordinances introduced by Germany under the Energy Performance of Buildings Directive (EPBD):

- German Energy Saving Act (Energieeinsparungsgesetz – EnEG)
- German Energy Saving Ordinance (Energieeinsparverordnung – EnEV)

- German Renewable Energies Heat Act (Erneuerbare-Energien-Wärmegesetz – EEWärmeG)

The GEG establishes binding standards for energy efficiency in both new constructions and renovations. It also provides guidance on structural requirements and heating systems to meet energy efficiency targets (*Gebäudeenergiegesetz*. The German Bundestag, 2020).

Federal Funding for Efficient Buildings (BEG)

To address the high costs of renovations, Germany has implemented comprehensive funding programs under the Federal Funding for Efficient Buildings (Bundesförderung für effiziente Gebäude – BEG) scheme. The basic eligibility criterion for BEG funding requires achieving an Efficiency House Standard of 55 for existing buildings or 40 for new constructions. The program is divided into the following subcategories: Federal funding for efficient buildings:

- Residential Buildings (Bundesförderung effiziente Gebäude: Wohngebäude - BEG WG)
- Federal funding for efficient buildings: Non-Residential Buildings (Bundesförderung effiziente Gebäude: Nichtwohngebäude BEG NWG)
- Federal funding for efficient buildings: Individual Measures (Bundesförderung effiziente Gebäude: Einzelmaßnahmen BEG EM)

The BEG WG program supports energy efficiency measures that achieve an Efficiency House Standard of 85 or better. This program is accessible to all types of property owners and enables homeowner associations (Wohnungseigentümergeinschaften – WEG) to apply for joint loans as commissioning investors. To ease the financial burden on low-income owners, the program includes special bonus provisions (Öko Zentrum NRW, 2023).

The BEG EM program is tailored to simpler ownership structures and is only available to homeowner associations when renovations involve common property. While homeowners can access both grants and loans under these programs, landlords are limited to loans only (März et al., 2020; Öko Zentrum NRW, 2023).

In 2023, a funding bonus was introduced to reward additional goals achieved during renovations (Öko Zentrum NRW, 2023). These incentives include:

1. The greater the energy efficiency achieved, the higher the repayment grant.

2. An additional 5% repayment bonus for reaching either the renewable energy class (EE class) or the sustainability class (NH class).
3. A 15% additional bonus for renovating worst-performance buildings (WPBs).

While Germany has made significant strides in addressing financial barriers through federal funding programs, the overall motivation to renovate at a broader social and moral level remains insufficient. Several arguments highlight the need for grants and funding to offset renovation costs. Without such financial support, the investment in energy-efficient renovations often cannot be recovered through rent or sales premiums, and the return periods tend to be long (Galvin, 2023b).

3.3 Policy actions in Dortmund

The main outcomes of the efforts taken at the Federal level are the Climate Air Action Plan 2030 and the Energy Utilization Plan (Energienutzung Plan - ENP).

Climate Air Action Plan 2030

The Climate Air Action Plan 2030 (Handlungsprogramm Klima-Luft 2030) is Dortmund's comprehensive strategy to address climate change and improve air quality by 2030. It outlines the workload for the next decade, detailing how Dortmund can achieve its goals of a 65% reduction in greenhouse gas (GHG) emissions by 2030 and climate neutrality by 2050 (Umweltamt, 2021).

The plan is structured around six fields of action, each with specific goals and guidelines for implementation: Overarching measures; Renewable energies and energy efficiency; Sustainable construction; Agriculture and nutrition; Mobility and Air quality. With respect to renovation of existing buildings there are 3 fields of action and their respective goals that are relevant, and they are: (See Table 1).

Number	Goal	Target group	Sponsors
Comprehensive Measure			
ÜB1	Activating citizens for climate protection: Targeted financial incentives (funding guidelines) and information provision.	Private individuals, especially house and apartment owners; Companies	Environmental Agency; DLZE; specialists for funding management
ÜB2	Activation of private capital for climate protection: Establishment of a climate protection fund for strengthening social initiatives.	Financially strong companies and private individuals; Capital-weak project sponsors	Environmental Agency; Bank and Savings Bank; Potential investors
ÜB3	Dortmund Network for Climate Protection: Targeted involvement of municipal subsidiaries and other active groups in the city's climate protection activities.	Private Individuals and Companies	Environmental Agency; Municipal Investors; Social groups involved in climate protection activities; Committed company

Renewable Energies and Energy Efficiencies			
EE1	Preparation of an Energy Use Plan (ENP): Creation of a binding planning instrument for the development of renewable energies and an appropriate information basis for the development of renewable energies and an appropriate information basis for public.	Private Individuals; Real Estate Companies	Urban planning and building regulations office; Surveying and land registry office; DEW21; RVR; LANUV
EE2	Campaign for the use of photovoltaics: expansion program for the use of PV on roof and open spaces and organization of those involved.	Private Individuals; Housing Cooperatives; Real Estate Offices	Environmental Agency; Dortmund Agency; DEW21; Electrical Engineering Guild; DLZE
EE3	The Dortmund CO2 calculator: Activating Dortmund citizens by providing information and targeted incentives for a climate-friendly lifestyle.	Private Individuals	Environmental Agency; Dortmund Agency

Sustainable Construction			
NB1	Climate-neutral building stock of municipal buildings and municipal subsidiaries: The city Creation of structures for information and coordination of climate protection in the food sector Dortmund as a model in sustainable construction with ambitious climate targets and model projects	Real Estate Companies and property managers; Public Housing; DOGEWO21	Property Office; Urban planning and building regulations office; Municipal subsidiaries and in-house operations; DOGEWO21; DEW21
NB2	Initiative for efficient buildings (new buildings and existing buildings): Expansion of the Energy Efficiency Service Centre (dlze) and implementation of campaigns to modernize residential and non-residential buildings	Private Owners; Housing Associations; Housing Companies	Environmental Agency; DLZE; Urban planning and building regulations office; Regionalverband Ruhr (RVR)
NB3	Promote sustainable construction: create standards, provide information and use of urban development planning to promote sustainable construction.	Private Housing Companies	Environmental Agency; DLZE; Urban planning and building regulations office; Economic Development Department
NB4	Expansion of renewable district heating networks: implementation of pilot projects and creation of Cooperation structures for the expansion of renewable energies in the heating sector	Public Housing Properties; Housing Associations	Environmental Agency; DLZE; DEW21; DOGEWO

Table 1 Goals, relevant Stakeholders and Target groups of the Action Plans under Climate-Air Action Plan 2030.

3.4 Reflections

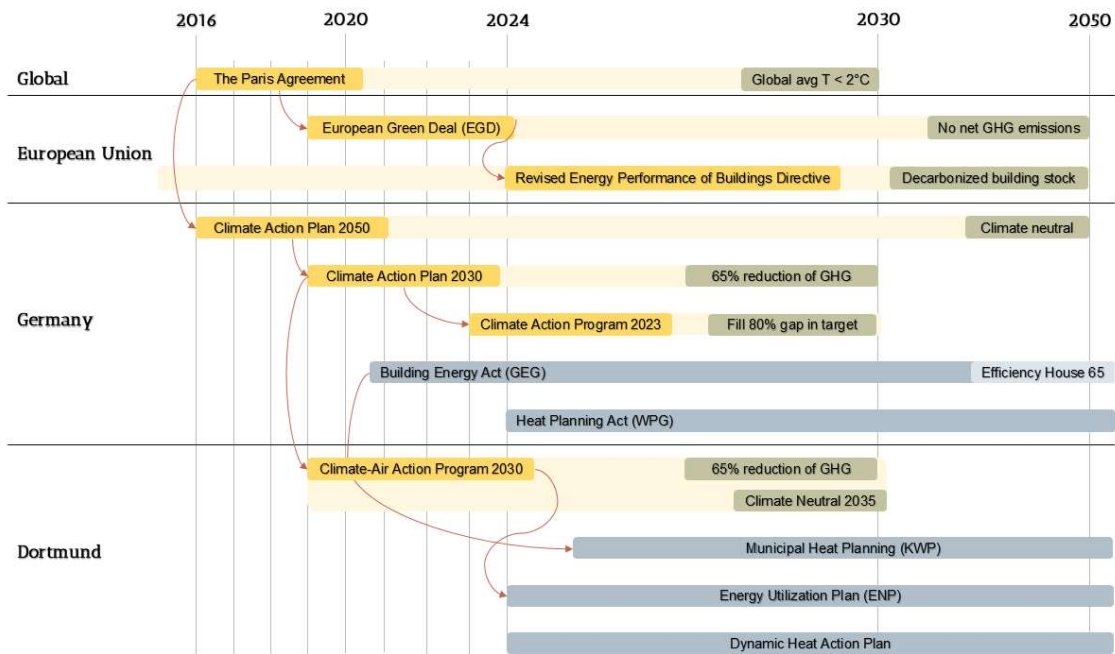


Figure 2 Energy goals and policy actions across various scales (Source: Author, 2025).

The topic of climate change and its mitigation through the renovation of existing buildings has been a prominent focus in policy discussions for decades. It remains a recurring subject in political debates, international agreements, and public advocacy. With each passing year, the urgency to curb emissions grows more pressing. Through the *Climate-Air 2030 Action Program*, Dortmund has committed to achieving climate neutrality 15 years ahead of Germany's national target. In April 2022, the city further accelerated its ambitions by joining the EU's *100 Climate-Neutral and Smart Cities* initiative, bringing its climate neutrality goal forward from 2035 to 2030.

While significant progress has been made on paper—through policies aimed at increasing efficiency standards, integrating renewable energy, and addressing the worst-performing buildings—translating these policies into tangible outcomes at the city level remains a considerable challenge. Dortmund's *Climate-Air Action Plan 2030* underscores the city's commitment to achieving climate neutrality by 2035. However, the 0.7% annual renovation rate in North Rhine-Westphalia, which translates to only 14% of buildings being renovated over the past couple of decade, highlights the inadequacy of the current approach to meet these ambitious targets (Umweltamt, 2021). A key issue is the heavy reliance on the voluntary motivation of private building owners to undertake renovations, often without sufficient localized or sector-specific incentives.

The success of Dortmund's "100 EnergyPlus Homes for Dortmund" initiative demonstrates the effectiveness of spatially concentrated and externally incentivized efforts. Such targeted programs, which combine financial support with tailored strategies for specific neighborhoods or building types, have shown a greater ability to drive tangible progress. They also align more closely with the needs and capacities of local stakeholders, offering a more practical model for scaling renovation efforts and meeting climate goals.

Given the urgency of the issue, the city must address two critical barriers: understanding the perspectives of property owners and identifying priority areas for action. A data-driven approach from the perspective of the owners can help city administrators identify key barriers, prioritize high-impact interventions, and allocate resources efficiently to accelerate renovation efforts in the residential sector.

4. Conceptual Framework: Inaccessibility

To ensure that energy renovation efforts are both effective and efficient, it is crucial to identify the appropriate locations and approaches, minimizing the risk of misdirected efforts. This thesis aims to determine where interventions are most needed and what type of efforts are most suitable. It seeks to provide a spatially informed response to both questions. To achieve this, the conceptual framework of the Theory of Planned Behavior (TPB) has been applied. This framework evaluates the role of equity in the transition to improved energy standards, situating the analysis within the broader and complex process of policy adoption.

What is accessibility?

In general, inaccessibility is understood as the inability or difficulty experienced by individuals or groups in accessing essential goods, services, opportunities, or spaces due to various physical, economic, social, or systemic barriers. This thesis, however, adopts an alternative interpretation of the term. Drawing on Berechman, 1981 conceptualization of accessibility as “the freedom of individuals to decide whether or not to participate in different activities,” this research frames inaccessibility in the context of energy renovation. Specifically, access to renovation is defined as the absence of freedom for individuals to decide whether to upgrade their property to higher energy efficiency standards. Following the approach of Kraaijvanger et al., 2023, this freedom is shaped by the presence or absence of specific barriers: barriers restrict renovation access, while their absence facilitates it. These barriers are studied in a later section of the report.

Understanding Adoption of Renovation

In Germany, energy efficiency for residential buildings is calculated based on the standards set by the Building Energy Act (*Gebäudeenergiegesetz* – GEG) (*Gebäudeenergiegesetz*. The German Bundestag, 2020). The performance of a building is documented in the Energy Performance Certificate (*Energieausweis*). To support homeowners in improving energy efficiency, an Individual Refurbishment Roadmap (*Individueller Sanierungsfahrplan* - iSFP) can be developed. This roadmap provides a step-by-step plan for energy-efficient refurbishments tailored to the specific needs of a building (German Energy Agency et al., 2017).

The EPC and iSFP are prepared by certified Energy Consultants who are trained in applying the GEG standards and assisting property owners in accessing funding programs. The renovation roadmap typically includes measures such as improving the thermal envelope to eliminate thermal bridges and leaks. These upgrades may involve:

- Insulating external walls, roofs, floors against the earth, floors above unheated spaces, and exposed ceilings.
- Replacing outdated windows and doors with high-efficiency alternatives.

In addition to structural improvements, old heating systems powered by non-renewable energy sources are often replaced with low-emission heat pumps. Where feasible, photovoltaic systems (PV) are installed to generate renewable electricity, which can sometimes be used directly for heating water (Aslani et al., 2019; Martinopoulos et al., 2018). The iSFP can be used to get subsidies from the Federal Office of Economics and Export Control (BAFA).

In Dortmund, significant efforts are underway to expand district heating, as outlined in the Energy Utilization Plan (Energienutzungsplan). Residents are encouraged to consider district heating as a sustainable alternative to conventional heating systems, contributing to the city's broader energy transition goals.

The Theory of Planned Behavior

Accessibility, defined in this thesis as the “freedom to decide,” aligns closely with the Theory of Planned Behavior (TPB). TPB acts as a lens to study the decision-making behavior of property owners regarding energy renovation. According to TPB, an individual's intention to perform a specific behavior can be accurately predicted by three core elements: attitude toward the behavior, social norms, and perceived behavioral control (Ajzen, 1991).

In the context of this research, the “freedom to decide whether or not to renovate” is influenced by:

1. **Attitude Toward the Behavior** – This reflects the importance an individual places on the outcomes of their actions. For instance, the belief that "renovation is a good way to reduce my environmental impact" represents a positive attitude that could drive decision-making. Such attitudes are intrinsic and shaped by personal values and goals (Ajzen, 1991; Kraaijvanger et al., 2023; Tan et al., 2023).
2. **Social Norms** – These are the perceived societal expectations or pressures that influence behavior (Ajzen, 1991; Kraaijvanger et al., 2023; Tan et al., 2023). For example, the sentiment "people important to me will appreciate it if I upgrade my house" highlights how social approval or recognition may motivate renovation efforts. This factor emphasizes the influence of community relationships and social networks.

3. **Perceived Behavioral Control** – This pertains to an individual’s perception of their ability to perform the behavior, considering potential barriers or enablers (Ajzen, 1991; Kraaijvanger et al., 2023; Tan et al., 2023). A perception of control of the situation can directly lead to the behavior of renovation even when the other factors are not present. For instance, the statement "I cannot afford to undertake renovation given my financial situation" illustrates how financial, organizational, or informational barriers can impede action, even when attitudes and social norms are supportive.

These three elements of TPB are applied to analyze how residential property owners in Dortmund approach decisions about energy renovation. By understanding how these elements interact, it is possible to identify the factors that encourage or deter pro-environmental behavior among property owners.

The following illustration conceptualizes how attitude, social norms, and perceived behavioral control collectively influence energy renovation decisions and promote pro-environmental behavior.

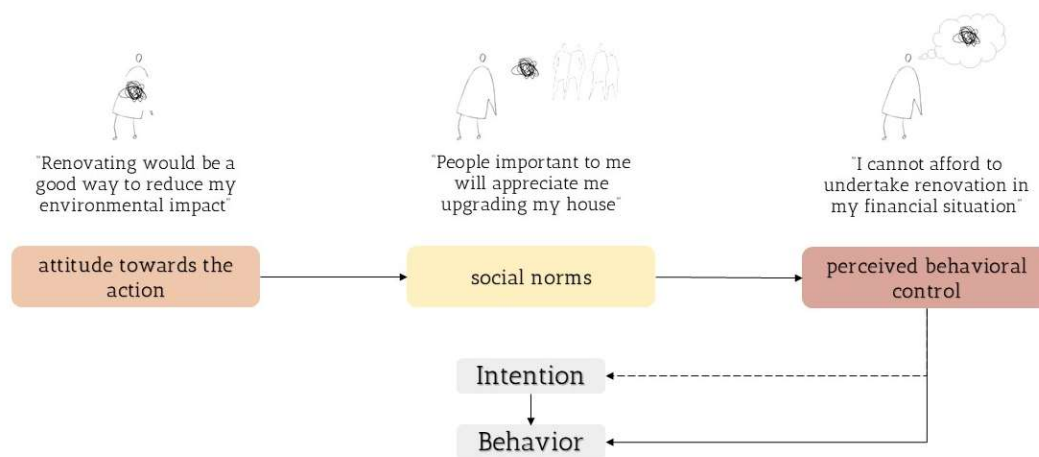


Figure 3 Theory of Planned Behavior applied to decision making behavior of owners regarding energy upgrade. (Source: Graphic by the author)

Barriers that impede owners at various stages of the decision-making process ultimately hinder their ability to make a positive decision and pursue energy renovation. Existing literature is used to identify individual barriers that affect the owner’s decision making process as described by the TPB. The first compilation of theoretical barriers as seen in a study by (Rhodin and Thollander, 2006) and later developed in (Thollander et al., 2020;

Thollander and Palm, 2013) is used to identify these barriers. They are categorized under the three elements of the Theory of Planned Behavior (TPB):

1. Attitude Toward Behavior

a. Lack of Value: Property owners who do not recognize the environmental or personal benefits of renovation often lack motivation to undertake it (Blomqvist et al., 2022; Heiskanen et al., 2012; Jakob, 2007; März, 2018b; Stieß and Dunkelberg, 2013).

b. Inertia: Even when owners acknowledge the value of renovation, a tendency to avoid risks or disruption may lead to maintaining the status quo and inaction (Ebrahimigharehbaghi, Qian, Vries, Visscher, 2022a; Heiskanen et al., 2012; März, 2018a; Stieß and Dunkelberg, 2013).

c. Bounded Rationality: Decisions are frequently influenced by short-term reasoning or simplified decision-making strategies, with owners prioritizing immediate costs over long-term benefits (Ameli and Brandt, 2015; Cairns et al., 2023).

2. Social Norms

a. Lack of System Value: The absence of social pressure or encouragement within neighborhoods can reduce motivation to engage in energy renovation (Cairns et al., 2023; Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022; Ebrahimigharehbaghi, Qian, Vries, Visscher, 2022a; Jakob, 2007).

b. Conflicting Views: Disagreement within communities about the necessity or value of renovation can discourage even motivated individuals from proceeding (Buessler et al., 2017; Cairns et al., 2023; Matschoss et al., 2013).

c. Lack of Credibility and Trust: A lack of trust in key stakeholders, such as government authorities, contractors, or energy consultants, undermines confidence in renovation benefits, including energy savings or cost-effectiveness (Buessler et al., 2017; Cairns et al., 2023; Matschoss et al., 2013; Stieß and Dunkelberg, 2013).

3. Perceived Behavioral Control

a. Informational Barriers:

Imperfect Information: Owners may lack the time, resources, or awareness to seek accurate information about energy-efficient measures, leading to missed opportunities (Blomqvist et al., 2022; Buessler et al., 2017; Ebrahimigharehbaghi, Qian, Vries, Visscher, 2022a; Jakob, 2007; März, 2018a; Weatherall et al., 2018).

Complex Form of Information: Technical and legal details related to energy efficiency are often too intricate for non-experts to understand. Conflicting or inconsistent advice further exacerbates uncertainty (Buessler et al., 2017; Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022; Heiskanen et al., 2012; Jakob, 2007; Stieß and Dunkelberg, 2013).

Complicated Procedures: Renovation processes often involve bureaucratic hurdles, which deter individuals from initiating or completing projects (Buessler et al., 2017; Cairns et al., 2023; Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022; Heiskanen et al., 2012; Matschoss et al., 2013).

b. Financial Barriers:

High Capital Costs: The perception of renovation as prohibitively expensive dissuades many owners, even when grants or subsidies are available (Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022; Heiskanen et al., 2012; März, 2018a; Stieß and Dunkelberg, 2013).

Lack of Access to Capital: Difficulty in obtaining loans or understanding subsidy eligibility criteria often prevents owners from pursuing renovations (Ameli and Brandt, 2015; Bertoldi et al., 2021; Blomqvist et al., 2022; Buessler et al., 2017; Cairns et al., 2023; Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022; Heiskanen et al., 2012; Jakob, 2007; Santamouris et al., 2007; Weatherall et al., 2018).

Split Incentives: This occurs when the costs and benefits of renovation are misaligned, such as landlords bearing the investment costs while tenants benefit from reduced energy bills (Ameli and Brandt, 2015; Blomqvist et al., 2022; Buessler et al., 2017; Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022; Heiskanen et al., 2012; März, 2018a; März et al., 2022; Weatherall et al., 2018).

Uncertain Return on Investment: Many owners are hesitant to invest due to uncertainty about whether energy savings and reduced costs will sufficiently offset the renovation expenses (Blomqvist et al., 2022; Galvin, 2023b; Heiskanen et al., 2012; Karatasou and Santamouris, 2019; März, 2018a, 2018b; Santamouris et al., 2007; Stieß and Dunkelberg, 2013).

The barriers identified in the literature are not experienced uniformly across different ownership types. An in-depth review of more than 40 academic studies led to the development of a matrix that highlights the barriers as examined and documented by various researchers. Individual private owners, including those in simple ownership structures and condominiums, appear to face the most significant challenges, followed by cooperative ownership models. This finding aligns with the study by Blomqvist et al., 2022 which concluded that private owners encounter more barriers compared to public

ownership entities. Financial barriers emerge as the most frequently studied topic in literature, with several researchers proposing alternative solutions. For instance, Galvin, 2023a suggests introducing individual corporate social responsibility initiatives to support small private landlords in financing renovations; Bagaini et al., 2022 explore the *one-stop-shop* model as a business strategy to enhance residential renovation rates.

Since these barriers vary significantly, it is crucial to understand the preconditions under which renovations are expected to take place. By identifying these patterns, policymakers can gain deeper insights into the local renovation landscape. It will also allow them to assess the impact on infrastructure and citizens more strategic interventions and efficient resource allocation can have.

Barriers	Simple Private	Condo-miniums	Public Cooperative Org.	Private Comp.
Lack of Values	X		X	X
Risk aversion	X	X		
Bounded Rationality	X	X		
Lack of Culture		X	X	
Confictual views		X	X	
Lack of Credibility and mistrust	X	X		
Imperfect Information	X	X	X	
Complex Form of Information	X	X		
Complicated Procedure	X	X		
High Capital cost	X			X
Lack of Access to Capital	X	X	X	X
Split Incentive		X	X	X
Uncertain Return on Investment	X	X	X	X

Figure 4 Matrix showing barriers affecting different ownership types as identified in existing literature (Source: Compiled by the Author)

5. Impact of renovation: The case of Dortmund

Dortmund's historical development is rooted in its coal mining, steel production, and brewing industries (ICLEI Case Studies, 2016). The rise of these industries created significant job opportunities, attracting waves of immigrants and driving high housing demand. Consequently, industries and factories were established in close proximity to residential areas, leading to a dense, polycentric urban structure with several historic sub-centers (Wittowsky et al., 2020).

Following the closure of coal mines in the 1960s and the steel crisis of 1975, Dortmund experienced severe economic decline and substantial out-migration. The city has implemented a series of measures to revitalize its economy and improve living standards. Notable initiatives include the “Phoenix Lake (East)” project, the “Phoenixsee” redevelopment, and the establishment of the Technologie Zentrum Dortmund (TZDO). These efforts have helped the city transition to a service-oriented economy, marking a recovery from its industrial downturn (Irle and Röllinghoff, 2008; Wittowsky et al., 2020).

Dortmund's housing market is characterized by diversity, with a significant proportion of privately owned buildings accommodating a heterogeneous social structure (Wittowsky et al., 2020). The city contains 96,242 residential buildings, encompassing over 317,678 residential units that reflect a wide range of housing conditions. This diversity and its resultant density strongly influence the conditions under which renovation is expected to take place.

This thesis investigates these preconditions to assess the impact of renovation initiatives at a citywide scale and evaluates the effectiveness of government efforts. Traditional approaches to energy renovations primarily focus on household- or building-level energy consumption metrics. While valuable, these methods often overlook the broader social, economic, and contextual dimensions of renovation. To bridge this gap, the study adopts an alternative framework that evaluates renovation success by analyzing its impact on three key urban conditions: urban agents (owners, as defined in Cozzolino and Moroni (2022)), urban objects (property as defined in Cozzolino and Moroni (2022)) and urban users (occupants). Specifically, the research identifies six ownership types, five property types, and two occupancy types, providing a comprehensive categorization of the conditions under which renovations occur.

These factors capture the diverse configurations of infrastructure affected by energy renovations, encompassing both citizens and properties (See **Error! Reference source not found.**). By analyzing these configurations, the study offers valuable insights into the

renovation needs and challenges across Dortmund, bridging the gap between technical energy metrics and the lived realities of urban stakeholders.

Since data for various ownership, property, and occupancy combinations are not available, each determinant is investigated individually. They are weighted according to stakeholders and infrastructure affected by the renovation process.

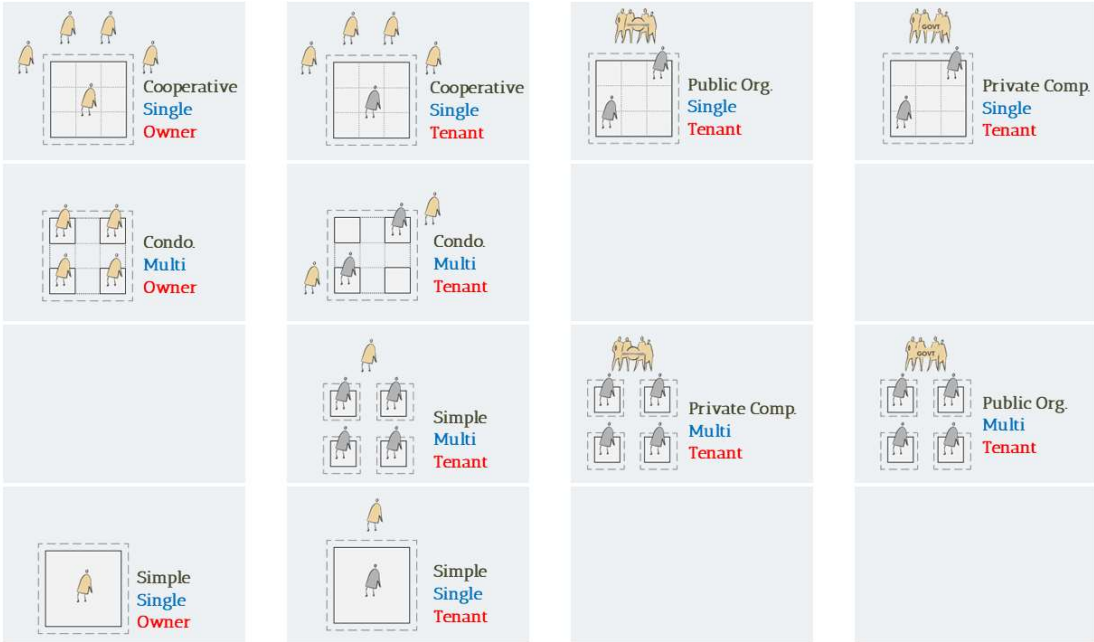


Figure 5 Possible condition of property, ownership and occupancy under which a renovation could be occurring.

5.1 Ownership Types

Ownership defines the legal relationship between an agent (owner) and an object (property), determining the degree of control over renovation decisions (Cozzolino and Moroni, 2021; Shaffer, 2009). Ownership types in Dortmund are weighted based on the stakeholders affected by a renovation process. This typically includes individual owners or entities, people with means to modify the built environment (Bobkova et al., 2017 - 2017). The identified ownership types include:

a. Private Individual Ownership

An individual or group of individuals owns both the built structure and the land, retaining complete decision-making authority over its use, disposal, legal claims or liabilities, construction, and renovation. This ownership type represents approximately 45% of buildings in Dortmund, slightly higher than the German national average of 36% of dwellings, making it the most prevalent form of ownership (Krapp et al., 2021; Zensusdatenbank: Ergebnisse des Zensus, 2011a).

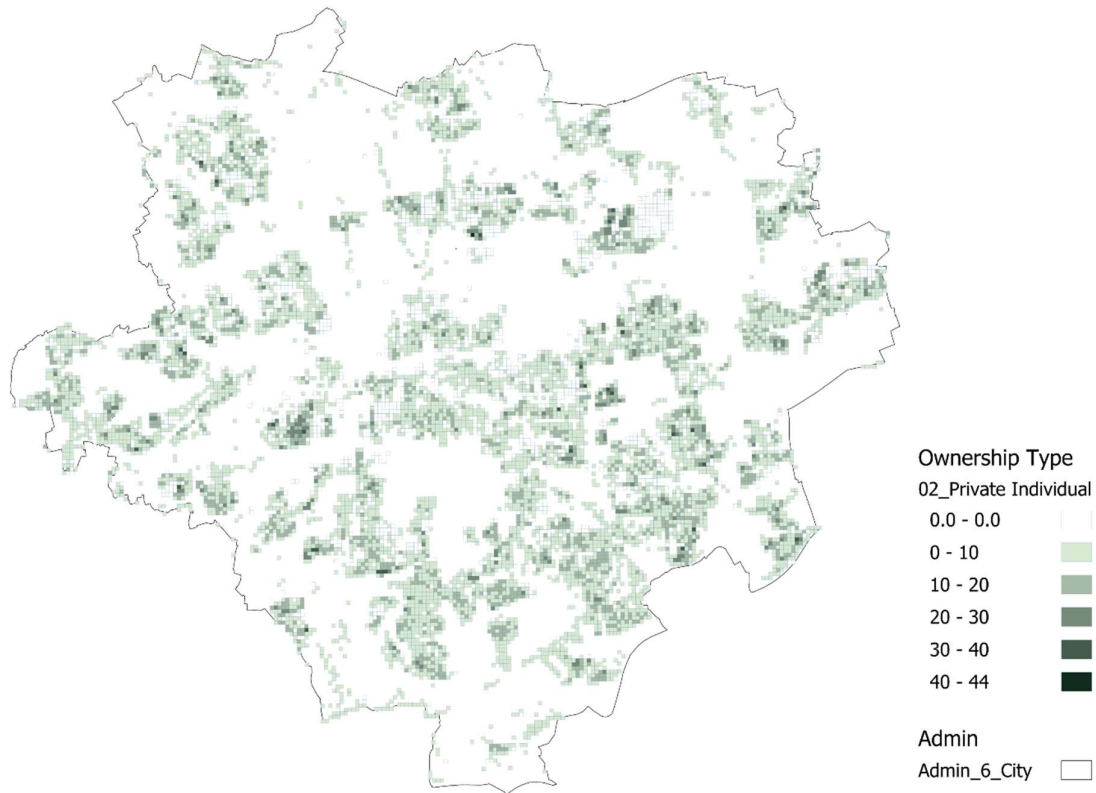


Figure 6 Concentration of simple private ownerships in Dortmund. Units: NA (number of buildings)

b. Commonhold Ownership

Individual units within a building are owned privately, while common areas and the land are collectively owned by an association of owners. While owners have full control over their individual units, decisions regarding shared spaces, including the land and the overall structure, must be made collectively. Major decisions, such as those related to renovations, are typically governed by the majority principle (Krapp et al., 2021). This ownership type accounts for approximately 10% of properties in Dortmund (Zensusdatenbank: Ergebnisse des Zensus, 2011a).

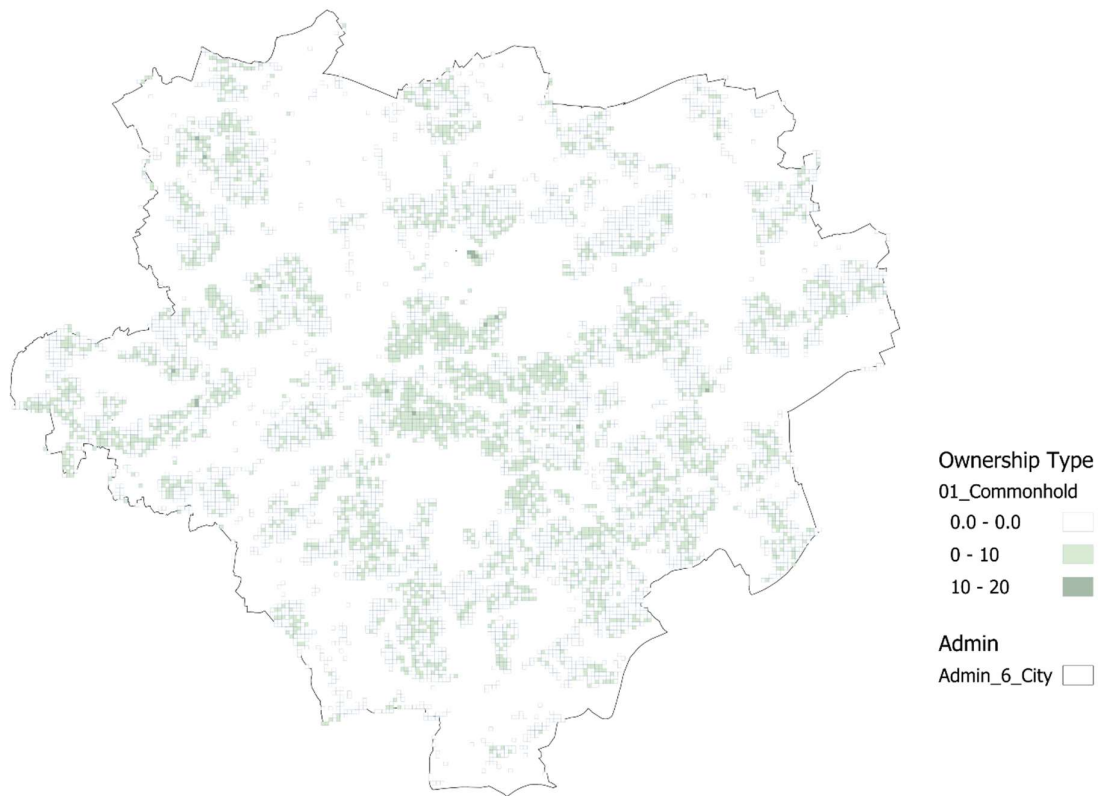


Figure 7 Concentration of Condominium ownership in Dortmund. Units: NA (number of buildings)

c. Cooperative Ownership

Cooperative housing involves collective ownership, where members hold shares in the cooperative rather than owning individual units (Cozzolino and Moroni, 2022; Zensusdatenbank: Ergebnisse des Zensus, 2011a). These cooperatives benefit from tax-exempt status under limited-liability cooperative regulations (Vermietungsgenossenschaft, § 5 Abs. 1 Nr.10 Körperschaftsteuergesetz). As in other collective ownership models, decisions must be made based on a majority principle, with each shareholder possessing one vote. Additionally, all decisions must align with the cooperative's established guidelines, adding further complexity to the decision-making process (Krapp et al., 2021). While this ownership type is relatively uncommon, it remains significant in certain urban areas.

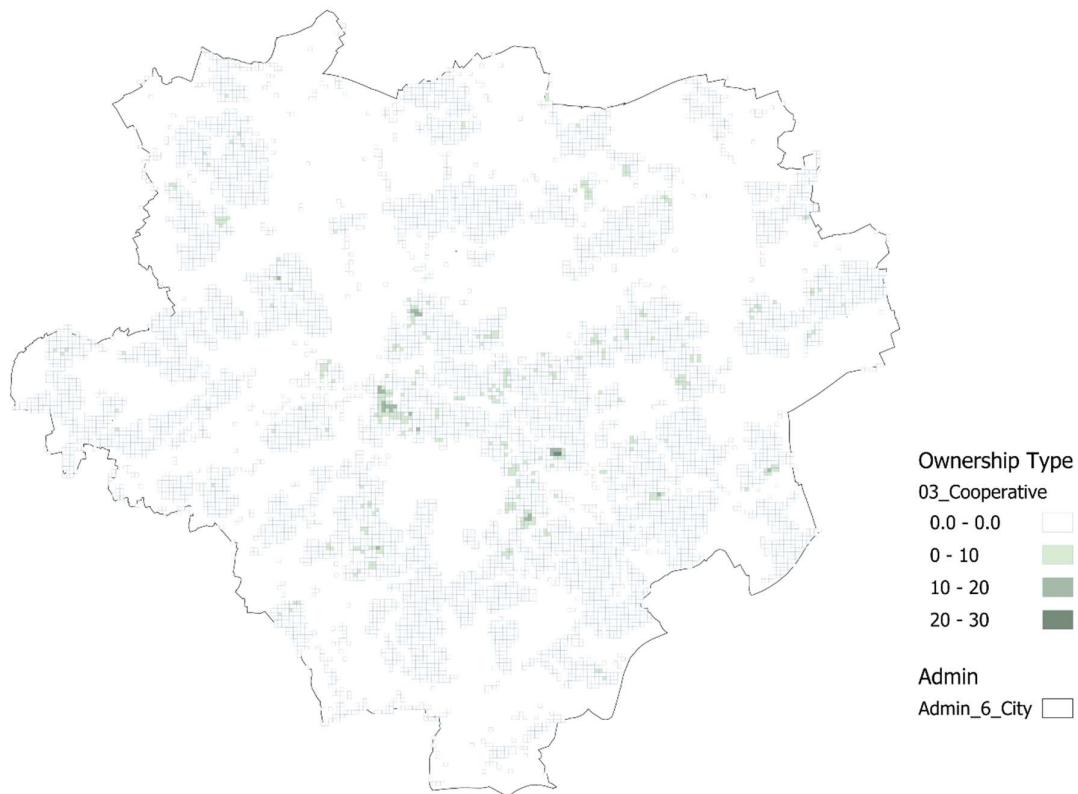


Figure 8 Concentration of Cooperative ownership in Dortmund. Units: NA (number of buildings)

d. Private Sector Housing Companies

These companies operate under private law and manage rentals or occupancy in accordance with §§549–577a of the German Civil Code (Bürgerliches Gesetzbuch, Mietverhältnisse über Wohnraum). A significant portion of this ownership type in Germany comprises privatized social housing sector companies (Krapp et al., 2021; Zensusdatenbank: Ergebnisse des Zensus, 2011a). These entities function as single decision-making bodies with direct authority over property-related matters.

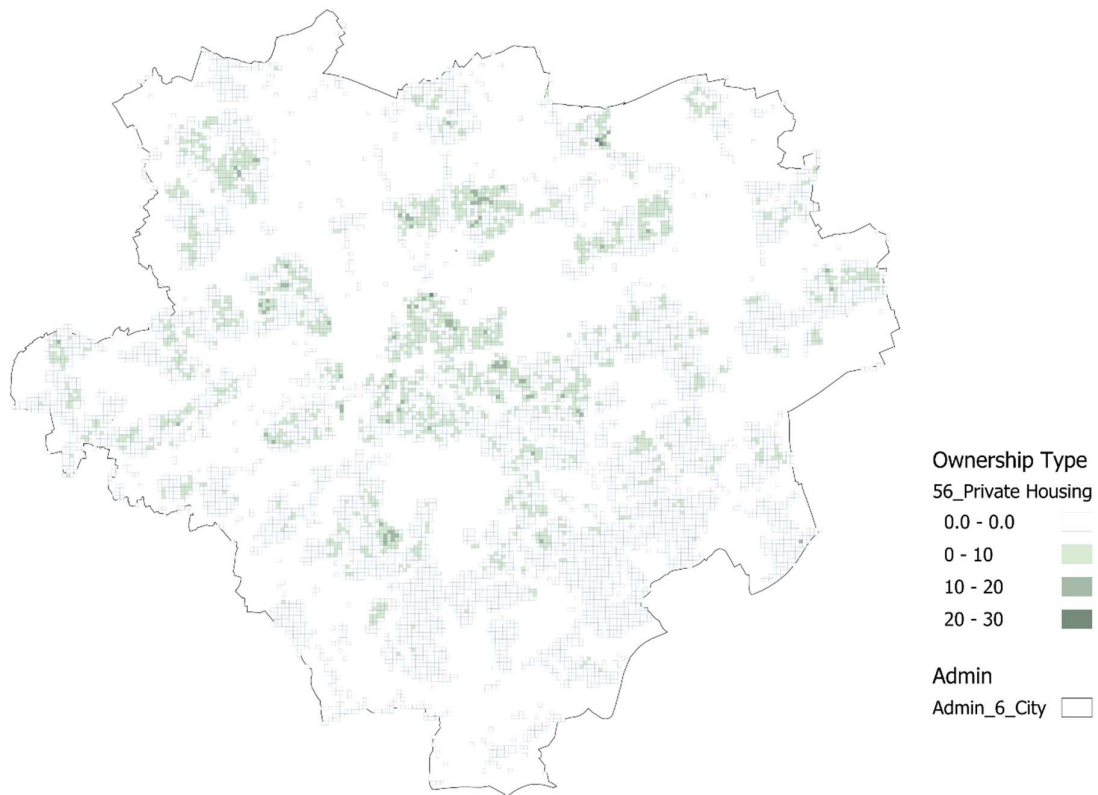


Figure 9 Concentration of buildings owned by private housing companies. Units: NA (number of buildings)

e. Public Sector Housing Companies

Owned or controlled by the state or municipality, these companies hold more than 50% of the nominal capital or voting rights (Zensusdatenbank: Ergebnisse des Zensus, 2011a). This category includes social housing with public rental tenures, owned by federal, state, or municipal authorities. Since 2006, regulatory jurisdiction for social housing has been under the purview of individual states. Currently, these properties operate under the same legal framework as market-rate housing, which allows rental rates to be determined by agreements between the involved parties, depending on the local supply and demand conditions.

Tenants are responsible for paying rent and utilities, while maintenance, repairs, and renovation fall under the control of the public organization. In some cases, municipalities are directly involved in property management, particularly in implementing energy efficiency initiatives (Krapp et al., 2021). Despite budgetary constraints, these organizations often prioritize environmentally sustainable decisions.

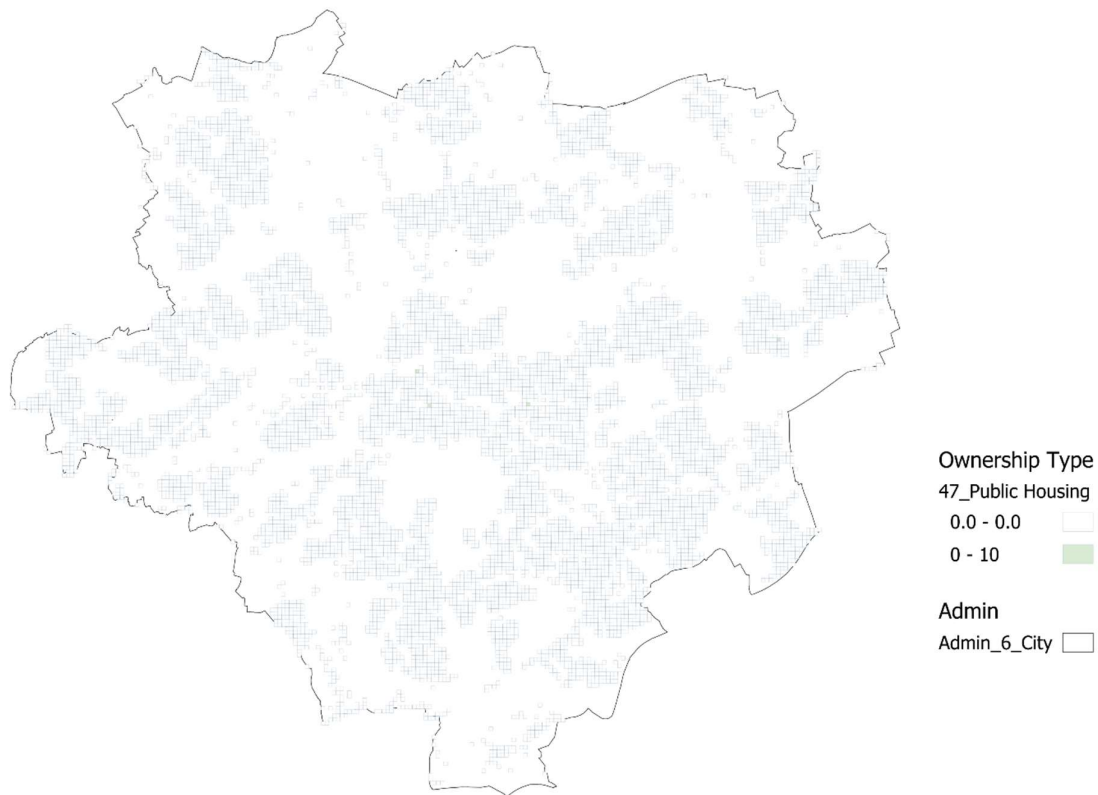


Figure 10 Concentration of buildings owned by Public housing companies. Units: NA (number of buildings)

f. Nonprofit Organizations

Entities such as churches and non-governmental organizations (NGOs) own and manage buildings for non-commercial purposes. Similar to public sector organizations, they frequently operate within constrained budgets and limited resources (Zensusdatenbank: Ergebnisse des Zensus, 2011a).

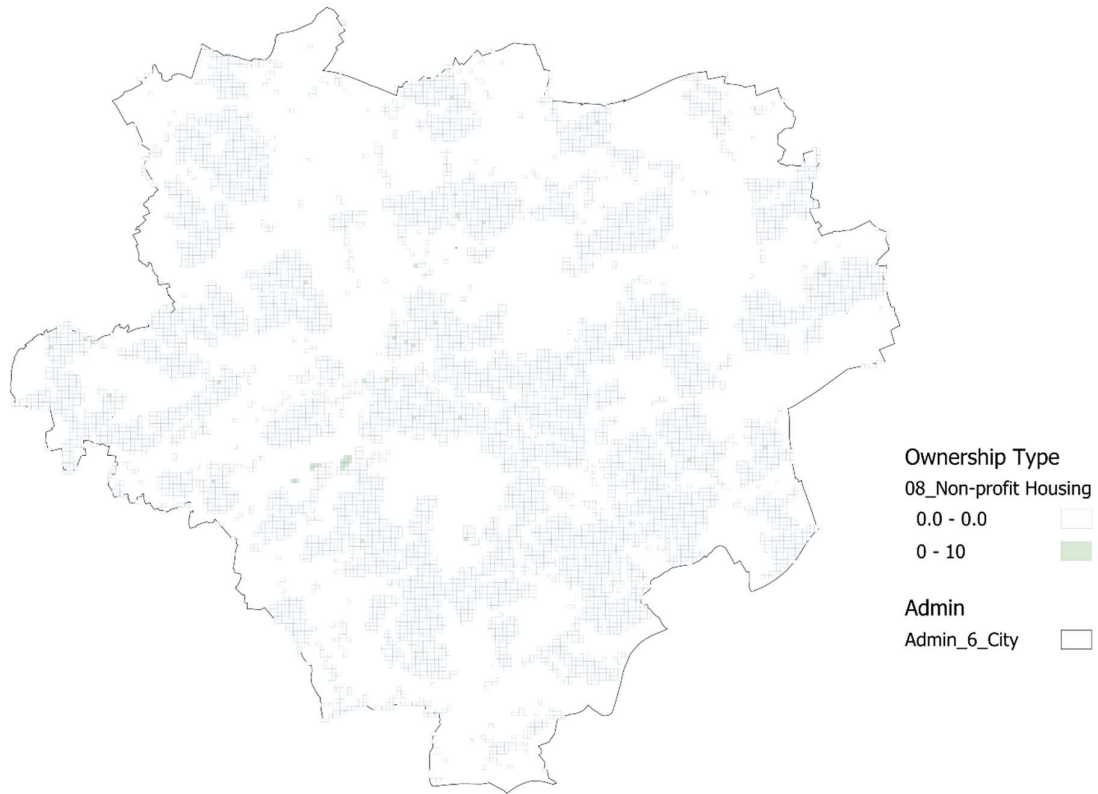


Figure 11 Concentration of buildings owned by Non-profits. Units: NA (number of buildings)

g. Density of Owners

Each ownership type is weighted according to the number of stakeholders affected by the renovation (See Table 2). In the case of ownership, this also corresponds to their respective decision-making capacity.

Ownership Type	Weightage	Reason
Simple Private	1	Only owners who have complete control over decision (Cozzolino and Moroni, 2022)
Commonhold	2	Owners and co-owners and each has partial control over decision (Cozzolino and Moroni, 2022)
Housing Cooperative	3	Owner, co-owner and the cooperative organization that have collective control over decision (Cozzolino and Moroni, 2022)
Private Sector Comp.	1	Institutions, as a single entity having complete control over decision.
Public Sector Comp.	1	
Non-Profit Org.	1	

Table 2 Weightage for different ownership types.

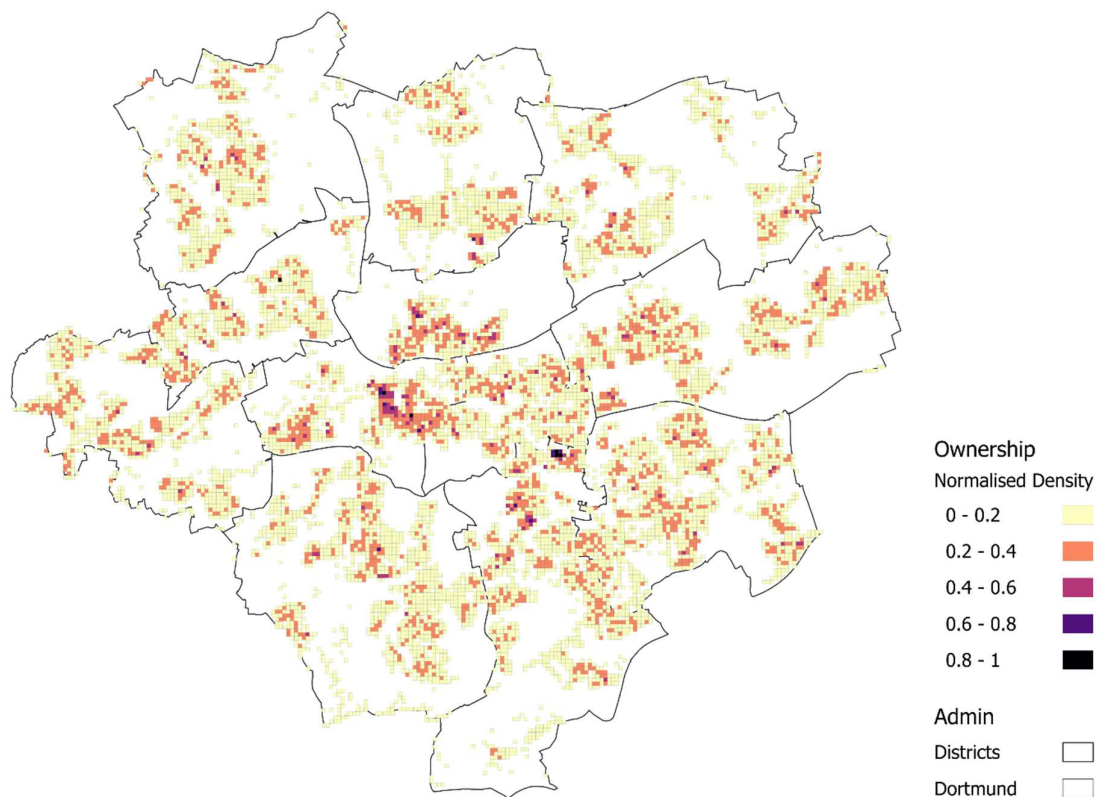


Figure 12 Density of ownership in Dortmund.

Mapping ownership density in Dortmund reveals a largely uniform distribution across the city, with a slight increase in density toward the city center. Simple private and commonhold ownership types tend to cluster in the central areas, where morphological density is also high. This fragmented property-ownership structure makes large-scale renovation projects more challenging due to the presence of multiple stakeholders.

5.2 Property Types

Property serves as the primary mechanism through which an urban agent can influence and modify the built environment (Cozzolino and Moroni, 2021). In their research, (Cozzolino and Moroni, 2021) argue that a dense pattern of property ownership positively contributes to the emergence of self-organizing neighborhoods. This decentralized ownership fosters localized decision-making and community-driven urban transformations. However, when it comes to the uptake of energy renovations, an area still largely driven by top-down initiatives and incentivized through financial schemes, smaller properties face disproportionately larger barriers. These barriers include limited access to financing, fragmented decision-making processes, and a lower return on investment compared to larger buildings. As a result, smaller property owners often struggle to initiate or sustain energy renovation efforts, leaving them unable to adapt effectively to evolving energy efficiency standards.

To better understand these dynamics, five distinct property types were identified, categorized based on the number of households per building:

a. Single-Family Houses

Attached, semi-detached or standalone residential units, typically owned by individual families or single entities. Single-family houses constitute 47.17% of all buildings in Dortmund and are predominantly located in suburban areas (Zensusdatenbank: Ergebnisse des Zensus, 2011b).

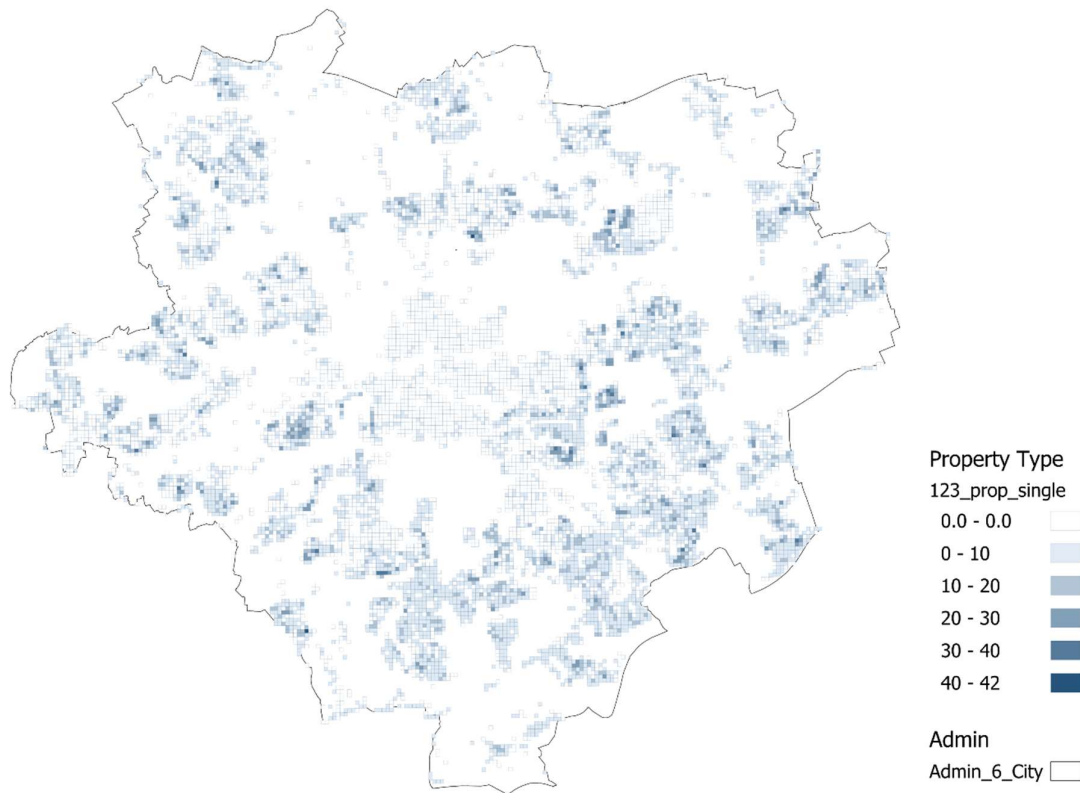


Figure 13 Concentration of single family house in Dortmund. Units: NA (number of buildings)

b. Two-Family Houses

Buildings with two separate households, often shared between owners or owner-occupants and tenants. Although less prevalent than single-family homes, they are common in suburban neighborhoods (Zensusdatenbank: Ergebnisse des Zensus, 2011b).

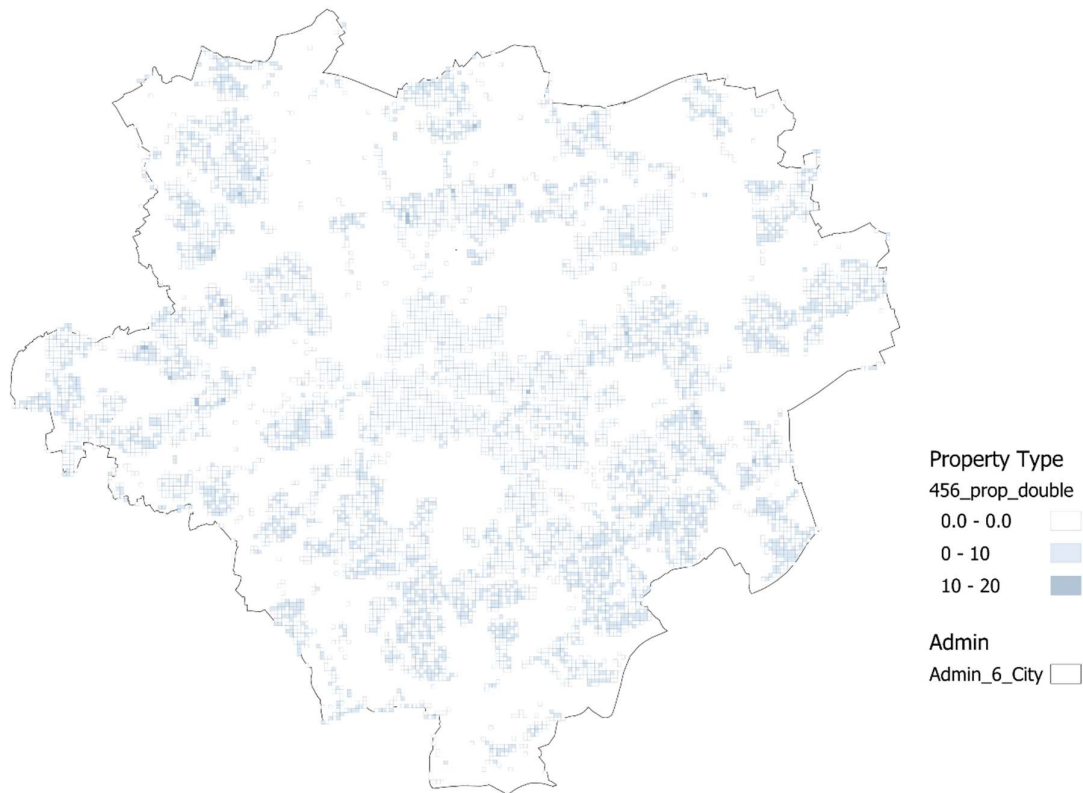


Figure 14 Concentration of double family house. Units: NA (number of buildings)

c. Small Apartment Buildings (3-6 Units)

Mid-sized buildings with multiple households, frequently owned by private landlords or homeowner associations. Representing 24.07% of all buildings in Dortmund, they are distributed across both suburban and urban areas (Zensusdatenbank: Ergebnisse des Zensus, 2011b).

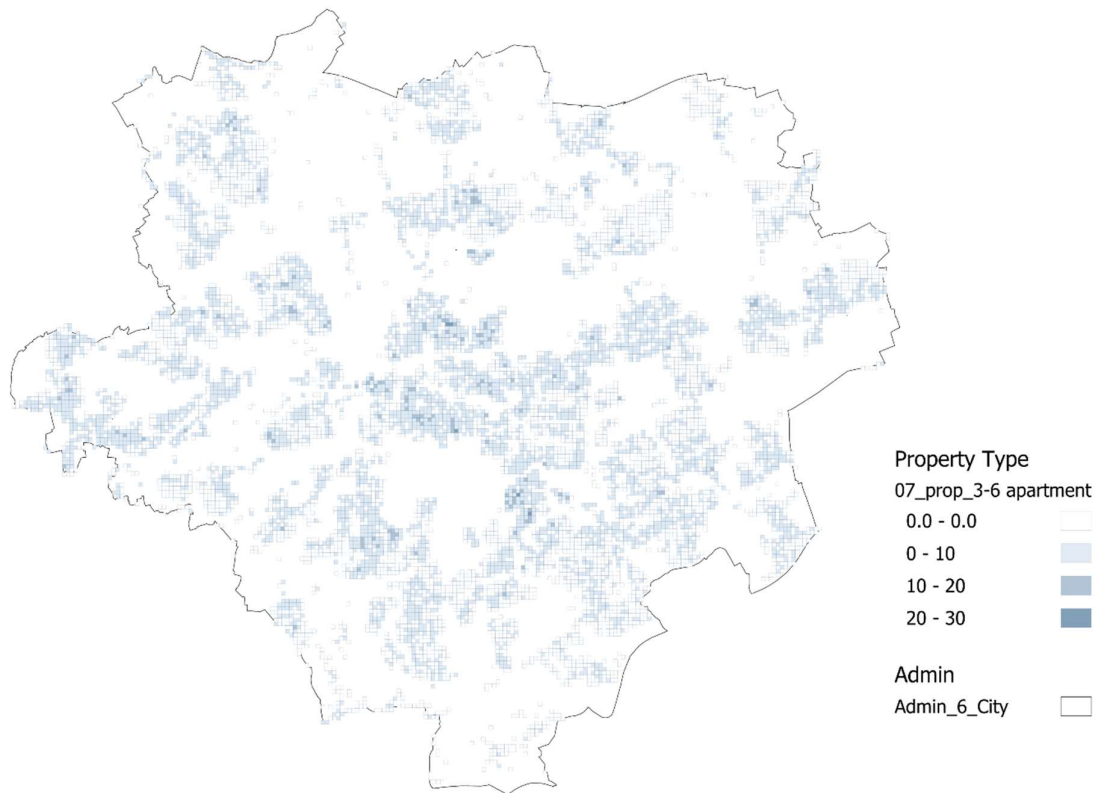


Figure 15 Concentration of buildings with 3-6 apartments. Units: NA (number of buildings)

d. Medium Apartment Buildings (7-12 Units)

High-density structures are typically owned by institutional investors, cooperatives, or municipal authorities. Found mostly in urban areas, these buildings accommodate multiple families but are less common than smaller apartment buildings (Zensusdatenbank: Ergebnisse des Zensus, 2011b).

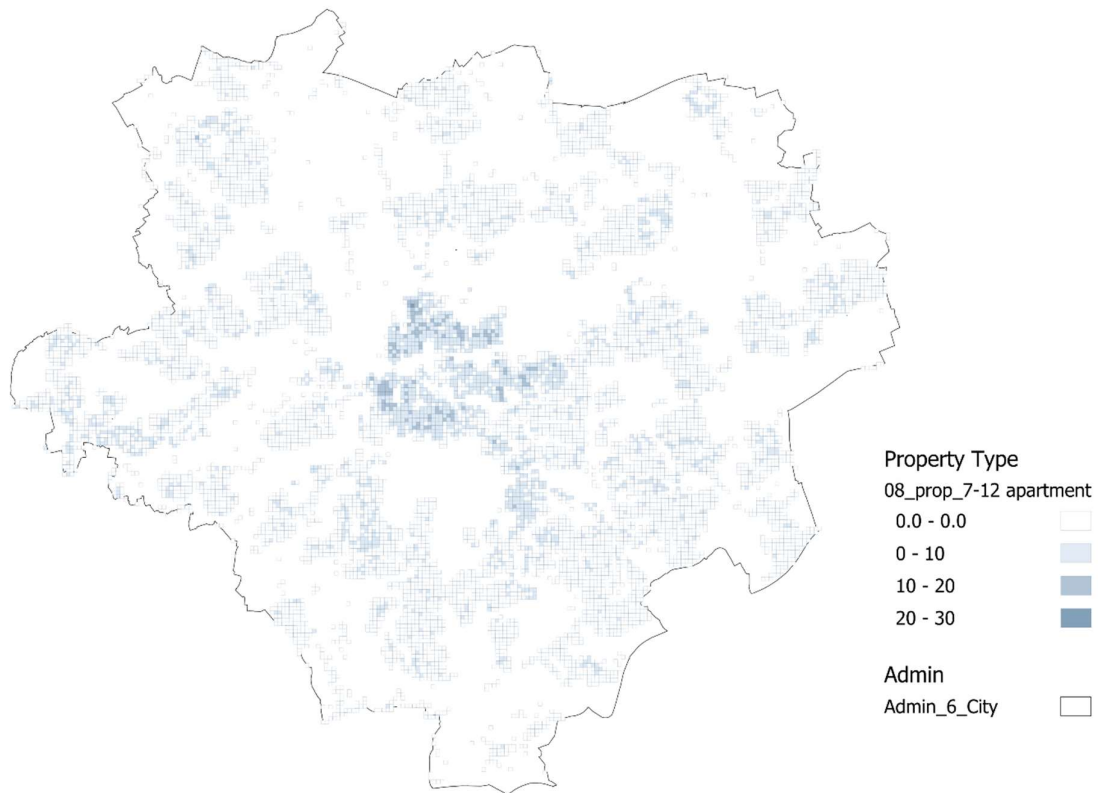


Figure 16 Concentration of buildings with 7-12 apartments. Units: NA (number of buildings)

e. Large Apartment Buildings (13+ Units)

Predominantly located in Dortmund's city center, these buildings contribute to the highest residential density in the area (Zensusdatenbank: Ergebnisse des Zensus, 2011b).

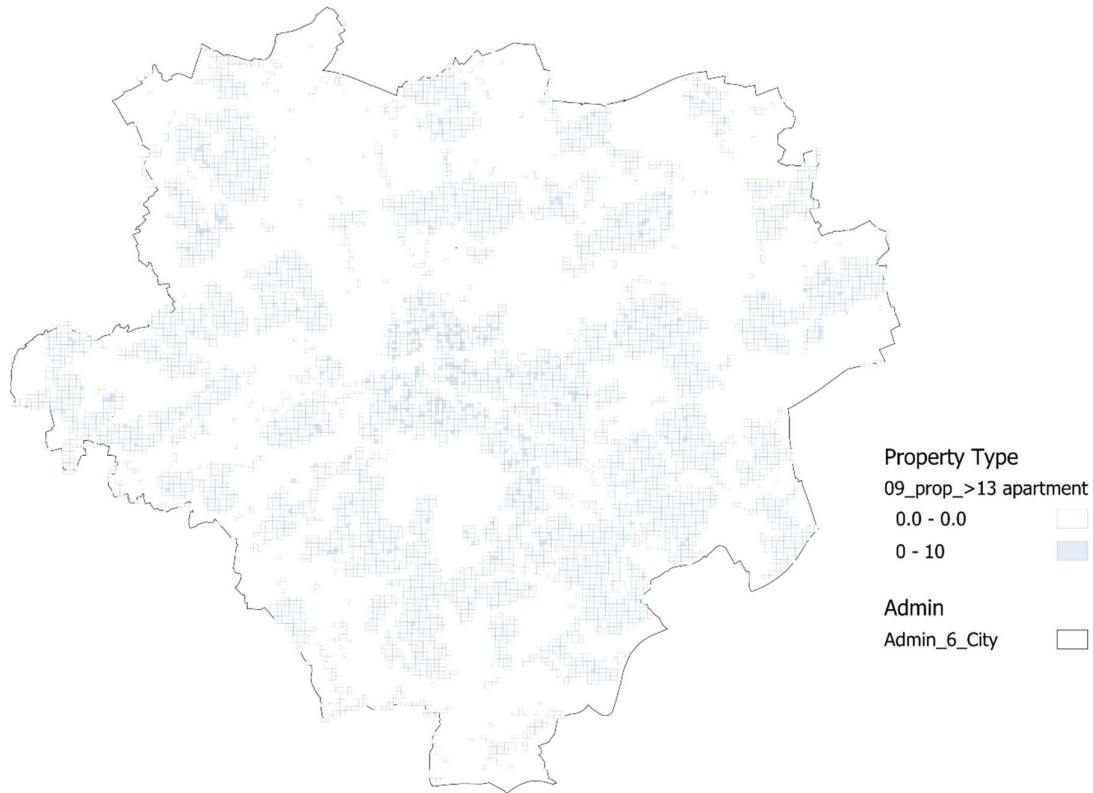


Figure 17 Concentration of buildings with 13 or more apartments. Units: NA (number of buildings)

f. Density of Property

Each property type presents unique challenges and opportunities regarding energy renovations, influenced by factors such as ownership structure, access to resources, and the complexity of stakeholder coordination. Notwithstanding the ownership structure, the density of properties reflects the scale of infrastructure involved and the number of households impacted by the renovation process. This underscores the importance of tailoring renovation strategies to address both the physical and social dimensions of property types, ensuring equitable and effective implementation across diverse urban contexts.

Property Type	Weightage	Reasoning
Single-family House	1	Based on average number of dwellings
Double-family House	2	
Small Apartment Building	4.5	
Medium Apartment Building	9.5	
Large Apartment Building	13	

Table 3 Weightage for different property types.

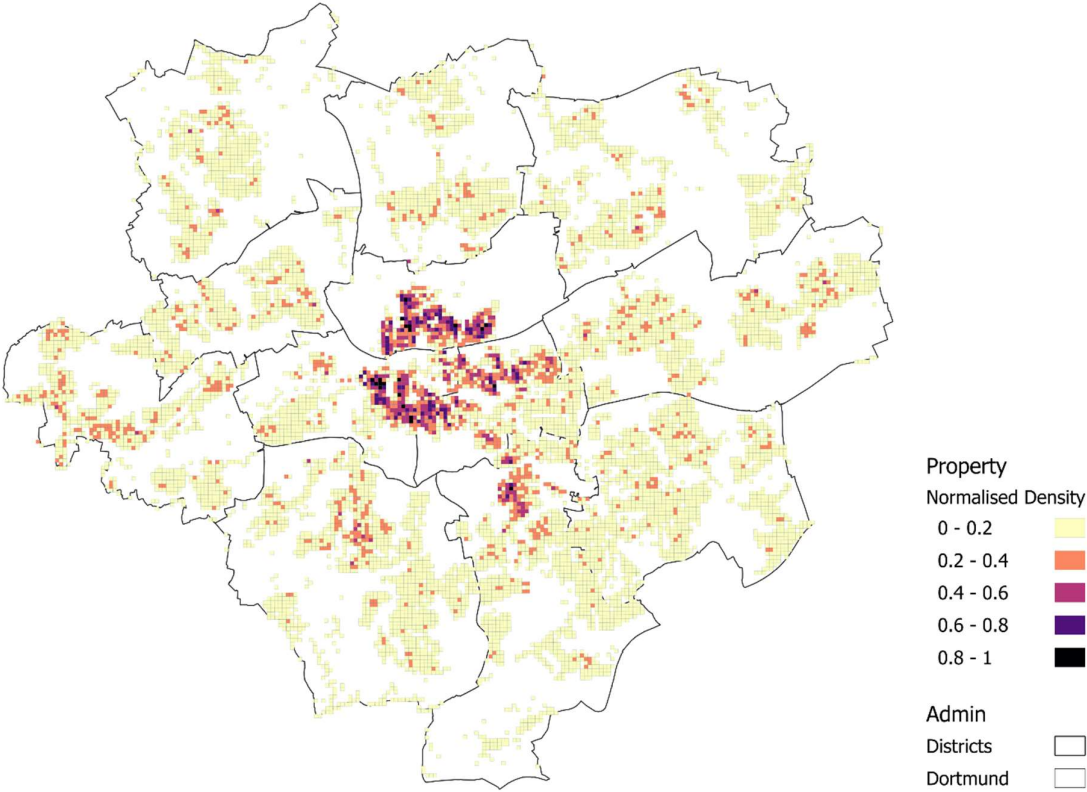


Figure 18 Density of property in Dortmund.

5.3 Occupancy Types

Occupancy refers to the active use of a property by an urban agent. (Cozzolino and Moroni, 2021) emphasized the importance of including tenants in the analysis of property ownership dynamics, as they are directly impacted by renovation outcomes, even if they lack decision-making authority. Two primary occupancy types were identified: owners and tenants. Dortmund, like many large German cities, predominantly operates under a rental housing system, with over 70% of dwellings occupied by tenants (Krapp et al., 2021; Zensusdatenbank: Ergebnisse des Zensus, 2011c).

a. Owner-Occupied

In this type, at least one occupant owns the dwelling. Owner-occupiers directly benefit from renovation efforts, therefore thermal comfort and improved living conditions are positive motivators. Since there is no split incentive between owner and occupant, renovations are more straightforward to implement. This type is generally associated with higher income and older demographics (Krapp et al., 2021; Zensusdatenbank: Ergebnisse des Zensus, 2011c).

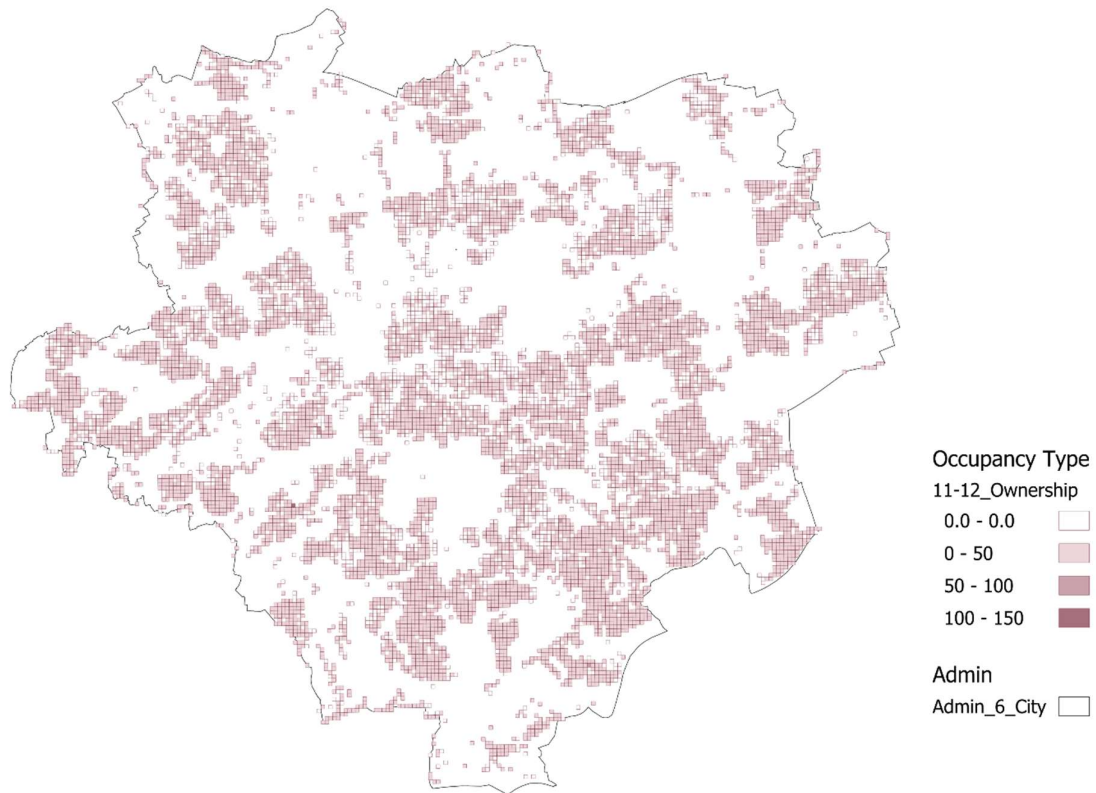


Figure 19 Concentration of owner-occupied households in Dortmund. Units: NA (number of households).

b. Rented Occupancy

In rented properties, occupants do not own the dwelling, regardless of whether they pay rent or reside rent-free. This occupancy type is more prevalent in high-density areas, particularly in the city center (Zensusdatenbank: Ergebnisse des Zensus, 2011c). While the majority of rentals are owned by private individuals, a significant share is offered by private housing companies, non-profits, and cooperatives. In all cases, the responsibility for renovations and maintenance falls to the landlord, who is allowed to pass on up to 8% of the modernization costs to tenants through rent increases under the Civil Law 559: Rent increase after modernising measures (Bürgerliches Gesetzbuch - BGB § 559: Mieterhöhung nach Modernisierungsmaßnahmen) (Galvin, 2023a; Republikanischer Anwälten- und Anwälteverein e.V.).

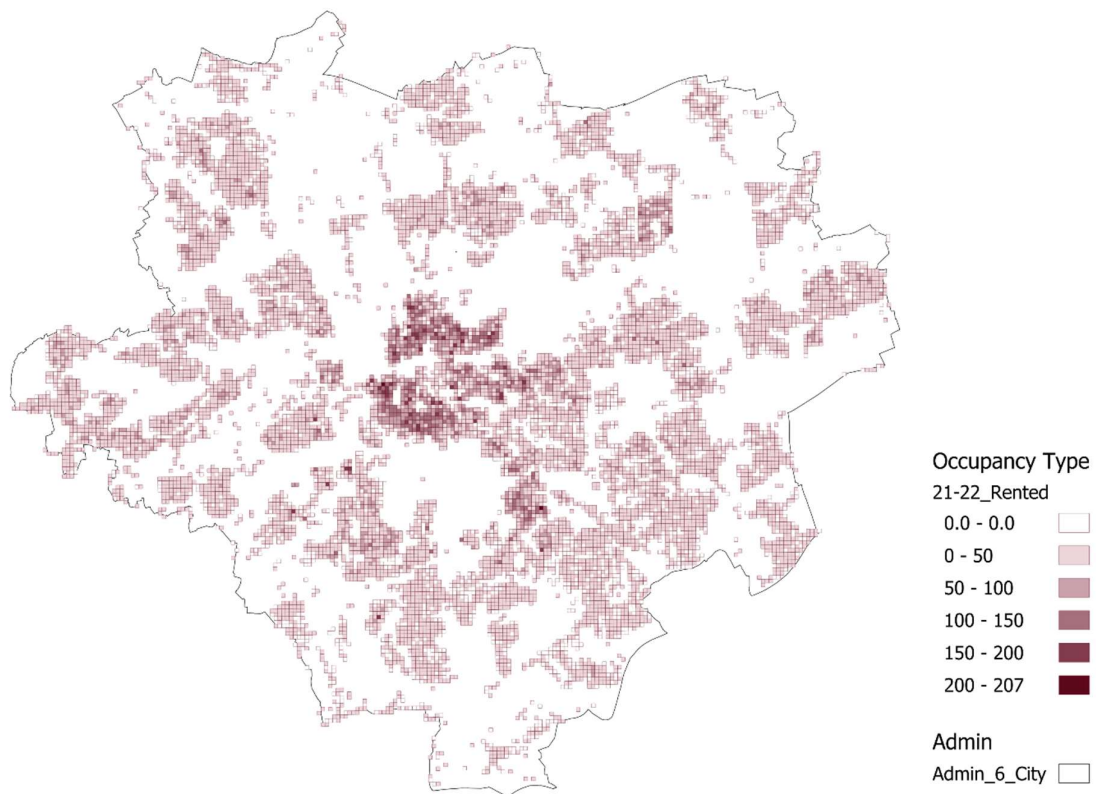


Figure 20 Concentration of tenant-occupied households in Dortmund. Units: NA (number of households).

c. Occupancy Density

The spatial distribution of occupancy in Dortmund reflects patterns typical of large German cities. The city center, characterized by higher property density, is predominantly composed of rental properties, highlighting the dominance of tenant-occupied dwellings in urban cores. Renovations in tenant-occupied units affect both tenants and property owners.

Occupancy Type	Weightage	Reason
Owner-occupied unit	1	Renovation only affects owner.
Tenant-occupied unit	2	Since renovation affects tenant as well (Buessler et al., 2017).

Table 4 Weightage for different occupancy types.

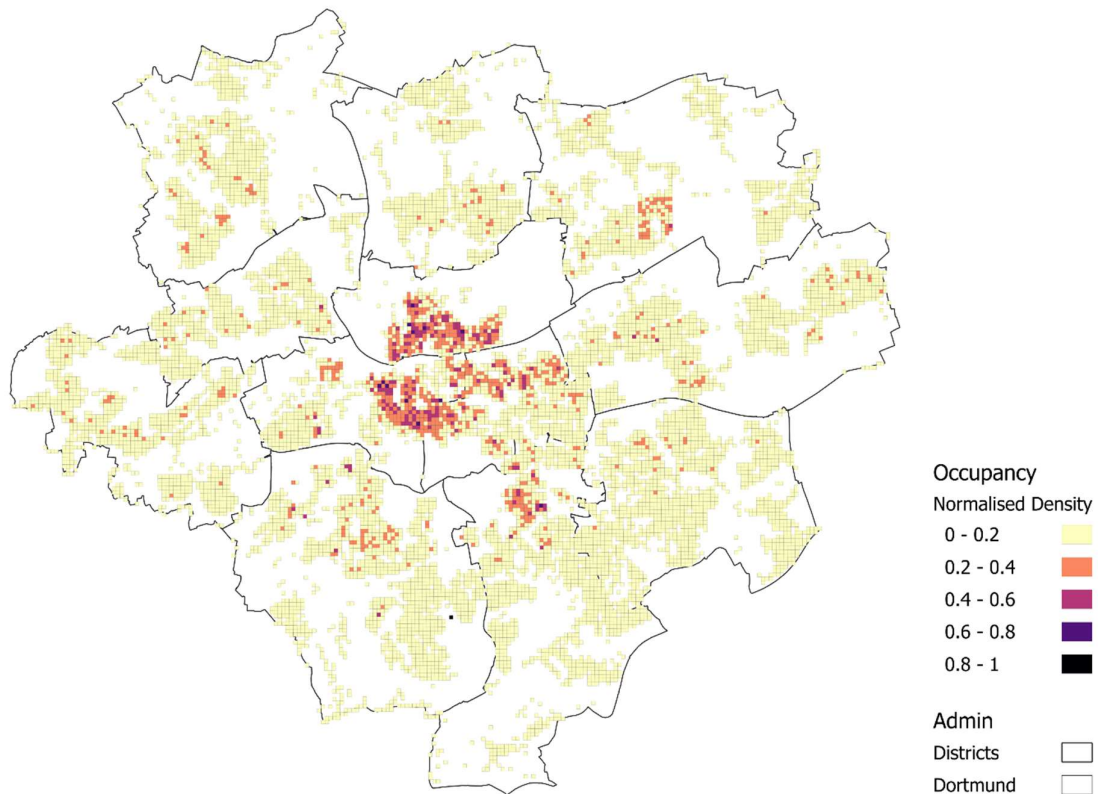


Figure 21 Density of occupants in Dortmund.

Therefore, interventions in the city center and in the former steel industrial sites in the northern part of Hörde must consider tenant-landlord dynamics, including financial and legal frameworks, such as rent increases permitted under modernization allowances. These considerations must be incorporated into renovation strategies to effectively address the unique challenges posed by these areas.

Overlapping Preconditioning Factors

When ownership, property type, and occupancy are analyzed geographically, a clear hotspot emerges in Dortmund's inner city, particularly in Nordstadt, the historic city center, and parts of Hörde. These districts exhibit the highest concentration of ownership diversity, property density, and rental occupancy. Prioritizing these areas could maximize the impact of energy renovation initiatives, enhancing both infrastructure and residents' quality of life.

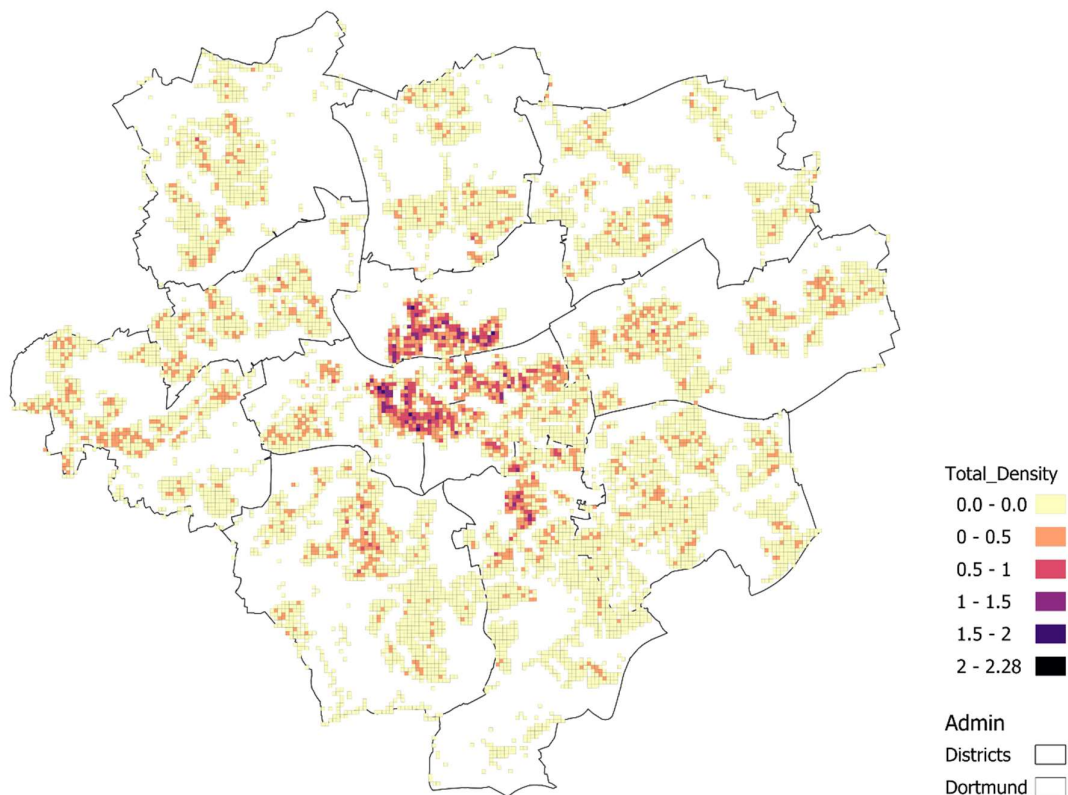


Figure 22 Degree of impact to infrastructure and quality of life.

6. Barriers to Energy Renovations

Two key outcomes of this research are the spatial and comparative analysis of barriers to energy renovation as experienced by property owners across Dortmund. This study not only quantifies the intensity of these barriers but also maps their geographical distribution, highlighting neighborhoods where energy renovation remains largely inaccessible.

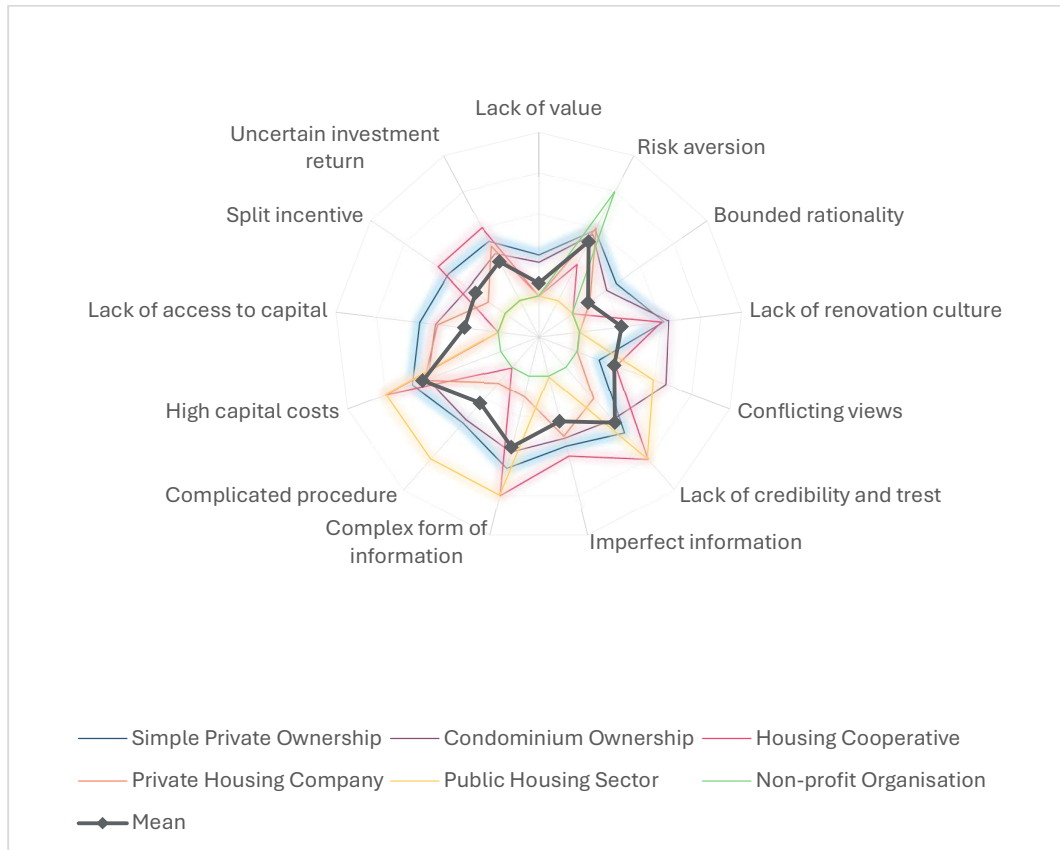


Figure 23 Windrose diagram showing the intensity of barriers perceived by different ownership groups.

To achieve an understanding of the owner's perspective, a qualitative survey was conducted exploring the perceived barriers and incentives for energy renovation among different ownership types. Respondents were categorized into three groups: private individuals, condominium owners, private sector housing companies, cooperatives, public housing companies and NGOs. This exercise provided a comprehensive understanding of how different barriers—financial, informational, cultural, and behavioral—are perceived by various ownership types and how these barriers influence

renovation decisions (See Figure 23). These findings are juxtaposed with documented research to identify patterns, deviations, and emerging trends in renovation challenges.

In the next step, the numerical equivalent of the Likert scale results is used to weigh the intensity with which a barrier is experienced in a neighborhood. The results are visualized in a grid-based format, where each grid represents the cumulative intensity of a specific barrier in each neighborhood:

- High Intensity: Neighborhoods where a particular barrier is perceived as a significant obstacle, making energy renovation largely inaccessible for property owners and reducing renovation adoption rates.
- Low Intensity: Neighborhoods where the barrier is either absent or minimally perceived, fostering positive decision-making behavior and increasing the likelihood of renovation adoption.

The weighted values are calculated by multiplying the intensity of a barrier experienced by each ownership type with the proportion of that ownership type present in the neighborhood. This method allows for a nuanced understanding of the interplay between ownership characteristics and the barriers to energy renovation.

This spatial analysis is critical for identifying neighborhoods that require targeted interventions. The next section provides insights into each barrier, as expressed by the survey respondents and the findings from literature. By highlighting areas where barriers are most prevalent, city administrators can prioritize their efforts, tailoring policies and resources to address specific challenges. Conversely, neighborhoods with low barrier intensity can serve as examples of effective renovation practices or as opportunities for incentivizing further progress.

Limitations of the survey findings:

A total of 32 responses were collected from the surveys (See Table 5). Due to the limited sample size, comparative analysis between survey findings and literature findings was conducted only for private individuals and condominium ownership. Other ownership types did not have sufficient responses to allow for a meaningful comparative analysis.

Public housing companies account for only 2.9% of the buildings in Dortmund. However, no survey responses were obtained from this category. Consequently, findings from literature were directly used in mapping for this ownership type.

Responses from private individuals, condominium owners, and private-sector housing companies were primarily gathered through the CATCH4D project conducted by ILS,

Dortmund. These responses were collected during the XXL Owner's Forum event, which was organized by the Urban Renewal Office and Nordstadt District Management. The remaining responses were obtained through independently distributed online surveys targeting private-sector housing companies.

Ownership	No. of respondents	% respond.	% Dort.	Used in theoretical	Used in mapping
Simple private	17	53.1%	71.4%	Yes	(from survey)
Condominium	11	34.4%	12.6%	Yes	(from survey)
Cooperative	1	0.03%	2.9%	NA	(from survey)
Private Housing	2	0.06%	9.9%	NA	(from survey)
Public Housing	x		2.9%	NA	(from lit.)
NGO	1	0.03%	0.4%	NA	(from survey)

Table 5 Information regarding respondents of the survey.

6.1 Findings from Individual Barriers

i.a Lack of Value

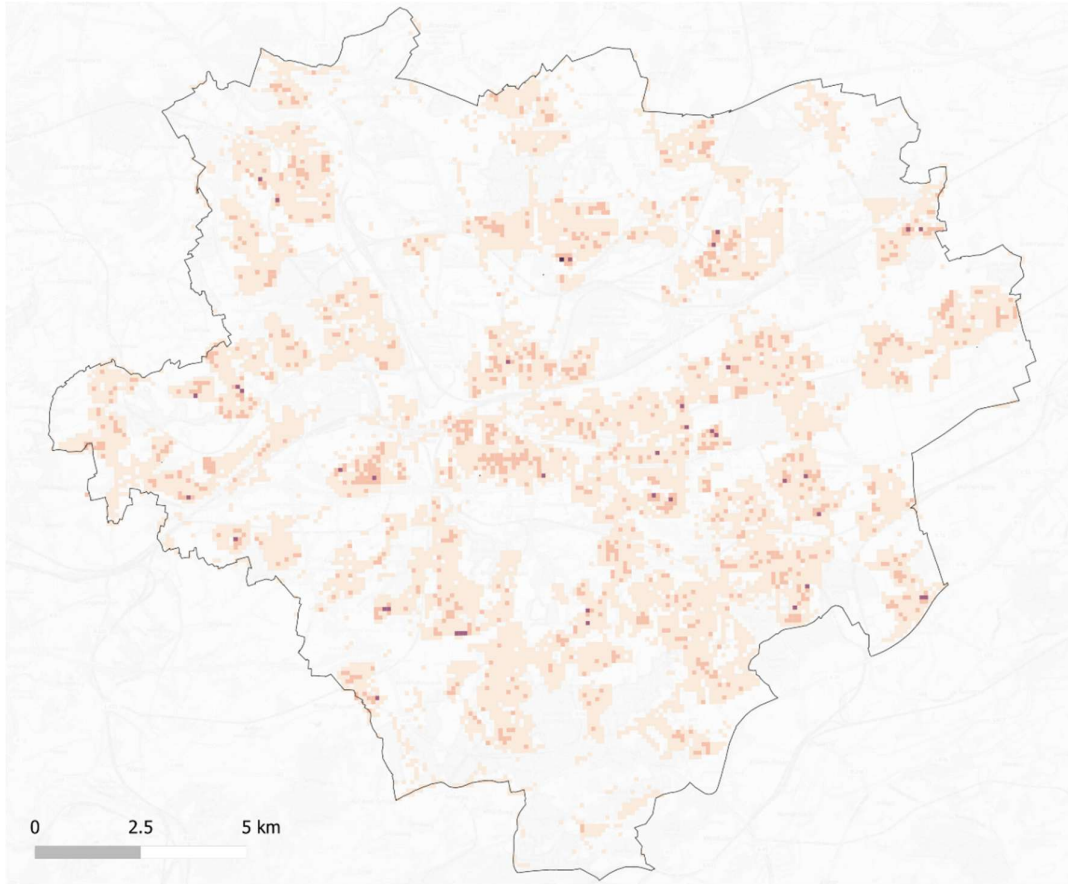


Figure 24 Intensity of owner's lack of values as a barrier to energy renovation.

The literature presents mixed views on the extent to which individuals value energy renovations. Jakob (2007) suggests that private individuals often lack awareness of the importance of energy renovations, viewing them as unnecessary or secondary concerns. Blomqvist et al. (2022) argues the same, where the research found non-energy related renovations are given more priority in residential buildings with public or cooperative ownerships. However, Heiskanen et al. (2012) provides a contrasting perspective for private owners, highlighting that private owners, particularly those with single-family homes (rented or owner-occupied), value their properties and are willing to maintain them, even when such efforts are financially challenging. This attitude corresponds to a need for healthier living with better thermal comfort, personal responsibility towards the environment and a genuine interest in new innovative technologies.

According to März (2018b), pro-environmental attitudes may serve as a gateway for exploring the topic of energy renovations, but they rarely function as the sole motivator. Interestingly, some individuals who have already undertaken renovations do not necessarily identify as advocates of sustainable behavior. This discrepancy indicates that while environmental consciousness may be present among owners, it does not always translate into renovation action, further underscoring the complex relationship between values and actions.

According to the survey findings, a larger majority do not doubt the positive effect energy renovation can have on the environment. This pro-environmental behavior is not enough to decide an owner’s decision making, but reflects whether or not the attitude towards the behavior is positive.

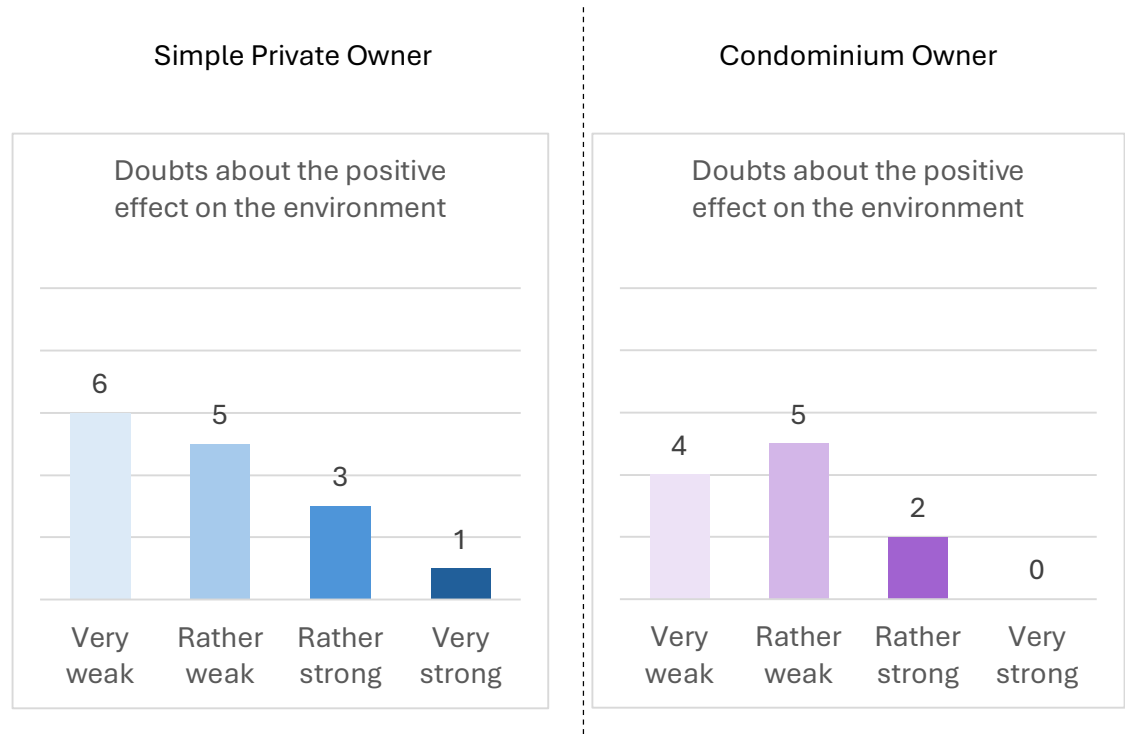


Table 6 Response of simple private and condominium owners to the lack of value as a barrier to renovation.

i.b Risk Aversion

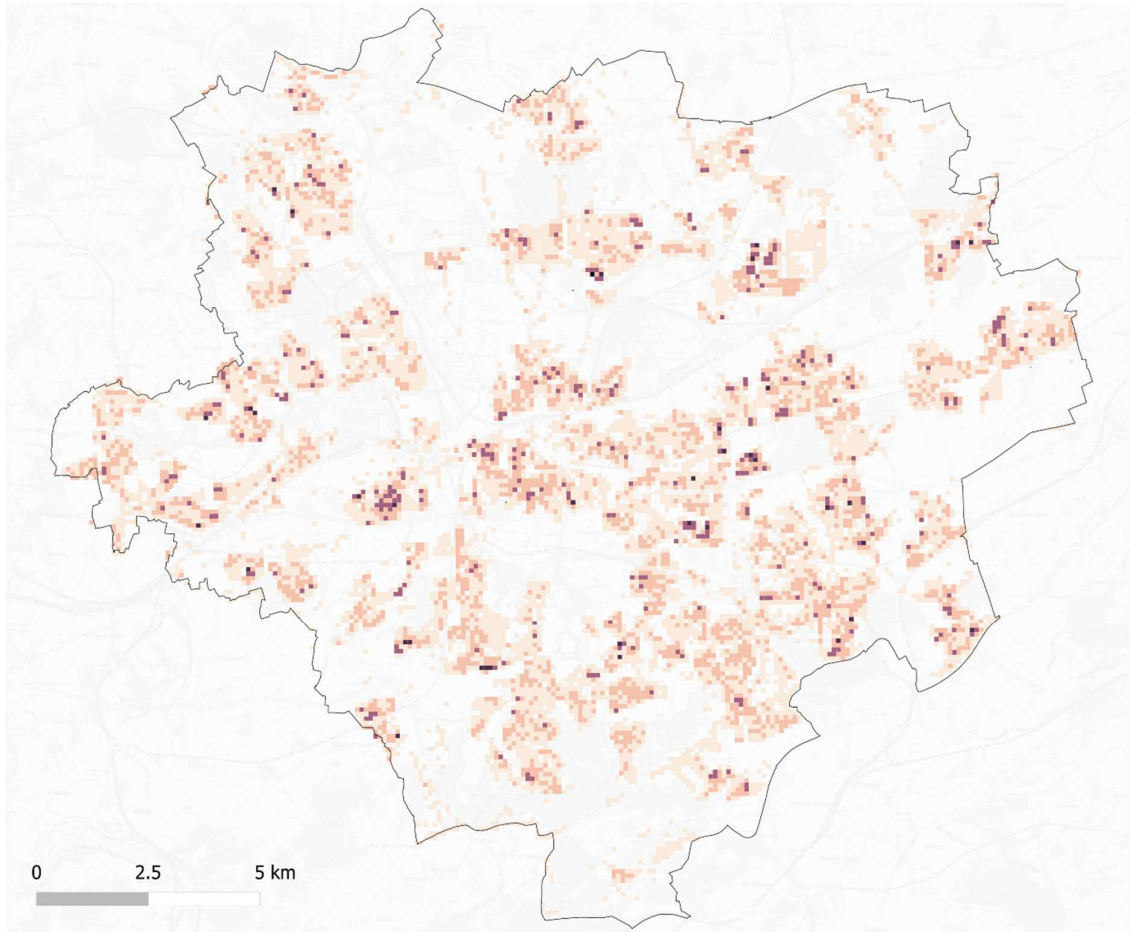


Figure 25 Intensity of owner's aversion to risk as a Barrier to Energy Renovation.

Private homeowners, particularly those in single-family houses, often exhibit a strong aversion to risk in energy renovations due to high personal liability (März, 2018b; Stieß and Dunkelberg, 2013). Many private owners prefer to use existing savings instead of taking loans, prioritizing basic expenses like routine maintenance over energy upgrades. Financial risks are further exacerbated for rented properties, where potential revenue loss during renovations can deter landlords. Additionally, non-financial nuisances such as noise, dust, and disruption during the renovation process contribute to hesitation (März, 2018b).

Like private owners, condominium owners are hesitant to take loans due to financial risks. However, their challenges extend beyond individual liability. Heiskanen et al. (2012), März (2018b) and Weatherall et al. (2018) highlight that renovations in

condominiums often come with added social risks. Disputes over the unequal distribution of benefits or costs can strain relationships among neighbors. Cairns et al. (2023) and Matschoss et al. (2013) emphasize that such social disturbances make owners wary of initiating renovations, fearing increased conflict within the shared ownership framework. While cooperatives could have similar issues, other ownership types do not face this issue.

The survey asked respondents about their attitude towards taking financial risks and it is a higher barrier in simple private ownership than in condominiums. Neither is the respondents of private housing companies considered this a barrier.

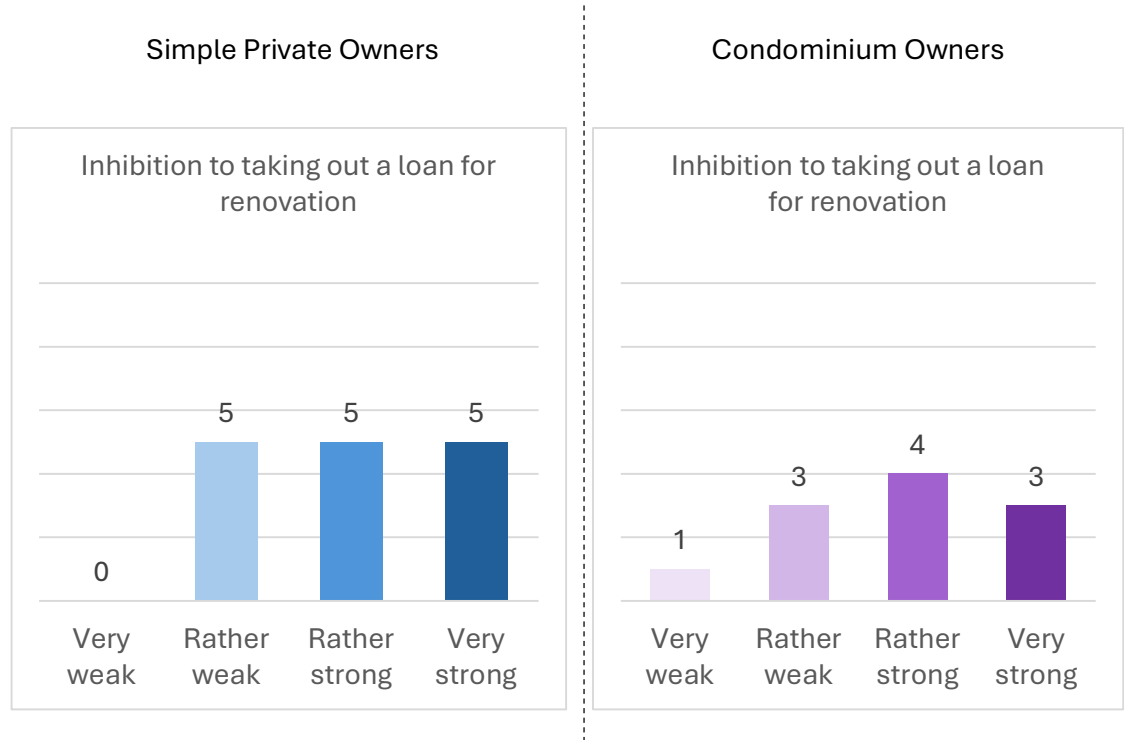


Table 7 Response of simple private and condominium owners to risk aversion as a barrier to renovation.

i.c Bounded Rationality

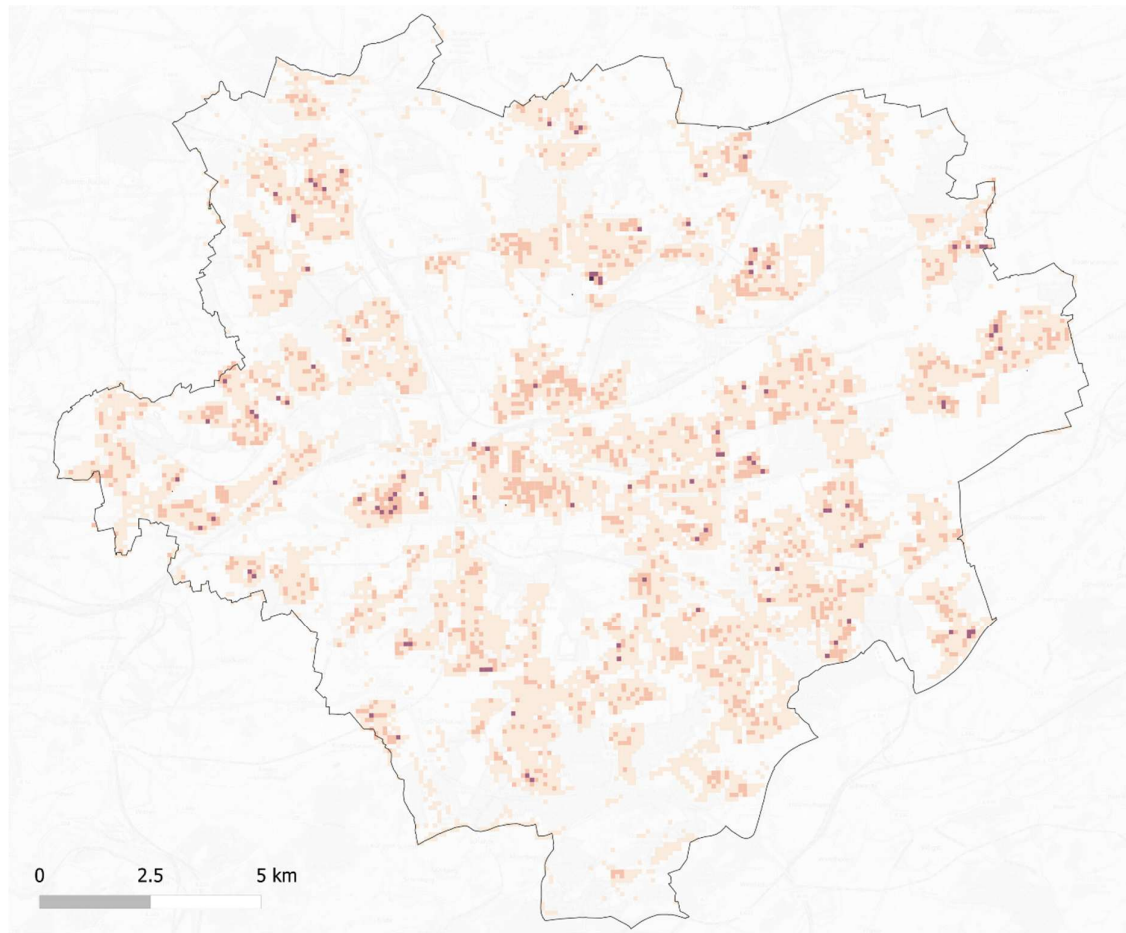


Figure 26 Intensity of owner's bounded rationality as a barrier to energy renovation.

Private individuals often display adverse selection of actions with short-term returns stemming from bounded rationality when deciding whether to renovate. This short-term perspective leads them to prioritize immediate financial savings over long-term thermal and environmental benefits. Ameli and Brandt, 2015 argue that owners are influenced by cognitive biases, causing them to rely on "rule of thumb" decisions. As a result, they frequently opt for the cheapest solutions rather than thermally and environmentally optimal options. Jakob (2007) highlights that this behavior stems from a lack of long-term thinking and a tendency to undervalue the future benefits of energy renovations, such as reduced energy bills and increased property value.

For condominium owners, bounded rationality is a significant barrier to energy renovations. Many individuals fail to perceive energy upgrades as a necessary step, even

when the benefits are evident. This issue is especially pronounced in rented apartments, where the decision to renovate depends heavily on the rationality and willingness of the property owner. Buessler et al. (2017) and Cairns et al. (2023) point out that the split incentive problem—where the benefits of renovation (e.g., lower energy bills) accrue to tenants rather than landlords—further discourages action. In such cases, the lack of a clear incentive structure undermines the motivation to invest in energy-efficient upgrades. This barrier does not affect the decision making for other ownership types.

This is a weak barrier in both types of ownership. Most private owners and companies are motivated to renovate by the long-term energy and cost saving aspect.

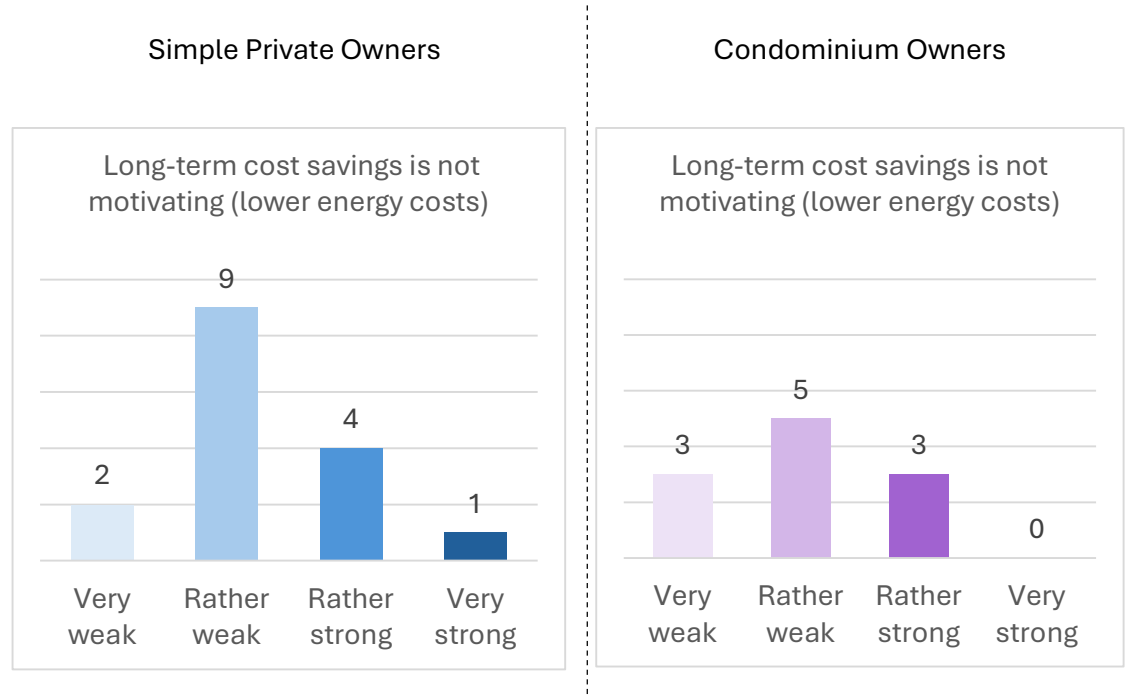


Table 8 Response of simple private and condominium owners to their bounded rationality as a barrier to renovation.

ii.a Lack of Renovation Culture

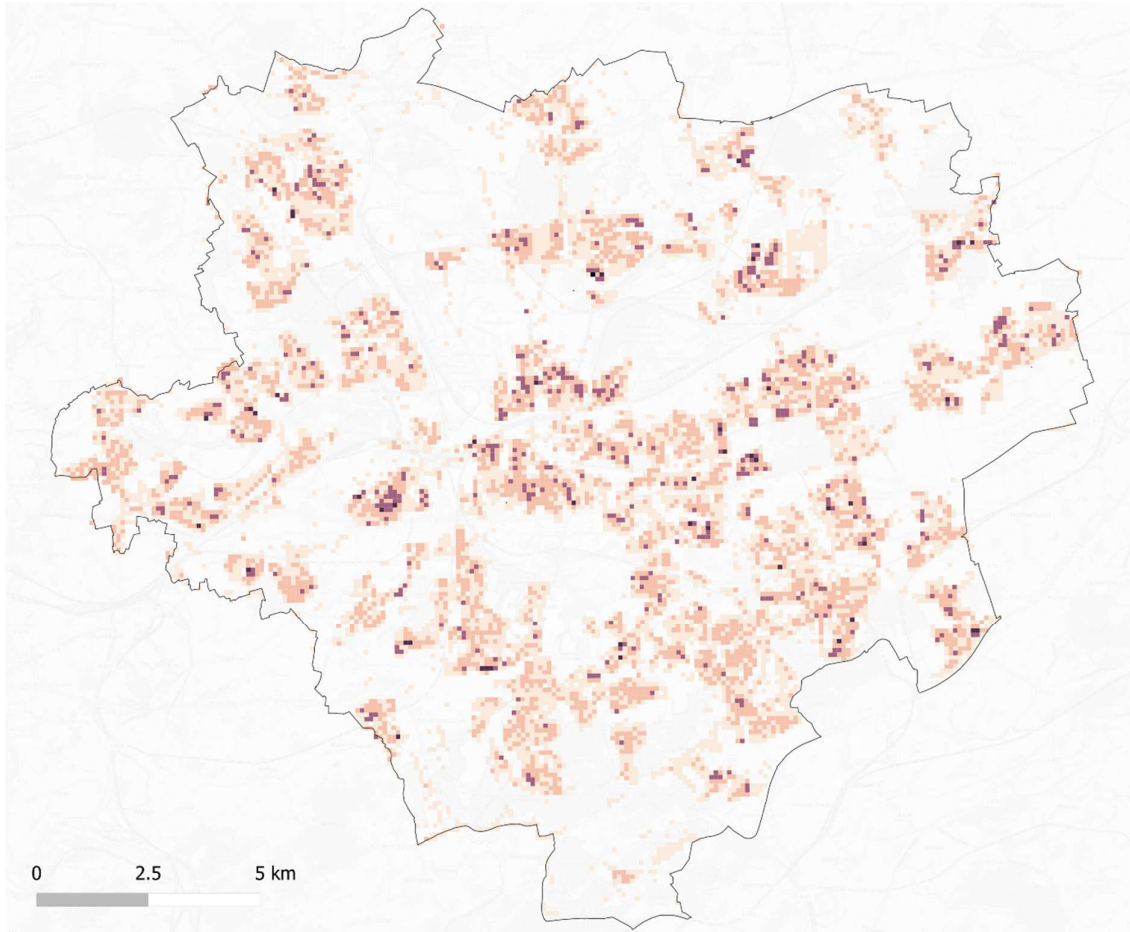


Figure 27 Intensity of lack of renovation culture as a barrier to energy renovation.

Literature explicitly identifies the absence of a strong organizational culture within housing companies or associations as a barrier to decisions on energy renovation (Blomqvist et al., 2022; Heiskanen et al., 2012). While literature does not directly address the lack of cultural influences as a barrier for private or condominium ownership, it raises an intriguing question: could social dynamics act as a catalyst for motivating renovations? The concept of the "neighborhood effect"—where individuals are influenced by the actions of those in their social or physical proximity—suggests that energy renovations could become more appealing if a critical mass of residents in a neighborhood values and prioritizes such upgrades. This normalization of energy renovations as part of local cultural norms could drive broader adoption.

Observing neighbors, friends, or community members undertaking energy-efficient upgrades might foster a sense of shared responsibility or even friendly competition, indirectly motivating others to follow suit. In the case of condominium ownership, where decision-making relies on collective agreement, shared values and a unified vision among owners could play a crucial role in facilitating renovation decisions. Conversely, a lack of shared priorities or misalignment among owners could hinder progress, especially when consensus is required to implement energy efficiency measures.

Although this perspective remains speculative, it opens important avenues for further research. Exploring the role of cultural norms, community dynamics, and collective motivations in shaping energy renovation decisions could provide valuable insights into overcoming barriers and promote broader adoption across ownership types.

Interestingly, the survey findings reveal that owners do not feel compelled to renovate even when observing others in their neighborhood undertaking similar actions. This suggests that, while neighborhood influence has the potential to be impactful, it is not currently a primary driver of energy renovation decisions. To foster broader adoption, cultural pressure will need to evolve, establishing energy renovations as a widely accepted and normalized practice in the future.

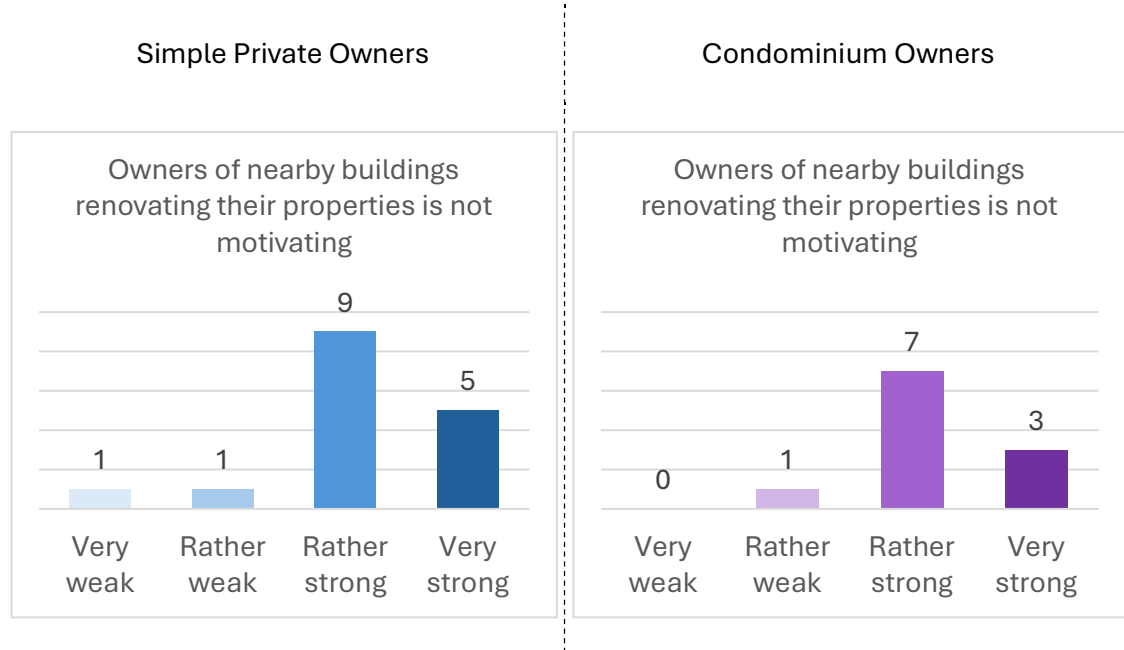


Table 9 Response of simple private and condominium owners to the lack of renovation culture as a barrier to renovation.

ii.b Conflicting Views

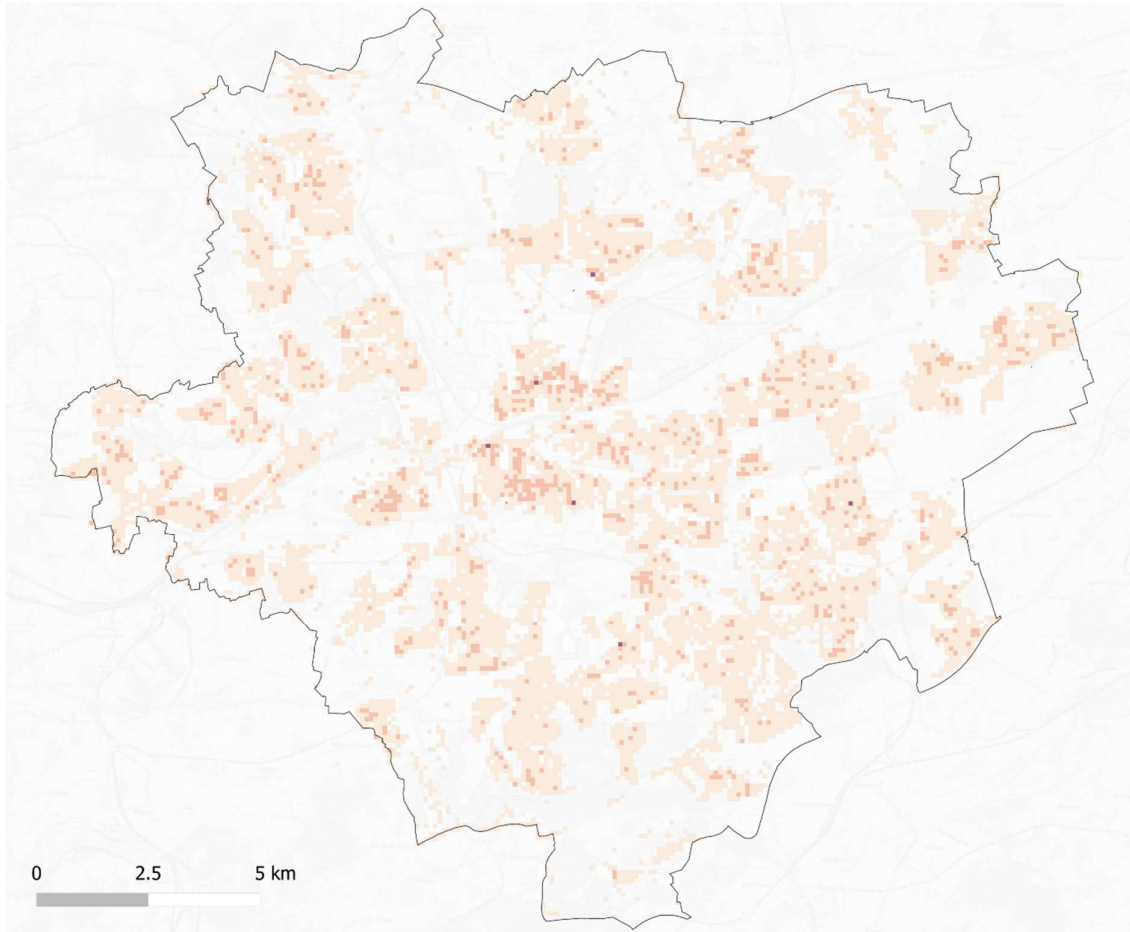


Figure 28 Intensity of conflicting views as a barrier to energy renovation.

For simple private ownership, conflicting views are generally not a significant barrier. Since the property is typically owned by an individual or a small group, decision-making processes are straightforward, with fewer opportunities for disagreements to arise. This streamlined ownership structure minimizes delays or resistance related to differing opinions about energy renovation.

In contrast, conflicting views present a more pronounced barrier in condominium and cooperative ownerships. Studies highlight that diverse and contradictory claims about the energy and cost savings of energy-efficient renovations can demotivate owners from pursuing such upgrades (Buessler et al., 2017). This discrepancy creates uncertainty, making it challenging for owners to agree on renovation decisions.

Additionally, the uneven distribution of benefits from full or partial energy renovations further exacerbates this issue. Owners who perceive little to no direct benefit from the upgrades may lack the motivation to support renovation projects (Ebrahimigharehbaghi, Qian, Vries, Visscher, 2022b).

The collective decision-making process inherent in condominium ownership adds another layer of complexity. Reaching consensus among owners can be difficult, especially when some are unavailable to participate in discussions or decisions. This lack of availability and alignment among owners is a significant barrier, as highlighted by various studies (Buessler et al., 2017; Cairns et al., 2023; Matschoss et al., 2013).

A small section of respondents indicated that their decision to undertake energy renovations depends on others. This could be attributed to the presence of tenants residing in the property, necessitating a collective decision-making process. This barrier is particularly pronounced in condominium ownership, where consensus among multiple stakeholders is required, making it a significantly stronger challenge compared to other ownership types.

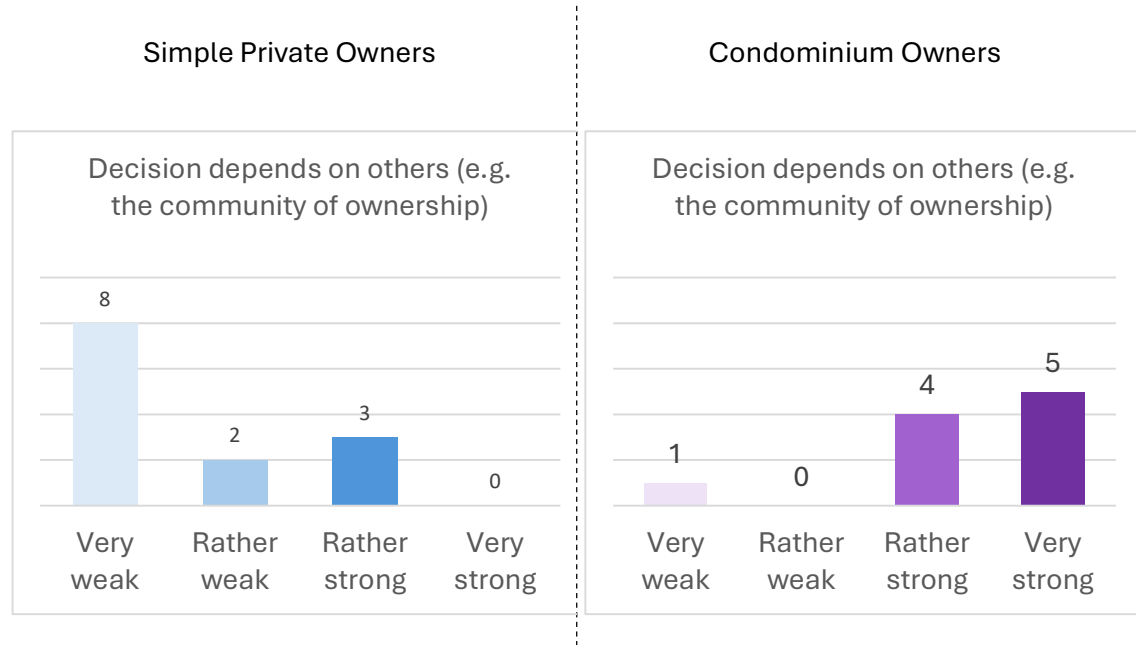


Table 10 Response of simple private and condominium owners to the conflicting views in their surroundings as a barrier to renovation.

ii.c Lack of Credibility and Trust

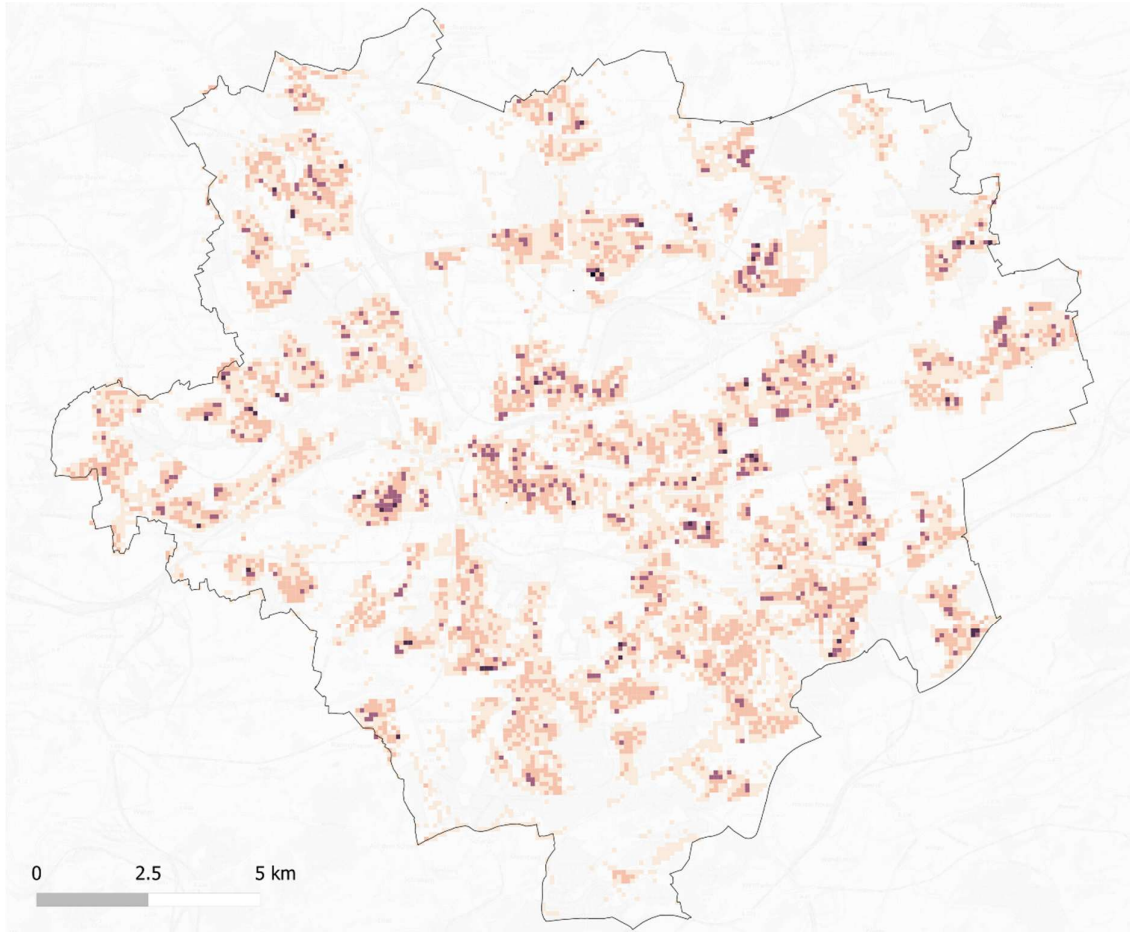


Figure 29 Intensity of lack of credibility and trust as a barrier to energy renovation.

For simple private owners, a lack of trust in professionals and the government is a significant barrier to energy-efficient renovations. While many owners are open to carrying out standard renovations, they often hesitate when it comes to energy efficiency upgrades due to doubts about the expertise and intentions of professionals involved. Instead of relying on industry experts, many prefer to seek advice from friends or acquaintances, as they perceive these sources to be more trustworthy (Jakob, 2007). This reliance on informal networks can lead to missed opportunities for effective energy renovations and limit the adoption of innovative, energy-saving technologies.

For condominium owners, the issue of trust extends to property managers and trustees as well, who often play a central role in organizing and overseeing renovations. Studies show that many owners distrust the skills and capabilities of these professionals to

manage energy-efficient renovations effectively (Buessler et al., 2017; Cairns et al., 2023). This distrust can lead to a loss of interest among owners, further delaying or derailing renovation efforts. In addition, the collective nature of decision-making in condominiums amplifies the impact of mistrust, as skepticism from even a few owners can hinder consensus on moving forward with renovation projects.

The survey revealed that both ownership types perceive a lack of support from the federal, state, or municipal governments, despite significant efforts to assist owners. Upon further investigation, owners in Nordstadt highlighted that the state-provided energy consulting services and the information shared by the Owners' Forum of Nordstadt were their most trusted sources for energy efficiency guidance, only preceded by their own research. This indicates that personalized and localized support plays a crucial role in building trust among owners. A more customized, neighborhood-focused approach could enhance the effectiveness of governmental efforts, potentially resulting in a higher uptake of energy renovations.

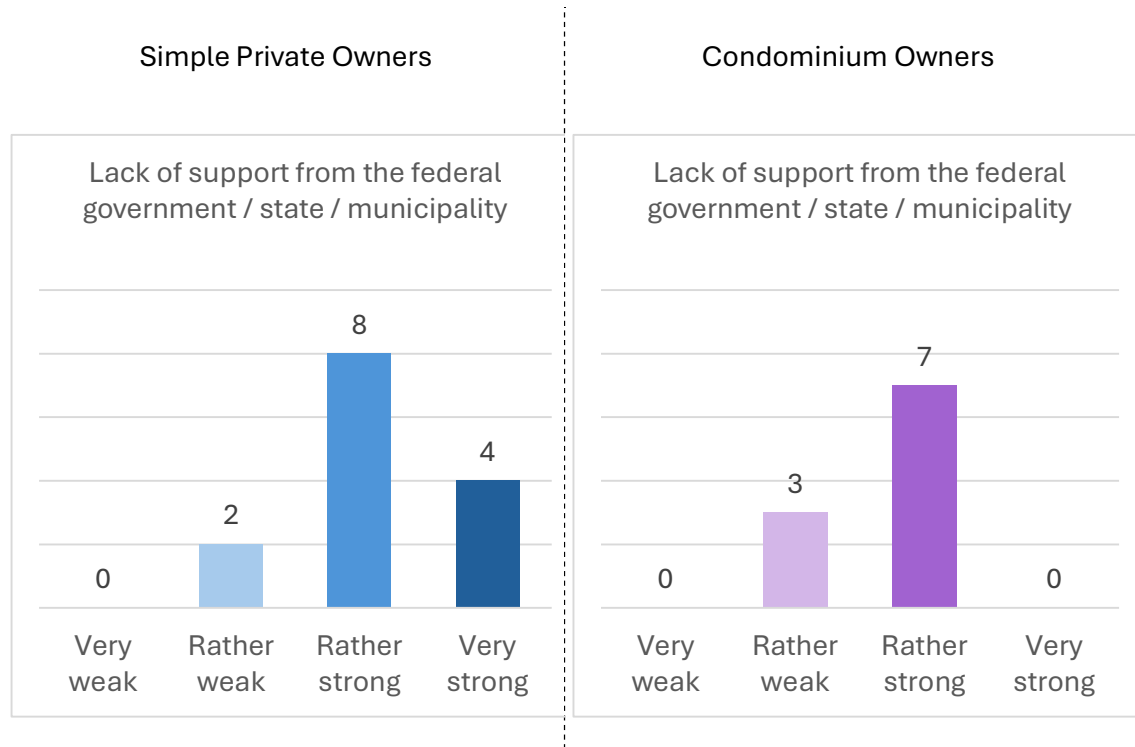


Table 11 Response of simple private and condominium owners to the lack of credibility and trust in state as a barrier to renovation.

iii.b Imperfect Information

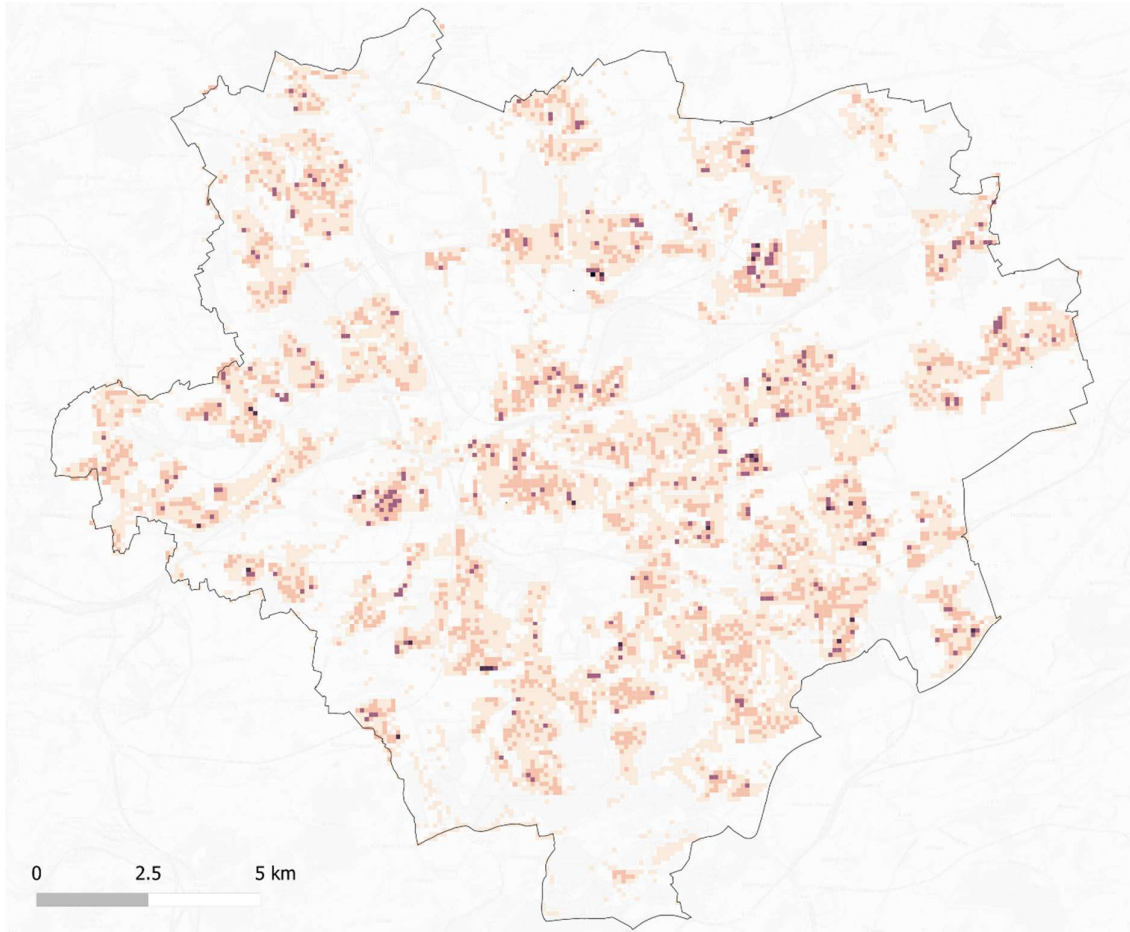


Figure 30 Intensity of Perceived imperfection of information as a Barrier to Energy Renovation.

For simple private owners, a lack of knowledge about energy renovations and new technologies can significantly hinder the uptake of such projects (Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022; Hope and Booth, 2014; März, 2018b). Limited understanding of available options and their potential benefits creates uncertainty, making owners hesitant to pursue energy-efficient upgrades (Heiskanen et al., 2012). Additionally, the time and effort required to gather and interpret complex technical information can act as a further deterrent, also in cooperatives. When faced with these challenges, many owners may prioritize simpler, more familiar renovations or choose not to act at all.

For condominium owners, insufficient knowledge is similarly a barrier to energy renovations. Bobkova et al. (2017 - 2017) highlighted that a lack of understanding of energy-efficient solutions and their long-term benefits can impede decision-making. This is particularly critical in condominium settings, where collective decisions require clear,

accessible information to align the interests of multiple stakeholders. Without adequate knowledge, owners may struggle to evaluate the costs, benefits, and feasibility of proposed renovations, further complicating the decision-making process. Public companies and cooperatives often cite their lean organizational structures as a reason for their inability to dedicate the necessary effort to seek out the right information (Blomqvist et al., 2022).

This is identified as a significant barrier for private simple owners, whereas it is less pronounced for condominium owners. The shared responsibility among condominium owners likely reduces the individual burden of information-seeking. Similarly, this barrier does not appear to hinder positive decision-making in private housing companies, where organizational structures and resources may already facilitate access to relevant information.

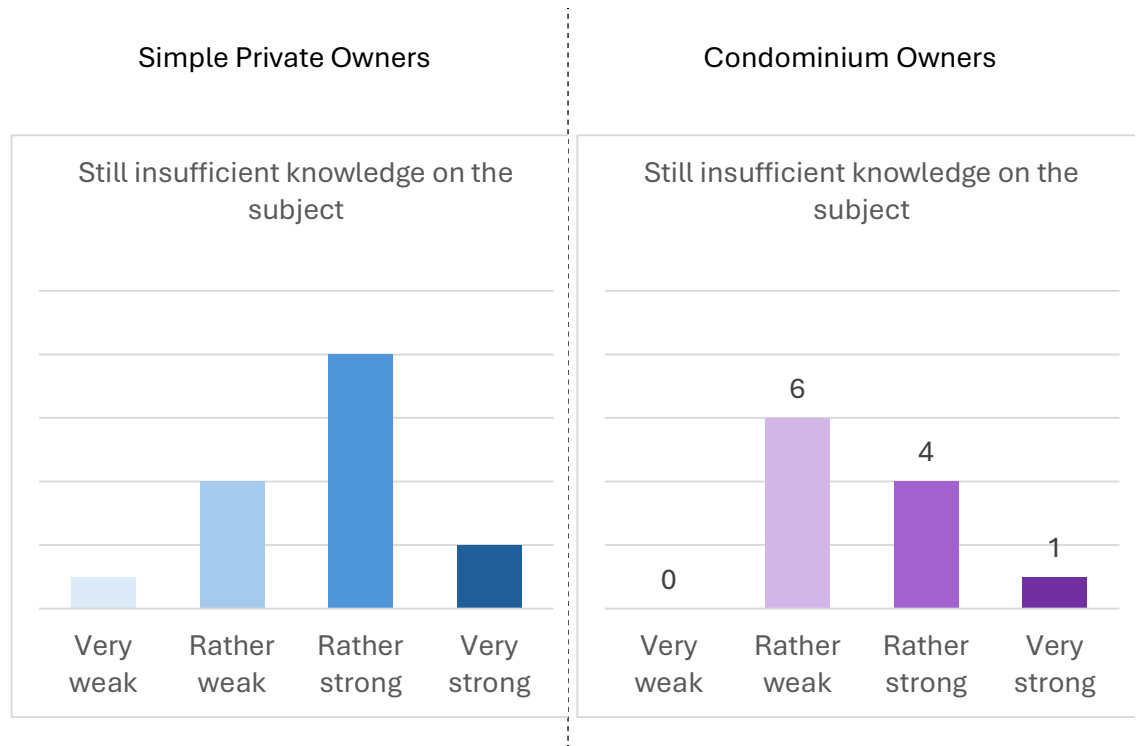


Table 12 Response of simple private and condominium owners to the lack of information as a barrier to renovation.

iii.a Complex Form of Information

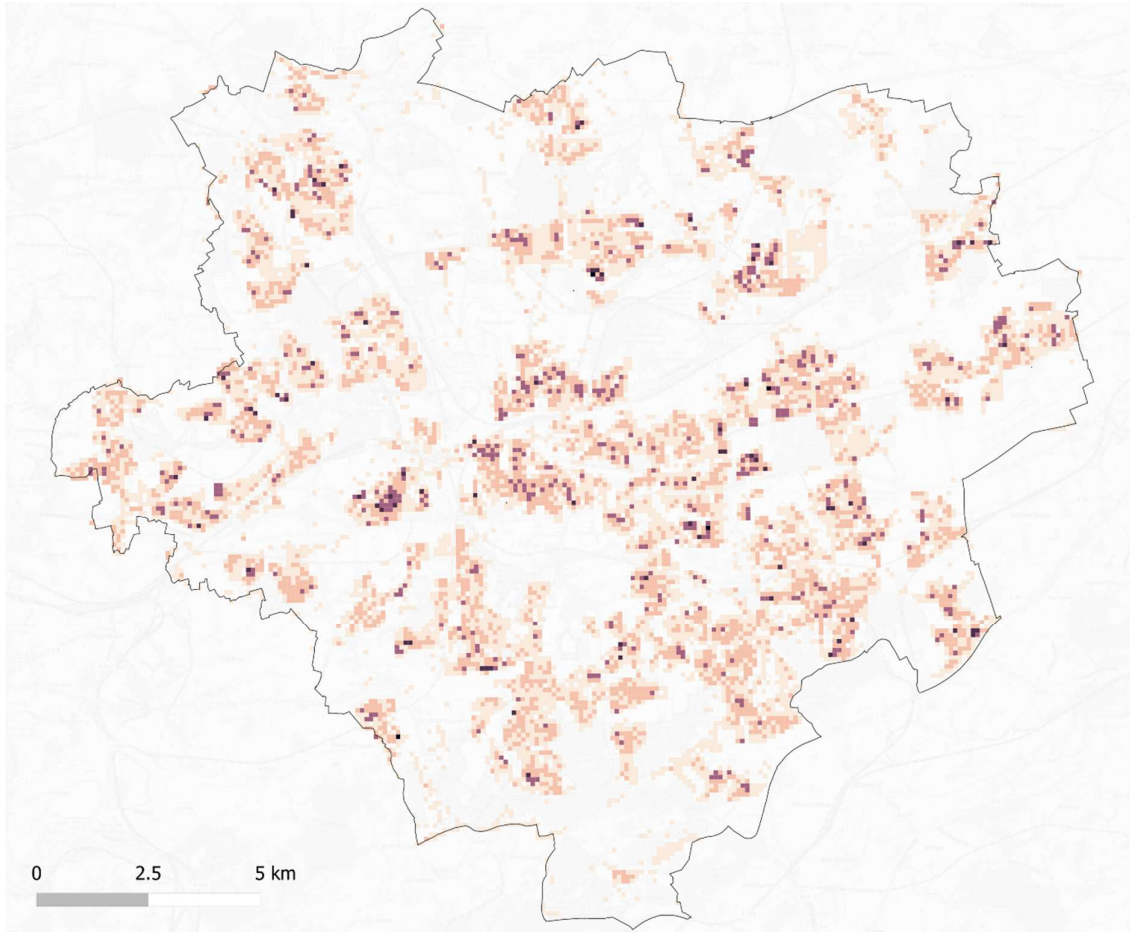


Figure 31 Intensity of Perceived complexity of information presented as a Barrier to Energy Renovation.

The complexity of existing information on energy renovations often deters simple private owners from acting. While some owners rely heavily on guidance from their personal network, such as friends or family (Jakob, 2007), the role of clear and targeted communication cannot be understated. Generic and overly technical language—such as using broad terms like "sustainability"—fails to resonate with many homeowners. Instead, tailored messaging delivered by credible and relatable sources can significantly influence decision-making and encourage positive actions (Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022). This highlights the importance of framing information in a way that aligns with the specific motivations and concerns of homeowners.

The literature does not explicitly identify the complexity of information as a barrier for condominium owners. However, given the collective decision-making processes in condominiums, the clarity and accessibility of information could indirectly influence renovation uptake. While not directly addressed in existing studies, this is an area that warrants further exploration. Furthermore, survey findings reveal that all three ownership types—private simple owners, condominiums, and housing companies—are negatively affected by the existing legal framework, which is often perceived as overly complex and confusing to the public.

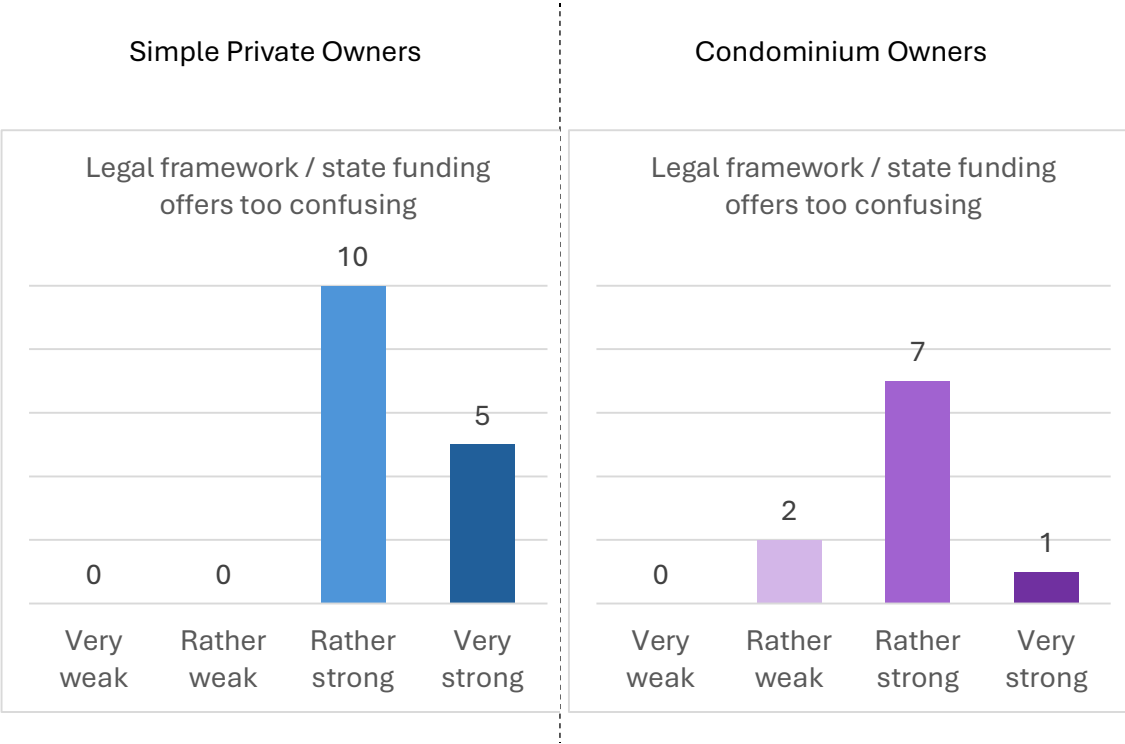


Table 13 Response of simple private and condominium owners to the lack of the lack of understanding of provided information as a barrier to renovation.

iii.c Complicated Procedure

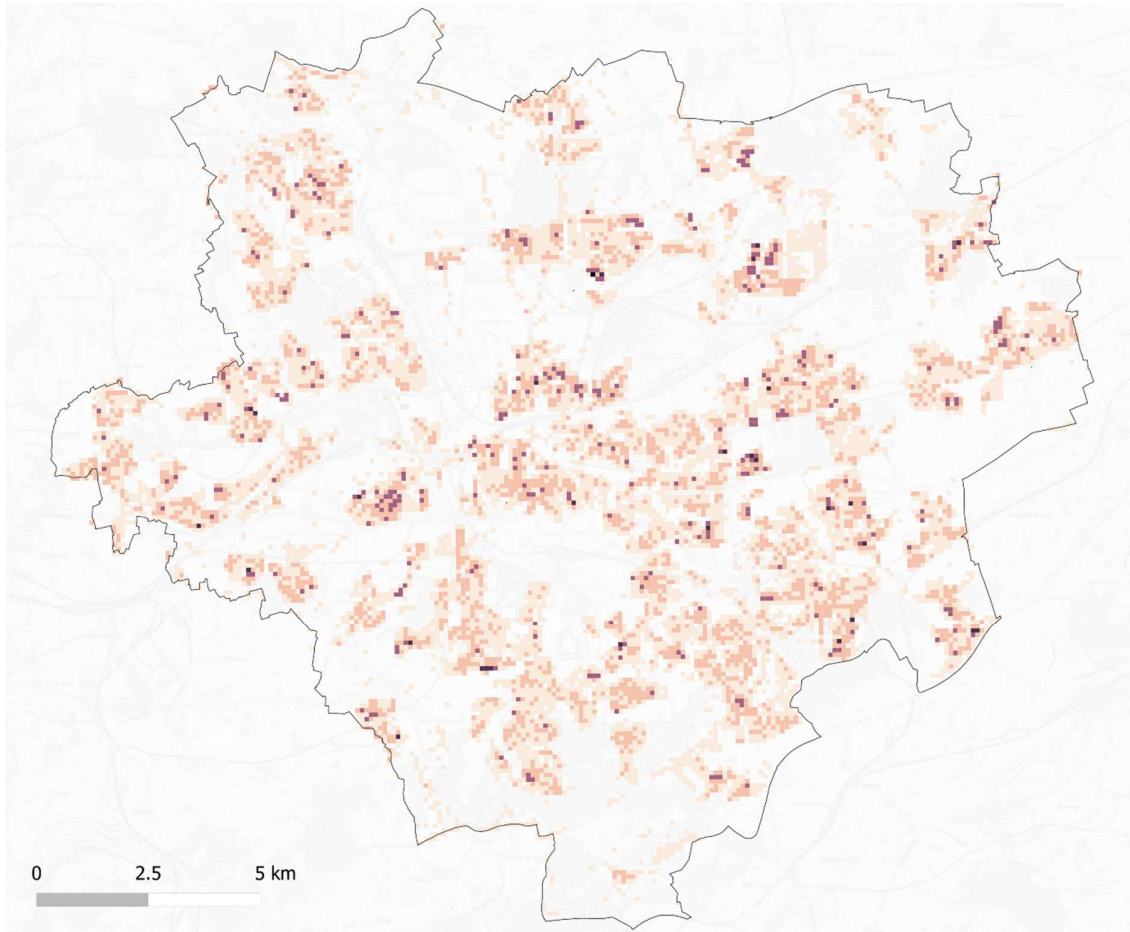


Figure 32 Intensity of Perceived complexity of procedure as a Barrier to Energy Renovation.

The literature does not identify the complexity of the renovation process as a significant barrier for simple private owners. This could be due to the relatively straightforward decision-making process involved when a single individual or a small family owns the property.

For condominium owners and cooperatives, however, the complexity of the renovation process poses a substantial barrier, also due to the existing legal structure. Decision-making in these settings requires collective agreement (a 50% majority in Germany), which is often hindered by absenteeism. This issue is prevalent not only in owner-occupied condominiums but also in those owned by landlords (Buessler et al., 2017; Cairns et al., 2023). Organizing general assemblies to discuss and vote on renovations is

already a challenging task, as these meetings typically occur only once a year in most apartment complexes. The infrequent nature of these meetings, combined with the need to coordinate among multiple stakeholders, leads to prolonged decision-making periods (Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022; Matschoss et al., 2013).

Most owners reported that the time and effort required to navigate through the complicated procedures associated with energy renovations pose a significant barrier.

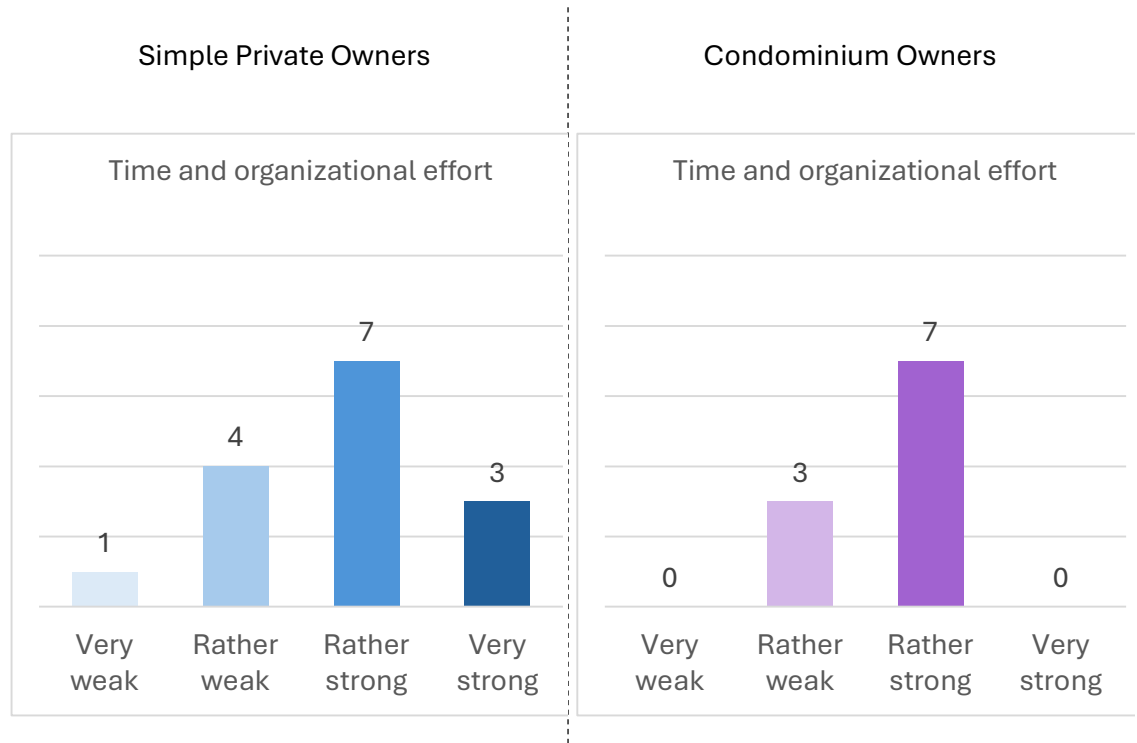


Table 14 Response of simple private and condominium owners to complex procedure as a barrier to renovation.

iii.d High Capital cost

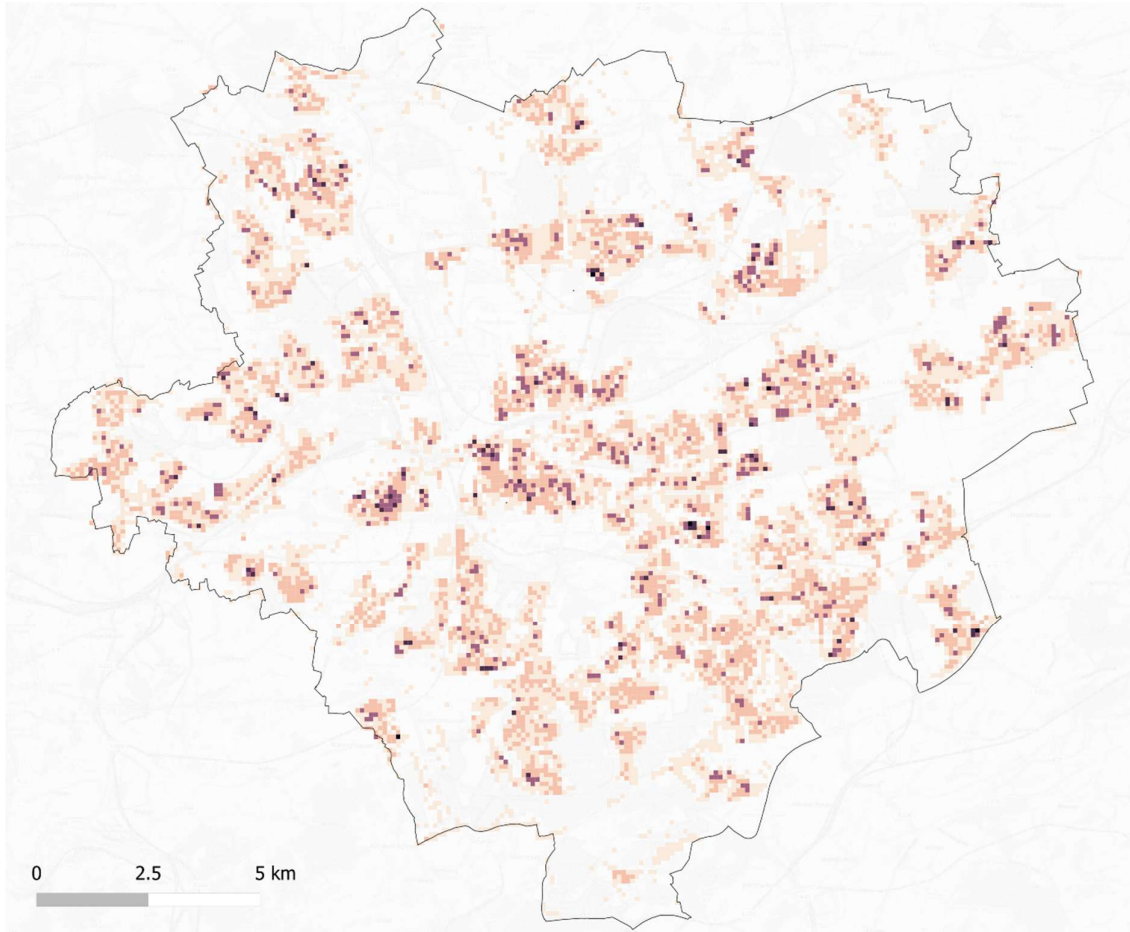


Figure 33 Intensity of Perceived high capital costs as a Barrier to Energy Renovation.

The high capital costs associated with energy renovations present a significant challenge across all types of private ownership. Investments in ventures with substantial upfront costs tend to decline with age, making older property owners, including landlords, particularly risk-averse (Ameli and Brandt, 2015). This is compounded by a general reluctance to take on loans, even when funding opportunities are available.

Financial constraints are among the most extensively discussed barriers in the literature (Ameli and Brandt, 2015; Heiskanen et al., 2012; März, 2018b; Stieß and Dunkelberg, 2013). Owners of single-family homes often prioritize partial renovations, as these can be managed within their savings without the need for external financing. However, even with various government subsidies and funding programs, many owners still find these measures insufficient to overcome the financial hurdles associated with full-scale energy renovations (Bertoldi et al., 2021).

Condominium owners face even greater financial barriers. According to Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022, many condominium associations lack the necessary funds for initial investments in energy renovations. This financial shortfall is particularly pronounced in rented condominium units located in city centers, where small private landlords, who are typically older than the general population, are less likely to engage in high-cost, high-risk investments (Galvin, 2023a). Furthermore, the collective decision-making process required for condominiums complicates efforts to raise funds. Galvin (2023a) suggests that adopting a corporate social responsibility model could help collective private ownership groups secure the funding necessary for renovation projects, but this approach has yet to gain widespread traction.

This is a significant barrier for simple owners and private housing companies but is less pronounced for condominium owners. In this case too, the aspect of shared responsibility among condominium owners could alleviate the burden, making the process slightly less daunting for individuals within this ownership type.

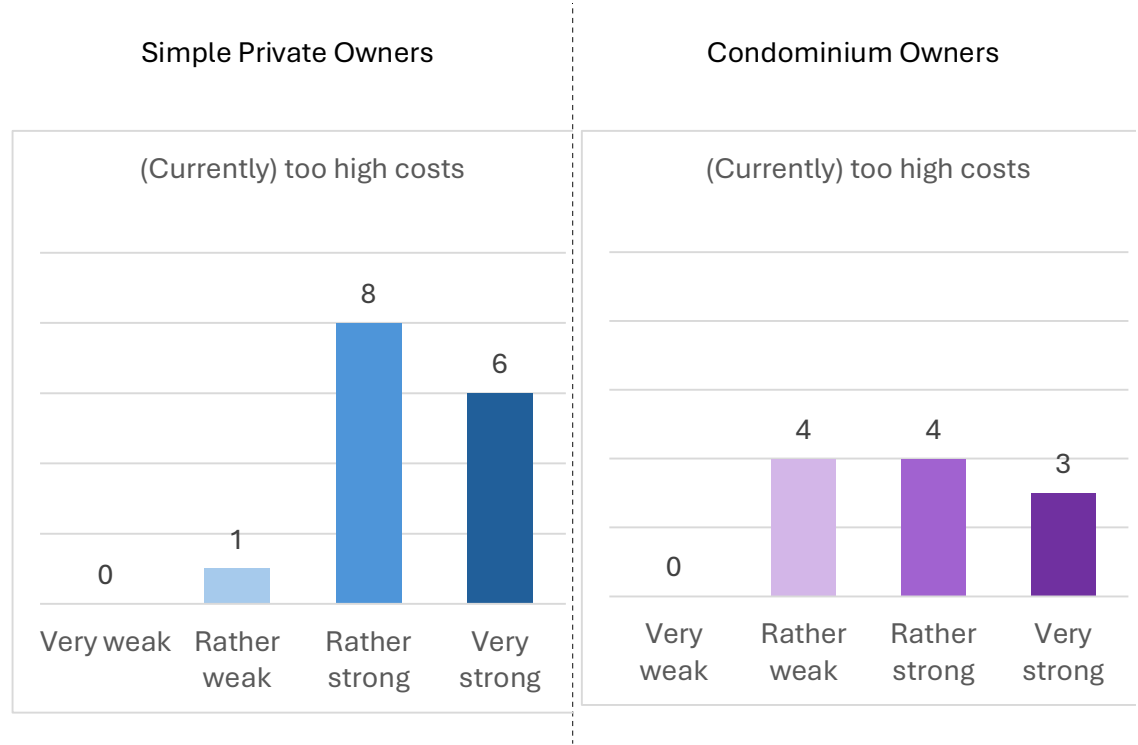


Table 15 Response of simple private and condominium owners to the high capital cost as a barrier to renovation.

iii.e Lack of Access to Capital

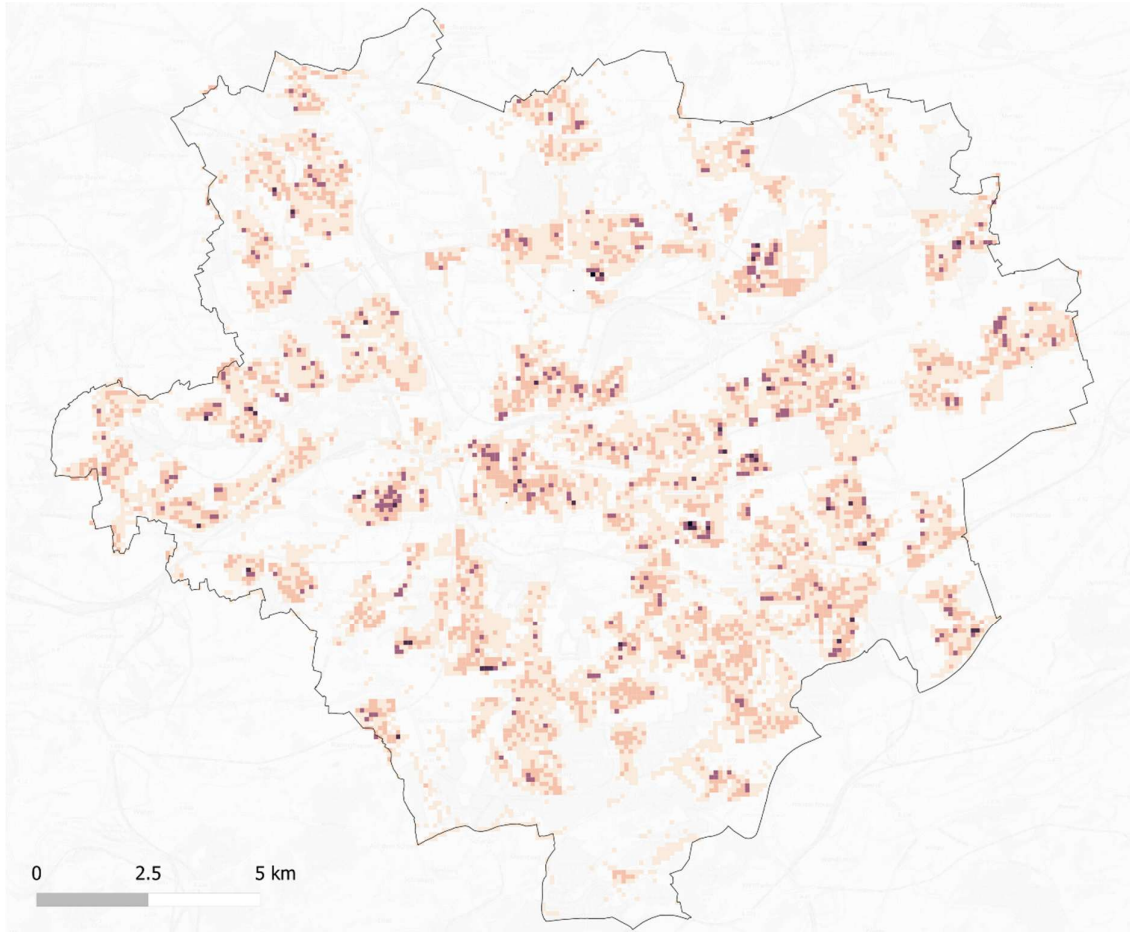


Figure 34 Intensity of Perceived Lack of access to capital as a Barrier to Energy Renovation.

Limited access to capital is a significant obstacle to energy renovation efforts, particularly among low-income property owners and within condominium associations. This issue is compounded by disparities in income, property values, and legal or institutional challenges that restrict access to financing.

For simple private owners, lack of access to capital is a pronounced barrier, especially in low-income households or in areas with low property values (Ameli and Brandt, 2015; Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022). Owners in these circumstances often struggle to secure loans or qualify for subsidies due to limited creditworthiness or the perceived low return on investment in properties with minimal market value. Furthermore, the inability to afford professional support to navigate the complexities of renovation projects further limits their capacity to undertake energy-efficient upgrades.

This combination of financial and information barriers leaves these owners disproportionately disadvantaged when it comes to energy renovation.

In condominium settings, the lack of access to capital presents a unique set of challenges. Unlike single-family homeowners, condominium associations rely on collective decision-making and shared financial responsibility, which can exacerbate funding difficulties. As noted by Blomqvist et al., 2022 and Hauge et al., 2013, the rights and responsibilities of condominium owners are equally distributed, but individual financial capacities often vary significantly. This disparity means that while some owners may have the financial means to invest in renovations, others may lack the resources or creditworthiness to contribute.

Further complicating matters is the restrictive legal framework governing condominiums, which often makes it difficult for associations to secure loans as a collective entity (Buessler et al., 2017). These legal barriers, combined with individual financial limitations, significantly hinder the ability of condominium associations to raise the necessary capital for energy renovations.

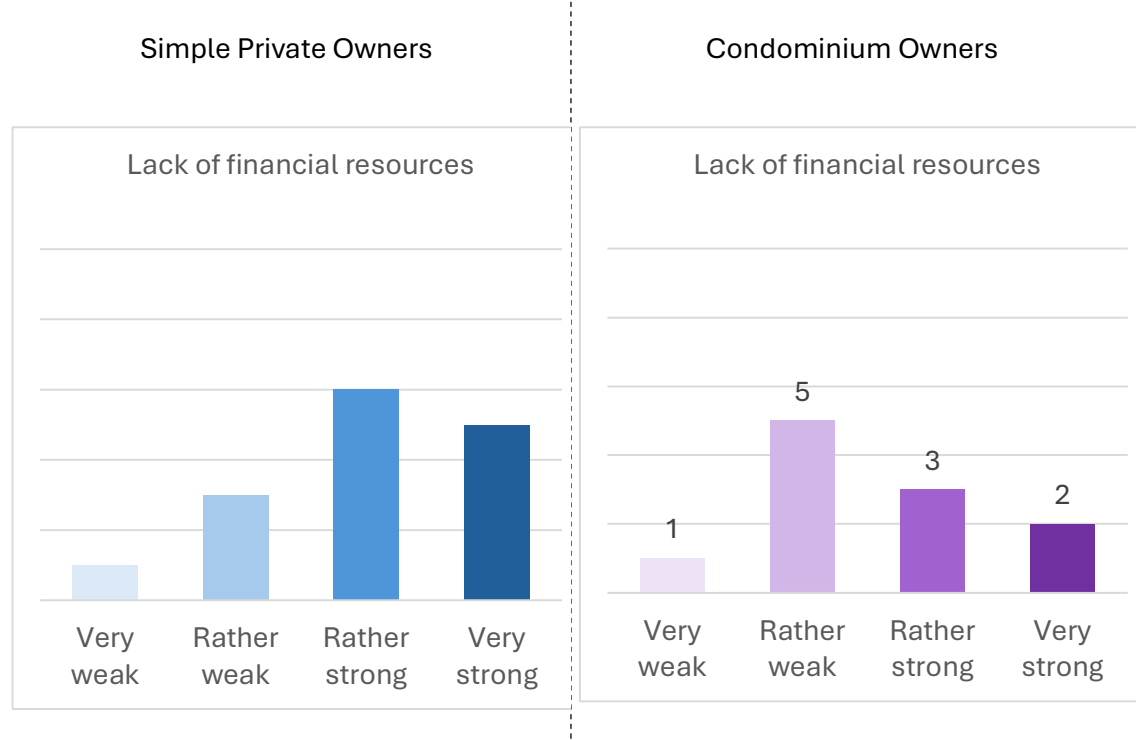


Table 16 Response of simple private and condominium owners to the lack of access to capital as a barrier to renovation.

Cooperatives often lack the budget for comprehensive renovations and can typically only afford partial upgrades. In contrast, this is not a significant barrier for private housing companies.

Private individuals, however, face considerable challenges in accessing capital for renovations. This barrier is notably lower for condominium owners, likely due to shared financial responsibility among members, and is minimal for private housing companies. Individual responses varied significantly, probably due to the diverse range of wealth among residents in the neighborhood, highlighting how individual financial capacity influences collective renovation decisions.

iii.f Split Incentive

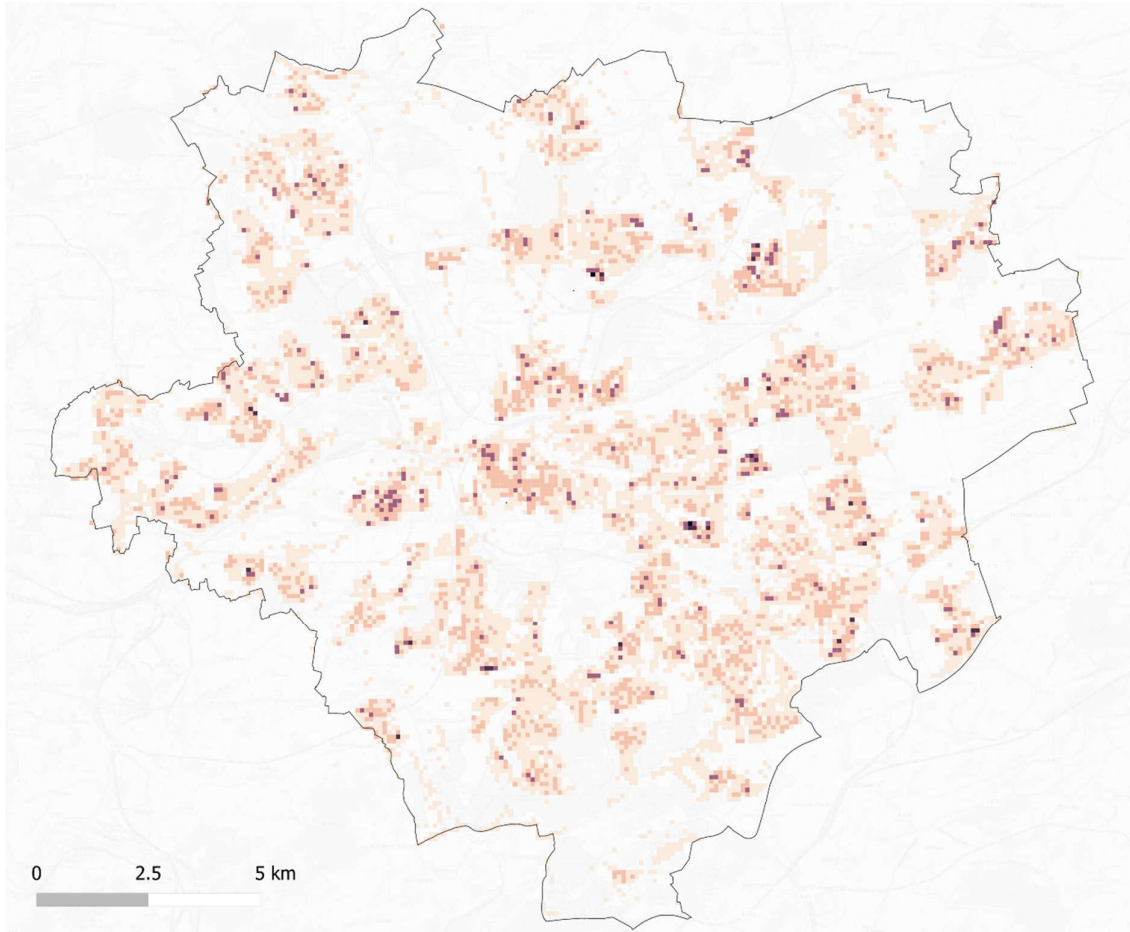


Figure 35 Intensity of Perceived split of incentives as a Barrier to Energy Renovation.

The "split incentive" problem is a key barrier to energy renovations in all ownership patterns that include multiple agents. Documents well the presence of this barrier in rental properties, called the landlord-tenant dilemma and condominiums with multiple owners. This issue arises when the party responsible for paying for the renovation does not directly benefit from the energy savings or improvements, leading to disincentives to invest in energy-efficient upgrades. In rental situations, the lack of long-term commitment from tenants, coupled with the absence of mandatory maintenance requirements in lease agreements, further exacerbates the problem. In multi-owner properties, individual owners may be reluctant to invest in improvements that do not offer direct personal benefits (Ebrahimigharehbaghi, Qian, Vries, Henk J., 2022; Hauge et al., 2013). This is prevalent in public sector housing companies as well (Blomqvist et al., 2022).

Since energy-efficient renovations can take years to fully pay off, the transient nature of renting discourages tenants from making these long-term investments (Ameli and Brandt, 2015). Furthermore, in many rental agreements, maintenance and upgrades are not mandatory, and tenants may not have the authority to initiate or influence renovation decisions. Without clear and immediate personal gain, renters are unlikely to prioritize energy-efficient upgrades.

For simple private properties, the split incentive problem is not commonly cited as a barrier in the literature. Many owners have a strong attachment to their property and are motivated to invest in its long-term upkeep and improvements. Since they fully benefit from energy savings and increased property value resulting from energy-efficient renovations, this barrier is not typically observed among single-owner properties.

The split incentive problem is prevalent in condominiums, especially in cases where ownership is divided among multiple parties. In such settings, individual owners may hesitate to invest in renovations that do not provide direct benefits to them. For example, ground-floor owners might be less inclined to contribute to the renovation of the roof, as they do not directly benefit from the improvements. This type of split incentive is an underexplored barrier in the literature and warrants further investigation, particularly in multi-owner properties such as condominiums in Dortmund (Weatherall et al., 2018).

Buessler et al. (2017) argue that involving tenants in the decision-making process could help address this issue in rental properties. By including tenants' perspectives, landlords may be more likely to make renovation decisions that benefit both parties, improving energy efficiency and fostering a more cooperative approach to upgrades.

The survey also considered the issue of split incentives, particularly in the context of landlords and tenants, as a significant portion of households in Dortmund are rented. Understanding the perspective of property owners in this situation is crucial. The lack of desire to increase rent after renovation is a much stronger barrier for simple private ownership, likely because individual owners typically own the entire building in Dortmund. In low-income neighborhoods like Nordstadt, an increase in rent could lead to a reduction in demand for apartments, as higher prices would likely make them less affordable for residents. For condominium owners, this issue is less of a barrier, while private housing companies seem to have divided opinions on the matter. The inability to increase rent following renovation highlights a key dilemma for landlords, underscoring the need for more effective solutions to address this challenge.

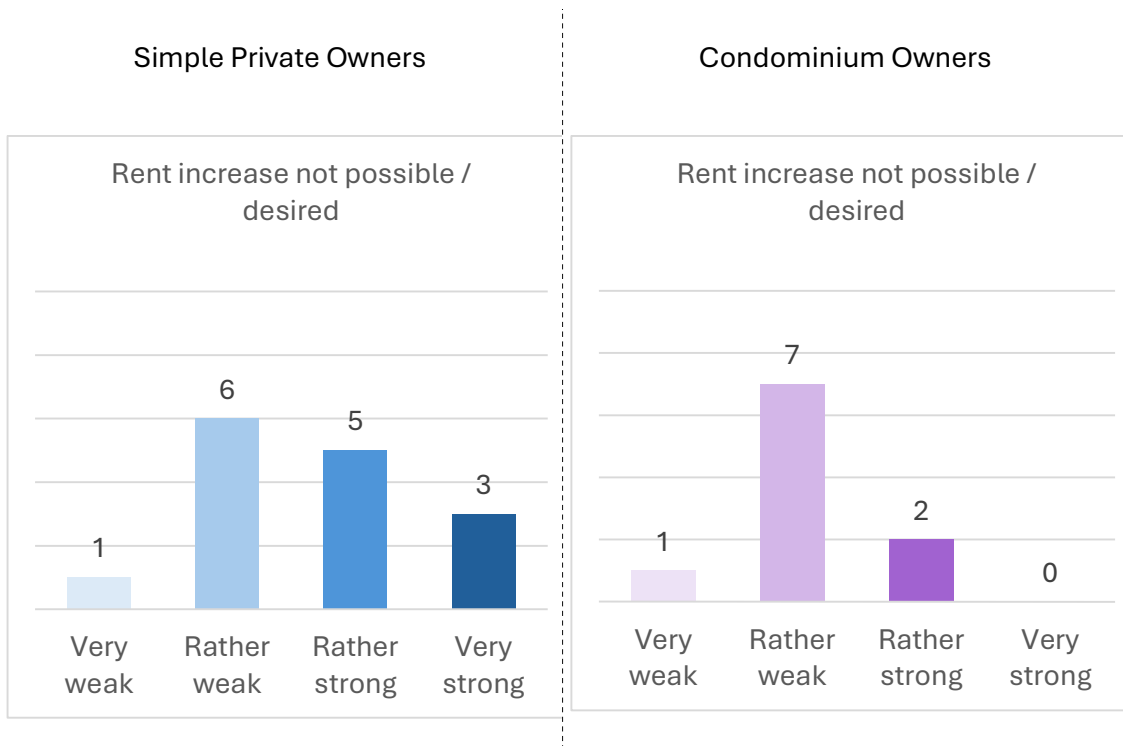


Table 17 Response of simple private and condominium owners to the lack of clear incentive as a barrier to renovation.

iii.g Uncertain Investment Returns

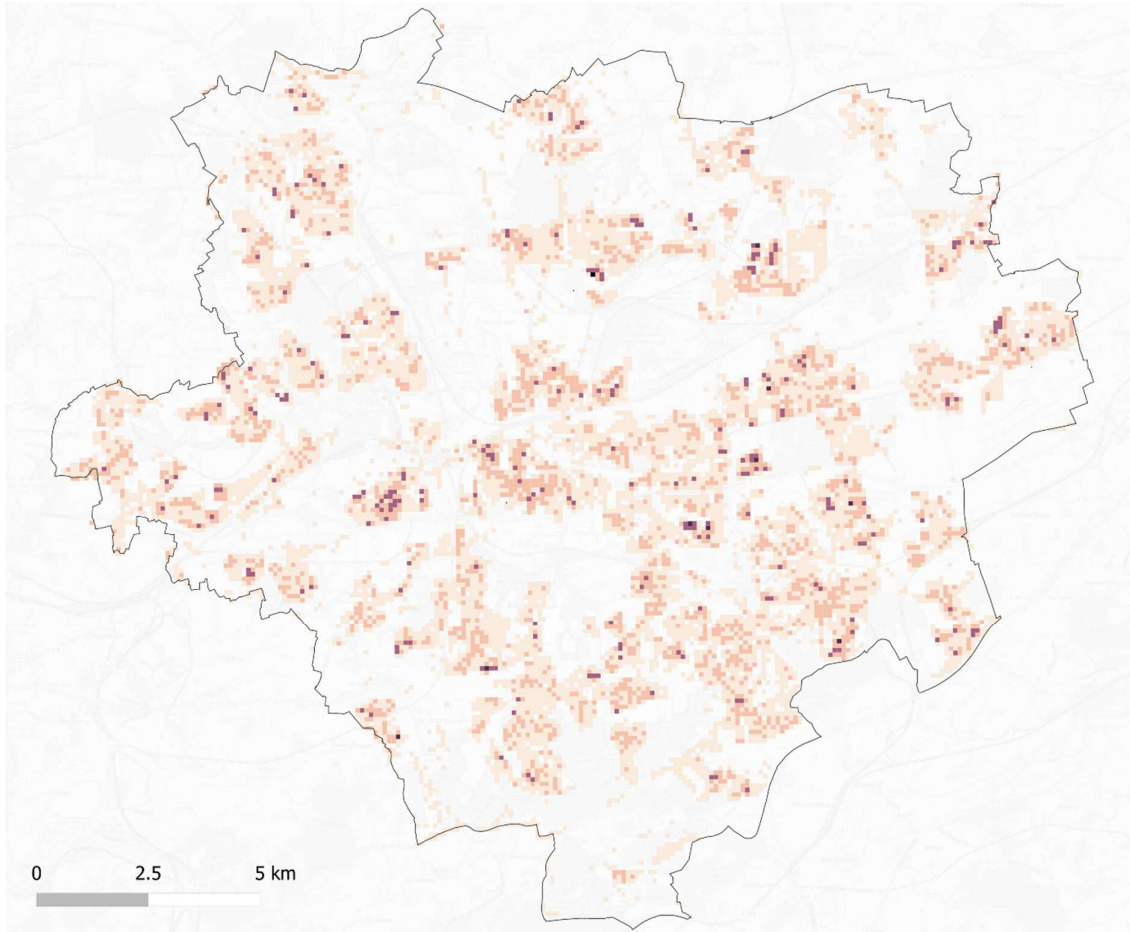


Figure 36 Intensity of Perceived uncertainty regarding the return of investment as a Barrier to Energy Renovation.

A key barrier to energy renovations in residential properties is owners' skepticism regarding the positive returns on investment (ROI). Many owners question whether the money invested in renovations will lead to substantial financial returns, especially when considering long payback periods or the perceived lack of immediate benefits. This barrier is present across both simple private owners and condominium owners, albeit in different contexts.

While some studies suggest that energy-efficient renovations can be financially beneficial in the long run, owners may doubt the financial return, particularly when considering the extended time required to break even. Galvin (2023b) calculated that, for many private homeowners, the payback period for energy renovations could be as long as 67 years, which may deter investment, especially among those with shorter-term

financial goals or concerns. This long horizon for return on investment might make owners hesitant, particularly when they cannot perceive immediate financial rewards.

In condominiums, a similar skepticism arises, particularly among low-income households. These households may reduce their energy usage to save money, a phenomenon referred to as the "pre-bound effect." As a result, some owners may feel that energy renovations are unnecessary, especially if they are already minimizing their energy consumption and prefer to tolerate poor thermal conditions. Galvin (2024) highlights that many owners in this category may not recognize the potential for energy-efficient renovations to generate a positive return, unless soft benefits—such as improved thermal comfort—are considered. This points to a need for further research to understand how these perceptions influence renovation decisions. Several recent studies have shown that, while the financial ROI may be low or even negligible, the indirect benefits of energy renovations, such as better comfort and healthier living conditions, might drive investment for some owners.

There is significantly higher uncertainty among individual private owners compared to condominium owners and private housing companies. This uncertainty may stem from the sole financial responsibility and decision-making authority of private owners, while condominium owners and private housing companies benefit from shared responsibility and resources, reducing the level of uncertainty.

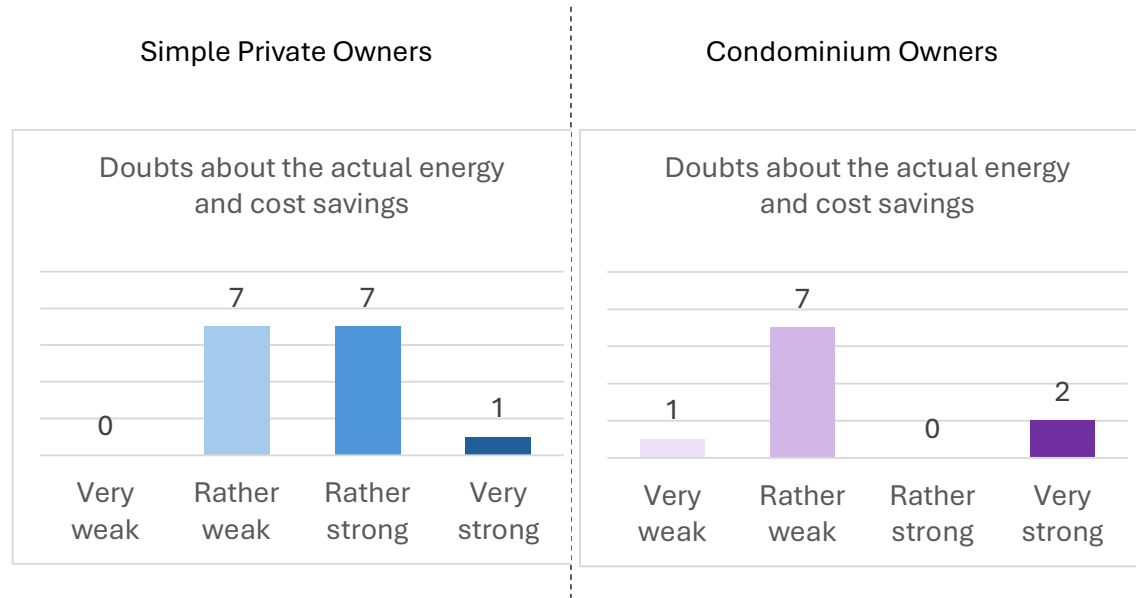


Table 18 Response of simple private and condominium owners to uncertainty regarding return of investment as a barrier to renovation.

6.2 Survey Findings Vs Literature

Simple Private Ownership

The literature identifies nine key barriers that limit simple private owners from undertaking energy renovations. While the survey finds align with many of these barriers, some results deviate from established perspectives. According to the survey, private owners do not feel compelled to renovate simply because their neighbors are doing so. Instead, the complexity of the renovation process emerges as a significant deterrent. The substantial transactional costs—time, effort, and money—associated with navigating these complexities discourage many owners from proceeding with renovations.

Additionally, the survey, conducted in Nordstadt, reveals a strong influence of tenancy-related barriers, such as the split incentive problem. This is particularly prominent in areas with a high degree of tenant-occupied properties, where landlords may lack the motivation to invest in renovations from which tenants primarily benefit. Probably due to the low-income characteristic of the neighborhood, landlords do not think that they can increase the rent to make up for the renovation costs.

Interestingly, the survey contradicts the literature regarding bounded rationality as a barrier. While Jakob (2007) suggests that external triggers, such as a building's physical or technical condition or expansion projects, often motivate renovations without necessarily focusing on energy efficiency, the survey findings indicate that long-term cost savings (2.71/4 on the Likert scale) play a notable role in driving renovation decisions. Compared to these existing issues with the buildings (2.41/4 on the Likert scale) was not a strong motivator for renovations.

Furthermore, most owners demonstrate a strong awareness of the environmental benefits of renovation and express a willingness to renovate, underscoring their value-driven approach. Unlike collective ownership structures, where conflicting views can hinder decision-making, simple ownership—with only one decision-maker—streamlines the process and fosters energy-conscious behavior.

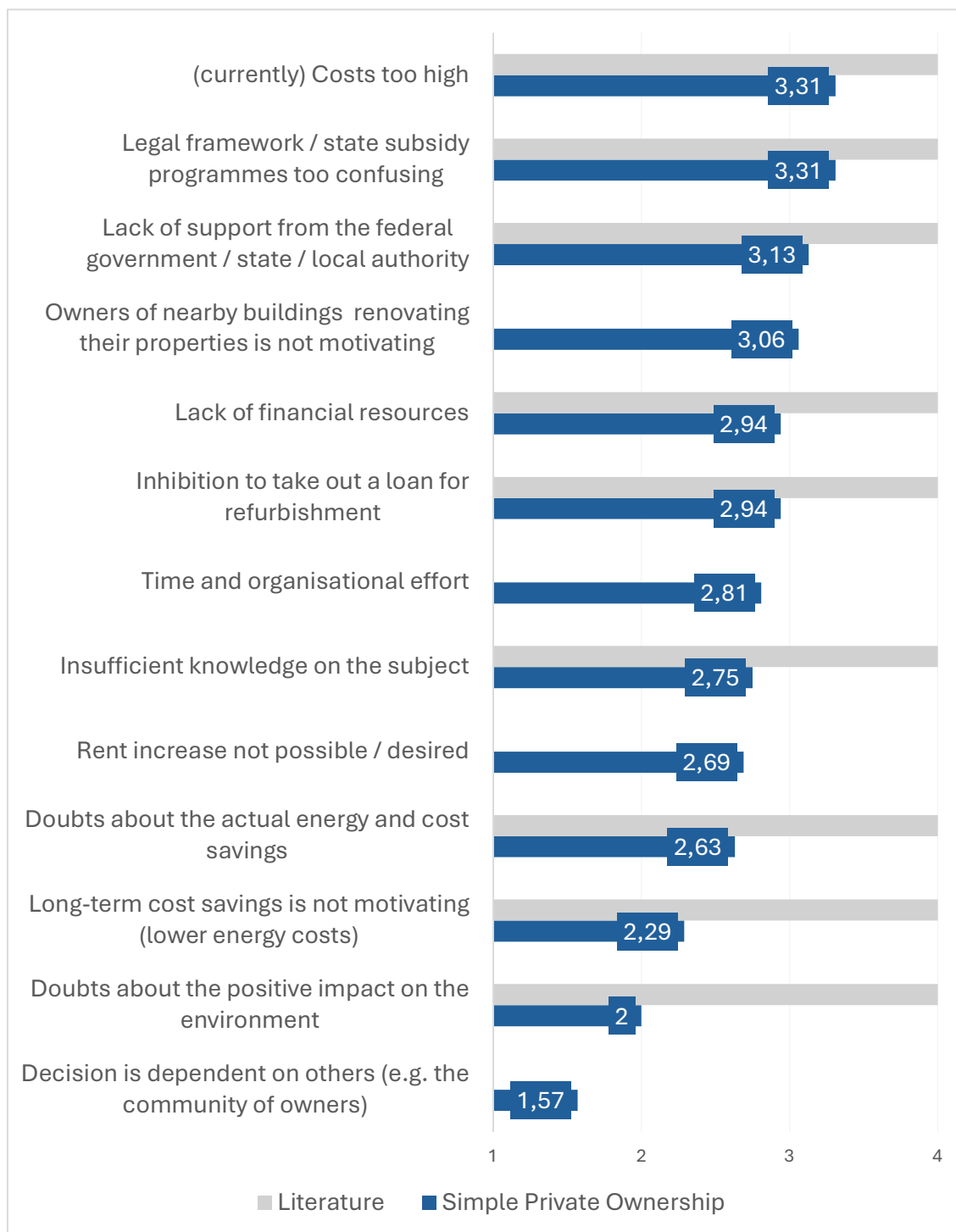


Figure 37 Barriers perceived by simple private ownership as compared to literature findings.

Condominium Ownership

The literature identifies ten key barriers specific to condominium ownership, many of which are influenced by whether the owners' association is formally registered. While the survey did not tackle registered and unregistered homeowner associations separately, it would be worth differentiating their barriers at a later stage. The survey findings confirm that a lack of social pressure to renovate—such as a general neighborhood trend toward energy efficiency—is not a significant motivator for condominium owners.

High upfront costs remain a notable barrier for condominiums. This challenge is further compounded by the complex legal structures and decision-making processes of condominium associations, which often hinder their ability to access financing for renovations. This issue is well-documented in recent studies (Elgendy et al., 2024). However, contrary to the literature, the survey respondents did not identify a lack of financial resources as a significant barrier (2.55/4 on the Likert scale).

Interestingly, condominium owners also do not perceive their lack of technical knowledge as a deterrent to undertaking renovations. While respondents did not consider themselves experts on energy efficiency, they probably viewed this as the responsibility of the maintenance company or the managing entity of the building rather than a personal priority.

Similarly, bounded rationality does not appear to be a barrier for condominium owners. Survey findings indicate that these owners are confident about the positive long-term cost savings associated with energy renovations. Notably, long-term financial benefits serve as a stronger motivator (3.0/4 on the Likert scale) for condominium owners than addressing immediate issues with the building (2.67/4 on the Likert scale).

In summary, while high upfront costs and legal complexities affecting finances remain significant barriers, the confidence of condominium owners in long-term cost savings and their delegation of technical responsibilities to professional entities provide an opportunity for targeted policies. Supporting condominium associations with financing mechanisms and streamlining decision-making processes could help accelerate energy renovation efforts in this ownership type (Galvin, 2023a).

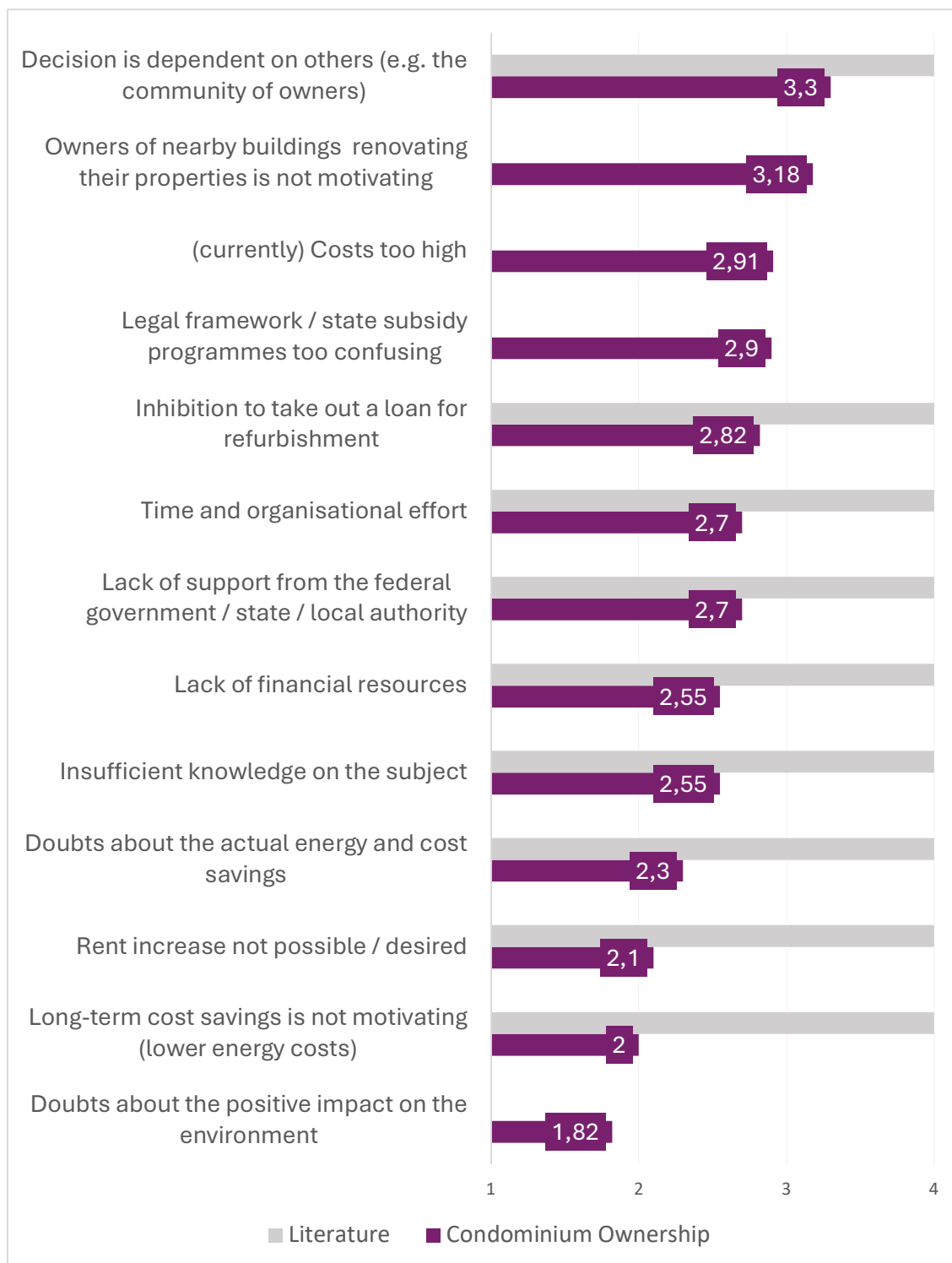


Figure 38 Barriers perceived by condominium owners as compared to literature findings.

6.3 Survey Findings Vs Ownership

Logically, conflicting views do not affect private owners as much as they do condominium owners, due to independent decision making. While both ownership types prefer to rely on their own research to make decisions, they also agree on the importance of information provided by the District Management Office of Nordstadt in guiding their choices. On average, condominium owners experience fewer barriers, likely due to shared responsibility, which reduces the perceived burden of renovation. However, this shared responsibility may also mean that individual condominium owners lack the motivation to persuade others to undertake renovation projects.

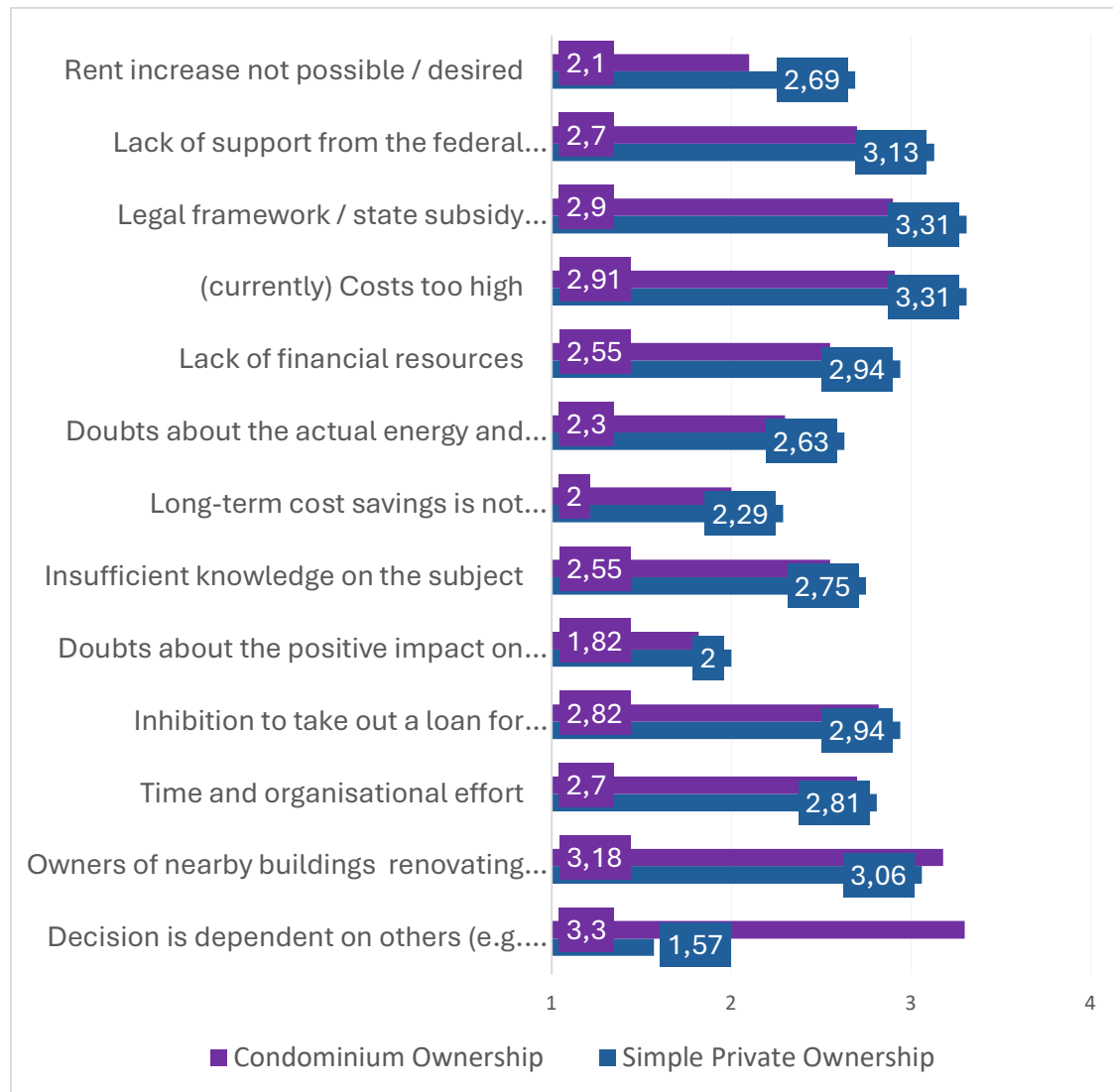


Figure 39 Comparison of barriers as perceived by simple owners and condominium owners.

6.4 Inaccessibility of Energy Renovations in Dortmund

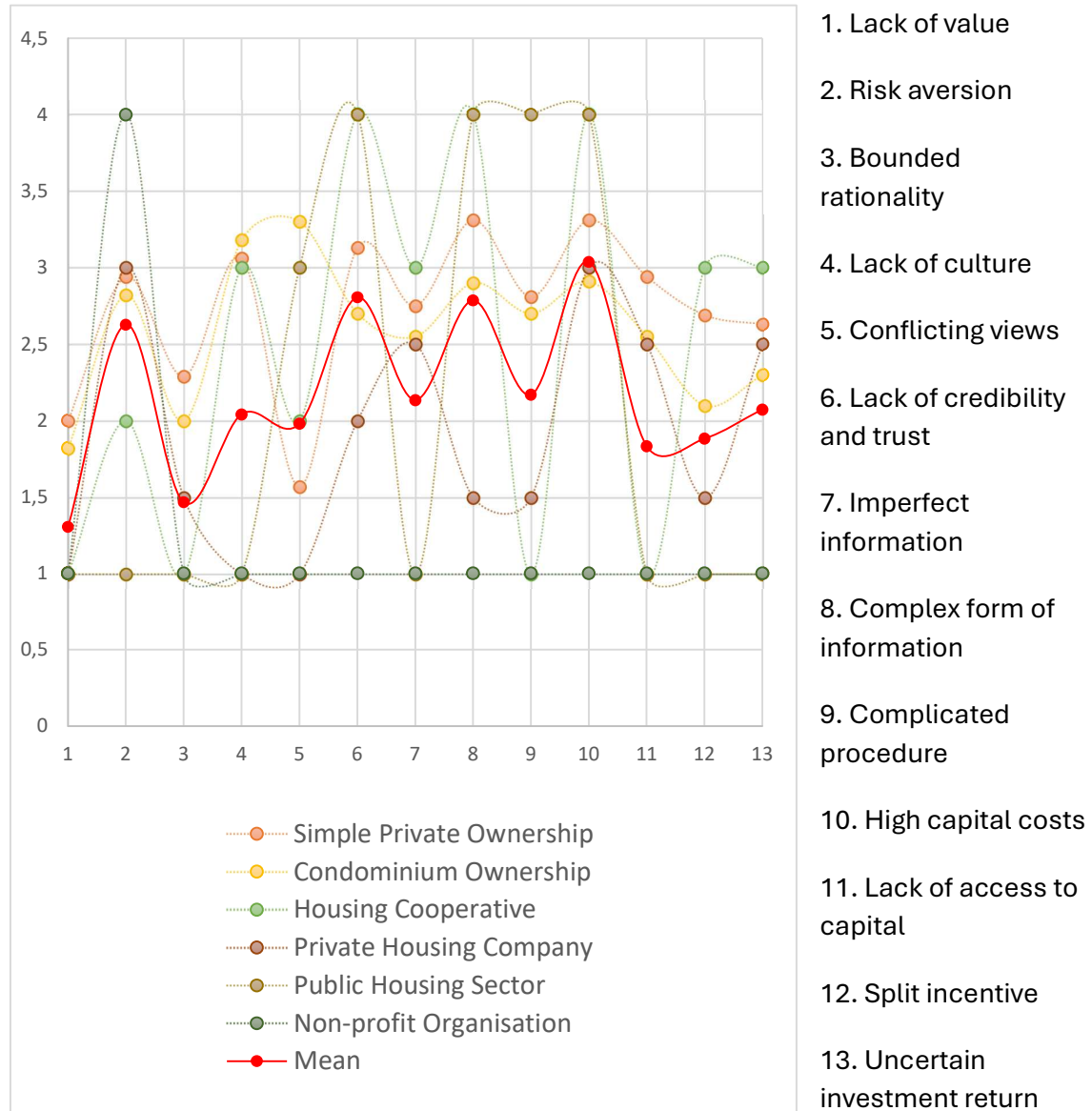


Figure 40 Intensity of barriers as perceived by different ownership types.

By incorporating findings from different ownership typologies (see Figure 40), we can map the distribution of barriers at the city scale using the following equation:

$$\sum_n (\text{buildings with ownership} - n) * (\text{intensity of barrier perceived by owner} - n)$$

This allows us to identify the overall intensity of barriers within each grid. The intensity increases with the number of property owners and the perceived severity of individual barriers. While barriers exist throughout the city, certain hotspots are particularly evident—especially near Dorstfeld, as well as the residential neighborhoods around Bauernkamp and Franz-Zimmer-Siedlung stations (see Figure 41). These areas have a high concentration of private households, which correlates with a greater prevalence of barriers.

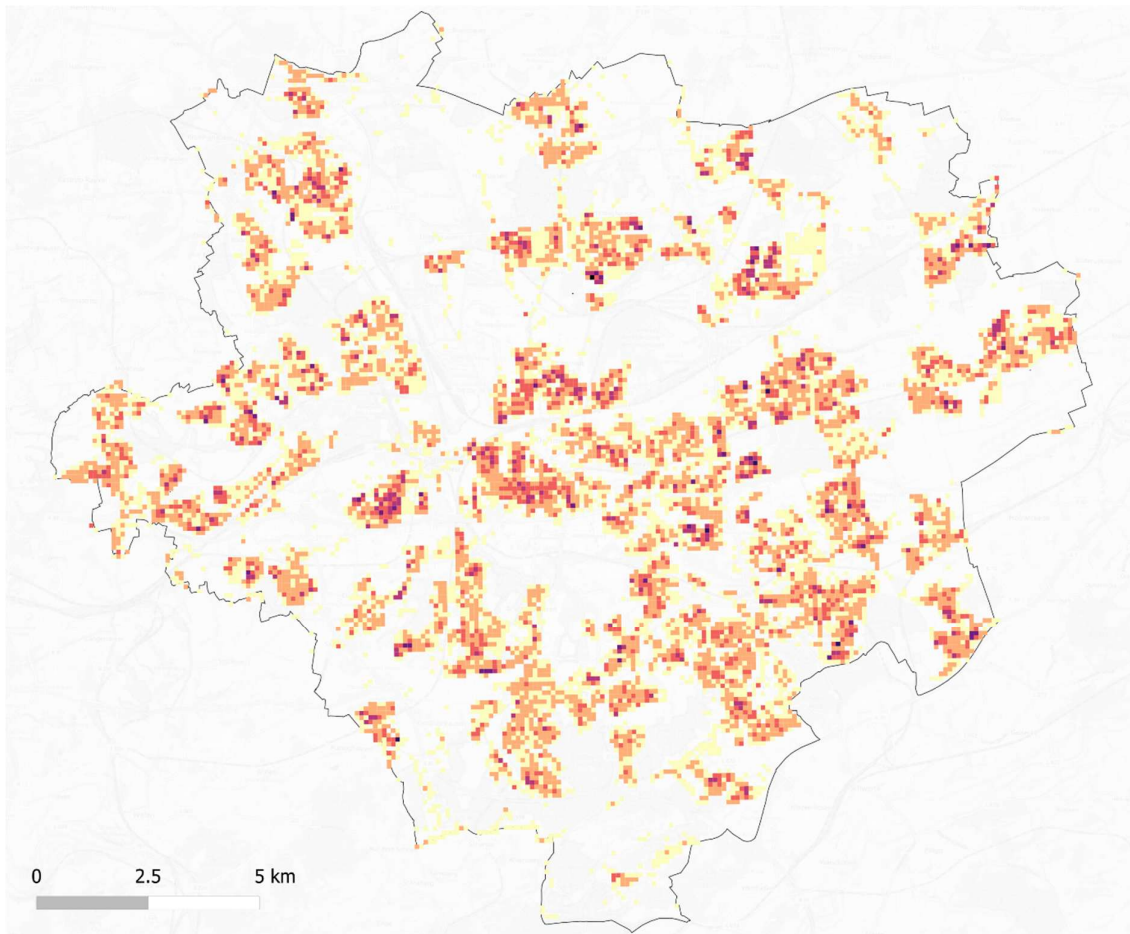


Figure 41 Intensity of barriers perceived by owners within neighborhoods in Dortmund.

6.5 Policy Implications

Once spatial inequalities in the perception of barriers are identified, policies can be directed toward vulnerable neighborhoods that require intervention. To illustrate this, ongoing projects under the Climate-Air Action Program 2030 are examined. Each of these projects addresses different barriers and must be implemented in specific neighborhoods identified through the mapping process to gain success.

Barrier tackled by projects related to the Climate Air-Action Program 2030

The current energy renovation projects in Dortmund are working to shift individual property owners' attitudes and social norms through both formal and informal approaches. For instance, areas like Nordstadt benefit from the establishment of a dedicated District Management Office that specifically addresses local issues. While these governance structures are effective in facilitating engagement, they still face limitations in terms of financial support.

At present, funding for energy renovation initiatives remains largely controlled at the federal level, which constrains the flexibility of the city in allocating resources. A potential solution to this challenge would be to transfer more financial authority to the state level. This decentralization could allow for a more targeted, context-specific allocation of funds, addressing localized financial challenges. In a city like Dortmund, where poverty is widespread, such an approach could ensure that energy renovation efforts are better tailored to the needs of the community, ultimately leading to a more equitable and efficient distribution of resources.

Name-English	Name-German	Barrier	Aim
DLZE Service Center for Energy Efficiency and Climate Protection	Dienstleistungszentrum Energieeffizienz und Klimaschutz	Imperfect Information; Lack of credibility and trust; Complicated procedure	serves as a comprehensive point of contact for queries related to climate protection, building renovation, new construction, and energy savings. This service center aims to simplify access to expert advice from energy consultants, empowering residents and organizations to take informed action toward sustainable energy practices.

Climate Protection Fund	Klimaschutzfonds	Lack of culture	supports active social initiatives that address climate change. By providing financial backing, this fund fosters grassroots efforts and innovative solutions that contribute to achieving the city's climate goals.
Lecture Series on Climate and Energy	Vortragsreihe Klima und Energie	Imperfect information; Complex form of information	offers informational events covering a wide range of topics related to energy renovations, sustainable construction practices, and climate protection strategies. These sessions are designed to educate the public and encourage community involvement.
Climate Barometer	Klimabarometer	Lack of culture; complex form of information	is an interactive progress meter that tracks the status of various climate initiatives in the city. This tool enhances transparency and allows citizens to monitor the city's progress toward its climate targets, creating a sense of collective accountability and motivation.
Consultation Group on Energy Efficiency and Climate Protection	KEK - Konsultationskreis Energieeffizienz und Klimaschutz	Conflicting views	aims to develop and intensify a collaborative task force. This group brings together stakeholders to align strategies and create impactful actions for energy efficiency and climate protection in Dortmund.
Energy Utilization Plan	ENP - Energienutzungsplan	Bounded rationality; Imperfect information	the municipal heating plan for Dortmund, includes answers to questions like which residential areas are suitable for district heating or geothermal heating.
Promotion of Geothermal Energy Use	Förderung der Nutzung von Geothermie	Imperfect information	initiative aims to expand renewable energy deployment in Dortmund by encouraging the use of geothermal energy.
Integrated Climate Adaptation Concept	MiKaDo - Klimaanpassungskonzept	Lack of culture; Lack of access to capital	promotes environmentally friendly and resilient urban development while ensuring that climate change considerations are consistently integrated into new measures, plans, and strategies. MiKaDo's focus is on proactive climate adaptation to future-proof urban planning efforts.
Solar Cadastre	Solardachkataster	Complex form of information; imperfect information	is an online tool that allows homeowners to assess the solar potential of their properties with just a few clicks. By providing an interactive map of the city's solar potential, this resource empowers residents to consider solar energy installations.

Table 19 Climate relation projects in Dortmund and the barriers they address.

7. Proposal – Inaccessibility Calculator

The report on Dortmund's progress toward mitigating climate change identifies two key obstacles preventing the city from achieving its renovation targets for existing residential buildings. To overcome these challenges, it is crucial for the city to understand the barriers perceived by property owners and to focus their efforts on where they can have the greatest impact.

An overlay of findings from section 5 and 6 allows us to identify typologies with varying impact potential and intensity of barriers. The city administration can use this information to strategically select neighborhoods of action, based on their current capacity. This approach provides the city with a clearer, more nuanced understanding of Dortmund's renovation landscape and highlights the ways in which the state can effectively intervene.

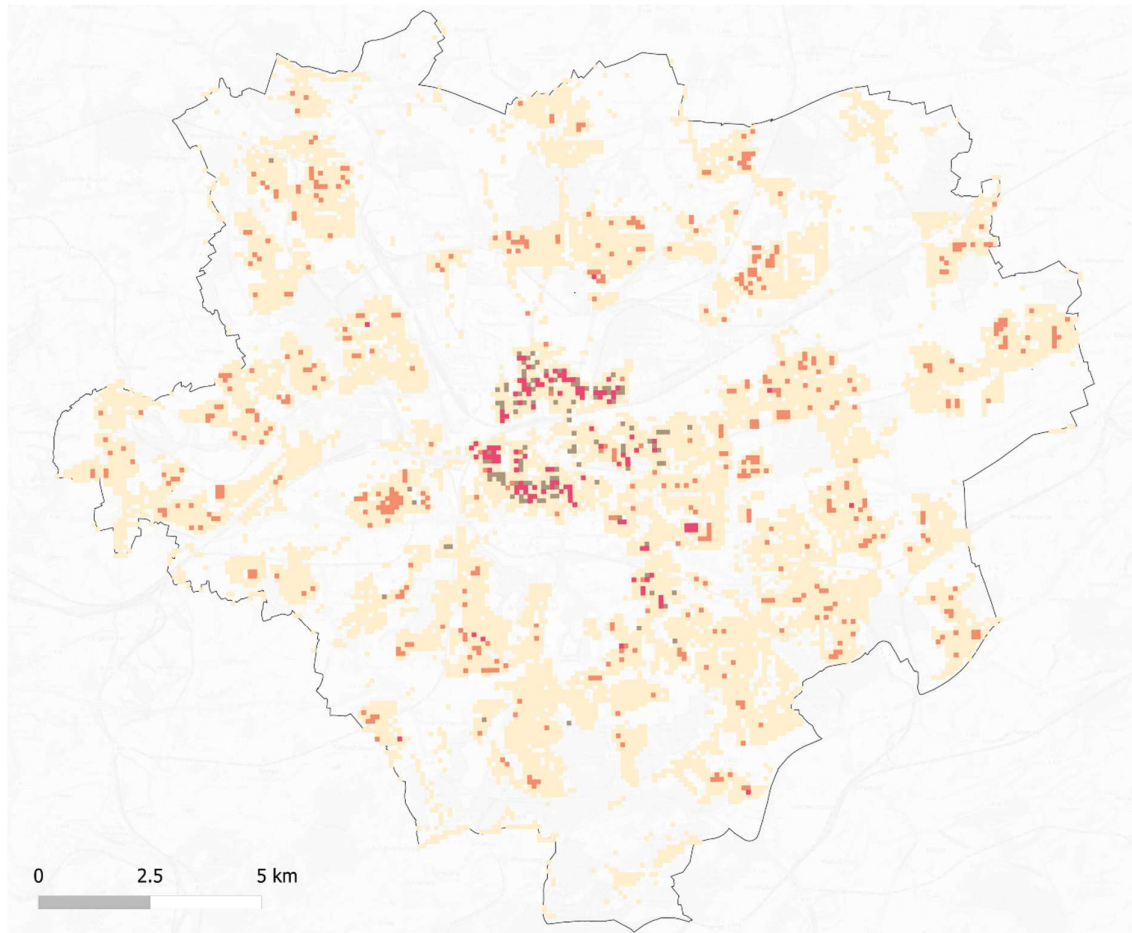


Figure 42 Typologies of neighborhood defining the renovation landscape in Dortmund.

By overlaying the final density maps of potential impact and barriers, we identify four typologies of blocks in Dortmund:

1. **High Impact - High Barrier:**

These areas are characterized by a high potential to impact a significant amount of infrastructure but face substantial barriers to renovation. Successfully addressing these neighborhoods would require considerable effort from the city administration. However, the rewards would be equally significant, as such efforts would positively influence a large population and numerous properties across the city.

2. **High Impact - Low Barrier:**

These blocks are the most favorable for initiating energy renovation projects. With high potential and relatively low barriers, only minimal effort is required to overcome existing challenges. As a result, these areas can achieve a significant impact with comparatively lower resource investment, making them an ideal starting point for interventions.

3. **Low Impact - High Barrier:**

These neighborhoods are the least favorable for renovation efforts. They have a small percentage of people and properties and are burdened with significant barriers. Addressing these areas would demand extensive effort with limited returns, making them a low-priority target.

4. **Low Impact - Low Barrier:**

While these areas lack the potential for significant outcomes, they are relatively easy to convince to undertake renovations. Intervening here requires minimal effort, but the overall impact remains modest compared to high-density areas.

This classification enables stakeholders to strategically narrow down their intervention efforts based on potential outcomes and resource availability. By focusing on the typologies with the greatest potential and manageable barriers, stakeholders can predict and achieve larger success in the future.

Web application

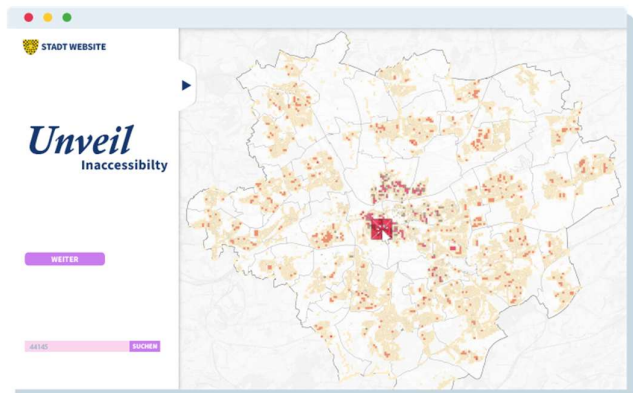


Figure 43 Unveil Inaccessibility Web platform

These maps is transformed into an interactive web platform, allowing stakeholders to study and compare neighborhoods based on their specific needs for support or to target a particular ownership type (see Figure 44, Figure 43). The straightforward calculation method enables the integration of live surveys into the platform, allowing property owners to continually contribute their perceptions of barriers. As new data is input, the

map is automatically updated, ensuring it remains dynamic and reflective of current conditions.

Such a platform would create a continuously improving tool, where additional layers of information—such as renovation rates, energy consumption, and emissions—could also be incorporated. This comprehensive resource would enable stakeholders to make informed decisions and refine their strategies for energy renovations, fostering a more efficient and targeted approach to achieving sustainability goals in the city.

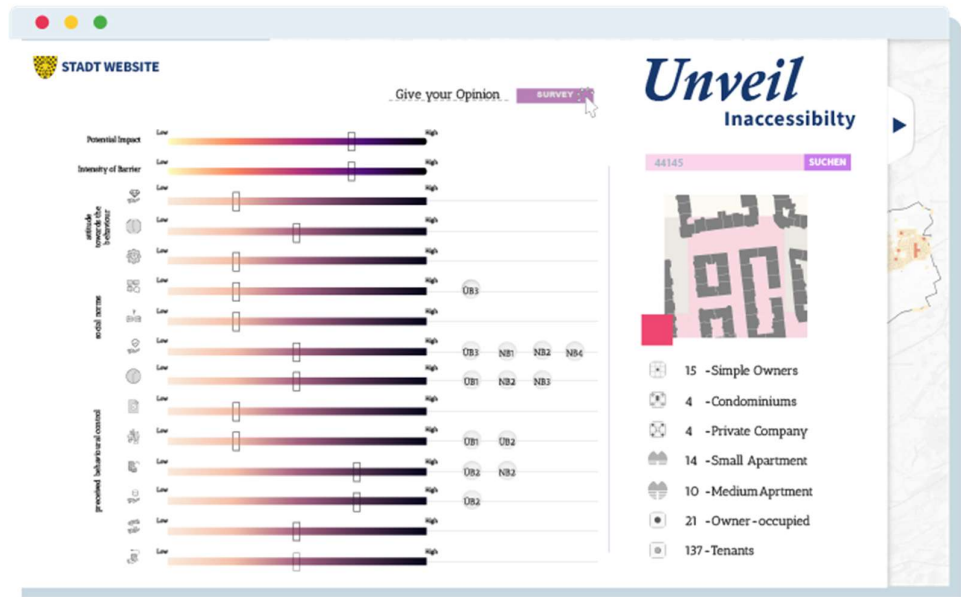


Figure 44 Web platform with detailed characteristics of the block, along with feasible solutions.

8. Conclusions and Recommendations

This research aimed to tackle the urgent challenge of increasing energy renovation rates in Dortmund's residential sector by developing a tool that maps barriers to energy renovation at the neighborhood level. The study identified and analyzed financial, informational, social, and behavioral barriers across different ownership types and spatially mapped their prevalence throughout the city. Using a matrix-based methodology, integrated with survey findings and spatial analysis, this research provides actionable insights for stakeholders to prioritize interventions effectively.

The findings reveal that both ownership structures and neighborhood contexts significantly influence the barriers faced by property owners. Private individual owners often struggle with financial constraints, informational complexity, and bureaucratic hurdles. Condominium owners, while benefiting from shared responsibility, encounter challenges related to collective decision-making. Private housing companies and cooperatives, though generally more structured, are often restricted by budgetary and systemic constraints. The results emphasize the need for tailored support mechanisms, as neighborhoods with high barriers and low renovation potential require different strategies compared to those with minimal barriers and high renovation feasibility.

By categorizing neighborhoods into four typologies—high density-high barrier, high density-low barrier, low density-high barrier, and low density-low barrier—this study provides a framework for municipalities to allocate resources based on administrative capacity and intervention priority.

This research contributes both theoretically and practically to improving energy renovation strategies in residential buildings. Theoretically, it expands on existing literature by offering a comprehensive, owner-centered perspective on renovation barriers. Practically, it delivers a decision-making tool that enables city administrations and stakeholders to optimize resource allocation, accelerate renovation rates, and reduce greenhouse gas emissions.

Furthermore, this tool fosters citizen engagement by enabling residents to better understand their neighborhood's renovation potential and challenges. By integrating a survey mechanism into the web platform, it amplifies public participation, ensuring that local voices inform energy renovation policies. With continuous updates and broader stakeholder involvement, the platform can evolve into a dynamic resource for shaping Dortmund's energy transition efforts.

In conclusion, while energy renovation barriers are complex and multifaceted, this research demonstrates that a combination of spatial analysis, stakeholder

engagement, and strategic policymaking can help overcome these challenges. By directing efforts where they are most needed and tailoring solutions to specific contexts, Dortmund can move closer to its climate neutrality goals, serving as a model for other cities striving for sustainable urban development.

Appendix

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10. List of Figures

Figure 1 Methodological framework of the research. (Source: Author)	10
Figure 2 Germany's GHG reduction targets for each decade leading upto climate neutrality in 2045. (Source: Forschungszentrum Jülich, 2024)	15
Figure 3 Energy goals and policy actions across various scales (Source: Author, 2025).	21
Figure 4 Theory of Planned Behaviour applied to decision making behaviour of owners regarding enrgy upgrade. (Source: Graphic by the author)	25
Figure 5 Matrix showing barriers affecting different ownership types as identified in existing literature (Source: Compiled by the Author)	28
Figure 6 Possible condition of property, ownership and occupancy under which a renovation could be occurring.	30
Figure 7 Concentration of simple private ownerships in Dortmund. Units: NA (number of buildings)	31
Figure 8 Concentration of Condominium ownership in Dortmund. Units: NA (number of buildings)	32
Figure 9 Concentration of Cooperative ownership in Dortmund. Units: NA (number of buildings)	33
Figure 10 Concentration of buildings owned by private housing companies. Units: NA (number of buildings)	34
Figure 11 Concentration of buildings owned by Public housing companies. Units: NA (number of buildings)	35
Figure 12 Concentration of buildings owned by Non-profits. Units: NA (number of buildings)	36
Figure 13 Density of ownership in Dortmund.	38
Figure 14 Concentration of single family house in Dortmund. Units: NA (number of buildings)	40
Figure 15 Concentration of double family house. Units: NA (number of buildings).....	41

Figure 16 Concentration of buildings with 3-6 apartments. Units: NA (number of buildings)	42
Figure 17 Concentration of buildings with 7-12 apartments. Units: NA (number of buildings)	43
Figure 18 Concentration of buildings with 13 or more apartments. Units: NA (number of buildings)	44
Figure 19 Density of property in Dortmund.	45
Figure 20 Concentration of owner-occupied households in Dortmund. Units: NA (number of households).	46
Figure 21 Concentration of tenant-occupied households in Dortmund. Units: NA (number of households).	47
Figure 22 Density of occupants in Dortmund.....	48
Figure 23 Degree of impact to infrastructure and quality of life.	49
Figure 24 Windrose diagram showing the intensity of barriers perceived by different ownership groups.	50
Figure 25 Intensity of owner's lack of values as a barrier to energy renovation.	53
Figure 26 Intensity of owner's aversion to risk as a Barrier to Energy Renovation.	55
Figure 27 Intensity of owner's bounded rationality as a barrier to energy renovation. ...	57
Figure 28 Intensity of lack of renovation culture as a barrier to energy renovation.....	59
Figure 29 Intensity of conflicting views as a barrier to energy renovation.....	61
Figure 30 Intensity of lack of credibility and trust as a barrier to energy renovation.....	63
Figure 31 Intensity of Perceived imperfection of information as a Barrier to Energy Renovation.	65
Figure 32 Intensity of Perceived complexity of information presented as a Barrier to Energy Renovation.	67
Figure 33 Intensity of Perceived complexity of procedure as a Barrier to Energy Renovation.	69

Figure 34 Intensity of Perceived high capital costs as a Barrier to Energy Renovation. . 71

Figure 35 Intensity of Perceived Lack of access to capital as a Barrier to Energy Renovation. 73

Figure 36 Intensity of Perceived split of incentives as a Barrier to Energy Renovation... 76

Figure 37Intensity of Perceived uncertainty regarding the return of investment as a Barrier to Energy Renovation. 79

Figure 38 Barriers perceived by simple private ownership as compared to literature findings. 82

Figure 39 Barriers perceived by condominium owners as compared to literature findings. 84

Figure 40 Comparison of barriers as perceived by simple owners and condominium owners. 85

Figure 41 Intensity of barriers as perceived by different ownership types..... 86

Figure 42 Intensity of barriers perceived by owners within neighborhoods in Dortmund. 87

Figure 43 Typologies of neighborhood defining the renovation landscape in Dortmund. 90

11. List of Tables

Table 1 Goals, relevant Stakeholders and Target groups of the Action Plans under Climate-Air Action Plan 2030.	20
Table 2 Weightage for different ownership types.....	37
Table 3 Weightage for different property types.....	45
Table 4 Weightage for different occupancy types.....	48
Table 5 Information regarding respondents of the survey.	52
Table 6 Response of simple private and condominium owners to the lack of value as a barrier to renovation.....	54
Table 7 Response of simple private and condominium owners to risk aversion as a barrier to renovation.	56
Table 8 Response of simple private and condominium owners to their bounded rationality as a barrier to renovation.	58
Table 9 Response of simple private and condominium owners to the lack of renovation culture as a barrier to renovation.....	60
Table 10 Response of simple private and condominium owners to the conflicting views in their surroundings as a barrier to renovation.....	62
Table 11 Response of simple private and condominium owners to the lack of credibility and trust in state as a barrier to renovation.	64
Table 12 Response of simple private and condominium owners to the lack of information as a barrier to renovation.	66
Table 13 Response of simple private and condominium owners to the lack of the lack of understanding of provided information as a barrier to renovation.	68
Table 14 Response of simple private and condominium owners to complex procedure as a barrier to renovation.	70
Table 15 Response of simple private and condominium owners to the high capital cost as a barrier to renovation.	72

Table 16 Response of simple private and condominium owners to the lack of access to capital as a barrier to renovation. 74

Table 17 Response of simple private and condominium owners to the lack of clear incentive as a barrier to renovation..... 78

Table 18 Response of simple private and condominium owners to uncertainty regarding return of investment as a barrier to renovation. 80

Table 19 Climate relation projects in Dortmund and the barriers they address. 89