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Energy renovation of Swedish single-family houses—a survey of barriers, drivers, and green loans

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According to the Energy Performance of Buildings Directive, 55% of the EU's emission reductions will require renovations of the least efficient buildings. Therefore, it is important to gain a deeper understanding of how owners of single-family houses perceive energy efficiency measures, energy renovation, and barriers and drivers that influence their decision-making. Moreover, the homeowner's perception of green loans is important, as one piece of the puzzle in how to finance these implementations. Swedish single-family houses account for 40% of residential energy use and 45% of heated area, and they are mostly privately owned. These decision-making processes are, to a large degree, unknown, as the main focus has been on professional actors and tenants, not on single-family and privately owned buildings. This paper presents the perspective of these owners and discussions related to their decision-making. It is therefore important to evaluate the barriers and drivers involved in this decision-making process from the perspective of house owners, and to include socio-economic factors as well as the potential for green loans. This study includes single-family house owners in two cities of different sizes who responded to a survey regarding their perspectives on energy renovation. The results showed that homeowners with lower incomes were more neutral about barriers to energy renovation. In contrast, house owners with higher incomes, and those who moved into their houses more recently, prioritized other types of renovations and investment over energy renovations. According to households where the respondents were over 60 years old, barriers such as lack of capital and time are not perceived as significant barriers to energy renovation. Moreover, this study showed that households with younger owners, those who moved recently to their homes, and those with higher incomes, are more likely to take loans for energy renovations. For these younger households and those who moved into their houses relatively recently a window of opportunity could therefore be identified, where tailored policies can be targeted toward the sector when houses are recently sold. In all cases, except for those over 70 years, respondents stated that green loans increased their interest in energy efficiency investments.

KEYWORDS

energy efficiency, energy renovation, energy efficiency measures, single-family houses, barriers, drivers, green loans

1 Introduction

The building sector represents about 40% of the total energy use and 36% of the greenhouse gas (GHG) emissions in the European Union (EU) (European Commission, 2020a). The process of achieving a more energy-efficient building sector is an important part in fulfilling the EU commitment to the Paris Agreement and to become climate neutral by 2050 (European Commission, 2018; 2019). Several EU acts address issues related to energy efficiency in buildings (Economidou et al., 2020), such as the Energy Performance of Buildings Directive (EPBD) (Directive 2018/844/EUE., 2018; Directive 2024/1275D. 2024/1275, 2024) and the Energy Efficiency Directive (Directive 2018/2002/EU, E., 2018). These directives both address the need to remove barriers to reach the targets. On the seventh of December 2023, the Council and Parliament reached a deal on a proposal to revise the Energy Performance of Buildings Directive[1]. The deal includes minimum energy performance standards (MEPS) (European Council, 2023). The co-legislators agreed that, in 2030, all non-residential buildings should be above the 16% worst performing buildings, and by 2033 above the 26% worst performing buildings. Concerning the renovation target for residential buildings, which is the focus of this paper, member states shall ensure that the residential building stock will reduce its average energy use by 16% in 2030 and by a range of between 20% and 22% in 2035. Fifty-five percent of the energy reduction will have to be achieved through renovation of the worst performing buildings. This puts clear focus on understanding how homeowners perceive and implement energy efficiency measures (EEMs).

Similar to the EU as a whole, in 2020, the Swedish building sector accounted for 34% of energy use, and 21% of GHG emissions, of which a quarter is attributable to space heating (SCB, 2022b). A total of 70 TWh of electricity was used in Sweden's residential and service sectors in 2020, which accounts for 58% of the total end use in the sector. It is estimated that about 60% of this is attributed to space heating and hot-tap water. The most common form of energy carrier in buildings is electricity, followed by district heating and biofuels (Swedish Energy Agency, 2022).

In 2020, the Swedish government implemented a strategy for energy-efficient renovation, which also addresses barriers to energy efficiency, e.g., split incentives, and lack of information or knowledge (Ministry of Infrastructure, 2020; Blomqvist et al., 2022). However, the focus is on professional actors and multi-family buildings and private housing cooperatives,[2] which have a different owner structure and a higher degree of professional actors than single-family houses.[3]

In a national context, the Swedish building and service sector is controlled and influenced by several policies. The Swedish Building Code (Swedish National Board of Housing, 2021) was launched in the 1960s and is a core part of the energy policy for the sector where, among other aspects such as thermal comfort, static design, daylighting, ventilation, permits, and minimum requirements for construction are set and controlled. In this building code, minimum requirements for energy efficiency and power are set. Other current policies and measures are the energy performance certificate (EPC), energy and climate advisory services, client groups and networks, and cross-sectoral policies and measures, such as the regulatory Environmental Code, and energy and carbon tax (Ministry of Infrastructure, 2020; European Environmental Agency, 2021). Several policies and measures of an economic and informational nature have also been put in place in the past decade, such as support for energy analysis surveys, conversion from direct electric heating or oil-based heating, and support for renovation and energy efficiency of rental apartments (European Environmental Agency, 2021; Blomqvist et al., 2022). Taking into account the position of the European Parliament on the EU taxonomy, the crucial role played by the financial sector, as well as the need for policies that will address market failures. The European Commission has proposed the introduction of green loans[4] in Europe. These are low-interest loans for the implementation of energy-related requirements such as achieving a certain energy class and passive houses (The Swedish National Board of Housing, Building and Planning, 2023), in order to incentivize the transition to a green economy and to encourage investments in green projects. Financing green investments is intended to increase the flow of financial resources to green projects. A green loan is a loan committed to green projects that addresses environmental concerns such as climate change, and air, water, and soil pollution (Spinaci, 2021).

There is a high share of single-family houses in Sweden whereas they account for 45% of the total heated area and 43% of the total number of households. In Sweden single family houses are to a high degree (91%) privately owned (SCB, 2018; Swedish Energy Agency, 2020). Also, 39% of all energy used for heating and hot-tap water in the Swedish residential and service sector relates to single-family houses (Swedish Energy Agency, 2020). In 2020, single-family houses accounted for about 75% of the total electricity used in the residential sector in Sweden. (SCB, 2022a). One main contributor to this high electricity use is the use of heat pumps for space heating in single-family houses in rural areas and suburbs. In Sweden heat pumps, which is to be considered efficient especially in suburban areas, are the most common heating method in single-family houses (around half of the houses) and especially in houses that are more than 30 years old. Natural gas is uncommon in Swedish built environment (Swedish Energy Agency, 2020) (see Figure 1).

The majority of single-family houses were built before the building code included specific requirements on energy performance.[5] More than half of the single-family houses were built before the 1970s (SCB, 2022c), which was before the time Sweden developed a range of policies and regulations

1 "Fit for 55": Council and Parliament reach deal on proposal to revise energy performance of buildings directive–Consilium (europa.eu).

2 Translated from the Swedish word "bostadsrätt" meaning private housing cooperative.

3 "Single-family houses" in this study refers to one- or two-dwelling buildings, which apply to "småhus" and "parhus" in Swedish.

4 According to Nordea Bank, green loans are loans that must be used for sustainable or environmentally friendly purposes, for example, to reduce carbon dioxide emissions or contribute to the transition to a greener society by developing environmentally friendly technology (Nordea Bank, 2023).

5 Energy performance in terms of EP in kWh/m2.

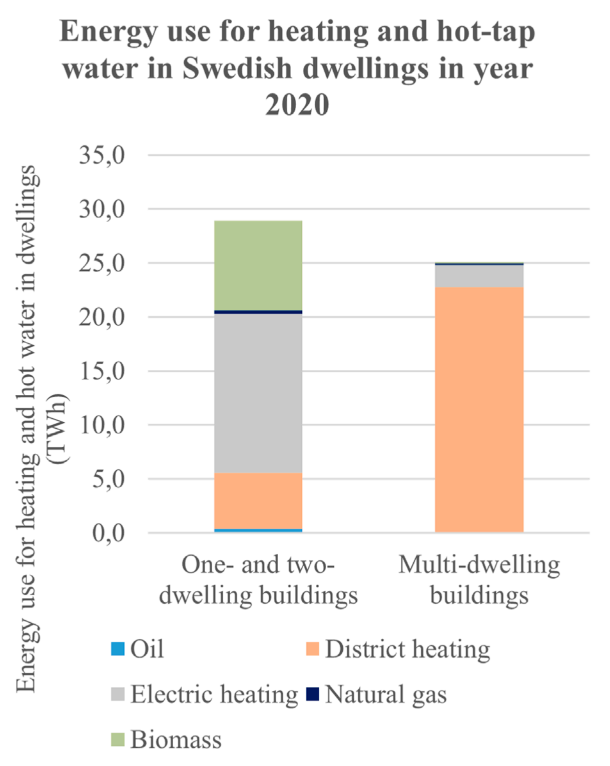

FIGURE 1
Energy use for heating and hot-tap water in Swedish single-family and multifamily buildings (Swedish Energy Agency, 2020).

aimed at reducing energy use in buildings (Kiss et al., 2010). According to Swedish Energy Agency reports, buildings built before 1960 use approximately twice as much energy for space heating and hot-tap water compared to buildings built after 2011 (Swedish Energy Agency, 2022). This shows the need to also focus on existing buildings and energy renovation.

Energy performance of building certificate is used to visualize the energy performance of a building. For new buildings this is mandatory, as all newly constructed buildings in Sweden, since 2009, require an EPC. Due to the costs involved in making an EPC for a single-family home, it is often not carried out until it becomes legally necessary, such as when the home is sold or rented. Therefore, a single-family house owner who plans to live in his house for a long period of time will not have a current EPC from which to plan a future EEM. It is estimated that 77% of single-family (in number) houses do not have a valid EPC in Sweden (Wahlström, 2022).

In order to meet the EU target of being carbon neutral by 2050, the renovation rate needs to increase to almost 3% and energy efficiency in buildings needs to be prioritized (Artola et al., 2016). In 2020, the European Commission introduced the renovation wave, which aims to double the share of renovations in the next 10 years to improve energy efficiency. In addition to reducing emissions, these renovations will improve the quality of life for those who live in these buildings (European Commission, 2020c). However, the renovation process may be hindered at different stages, from the decision to renovate through to the budgeting and finalizing stages. In Sweden, multi-family buildings are usually managed by boards of directors, while most single-family houses are privately owned and operated. Although single-family house owners have greater flexibility and more economic motivations when it comes to renovating their homes compared to those living in apartment complexes (Barr et al., 2005), they still face economic, technical, and behavioral barriers to making these choices. It is possible for homeowners to be unaware or not sure of the benefits of renovations (European Commission, 2020b). Furthermore, for single-family houses, transaction costs can be substantial, which may hinder the adoption of EEMs and energy renovation (Lundmark, 2024). It is therefore essential to understand individual homeowners' perspectives on how they operate, maintain, and manage their houses. This includes their opinions regarding the renovation strategies, economic factors, information, how they choose measures, and their perspective regarding the management and maintenance of houses and technologies.

The decision-making process around energy efficiency and renovation of single-family homeowners is influenced by many factors, and there is a lack of knowledge about how this group perceives barriers and drivers to energy efficiency, and the reasoning behind their decisions. These factors include economic as well as organizational and behavioral aspects. Understanding these barriers and drivers related to energy efficiency in single-family buildings allows policymakers to better tailor policy toward this group and identify more efficient support actions. In recent years, several studies have explored the barriers to and drivers for energy renovation and EEM implementation in residential buildings (Cooke et al., 2007; Persson and Grönkvist, 2015), as well as the process of decision-making on energy renovation of single-family houses based on demographic factors (Pelenur and Cruickshank, 2012; Stieß and Dunkelberg, 2013; Achtnicht and Madlener, 2014; Mortensen et al., 2016; Klöckner and Nayum, 2017; Azizi et al., 2019; Abreu et al., 2020; Jovović et al., 2023). The unique aspect of the study refers to the assessment of barriers and drivers in two cities of different sizes, as well as an investigation of whether regular and low-interest loans can facilitate energy renovation decisions by single-family house owners. It also tries to explore how these loans should be constructed efficiently to encourage energy renovation.

The aim of this paper is to 1) investigate the significance of different barriers to implementation of EEMs and energy renovation in single-family house buildings. The paper also aims to investigate 2) what perceived drivers influence house owners to invest in energy-efficient technology and renovation. The study does this by also examining the perceptions of house owners with different demographic and economic characteristics. One of the unique aspects of this study, and where there is a research gap, is investigating the perception of single-family house owners, in cold climate, who are not experienced in energy-renovation. Moreover, this study examined the influence of green loans on increasing interest in energy renovation among these households. The study is carried out in two cities in Sweden: Stockholm (population approximately 1 million) and Linköping (population approximately 0.17 million) (SCB, 2022d).

2 Related works

Several relevant studies related to household characteristics address energy efficiency decisions in single-family houses.

Abreu et al. (2020) investigated the role of the owner's age in energy renovations in Portuguese single-family houses. They performed a survey along with a qualitative research method that involved structured behavioral observation. Younger house owners showed more awareness and concern for the environment and energy renovation. However, a lack of financial resources was also a significant barrier for this group. The financial capability of older households was larger, but the willingness to undergo energy renovation was lower due to the disruption caused.

As part of their research, Jovović et al. (2023) looked at a wide variety of household characteristics associated with energy renovation, including socio-economic factors, building and location characteristics, as well as potential barriers and drivers to energy renovation in Slovenia. They did an online survey with 2537 respondents of both multi-family and single-family dwellings. Their research revealed that lack of renovation funding is an important issue that could be addressed to resolve financial barriers. Moreover, they found there is an information barrier, and individuals without relevant and appropriate information could benefit from advice.

A study by Klöckner and Nayum (2017) examined whether there are relevant differences regarding socio-demographic and housing characteristics among single-family house owners and their perceptions of barriers and drivers within Norwegian households. They introduced psychological approaches to decision-making in environmental issues, including attitudes and investments related to EEMs. They found that insecurity about savings potential and a lack of economic resources were two main barriers to house rehabilitation, from the residents' perspective.

Mortensen et al. (2016) examined whether homeowners can be regarded as one homogenous group regarding their interest in energy renovations and motivating factors, or if they differ significantly, requiring special attention and motivation. The study analyzed 4000 Danish single-family homeowners to find possible differences in energy renovation interest caused by demographic variables such as age, household composition, ownership duration, education, occupation, and income. The results showed that in addition to income level and age, time period house owners are living in their houses and whether the houses are in large or small cities affect the level of interest in energy renovation.

In a Swedish context, Azizi et al. (2019) investigated the benefits of and barriers to energy renovation from the perspective of owners' of single-family houses. They investigated how benefits and barriers may affect energy renovation, and owners' relationship to influential factors. The study indicated that economic objectives and environmental concerns were not effective motivators of energy renovation and that finding low-interest loans and credible information were among the biggest barriers to energy renovation for different groups of single-family house owners.

It is therefore important to investigate the barriers to energy renovation and the implementation of EEMs from the perspective of house owners, and to study how these barriers relate to different demographic backgrounds. This will help to identify suitable strategies to understand the energy efficiency gap and investment decisions on energy renovations. Also, as investments are in focus in this process, and an important part in the EUs 'Fit for 55,' investigating the house owners' perception of taking different types of loans to implement EEMs is included.

3 Theoretical framework

3.1 Energy-efficiency gap and household characteristics

"Energy-efficiency gap" refers to the potential for improving energy efficiency, defined as the gap between optimal energy use and current or future energy use (Hirst and Brown, 1990; Jaffe and Stavins, 1994). According to Jaffe and Stavins (1994) the "gap" can be explained as a paradox where apparent cost-effective and energy-efficient technologies fail to achieve a sufficient impact, implementation rate, or spread. A number of publications have addressed this, including those in the fields of industry, construction, and transportation (National Research Council, 1984; Hirst and Brown, 1990; Gruber and Brand, 1991; Stern, 1992; DeCanio, 1993; Jaffe and Stavins, 1994; Sanstad and Howarth, 1994; Weber, 1997; Sorrell et al., 2000; Brown, 2001; De Groot et al., 2001; Schleich, 2004; Rohdin and Thollander, 2006; Rohdin et al., 2007; Backlund et al., 2012; Chai and Yeo, 2012; Cooremans and Schönenberger, 2019; Economidou et al., 2020; Thollander et al., 2020; Blomqvist et al., 2022). This paradox is explained by a set of perceived barriers (Hirst and Brown, 1990; Jaffe and Stavins, 1994), which may be defined as a proposed mechanism that hinders investments that are both cost- and energy efficient (Sorrell et al., 2000).

Based on Jaffe and Stavins' findings (Jaffe and Stavins, 1994), the magnitude of the gap varies depending on the definition of energy efficiency potential and the scope of the evaluation. Energy efficiency gaps between cost-effective and actually-implemented measures can be explained by market failures and barriers. Levine et al. (1995) define market failure as "a condition in any market that results in an inefficient allocation of resources." Market failure can be expected when a violation of a free market occurs. This can lead to inefficient use of energy and inefficient investment in EEMs. To identify the most effective policy interventions, more research on the behavioral effects of market failures is required (Cattaneo, 2019).

3.2 Barriers to and drivers for energy efficiency

According to Sorrell et al. (2000), a barrier to energy efficiency is defined as a "postulated mechanism that inhibits investment in technologies that are both energy-efficient and (apparently) economically efficient." Although technology and innovation contribute to improving energy efficiency, there are several barriers that prevent their adoption. Among the most common barriers identified to energy-efficient renovations in private households, including many single-family houses, are finance, information, and decision-making. There are a few financial barriers, including a lack of capital and concern over the possibility of recovering spent funds (Team, 2011). Lack of reliable and easy-to-access information about efficiency measures is one of the information barriers (COI, 2010). Decision-making barriers include the challenge of making complicated and long-term decisions (Phillips, 2012).

There are a variety of barriers and a wide range of ways in which they can be classified (Bjørneboe et al., 2018; Cristino et al., 2021). It is important to note, however, that none of these are unambiguous, since a real-world event can be described by several theoretical barriers (Weber, 1997). The theoretical categorization of barriers used in this study can be found in several studies on other sectors, such as small and medium-sized non-energy-intensive industries (Rohdin and Thollander, 2006), the energy-intensive foundry industry (Rohdin et al., 2007), and the pulp and paper industry (Lawrence et al., 2019). These studies have identified and categorized barriers to energy efficiency in the industrial sector under the following categories: economic, behavioral, and organizational. This framework has been the basis for the survey used in this paper. Blomqvist et al. (2022) have also used these theoretical barriers to analyze the barriers to increasing energy efficiency in multi-family buildings in Sweden. The barriers theory has also been further developed in Bertoldi et al. (2021b) and Della Valle and Bertoldi (2022). Apartment buildings in Sweden are owned and operated in a professional manner, with experts, technicians, economists, and often a board of directors who are responsible for managing and making decisions regarding these buildings. In single-family homes, however, the owner is responsible for making all decisions and they are not usually professionals in the field of energy efficiency or renovation. Therefore, single-family houses cannot be subjected to organizational barriers such as those related to principal-agent relationships and power relations among all the categories mentioned earlier. Artola et al. (2016) evaluate various policy options and how they can contribute to improving energy-efficient building renovation throughout Europe. Their findings show that different policy measures address different barriers to energy efficiency. Artola et al. (2016) categorize barriers to buildings renovation in the EU in the following categories: Financial, Technical, Process, Regulatory and Awareness. Several of these categories from Blomqvist et al. (2022) and Artola et al. (2016) were used as inspiration in this study. In Table 1, the theoretical framework, barriers used in this study and a description of the barriers are presented.

Homeowners may also be encouraged to do renovations to improve the efficiency of their houses due to driving forces and added values. As described by Blomqvist et al. (2022), a driver of energy efficiency encourages homeowners to implement cost- and energy-efficient measures. Several benefits have been demonstrated as a result of implementing energy efficiency improvement measures, including energy savings and reduced energy costs (Nehler and Rasmussen, 2016). Furthermore, these effects, known as non-energy benefits, could be observed at various levels and represent a wide variety of benefits. A few examples include improved thermal comfort, improved acoustic environment, and increased property values (Nehler, 2018). Azizi et al. (2019) attempted to identify socio-behavioral factors contributing to energy renovation. In addition to the factors mentioned above, they examined homeowners' perceptions regarding energy cost reduction, minimizing house maintenance, improving aesthetics, and enhancing living space. A study of these drivers was conducted to get a better understanding of homeowners' motivations beyond energy efficiency. In this study homeowners were asked about their perspective and whether they perceive other benefits of energy efficiency in addition to reducing energy use. These included a sense of responsibility for the environment and economic aspects as well (see Table 2).

3.3 EEMs in single-family houses

In existing buildings, the application of EEMs can result in a reduction in final energy end use or in increased energy efficiency. These measures can be divided into envelope measures, heating, ventilation and air conditioning (HVAC) and tap water measures, supply system measures, and building services. Within these groups there are an array of measures and technologies to enable improved performance, such as improving the building envelope and HVAC system, including insulation, changing windows, improving airtightness, and improving the hot-tap water system. Additionally, improved environmental performance can also be achieved by conversion, i.e., changing the building's supply system. The included EEMs in this study, presented in Table 3, were measures that are common but efficient in existing single-family buildings (Penna et al., 2015; Gupta and Chakraborty, 2021).

Despite the fact that there are many financial aids available to assist homeowners in implementing EEMs, including green loans and tax reductions, it is important to assess how homeowners perceive implementing energy EEMs and whether or not they intend to utilize these aids.

4 Methods

According to Yin (2014), a survey is appropriate when the questions are "who," "where," and "what." It is preferable to conduct a survey study when explaining how frequently or widely a phenomenon occurs (Yin, 2014). The survey in this study aims to find out which drivers of and barriers ("what") exist for Swedish ("where") households living in single-family buildings ("who") to energy renovations investing in EEMs and their perception of financial alternatives such as green loans.

Single-family houses present a particularly challenging situation in terms of collecting information about energy characteristics and measuring energy use. Often, it is difficult to reach a large group of these homeowners, and due to their dispersed nature, it is difficult to collect data in a structured way without contacting each individual. In April 2021 a questionnaire survey was sent to 500 owners of single-family homes in two districts in Linköping and three districts in Stockholm, each consisting of 100 selected households. To conduct this study, different districts with different income levels and socioeconomic backgrounds were chosen. The questionnaires were distributed in the form of both paper and

TABLE 1 Barriers to energy renovation for single-family house owners, inspired by Artola et al. (2016), Blomqvist et al. (2022), and Rohdin and Thollander (2006).

<table>
<tr><th>Theoretical frameworks</th><th>Theoretical barriers</th><th>Description of barriers</th></tr>
<tr><td rowspan="3">Financial</td><td>Access to capital</td><td>Lack of capital</td></tr>
<tr><td rowspan="4">Risk</td><td>Uncertainty about financial savings after renovation</td></tr>
<tr><td>Possible cost during renovation/installation</td></tr>
<tr><td rowspan="5">Process</td><td>Risk, such as damage to the building</td></tr>
<tr><td>Uncertainty about how long house owners will stay</td></tr>
<tr><td>Credibility and trust</td><td>Little trust in contractor and construction workers</td></tr>
<tr><td>Hidden costs</td><td>Lack of time</td></tr>
<tr><td rowspan="2">Value</td><td>Other types of renovation are prioritized</td></tr>
<tr><td rowspan="2">Awareness/Information</td><td>Lack of knowledge/interest in energy issues</td></tr>
<tr><td>Imperfect information and form of information</td><td>Lack of information</td></tr>
<tr><td rowspan="2">Technical</td><td>Heterogeneity</td><td>Technology does not suit the house</td></tr>
<tr><td>Adverse selection</td><td>Uncertainty about performance of the new technology</td></tr>
</table>

TABLE 2 Investigated drivers of energy renovation for single-family house owners.

Drivers
Energy renovation reduces the operational costs of the house
Energy renovation decreases the consequences of increasing energy prices
Energy renovation is a sense of responsibility
My/our interest in the environment is important and motivates to implement EEMs
Energy renovation provides more comfort
Energy renovation increases value of the house

a web-based survey. The response rate in this study was 43% (206 respondents), which can be considered a high response rate compared to similar studies (Nair et al., 2010; Azizi et al., 2019). The survey was conducted to effectively map out how energy use is correlated with house owners' perspectives. Questionnaires were used to ask participants about their perceptions of energy renovation barriers and different categories of EEMs in order to acquire a more in-depth knowledge of energy use and decision-making in single-family homes.

To improve the reliability of responses, the questionnaire is specifically designed for homeowners of a single-family home. It is essential to avoid complex technical terms to ensure that homeowners are able to comprehend the survey as well as complete it with the least amount of confusion as possible (Malhotra, 2006). The questionnaire was divided into four categories: a) Background questions covering demographic and socio-economic factors such as income level, educational level, number of the years living in the house. b) Homeowners' perception about barriers and derivers. Homeowners were asked to rate the importance of barriers such as lack of capital and time, uncertainty about new technology, and financial savings after renovation on a scale of 1–5 (1 is "do not agree at all" and 5 is "fully agreed"). Additionally, the respondents were asked to rate the importance of drivers, which provides a higher level of comfort and increases the house's value on a scale of 1–5 (1 is "not true at all" and 5 is "completely true". c) Homeowners' perception of implementing different EEMs. The respondents were asked if they had implemented EEMs, such as installing energy-efficient windows and exhaust air heat recovery, in the past 10 years as well as what their plans were for implementing measures in the next 5 years. The questions were to be answered with yes, no, or planning to implement. d) Homeowners' perspective on green loans. As part of the survey, all residents were asked to answer yes/no questions regarding whether loans and particularly green loans would increase their interest in energy renovation and EEMs.

The results were analyzed and discussed based on household income, and demographic factors, such as age and type of household also have that influence energy use and energy-related behaviors. In this regard, as part of the survey, homeowners were asked about the age of those living in the household, how long they had lived in their home, and if they had any plans to move in the future. Since household income is often described as an important factor when making renovation decisions as well as in obtaining loans, there were questions regarding the total household income as well (Mortensen et al., 2016; Azizi et al., 2019).

TABLE 3 List of included EEMs in this study.

Buildings' envelope	Building envelope airtightness (sealed around windows, cracks, etc.)
	Building envelope thermal insulation (walls, roof, and doors)
	Installing energy-efficient windows
HVAC and tap water	Improving the hot-tap water system
	Demand control ventilation (ventilation adjusts automatically to demand)
	Hot water recirculation
	Installing cooling system
	Installing exhaust air heat recovery system
	New ventilation system
Supply system	Change of building's heating system (e.g., from electric heating to district heating system)
	Installing battery storage for self-produced electricity
	Installing photovoltaic cells (PV)
Building services	Energy-efficient lighting
	Installing electric car charger
	Motion sensor-controlled lighting

Additionally, the survey includes questions about the implementation of EEMs in the past decade and the plans for the next 5 years. Homeowners were asked if they have implemented the specified EEM already, if they planned to do so in the future, or if they do not intend to implement it at all. This is designed to obtain an understanding of the renovation activity among Swedish single-family houses. By utilizing this information, it is possible to identify areas of potential improvement in energy efficiency and identify where specific EEMs might be efficient.

Regarding the financial aspects of a renovation plan, households were asked whether they would be willing to apply for a loan to implement EEMs and whether the possibility of obtaining a green loan with a lower interest rate would increase their interest in doing so. This is to determine how likely it is that homeowners are willing to take out energy efficiency loans, but also to see how a green loan can encourage them to implement EEM.

There are a few studies that investigated drivers and/or barriers in house owners' perception or their attitude regarding energy renovation and EEMs implementation and how this relates to different household demographics (Nair et al., 2010; Mortensen et al., 2016; Bjørneboe et al., 2017; Klöckner and Nayum, 2017; Azizi et al., 2019; Mahapatra et al., 2019; Abreu et al., 2020; Jović et al., 2023). Based on these analyses, various demographics have been selected for this study (see Table 4).

On a 5-point Likert scale, the homeowner answered questions regarding barriers and drivers to implement EEM, with 1 being "don't agree at all" and "not true at all" and 5 being "completely agree" and "completely true" respectively. In order to make the scale scores comparable to the individual items, the mean scores for each barrier and driver were taken into account (Willits et al., 2016).

5 Result and discussion

5.1 Barriers hindering implementation of EEMs

Perceived barriers to energy renovation among homeowners were investigated in the questionnaire and the total results for all households are presented in Figure 2.

In the study 15% completely agreed that 'uncertainty about how long they will stay in their home' and 12% of respondents completely agreed that and "other types of renovation are prioritized," were barriers to energy renovations. The largest percentage of house owners cited "don't agree at all" responses for barriers such as "lack of capital," "risk, such as damage to the buildings," and "lack of knowledge/interest in energy issues." Considering the mean value of the Likert scale rating for barriers, the overall results showed that, according to single-family households, the main barriers to energy renovation and implementing EEMs are that "technology does not suit the house" and "other types of renovation are prioritized." Conversely, "lack of knowledge" and "lack of capital" were the least significant barriers from the households' perspective. Cattaneo (2019) explains that, in most cases, it is difficult to isolate barriers from one another. While "lack of knowledge" was among the least significant barriers among house owners, the most significant barrier for them was "technology does not suit

TABLE 4 Four analysis groups and their parameters.

Analysis group	Parameters	Comments
1) Income[6] per year	(a) < 600 kSEK (59,400 EUR)	Homeowners' income levels can affect their willingness to renovate their homes for energy efficiency. Azizi et al. (2019) found that households with different income levels behave differently regarding energy renovation
	(b) 600–999 kSEK (59,400–99,000 EUR)	
	(c) 1000–1,299 kSEK (99,000–128,700 EUR)	
	(d) > 1,300 kSEK (128,700 EUR)	
2) House owners' age	(a) > 70 years	The age of the homeowner is directly related to the lifestyle that may encourage energy renovations (Abreu et al., 2020)
	(b) 60–69 years	
	(c) 50–59 years	
	(d) < 50 years	
3) How long house owners have lived in the house	(a) < 10 years	According to Mortensen et al. (2016), the duration of homeowners' residence affects their interest in energy renovations
	(b) 11–20 years	
	(c) 21–30 years	
	(d) > 30 years	
4) Neighborhoods	(a) Nockebyhov (Stockholm)	This Study uses a classification developed by Dijkstra and Poelman (2014)
	(b) Norra Ängby (Stockholm)	
	(c) Skarpnäck (Stockholm)	
	(d) Valla (Linköping)	
	(e) Ryd (Linköping)	

the house." This might be due to the consequence of asymmetric information about the various technologies they can adopt to improve energy efficiency. It can also be argued that prioritizing other renovations may be due to a lack of information about how well implementing EEMs can contribute to reducing future energy costs and help them obtain other benefits such as improved thermal comfort. There is a lack of comprehensive and available information regarding EEMs in the market for building renovations and replacements compared to measures and information on the market for new construction. In this regard one novel idea that has been investigated is one-stop shops which offers potential to streamline energy renovation processes and offer integrated solutions (Bertoldi et al., 2021a).

In their study, Blomqvist et al. (2022) investigated the barriers to energy efficiency in Swedish multi-family buildings. The results of that study indicated that "technology does not suit the organization" is among the least important barriers. In the present study "technology does not suit the house" was the most significant barrier in single-family houses. As a significant barrier to multi-family building energy renovation, "lack of time" was the most significant factor, while it does not play an important role for single-family houses. It is important to understand that not having enough time can mean different things to private house owners and organizations.

5.2 Barrier analysis of households with different characteristics

5.2.1 Different income levels

In the questionnaire for allocating income levels, there was also the option not to mention it. This meant the total number of respondents who stated their income level decreased compared to the entire number of respondents. A total of 181 respondents provided information about their income level. The result from questionnaires showed that people with lower income levels were more neutral about all barriers to energy renovation. According to Organ et al. (2013), this does not necessarily mean that low-income groups care less about the environment, but they often have limited financial resources and must prioritize their spending – and renovation, with the purpose of less energy use, and decarbonization, may not be seen as immediate priorities. "Lack of capital" is observed as less important as income levels increase. In general, people with higher incomes have access to more capital, either through personal savings or access to credit.

6 For a clearer understanding of income levels, it is important to mention that, in April 2021, 1 SEK = 0.09857 EUR.

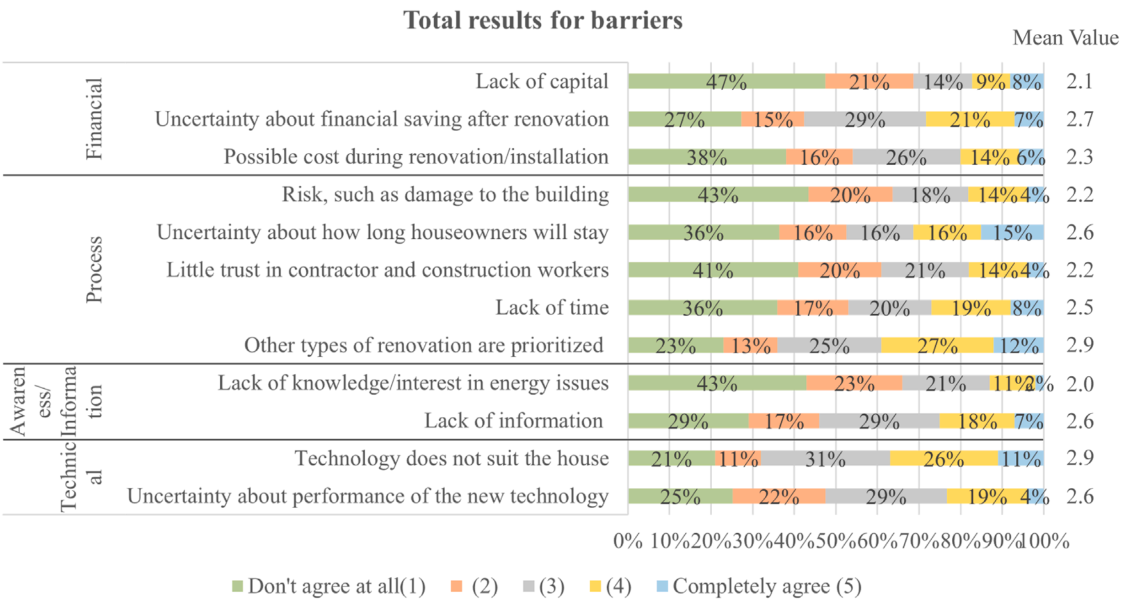

FIGURE 2
Total results for investigated barriers for single-family house owners (n = 206).

According to findings in this study, an increase in income leads to "other types of renovation are prioritized" and "uncertainty about financial savings after the renovation" being barriers, with a greater number of respondents agreeing completely on the Likert scale (see Figure 3). According to Pan (2005), while earning power varies widely among individuals, households may be able or willing to enjoy some level of luxury. In this case, individuals, to a larger degree, state that they prioritize other renovations, including remodeling their interiors and upgrading the home's appearance, over energy renovation and implementing EEMs.

5.2.2 Different districts in two cities

Based on the results in this study, "Lack of time" and "lack of capital" were two barriers that seem to be most important in all three districts located in Stockholm region compared to the two districts in Linköping. In larger cities, residents must spend more time commuting, as well as generally having higher expenses. This implies that residents of larger cities have less time and resources to pursue energy renovations and EEMs (see Figure 4).

5.2.3 House owners' duration of residence and house owners' age

The findings from questionnaires show that there is a correlation between house owners' age and the years they have been living in their houses, for barriers associated with energy renovation and EEM implementation. According to Mortensen et al. (2016), these two parameters have a significant influence on energy renovation decisions in Danish single-family households. Similarly, the results of this study demonstrated a similar outcome in Swedish single-family homes. This may be due to the fact that older people have probably lived in their homes for a longer period of time, and these categorizations are likely to produce similar results. Based on the results from questionnaires, as people lived in their homes for a longer period of time, they expressed a higher response on the scale of 1 (do not agree at all) to 'lack of information.' The results also indicated the same pattern for older people (people aged 50 and over) for this barrier. A similar pattern was also observed for the barrier "risk, such as damage to the building" as well. The older they were, or the longer they lived in their house, the higher the percentage was of people who did not agree that this barrier prevented them from renovating their homes. As they grew older or had lived in their house for a longer time, the more confident they felt in their knowledge of their home, and thus felt the barrier was less significant. A person who is opposed to change is more likely to ignore EEMs and renovations–a result of a primary behavior referred to as inertia (Rohdin and Thollander, 2006) (see Figures 5, 6).

It has been observed that people of younger ages and those who moved into their houses earlier are more likely to agree with the barrier that they prioritize other types of renovations over energy renovations. Renovating an outdated kitchen or living room enhances houses' aesthetic aspect and increases value. Energy renovations, such as replacing windows or adding insulation, reduce energy use and improve indoor comfort; however, they do not improve the visual aspect of the home. Also, Reindl et al. (2024) indicated the preference to prioritize technical installations and building design over energy performance is an important barrier. The findings indicated that more senior households, and those who have lived in their home for a longer period of time, were less likely to fully agree with this barrier (prioritizing other types of renovation) to energy efficiency renovations. Over time, people get used to their houses and their different specifications. This makes them less inclined to make changes that disrupt their routines. It may also be difficult for them to estimate the benefits of energy efficiency renovations, and they may be less inclined to consider such improvements.

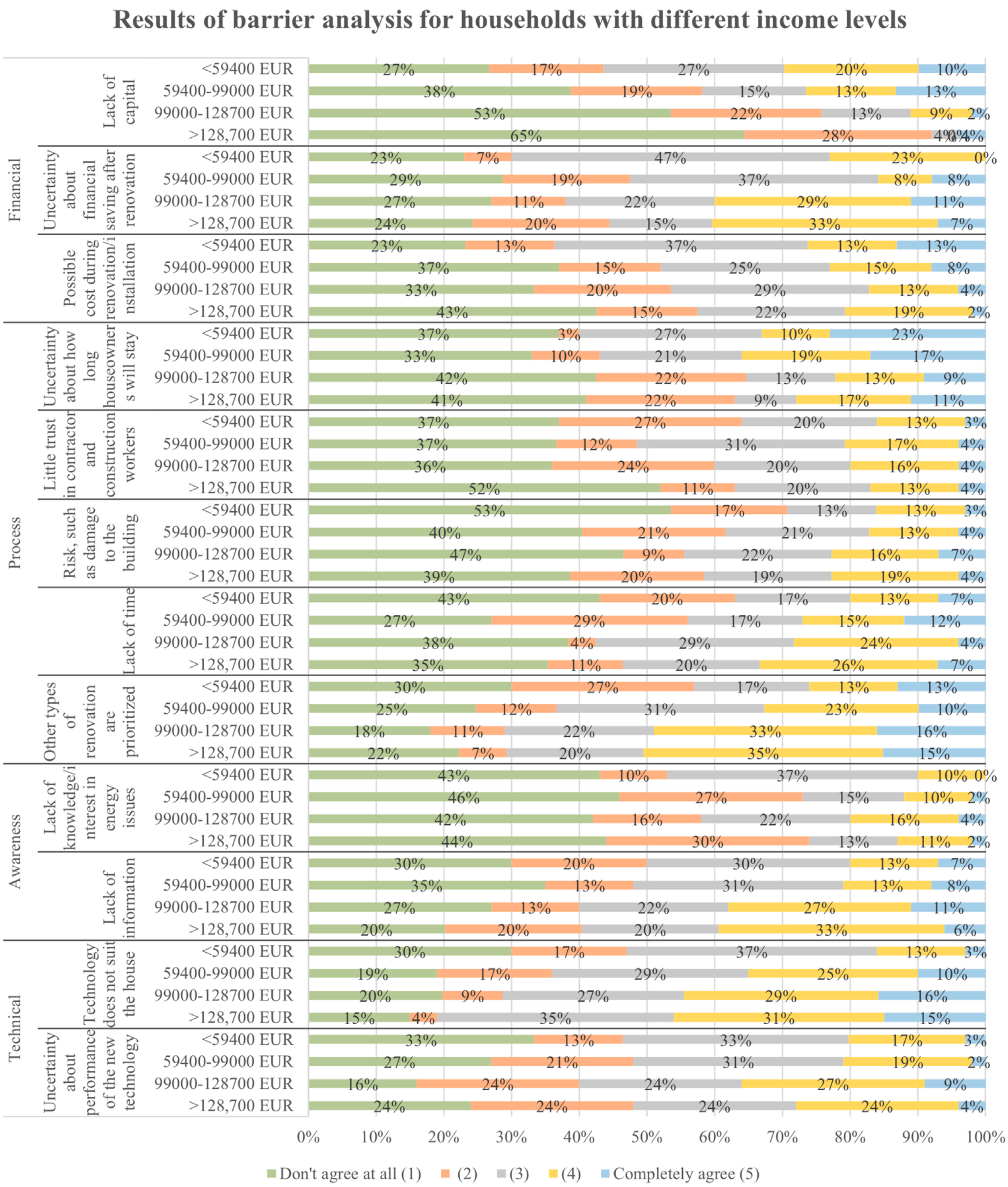

FIGURE 3
Barrier results for households with different income levels. Annual income levels lower than 59,400 EUR (n = 30). Annual income levels between 59,400 EUR, and 98,910 EUR (n = 52). Annual income levels between 98,910 EUR and 128,712 EUR (n = 45). Annual income levels higher than 128,712 EUR (n = 54).

Results from this study showed that younger people or those who moved into their houses more recently indicated that 'lack of time' was a significant barrier to the energy renovation of their homes. The young households that may have moved into single-family houses recently are likely to be of working age in Sweden and to have children of a younger age. As a result, they also perceived that they have less time, and the energy renovation process may take a significant amount of their time. In contrast, those in older households or those who have lived in their houses for a longer period of time indicated that 'lack of time' was not an important barrier to the energy renovation. Due to their reduced workload, older households perceived that they have more time available for energy renovations compared to younger owners.

In this study "lack of capital" was cited as a noticeable barrier in households with younger owners or those that had recently moved into the house. It is likely that households with young owners and those who have moved recently are dealing with house loans and have children to support, which can lead to the statements

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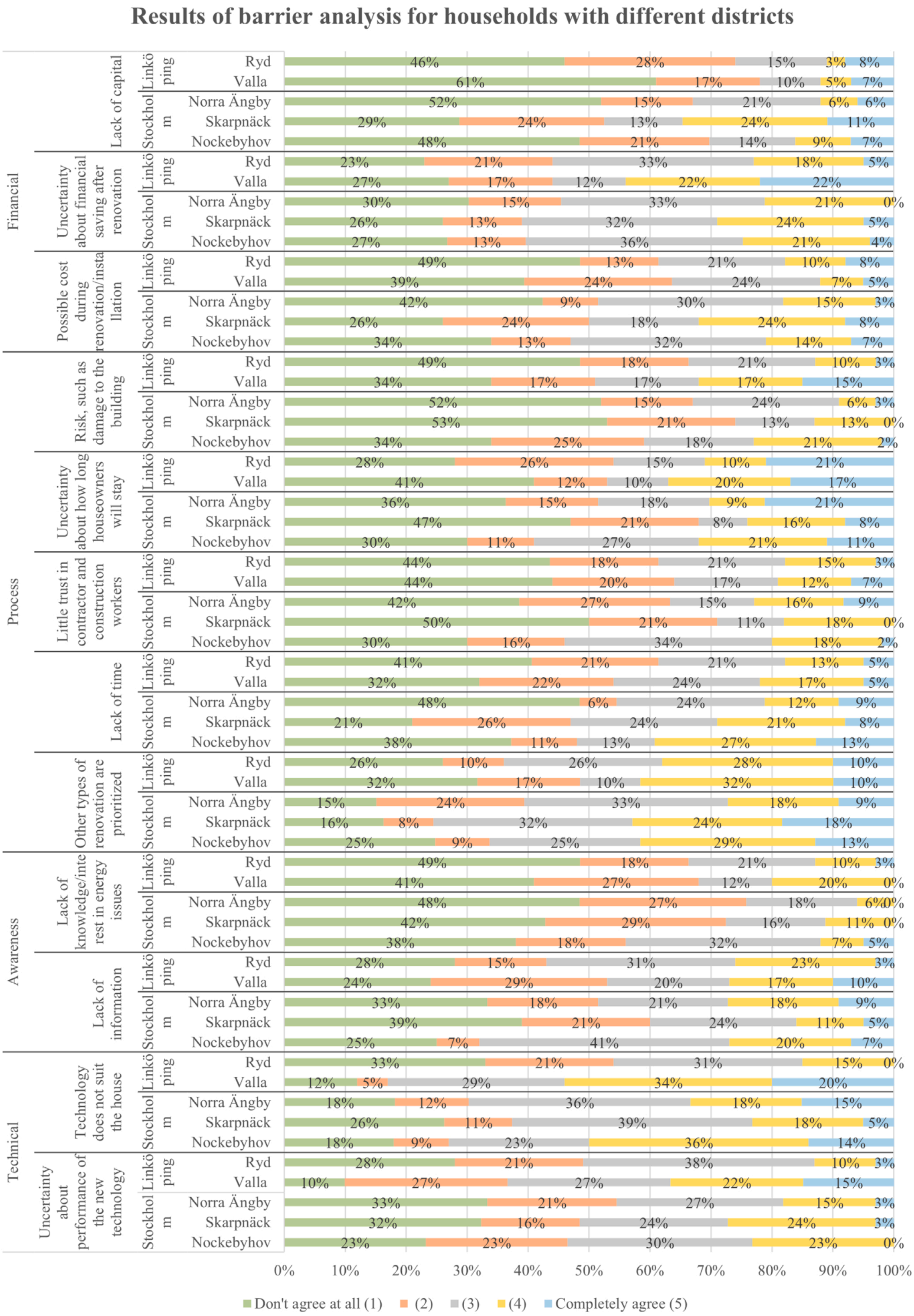

FIGURE 4
Barrier results for households in different districts. Nockebyhov, located in Stockholm (n = 56). Skarpnäck, located in Stockholm (n = 38). Norra Ängby, located in Stockholm (n = 33). Valla, located in Linköping (n = 41). Ryd, located in Linköping (n = 39).

that "lack of capital" is a significant barrier to energy renovation. Results showed that in households with older owners, and among those who have lived in their homes for long periods, they stated that this barrier is not important. This may be explained by the fact that these households have less house loans and they are in a better financial position.

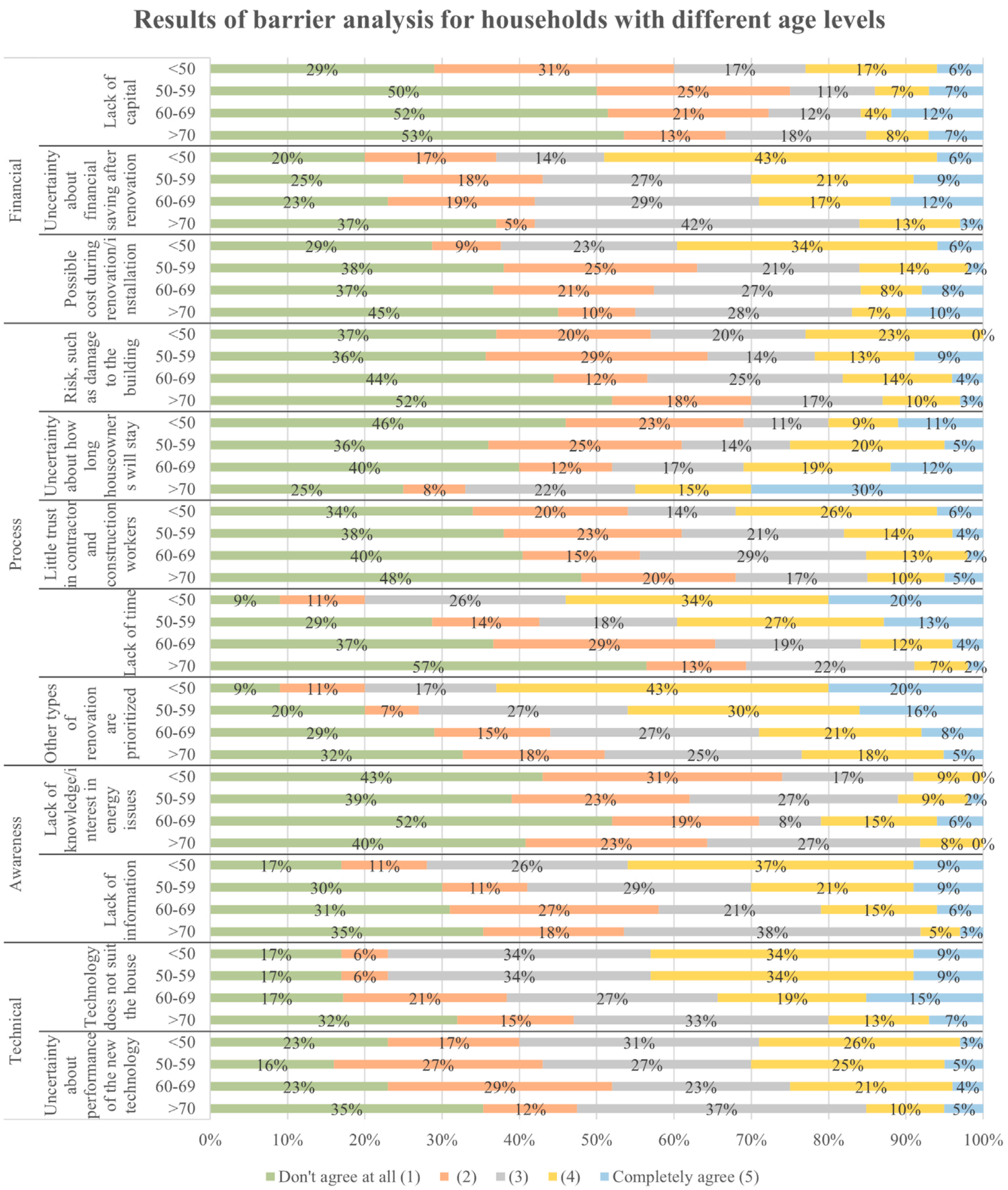

FIGURE 5
Barrier results for households with different age levels. Households with occupants aged over 70 years (n = 60). Households with the age between 60 and 69 years (n = 52). Households with the age between 50 and 59 years (n = 56). Households with the age less than 50 years (n = 38).

5.3 Drivers for implementing EEMs

The house owners identified two drivers with the highest percentage of "completely true" as their answer: "energy renovation reduces operation costs of the house" and "energy renovation gives a sense of responsibility." Despite this, "energy renovation increases the value of the house" and "energy renovation provides more comfort" were the drivers with the lowest percentage of the rank "completely true" (see Figure 7).

According to the overall average of drivers, the most significant drivers in house owners' perception was that "energy renovation reduces the operational cost of the house" along with "energy renovation decreases the consequences of increasing energy prices." "Energy renovation increases the value of the house" and "energy renovation provides improved comfort" were the least significant drivers among homeowners of single-family buildings. It is worth noting that even these drivers are well ranked and above average among barriers (see Figure 7).

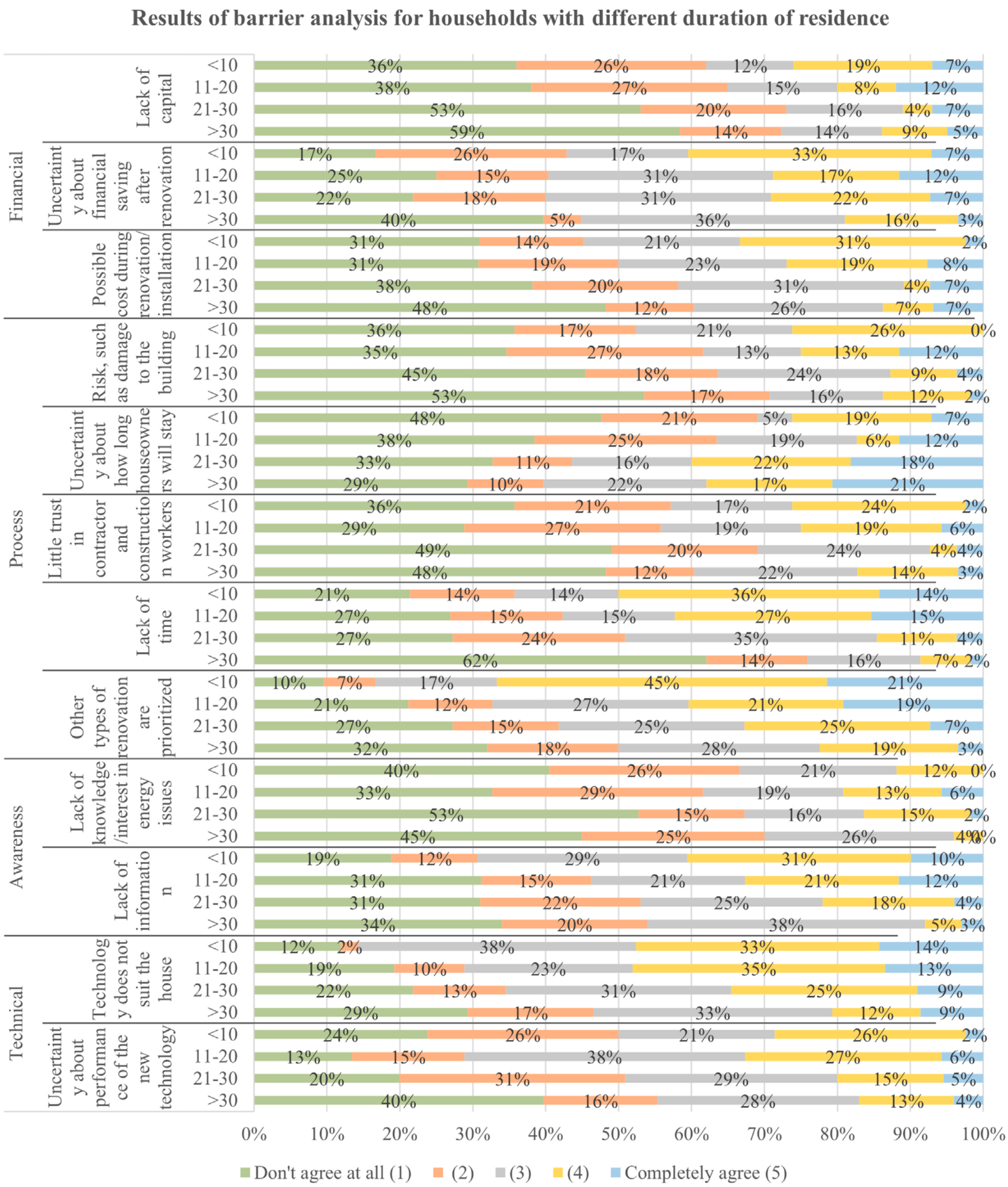

FIGURE 6
Barrier results for households with different durations of residence in their houses. Households who have lived in their houses more than 30 years (n = 58). Households who have lived in their houses between 21 and 30 years (n = 55). Households who have lived in their houses between 11 and 20 years (n = 52). Households who have lived in their houses less than 10 years (n = 42).

The most significant driver for those respondents whose annual income is less than 59,400 EUR is reducing operating costs due to renovation, while for other income levels, a sense of responsibility is the most important driver.

The most important drivers for respondents over 70 years of age and those who have lived in their single-family homes for more than 30 years are reducing the operating costs of houses and reducing the consequences of increasing energy costs, respectively. The most important driver for households who moved into their residences less than 10 years ago is their interest in the environment, which gives a sense of responsibility and motivates them to implement EEMs.

5.4 Implementation of EEMs

In this study, when asked about implemented EEMs during the last 10 years, several EEMs are not commonly implemented,

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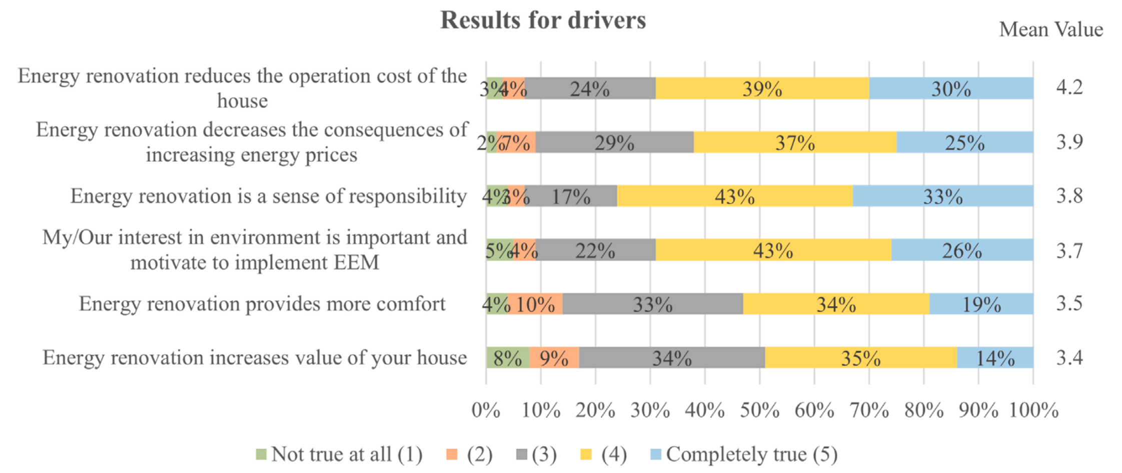

FIGURE 7
Total results for investigated drivers for single-family house owners.

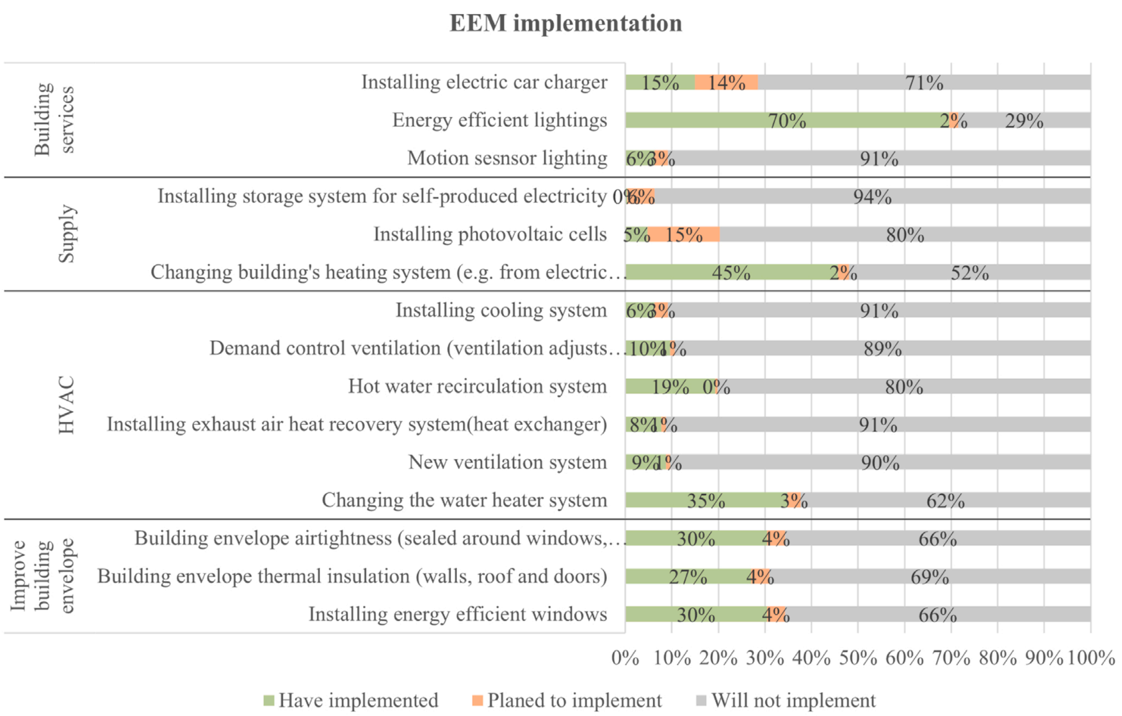

FIGURE 8
Investigated EEMs for single-family house owners.

such as battery storage for self-produced electricity, exhaust air heat recovery, and cooling systems (see Figure 8). Also, the most implemented EEMs were the installation of energy-efficient lighting, changing the heating system and the hot-tap water system, followed by measures related to building envelope airtightness. EEMs categorized in the group of supply systems such as photovoltaics (PV), and storage systems for self-produced electricity as well as electric car chargers are among the less common EEMs that have been implemented in studied single-family houses according to respondents. However, they are among the most common EEMs that the owners plan to install during the coming 5 years.

The relationship between EEM implementation in the last 10 years and the households' income shows that households with the lowest income (less than 59,400 EUR per year) and households with the highest income (more than 128,700 EUR per year) were among the groups that implemented the highest percentage of EEMs. The three EEMs in the buildings envelope category, as well as changing the heating system, installing motion sensors and

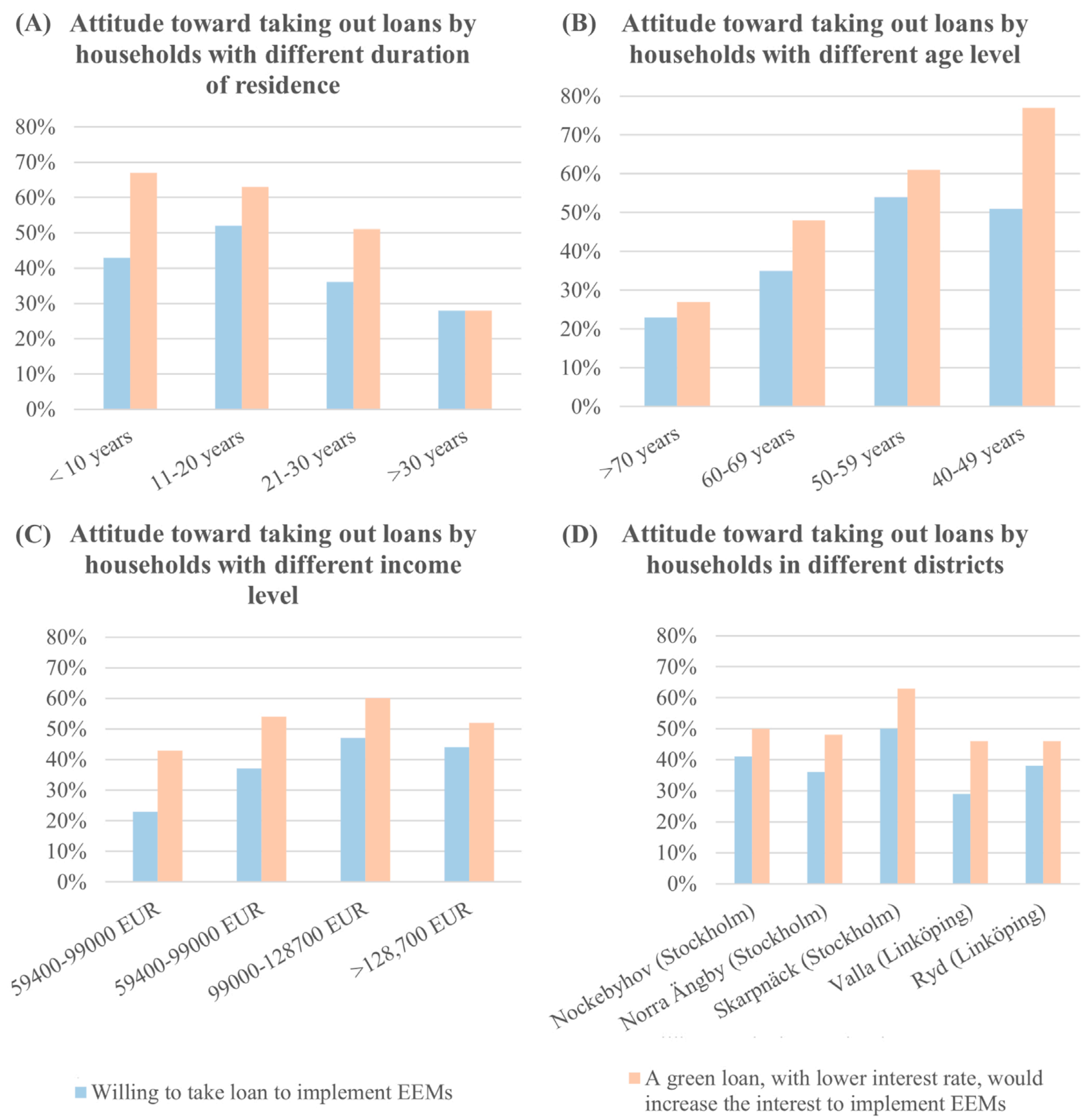

FIGURE 9
Attitude toward regular loans and green loans among households with different demographics. **(A)** Households with different durations of residence in their single-family houses **(B)** Households of different age groups, **(C)** Households with different income levels, **(D)** Households in different districts in Stockholm and Linköping in Sweden.

energy-efficient lighting, improving the hot-tap water system and hot water recirculation system, were all prioritized by these two income groups. However, for the future implementation of EEMs, the top two income levels have the highest percentage of EEMs in the envelope, supply systems, as well as building service categories such as installing energy-efficient windows, PV, and electric car chargers.

Result showed that single-family house owners were more inclined to adopt EEMs that generate electricity, such as PV. A study by Alev et al. (2014) shows that old (rural) Swedish single-family houses' ventilation and heating systems (EEMs related to the HVAC category in this study) offer the greatest potential for energy savings (up to 47% in primary energy and up to 80% in delivered energy) due to the low energy efficiency in existing HVAC systems in these houses. While implementing EEMs related to the HVAC categories can save a considerable share of energy, the house owners were more interested in EEMs related to energy supply, such as PV.

5.5 Attitude toward green loans

One way to finance investment in energy renovations or EEMs is through external funding, such as loans. While Galvin (2024) presented that the payback period for deep energy renovations in multi-family buildings often exceeds 25 years, this research focuses on single-family houses. These investments have the potential to be beneficial over the EEMs lifetime as they reduce the energy cost of buildings during their operational life. An improvement in energy efficiency requires an initial investment and potentially ongoing costs but may save money over the life of the implemented EEMs through energy savings (Erbach, 2015). In order to implement EEMs and energy renovations in the residential sector, at the pace required under the EUs "Fit for 55," substantial investments need to be made rapidly. One way to facilitate part of these resources can be through green loans. Currently, there are Swedish banks already offering green loans (The Swedish National Board of Housing, Building and Planning, 2023). Green loans, in the context of this study, are seen as loans to support individual house owners and their investments in energy-efficient or environmentally friendly technology.

In total, 34% of the respondents said yes when asked whether they would consider taking out loans to implement EEMs, as well as yes to the possibility of taking out a green loan. Yet, 17% of respondents indicated they would not take out a loan without the benefits of it being a green loan. Furthermore, 44% of the house owners declined any type of loan for the purpose of implementing EEM.

It was also observed that willingness to take out a loan differed depending on income level. As a result, the group with the highest percentage (47%) of those who are willing to obtain a loan is in the group that earns between 98,910 EUR and 128,712 EUR, followed by 44% of those earning over 128,712 EUR per year. Additionally, those with the lowest income (less than 59,400 EUR per year) are less likely to be interested in taking out a loan (23%), as well as a green loan (43%). Overall results represent that, as household income increases, household members were more inclined to take out loans to implement EEMs and benefit from a favorable interest rate on loans, which was stated as motivating them further. In terms of household age, the age group 50–59 is the one with the highest percentage (54%) of respondents who are willing to take out a loan, followed by the age group 40–49 (51%). In this study, it has been found that people over 70 and those who have resided in the house for more than 30 years are the least likely to take out a loan to finance an energy renovation or investment in EEMs.

The households aged over 70 have the lowest percentage (23%) of households who answered yes to taking out a loan for energy renovation. It is possible that subsidies can provide beneficial financial assistance to low-income and vulnerable households, such as older households. In Sweden, there are tax reductions that replaces the government subsidy which individuals could receive after installing PV, electric car chargers, and battery storage for self-produced electricity, as well as tax reduction for the labor cost of renovation activities (Skatteverket.se, 2023). However, their availability may be limited due to public finance concerns (Bertoldi et al., 2021b).

When it comes to the relationship between willingness to take out a loan and the time the respondents have lived in their houses, it has been found that house owners with a residency between 11 and 20 years have the highest percentage (52%), while those with a residency of more than 30 years have the lowest percentage (28%). It is worth mentioning that, for those who have been living longer than 30 years in the house, offering green loans did not have any effect on their interest in taking out loans. This differs when looking at the house owners who have lived in their home less than 10 years, where an offer of green loans noticeably increases their interest (see Figure 9).

6 Conclusion

The main objective of energy and climate goals in the EU is achieving a decarbonized building stock by 2050. This requires ambitious concepts for new buildings but also deep renovation strategies for residential buildings. The contribution of this paper is to explore the house owners' perception of barriers to and drivers for energy renovation and green loans in this process, as well as to explore their views on implementation of specific EEMs. The results provide insight into the potential for house owners with different characteristics to improve the rate of energy renovation by lowering the energy use during the operational life of the building. There was a combination of characteristics that affected people's perceptions regarding barriers and drivers associated with energy renovation and EEM implementation, where the strongest characteristics was income level and how long the respondents had been living in their house.

In the last decade, energy-efficient lighting, replacing heating and hot-tap water systems, and improving building envelope airtightness were among the most implemented EEMs in the survey. Among the least common EEMs already implemented in single-family houses studied are PVs, electric car chargers, and battery storage for self-produced electricity. However, respondents stated that PV and car chargers are EEMs that they are likely to install in the next 5 years.

There was a conclusion that, for the whole population of results, the barrier "other types of renovations are prioritized" was common. This barrier was even more significant in high-income single-family households. It was perceived that "lack of capital" was the barrier with the least importance by house owners in general; however, households with lower income levels were more neutral to it and found it to be more significant than households with higher income levels. An interesting finding is that in the present study "technology does not suit the house" was the most significant barrier in single-family houses. For property owners, and larger companies owning and managing residential buildings "technology does not suit the organization" is among the least important barriers. This also highlights another aspect and opportunity to improve implementation in single-family houses.

A further conclusion was that a comparison of barriers within two different Swedish cities was conducted. In the opinion of single-family residents in Stockholm, "lack of time" and "lack of capital" constituted the most significant barriers. This highlights the difference depending on if it's a larger or smaller city, which is also seen in other studies where rural towns and cities are compared.

There were several barriers identified by older house owners and house owners who have lived in their houses for a longer period of time as unimportant, including "lack of information," "lack of time," and "lack of capital." One of the biggest barriers for this group was being uncertain about how long they will stay in their homes. This can arguably be seen as rational behavior for this group. In the case of younger households and those who moved more recently, the most significant barrier was that other types of renovations are prioritized. Furthermore, younger households reported that 'lack of time' was another barrier to implementing EEMs and energy renovations.

While financial barriers seemed to be less important to house owners, the financial aspects of drivers played an important role. The house owners stated that the most important drivers were that energy renovation decreases the operational cost of the house and reduces the consequences of increasing energy prices. Among the households that participated in the survey, households with low-income levels (less than 59,400 EUR per year) and households with high income levels (more than 128,700 EUR per year) implemented the largest percentage of EEMs during the past decade. As part of the planning for the future implementation of EEMs, the two highest income groups (above 99,000 EUR per year) were more interested in implementing EEMs than the other two.

It was concluded that taking out a loan for energy renovation or EEM implementation varied considerably depending on household characteristics. Households with higher incomes, households who moved more recently into their homes (less than 20 years ago), as well as younger households (less than 60 years of age) stated they were more likely to take out a loan than other groups. Even though less than half of the people in this study had no interest in a loan of any kind, a green loan increases the interest of a significant number of households. For the younger households and those who moved into their houses relatively recently, a window of opportunity could therefore be identified, where tailored policy can be targeted toward the sector when houses are sold.

From an administrative, information, and technical perspective it is arguably more challenging to improve energy efficiency in single-family buildings than in multi-family buildings, since energy renovation relies more heavily on the owners. A combination of administrative policy, when houses are sold, in combination with information and financial incentives like green loans, is arguably an efficient way forward.

The methodology and theory used in this study can be applied to similar research in other countries, where policy landscape, cultural, environmental, and climate conditions might influence the perception of energy renovation and EEMs implementation differently. In further research it could also be interesting to study the house owners' perception of renovation measures to better understand the connection between the perception and, e.g., the economic and policy landscape in different countries.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

PN: Conceptualization, Data curation, Formal Analysis, Investigation, Visualization, Writing–original draft. GH: Data curation, Investigation, Writing–review and editing. PT: Conceptualization, Methodology, Writing–review and editing. PR: Conceptualization, Funding acquisition, Methodology, Supervision, Writing–original draft, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer PB declared a past co-authorship with the authors PT and PR.

Publisher's note

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