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Managing energy performance through heat pumps. Success drivers and barriers in residential sector

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Abstract. *Despite the increasing interest in modern solutions for energy performance improvement in residential sector, a gap persists between literature development and current implementation practices on domestic heating and cooling through heat pumps technology. Homeowners are encouraged to manage their energy-related issues in a systematic manner to ensure continual improvement of energy efficiency. This paper attempts to explore the drivers and obstacles to the use of heat pumps system for domestic heating, cooling, and hot water production in the residential sector, in order to improve dwellings' energy performance and reduce the carbon footprint. The study uses a regression model with a sample of 389 participants from Romania and shows that the availability of energy plans, voluntary association in an energy community, and mixed funding exert a positive influence, whereas bureaucracy, poor energy efficiency-related information, and fiscal incentives exert a negative influence on the intention of adopting heat pumps technology by homeowners.*

Keywords: *managing energy performance; heat pumps system; energy efficiency improvement; drivers and obstacles; residential sector; homeowners.*

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Introduction

The world is currently undergoing a shift towards sustainability and a circular economy, driven by environmental, social, economic, and political factors. The energy industry is also moving in this direction, adopting more sustainable practices and technologies, which has led to the emergence of the green transition (Finkelstein et al., 2020). The energy market is experiencing significant growth at European level, driven by the increasing focus on climate change, sustainability, and the need for efficient energy usage. To tackle the effects of pollution and greenhouse emissions and stimulate the increase of renewable energy use, the European Union has imposed increasingly ambitious targets on its countries. The main objectives to be achieved by 2030 are to reduce greenhouse gas emissions by 40%, to

increase renewable energy consumption by 32%, to increase energy efficiency by 32.5%, and to increase the 15% interconnectivity of the energy market (European Commission, 2019).

The global, pressing needs to protect the environment, save energy and reduce greenhouse gas emissions have prompted the residential sector to implement both individual energy saving measures, as well as a more systematic approach to improve the overall energy performance of residential areas. In recent years, the overall energy industry has witnessed a growing awareness and adoption of sustainable practices and technologies, such as heat pumps technology, thermal energy storage, or smart control systems, resulting in the development of new markets and opportunities. Understanding the factors that influence the adoption of such practices is essential to fully grasp the scope of the green transition and its potential to drive sustainable growth. In Romania, for instance, and generally in Europe, many of the residential and commercial buildings are not energy efficient (Muresan & Attia, 2017). However, investors and developers in the real estate sector, focused on office and residential buildings, have shown a prone interest in developing sustainable buildings equipped with energy efficiency solutions. Studies show that the heating, lighting, ventilation, and air conditioning systems consume the highest amounts within the commercial buildings: up to 35% of the entire energy consumption (Moghaddam et al., 2016). Furthermore, the residential sector is responsible for 20% of the total energy consumption worldwide, with fossil fuels being its main energy source (Karytsas & Choropanitis, 2017). Thus, both the developers and policymakers seek to find innovative solutions and measures in order to minimise the energy consumption and reduce the carbon footprint in residential buildings. Heat pumps (HP) systems are an alternative option for heating, cooling, and domestic hot water production in the residential sector, offering several advantages compared to conventional systems (Decuypere et al., 2022).

Recent statistics show that domestic heating, cooling, and lighting have a large share in the total energy consumption in Romanian's residential buildings and homes and contribute significantly to the increase in greenhouse gas emissions (Eurostat, 2022; Eurostat, 2023). Therefore, decarbonising both the heating and cooling systems is essential. An option to achieve this is by heating system electrification through heat pumps installation in combination with renewable power generation (Renaldi et al., 2017) or other modern technologies.

The current paper aims to explore the drivers and obstacles to the use of heat pump systems for domestic heating, cooling, and hot water production in residential places and other owners' homes to improve their energy performance and reduce carbon footprint. The study seeks to provide insights into how local public administration can incentivise households and homeowners to invest in green energy efficiency solutions.

The paper proceeds as follows. The theoretical framework discusses the drivers and barriers to adoption of modern solutions for improving energy efficiency and reducing carbon emissions in residential buildings, specifically the heat pump technology. This section introduces the research hypotheses developed based on the analysis of relevant literature. A section of methodology follows that explains the research design and how we tested the hypotheses. Next, we present the results of the analysis and discuss the findings. Lastly, the final section presents the concluding remarks and makes recommendations to stimulate the adoption of heat pumps in the residential sector as a more sustainable alternative to the existing ones. Research limitations follow, as well as avenues for future research.

Theoretical framework and hypotheses development

An important tendency on the energy market is the increasing focus on energy efficiency and performance. The use of energy-efficient technologies and practices spreads wide as businesses and individuals seek to reduce their energy consumption and costs. Energy efficiency measures not only reduce carbon emissions but also provide significant cost savings for businesses, households, and residents. At the European level, advances in digital technologies, such as the Internet of Things and Artificial Intelligence, are already transforming the way energy is generated, distributed, and consumed (Shehmir, 2022). Furthermore, there is growing interest in the use of modern solutions to improve energy efficiency, which could open up new opportunities for the energy industry in the future.

The electrification of heating and cooling of residential and commercial buildings is one of the key solutions in improving energy efficiency and decreasing emission of greenhouse gases (Moghaddam et al., 2016). Heat pumps play an important role in this regard. The heating market also witnesses the increasing adoption of various smart control-compatible heating systems (Janhunen et al., 2022). Although the benefits and applications of heat pumps are well established, the technology has not been adopted on a scale, thus limiting the understanding of potential energy consumption and emission reductions or other benefits for residents. Heat pump technology offers a path toward reducing the use of fossil fuels to heat space, saving on energy bills and reducing air pollution and greenhouse gasses emissions (Gradziuk et al., 2022). The choice of the heating methods in residential homes is based on costs. Efficient electric heat pumps have the potential to significantly reduce greenhouse gas emissions from heating and cooling buildings. However, the initial costs of heat pumps can be prohibitively high, while the lifetime costs are only situationally competitive with incumbent technologies (Kircher & Zhang, 2021).

Overall, as the part of renewables within the total energy mix grows, heat pumps represent a technology which can contribute to tackling numerous issues related to climate change. The prospect of heat pumps is to reduce emissions, but it is important to decide on the particular type of technology, location, and electricity mix (Dincă et al., 2022). Even though they present advantages for the environment and offer a feasible course for decarbonising the heating sector, there still are economic, administrative, structural, and infrastructural obstacles, which may impede the degree of heat pump implementation (Sanner, 2017).

Currently, there is broad research that identifies and examines different forms of household energy efficiency improvement solutions (for example, Sivagami & Jothi Swaroopan, 2020; Smith et al., 2021). While improving buildings' energy efficiency and performance is a key concern in the residential sector, both developers and policymakers are also concerned with ensuring and maintaining a reasonable level of comfort and well-being in the home. In addition to simply reducing a household's energy bill, energy efficiency means improved health outcomes and work productivity, increased energy security, and reduced pollution (McAndrew et al., 2021). Therefore, the development of specific energy management plans and strategies that take into account the needs and challenges of owners' associations and that also comply with local administration energy objectives and targets could be beneficial to encouraging positive attitudes towards the adoption of modern solutions, like heat pumps, to improve energy efficiency. Such local plans can be designed to minimise energy consumption and reduce the carbon footprint in the medium and long term. Also, citizens, particularly homeowners, are increasingly encouraged to assume more diverse

roles in improving energy efficiency, ranging from active consumer to more participative prosumer arrangements (Lennon et al., 2023). As such, citizen voluntary engagement in energy communities that tackle diverse aspects of low-carbon energy transitions helps with the democratisation and diversification of how energy is produced and consumed (Dudka et al., 2023). Thus, our first hypothesis states:

H1: (a) Development of energy management plans in the residential sector, at the owners' association or local level, positively influences residents' intention to adopt the heat pumps system.

(b) The availability of residents for voluntary association in an energy community positively influences their intention to adopt the heat pumps technology.

Peñaloza et al. (2022) carried out compelling research that analysed the main factors that impact the social and economic reception of heat pumps in buildings within European states. It was identified that access to diverse funding sources can determine a positive perception towards a favourable implementation of the technology. For example, a scheme which can be mentioned here for helping reducing upfront investment costs is a settlement between the building owner and the tenants, in which the economic, performance, or technical risks of installing a heat pump are passed on to a specialised service company, such as energy service companies (ESCOs), which recovers the upfront cost through a regular fee over a pre-established period, sometimes founded on actual energy savings (Decuypere et al., 2022). Business models have been implemented in the main heating markets targeted to provide an option to loans. In several contexts, the heat pump remains the property of the energy service company, reducing the financial risk for the property owner (Dima & Vasilache, 2013). These finance mechanisms are growing, with the ESCO market continuously increasing over time, driving innovation in the delivery of energy savings (International Energy Agency, 2018). Insufficient funding for implementation and research and development in heat pumps have been identified by Gaur et al. (2021) as an important barrier that could impede a positive perception of the public for such technologies. Citizens living in households that benefit from different funding sources to switch to heat pumps have a more favourable attitude towards this technology. It is reinforced that financial schemes for heat pump implementation should favour cleaner and more efficient consumer decisions and also take into account the revenue categories existing for the population of the respective country. It was identified that households with smaller revenues could be disadvantaged as they obtain in general smaller savings and longer payback periods within the process of changing to heat pumps, which can again generate a negative perception towards the respective technology. Therefore, our second hypothesis states:

H2: The access to diverse funding sources for implementation of heat pumps system positively influences individuals' perceived intention to adopt this technology for domestic heating, cooling, and hot water production.

Financial concerns are the component that is most often mentioned in the literature, and it was recognised as a notable difficulty in this research as well. Citizens' concerns are linked to the initial cost, reimbursement period, access to financing schemes/ subsidies, maintenance expenses, and property value. Even though the potential cost savings (over a particular time span) achieved from changing to heat pumps are not small, many users are not financially capable to substitute their existing heating system, the main issue indicated

being the considerable initial installation cost (International Energy Agency, 2022). In some states, the framework of electricity tariffs and energy taxation can create a downside for the technology of heat pumps compared to fossil fuel boilers and therefore generate a negative attitude from the part of the consumers (Lillemo et al., 2013).

Even though the expenses of a heat pump can be recovered, fiscal incentives, such as grants and low-interest loans, may still be useful to lower the initial cost difficulties, which can discourage the building owner from installing a heat pump in the first place (Fan et al., 2021). On a European level, there are several types of fiscal incentive schemes, showing the variety of political will, national policy plans, and local specificities. Therefore, fiscal incentives as support for installing a heat pump need to be considered and designed by policy makers because they can positively influence potential users and create a favourable perception towards the technology (Bai et al*.,* 2022). Thus, our third hypothesis states:

H3: (a) Individuals who can benefit from fiscal incentives for the implementation of heat pumps system are more inclined to adopt this technology for domestic heating, cooling, and hot water production.

(b): The poor provision of fiscal incentives for the implementation of heat pumps system increases individuals' reluctance to adopt this technology.

According to the International Energy Agency (2022), international demand for installing heat pumps will grow four times by 2030 and therefore training requirements will increase accordingly. Training will be fundamental to broaden the heat pump technology on a European and international level and therefore installation training programmes (for example those initiated by industry associations and manufacturers) will need to cover urban but also rural areas (Gleeson, 2016). However, it was observed that training is costly, which can discourage new applicants interested in installing heat pumps. Decent remuneration for apprenticeships and public funding of retraining schemes are important factors in attracting new users and citizens who implement technology. Governments can also play an important role in promoting training for heat pump installation to potentially induce a positive perception (Kim et al., 2022). Thus, we hypothesize the following:

H4: Access to training for the implementation of heat pumps system positively influences individuals' perceived intention to adopt this technology.

The heat pump industry demands various types of experts within the value chain, skilled in different professional areas. In many studies (for example, Karytsas & Theodoropoulou, 2014; Gaur et al., 2021), the scarcity of manufacturing workers and those who work in the installation of heating pumps has been acknowledged as a potential factor that negatively influences the willingness and openness of the public toward the technology. Many of the skills necessary for the heat pump industry are transferrable from similar jobs in the manufacturing and heating industry, hence providing a different career trajectory to workers in the fossil fuel heating industry (for example, gas boiler installers) and therefore facilitating the recruitment of new workers (Karytsas & Theodoropoulou, 2014).

According to the International Energy Agency (2022), approximatively 170,000 more workers are necessary to sustain and assist the supplementary heat pumps that will be implemented on a global level by 2030. Hiring and training all these employees is a notable task and, to date, there are concerns in the sector whether all these jobs could be covered

given the ongoing tight labour markets linked to heating, which can negatively affect the intention of citizens toward adopting this technology. Thus, we hypothesize the following:

H5: Poor provision of information (a) and experts (b) for implementation of heat pumps system increases individuals' reluctance to adopt this technology.

Heat pumps demand electricity to operate and, in some countries, the poor electricity infrastructure, and enhanced bureaucracy due to policy change could encounter difficulties to face this additional demand, which can trigger a negative attitude toward heat pumps from the part of citizens (Lowes et al., 2019; Reid & Ellsworth-Krebs, 2021). However, substituting away from natural gas or other fossil fuels for home heating and cooling and towards electric heat pumps offers the potential for large-scale reductions in energy consumption and carbon emissions (Davis, 2023). Policymakers are increasingly introducing subsidies and other incentives for heat pumps in an effort to accelerate this substitution by households and counterbalance the complexity of the process and associated bureaucracy (Davis, 2023). In what concerns the infrastructure, another important problem to be considered is the one of insulation because heat pumps are highly effective in well-insulated buildings (Meles & Ryan, 2022). As the International Energy Agency (2022) specified, installing this insulation will add another high cost to households and it should be considered when designing new buildings with an appropriate electrical infrastructure for the future. In this perspective, building owners should coordinate with architects, engineers, and designers early in the process to make sure that building design is optimized for heat pumps. As the transition to energy systems is ongoing, electricity demand could triple by 2050. In several regions, electricity demand could overcome the capacity if an electrical grid's infrastructure has not been updated to fulfil higher demand peaks. This could negatively influence the intention of potential users to implement heat pumps (Fischer & Madani, 2017). Thus, our final hypothesis states:

H6: The high bureaucracy (a) and the poor infrastructure (b) for the implementation of heat pump systems and energy distribution increase the reluctance of individuals to adopt this technology.

Method

This study aims to examine the driving factors and obstacles to the adoption of the heat pumps systems in residential places and homes as an alternative to more polluting conventional heating and cooling systems. The research hypotheses, developed based on the relevant literature, are tested by employing multiple regression models. Data were collected by using a questionnaire-based survey (built in Google Docs), administered online from March to June 2023. Data analysis was performed in SPSS.

The target population in our study is represented by residents of Romania owning or living in a housing where they can influence decisions regarding the energy efficiency, while a special focus lies on the young generation, representatives of Generation Z. Various studies (for instance, De Witte, 2022) acknowledge that this generation grew up with climate anxiety and is therefore considered to care more about ecological issues and sustainable use of resources and, in the same time, to have a pragmatic attitude about how to address these issues. The sample size computed for a confidence level of 95%, a margin of error of 5%, a population size of 9,655,685 according to the Romanian Institute of Statistics at 31st of

December 2022 (INS, 2022) and a recommended p̂ of 0.5 was 385 valid responses. Our study reports the results of a sample of 389 valid responses collected from people residing in private households and residential buildings in Romania. Thus, we consider that the statistical constraint regarding the sample size is met.

A nonprobabilistic sampling method, namely convenience sampling, was used in order to maximise the number of responses. This sampling method is relevant in relation to the objectives and hypotheses of the research, emphasising its exploratory nature (Edgar & Manz, 2017). To select the sample, a list of contacts who met the research criteria was established, to whom an invitation was sent, including the link to the questionnaire. This population was invited to further disseminate the link to other young people the same. The interested participants could complete the questionnaire in a self-administrated manner. For ensuring safety and confidentiality of responses, there was no personal information that could lead to the identification of the subjects. A statement about the nature, purpose, and expected duration of the research was included at the beginning of the survey in the invitation.

The research tool was developed based on literature research and focus groups with experts within the framework of the project "The potential for starting and developing a business for integrated technology based on heat pumps, thermal energy storage, and smart control systems in order to enable the decarbonisation in Romania", financed by EEA and Norway grants and implemented by the Bucharest University of Economic Studies, Romania. The questionnaire aimed at assessing Romanian citizens' overall perception toward the implementation of new modern solutions (e.g., integrated technology based on heat pumps, thermal energy storage, and smart control systems) to improve energy efficiency in their residential place. The questionnaire entails three main parts: the first part contains demographic questions and questions related to the housing of respondents, the second part aims at measuring the attitude towards energy performance and reducing the carbon footprint, while the third section evaluates the factors that might influence the attitude and perception of respondents about adoption of modern energy efficiency improvement solutions. For this current research, only data pertaining to the drivers for and obstacles to adoption of heat pumps system were analysed and are further presented in the paper. Before pursuing with the data collection plan, a pilot study was conducted, feedback was integrated, and the final questionnaire was validated by internal and external experts in the project. All questions in the questionnaire were closed-ended, measured on a Likert scale from 1 – strongly disagree to 5 – strongly agree.

Analysis and results

Data characteristics

The sample characteristics are provided in Table 1. As we can see, 87.7% of the respondents live in urban areas, 68.3% are under 25 years old, and 78.7% of them live in thermally insulated homes. 80.7% of our respondents report that they do not have any energy-related work experience. Our sample is fairly well balanced in terms of gender and education level of respondents.

Table 1. Sample characteristics

Variable	Levels	Percentage (%)
Residence	Urban	87.7
	Rural	12.3
Age group	18-25 years	68.3
	26-35 years	9.3
	36-45 years	11.1
	46-55 years	9.0
	56-65 years	1.3
	Over 65 years	1.0
Gender	Feminine	56.6
	Masculine	43.4
Education	Highschool	51.2
	Bachelor	22.6
	Master	14.9
	Postgraduate studies	6.4
	PhD	4.9
Thermal insulation	Thermally insulated	78.7
	Partially thermally insulated	12.8
	Not thermally insulated	8.5
Energy work experience	No experience in the energy field	80.7
	Experience in the energy field	19.3

Source: Authors' own research.

We employed multiple regression models to determine the potential influence of various driving factors and obstacles on the intention of adopting of heat pumps system in the residential sector. Table 2 shows the descriptive statistics of the items used to measure the research variables. The study uses two items to measure "Intention to adopt heat pumps system in residential places, for domestic heating, cooling and hot water production" (*HeatPump*), five items to measure driving factors of this intention, and seven items to measure obstacles. A detailed presentation of all these items is offered in Appendix 1.

Table 2. Descriptive statistics of the items

Variable	Items	C. alpha	Mean	Std. Deviation (SD)	Skewness		Kurtosis	
					Statistic	Std. Error	Statistic	Std. Error
HeatPump (2 items)	Q1	0.748	3.8226	0.8384	-0.421	0.124	0.203	0.247
	Q2		3.7918	0.8617	-0.411	0.124	0.056	0.247
Drivers (5 items)	Q3	0.774	3.9717	0.8196	-0.738	0.124	0.746	0.247
	Q4		4.1645	0.9158	-1.221	0.124	1.505	0.247
	Q5		4.2365	0.8252	-1.294	0.124	2.290	0.247
	Q6		3.7147	0.9351	-0.410	0.124	-0.248	0.247
	Q7		4.2725	0.7376	-0.907	0.124	1.193	0.247
Obstacles (7 items)	Q8	0.787	4.0257	0.9077	-0.882	0.124	0.711	0.247
	Q9		4.0437	0.8283	-0.738	0.124	0.602	0.247
	Q10		3.9692	0.9328	-0.819	0.124	0.352	0.247
	Q11		3.5913	0.9605	-0.437	0.124	-0.143	0.247
	Q12		4.1285	0.8273	-0.820	0.124	0.406	0.247
	Q13		3.9563	0.8649	-0.540	0.124	-0.104	0.247
	Q14		3.9332	0.8438	-0.597	0.124	0.413	0.247

Source: Authors' own research.

As we can see in Table 2, the mean values for all observable variables exhibit values greater than 3.5. The smallest value refers to the obstacle "Lack of specialists in the field of energy" (3.5913) followed by the driver "Citizens' availability for the establishment/ voluntary association in an energy community" (3.7147), while the highest values are exhibited by the drivers "Various sources of financing (European funds, local public administration, state budget, private investment funds etc.) for heat pumps, thermal energy storage systems, smart control systems" (4.2725), and "Opportunities for educating and training citizens on energy management (energy efficiency, renewable energy sources, metering, heat pumps)" (4.2365). These results reveal that financial incentives combined with training represent in the opinion of respondents the most important factors for adopting green energy practices, while the lack of experts and expertise in the field does not play a very important role.

The Skewness index has negative values for all items, which indicates that the distribution is shifted to the right, namely, the answers were rather positive (more values above 2.5 than below 2.5), while the Kurtosis has both positive and negative values. The positive values for certain items indicate a leptokurtic (bolted) distribution, while the negative values suggest a platykurtic distribution. The negative values of Kurtosis indicate that there are many values that lie at the border of the distribution, suggesting therefore the divergence of opinions: some respondents consider the availability for the establishment/ voluntary association in a citizens' energy community a very important driver for switching to modern energy sources such as heat pumps, while others, on the contrary, not relevant at all. The same divergence of opinions can also be identified in the case of the obstacles "Lack of specialists in the energy field" and "Poor infrastructure for energy distribution", as reflected by the negative values of Kurtosis. We can also notice from Table 2 that the Cronbach alpha coefficients for our research variables are higher than 0.7, showing there is a high internal consistency of our data ($\alpha>0.7$).

We considered it was important to compare the means of the variable "Intention to adopt heat pumps system in residential places, for domestic heating, cooling, and hot water production" for multiple demographics: males and females, residents of rural and urban areas, people of varied ages, educational level, income level, and energy-related knowledge. The ANOVA analysis, the Welch Robust Test of Equality of Means, and the nonparametric test Kruskal-Wallis do not support the existence of a statistically significant difference in means (p value>0.1) for the following categories: i) males and females, and ii) level of income. According to the same tests mentioned above, there are significant differences between means of: i) urban and rural residents (p value<0.1), rural residents exhibiting greater means than urban ones (4.00 versus 3.78); ii) different age groups (p value<0.01): the age-groups 36-65 exhibit greater average values than the others; iii) level of education (p value<0.05): higher levels of education are associated with higher average values of the intention of switching to heat pumps; iv) experience in the field of energy (p value<0.01): respondents with no work experience in the field of energy exhibit lower average values than respondents with relevant experience in this sector (3.75 versus 4.03).

The analysis of the means also reveals that people between 36-65 years old, living in rural areas, having a higher level of education and work experience and implicitly knowledge in the field of energy exhibit larger average values related to the intention of adopting heat pumps in their households.

Regression analysis of the drivers of heat pumps system adoption

A linear regression was performed to determine if the intention to adopt heat pumps system in residential places, for domestic heating, cooling and hot water production, can be positively predicted based on several variables, identified as drivers for improving energy performance and reducing carbon footprint. Thus, our first model of regression tests the influence of five drivers (independent variables) on the intention to adopt heat pumps system by homeowners and residents for domestic heating, cooling and hot water production (*HeatPump*) (dependent variable) (see Table 3). The drivers investigated are: (a) Plans/strategies at local or owners' association level for managing and reducing energy consumption in the medium and long term (*LocEnStrateg*); (b) Fiscal regulations (incentives, tax deduction) for encouraging reduction of energy consumption and carbon emissions (*FiscIncent*); (c) Opportunities for educating and training citizens on energy management (energy efficiency, renewable energy sources, metering, heat pumps) (*TrainOpport*); (d) Citizens' availability for voluntary association in an energy community (*EnCommunit*); and (e) Various sources of financing (European funds, local public administration funding, state budget, private investment funds, etc.) for heat pumps, thermal energy storage systems, smart control systems (*MixFund*).

Table 3. Descriptive statistics, Pearson correlations and model summary for the drivers of heat pumps[b]

	Mean	SD	HeatPump	LocEnStrateg	FiscIncent	TrainOpport	EnCommunit	MixFund
HeatPump	3.8072	0.75988	1.000	0.343***	0.283***	0.330***	0.336***	0.404***
LocEnStrateg	3.9717	0.81968		1.000	0.453***	0.540***	0.363***	0.435***
FiscIncent	4.1645	0.91588			1.000	0.497***	0.239***	0.510***
TrainOpport	4.2365	0.82525				1.000	0.265***	0.457***
EnCommunit	3.7147	0.93518					1.000	0.412***
MixFund	4.2725	0.73764						1.000
R	0.478[a]							
R Square	0.229							
Adjusted R Square	0.219							
Std. Error of the Estimate	0.67166							
Durbin-Watson	2.213							
F	22.725***							

Note: N=389, *** = p<0.001; ** = p<0.01; * = p<0.05

a. Predictors: (Constant), MixFund, EnCommunit, TrainOpport, FiscIncent, LocEnStrateg

b. Dependent Variable: HeatPump

Source: Authors' own research.

The regression model reveals that the examined drivers can explain 23% of the variation in the intention of to adopt heat pumps (Table 3). The remaining almost 77% is explained by other variables, which are not included in the model. The regression model is statistically significant, as illustrated by the value of F of 22.725 at a significance level Sig.= 0.000. As we can see in Table 4, two independent variables, "Citizens' availability for voluntary association in an energy community" and "Various sources of financing (European funds, local public administration funding, state budget, private investment funds, etc.) for

heat pumps, thermal energy storage systems, smart control systems", are statistically significant at a significance level Sig.<0.001, one independent variable "Plans/strategies at local or owners' association level for managing and reducing energy consumption in the medium and long term", is statistically significant at Sig.<0.05, while one independent variable "Opportunities for educating and training citizens on energy management (energy efficiency, renewable energy sources, metering, heat pumps)" is statistically significant at Sig.<0.1. Analysing the regression coefficients (Table 4), we can state that the greatest influence on the intention of adopting heat pumps is exerted by the mixt driver funding (*MixFund*), followed by the availability for establishing an energy community (*EnCommunit*) and the development of energy plans at the local or owners' association level (*LocEnStrateg*). Therefore, hypotheses H1(a), H1(b), and H2 were fully supported, while H3(a) and H4 were not confirmed based on the data analysed in the paper.

Table 4. Coefficients for the drivers of heat pumps

Model		Unstandardized Coefficients		Standard. Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Err.	Beta			Tolerance	VIF
1	(Constant)	1.387	0.233		5.953	0.000		
	LocEnStrateg	0.107	0.053	0.116	2.025	**0.044**	0.616	1.624
	FiscIncent	0.018	0.047	0.022	0.384	0.702	0.631	1.586
	TrainOpport	0.101	0.053	0.110	1.908	0.057	0.606	1.649
	EnCommunit	0.136	0.041	0.167	3.312	**0.001**	0.788	1.269
	MixFund	0.230	0.059	0.224	3.893	**0.000**	0.610	1.641

Dependent variable: HeatPump

Source: Authors' own research.

Regression analysis of the obstacles of heat pumps system adoption

The study employed a new linear regression to examine if the intention to adopt heat pumps system in residential places, for domestic heating, cooling, and hot water production, can be negatively predicted based on several variables, identified as obstacles to improving energy performance and reducing carbon footprint. Thus, our second model of regression (Table 5) tests the influence of seven obstacles (independent variables) on the intention to adopt heat pumps system by homeowners and residents for domestic heating, cooling, and hot water production (*HeatPump*) (dependent variable). The obstacles examined in the study are: (a) Bureaucracy (poor policy development, increased paperwork) (*Bureaucracy*); (b) Poor legislation (including poor regulations and inefficient local public policies) (*PoorLaw*); (c) Lack of funding sources (*PoorFund*); (d) Lack of specialists in the field of energy (*PoorExpert*); (e) Lack of consumer information in the field of energy (*PoorEnInfo*); (f) Poor infrastructure for energy distribution (*PoorInfrastr*); and (g) Lack of fiscal incentives (*PoorFiscIncent*).

Table 5. Descriptive statistics, Pearson correlations and model summary for the obstacles of heat pumps[b]

	Mean	Std. Deviation	HeatPump	Bureaucracy	PoorLaw	PoorFund	PoorExpert	PoorEnInfo	PoorInfrastr	PoorFiscInce
HeatPump	3.8072	0.75988	1.000	0.207***	0.165***	0.182***	0.174***	0.281***	0.226***	0.309***
Bureaucracy	4.0257	0.90779		1.000	0.643***	0.281***	0.089*	0.229***	0.313***	0.399***
PoorLaw	4.0437	0.82839			1.000	0.342***	0.129**	0.319***	0.380***	0.465***

	Mean	Std. Deviation	HeatPump	Bureaucracy	PoorLaw	PoorFund	PoorExpert	PoorEnInfo	PoorInfrastr	PoorFiscInce
PoorFund	3.9692	0.93283				1.000	0.371***	0.236***	0.350***	0.374***
PoorExpert	3.5913	0.96058					1.000	0.420***	0.341***	0.326***
PoorEnInfo	4.1285	0.82733						1.000	0.418***	0.459***
PoorInfrastr	3.9563	0.86492							1.000	0.480***
PoorFiscInce	3.9332	0.84381								1.000
R	0.367[a]									
R Square	0.135									
Adjusted R Square	0.119									
Std. Error of the Estimate	0.71338									
Durbin-Watson	2.132									
F	8.462***									

Note: N=389, *** = p<0.001; ** = p<0.01; * = p<0.05

a. Predictors: (Constant), PoorFiscIncent, PoorExpert, Bureacracy, PoorFund, PoorEnInfo, PoorInfrastr, PoorLaw

b. Dependent Variable: HeatPump

Source: Authors' own research.

As outlined in the second regression model (Table 5) the independent variables investigated explain 13.5% of the variation in the intention of adopting heat pumps by homeowners and residents. The regression model is statistically significant, as illustrated by the value of F of 8.462 at a significance level Sig.= 0.000. At a significance level Sig.<0.01, variables related to lack of information in the field of energy performance and poor fiscal incentives are statistically significant, while the variable *Bureaucracy* is statistically significant at Sig.<0.05 (Table 6). The other variables do not appear to play a role in consumers' intention to adopt or not the technology of heat pumps for heating or cooling their dwellings.

Table 6. Coefficients for the obstacles of heat pumps

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**	**Collinearity Statistics**	
		B	**Std. Err.**	**Beta**			**Tolerance**	**VIF**
1	(Constant)	2.100	0.250		8.387	0.000		
	Bureaucracy	0.104	0.053	0.124	1.965	**0.050**	0.569	1.757
	PoorLaw	-0.079	0.061	-0.086	-1.293	0.197	0.507	1.971
	PoorFund	0.042	0.045	0.051	0.918	0.359	0.736	1.359
	PoorExpert	0.011	0.045	0.014	0.246	0.806	0.713	1.403
	PoorEnInfo	0.148	0.054	0.161	2.764	**0.006**	0.668	1.498
	PoorInfrastr	0.038	0.051	0.043	0.737	0.461	0.665	1.503
	PoorFiscIncent	0.164	0.056	0.182	2.935	**0.004**	0.592	1.691

Dependent Variable: HeatPump

Source: Authors' own research.

Analysing the regression coefficients, we can state that the greatest influence on the intention of adopting heat pumps is exerted by the obstacle related to the lack of fiscal incentives (*PoorFiscIncent*), followed by poor information in the field of energy performance

(*PoorEnInfo*), and high bureaucracy (*Bureaucracy*). Therefore, hypotheses H3(b), was fully supported, while H5 and H6 were partially confirmed based on the data analysed in the paper. The summary of the hypotheses testing is presented in Table 7.

Table 7. Summary of hypotheses testing

Hypothesis	Test	Result
H1(a): LocEnStrateg → HeatPumps	b=0.107, p<0.05	Confirmed
H1(b): EnCommunit → HeatPumps	b=0.136, p<0.001	Confirmed
H2: MixFund → HeatPumps	b=0.230, p<0.001	Confirmed
H3(a): FiscIncent → HeatPumps	b=0.018, p>0.05	Not supported
H3(b): PoorFiscIncent → HeatPumps	b=0.164, p<0.01	Confirmed
H4: TrainOpport → HeatPumps	b=0.101, p>0.05	Not supported
H5: PoorEnInfo & PoorExpert → HeatPumps	b=0.148, p<0.01 b=0.011, p>0.05	Partially confirmed
H6: Bureaucracy & PoorInfrastr → HeatPumps	b=0.104, p<0.05 b=0.038, p>0.05	Partially confirmed

Source: Authors' own research.

Discussion

Our study attempted to explore the drivers and obstacles to the use of heat pumps system for domestic heating, cooling, and hot water production in the residential sector in order to improve dwellings' energy performance and reduce carbon footprint. This is highly relevant in the current political situation generated by Russia's invasion in Ukraine, as well as the unprecedent global climate changes, which urge the need to adopt efficient climate neutral heating and cooling solutions in both commercial buildings and the residential sector. As is well known, the European Commission requests all member states to fully implement the proposals within the Strategic Program "FIT for 55" by intensifying the measures regarding the increase in energy efficiency that will allow reducing the need for natural gas by 30% until 2030 (European Commission, 2021). One way to address this issue is by considering green energy solutions based on heat pumps system and on the use of electricity (instead of fuels). This would be most relevant, not only in Romania, but also in all the European countries.

The need for modern green energy solutions will continue to increase in Europe. As one of those modern solutions, the heat pumps systems can combine the area of heat and electricity in much more efficient ways compared to today's conventional energy converters (gas/oil condensing boilers + electricity) (Olympios et al., 2022). Heat pumps take most of the energy from a renewable energy source in the form of water, geothermal energy, or air (Kelly et al., 2016). The electricity which is needed for driving the heat pump can be obtained from a renewable energy source (photovoltaic panels). Therefore, modern heat pump systems represent an important energy storage solution that could compensate for the power fluctuations in the grid caused by renewable energy sources (Renaldi et al., 2017).

To help entrepreneurs and companies to create and implement new heat pump systems with thermal energy storage and control smart systems, there is a need to identify and understand the main driving factors and obstacles which influence the promotion and implementation of such a technology in Romania. In addition, we need to understand how to foster and make visible an ecosystem to develop these technologies in Romania. Such an endeavour will also prompt public authorities, either at the local, regional, or national level,

to enact supportive legislation and specific programmes conducive to the adoption of this type of technology. For this, the European Commission promotes the implementation of new projects for renewable sources, but also the installation of 10 million heat pumps in the next 5 years (European Commission, 2021). Our study brought about several theoretical and practical contributions in this regard.

This study proved that the availability of energy plans and strategies for improving energy efficiency and reducing carbon footprint, at the local or regional level, will increase citizens' interest in the adoption of the heat pumps system in their households for domestic heating, cooling, and hot water production. Moreover, the availability of homeowners for voluntary association in an energy community positively influences their intention to adopt the heat pumps technology. In this regard, McAndrew et al.'s (2021) work argued on the need for implementation of a combination of energy-efficient measures. Thus, homeowners can improve the energy performance of their homes and contribute to a more sustainable future. The value of reducing energy consumption in buildings has increased worldwide, so the adoption of energy efficiency techniques during the construction and operation of office and residential buildings would play an important role in the creation of sustainable cities in the future (Kim et al., 2022). Energy performance and efficiency in the home is a major concern for households. Efficient energy consumption in residential places is one of the most affordable ways to lower the detrimental effects of climate change and health-related problems. It reduces household energy consumption and expenses and decreases carbon dioxide emissions (Moghaddam et al., 2016).

Moreover, our research provided evidence regarding the positive influence that the access to various sources of financing exerts on citizens' intention to implement heat pumps technology for domestic use in their households. In addition, while the availability of fiscal incentives and tax deduction do not necessarily act as a driver for the intention to adopt heat pumps by homeowners, the absence of them could negatively influence residents' perception about the value and benefits of this technology. This finding is supported by Gaur et al. (2021), who found that insufficient funding for research and development in heat pumps acted as an important barrier that could impede a positive perception of the public about heat pumps.

Another finding of our research showed that the poor provision of information regarding energy efficiency and performance of heat pumps technology negatively influences citizens' perception related to their intention to adopt the system and moreover increases their reluctance to implementing the technology in their residential place. Yet, the absence of training opportunities, in general, in the field of energy performance and particularly for implementation of heat pumps system in the residential sector, together with limited available expertise and experts in the field, do not exert an influence on citizens' intention to adopt the technology. Our findings are supported by the work of Decuypere et al. (2022) who claimed that transition to climate neutral buildings should be supported by informing, guiding, and sensitising intermediaries in recommending heat pumps to private homeowners, providing them non-complex information in a centralised and accessible place, as well as up-to-date heat pump installations.

Lastly, our research proved that high bureaucracy continues to exert a negative influence on citizens' intention to adopt the heat pumps technology for domestic heating and cooling and to increase their reluctance in the system. Yet, poor infrastructure for implementation of heat pump systems and energy distribution seem to not affect residents'

perception of the technology. Kokoni & Leach (2021) also acknowledged the need to minimise bureaucracy and establish right policy mechanisms that would enable heat pump deployment. Key policy recommendations identified by them include the removal of the climate policy cost from electricity prices and the introduction of financial incentives (Kokoni & Leach, 2021).

The energy consumption may be reduced on short term by implementing certain measures related to attitude and behavioural changes. Nonetheless, in order to determine exactly how the energy consumption will be reduced prior to making the investments previously referred to, more data analysis should be conducted, and more information should be made available. Nonetheless, our research results bring added value to the residential sector, as more and more developers, policymakers, as well as individuals become more shifted to the European Green Deal and other related policies and on the reduction of the energy consumption and carbon footprint.

Conclusion

The paper introduced and examined five drivers and seven obstacles to the intention of adopting heat pumps system for domestic heating, cooling and hot water production in the residential sector, to improve dwellings' energy performance and reduce carbon footprint. The study also provided insights into how local administration and public policies can support and incentivize households and homeowners to invest in energy efficiency solutions.

Our study proved that, in order to stimulate the adoption of heat pumps in the residential sector as a more sustainable alternative to the existing ones, it is recommended that: i) various funding opportunities as well as fiscal incentives for adopting this greener technology are provided by the state – fiscal incentives act rather like a hygiene factor: they do not necessarily represent a driver, but their absence does represent an obstacle; ii) bureaucracy is simplified; iii) more information and awareness raising campaigns related to adoption of green solutions for energy production, particularly heat pumps system, should be launched and mediatised in the public space; iv) authorities develop and implement medium and long term strategies at local, regional, and national level, based on which consumers can establish their own strategies for adopting a greener behaviour in the energy sector.

The main limitation of the present study refers to the sample: the statistical results cannot be generalised, and the sample should be more diversified. At the same time, triangulation of research data is recommended. Future studies should further analyse other categories of stakeholders, such as producers of heat pumps or state representatives, for gaining a comprehensive perspective regarding challenges of heat pumps technology adoption in the residential sector, but also in commercial buildings. Another limitation refers to the use of the Likert scale. This might have led to some biases, since people tend to over-self-evaluate themselves related to issues that they perceive as having a positive connotation.

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Appendix 1

Variable measures

Variable	**Items**	**Sources**
HeatPump (2 items)	Q1: Replacement of heating equipment with heat pumps for domestic heating and hot water production Q2: Replacement of air conditioning equipment with heat pumps for domestic cooling and ventilation	Moghaddam et al. (2016) Olympios et al. (2022)
Drivers (5 items)	Q3: Plans/strategies at local level or owners' association level for managing and reducing energy consumption in the medium and long term Q4: Fiscal regulations (incentives, tax deduction) for encouraging reduction of energy consumption and carbon emissions Q5: Opportunities for educating and training citizens on energy management (energy efficiency, renewable energy sources, metering, heat pumps) Q6: Citizens' availability for the establishment/ voluntary association in an energy community Q7: Various sources of financing (European funds, local public administration funding, state budget, private investment funds etc.) for heat pumps, thermal energy storage systems, smart control systems	Bai et al. (2022) Decuypere et al. (2022). Fan et al. (2021) Lennon et al. (2023) Peñaloza et al. (2022)
Obstacles (7 items)	Q8: Bureaucracy (poor policy development, increased paperwork, etc.) Q9: Poor legislation (including poor regulations and inefficient local public policies) Q10: Lack of funding sources Q11: Lack of specialists in the field of energy Q12: Lack of consumer information in the field of energy Q13: Poor infrastructure for energy distribution Q14: Lack of fiscal incentives	Gaur et al. (2021) Fischer & Madani (2017) Meles & Ryan (2022)