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An empirical study

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Research paper

Adoption of renewable heating systems and thermal energy communities in the Netherlands: An empirical study

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ABSTRACT

Renewable heating systems (RHS), such as solar thermal, geothermal, heat pumps, wood pellets, biomass, are essential to reduce dependence on fossil fuel-based heating systems and resulting CO_2 emissions. Despite their benefits in terms of CO_2 emissions, the widespread adoption of RHS has yet to be achieved. This paper aims to get insights into the intention to adopt RHS in the Netherlands For this purpose, it designs and conducts a survey based on the extended version of the theory of planned behavior, with five components: attitude, subjective norms, perceived behavioral control, personal norms, and descriptive norms. The survey also includes questions on participation in a thermal energy community. The results show that several factors affect individuals' intention to adopt RHS. Many individuals in the Netherlands have a positive attitude toward adopting RHS, which is primarily caused by environmental concerns and wanting energy independence for their country. However, the majority of individuals think that they do not have the knowledge, financial means, or time to adopt RHS. Also, individuals who feel strong moral values and responsibilities are more likely to adopt RHS. Most individuals are willing to participate in a thermal energy community, and prefer participating in an energy community over adopting RHS individually. Based on these insights, a number of recommendations are made to stimulate the adoption of RHS in the Netherlands, such as taking into account moral norms, introducing policies to incentivize thermal energy communities, and addressing issues of injustice.

1. Introduction

The Dutch government has set targets to reduce CO_2 emissions by 50% in 2030, compared to 1990 levels (Rijksoverheid, 2023). These targets require major steps in energy transition, which refers to the shift from fossil fuels to sustainable and renewable energy sources. A significant part of this transition occurs in the heating sector. In the Netherlands, nearly 70% of the energy demand in the built environment is used for heating purposes, while the energy demand from the built environment accounts for one-third of final energy demand Schoots et al. (2016). This makes the heating demand in the built environment responsible for a large share of CO2 emissions. Therefore, switching to renewable-based heating systems from fossil fuel-based heating systems is crucial to achieve the country's targets.

Renewable heating systems (RHS), such as solar thermal, geothermal, heat pumps, wood pellets, biomass, etc., use renewable energy sources to produce heat Seyboth et al. (2008). Despite their benefits in terms of CO_2 emissions, the widespread adoption of RHS has yet to be achieved. Therefore, a number of papers in the literature look into how policies can influence the adoption of RHS. For instance, Kranzl et al. (2013) studies the impact of a number of policy instruments on deploying renewable heating technologies in various European countries. Germeshausen et al. (2022) assesses the effect of a new policy in Germany on the uptake of renewable heating technologies. Similarly, Bjørnstad (2012) aims to evaluate the success of a household subsidy program related to RHS in Norway.

Some papers explore individuals' preferences and acceptance toward adopting RHS, while focusing on a certain technology. For instance, Jingchao et al. (2018) aims to explore the public acceptance for low temperature air source heat pump in China. Peñaloza et al. (2022) explores factors that influence social and market acceptance of solar photovoltaic panels and heat pumps in buildings in Europe. Moreover, Karytsas and Theodoropoulou (2014) studies public awareness and willingness to adopt ground-source heat pumps for domestic heating and cooling in Greece.

The choice experiment is a popular method to systematically understand individuals' preferences toward adopting RHS. For exam-

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ple, Troiano et al. (2019) aims to understand the importance given by customers to the environmental impact (in terms of CO_2 emissions) when purchasing a new heating system. It conducts a choice experiment in Italy between heat pump, wood pellet, and natural gas boiler. Achtnicht (2011) uses discrete choice modeling to understand whether individuals in Germany choose a modern heating system or improved thermal insulation for their home. The study in Ruokamo (2016) applies a choice experiment in Finland in order to provide information on household preferences towards hybrid home heating systems, which utilize a supplementary RHS along with a main heating system. In addition, Franceschinis et al. (2017) uses a choice experiment to analyze the preferences of households in Italy for different heating systems, both renewable-based and fossil fuel-based. Despite the choice experiment being used commonly, to the best of the authors' knowledge, the theory of planned behavior has not been used extensively to better understand the adoption of RHS, although it has been used, within the context of heating systems, to understand the intention to reduce heating-related consumption by lowering home temperature (Conradie et al., 2023).

RHS technologies can be implemented at an individual household level or at a neighborhood level, as a thermal energy community. Energy communities are collective organizations where energy (both electricity and heating) is generated locally and consumed among a community of households (Official Journal of the European Union, 2018). These communities enable citizen-led energy actions to support the energy transition. In thermal energy communities, households collectively invest in renewable heating systems to jointly generate and consume thermal energy (Fouladvand et al., 2022a; Fouladvand, 2023). Thermal energy communities receive less attention in the literature, compared to their electricity counterparts (Fouladvand et al., 2022a). Although a number of papers study the formation and characteristics of thermal energy communities in the Netherlands through modeling (Fouladvand et al., 2022b; Fouladvand, 2022), individuals' opinions towards participating in thermal energy communities are not explored in an empirical study. The same also applies to energy communities in real life. For instance, according to HIER (2023), there were only 78 collective heating projects in the Netherlands in 2022, whereas 1093 collective solar projects were being conducted in the same period.

In order to address these knowledge gaps, this paper aims to gain a better understanding of individuals' intentions to adopt RHS in the Netherlands by collecting empirical data through a survey. The contributions of this paper are as follows:

- We conduct a survey that is designed based on an extended version of the theory of planned behavior with the objective of understanding the intention to adopt RHS, to replace fossil fuel-based heating technologies, without singling out a certain technology. This enables us to identify drivers and barriers related to the adoption of RHS within the Dutch heating transition.
- This paper focuses on the adoption of RHS in the Netherlands, which has not been explored extensively, even though the Netherlands is in a special position regarding heating systems, due to several reasons: (1) Dutch national targets to reduce CO_2 by 49% by 2030, which have influenced the heating sector (Rijksoverheid, 2023), (2) available natural gas field (Dempsey and Suckale, 2017), and (3) conflicting opinions towards natural gas (Jansma et al., 2020) which can also eventually impact the perception towards RHS.
- We also study the opinions towards thermal energy communities: whether individuals in the Netherlands are willing to participate in a thermal energy community, and taking which role.

The remainder of this paper is organized as follows. Section 2.1 provides information on the theory of planned behavior. The research method employed in this paper is explained in Section 2.2. The results are presented in Section 3, and are discussed in Section 4. Finally, conclusions are drawn in Section 5.

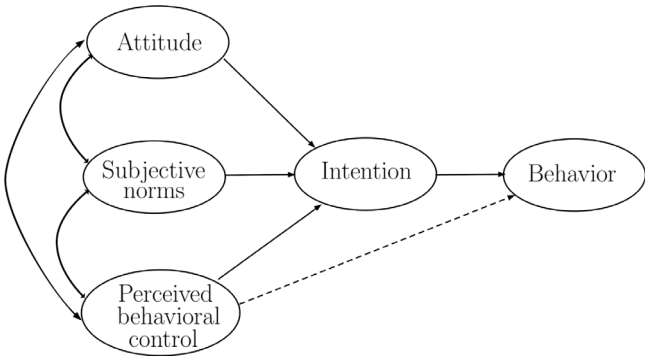

Fig. 1. Theory of Planned Behavior (Ajzen, 1991).

2. Research approach

This paper aims to collect empirical data on the adoption of RHS in the Netherlands by conducting a survey. This section explains the theory used in the survey, as well as the survey design.

2.1. Theory of planned behavior

This paper utilizes the theory of planned behavior to better understand the adoption of RHS in the Netherlands. The theory of planned behavior (TPB) is a theory that aims to understand and predict individual's behavior (Ajzen, 1991, 2020). According to the TPB, individual's intention to conduct a specific behavior is influenced by three components: (i) attitude towards this behavior, (ii) subjective norms, and (iii) perceived behavioral control. This framework is depicted in Fig. 1. Attitude refers to individual's feelings (negative or positive) to perform a specific behavior. Subjective norm refers to individual's perception of whether others who are important to them believe a particular behavior should be performed (Niemiec et al., 2020). In other words, subjective norms are very closely linked with social expectations and social pressure from others. Perceived behavioral control concentrates on individual's opinion of how easy or difficult performing the behavior would be. It reflects external factors such as availability of time, money, social support, etc., and internal factors such as knowledge, ability, skill, etc. These three components are used together in order to understand the intention to conduct a specific behavior. The intention involves how willing the individual is to perform the behavior, and how much effort they can put in to do so.

TPB has been applied to understand the behavior in a wide range of fields, such as health (Godin and Kok, 1996), transport (Chen and Chao, 2011; Heath and Gifford, 2002), protection of privacy (Saeri et al., 2014), and also energy (Gao et al., 2017; Du and Pan, 2021; Clement et al., 2014). Within the energy field, Wang et al. (2016) employs an extended version of TBP to understand the adoption of hybrid Electric Vehicles (EVs) in China. The extended version involves personal moral norms, to assess the impacts of moral responsibility on the intention to adopt hybrid EVs. Similarly, Du and Pan (2021) also incorporates personal moral norms in TBP, and applies this to examine energy-saving behaviors in student dormitories. People's energy savings and carbon reduction behavioral intentions to mitigate climate change in Taiwan is explained through TBP in Chen (2016). Another application of the extended TBP is carried out in Tan et al. (2023), to understand the willingness for retrofitting rooftops with solar photovoltaic tiles. Tan et al. (2017) and Bhutto et al. (2020) also extend TPB by adding moral norms, and applying them to understand consumers' intention to adopt energy-efficient appliances in Malaysia and Pakistan, respectively. Furthermore, Gao et al. (2017) added both personal moral norms and descriptive norms to the TBP so as to understand individuals' energy-saving behavior in workplaces.

To the best of the authors' knowledge, TPB has not been applied to better understand the adoption of RHS in the Netherlands. Meles et al. (2022) employs a latent class analysis based on TPB to understand the viewpoints of Irish individuals towards heat pumps. However, this paper has a different geographical focus and only specializes in a single RHS technology, namely heat pump. Therefore, this paper adopts the extended version of TPB with personal moral norms and descriptive norms, in order to explore the individual's intention to adopt RHS in their households in the Netherlands. The extended version includes personal moral norms and descriptive norms, in addition to the aforementioned three original TPB components. Personal moral norms refer to personal values and expectations of how one should perform a specific behavior (Schwartz, 1973), while descriptive norms refer to the perception of how other people actually behave (Niemiec et al., 2020). It is studied in the literature that adding personal moral norms increases the TPB's power when explaining individual's intention to perform a certain behavior (Wang et al., 2018; Ru et al., 2019). Hence, using the extended version of TPB offers a more detailed approach to study the adoption of RHS.

2.2. Research method

This paper aims to collect empirical data on the adoption of RHS in the Netherlands by conducting a survey. The survey consists of three parts: (i) questions on the socio-demographic data, (ii) questions on the intention for adopting RHS, (iii) questions on preferences regarding RHS. The first part includes questions on socio-demographic indicators such as age, education, employment, the number of people in a household, etc. The second part involves 19 questions about the adoption of RHS, which consist of statements, developed based on the components of TPB, as explained in Section 2.1. These statements are given on a 5-point Likert scale that the respondent must rate based on the level of agreement/disagreement. In this scale, 1 indicates 'Strongly disagree' and 5 indicates 'Strongly agree'. Some examples of such statements are as follows: 'I think adopting renewable heating systems in my house is important to protect the environment.' and 'It is affordable to adopt renewable heating systems in my house.'. The third part deals with a number of questions about the respondent's preferred RHS technologies and their participation in a thermal energy community. Overall, these survey parts enable us to explore the impact of TPB components on the intentions for adopting RHS, and to analyze their opinion toward participation in a thermal energy community.

The survey is designed in line with the European General Data Protection Regulation (GDPR) guidelines (e.g., the respondents are informed about the purpose of the questionnaire, the data gathering and storage process, and they should be older than eighteen years old). The complete list of questions in the survey is provided in Appendix A.

3. Results

The survey was conducted from the beginning of January 2023 to the beginning of March 2023, using an online questionnaire tool of Qualtrics, which is a commonly used online platform for creating and disseminating surveys. The winter months were selected on purpose to conduct to the survey, so that individuals could better reflect on the heating situation in their households. 165 individuals from the Netherlands completed the questionnaire. The socio-demographic characteristics of the respondents are demonstrated in Table 1.

As can be seen in Table 1, the respondents were almost evenly distributed in terms of gender. Most respondents were of the age group between 25 and 34 years (adults, 46.1%); 28.5% were between 35 and 49 years (middle-age adults), 10.3% were between 50 and 64 years (old-age adults), 11% were between 18 and 24 years (young adults), and 4.2% were above 65 years (senior). With regard to education level, most respondents have a university degree (32.1% PhD + 44.8% MSc + 21.2 BSc = 98.1%). Therefore, the education level in the respondent group is highly skewed towards highly educated people. Moreover, the majority of the respondents were working full-time (70.3%), while 6.7% were working part-time and 16.4% were students. A large number of the respondents were living with their families (57.6%), and nearly 25% of them were living alone, and 15.8% living in a shared house. Regarding location, more than 94% of the respondents were living in an urban area (either city centre or city periphery), while only 5.5% were living in rural areas. Overall, looking at the socio-demographic characteristics, although for some characteristics, such as education level, the data is dominated by specific group, the majority of the characteristics are in line with the Dutch population (Koirala et al., 2018).

Table 1
Socio-demographic data form the survey.

Question	Answers	Numbers	Percentage
Gender	Male	90	54.5
	Female	72	43.6
	Non-Binary	2	1.2
	Prefer not to say	1	0.6
	Others	0	0
Age	18–24	18	11
	25–34	76	46.1
	35–49	47	28.5
	50–64	17	10.3
	=> 65	7	4.2
Education	No degree	0	0
	High school	2	1.2
	Professional training	1	0.6
	Undergraduate	35	21.2
	Master	74	44.8
	PhD	53	32.1
Employment	Part-time	11	6.7
	Full-time	116	70.3
	Student	27	16.4
	Unemployed	5	3.0
	Retired	3	1.8
	Others	3	1.8
Household	Only me	40	24.2
	Family house (2 to 5)	95	57.6
	Shared house (2 to 5)	26	15.8
	Family house (>5)	0	0
	Shared house (>5)	4	2.4
Localization	Urban city centre	70	42.4
	Urban city periphery	86	52.1
	Rural area	9	5.5

3.1. Analyzing the TBP components

This section presents the survey data for each TPB component. As discussed in Section 2.1, an extended version of TPB is used, which includes five main following components to study the intentions and behaviors for adopting RHS: (i) attributes, (ii) subjective norms, (iii) perceived control behavior, (iv) personal moral norms, and (v) descriptive norms. Table 2 demonstrates the results of the survey on these components.

Firstly, the parameters related to *Attitude* indicates that the respondents generally have a positive attitude towards RHS. They are most motivated by protecting the environment, and having a sustainable energy system in their country. Moreover, the results indicate that they are more interested in their country becoming independent, than themselves (as a household) becoming independent from the grid. In fact, they are least interested in becoming independent from the grid.

Secondly, the results related to *Subjective norms* score moderately, with the average value of 2.94 out of 5-point Likert scale. This shows that the respondents are influenced to a moderate extent by what people around them think they should do regarding the decision on adopting RHS. The data also indicate that the respondents are likely to be influenced by what other people around them by a similar extent,

Table 2
Survey data related to theory of planned behavior components, given in 5-point Likert-scale.

TBP components	Questionnumber	Statements	Score
Attitude	Q1–1	Protecting environment	4.48
	Q1–2	Saving money	3.74
	Q1–3	Independence from national grid	3.65
	Q1–4	Making my country energy independent	4.07
	Q1–5	Making my country's energy system more sustainable and efficient	4.33
Subjective norms	Q2–1	Influence of family and friends	2.94
	Q2–2	Influence of my neighbours	2.78
	Q2–3	Influence of my colleagues	3.15
	Q2–4	Influence of me on my friends and family	2.89
Perceived behavioral control	Q3–1	Access to the required knowledge	3.42
	Q3–2	Affordable (money)	2.42
	Q3–3	Having enough time	2.58
	Q3–4	Having control	2.31
Personal moral norms	Q4–1	I have a moral responsibility	3.81
Descriptive norms	Q4–2	My family and friends did it	3.01
	Q4–3	My neighbours did it	3.05
	Q4–4	My colleagues did it	3.27
Intention & Behavior	Q5–1	I am willing to adopt RHS	4.28
	Q5–2	I will make an effort to adopt RHS	3.50

even though the parameter associated with colleagues is slightly higher than the other two parameters.

The parameters concerning *Perceived behavioral control* score the lowest among all the TBP components. The majority of the respondents are of the opinion that they do not have the knowledge, financial means, or time to adopt RHS. Among these parameters, time and money are perceived to be greater problems than the required knowledge or skill. Moreover, the respondents were asked whether or not it is completely up to them to adopt RHS in their house. This question scored very low, which can be explained by the lack of options (e.g., the respondents do not feel have enough resources such as finances) or the house ownership (i.e., the respondents might be tenants) and etc.

The parameter related to *Personal moral norms* has a score of 3.81, which indicates that a high number of respondents feel morally responsible for adopting RHS. Also, the average score of parameters about *Descriptive norms* is 3.11, which is a moderate score similar to subjective norms.

Lastly, the parameters concerning *Intention & Behavior* are divided into two categories: willingness to adopt RHS, and making an effort to adopt RHS. These parameters show that respondents' willingness to adopt RHS is considerably higher than the effort they are ready to actually put in: the willingness to adopt RHS has a score of 4.28, while the effort to adopt RHS has a score of 3.5. This means that not everyone who is willing will put in the effort to adopt RHS, which will be discussed further in Section 4.

3.2. Correlations

To be able to understand how willingness and effort to adopt RHS in the Netherlands are influenced by these TBP components, the correlation between these is analyzed and presented in Fig. 2. The method we used is based on Pearson's coefficient correlation (Cohen et al., 2009). This measures the strength and direction of the linear relationship between two variables. It ranges from −1 to 1, where 1 indicates a perfect positive correlation, −1 indicates a perfect negative correlation, and 0 indicates no correlation. Fig. 2 illustrates that the willingness to adopt RHS (Q5_1) is highly correlated with the attitude towards RHS (Q1). In fact, on average, the highest correlation can be seen between willingness and attitude questions. On the other hand, attitude parameters are not as strongly correlated with effort (Q5_2), being very low and negative in one case. This might indicate that people who possess a positive attitude towards RHS are very likely to be willing to adopt RHS, but will not put much effort into doing that.

Subjective norm parameters are moderately correlated with willingness and effort. Similar numbers can be observed for descriptive norms as well. This means that people are affected by people around them (their expectations and what they actually do) to a small to moderate extent.

Fig. 2 also shows that PBC parameters are lowly correlated with willingness and effort. The correlation between PBC and effort (0.30 on average) is higher compared to the correlation between PBC and willingness (0.14 on average). This means that people who possess time, money, and knowledge are more likely to put in the effort to adopt RHS. Therefore, PBC is a very crucial factor in decision making on whether to adopt RHS. However, as previously discussed in Section 3.1, PBC parameters score the lowest, meaning that most people do not have the time, money, or knowledge to adopt RHS, despite it being a very significant factor.

Another strong correlation can be observed between moral responsibility and willingness and effort. Based on this, people who believe they have a moral responsibility to adopt RHS are more likely to adopt RHS. Furthermore, there is not an exceptionally strong correlation between willingness and effort (only 0.38), also suggesting that not everyone who is eager will put in the effort for adopting RHS, which is in line with the previous findings discussed in Section 3.1.

3.3. Preferences regarding renewable heating systems

The respondents were asked a number of questions about their preferences in RHS. These questions can be grouped into two categories: (1) preferences regarding RHS technologies, and (2) preferences regarding participating in an energy community. This section provides results in these two categories.

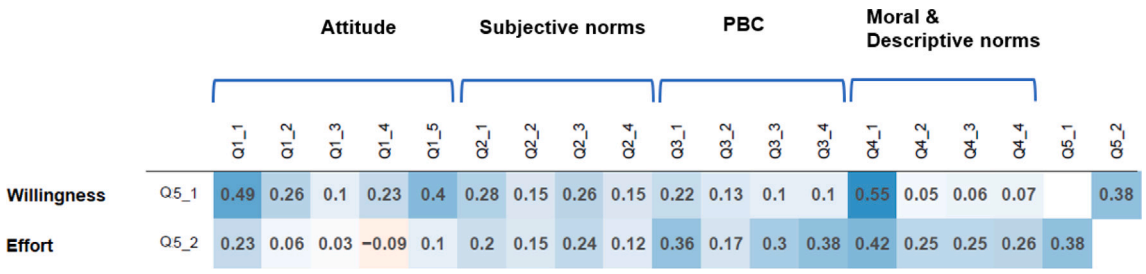

Fig. 2. Correlation of different parameters with Willingness and Effort. Question numbers are given in Table 2.

3.3.1. Preferences in RHS technologies

The respondents were asked about the RHS technologies they find desirable to adopt for heating in their home. Note that it was possible to give multiple answers for this question. The results to this question are shown in Fig. 3. This figure indicates that the respondents find certain technologies more desirable than others. Heat pumps (28.5%) and solar thermal (26.8%) are the two most desirable RHS technologies, which can be implemented both individual and neighborhood levels. On the other hand, geothermal is the collective-level RHS technology that the respondents prefer the most. Additionally, 16 respondents said they are not familiar with RHS, which can be interpreted as a lack of knowledge, and hence align with the analysis

In addition to this question, the respondents were also asked to state when they would adopt RHS in their house, which is also shown in Fig. 3. Most respondents were positive to this question; 76% said either they had already adopted RHS in their house, or they will adopt RHS as soon as possible, in their next house renovation, or in their next house. Only a very small percentage of the respondents answered this question as Never. 22.4% indicated they did not know when the adoption of RHS would take place in their house, which is still a considerable share.

3.3.2. Participating in a thermal energy community

The respondents were asked whether they were willing to participate in a thermal energy community with their neighbors to adopt RHS. Fig. 4 is a pie chart depicting the distribution of the respondents' willingness to participate in a thermal energy community to adopt RHS. This figure shows that a significant portion of the respondents (78.1%) were interested in taking part in a community: 63.6% as a participant and 14.5% as a leader in the community. While 15.8% of the respondents were uncertain about their decision, only 6.1% were not interested in participating.

To be able to gain a better understanding of the intention to participate in a thermal energy community, a number of 5-point Likert-scale questions were asked, which are presented in Table 3. The respondents were asked if they preferred participating in a thermal energy community for heating purposes over making individual investments in RHS. This statement scored high (3.5 in a 5-point Likert-scale), suggesting it is preferable for many of the respondents to participate in a community to adopt RHS, over making an individual investment for this purpose. In addition, according to this table, most of the respondents think that participating in an energy community increases engagement in the neighborhood, and is also a more affordable choice than consuming natural gas. Nonetheless, the respondents are less convinced that participating in an energy community can bring more continuous access than natural gas.

4. Discussions

This paper applied the extended version of TBP to understand the behavior of adopting RHS in the Netherlands. This section discusses the main findings of the paper, as well as its limitations.

Table 3
Statements about participating in a thermal energy community to adopt RHS, scored in a 5-point Likert-scale.

Statements	Likert-scale score
More preferred over individual investment in RHS	3.51
Increases engagement in my neighbourhood	3.84
More affordable choice than natural gas	3.46
More continuous access to energy than natural gas	3.08

4.1. Key factors influencing adoption of renewable heating systems

The results in this paper show that several factors affect individuals' intention to adopt RHS. Many individuals in the Netherlands have a positive attitude towards adopting RHS. This positive attitude is primarily caused by environmental concerns and wanting energy independence for the country. However, the majority of individuals think that they do not have the knowledge, financial means, or time to adopt RHS (as part of perceived behavioral control). This suggests that these factors, especially time and financial means, are the biggest barriers to the adoption of RHS in the Netherlands. This aligns with findings from previous papers on the adoption of solar panels in the Netherlands (Kraaijvanger et al., 2023). As mentioned previously, the sample in the survey is skewed toward higher-educated people. This means that the less-educated people are not well represented in this sample. However, considering higher-educated people, with arguably higher income on average, find financial means and time to be the biggest barrier, it is likely that similar responses can be expected from less-educated people as well.

According to the results, subjective norms and descriptive norms score moderately (2.94 and 3.11 out of 5-point Likert scale, respectively). This means individuals are affected to a moderate extent by what people around them think they should do regarding the decision to adopt RHS and what people around them actually do. Subjective norms are associated with social expectations and social pressure from others, and descriptive norms are about what others actually do. Hence, not having high scores on these norms can be attributed to the individualistic culture in the Netherlands (Allik and Realo, 2004), where people tend to be independent and self-oriented, whereas a collectivistic culture stresses connections with others and the importance of community (Allik and Realo, 2004; Beilmann and Realo, 2012). A previous study in Van Hooft and De Jong (2009) explores the impact of individualistic/collectivistic societies on TBP.

The results show that personal moral norm greatly impacts the intention to adopt RHS. This suggests that individuals who feel strong moral values and moral responsibilities are more likely to have the intention to adopt RHS. Another point worth noting is the discrepancy between the results for willingness and effort to adopt RHS. More specifically, the results indicate that the willingness to adopt RHS is significantly higher than the effort they intend to make. This means individuals might not take concrete steps in adopting RHS. This can be explained by the results regarding perceived behavioral control. That is to say, since most individuals do not think they have sufficient time, financial means, or knowledge to adopt RHS, they perceive this

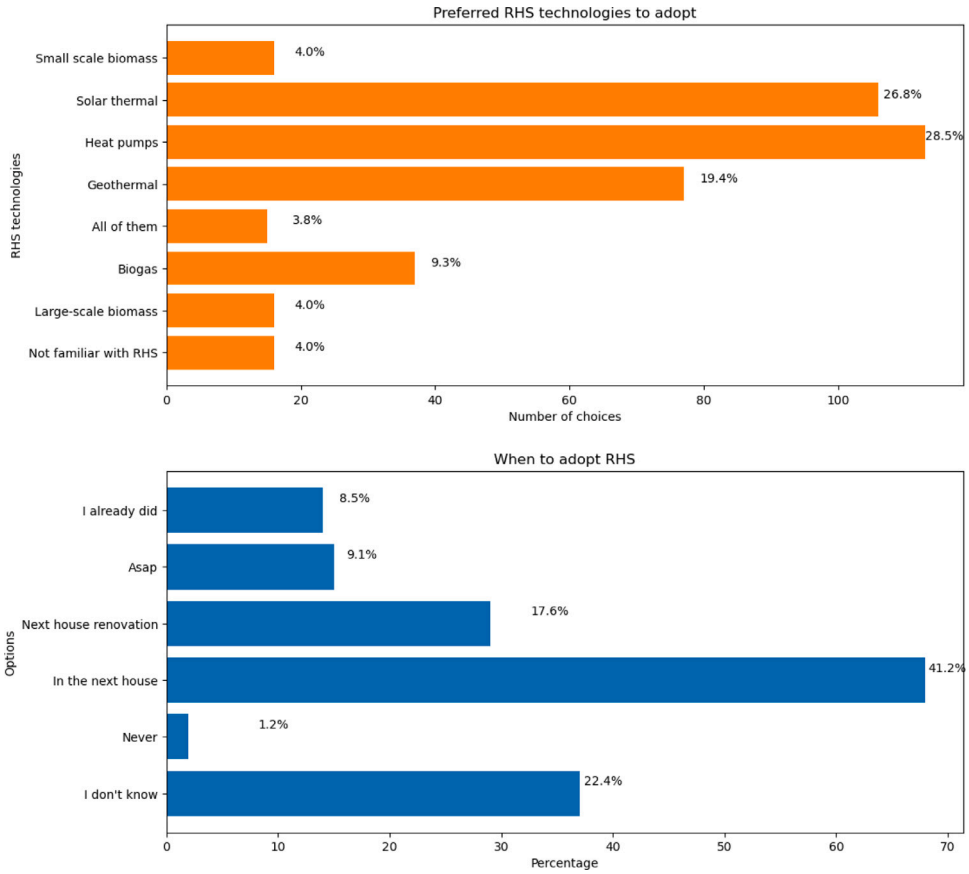

Fig. 3. The upper bar chart indicates the RHS technologies the respondents find desirable to adopt in their house, given in percentage. The lower bar chart indicates when they plan to adopt RHS in their house, given in percentage.

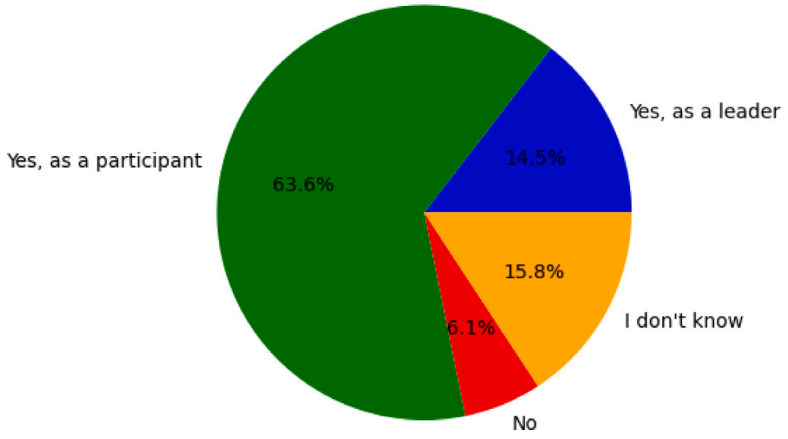

Fig. 4. Respondent's willingness to participate in a thermal energy community to adopt RHS.

behavior to be challenging to perform, and thus choose not to adopt RHS, despite their willingness and positive attitude.

Regarding RHS technologies, individuals find heat pumps and solar thermal to be most desirable. This can be attributed to the Dutch government's effort to stimulate solar energy by introducing new policies (Government of the Netherlands, 2023), which played a major role in the increase in the number of solar panels installed in the Netherlands in recent years (Centraal Bureau voor de Statistiek, 2023). Furthermore, it is also important to mention that the results show that individuals' perceptions of thermal energy communities are predominantly positive. Most individuals are willing to participate in a thermal energy community as a participant (63.6%) or as a leader (14.5%), stating reasons such as increasing community engagement and having a more affordable choice. Most individuals prefer participating in an energy community over adopting RHS individually. Note that the most preferred RHS technologies, heat pumps, solar thermal and geothermal, can all be implemented collectively in a community.

4.2. Suggestions for encouraging adoption of RHS

The results identified in the extended TPB, which includes attitude, perceived behavioral control, personal moral norms, and descriptive norms, enable a better understanding of the behavior of adopting RHS in the Netherlands. According to these results, the following interventions are recommended:

Attitude vs. Perceived control behavior: The results show that while individuals in the Netherlands primarily have a positive attitude towards adopting RHS, a large number believe that they are not capable of doing so, mainly stating financial reasons and not having enough time. This means that many individuals, particularly from low-income households, are unable to seize the benefits of renewable heating. This raises concerns about fairness and energy justice in the Dutch heating transition. Thus, policymakers in the Netherlands should address these groups in their decision-making process. For instance, financial subsidies for low-income households, special tariffs as done with solar panels (Chapman et al., 2016), and policies oriented towards social housing (McCabe et al., 2018) can be considered. Yet, designing concrete policies for this purpose requires more research, and thus beyond the scope of this paper. Moreover, to get better insights into justice issues in the Dutch heating transition, it can be interesting to analyze the actual adoption numbers of RHS technologies in different socioeconomic groups as future research.

Taking into account moral norms: The results show that environmental concerns and moral responsibilities towards the environment can have a positive impact on intention. This finding underscores the importance of moral considerations in shaping individuals' intention to adopt RHS. This implies that to enhance individuals' intention to adopt RHS, policymakers in the Netherlands could pay more attention to ways to place people under great moral obligation to the environment, such as developing communication strategies that appeal to individuals' intrinsic values, and that can facilitate a sense of collective responsibility for the environment. On the contrary, individuals in the Netherlands are affected to a small extent by what people around them think they should do regarding the decision on adopting RHS, and what people around them actually do.

The effect of other policies: The results show that individuals find heat pumps and solar thermal to be most desirable as RHS technologies. Since this can be explained by the Dutch policies to stimulate solar panels and solar energy generation, it is especially important for policymakers to be mindful of how other policies in the renewable energy field can impact the intention to adopt RHS.

Thermal energy communities: According to the results, many individuals find thermal energy communities favorable; they are positive about participating in a thermal energy community. This means thermal energy communities could be an effective way to get individuals to adopt RHS. As mentioned previously, there were 78 collective heating projects in the Netherlands in 2022, while 1093 collective solar panel projects were carried out (HIER, 2023). This indicates that few thermal energy communities have been formed, despite the interest from individuals according to the survey. Therefore, Dutch policymakers can consider prioritizing regulations on RHS on a community level over regulations on individual RHS, and thus can make the adoption of RHS more attractive. It is also possible to transform their solar panel-based energy community into a thermal energy community, by introducing RHS. It could be useful to introduce regulations that allow and encourage individuals to do so.

4.3. Limitations

This paper has several limitations that need to be highlighted. Firstly, the data in this study were collected only from the Netherlands, which may restrict how generalizable the results are. Although the Netherlands shares some common characteristics with other countries, particularly European countries, it also possesses distinct characteristics, such as different socio-economic status and many discussions around natural gas and heating due to the aforementioned reasons. Therefore, the findings may not be suitable for other countries. In future research, it is beneficial to collect and analyze data from other countries.

Another limitation concerns the survey's data sample, which is filled in by a total of 165 people from the Netherlands. Even though this sample shows characteristics of the Dutch population to a large extent, the number is not high enough to be representative of the entire Netherlands. For this reason, the correlation between the intention to adopt RHS and socio-demographic characteristics is not studied in this paper. With a larger sample size, it could be interesting to focus on which social groups are more likely to adopt RHS. Moreover, additional details, such as occupation and house ownership (tenant/house owner), could add more in-depth information about individuals' intentions to adopt RHS.

This paper opted for an online survey as the research method, which has certain technological requirements for participants: access to the internet through smartphones or computers. Such limitation could potentially bias the results, as certain social groups cannot access such technologies. However, an online survey is beneficial to reach a broader audience. For future research, interviews or workshops with focused groups can provide different perspectives regarding individuals' intentions to adopt RHS.

This study focuses on the adoption of RHS solely in the residential sector; other sectors, namely service and industrial sectors, are omitted. It is worth looking into the intention to adopt RHS in these sectors, and comparing it with the residential sector since businesses and industrial organizations might have different barriers and motivations.

This paper employs the theory of planned behavior in order to give insights on individuals' intention to adopt RHS in the Netherlands. However, applying other theories, such as Ostrom's Collective Action theory (Ostrom, 2014) and the behavioral reasoning theory (Westaby, 2005) could also be beneficial. The TPB is well-suited for understanding individual decision-making processes and intentions by considering individuals' attitudes, subjective norms, and perceived behavioral control. On the other hand, behavioral reasoning theory focuses on the cognitive processes underlying behavior, emphasizing the role of reasoning and goals. In this sense, behavioral reasoning theory could offer valuable perspectives and enrich the understanding of the intention to adopt RHS. Ostrom's Collective Action theory focuses on collective decision-making and the management of common pool resources by groups, which can be better suited particularly while studying thermal energy communities.

Lastly, although this paper is concerned with RHS, thermal energy storage is out of the scope of this paper, which is a device that can store thermal energy to tackle the mismatch between supply and demand Arteconi et al. (2012). Thus, the results do not include the intention to adopt thermal energy storage, which can be interesting to explore in a future study. Similarly, it could also be interesting to study how the intention to adopt thermal energy storage affects the intention to adopt RHS.

5. Conclusion and further research

This paper aims to get insights into the intention to adopt renewable heating systems (RHS) in the Netherlands. For this purpose, it designs and conducts a survey based on the extended version of the theory of planned behavior, with five components: attitude, subjective norms, perceived behavioral control, personal norms, and descriptive norms. The survey also includes questions on their preferences for RHS technologies and participation in a thermal energy community.

The results show that several factors affect individuals' intention to adopt RHS. Many individuals in the Netherlands have a positive attitude toward adopting RHS, which is primarily caused by environmental concerns and wanting energy independence for their country. However, the majority of individuals think that they do not have the knowledge, financial means, or time to adopt RHS. This suggests that these factors, especially time and financial means, are the biggest barriers to the adoption of RHS in the Netherlands. Also, individuals who feel strong moral values and moral responsibilities are more likely to intend to adopt RHS. Most individuals are willing to participate in a thermal energy community, and prefer participating in an energy community

Table A.4
Question 1 - Attitude, 1-5 Likert scale. 1 means 'Strongly disagree' and 5 means 'Strongly agree'.

I think adopting renewable heating systems in my house is important to protect the environment.
I think adopting renewable heating systems in my house is desirable to save money.
I think adopting renewable heating systems makes me more independent from the national grid.
I think adopting renewable heating systems in my house is important for my country to become energy-independent.

Table A.5
Question 2 - subjective norm, 1-5 Likert scale.

Most of my family and friends think that I should adopt renewable heating systems in my house.
Most of my neighbours think that I should adopt renewable heating systems in my house.
Most of my colleagues think I should adopt renewable heating systems at home.
If I adopt renewable heating systems, then most people who are important to me also adopt renewable heating systems.

Table A.6
Question 3 - Perceived behavioral control, 1-5 Likert scale.

I can find (already have) the needed knowledge and skills to adopt renewable heating systems in my house.
It is affordable to adopt renewable heating systems in my house.
I have sufficient time to adopt renewable heating systems in my house.
Whether or not it is completely up to me to adopt renewable heating systems in my house.

Table A.7
Question 4 - Personal moral and descriptive norms, 1-5 Likert scale.

I think I have a moral responsibility to adopt renewable heating systems in my house.
A number of my family members/ friends have adopted renewable heating systems in their households.
A number of my neighbours and fellow citizens have adopted renewable heating systems in their households.
A number of my colleagues have adopted renewable heating systems in their households.

Table A.8
Question 5 - Intention & Behavior, 1-5 Likert scale.

I am willing to adopt renewable heating systems in my house.
I will make an effort to adopt renewable heating systems in my house.

over adopting RHS individually. Based on these insights, a number of recommendations are made to stimulate the adoption of RHS in the Netherlands, such as taking into account moral norms, introducing policies to incentivize thermal energy communities, and addressing issues of injustice. Future research can include conducting interviews to get more in-depth information, understanding individuals' intention to adopt RHS in the service and industrial sectors, as well as opinions toward thermal energy storage.

CRediT authorship contribution statement

Özge Okur: Writing – original draft, Visualization, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Francesco Fiori:** Methodology, Investigation, Formal analysis. **Javanshir Fouladvand:** Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Survey questions

See Tables A.4–A.8

6. Which of the following renewable heating resources is more desirable for you to adopt for heating your home?
a. Biomass
b. Solar
c. Heat pumps
d. Geothermal
e. All of them
f. I am not familiar with renewable heating systems

7. When do you intend to adopt renewable heating systems?
a. I have already adopted renewable heating systems
b. As soon as possible
c. In the next renovation of my home
d. When I am buying a new house
e. Never
f. I do not know

8. Are you willing to adopt renewable heating systems with your neighbours in the form of an energy community?
a. Yes, as a leader
b. Yes, as a participant
c. No

9. I think participating in an energy community for heating purposes is increasing the engagement in my neighbourhood. 1-5 Likert scale
10. I think participating in an energy community for heating purposes is a more affordable choice than natural gas consumption. 1-5 Likert scale
11. I think participating in an energy community for heating purposes brings more security of supply than natural gas consumption. 1-5 Likert scale

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