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Willingness to pay for innovative heating/cooling systems: A comprehensive appraisal of drivers and barriers to adoption in Ireland and Italy

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A R T I C L E I N F O

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A B S T R A C T

This paper investigates drivers or hindrances to households' adoption of behavioural changes concerning energy efficiency at home. A Choice Experiment survey has been conducted to elicit households' preferences regarding adoption of innovative heating/cooling systems in Ireland and Italy. The choice data is analysed through a Latent Class model, and posterior analysis is used for class profiling, aimed to detect the emergence of factors identified in the literature. In both country samples respondents could be grouped in three classes according to their preferences and willingness to pay for adoption of innovative heat pump systems. Early adopters, younger and with higher education, exhibit strong pro-innovation attitudes. Conversely, Laggards, typically older and less educated, display hesitancy, and may require substantial subsidies for adoption. Late adopters value trialability and rely less on social networks. Information processing varies according to individual capabilities and social contexts. Hence, we recommend targeted information to enhance awareness of benefits and on feasibility of installation in different types of dwelling. Technical information and support, possibly complemented by demonstration activities, is suggested to foster innovation, especially among less advantaged households.

1. Introduction

The European Union has set compelling targets of reduction of carbon footprint in the residential sector, both in new constructions and in refurbishments, that demand fast phasing out fossil fuels in heating and cooling systems. Nowadays, buildings still account for 36% of CO2 emissions and 40% of energy consumed in European Union, and heating, cooling and domestic hot water account for 80% of the energy that households consume [1]. The 2050 long-term strategy for a carbon neutral economy, subsumed in the European Climate Law in June 2021, requires that European member states implement specific policies addressed to upgrade existing buildings stocks towards Near Zero Emissions levels, while at the same time ensuring proper levels of indoor air quality (IAQ), comfort and health conditions. A viable solution to reach the standards set by the Near Zero Building Directive (2021) is offered by the diffusion of heat pump technologies. In particular, hydronic thermal systems with heat pumps and thermal storage for space heating, cooling, and for production of domestic hot water, would represent a cost-effective and efficient technological option [2,3]. Yet, according to IEA (2021) [2], *"Heat pumps still meet only around 10% of the global heating need in buildings, below the deployment level required to get on track with the Net Zero Emissions by 2050"*, even though these are mature technologies. Policy actions aimed at reducing the financial burden of the investment (feed-in-tariffs, loans, tax allowances), and increasing awareness of the benefits seem not sufficient to achieve substantial adoption of this technology, as sales have remained modest in many countries [4]. As observed by Frederiks et al. (2015) [5], *"even where energy-saving measures are demonstrably cost-effective [...] many people remain reluctant to introduce these things into their lives and homes"*. This evidence raises doubts on the efficacy of dissemination programs

Abbreviations: CE, Choice Experiment; DOI, Diffusion of Innovation; HP, Heat pumps; LC, Latent Class; MNL, Multinomial Logit; PV, Photovoltaics; RUM, Random Utility Model; TPB, Theory of Planned Behaviour; VBN, Value-Belief-Norm; WTP, Willingness To Pay.

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aimed at the general public, and calls for a segmented communication approach, with specific channels and appropriate contents aimed at different audiences. Thus, it is important to get a better grasp of the decision process behind the choice, to provide sound guidance on policy measures and information campaigns that leverage on further elements than just economic and environmental considerations.

Models such as Rogers' Diffusion of Innovation (DOI) [6], or Ajzen's Theory of Planned Behaviour (TPB) [7] are examples of rational choice theories (cf. [8,9]), which depart from the assumption of standard economic models according to which choices derive from objective costs-benefits evaluations. According to these theories, behaviour is the result of a reasoned process where the evaluation of advantages and disadvantages is influenced by attitudes, beliefs and constraints which affect the final outcome (behaviour or intended behaviour): applications of the TPB model in the context of domestic green technologies can be found for example in Wall et al. (2021) [10], Korcaj et al. (2015) [11], Kim et al. (2014) [12]. The DOI model has been employed in stated preference surveys regarding households' adoption of PV [13] and heating systems [14]. Other theories have weaker links with the rational choice model: for example, the Value-Belief-Norm model by Stern (2000) [15] assumes that behaviour is mainly guided by personal values, norms, attitudes, and awareness of consequences on the objects that are valued, which lead to a behavioural change. This model has been quite extensively used to explain environmentally relevant behaviour and has received attention also in the context of adoption of green technologies. Fornara et al. (2016) [16] apply the VBN model to explain the decision to install energy efficient technologies, while Wolske et al. (2017) [9] integrate the VBN model with DOI and TPB to explain interest in domestic PV systems.

Survey methods have been extensively employed to analyse the determinants of environmentally friendly behaviour. A comprehensive survey of the literature regarding acceptance of photovoltaic panels and heat pumps can be found in Peñaloza et al. (2022) [17]. An important distinction needs to be made between socio-psychological studies focused on the attitudinal antecedents of the environmentally relevant behaviour, and economics studies aimed at eliciting the consumers' demand function, while accounting for psychological factors which influence the intention to adopt a new heating/cooling technology. Stated preference techniques are useful instruments to estimate potential market demand for goods which are not in the market yet, besides environmental or other non-market goods [18]. In particular, the Choice Experiment approach allows elicitation of trade-offs between different attributes of heating/cooling technologies and estimation of willingness to pay (WTP) for changes in specific characteristics of the product. In addition, the Choice Experiment method is deemed more robust than other stated preference methods, e.g. Contingent Valuation, to strategic behaviour by respondents [19], although not completely immune to incentive compatibility issues [20].

A problem in stated preference studies, and particularly those regarding pro-environmental behaviour, is that inclusion of socioeconomic covariates in the econometric model is often of little help in explaining heterogeneity in preferences, whereas socio-psychological factors seem to have a better explanatory power [21]. Sutterlin et al. (2011) [22] note that socio-demographic factors have limited explanatory power when it comes to understanding variations in pro-environmental behaviour, finding that these factors were less effective in predicting energy-saving behaviour compared to attitudinal and behavioural variables.

Socio-psychological factors can be accounted for in CE analysis through implementation of hybrid choice models [23]. Unfortunately, integration of latent variables in the statistical model requires setting-up a very complex structure, and estimation of interaction effects with large numbers of covariates, both observed and latent, is often practically unfeasible. If the analysis is aimed at profiling respondents in order to inform market or policy strategies, a viable option, suggested by Train (2009) [24] and implemented by Richter and Pollitt (2018) [25], is the adoption of a two-steps approach: a discrete choice model is first estimated, allowing for unexplained heterogeneity of preferences across individuals; subsequently, the posterior estimates of individual parameters obtained from the choice model are analysed testing for statistically significant differences in group means, to create profiles of respondents characterised by different socioeconomic and attitudinal traits. This paper will use this approach for households' profiling regarding preferences on heating/cooling systems, allowing to answer the following main research question: what are the primary socio-psychological and demographic factors influencing households' preferences and willingness to adopt innovative heating/cooling systems?

This work is part of a more comprehensive research on *User Community Engagement* within the IDEAS[1] project financed by EU Horizon 2020. Select results are presented from a survey on homeowners' willingness to adopt and pay for innovative heat pump technologies, such as the IDEAS system, in two countries characterised by different climate conditions: Italy and Ireland. A Choice Experiment has been designed, with different options including technological characteristics of the heating/cooling system (hydronic heat pumps, possibly combined with a gas boiler or with photovoltaic panels), along with financial elements, such as the upfront cost of the system, payback time of the investment, savings, and non-financial features, such as improvements in indoor air quality and comfort, and reduction of emissions generated by the system. The modelling approach taken in this paper is based on a Latent Class framework which will be used to define groups of individuals with homogeneous tastes regarding the characteristics of the heating/cooling systems proposed. Information is gathered on a wide range of socio-psychological and socioeconomic traits of respondents, and structural characteristics of their dwelling, which allows profiling of individuals in postestimation analysis.

The remainder of the paper is as follows: section 2 presents a review of studies dealing with households' preferences for eco-friendly heating/cooling systems, possibly associated with renewable energy technologies; next, section 3 provides details about the case study, the survey and the questions used, as well as the design of the choice experiment; section 4 reports on the methodology employed to jointly model choice experiment data and psychometric scales; section 5 presents the results, and finally, section 6 concludes the paper.

2. Residential heating systems: overview of literature

The theoretical models commonly employed to explain the decision to make a relevant behavioural change at home, such as adoption of innovative heating systems, assume that the decision process depends on technical factors and some combination of socio-psychological, socioeconomic, and contextual factors. This section provides a review of empirical analyses of behavioural change, focusing on the adoption of environment friendly heating/cooling technologies, and other energy efficient behaviour. The studies reviewed often contained a discrete choice experiment embedded in the surveys administered.

The decision to invest in a new heating/cooling system depends on economic considerations, with investment costs often highlighted as a key factor [14,17,26–33]. Up-front costs, installation and maintenance costs differ across technologies, and may be seen as a barrier to innovation for specific types of systems. For example, high installation costs were found to be one of the main barriers to the adoption of ground source heat pumps [34,35], as well as of photovoltaic systems [36].

[1] **IDEAS** project – Novel building Integration Designs for increased Efficiencies in Advanced Climatically Tunable Renewable Energy Systems, EU Horizon 2020, https://horizon2020ideas.eu. The project aimed at creating an innovative building integrated renewable energy system: the IDEAS system is an electrically driven multi-source heat pump system powered by electricity from PV/thermal panels.

Expected energy cost savings have been observed as having an impact on the likelihood to undertake energy retrofit activities [37–39], on adoption rates of new home heating systems [26,40], photovoltaic solar panels [13,41] and solar thermal energy systems [27]. Another indicator of the economic advantage of an investment is the payback period: a long payback period appears as the most important barrier to the use of solar systems [42,43] and other energy systems as well [37,39, 41].

Benefits related to technical aspects of heating/cooling systems also regard non-economic aspects. Indoor air quality and/or thermal comfort are typically accounted for when evaluating an investment in a new heating system. Air quality was found to be a major factor [31,44,45]. However, whilst in Lillemo et al. (2013) [44] respondents who especially cared about indoor air quality and improvements in health were more likely to choose heat pumps, the opposite was found by Sopha et al. (2010) [46] for air-to-air heat pumps. Increased thermal comfort has a significant effect in investment decisions [38,47].

Environmental benefits associated with specific technologies are also deemed to have an impact on the choice of heating systems [48], albeit to a lesser extent when compared to investment costs and saving potentials [27,31]. Significantly higher willingness to pay is found for higher environmental sustainability [26]. Moreover, environmental friendliness appears to be an important factor for choosing ground heating and district heating over other systems [28]. With specific reference to heat pumps, these were identified as the best in relation to environmental benignity and low GHG emissions [31]. Furthermore, CO_2 savings significantly influence the choice of heating systems [17,37, 49].

Individuals' values may influence several pro-environmental beliefs and preferences [50,51]. For instance, there is evidence of a positive relationship between pro-environmental values and actions to reduce energy consumptions [52]. Egoistic values likely trigger negative attitudes toward environmental protection and emphasise inconvenience issues associated with the purchase of energy efficient appliances; the converse happens for Biospheric and altruistic values [53]. On the other hand, egoistic values may activate the perception of economic benefits: for example, Wolske et al. (2017) [9] found that interest in buying a PV system is influenced directly by self-interest and indirectly by altruism [9].

Advantages and disadvantages of specific characteristics of a technology may be conditioned by subjective psychological factors too, as hypothesised by the TPB [7]. Individuals' attitudes differ: people who consider important to reduce energy use at home, value to a greater extent energy efficiency improvements [54]; those who consider independence from fossil fuels as an important factor, will be more favourable to renewable energy plants [55]; those who consider important to reduce energy consumption to protect the environment will be more willing to engage in energy saving behaviour [39,42,56].

The TPB [7] postulates that attitudes are activated by social norms, which define the behaviour that a social reference group views as appropriate in a specific context. The effect of social norms has been seen in energy savings choices [57–62] and adoption of energy efficient technologies [16,63]. It has been found that social norms activate a sense of moral obligation to perform an energy efficient behaviour (or at least declare the intention). Moreover, according to the VBN theory, another critical factor is the belief regarding the consequences of performing that behaviour: for example, if people are aware of the consequences of the impact of their consumption habits on climate change, the local environment, health etc., they will feel more obliged to change their behaviour. Indeed, research has consistently found a positive and significant indirect effect of awareness of consequences on behaviour, through moral (personal) norms, and attitudes [9,16,57,62].

Individuals' attitudes toward innovations, as proposed by the DOI theory, were also found to have an influence on households' choices regarding energy and heating systems. For example, in Wolske et al. (2017) [9] *the novelty seeking* attitude is associated with higher interest in residential photovoltaics; similarly, Franceschinis et al. (2017) [14] found that individuals with higher propensity to innovate (early adopters) seemed to have stronger preferences towards innovative biomass-based heating systems. The choice of a specific technology may also be guided by beliefs regarding technical complexity [14,28,56]. Additional beliefs regarding technical aspects involve feasibility considerations; for example, space constraints could impede the installation of solar panels [9] or ground source heat pumps [34]. Individuals less prone to innovations and those who depend on others to inform their purchasing decisions, on the other hand, can have a greater need for trialability, i.e., they would try the technology before the potential adoption [14]. As put forth by Wolske et al. (2017) [9] *"individuals who depend on others to inform their purchasing decisions have a greater need to "try out"* [residential photovoltaic, author's note] *and learn about it from current adopters"*. However, in some situations there are no precedents to follow: either when the innovation is at its initial stage, so that early adopters need a personal trial; or when individuals do not have social connections with peers that, in the words of Rogers ([6], p. 244), can *"act as a kind of vicarious trial"* for them. In fact, the presence of trustworthy information channels is another relevant factor in the DOI theory. Installers and personal relations often emerge as the most valuable vehicles for information and communication. Mahapatra & Gustavsson (2008) [32], for example, underline their importance with reference to innovative residential heating systems in Sweden; in Fornara et al. (2016) [16], trust in friends/relatives and neighbours emerged as one of the most powerful predictors of the intention to use renewable energy devices, while also mediating the effects of both injunctive and descriptive norms on it. With regards to residential solar photovoltaics, Rai et al. (2016) [64] highlight the role played by installers and neighbours in influencing both the decision to adopt and the mode of adoption (buy versus third-party ownership); similarly, Wolske et al. (2017) [9] found that the perceived pros and cons of going solar were influenced by trust in the PV industry (which increased relative advantage, while reducing need for trialability and perceived riskiness) and in one's social network but not by exposure to PV marketing.

Whilst being generally poor direct predictors of energy choices, sociodemographic variables may influence behavioural traits. Age appears to be consistently associated with energy efficient decisions: younger people are generally more interested in installing a new technology or in adopting an energy saving behaviour [13,19,28,36,37,39, 41,55,65,66]. When the energy efficient behaviour involves costly investments, budget constraints are found to significantly influence the choice: this has been seen in decisions regarding installation of heat pumps [26,44,55,66], ground heating [28,29], photovoltaic systems [36] and decisions related to energy retrofit measures [39]. Possibly correlated with income is education, and in fact higher education levels are found to be associated with greater interest in heat pump technologies and adoption of energy efficient behaviour [26,28,36,37,41,67]. Household size has been found in some studies to have a positive effect on the choice of energy saving technologies [44], possibly because the larger the household the higher the levels of consumption; however, in other studies the effect is not significant [66]. There might be an effect of larger size on household's expenditures, and hence on investment capability of the household, so the effect may be undetermined. The type and location of dwellings can also be significant due to possible space, regulatory, or infrastructural constraints [68]. Living in detached dwellings favours adoption of new heating systems [44,55], especially if associated with renewable energy [41] or more cumbersome technologies such as the combined ground source heat pumps, solar thermal panels and thermal energy storage [67].

A notable research gap emerging from this review is the need for a more nuanced understanding of how individual characteristics and contextual factors interact to influence the adoption of energy-efficient heating and cooling systems. While existing theoretical models, such as the Diffusion of Innovation (DOI), Theory of Planned Behaviour (TPB), and Value-Belief-Norm (VBN), highlight the role of psychological factors, the empirical evidence suggests that socioeconomic, demographic, and dwelling characteristics alone often fail to explain adoption decisions adequately. Therefore, this study aims to better understand the multi-dimensional factors influencing the adoption of energy-efficient heating and cooling systems and to aid the development of more effective, tailored policy interventions.

3. Survey

3.1. Case studies

The two countries selected as case studies for this analysis, Ireland and Italy, are characterised by different climatic conditions. This leads to different energy requirements for heating and cooling in households. Trends and forecasts of Heating Degree Days (HDD) and Cooling Degree Days (CDD) from 1981 to 2100 indicate a significant decrease in HDD in all European countries, including Northern Europe and Scandinavian countries, and a major increase in CDD, especially in the Mediterranean countries and with relevant effects also in the Central and Northern countries, but not in Ireland [69]. In Italy, heating needs are mainly covered by natural gas (59.9%), with renewables (28.9%) ranking second; oil and petroleum products account for 6.9%, derived heat for 3.8% and electricity for just 0.4%. Ireland mostly relies on oil and petroleum products (54.8%) for space heating, followed by natural gas (21.9%); solid fuels still account for 17.2% of heating energy needs, electricity for 3.7% and renewables only for 2.3%.

The survey was distributed in May 2021 to households in Ireland and Italy. The *Qualtrics XM* platform was used for compilation of the questionnaire and collection of the data. A market research company managed the administration of the survey to paid subscribers of panels. The initial sampling plan comprised 3000 respondents, 1500 in each country, selected from homeowners aged from 18 to 75. Quota sampling was used for gender, age, and geographical area (3 per country), to match census distribution in each macro-area. After data cleansing, a total of 2716 observations are used in this study, 1299 for the Irish sample and 1417 for the Italian sample. Sample statistics are reported in Tables A1, A2 and A3 in Appendix.

In order to account for different climatic and economic conditions, three territorial areas have been considered in the sampling plan for each Country. In both cases the division was based on the *Nomenclature of Territorial Units for Statistics* (NUTS): more specifically, NUTS level 2 for Ireland, and NUTS level 1 for Italy.

As regards Ireland, NUTS 2 refers to the following 3 subdivisions (in parentheses the Local Government areas they include):

- *Northern and Western* (Cavan, Donegal, Leitrim, Monaghan, Sligo; Mayo, Roscommon, Galway and Galway City)
- *Eastern and Midland* (Dublin City, Dún Laoghaire–Rathdown, Fingal and South Dublin; Kildare, Meath, Wicklow, Louth; Laois, Longford, Offaly, Westmeath)
- *Southern* (Clare, Tipperary, Limerick City & County; Carlow, Kilkenny, Wexford, Waterford City & County; Kerry, Cork and Cork City)

With regards to Italy, NUTS 1 actually refers to 5 geographical areas, which, according to standard criteria for national statistics, in this study are grouped into 3 areas, relatively homogeneous in terms of socioeconomic and climatic characteristics. The three areas are the following:

- *Northern*, which includes Northwest (Valle d'Aosta, Piemonte, Lombardia, Liguria) and Northeast (Trentino Alto Adige, Friuli-Venezia Giulia, Veneto, Emilia-Romagna)
- *Central* (Toscana, Marche, Umbria, Lazio)
- *South and Insular*, which includes South (Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria) and Insular (Sicilia, Sardegna)

In both countries the sample distribution in the macro-areas is reasonably close to the geographical distribution of the population. With regards to gender, while the Italian sample is representative of the population (50% males, 50% females), in Ireland women are over-represented (56% in the sample, 50.6% in the population). This is particularly evident in Northern & Western Ireland, where men represent only 37.7% of the subsample. A similar situation can be seen with regards to age: while for the Italian sample the distribution resembles quite closely that of the corresponding population, in the Irish sample the 30–44 years old individuals are over-represented (36.8% vs 31.6%) at the expense of 65–75 age group (9.1% vs 12.7%). Education levels are grouped into 3 macro-categories.[2] Overall, Irish respondents are more educated than Italians: 57.4% achieved a high level of education (Bachelor's or higher), against 36% of Italians, while 56% of Italian respondents are in the intermediate level vs 38.7% of the Irish sample.

3.2. The questionnaire

The survey instrument consisted of 5 sections: the first section explored respondents' attitudes and beliefs with measures based on the VBN theory; the second section concerned dwelling characteristics and heating/cooling systems; the successive section presented the IDEAS system, and included questions – mainly based on the TPB and the DOI theory - aimed at understanding respondents' opinions about it; the fourth section contained the Choice Experiment study; finally, the fifth section contained socio-demographic information.

In the scales used to measure the latent variables, for each item respondents had to express their agreement (or disagreement) on a 5-point Likert scale from 1 (*Strongly disagree*) to 5 (*Strongly agree*). Biospheric and Egoistic Values were rated on a 5-point scale from 1 = Not at all important to 5 = Very important.

3.3. Choice experiments design

The Choice Experiment, designed using NGENE™ software and based on a MNL-d efficient design, consisted in 36 choice cards, divided in 4 blocks. Each respondent faced 9 choice cards, always presented in randomised order. Each choice card included 3 alternatives: "System A"

Table 1
Attributes and levels.

Attributes	Levels		
Technology	Heat Pumps + Gas	Heat Pumps	Heat Pumps + Photovoltaics
Investment Cost	€ 2500	€ 4500	€ 8500
	€ 4500	€ 6500	€ 11,500
	€ 6500	€ 8500	€ 14,500
Payback Period	3 years	5 years	7 years
	5 years	7 years	9 years
	7 years	9 years	11 years
Reduction of CO2 and PM emissions	30%	50%	70%
	40%	60%	80%
	50%	70%	90%
Comfort and Indoor Air Quality	Good	Good	Good
	Very good	Very good	Very good
	Excellent	Excellent	Excellent
Savings on Energy Bill	20%	40%	60%
	30%	50%	75%
	40%	60%	90%

[2] The 3 categories, based on the 2011 version of the International Standard Classification of Education (ISCED 2011), are defined as follows: "*Primary*": Not completed primary education, Primary, Lower secondary; "*Secondary*": Upper secondary, Post-secondary non tertiary, Short-cycle tertiary; "*Tertiary*": Bachelor's or equivalent, Master's or equivalent, Doctoral or equivalent.

Table 2
Latent Class Model: estimates of utility parameters and WTP.

	IRELAND			ITALY		
	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
	Coeff. (St. Err.)	Coeff. (St. Err.)	Coeff. (St. Err.)	Coeff. (St. Err.)	Coeff. (St. Err.)	Coeff. (St. Err.)
Investment Cost	−0.201***	−0.363***	−0.123***	−0.088***	−0.241***	−0.333***
	(0.017)	(0.035)	(0.024)	(0.014)	(0.047)	(0.026)
Payback	−0.025	−0.140***	−0.206***	−0.136***	−0.103*	−0.022
	(0.017)	(0.036)	(0.029)	(0.015)	(0.060)	(0.022)
Indoor	0.213***	−0.017	0.264***	0.180***	0.073	0.289***
	(0.031)	(0.071)	(0.048)	(0.027)	(0.109)	(0.044)
Savings	0.783**	0.750	3.350***	1.838***	3.136**	0.760
	(0.329)	(0.809)	(0.489)	(0.266)	(1.271)	(0.471)
Emissions	0.709**	−0.060	2.335***	0.605**	1.948*	0.028
	(0.302)	(0.617)	(0.531)	(0.265)	(1.027)	(0.406)
HP + GAS	1.927***	0.369	−0.677	1.207***	−3.603***	1.866***
	(0.290)	(0.584)	(0.465)	(0.239)	(0.929)	(0.378)
HP	2.027***	0.687	0.256	1.796***	−3.834***	1.933***
	(0.393)	(0.839)	(0.639)	(0.330)	(1.317)	(0.526)
HP + PV	1.994***	1.674	0.814	2.419***	−3.599***	1.924***
	(0.526)	(1.155)	(0.812)	(0.434)	(1.807)	(0.710)
	WTP (St. Err.)	WTP (St. Err.)	WTP (St. Err.)	WTP (St. Err.)	WTP (St. Err.)	WTP (St. Err.)
Payback	−127	−387***	−1673***	−1549***	−430	−65
	(98)	(96)	(337)	(262)	(347)	(70)
Indoor	1063***	−47	2144***	2054***	305	867***
	(188)	(240)	(667)	(406)	(439)	(153)
Savings	392***	204	2717***	2097***	1302***	228*
	(167)	(203)	(676)	(426)	(441)	(135)
Emissions	353***	−14	1894***	690***	809**	9
	(156)	(186)	(702)	(294)	(421)	(113)
HP + GAS	9598***	1014	−5500	13,767***	−14,968***	5602***
	(1693)	(1701)	(5199)	(3398)	(4527)	(1173)
HP	10,093***	1888	2074	20,477***	−15,919***	5805***
	(2021)	(2308)	(6234)	(4557)	(5328)	(1548)
HP + PV	9931***	4609	6594	27,588***	−14,936***	5776***
	(2572)	(2981)	(7468)	(5815)	(6706)	(2028)
Average Class Probabilities	42%	26%	32%	52%	21%	27%
Number of ind.	1299			1417		
Number of obs.	11,691			12,753		
Number of param.	26			26		
Log likelihood	−9845.21			−10,586.06		
McFadden Pseudo R^2	0.233			0.244		
AIC	19,742.4			21,224.1		
BIC	19,934.0			21,417.9		

Level of significance: 1% ***, 5% **, 10% *. WTP expressed in Euro (€).

and "System B" represented different models of hypothetical heating systems, whereas the "Current Situation" meant choosing no investments.

The selection of the attributes was based on previous literature and on results of a qualitative phase of this research, which entailed a series of in-depth interviews with Irish and Italian stakeholders dealing with energy efficiency in the building sector, and two focus groups with technicians and potential end users.

The first attribute is the type of heating/cooling technology to be installed. Three systems based on the use of heat pumps were identified, possibly combined with latest generation gas boiler (methane or LPG) in the system labelled "*Heat Pumps + Gas*", or with a photovoltaic system in the "*Heat Pumps + Photovoltaics*" option, or heath pumps only (system labelled "*Heat Pumps*"). All systems were proposed as a package including *air-to-water heat pumps* or, if allowed by space and local conditions, *ground source-to-water* heat pumps; the most suitable terminals for the respondent's dwelling (radiators, radiant heating panels or fan coil units); thermal storage; and a climate control system.

The proposed options included three economic factors: the total investment cost (to be considered net of any financial support from the government, to offset the effect of different subsidising policies across countries); the expected savings on energy bill, determined by use of renewable sources and/or by higher efficiency of the system; and the payback period, i.e., the time needed to recover the initial investment. The environmental advantage of innovation was defined in terms of reduction in the amount of pollutant emissions produced by the heating system, such as CO_2 and particulate matter (PM) released in the surrounding environment. Finally, the impact of heating systems on indoor air quality was included to take into account health advantages possibly associated with the investment decision. The effect was described both in terms of thermal comfort (defined as a feeling of well-being, i.e., the state in which people do not feel hot or cold) and of quality of the air inside the house, potentially influenced by factors such as moisture, mould, dust, and allergens. Such impact was defined as "*Good*", "*Very good*" or "*Excellent*", implying different combinations of levels of thermal comfort (respectively "almost always satisfactory", "always satisfactory", "always optimal") and controlling the spreading of mould and allergens (respectively "fair", "good" and "perfect" control).

An example of choice card is reported in Fig. 1 below.

The CE exercise was introduced with the aid of an information sheet which included a brief description of the 6 elements considered in the choice cards: technology used, investment cost, payback period, environmental impact (reduction of CO_2 and PM emissions), impact on comfort and indoor air quality, potential savings on energy bills. Respondents were asked to make realistic choices, keeping in mind their own budget constraint, their energy bills (they were previously asked to

Table 3
Classes' structural composition and associated characteristics.

			IRELAND			ITALY		
			Class 1 Early adopters (N = 549)	Class 2 Laggards (N = 340)	Class 3 Late adopters (N = 410)	Class 1 Early adopters (N = 745)	Class 2 Laggards (N = 300)	Class 3 Late adopters (N = 372)
SOCIO-DEMOGRAPHIC CHARACTERISTICS	Geographical area	North_West (IE)/ Northern (IT)	–	+	=	=	=	=
		East_Midland (IE)/ Central (IT)	+	=	=	–	+	=
	Age	18–29	+	–	+	+	–	=
		30–44	+	–	=	=	–	=
		45–64	–	+	=	–	+	=
		65–75	–	+	–	–	+	=
	Education	Primary	=	+	=	=	=	=
		Secondary	–	+	=	–	+	=
		Tertiary	+	–	=	+	–	=
	Income	Under 25,000 €	=	+	–	–	=	=
		25,001–50,000 €	=	=	=	=	–	=
		Over 50,001 €	+	–	+	=	=	=
DWELLING	Location	Urban centre	+	=	–	=	=	=
	Home Type	Detached	=	=	=	+	=	=
		Flat	=	=	=	–	=	=
	Construction Period	Before 1970	–	+	=	=	=	=
		After 2000	+	–	=	=	=	=
	Available spaces	Garden	=	=	=	+	=	=
		Terrace	+	–	=	=	=	=
		Balcony	+	–	=	=	=	=
HEATING & COOLING		Use of Cooling Systems	+	–	=	+	–	=
		PV	+	–	=	=	=	=
		Satisfaction with current HS	=	+	–	=	+	=
		Evaluated Replacement HS	+	–	+	+	–	=
		IAQ Problems	+	–	=	+	–	=
	Power Source	Gas boiler (natural gas/LPG)	=	=	–	=	=	=
		Oil boiler	–	=	=	=	=	–
VALUES & BELIEFS		Biospheric Values	=	–	+	+	–	=
		Egoistic Values	+	–	=	+	–	=
		Ecological Worldview	=	–	+	=	–	=
		Awareness of Consequences	=	–	+	+	–	=
		Ascription of Responsibility	+	–	+	+	–	=
		Personal Norms	+	–	+	+	–	–
		Social Norms	+	–	+	+	–	–
		Personal Benefits	+	–	+	+	–	=
		Health Concern	+	–	=	+	–	=
		Environmental Benefits	+	–	+	+	–	=
		Feasibility	+	–	+	+	–	–
		Trialability	=	–	+	+	–	+
		Cons. Novelty Seeking	+	–	+	+	–	=
		Cons. Judgement Making	+	–	=	+	–	=
		Trust Info Mass Media	+	–	=	+	–	=
		Trust Info Installers	+	–	=	+	–	=
		Trust Info Relatives	+	–	=	+	–	–
		Intention	+	–	+	+	–	=

Signs refer to class mean values significantly higher (+), lower (–) or not significantly different (=) with respect to mean values of the rest of the sample (p-values ≤0.05).

report the amount of yearly electricity and heating bills), and the characteristics of their dwelling (e.g., structure, spaces, location). The attributes and levels of the choice experiments are summarised in Table 1 below.

4. Econometric model and WTP

Based on the Random Utility Model (RUM) [70], the utility that the decision maker n derives from alternative i in the choice situation t is defined as:

$$U_{int} = V_{int} + \varepsilon_{int} = \beta' x_{int} + \varepsilon_{int} \tag{1}$$

where x_{int} is the matrix of the attributes, and β is the vector of coefficients to be estimated, representing the marginal utility associated with each attribute.

Assuming the error terms ε_{int} to be independently and identically

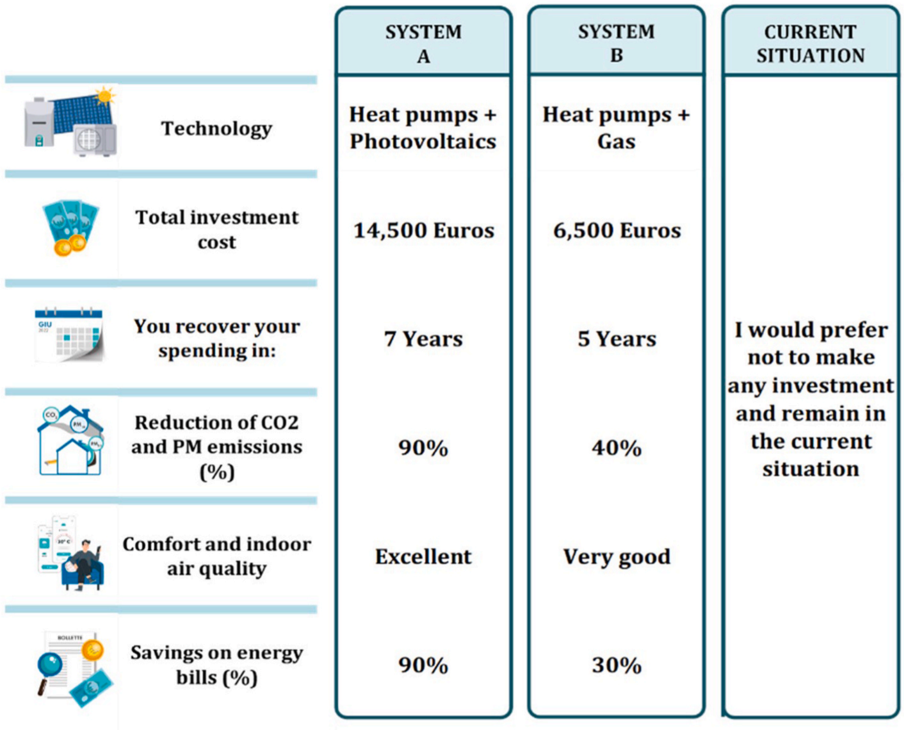

Fig. 1. Example of choice task.

distributed (IID) as a Type I GEV (or Gumbel) distribution, a MNL model is derived, where the probability that individual n chooses y_i in the choice situation t is given by:

$$\mathrm{Prob}(y_{int}|x_{nt}) = P_{nt} = \frac{\exp\left(\beta' x_{int}\right)}{\sum_{j=1}^{J} \exp\left(\beta' x_{jnt}\right)} \tag{2}$$

The probability of a sequence of choices is obtained as the product of the probabilities in equation (2):

$$P_n = \prod_{t=1}^{T} P_{nt} = \prod_{t=1}^{T} \frac{\exp\left(\beta' x_{int}\right)}{\sum_{j=1}^{J} \exp\left(\beta' x_{jnt}\right)} \tag{3}$$

In this paper individual heterogeneity of preferences is modelled using a Latent Class (LC) framework [71]. According to this model, individual taste parameters are allowed to vary in a discrete number of classes. In each class, individuals are assumed to have the same preference for attributes levels, but heterogeneity is allowed across classes. The class membership probability is a latent variable depending on the probability of observing a given choice, conditional on the utility of the alternatives faced by the respondent. The probability of a sequence of choices conditional on class c membership is

$$P_{n|c} = \prod_{t=1}^{T} \frac{\exp\left(\beta_c' x_{int}\right)}{\sum_{j=1}^{J} \exp\left(\beta_c' x_{jnt}\right)} \tag{4}$$

Class membership conditional on individual choices will be used in this paper in post-estimation analysis for class profiling in terms of socio-economic, psychological and contextual characteristics.

In this paper the class membership is modelled as a logit:

$$\mathrm{Prob}(c) = q_{n,c} = \frac{\exp\left(\delta_0\right)}{\sum_{c=1}^{C} \exp\left(\delta_0\right)} \tag{5}$$

Hence, the unconditional probability of a choice is

$$Prob(y_{int}|x_n) = P_{n,c} = \sum_{c=1}^{C} q_{n,c} \times P_{n|c} \tag{6}$$

i.e. the expectation of the probability of the sequence of choices over the probability distribution of the class membership.

This model allows to estimate WTP for each attribute for each class, as opposed to one WTP per attribute provided by the MNL that assumes homogeneity in preferences. For each class, the WTP for a given non-monetary attribute (out of the k attributes) is computed as the ratio between the coefficient associated with the non-monetary attribute (β_k) over the coefficient associated with the monetary attribute (β_m):

$$WTP_{k|c} = -\frac{\beta_{k|c}}{\beta_{m|c}} \tag{7}$$

The Latent Class model produces a segmentation of respondents based on preferences and observed behaviour in the CE exercise. As in Richter and Pollitt [25], a post-estimation analysis can be conducted to gather information useful for class profiling: socioeconomic, socio-psychological, and contextual characteristics of individuals in each class are compared with those of individuals in other classes, and mean differences are tested across classes. This exploratory approach is a starting point for more complex statistical analyses aimed at uncovering the decision process behind a given pattern of choices, where correlations between variables, either observed or latent, are accounted for in the model specification.[3]

[3] Multivariate hybrid models combining structural equations and discrete choice models are presented in companion papers [74], but their estimation is outside the scope of this work.

5. Model estimation and results

5.1. Latent Class model

A preliminary analysis of the choice data was carried out through a basic Multinomial Logit (MNL) model. The utility coefficients obtained from the MNL model have then been used as starting values for the parameters to be estimated through the Latent Class (LC) models.

The three classes specification was chosen following a comparison of goodness of fit indicators as well as assessing the interpretability of the classes [72]. For both samples, the 3-classes estimator showed a marked improvement over a MNL specification, and a substantial better fit than the 2-classes specification, whilst revealing important differences between classes. When moving to a 4-classes model, a marginal increase in fit is gained at the cost of a less clear interpretation of the classes. Given the research aims of this paper, the three-class model was selected for the analysis. Table 2 presents the estimated coefficients, in the upper panel, as well as the resulting WTP, in the lower panel of the Table.

Starting from the Irish case, it can be observed that Class 1, which accounts for 42% of respondents, is composed of individuals who value all attributes but the payback period. What especially characterises the individuals in this class is their interest in innovating the current heating system: for all three technological options the preference parameters are significantly different from the status quo reference. Yet, these individuals do not display a particular interest for more environment-friendly alternatives, as no significant difference was found between greener options and the hybrid HP + GAS option. Class 2, amounting to 26% of the sample, consists of individuals who only look at the cost and the payback period of the investment: as it will be seen below, these individuals would adopt a new heating system only if sufficiently subsidised. Finally, Class 3, composed of 32% of the sample, includes people who, as those in Class 2, do not seem particularly interested in technological characteristics, but in this case other attributes may be decisive to induce innovation: savings, indoor quality and emission reductions may lead to a positive evaluation of the change.

Class 1 is the largest group in the Italian case too, accounting for 53% of the sample. While individuals in this class are willing to adopt any of the new systems proposed, they show a preference for greener systems (HP and especially HP and PV). These individuals evaluate all the features of the investment, in particular the payback period, while the investment cost appears less important when comparing with the other classes. Indoor quality improvements, savings in energy bills and emission reductions are quite relevant in driving the choice for this class of respondents. Individuals in Class 3 are willing to adopt a new system, yet they do not display particular interest in green technologies. Investment cost, improvements in thermal comfort and healthy indoor conditions are important determinants of the choice; on the other hand, payback, savings and emissions' reductions are not significant. Finally, Class 2 is composed of individuals who are not interested in a new system as they prefer the status quo. In the Choice Experiments they give importance to the cost of the investment and associated savings on energy bills; payback and emissions' reductions seem less important, while improvements in indoor conditions are not a significant element of the choice.

The preferences described above are reflected in the monetary valuations. In Ireland, only individuals in Class 1 are willing to pay to install a new heating system: for any of the technological options they would be willing to pay up to 10,000 €. They would add about 1000 € for one level upgrade in indoor comfort. For any additional 10% savings in the energy bills these individuals are willing to add 390 € to the investment cost, while a 10% reduction in the emissions is valued 350 €, and no value is attached to reductions in the payback period. Individuals in both Classes 2 and 3 are characterised by WTP estimates for the systems which are not significantly different from zero. Individuals in class 3 would invest in a system such as IDEAS if it allows high improvements in indoor air quality, high savings in the energy bill, high reductions in the emissions and relatively short payback period. These respondents seem more interested in greener systems than in the hybrid HP + GAS system, but the estimates are statistically not significant, possibly due to further unexplained heterogeneity within this class, which is not tackled in this work.

Finally, Irish respondents in Class 2 value the status quo better than the alternatives, even when presented with considerable benefits for the household and the environment: the only attribute they value is the payback period. For this Class, a change of their current heating system with any of the proposed alternatives would be possible only if heavily subsidised.

A similar situation is observed for individuals in Class 2 in Italy. Although these respondents attach some value to bill savings and emissions' reductions, these elements alone cannot realistically induce individuals in class 2 to adopt any of the technologies proposed: they would require a lump sum subsidy of about 15,000 € to be persuaded to change their current system. In contrast, individuals in Class 1 would be willing to invest a substantial amount of money to innovate, especially with systems such as IDEAS: in the case of HP integrated with PV panels the amount could be as high as 27,500 €, although the amount decreases by 1500 € per additional year of payback period. These individuals are willing to pay substantial amounts (about 2000 €) for indoor quality improvements and savings, but also for further emissions' reductions (almost 700 € for an additional 10% decrease in emissions with respect to the base level). Finally, individuals in Class 3 are willing to pay a moderate amount (less than 6000 €) for any of the technologies proposed: these respondents are not specifically interested in zero emissions systems. The only attribute they value is an increase in the level of indoor comfort, for which they would be willing to pay almost 900 € per additional level.

5.2. Class profiling

This section provides a post-estimation analysis of individual class membership and preferences for heating/cooling systems, based on the LC models discussed earlier. It explores the attitudes and characteristics of respondents in different classes in both Ireland and Italy, shedding light on their willingness to invest in new technologies and their pro-environmental behaviour. Mean values of variables in each class (Table A5 in Appendix) are compared with the rest of the sample, and t-tests are carried out to identify significant differences (Table 3). Based on these results, and the WTP for the attributes of the proposed scenarios estimated for each class, it is possible to provide a profile of respondents. The three groups arising from the Latent Class model are identified as Early adopters, Late adopters and Laggards, with a coarser classification than in Rogers' [6] DOI theory, which comprises five adopter categories. Each group is characterised by specific structural and sociopsychological traits, providing further evidence of the influence of attitudes, beliefs, values, social norms and contextual effects, in addition to personal and financial constraints, on preferences regarding the adoption of innovative energy efficient systems, and related WTP. The resulting profiles largely confirm previous findings in the literature regarding drivers and barriers to energy efficient behaviour, which have been examined in Section 2. For brevity, the following discussion of profiles will not include those references, and the reader is referred to the literature review section for a straightforward matching of results.

5.2.1. Class 1: Early adopters

In both Ireland and Italy, Class 1 represents individuals ready to invest in the new heating/cooling systems proposed. Italians in this class show a strong preference for zero-emission heating systems, being willing to pay up to €13,800 for hybrid systems with gas, up to €20,500 for heat pump-only systems, and up to €27,000 for heat pumps with photovoltaic panels. In contrast, Irish Class 1 members are open to all technological options, willing to spend around €10,000. The high percentage of Irish households currently using oil for heating makes the adoption of hybrid systems a cleaner energy option with respect to the current situation, and this could in part explain the attractiveness of the hybrid system for this class of respondents.

As predicted by the DOI theory, people willing to adopt the innovation earlier than others are younger, better-off, better educated: this holds for this class in both countries. In the case of Ireland, people living in urban centres rather than in rural areas are more likely in this class. This category of respondents is characterised by strong self-enhancement values and attitudes toward innovation; they recognize economic, environmental and health benefits from changing their current heating system and feel that they can (it is feasible) and should (personal norms) make this change. Their social network is supportive of the innovation: their peers would approve (social norms), and they are connected to networks providing technical information that they trust. In the Italian sample, respondents in this class are characterised by stronger pro-environmental values and beliefs with respect to their national counterparts, and this aligns with preference and higher WTP for zero emission technologies than for the hybrid system with gas.

5.2.2. Class 2: Laggards

Class 2 represents the counterpart of Class 1, and may be defined as the class of Laggards, as per the DOI theory: defining characteristics of its members are their reluctance to adopt a new product, and to rely on old technology as long as they can. Laggards tend to be older, less educated, and worse-off than the rest of the population, as in Class 2 both in Ireland and Italy. Individuals in this class are not willing to pay even little money for these technologies and in fact may require financial support, such as subsidies, to be convinced to install these systems at home. They declare satisfaction with their current heating system and did not contemplate replacement. In fact, they do not appreciate benefits from the proposed change, neither in economic, environmental or comfort and health terms. Low pro-environmental values and scarce propensity toward innovation may partly explain why they do not feel any personal obligation to make a change; moreover, they do not feel any social pressure to do so. This demonstrates significant socio-psychological factors, in addition to financial constraints, which act as a barrier to the adoption of more sustainable heating/cooling solutions in this segment of the population. Lack of solid and trustworthy information networks, also regarding technical and financial support, possibly reinforce the opinion that systems such as those proposed in the CE exercise are outside the reach of most people in this category.

5.2.3. Class 3: Late adopters

Individuals in the third class are broadly identified as Late adopters, although they exhibit varying characteristics across the two country samples, both in terms of preferences for technological options and in some socioeconomic and psychological traits. Irish respondents in this class are characterised by strong preferences for non-technical attributes, such as emissions reduction, payback period, energy bill savings, indoor air quality, and thermal comfort. They are fairly close to the class of Early adopters in terms of education, age and income, while an important difference is that they are more likely to be located in rural areas. They display pro-environmental values and attitudes, suggesting a propensity for green heating systems even higher than Early adopters; however, their WTP for the proposed systems is quite low, such that they probably would not acquire any of the proposed systems at current market conditions. In comparison with member of Class 1, they have lower scores for Consumer Judgment Making and Trust Information: this suggests that contextual factors, such as living in rural areas, where applications of innovative technologies may be sparser, and networks of technical support weaker, may be relevant hindrances to innovation. On the other hand, Late adopters, both in Ireland and in Italy, mark high scores for the Trialability factor, suggesting an interest for more information and experimentation with technologies before making decisions. Italian people in this class are WTP some money, about 5700 €, for changing their heating system, similarly to their Irish counterparts. The difference is that Italian Late adopters do not make a difference between zero emission systems and a hybrid system with gas. They exhibit weaker pro-environmental values and attitudes compared to Early adopters, and the same can be said for their perception of benefits from changing the system. Even weaker, and similar to the category of Laggards, are their beliefs regarding moral and social norms, indicating a scarce sense of personal obligation and social pressure to invest in energy improvements. A further deterrent can be the perception of limited feasibility, again in resemblance with Laggards. All this is reflected in a weak Intention to innovate. Even more than in the Irish case, Italian individuals in Class 3 seem to lack reliable social connections that help transmission of information and support innovation: trust is lower than in Class 1 for all sources of technical information, and especially the informal network of friends and relatives.

6. Concluding remarks

This paper reports select results from a Choice Experiment study aimed at eliciting households' preferences regarding adoption of innovative heating/cooling systems in Ireland and Italy. A review of literature provides an overview of factors which influence willingness to adopt renewable energy systems, and more in general energy saving behaviour, and WTP for such changes. Reference is made to models of innovation, such as DOI, TPB and VBN, which hypothesise that the decision process leading to innovation is mainly driven by psychological factors such as attitudes, beliefs, and values, with structural characteristics having a moderating effect on the latent constructs. The review of empirical literature confirms that socioeconomic, demographic, and dwelling characteristics of respondents have typically less explanatory power than socio-psychological factors in models of innovation behaviour, although strong correlations can be found between attitudinal and structural factors.

An exploratory approach is used to detect individual characteristics associated with specific preference patterns that emerge from the CE survey. This represents a preliminary step for more complex analyses, based on hybrid choice modelling, for estimation of the effect of latent socio-psychological variables, possibly in multi-layer structures [73]. Results suggest that an integrated modelling approach, combining elements of different innovation models, would be appropriate for the data at hand, as in Wolske et al. (2017) [9].

It should be recognised that the CE approach has an inherent hypothetical nature, and for some respondents it might not have been straightforward to process the information presented in the scenarios. Yet, responses appear to be consistent, and results aligned with the literature, providing a wide-ranging picture of the variety of concurring factors which shape the demand for energy efficient technologies in the two countries.

In both Ireland and Italy respondents could be grouped in three classes according to their preferences and WTP for adoption of innovative heating/cooling systems: Early adopters, Late adopters, and Laggards. In both countries strong associations have been found between class membership and specific socio-psychological factors, as hypothesised by DOI (innovativeness, feasibility, trialability), by TPB (perception of benefits, social norms, feasibility) and by VBN (values, awareness, moral norms) models. The DOI theory associates different categories of innovators with classes of age, education, income: it turns out that these are prominent structural characteristics associated with class membership in both countries, along with location in urban or rural areas in Ireland.

The results provide interesting insights, which allow to shed some light on the issue discussed in the introductory section of this paper, i.e. that communication of economic or other personal advantages, or of environmental benefits seems not a sufficient driver to households' decision to adopt green heating/cooling systems at home. Previous studies also indicated that information processing could vary based on personal capabilities and the social context. In both countries the class of

Laggards comprises people who are less educated, older, and relatively less well-off than in other classes. These individuals require substantial subsidies to consider adopting new technologies. This highlights the importance of tailored communication campaigns aimed at increasing awareness of economic and health advantages for this group, complementary to measures providing financial support.

It was also emphasized that communication regarding the environmental impact of heating systems could be targeted to increase environmental awareness and normative beliefs. Our findings reinforce this by indicating that individuals in the class of Early adopters in Italy are more inclined toward greener technologies, while it is highlighted the need for targeted communication campaigns in Ireland to enhance awareness of environmental benefits and increase the perception of personal advantages, in terms of both economic and health benefits deriving from zero emission systems.

Finally, previous research suggested that individuals less prone to innovations and more distant from innovative social environments may have a greater need for a direct observation and for experimenting how these innovative systems work. Our results reflect this by showing that Late adopters are individuals who cannot rely on consistent social networks for technological information. This suggests the importance of implementing policy measures to facilitate experimentation with heat pump technologies and to enrich technological communication channels, especially in rural areas in the case of Ireland.

These results have important and actionable policy implications. For Early adopters, policies should focus on facilitating access and affordability, while for Late adopters, extensive awareness campaigns emphasizing economic and environmental benefits are essential. Measures for Laggards should aim not only to alleviate financial burdens but also to address knowledge gaps and create a stronger sense of the economic and environmental benefits of adopting energy-efficient systems. These campaigns should be clear, persuasive, and accessible to individuals who may have limited exposure to these technologies and their advantages.

The practical indications provided in this work support the Near Zero Building Directive (2021), even more important in the current geopolitical scenario where energy efficient homes would be better protected from rising energy prices [74]. All in all, this comprehensive exploration of factors influencing the adoption of energy-efficient technologies and behaviours in households provides valuable insights on the complex interplay of socio-psychological and structural determinants. Notably, the prominence of socio-psychological factors over structural characteristics in shaping adoption decisions highlights the importance of targeted communication and awareness campaigns. Furthermore, the identification of distinct groups, here identified as Early adopters, Laggards, and Late adopters, demonstrates the diversity of preferences and needs among households. As we navigate an increasingly energy-conscious landscape, these insights serve as a vital resource for policymakers and stakeholders aiming to promote energy efficiency, ultimately contributing to a more sustainable and environmentally responsible future in the face of rising energy costs and global challenges.

CRediT authorship contribution statement

Elisabetta Strazzera: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition. **Daniela Meleddu:** Software, Formal analysis, Data curation, Project administration, Visualization. **Davide Contu:** Methodology, Software, Formal analysis, Writing - original draft, Writing - review & editing. **Ferdinando Fornara:** Conceptualization, Validation, Supervision.

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

Table A.1
Adult population (18–75) and sample by area, gender and age - Ireland

	IRELAND							
	Geographical area							
	Northern & Western		Eastern & Midland		Southern		TOTAL	
	Pop.	Sample	Pop.	Sample	Pop.	Sample	Pop.	Sample
Area	17.4%	18.2%	49.7%	52.0%	32.9%	29.8%	100%	100%
Gender								
Male	49.7%	37.7%	49.1%	47.2%	49.7%	42.4%	49.4%	44.0%
Female	50.3%	62.3%	50.9%	52.8%	50.3%	57.6%	50.6%	56.0%
Age								
18–29	19.7%	17.0%	21.6%	20.7%	19.9%	18.4%	20.7%	19.3%
30–44	29.3%	41.5%	33.6%	38.2%	29.7%	31.5%	31.6%	36.8%
45–64	36.6%	33.9%	33.5%	32.4%	36.4%	39.5%	35.0%	34.8%
65–75	14.4%	7.6%	11.3%	8.7%	13.9%	10.6%	12.7%	9.1%

Table A.2
Adult population (18–75) and sample by area, gender and age - Italy

	ITALY							
	Geographical area							
	Northern		Central		South & Insular		TOTAL	
	Pop.	Sample	Pop.	Sample	Pop.	Sample	Pop.	Sample
Area	45.9%	47.1%	19.8%	19.3%	34.3%	33.6%	100%	100%
Gender								
Male	49.7%	50.7%	49.0%	50.4%	49.3%	48.7%	49.5%	50.0%
Female	50.3%	49.3%	51.0%	49.6%	50.7%	51.3%	50.5%	50.0%
Age								
18–29	15.9%	14.7%	15.6%	12.0%	18.1%	17.0%	16.6%	15.0%
30–44	24.9%	26.5%	25.4%	26.6%	25.7%	26.9%	25.3%	26.7%
45–64	42.2%	43.8%	42.0%	46.4%	39.8%	43.3%	41.3%	44.1%
65–75	17.1%	15.0%	17.0%	15.0%	16.3%	12.8%	16.8%	14.3%

Table A.3
Summary of socio-demographic, economic and psychological variables

	IRELAND	ITALY
Geographical area		
Northern & Western (IE)/Northern (IT)	18.2%	47.1%
Eastern & Midland (IE)/Central (IT)	52.0%	19.3%
Southern (IE)/South & Insular (IT)	29.8%	33.6%
Age		
Mean	42.9	46.8
18–29	19.3%	15.0%
30–44	36.8%	26.7%
45–64	34.8%	44.1%
65–75	9.1%	14.3%
Education		
Primary	3.9%	8.3%
Secondary	38.7%	55.7%
Tertiary	57.4%	36.0%
Household Net Annual Income [Obs.: IE 1199; IT 1300]		
Under 25,000 €	13.8%	38.5%
25,001–50,000 €	34.0%	48.0%
Over 50,001 €	52.1%	13.5%
Location		
Urban centre	62.0%	77.4%
Rural area	38.0%	22.7%
Home Type		
Detached house	49.7%	32.0%
Semi-detached/terraced house	45.9%	11.6%
Flat	4.5%	56.3%
Construction Period		
Before 1970	19.4%	32.0%
Between 1970 and 2000	38.4%	46.1%
After 2000	42.2%	21.8%
Available spaces		
Garden	93.5%	50.7%
Terrace	27.8%	51.5%
Balcony	16.2%	79.0%
Use of Heating Systems	89.2%	88.5%
Use of Cooling Systems	18.6%	59.6%
PV	20.7%	12.5%
Satisfaction with current Heating System [Obs.: IE 1159; IT 1254]		
Not satisfied at all	4.4%	2.9%
Not very satisfied	20.7%	18.7%
Quite satisfied	57.7%	59.4%
Very satisfied	17.2%	19.0%
Evaluated Replacement Heating System [Obs.: IE 1159; IT 1254]	47.4%	40.2%
Number of IAQ Problems usually experienced at home		
0	45.0%	39.0%
1	18.7%	24.1%
2	17.6%	20.1%
3	11.0%	11.2%
4	7.7%	5.7%
Power Source [Obs.: IE 727; IT 870]		
Gas boiler (natural gas/LPG)	42.8%	79.0%
Oil boiler	39.6%	3.2%
Biomass boiler/stove/thermal fireplace	10.0%	9.3%

(*continued on next page*)

Table A.3 (*continued*)

	IRELAND	ITALY
Heat pumps	5.5%	6.1%
District heating	2.1%	2.4%
Factor loading		
	IRELAND	ITALY
Biospheric Values		
Protecting the environment: preserving nature	0.887	**0.904**
Unity with nature: fitting into nature	0.830	**0.847**
Preventing pollution, protecting natural resources	0.871	**0.889**
Cronbach's Alpha	**0.83**	0.85
Egoistic Values		
Wealth: material possessions, money	0.612	**0.689**
Ambitious: hard-working, aspiring	0.820	**0.825**
Capable: competent, effective, efficient	0.716	**0.735**
Cronbach's Alpha	**0.52**	0.61
Ecological Worldview		
Human progress can be achieved only by maintaining ecological balance	0.873	0.876
Preserving nature now means ensuring the future for human beings	0.831	0.882
Human beings can progress only by conserving nature's resources	0.860	0.894
Cronbach's Alpha	**0.82**	**0.86**
Awareness Of Consequences		
Global warming is a problem for society	0.894	0.898
Energy savings help reduce global warming	0.894	0.898
Cronbach's Alpha	**0.75**	**0.76**
Ascription Of Responsibility		
I feel jointly responsible for global warming	0.886	0.896
Not only the government and industry are responsible for high energy consumption levels, but me too	0.803	0.874
I feel jointly responsible for local pollution	0.871	0.890
Cronbach's Alpha	**0.81**	**0.86**
Personal Norms		
I feel morally obligated to invest in energy improvements, regardless of what others are doing	0.874	0.883
I feel guilty if I don't invest in improving energy in my home	0.846	0.861
I feel good about myself if I invest in improving energy in my home	0.821	0.858
Cronbach's Alpha	**0.80**	**0.83**
Social Norms		
People who are important to me would be in favour of installing a system such as IDEAS	0.841	0.832
Many of my relatives and friends would adopt a system such as IDEAS	0.881	0.894
Many of my neighbours would adopt a system such as IDEAS	0.866	0.846
Cronbach's Alpha	**0.83**	**0.82**

All items were rated on a 5-point Likert scale from 1 = Strongly disagree to 5 = Strongly agree, except for Biospheric and Egoistic Values which were rated on 5-point scale from 1 = Not at all important to 5 = Very important.

Table A.4
Latent variables and Factor Loadings (Part 1)

Factor loading	IRELAND	ITALY
Personal Benefits		
Using a system such as IDEAS would save me money	0.866	0.892
A system such as IDEAS would increase my property value	0.866	0.892
Cronbach's Alpha	0.67	0.74
Health Concern		
I think of myself as a person who is concerned about healthy indoor environment	0.872	0.861
I'm very concerned about the health-related consequences of home heating systems	0.872	0.861
Cronbach's Alpha	0.68	0.64
Environmental Benefits		
Environmental quality will improve if we use less fossil fuels	0.832	0.826
Using a system such as IDEAS would be a good way to reduce my environmental impact	0.832	0.826
Cronbach's Alpha	0.55	0.53
Feasibility		
It is feasible to install a solar photovoltaic system in my house	0.846	0.870
It is feasible to install a geothermal system in my house	0.877	0.888
It is feasible to install a thermal storage in my house	0.898	0.926
Cronbach's Alpha	0.84	0.87
Trialability		
Before contacting an installer, I would like to see a system such as IDEAS up close in someone else's house	0.849	0.895
Before considering a system such as IDEAS, I would want to talk to someone who has a system such as IDEAS in their home	0.845	0.898
I would be more interested in a system such as IDEAS if there were some way for me to try it out before installing it	0.804	0.868
Cronbach's Alpha	0.78	0.86

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Table A.4 (*continued*)

Factor loading	IRELAND	ITALY
Consumer Innovativeness		
Consumer Novelty Seeking		
I continuously look for new experiences from new products	0.915	0.939
I continuously look for new products and brands	0.915	0.939
Cronbach's Alpha	0.80	0.86
Consumer Judgment Making		
Before I buy a new product or service, I often ask acquaintances about their experiences with that product or service	0.883	0.898
When considering a new product/service, I usually trust the opinions of friends who have used the product/service	0.883	0.898
Cronbach's Alpha	0.72	0.76
Intention		
I intend to use a system such as IDEAS in the near future	0.854	0.897
I will recommend others to use a system such as IDEAS	0.833	0.858
I will use a system such as IDEAS if the technology concerned is readily available	0.835	0.870
I am willing to spend money to install a system such as IDEAS	0.858	0.863
Cronbach's Alpha	0.87	0.89

All items were rated on a 5-point Likert scale from 1 = Strongly disagree to 5 = Strongly agree.Table A.4 Latent variables and Factor Loadings (Part 2).

Table A.5
Means per class of socio-demographic, economic and psychological variables

			IRELAND			ITALY		
			Class 1 (N = 549)	Class 2 (N = 340)	Class 3 (N = 410)	Class 1 (N = 745)	Class 2 (N = 300)	Class 3 (N = 372)
SOCIO-DEMOGRAPHIC CHARACTERISTICS	Geographical area	North_West (IE)/ Northern (IT)	0.14	0.22	0.20	0.47	0.47	0.47
		East_Midland (IE)/ Central (IT)	0.56	0.49	0.49	0.17	0.24	0.20
	Age	18–29	0.23	0.09	0.23	0.18	0.06	0.15
		30–44	0.41	0.29	0.39	0.28	0.20	0.29
		45–64	0.31	0.43	0.33	0.42	0.50	0.44
		65–75	0.05	0.20	0.06	0.12	0.24	0.12
	Education	Primary	0.03	0.06	0.03	0.10	0.08	0.06
		Secondary	0.35	0.46	0.38	0.52	0.62	0.58
		Tertiary	0.62	0.47	0.60	0.38	0.30	0.36
	Income	Under 25,000 €	0.13	0.19	0.08	0.33	0.40	0.37
		25,001–50,000 €	0.30	0.35	0.30	0.46	0.39	0.44
		Over 50,001 €	0.51	0.35	0.55	0.14	0.10	0.12
DWELLING	Location	Urban centre	0.69	0.59	0.55	0.77	0.77	0.79
	Home	Detached	0.49	0.49	0.51	0.35	0.30	0.29
	Type	Flat	0.04	0.05	0.04	0.53	0.59	0.60
	Construction	Before 1970	0.14	0.29	0.19	0.30	0.34	0.35
	Period	After 2000	0.47	0.30	0.46	0.23	0.21	0.20
	Available spaces	Garden	0.95	0.91	0.93	0.54	0.46	0.48
		Terrace	0.33	0.21	0.27	0.53	0.49	0.50
		Balcony	0.22	0.10	0.14	0.80	0.78	0.78
HEATING & COOLING		Use of Cooling Systems	0.28	0.06	0.16	0.63	0.52	0.59
		PV	0.28	0.12	0.19	0.14	0.12	0.10
		Satisfaction with current HS	2.85	3.06	2.76	2.91	3.06	2.92
		Evaluated Replacement HS	0.48	0.22	0.51	0.43	0.19	0.35
		IAQ Problems	1.38	0.79	1.23	1.30	0.94	1.24
	Power Source	Gas boiler (natural gas/ LPG)	0.28	0.22	0.20	0.47	0.47	0.52
		Oil boiler	0.20	0.23	0.24	0.02	0.03	0.01
VALUES & BELIEFS		Biospheric Values	0.03	−0.16	0.09	0.08	−0.11	−0.06
		Egoistic Values	0.09	−0.20	0.04	0.11	−0.16	−0.08
		Ecological Worldview	0.05	−0.18	0.09	0.04	−0.12	0.01
		Awareness of Consequences	0.04	−0.26	0.16	0.07	−0.12	−0.05
		Ascription of Responsibility	0.13	−0.36	0.12	0.10	−0.23	−0.02
		Personal Norms	0.10	−0.38	0.18	0.19	−0.32	−0.13
		Social Norms	0.18	−0.48	0.15	0.28	−0.55	−0.12
		Personal Benefits	0.10	−0.42	0.21	0.21	−0.51	−0.01
		Health Concern	0.11	−0.25	0.06	0.14	−0.24	−0.08
		Environmental Benefits	0.08	−0.33	0.16	0.14	−0.34	0.00
		Feasibility	0.18	−0.48	0.16	0.29	−0.53	−0.15
		Trialability	0.02	−0.21	0.15	0.18	−0.55	0.09
		Cons. Novelty Seeking	0.14	−0.35	0.10	0.15	−0.31	−0.04
		Cons. Judgement Making	0.12	−0.24	0.04	0.13	−0.23	−0.09

(*continued on next page*)

Table A.5 (*continued*)

	IRELAND			ITALY		
	Class 1 (N = 549)	Class 2 (N = 340)	Class 3 (N = 410)	Class 1 (N = 745)	Class 2 (N = 300)	Class 3 (N = 372)
Trust Info Mass Media	3.26	2.73	3.00	3.17	2.69	3.03
Trust Info Installers	3.67	3.25	3.60	3.66	3.10	3.52
Trust Info Relatives	3.94	3.74	3.90	3.62	3.17	3.38
Intention	0.22	−0.66	0.25	0.33	−0.81	−0.01

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