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Research article

What does it matter? Analysing the role of attitudes to the adoption of solar photovoltaic technology in Spain

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A B S T R A C T

Solar photovoltaic (PV) systems are believed to have great potential in combating climate change and contributing to decarbonisation, especially in the residential sector. It is essential to determine the factors that shape individual decisions to adopt this technology, in order to facilitate its deployment. This paper analyses predictors of the intention to adopt solar PV in the residential sector, using a representative sample of 945 non-adopters in Spain who responded to an online anonymous survey. We aim to determine the direct and mediated effects of the Theory of Planned Behaviour constructs, other attitudinal variables (perceived benefits, perceived barriers and environmental values), peer effects, socio-demographics and house characteristics, on the intention to adopt solar PV. Two complementary statistical modelling approaches were used. First, a logistic regression analysis predicting intention to adopt suggested that TPB variables such as attitude (OR = 2.39) and subjective norms (OR = 2.12) were the most relevant, while perceived behavioural control (OR = 1.28) was shown to be less relevant. Moreover, logistic modelling indicated that perceived economic barriers (OR = 0.66), having university studies (OR = 2.96), and living in a house (OR = 3.85) also play an important role in the intention to install solar PV. The second analytic approach was path analysis through Structural Equation Modelling aimed at quantifying the determinants that both directly and indirectly influence the intention to adopt. Its results revealed attitude (β = 0.19) and subjective norms (β = 0.18) as the factors having most influence on the intention to adopt. Consequently, different attitudinal variables should be taken into account when considering public willingness to install solar PV. We recommend that both policymakers and the market strengthen their recognition of economic and environmental benefits and enact measures to overcome economic barriers for potential solar PV adopters.

1. Introduction

The need to reduce greenhouse gas emissions in order to combat climate change and contribute to decarbonisation has become the

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Abbreviations

PV	Photovoltaic
TPB	Theory of Planned Behaviour
SEM	Structural Equation Modelling
PCA	Principal Component Analysis

main driver for the promotion of renewable energies. The Intergovernmental Panel on Climate Change (IPCC) has pointed out the importance of using renewable energy for the generation of electricity [1]. Likewise, the crises of the COVID 19 pandemic, the Russian invasion of Ukraine, and the risk of conflict in the Middle East have highlighted the need to adopt energy systems that ensure the global population's continued access to electricity [2].

The building sector is currently one of the largest in terms of energy consumption. In 2021, the operation of buildings accounted for 30 % of total global energy consumption, and 26 % of global energy-related emissions [3]. In 2022, the building sector consumed approximately 1 % more energy than in the previous year [3]. Adopting energy efficiency measures alongside the use of renewable energy technologies is key to improving energy consumption in buildings [1].

Among renewable technologies, solar PV is believed to hold the greatest potential. Evidence of this can be seen in the continued growth of installed capacity, and the ambition to increase its share in the electricity mix in order to achieve carbon neutrality. In 2022, 236 GW of solar PV were installed globally [4], delivering a total cumulative capacity of 1183 GW, an increase of 35 % compared with the previous year. Rooftop installation grew by 50 % in 2022 worldwide, reaching 118 GW, up from 79 GW the previous year [5], confirming this type of application as an emerging market for the future. In a situation of high electricity prices and international instability of the type exemplified by the Ukrainian war, distributed solar energy represents an option for both countries and citizens to become more resilient to external shocks. Projections by SolarPower Europe [5] forecast a total of 268 GW of rooftop solar PV by 2027, assuming a moderate scenario.

1.1. Residential photovoltaics in Spain

The Snapshot of Global PV Markets 2023 report, published by the International Energy Agency (IEA) and the Photovoltaic Energy Systems Program (PVPS) [6], highlights the status of Spain as one of the world's leading solar PV nations. This report also points out that Spain is the top country in Europe and the fifth country in the world as measured by installed solar PV power in 2022, with a total of 8.1 GW, and the seventh by accumulated solar PV capacity, with a total of 26.6 GW. In addition, in 2022 the IEA awarded Spain first place in the world for solar PV penetration, with a rate of 19 %. The growth of the new installed capacity of solar PV panels between 2016 and 2023 was 166 %, with increases exceeding 20 % per year since 2020 [7]. Thus, in 2023, the installed capacity of solar panels equated to 10.4 m^2 per inhabitant [7,8]. According to data recorded by the Spanish Photovoltaic Union (UNEF), the leading Spanish association of solar energy, there were, in 2023, around 84,545 new residential self-consumption installations in Spain [9].

In March 2022, the Spanish Government published Royal Decree-Law June 2022 [10] with the aim of adopting urgent measures, using solar PV technology, in response to the high volatility, uncertainty and instability of energy prices resulting from the war in Ukraine. This law reserves 10 % of total available energy capacity for self-consumption, with the aim of promoting its adoption.

Royal Decree-Law 18/2022 [11] introduces simplified administrative procedures for self-consumption installations, allowing the competent administrations to waive the requirement to obtain prior administrative and construction authorisation for self-consumption below 500 kW.

Additionally, Royal Decree-Law 477/2021 [12] allocated €660 million in aid for, among other things, self-consumption and air-conditioning installations using renewable energy. The management of the subsidies is devolved to the Spanish Autonomous Communities.

Finally, the installation of solar PV at the residential level is financially supported by the Communities. Although there are some differences among them, in general, up to 40 % of the total installation cost is subsidized, provided that it does not exceed €3000 [13]. Some Communities provide subsidies on the basis of the type of installation (individual or collective), and the kWp installed. Moreover, 41 % of Spanish municipalities grant property tax rebates ranging from 30 % to 50 %, for a period of 3–5 years or even longer [13]. Many municipalities offer ICIO (Tax on Construction, Installations and Works) rebates of up to 95 % to promote energy self-consumption and sustainability [13]. The installation of solar PV panels also attracts a reduction in personal income tax, which can be claimed by anyone who has carried out energy renovation work on their home.

Despite incentives for self-consumption, some barriers related to complex administrative procedures, insufficient integration with the electricity grid, the lack of a stable regulatory framework or the lack of public awareness are hindering the deployment of collective self-consumption in Spain [14].

In Spain, according to the IEA [15], the typical price of a standard crystalline silicon module is €0.22/W, based on a 10–50 MW installation. According to the report, turnkey solar PV system prices are between €1.6 and €1.7W for grid-connected residential rooftop systems of 5–10 kW. For large grid-connected consumer systems, the average price is €0.67/W, and for a centralised system of more than 20 MW, the price ranges from €0.59 to €0.62/W.

The return on investment (ROI) or profitability of each installation varies, depending on the following factors: annual energy consumption, geographical location, size of the installation, lifetime of the installation, efficiency of the solar PV panels, overcompensation, initial investment, inflation and the price of electricity. In general, the average break-even point is between 5 and 10 years, but this is highly dependent on the above factors [16].

The operations and maintenance (O&M) costs for Spain are estimated to range from €6.80 to €14.70 per year for each 1 kWp installed. For Europe as a whole, the costs range from €5.20 to €18.90 per year for each 1 kWp installed [17].

1.2. Solar PV adoption and the psychosocial dimension

The novelty of technologies such as solar PV has raised questions about their adoption by the general public. In this regard, there is a need to analyse the factors that shape individual decisions to adopt this technology, in order to facilitate its deployment. Alongside economic, regulatory and structural factors, personal and social considerations affect individual decisions to purchase solar PV panels. The Theory of Planned Behaviour (TPB) [18,19] is one of the most widely used theoretical frameworks for explaining solar PV adoption behaviour [20–22]. It is a widely used psychological model that explains how individual behaviour is shaped by three main factors: attitudes toward the behaviour (the individual's positive or negative evaluation of performing the behaviour), perceived social norms (the perceived social pressure to perform or not perform the behaviour), and perceived behavioural control (the perceived ease or difficulty of performing the behaviour, similar to self-efficacy). According to TPB, these factors jointly influence behavioural intentions, which are the most immediate predictors of actual behaviour. Some studies extend the TPB, using alternative variables that better suit the case of solar PV adoption [23]. As was highlighted by Shakeel & Rajala [24], 'the rationale of combining theories/extending the original framework has been to integrate new variables that could have an impact on the adoption of solar PV.'

This paper analyses the public's intention to adopt solar PV in the residential sector through some of its principal predictive determinants in a representative sample of non-adopters in Spain. Despite the large number of studies on the topic, questions remain regarding the role of different predictors for solar PV adoption [25]. We aim to determine the direct and mediated effects of typical TPB constructs (attitude, subjective norms and perceived behavioural control), as well as additional attitudinal variables (peer effects, perceived benefits and barriers, and environmental values), on the intention to adopt solar PV, the latter being key predictors of actual behaviour [18]. This research paper contributes to the scientific debate by testing the role of environmental values, peer effects, and perceived benefits and barriers in explaining the intention to adopt residential solar PV. Thus, this model is based on the TPB but extends it by considering additional findings from the meta-analysis of Schulte et al. [25].

2. Theoretical framework

2.1. Insights into the most recent research on residential solar PV intention to adopt

Residential solar PV adoption is a rapidly growing area of research. A significant number of articles has been published on the topic in recent years, in several countries worldwide. As the starting point for our study, we highlight the most recent ones here, focusing on those dealing with literature reviews or meta-analysis.

Shakeel & Rajala [24] used the Scopus database to conduct a systematic review of the factors influencing households' intention to adopt solar PV. They found 39 relevant articles identifying a number of factors that could influence adoption. These factors can be divided into six categories: socio-demographic variables (age, gender, education level, occupation, income, etc.); personal factors (individual environmental attitudes, perceived benefits, technological knowledge, perceived behavioural control, etc.); social variables (installation of solar PV by neighbours, overall level of installation in the locality, visibility and observability of the technology); technical issues (ease of use, utility, compatibility, relative advantage, risk of use and after-sales repair and maintenance); economic factors (high cost of the technology, up-front cost, financing options, ROI, whole-life savings and energy bill reduction); and external factors (energy market price, subsidies, regulatory framework and installation incentives). Among these predictors, economic factors were found to be the most significant in influencing adoption decisions.

Alipour et al. [26] conducted a systematic quantitative literature review to identify studies covering the adoption and diffusion of solar PV in the residential sector, using the Web of Science and Scopus databases. The review covered the economic, technical, socio-demographic and individual predictors that influence customer decision-making. They found 173 relevant studies and a total of 333 predictors. The authors created a taxonomy of predictors based on the findings of previous studies. They grouped all the predictors into three main dimensions (social, informational and individual), each with various categories. The individual dimension included values (environmental and personal), general attitudes, and perceived risk, among others. The social dimension included demographics (age, gender, education level, income, socio-political orientation, etc.) as well as house characteristics and family structure. The information dimension included knowledge (financial and technical) and information channels. The authors highlighted that the physical and non-physical characteristics of buildings are significant determinants of adoption decisions for residential solar PV, since these attributes determine both the technical feasibility and cost of installation.

Alipour et al. [27] systematically reviewed the adopted theories, methods and approaches in solar PV adoption behaviour studies. They examined 199 original quantitative, qualitative, statistical, and non-statistical articles. They found ten main dependent variables, the most common of them being the actual decision to adopt (40 % of the studies), followed by diffusion of solar PV (18 %), attitude towards solar PV (13 %), and the intention to adopt (9 %). The authors classified the independent variables as economic and non-economic and highlighted that, compared with economic variables; the influence on behaviour of non-economic parameters has been considerably less investigated. The majority of the reviewed studies used mainly online or face-to-face cross-sectional surveys for data collection (96 %) at the national or the state/province level. The complexity of individual decisions was understood through 13 forms of behavioural theories, Diffusion of Innovation (DoI) and the TPB being principal among them. Regression analysis was the most commonly used statistical analysis method, followed by descriptive statistics, and Structural Equation Modelling (SEM). They found that the most frequently applied predictors (age, income, and financial knowledge) were less correlated with behaviour than were attitudinal traits.

Nurwidiana, Sopha, & Widyaparaga [28] conducted a systematic literature review focused on the adoption of solar PV systems in the household sector. They used the Scopus database covering the period from 2006 to 2019, obtaining 67 articles, mainly from Europe (42 %), the USA (31 %), and Asia (19 %). It was concluded that the number of studies had increased over time. A total of 52 out of the 67 papers modelled the quantitative adoption of solar PV. Equation Based Modelling (EBM) was the most widely used approach, followed by Agent Based Modelling (ABM). The authors reported that various diffusion theories such as the Bass model, the TPB, the Technology Acceptance Model (TAM), and the Theory of Reasoned Action (TRA) have been used for modelling the adoption of solar PV using EBM. It is shown that based on the TPB, solar PV adoption modelling has been carried out by exploring purchase motives, while subjective norms were assessed in accordance with peer behaviour and expectations. Furthermore, attitudes towards solar PV systems are based on aspirations for social status, autonomy, financial benefits, costs, perceived effort, and associated risks [23]. The TPB has also been used to investigate the effect of socio-psychological factors (environmental attitudes, perceived behavioural control, and subjective and descriptive norms, including knowledge of renewable energy) on individual intentions to adopt renewable energy solutions [29].

Schulte et al. [25] carried out a meta-analysis of residential solar PV adoption, from a sample of eight previously published papers that provided sufficient data with which to conduct the analysis. They found medium to large correlations between environmental concern, novelty seeking, perceived benefits, subjective norms and intention to adopt, whereas socio-demographic variables were not found to be correlated with intention. In this study, a further meta-analysis using SEM revealed a model in which adoption intention was predicted by perceived benefits and behavioural control, while benefits could, in turn, be explained by environmental concern, novelty seeking, and subjective norms. These authors highlighted the key role of perceived benefits in the intention to adopt solar PV at the residential level. They also suggested that, to facilitate the future aggregation of scientific evidence, it is important that future studies include consistent predictors (in the previous studies, predictors relating to the same underlying concept have various different names) and report bivariate correlations.

Finally, Fauzi et al. [30] carried out a bibliometric analysis of residential rooftop solar PV adoption behaviour. They retrieved 564 publications from the Web of Science platform and classified the studies into three clusters. The first cluster included studies dealing with motives to adopt, highlighting the predictive role of some variables such as financial support, general problem awareness, interest in technical innovation, and environmental benefits. The second cluster included those studies relying on fundamental theory, such as the Diffusion of Innovation theory or the TPB. The third cluster included those articles dealing with peer and neighbour effects. The studies in this cluster showed that neighbours and peers play an important and complementary role in residents' adoption decisions.

These literature reviews and meta-analyses provide invaluable insight into the antecedents of solar PV adoption. While there is consensus on the need to consider psychological and social factors in predicting the intention to adopt solar PV panels (in addition to economic and structural factors), the results are, at times, contradictory. For example, some studies definitively point to attitude as the best predictor, while others highlight the important role of subjective norms and perceived behavioural control. Furthermore, while studies such as those of Shakeel & Rajala [24] and Alipour et al. [26] emphasise the importance of economic factors, others, such as Schulte et al. [25] and Fauzi et al. [30], highlight the relevance of perceived benefits. The role of demographic variables is also unclear. This reinforces the need for further study of the attitudinal and social factors that help in understanding the intention to adopt solar PV panels. As the study by Alipour et al. [27] clearly points out, economic variables have been studied in more depth, while the influence of non-economic parameters on behaviour is considerably less explored.

2.2. Constructs

Based on previous studies, the main constructs we use in our model are the following.

2.2.1. Intention to adopt

Behavioural intention is an individual's readiness to perform a given behaviour and is assumed to be an immediate antecedent of that behaviour [19]. Behavioural intention has been proposed in popular conceptual theories of innovation diffusion as a dominant predictor of adoption [18,31,32]. Behavioural intention has also been recognised as a significant predictor in several recent studies on residential solar PV adoption. We use the intention to adopt solar PV as our primary dependent variable.

2.2.2. Attitude

Personal attitudes towards a particular behaviour encompass an individual's beliefs and knowledge about the consequences of that behaviour [33]. The literature indicates that the attitude of individuals towards a given technology is one of the best predictors of the intention to adopt it [32,34]. Several recent studies have found that attitudes have a significant and positive impact on the intention to adopt solar PV [21,35,36]. However, not all studies concur: a recent investigation conducted by Lundheim et al. [37] found that attitudes have an only marginally significant impact on the intention to adopt.

2.2.3. Subjective norms

Subjective norms have been defined as an individual's perception of how much people value a certain behaviour, or of social expectations regarding their own behaviour [18]. Subjective norms have been proposed as one of the factors that determine intention. Recent studies of the intention to adopt solar PV have found that the expectations of significant others such as family members, friends or neighbours have a strong effect on the intention to adopt [21,23,38].

2.2.4. Perceived behavioural control

Perceived behavioural control measures an individual's perception of their ability to control a behaviour. This control depends on an individual's perception of internal factors, such as their own level of ability and determination, as well as external factors such as resources and support. Recent studies of the intention to adopt solar PV found that perceived behavioural control is positively correlated with the intention to purchase rooftop solar PV panel systems [35,37,39].

2.2.5. Peer effects

Peer effect (or social influence) is the degree to which an individual feels pressured by others to adopt an innovation [38]. The literature suggests that peer effects are an important driver of solar PV diffusion, as existing adopters influence others to do likewise [26,40,41]. Some previous studies have found that peer effects influence the intention to install solar PV [38,42–44]. Petrovich et al. [45] found that strong preferences for adoption correlate positively with the number of friends and family members who have already installed solar PV.

2.2.6. Environmental values

Environmental values have been defined as the enduring beliefs that directly reflect an individual's environmental concerns [46]. Environmental concerns include the evaluation of one's own behaviour in terms of its consequences for the environment [47]. There is no consensus about the effect of environmental values on the intention to adopt solar PV. Although some recent studies have found that environmental values and environmental concerns are associated with the intention to adopt solar PV [35,46,48], other studies do not confirm the influence of those concerns [49,50]. The study by Scheller et al. [51] tested the role of environmental concerns in explaining attitude and intention to adopt solar PV in the residential sector.

2.2.7. Perceived benefits

Perceived benefits can be defined as an individual's perception of the advantages and gains offered by a particular technology. In the recent study conducted by Schulte et al. [25], perceived benefits have been found to be the strongest determinant of the intention to adopt. Different types of benefits such as economic, environmental or social have been studied in the literature on the intention to adopt solar PV [52]. In general, there is consensus on the positive and significant influence of perceived benefits [53–55], but some perceived benefits have been shown to be more closely correlated with the intention to adopt than others [52]. Some previous studies have tested the role of perceived benefits as an antecedent of attitude towards solar PV systems [23,51,52].

2.2.8. Perceived barriers

Perceived barriers can be defined as an individual's perception of the disadvantages and difficulties of adopting a given technology. In general, there is consensus among the studies as to the negative effects of perceived barriers on the intention to adopt solar PV [23,56]. According to Karakaya & Sriwannawit [56] the main barriers to the adoption of solar PV systems in the residential sector can be categorised as economic, sociotechnical, policy, and technology management.

In terms of economic barriers, the most studied are initial costs, payback time, the availability of subsidies, maintenance costs, and access to finance [23,53,55]. In the case of sociotechnical barriers, some studies imply that the complexity, reliability, and performance of a technology can reduce the intention to adopt [38]. Other barriers, such as ineffective policy measures, political commitment, and technology management, are related to the policy dimension.

As in the case of perceived benefits and environmental concerns, perceived barriers were studied by Korcaj et al. [23] in the original TPB model as antecedents of attitude, and used by other authors such as Filgueira, Lima & Castelo [52] and Scheller et al. [51].

In summary, we anticipate that the effects of subjective norms, perceived behavioural control, and attitude towards solar PV panels will be in line with the TPB. We therefore expect these variables, along with peer effects, to predict intention to adopt. Furthermore, we suppose environmental values, perceived benefits and perceived barriers to predict attitude towards and, indirectly, intention to adopt solar PV.

2.2.9. Socio-demographic variables

Socio-demographic factors are one of the most commonly used predictors of intention to adopt solar PV. Several recent studies have considered socio-demographic variables, the most frequent being age, gender, educational level, and income [57–59]. However, their influence is somewhat less clear, and some authors doubt their value as predictors [25,26].

The relationship between age and solar PV adoption is inconclusive. Some studies showed a negative relationship between age and solar PV adoption [60,61] while other studies found no such correlation [45,51,62,63].

Concerning the impact of gender, some studies have argued that women have a lower intention to adopt solar PV [45,64], while others conclude that gender has no effect [51,58,63].

Regarding educational level, there is some previous evidence that educational level is positively associated with solar PV adoption [62,65]. However, some other studies identify no such relationship [49,61].

Finally, a set of studies found a positive relationship between household income and solar PV adoption [62,66–68], while others show that its impact is not relevant [51,63,69].

2.2.10. Housing characteristics

Housing characteristics such as the ownership of property, the type of house and the area of residence are less salient in previous studies related to intention to adopt solar PV [68,70].

Nonetheless, home ownership seems to play a pivotal role in the decision to install solar PV panels at the residential level [71]. Some recent studies have found that those who own their own homes are more willing to invest in solar PV [61,68].

The type of house could also influence the intention to adopt solar PV. Some studies found that living in a house as opposed to an apartment increases the likelihood of adoption [64,72]. Other studies found that the type of house is not a significant predictor [70,73].

Finally, housing location (urban versus rural) is another variable that could influence the intention to adopt solar PV. Some previous studies found that living in a rural area positively affects intention to adopt solar PV [64,74].

3. Materials and methods

3.1. Participants

A sample of 945 solar PV non-adopters aged 18 or over, drawn from the general population of Spain, took part in the online survey in April 2023. Given the high rate of internet penetration, an online survey was selected as a cost-efficient method for quickly collecting data from a large and geographically dispersed sample, while avoiding selection bias. A high response rate was assured by enlisting the help of a market research company to administer the survey and collect the data via its website. Internal validity, often criticized in online surveys, is guaranteed in this study, as control questions were included to rule out random responses. In addition, social desirability has been reduced through anonymity. Stratified random sampling was employed to obtain a representative sample of non-adopters in the Spanish population, based on quotas of age, gender, educational level and geographical areas, with proportional allocation in accordance with official data [75]. The survey included an initial screening question to exclude solar PV adopters. The sampling was conducted separately in the 7 Spanish Nielsen Zones, which define areas with relatively homogeneous marketing characteristics. The sampling error for the final number respondents (945) was ± 3.1 % for a confidence level of 95 %, assuming the maximum variability for binary responses ($p = .5$). The socio-demographic characteristics of the sample are shown in Table 1.

The study sample was comprised of 48.5 % men and 51.5 % women. The average age of the participants was 48.3 years (SD = 16.4). Most respondents had a university education (40.6 %). Regarding household incomes, 51.3 % of the sample reported managing on their current income, while around 27 % declared themselves as having difficulty in living on their current income. Two out of ten participants were living comfortably or very comfortably on their current income. With respect to the characteristics of participants' houses, Table 1 shows that most of respondents lived in a large city (64.2 %), and mainly in a flat or apartment (70 %). Most of the houses were owner occupied (76 %).

It should be noted that this study did not require ethical approval, as confirmed by the Research Ethics Committee of the Universitat Auntonoma de Barcelona (CERec). The participants were volunteers and gave their consent to take part in this study, in accordance with the panel's rules.

Table 1
Descriptive characteristics of participants: socio-demographic profile and housing-related variables(N = 945).

Variable	Categories/Range	*N* (%)
Gender	Male	458 (48.5)
	Female	487 (51.5)
Age	18–24	95 (10.1)
	25–34	131 (13.9)
	35–44	184 (19.5)
	45–54	175 (18.5)
	55–64	145 (15.3)
	65 and above	215 (22.8)
Education level	Basic education	360 (38.1)
	Higher or vocational education	201 (21.3)
	University education	384 (40.6)
Household income	Very difficult to live on current income	107 (11.3)
	Difficult to live on current income	153 (16.2)
	Managing with current income	485 (51.3)
	Living comfortably on current income	176 (18.6)
	Living very comfortably on current income	24 (2.5)
Area of residence	Rural	338 (35.8)
	City	607 (64.2)
Type of residence	Flat or Apartment	661 (70.0)
	House	284 (30.0)
Ownership	No	227 (24.0)
	Yes	718 (76.0)

3.2. Measures

An *ad hoc* questionnaire was designed in order to assess the public's intention to adopt solar PV panels and discover potential predictive determinants or factors. The questionnaire included 36 items and was specifically developed by the research team, based on a literature review of pre-existing international studies on the topic.

The questionnaire was structured in the following sections: i) socio-demographic questions (4 items); ii) questions about the characteristics of participants' houses (3 items); iii) questions about environmental values (5 items); and iv) attitudinal questions regarding solar PV panel adoption (24 items). Table 2 gives an overview of the constructs considered in this study. It shows the number of items included for the measurement of each theoretical construct, as well as the studies from which the items were drawn.

Single items were used only in the case of well-established theoretical constructs, when there were previous reputable studies that had used single item measures, and to encourage a reduction in the length (total number of items) of the final questionnaire. Social desirability was counterbalanced by the anonymity guaranteed by an individual online survey and by the fact that there is no financial or other reward for particular responses.

A detailed list of items included in the questionnaire is provided in the Supplementary Information.

3.3. Procedure

Prior to data collection, a pilot test was carried out with a sample of 17 people in order to check that the questionnaire was easy to understand and quick to complete, and whether the response options were exhaustive. Afterwards, the questionnaire was prepared in electronic form and sent to participants by e-mail. A market research company assisted with the programming and survey administration process, and sent invitations to panel members to take part in the survey. Informed consent was obtained from participants before they participated in the study. Participants were informed of the anonymous and confidential nature of the data provided in the survey. Filling out the questionnaire took an average of 9 min.

3.4. Analytic approach

Data analysis was conducted using Stata 18 software. First, to explore the factorial structure of the questionnaire, a Principal Component Analysis (PCA) was carried out. PCA was selected in preference to Confirmatory Factorial Analysis (CFA) or Exploratory Structural Equation Modelling (ESEM) for two reasons: because the measurement instrument was constructed ad-hoc for the survey, and because the high overlap in the semantic definition of the constructs allowed items to load in more than one factor. Barlett's test, the Kaiser-Meyer-Olkin test, and the PCA were performed. To select the optimum number of retained factors, four criteria were assessed: whether the eigenvalue was greater than 1; slope changes in the Cattell's scree-plot; the total percentage of variability explained; and the result of a parallel analysis executed with 100 random samples. The retained factors were rotated using the varimax and oblimin functions. Communalities and residuals were calculated to assess the goodness of fit of the selected factorial solution.

The best predictive model of binary intention to adopt solar PV was selected through a backward stepwise logistic regression, with 0.05 as the inclusion and 0.10 as the exclusion probabilities. Once the best model was selected, a Poisson regression model with robust standard errors was estimated to obtain the prevalence ratio associated to each predictor. McFadden pseudo-R^2 and the area under the ROC curve were calculated to assess the predictive capability of the model [78].

Finally, the explanatory model of the binary intention to adopt solar PV was assessed with SEM. The measurement model included hypothesized direct and indirect effects, non-null covariances between exogenous variables, type of housing, and education level, as adjustment terms. The estimates were conducted using maximum likelihood and observed information matrices for the standard error (the normality of the measures was checked in advance). Degree of fit was evaluated using root-mean-square error of approximation (RMSEA), the Tucker-Lewis index (TLI), the comparative fit index (CFI), and the standardised mean-square residual (SMSR). The model's fit was adequate when TLI or CFI were above 0.90 (acceptable) or 0.95 (excellent), RMSEA below 0.08 (acceptable) or 0.06 (excellent), and SMSR was under 0.08 [79]. Indirect effects were tested even though the direct or total effect was not statistically significant, using the product-of-coefficients test [80].

Table 2
Constructs measured in the questionnaire and their original or adapted sources.

Theoretical constructs	N° of items	Adapted from:
Environmental values	5	[46]
Intention to adopt	1	[76]
Subjective norms	1	[74]
Perceived Behavioural Control	1	[23]
Peer effects	2	[45]
Attitude	1	[77]
Perceived benefits	9	[23,54,55,74,76]
Perceived barriers	9	[23,54,55,74,76]

4. Results

4.1. Validity and reliability of the measurement model

PCA was used with a non-orthogonal oblimin rotation to establish the validity of the measurement model for the latent variables, using 25 items from the questionnaire (as can be seen in Table 2, Intention to adopt, subjective norms, perceived behavioural control and attitude were mono-items so they were not factorised). The result of Barlett's test was statistically significant ($p < .001$), reflecting that items were intercorrelated. The Kaiser-Meyer-Olkin test index was 0.86, which according to Kaiser [81] was considered high enough to try to factorise the items. Results from the PCA showed 6 factors with eigenvalues >1, accounting for 66.4 % of the total variance. The scree-plot suggested selecting 2 or 6 factors. Results from parallel analysis indicated that the first 6 factors explained greater or practically the same variability as chance, and from the seventh factor onwards random factors explained more variance than empirical ones. Given these results, the 6-factor solution was selected. Communalities were largely homogeneous from 0.42 to 0.82. Residuals, calculated as observed less fitted correlations, were low, with a mean of 0.03 and with 81.7 % of them below 0.05.

As shown in Table 3, the selected PCA solution yielded a structure in which seven items of benefits loaded in Factor 1, while another two benefits (those dealing with social and aesthetic aspects) loaded in Factor 5. The same occurred for perceived barriers: six items loaded in Factor 3, while three items (those dealing with economic aspects) loaded in Factor 4. The other factors were environmental values as Factor 2, and peer effects as Factor 6. All factor loads were higher than 0.50. Average variance extracted (AVE) values were all above 0.50 except for Factor 3 (0.44), which following Hair et al. [82] indicated that variance captured by the constructs was high in relation to the amount of variance of error. Cronbach's alpha for the 6 derived factors was acceptable except for Factor 6 (probably due in part to it containing only 2 items).

As shown in Table 4, correlations between the 6 factors were low in general, but three values were higher than 0.20. Factor 1 was correlated with Factors 2 and 5, and Factor 3 was correlated with Factor 4.

Table 3
Exploratory factor analysis results, including factor loadings, average variance extracted (AVE), and internal consistency (Cronbach's alpha).

Factors and factor loading	1	2	3	4	5	6
1. Economic and environmental benefits						
I would recover the investment and make a profit.	0.788					
It would reduce my energy bill significantly.	0.859					
It would protect me from rising electricity prices.	0.872					
I would get tax benefits.	0.633					
It would make me self-sufficient.	0.703					
I would reduce my dependency on oil/gas and reduce greenhouse gases.	0.715					
It would increase my property value.	0.628					
2. Environmental values						
It is important to me that the products I use do not harm the environment.		0.853				
I consider the potential environmental impact of my actions.		0.892				
I am concerned about wasting the resources of our planet.		0.813				
I would describe myself as environmentally responsible.		0.852				
I am willing to be inconvenienced in order to be environmentally friendly.		0.784				
3. Non-economic barriers						
I would have infrastructure difficulties.			0.619			
It would not provide the level of benefits I would be expecting			0.502			
It is too technically complex			0.777			
It would require lot of maintenance			0.725			
I would be concerned about its safety			0.687			
It would worsen the aesthetics of my property			0.620			
4. Economic barriers						
Initial costs of installing solar photovoltaic panels would be too high				0.848		
It would take too long to recover the initial investment				0.859		
There would be a lack of financial support				0.872		
5. Other benefits: social & aesthetics						
It will improve my social status in the community					0.805	
It would make my property look nicer					0.867	
6. Peer effects						
How many of your neighbours have installed solar PV?						0.886
How many of your friends and family members have installed solar PV?						0.875
Eigenvalue	6.06	3.56	2.34	2.05	1.45	1.13
% of explained variance	20.5	17.6	12.6	11.4	9.1	6.7
Average Variance Extracted	0.56	0.70	0.44	0.74	0.70	0.78
Cronbach's alpha	0.89	0.90	0.76	0.85	0.80	0.71

Note: only the highest factor loading for each item is shown.

Table 4
Correlations among the six factors identified in the factor analysis.

	Environ-mental values	Non-economic barriers	Economic barriers	Other benefits	Peer effects
Economic & environmental benefits	0.37	−0.14	0.03	0.24	−0.10
Environmental values		−0.08	0.06	0.15	−0.05
Non-economic barriers			0.29	0.00	0.09
Economic barriers				−0.09	−0.10
Other benefits					0.07

Six new scales were created from the results of the PCA as the mean of the items involved, labelled as indicated in the six first rows of Table 5. Additionally, for posterior predictive models, the three single-item measures representing subjective norms, perceived behavioural control and attitude were also used. Table 5 presents the descriptive of these factors and variables that in the posterior regression model will act as predictors of the intention to adopt solar PV, as well as the descriptive of the intention to adopt.

Attitude towards residential solar PV was quite favourable overall whereas intention to adopt was quite low. Participants also scored highly for environmental values. Economic barriers were perceived as higher than non-economic ones (social and aesthetic). Economic and environmental benefits were also perceived as higher than other benefits (infrastructure, technical aspects and maintenance, safety, and aesthetics). Peer effects in the sample were quite low.

As shown in Table 6, the intention to adopt was directly correlated with attitude ($r = 0.28$), subjective norms ($r = 0.28$), peer effects ($r = 0.23$) and perceived behavioural control ($r = 0.21$), and inversely with perceptions of economic barriers ($r = -0.10$) and non-economic barriers ($r = -0.20$).

4.2. Predictive analysis of the intention to adopt solar PV panels

In order to predict the intention to adopt solar PV, a backward stepwise logistic regression analysis was conducted. Predictors included in the maximum initial model were the six factors from the PCA, the 3 items measuring subjective norms, perceived behavioural control and attitude, and a set of demographic variables (gender, age, education level (as yes/no for university education) and household income) and other potential influencers (type of house, place of residence, and ownership of the dwelling). The best model obtained is shown in Table 7, which besides the odds ratio (*OR*) and its *p*-value, also contains the estimated prevalence ratio (*PR*).

The selected logistic model had an acceptable predictive capability with a McFadden pseudo-$R^2 = 0.26$. With an optimal cut-off of the predicted probability equal to 0.161, the maximum values of sensitivity = 0.77 and specificity = 0.77 were achieved. The area under the ROC curve was $AUC = 0.84$ (CI95 % 0.82 to 0.87). The fitted ROC curve is shown in Fig. 1. The model included six statistically significant predictors: subjective norms, perceived behavioural control and attitude were associated with an increased probability of intention to adopt solar PV, and conversely, economic barriers were associated with a reduction in intention to adopt. Moreover, living in a house instead of a flat or apartment, and having a university education were associated with an increased intention to adopt solar PV.

4.3. Path analysis explaining the intention to adopt solar PV panels

An SEM analysis of the six factors obtained in PCA plus the three variables from the TPB model [18] was conducted. Additionally, the two sociodemographic predictors that were statistically significant in the previous predictive logistic model (type of house and education level) were included as adjustment terms. The model provided a moderate fit of the data ($CFI = 0.892$, $TLI = 0.773$, $SRMR = 0.027$, $RMSEA = 0.087$ with 90 % $CI = 0.070$ to 0.105).

Fig. 2 shows direct effects and Table 8 provides information about indirect and total standardised effects on intention to adopt solar PV panels. The significant effects on attitude were positive from economic and environmental benefits ($\beta = 0.46$) and environmental values ($\beta = 0.15$), and negative from non-economic barriers ($\beta = -0.17$). The three significant direct effects on intention to adopt were

Table 5
Summary statistics for the variables used to explain intention to adopt solar photovoltaic systems.

Predictors of Intention to adopt solar PV	*Min-max*	*M*	*SD*	*Md*
Economic and environmental benefits	1–5	3.52	0.70	3.57
Environmental values	1–5	3.86	0.74	4.00
Non-economic barriers	1–5	3.08	0.63	3.00
Economic barriers	1–5	3.77	0.78	4.00
Other benefits	1–5	2.61	0.85	3.00
Peer effects	1–5	2.05	1.40	1.50
Subjective norms	1–5	2.61	0.92	3.00
Perceived behavioural control	1–5	2.62	1.16	3.00
Attitude	1–5	3.52	1.03	4.00
Intention to adopt (Yes) - N (%)	142 (15.0 %)			

Table 6
Direct correlations between key explanatory variables and intention to adopt solar PV panels.

	Intention to adopt
Economic and environmental benefits	0.18**
Environmental values	0.10**
Non-economic barriers	−0.20**
Economic barriers	−0.10*
Other benefits	0.10**
Peer effects	0.23**
Subjective norms	0.28**
Perceived behavioural control	0.21**
Attitude	0.28**

*p < .05; **p < .001.

Table 7
Logistic regression results predicting the intention to adopt residential solar photovoltaic (PV) panels.

Predictor	*OR*	*95 % CI OR*	*p*	*PR*	*95 % CI RR*
Economic barriers	0.658	0.494–0.877	0.004	0.803	0.670–0.961
Subjective norms	2.123	1.570–2.871	<0.001	1.500	1.268–1.775
Perceived behavioural control	1.277	1.043–1.563	0.0018	1.166	1.022–1.331
Attitude	2.393	1.829–3.130	<0.001	1.773	1.432–2.194
Type of residence (house)	3.846	2.437–6.068	<0.001	2.323	1.716–3.163
Education level (university)	2.961	1.889–4.644	<0.001	1.823	1.390–2.391

OR: Odds ratio (indicates the multiplicative factor of the intention to adopt associated with a unit increase in the predictor, so values statistically significant and higher than 1 mean that the higher the exposure, the higher the response); PR: Proportion ratio (same interpretation as OR but in terms of proportion rather than odds).

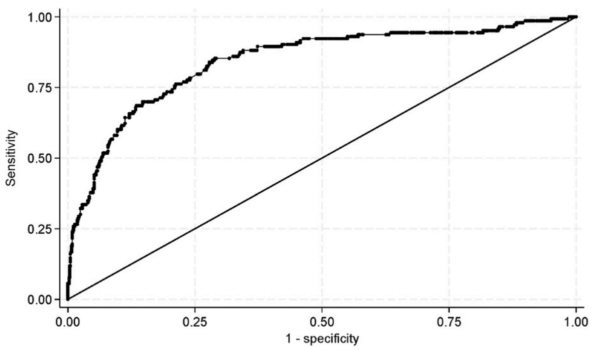

Fig. 1. Predictive accuracy of the logistic model: ROC curve for intention to adopt solar PV panels.

positive, from the maximum of attitude ($\beta = 0.19$) to the lowest of perceived behavioural control ($\beta = 0.08$). Of the set of indirect effects mediated by attitude only that from economic and environmental benefits ($\beta = 0.09$) had a relevant magnitude. With regards to the total effects, attitude ($\beta = 0.19$), subjective norms ($\beta = 0.18$), economic and environmental benefits ($\beta = 0.09$) and perceived behavioural control ($\beta = 0.08$) showed statistically significant standardized coefficients above 0.05.

5. Discussion

5.1. Overview

Understanding the public's attitude towards and intention to adopt solar PV is crucial for the deployment of the technology. Thus, studying the predictors of intention to adopt, as the precursor of eventual adoption, might be relevant for the formulation of evidence-based policies and the orientation of marketing efforts.

The results from PCA revealed that the perceived benefits of and barriers to adopting solar PV panels are not unidimensional. If we consider perceived benefits, PCA results indicate that economic and environmental benefits can be grouped together, while social and aesthetic benefits can be grouped as another factor. Thus, when people consider the benefits of installing solar PV at home, they may consider these two aspects separately. A similar pattern was observed for perceived barriers: participants may consider economic barriers (e.g., initial cost) and financial support (e.g., subsidies or grants) as distinct factors, alongside non-economic barriers such as

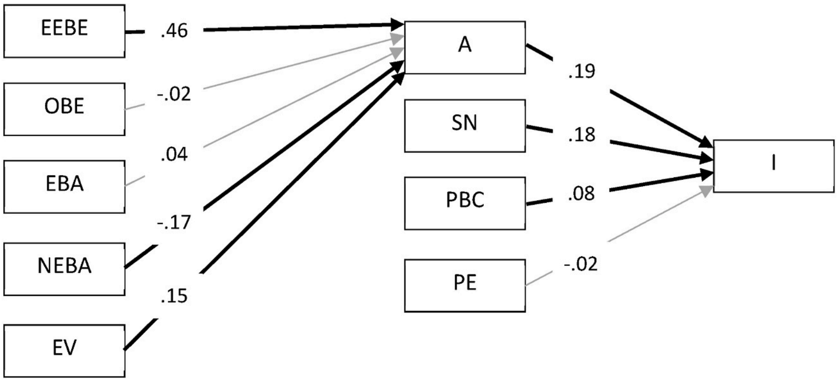

Fig. 2. Proposed model and hypothesized pathways influencing the intention to adopt solar PV panels In bold: statistically significant direct effects. In grey: non-significant direct effects. Covariances among exogenous measures and adjustment by type of housing and education level are not shown.

Table 8
Standardized estimates of indirect and total effects influencing intention to adopt solar PV panels.

	Indirect effect		Total effect	
Predictor	Standardized coefficient	*p*	Standardized coefficient	*p*
Economic and environmental benefits	0.09	<0.001	0.09	<0.001
Other benefits	0.00	0.483	0.00	0.483
Economic barriers	0.01	0.237	0.01	0.237
Non-economic barriers	−0.03	<0.001	−0.03	<0.001
Environmental values	0.03	<0.001	0.03	<0.001
Attitude			0.19	<0.001
Subjective norms			0.18	<0.001
Perceived behavioural control			0.08	0.019
Peer effects			−0.02	0.544

Indirect effects are effects of the predictor on the intention to adopt through attitude. Total effects are the sum of direct (not shown) and indirect effects.

infrastructure difficulties, technical issues, safety concerns, maintenance needs, and aesthetics. In our sample, economic barriers scored higher than non-economic ones, while economic and environmental benefits were rated more prominently than other benefits.

This study also evaluated the capability of six attitudinal attributes (environmental values, peer effects, economic and environmental benefits, other benefits, economic barriers and non-economic barriers), variables of the TPB model (attitude, subjective norms, and perceived behavioural control), and some other potentially relevant variables (socio-demographics and house characteristics) in a logistic regression model, to predict the intention to adopt solar PV.

The findings from the predictive logistic regression analysis highlighted and verified that the TPB variables (especially attitude and subjective norms) were the most important predictors of the intention to adopt solar PV panels at the residential level, while perceived behavioural control was shown to be less relevant. Likewise, the analysis highlighted the importance of economic barriers for decision-making: the greatest economic barriers were associated with a decreased intention to adopt.

Moreover, we found that the type of residence appeared as a very relevant predictor: living in a house instead of a flat or apartment appeared to be the most predictive variable when considering the probability of deciding to install a solar PV system. Having a university education had a similar effect. Thus, these two variables might play an important role in decision-making, and should be considered, together with attitudinal variables, when studying the intention to adopt this technology.

Finally, a path-analysis was carried out to assess an explanatory model of the intention to adopt. The five attitudinal factors found in factorial analysis provided an explanation of the more general attitude construct, which together with the three TPB constructs explained the intention to adopt. It was found that attitude and subjective norms had the highest direct effects when explaining the intention to adopt solar PV. At the same time, perceived environmental and economic benefits appeared as important variables when predicting the intention to adopt, together with non-economic barriers and environmental values, having their influence through attitude. Curiously, the direct and indirect effects of economic barriers were non-significant overall, even though they were a significant predictor of the intention to adopt in the regression model. Peer effects and other benefits have a non-significant effect on attitude and the intention to adopt.

5.2. Comparison with previous research findings

Our empirical results show similarities with, and differences from, those found in other empirical literature on the adoption of solar PV. Regarding the key role of the variables comprising the TPB model, we confirm the evidence from the literature that the strongest relationship was found between attitude and behavioural intention [83]. Our results also corroborate Abreu et al. [21] in that social norms and attitudes were found to have a significant impact on forming intentions to adopt solar PV. Our results, however, contradict the findings of Lundheim et al. [37]. They conducted a cross-sectional survey study in Norway based on an extended version of the TPB model as the main theoretical perspective. By means of SEM analysis to identify significant psychological factors for increasing the adoption of solar panels, they found that perceived behavioural control has the biggest influence on the intention to adopt solar panels. In their study, however, attitude has only a marginally significant impact on intention to adopt. Fatoki [35] also found that attitude and perceived behavioural control were positively related to the intention to purchase solar PV. In the present study, the low t-value of perceived behavioural control means that the perceived difficulty or ease of an individual purchase of solar PV panels would be less influential. This could be explained in part by the fact that the Spanish population has low perceived behavioural control regarding solar PV panels. Perhaps their awareness of government incentives to adopt solar panels is low, while other aspects such as the possibility of an important person approving or disapproving this behaviour (subjective norm) are much clearer to them. It would be interesting in future studies to assess more specifically the beliefs that individuals have about these aspects of solar PV adoption. As highlighted by Klöckner & Nayum [84], the closer an individual gets to behaviour implementation, the more important these issues become.

Concerning the role of perceived benefits and barriers, our results indicate that both are related to attitude. By contrast, Claudy et al. [76] pointed towards a meaningful distinction between attitude, which arises exclusively from positive statements, and perceived behavioural control, which recognises all types of barriers. Their results imply that whereas benefits have a strong and significant positive correlation with attitude, but not with intention, barriers have a moderately significant negative relationship with intention, but not with attitude.

Our results partially validate the earlier findings of Vasseur & Kemp [85] or Jacksohn et al. [64] regarding the key role of costs. The analysis of Jacksohn et al. [64] suggested that economic factors (costs and revenues) were the most important factors for explaining adoption. In their study, environmental concerns had comparatively low relevance. Vasseur & Kemp [85] highlighted the cost of solar PV as an important predictor of adoption or non-adoption. In the Netherlands, they found that for adopters, the costs of adoption were considered affordable whereas for non-adopters they were viewed as being too high. Given that 8 years have passed since this study, this difference in results may be due to the fact that concern about the climate crisis has increased in recent years.

Concerning environmental values, we partially confirmed the findings by Fatoki [35], who conducted a cross-sectional survey to examine the determinants of intention to purchase rooftop solar PV panel systems in residences in South Africa. By means of SEM he found that environmental concern was associated with attitudes to and the intention to purchase solar PV panels. In our study, environmental values were mainly related to attitude, which predicts the intention to adopt. Wolske et al. [86] showed that irrespective of income differences, current solar PV adopters in the US were characterised by strong pro-environmental norms and a strong propensity for early adoption.

As regards peer effect, many studies have confirmed that the propensity to install solar PV panels increases with the number of previously installed systems in spatial proximity, due to social interactions among the individuals [40,41,67,87]. In a more recent study in Sweden, by Mundaca & Samahita [88], results showed that subsidies and peer effects were significant factors driving the likelihood of adopting solar PV. Our findings indicate a moderate and significant bivariate association, but this disappears when other determinants of intention to adopt are taken into account. Peer effects can play an important role when individuals learn from their neighbours, friends and family how to use a technology, but the low adoption rate in Spain may partly explain the low peer effects found in the present study. As noted in the diffusion of innovation theory [89], there are different stages in the decision to adopt a technology: (1) 'not in decision mode', (2) 'deciding what to do', (3) 'deciding how to do it', and (4) 'planning implementation'. Diffusion in this context is described as a form of communication in which innovation is shared through various channels over time among members of a social system. Thus, it is possible that peer effect plays a more important role at a later stage of decision-making.

The role of socio-demographics when predicting intention to adopt new energy technologies has long been discussed. Some authors, such as Alipour et al. [26], suggested that the most frequently applied predictors (age, income, financial knowledge) are less correlated with behaviour than are attitudinal traits. Our findings, nonetheless, indicate a key role for educational level. This substantiates the findings of some previous studies showing that the more highly educated are more likely to adopt solar PV [41,62,65]. The specific role of socio-demographic variables could be related to the socio-economic and cultural context of different countries, so that in some contexts the explanatory power of some demographic variables in the purchase decision would be more important than in others. This would explain the inconsistencies found in various previous studies. In the case of Spain, for example, where education level seems to play an important role, it could be because a certain level of education is still needed to understand the financial costs and benefits of solar PV systems (which is not available for those less educated).

This was also the case for the type of residence, which was revealed in our analysis as a crucial variable when studying the intention to adopt solar PV. The meta-analysis by Schulte et al. [25] suggested the presence of a variety of moderating variables that could be linked to, among others, the technical condition of the respondent's house. However, our findings did not confirm those of some previous studies, which reported that homeowners may be more likely to install than tenants [40,61,73].

5.3. Implications

These findings have important theoretical and practical implications. First, at the theoretical level, the usefulness of extending the TPB has been confirmed because, although the variables of this model have important predictive power, there are other variables that have also been shown to play a relevant role in predicting the intention to adopt solar PV panels, such as perceptions of benefits and barriers. Therefore, it has been shown that there is a need to move towards more holistic models that provide a broader view of individual adoption of this technology.

Second, given the significance of attitudinal variables in the prediction of the intention to adopt solar PV, it would be important to consider these variables in communication campaigns, to better orientate marketing efforts. By this we mean that when it comes to explaining why people want to adopt this technology, the attitudinal part (i.e., people's mental disposition) is very important. Subjective norms, i.e., each person's individual perception of what is right or wrong, also play a role. Thus, we cannot limit the prediction of behaviour solely to the actual costs and benefits. As highlighted by Ahmed et al. [83], attitude is the ideal attribute to measure when determining intention and later solar PV adoption by consumers. This is why it was suggested that attitude is a crucial determinant of intention to use solar PV.

Based on our findings, we tentatively suggest some implications for public communication on solar PV panels, that could benefit marketers or companies in the renewable energy sector when it comes to strengthening promotion strategies linked to solar PV. Market communication campaigns may use subjective norms in order to increase the intention among the general population to buy this technology, by showing that it is the right thing to do both for the environment and the household economy. Our model showed that the perceived economic and environmental benefits of solar PV adoption may have the greatest direct impact on people's intention to adopt this technology. Therefore, the perception of economic and environmental benefits is likely to increase adoption, while denial of difficulties or (non-economic) barriers will reduce it. In order to instil a positive attitude towards the technology, campaigns might emphasise the accrual of technology benefits, both economic and environmental, and the reduction of non-economic barriers. As suggested by Lundheim et al. [37], these results provide suggestions for shaping pro-solar PV messages for the target group of people who are positive towards solar panels but have not yet decided to install. Taking our findings into account, people with a university degree could be a first and easier target for communication campaigns, as well as those living in a house instead of a flat.

Our findings might also be helpful to policymakers in the formulation of evidence-based policies. Policymakers might consider the need to take the social dimension into account when designing, implementing and evaluating public policies for energy transition. After all, citizens are the end users of renewable technologies, so it is very important to know why people decide to buy a technology and why they don't.

In this case, the model revealed that perceived benefits are more important than barriers in predicting adoption intention. In this sense, public policies must be directed towards promoting and facilitating these benefits, both environmental and economic. For example, if public policies make it easier for those who adopt the technology to reap better and faster economic benefits, the adoption rate is likely to increase.

5.4. Limitations and future research recommendations

We would like to highlight some weaknesses in our study. Regarding the scope of work, we may have overlooked some other potentially relevant attitudinal variables that have been pointed out in the pre-existing literature, such as novelty seeking, technological affinity, awareness and knowledge. Nonetheless, these variables go beyond the parameters of our project.

Regarding the sample, we focused on the general population of non-adopters but, in fact, not all the participants had a realistic possibility of installing solar PV at home. For instance, some of them were not owners of their property and others lived in a flat or an apartment, where it is more difficult to install. As in other previous studies worldwide [21,45,77,90], we focused on non-adopters, because this target population is the most interesting for industry and policy makers as future potential adopters of this technology. This could narrow the generalisability of our findings to the whole population (that includes adopters and non-adopters). Nevertheless, our results can be generalised to any western culture similar to Spain and with similar cultural context, energy policies, or climatic conditions.

Regarding the design of the survey, we used single-item measures for the constructs of the TPB model. Although it is considered reasonable to develop a single-item measure when the construct is concrete and well defined [91], it is not possible to contrast the reliability of these measures with other constructs in which the multi-item approach has been used.

Regarding the method, there is possible bias associated to the use of self-reported measurements. However, social desirability was counterbalanced by the anonymity and by the fact that there is no financial or other reward for particular responses. Future longitudinal studies would be beneficial to study the well know gap between self-reported intentions and real adoption behaviour.

Finally, there remain several avenues for future research. First, the study of and comparison among a sample of adopters would be of great interest. As suggested by Vasseur & Kemp [85] there could be relevant differences among them in terms of what they value more (benefits or costs). It would also be interesting to assess what kind of benefits are more powerful when considering the adoption of solar PV. In that sense, Schelly & Letzelter [92] find that, for adopters, environmental motivations were slightly more important than economics. Conversely, Zander et al. [93] revealed that economic considerations were of higher importance than environmental motivations. Similarly, Scheller et al. [51] reported that while environmental benefits are important in developing positive attitudes towards low carbon technologies, the perceived financial benefits associated with the technology become a more crucial evaluative criterion as homeowners progress through the decision-making process.

In carrying out survey experiments, such as the one developed by Wolske et al. [86] or Mundaca & Samahita [88] in Sweden, it would be interesting to explore the effects of message framing on consumer behaviour. Economic factors, environmental responsiveness, and social norms could be explored as potentially effective message frames. Additionally, experimental studies on the impact of financial literacy and innovation-seeking behaviour would provide valuable insights.

In future studies, it would also be interesting to explore the role of different population profiles in terms of socio-demographics and house characteristics, as well as studying regional and cultural inclinations towards solar PV panels by means of cross-country comparative studies. As suggested by Wolske et al. [86], 'tailoring messages to targeted consumer segments may be more effective than attempts to market the financial benefits of PV to broad audiences'. Moreover, a detailed analysis of the cost-benefit ratio of installing solar PV systems would perfectly complement attitudinal studies.

CRediT authorship contribution statement

Roser Sala: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Silvia Germán:** Writing – original draft, Methodology, Investigation, Conceptualization, Data curation, Writing – review & editing. **M. Carmen Alonso-García:** Writing – original draft, Supervision, Project administration, Funding acquisition, Conceptualization, Methodology, Writing – review & editing. **Félix García-Rosillo:** Writing – review & editing, Conceptualization, Methodology, Validation, Writing – original draft. **José- Blas Navarro:** Writing – original draft, Methodology, Formal analysis, Data curation, Writing – review & editing.

Declarations

The authors declare that they did not use AI or AI-assisted technologies in the writing process of this manuscript.

Data availability statement

Data are available on request.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Roser Sala reports financial support was provided by Spain Ministry of Science and Innovation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

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