



Exploring the adoption of plug-in solar devices ('balcony power plants'): the role of economic, technological, and ecological considerations among different consumer attitudes – an evidence from Germany

Khanh Nguyen¹ · Simon Stahlschmidt² · Bettina Lis¹

Received: 5 September 2025 / Revised: 30 March 2026 / Accepted: 17 May 2026
© The Author(s) 2026

Abstract

Despite the rapid increase in the use of plug-in solar devices in Germany, the adoption drivers remain insufficiently differentiated across consumer segments. The present study examines the impact of economic, technical, and ecological determinants on the adoption of the mini photovoltaic systems and compares the groups of owners ($N=111$), interested ($N=110$), and rejecters ($N=139$) with each other, using a PLS-MGA. The findings indicate that technical aspects tend to be less influential compared to sustainability-related factors, notably sustainability expectations and pro-environmental behaviour, which are significant drivers for the adoption. Conversely, performance expectancy and social influence are more pronounced among the group of rejecters. These insights imply that effective promotional strategies must concurrently enhance sustainability motivation and reduce technological scepticism.

Keywords Renewable energy · Solar · Usage behavior · Environmental behavior

1 Introduction

To implement the Paris Climate Agreement, the signatory states have formulated their own Nationally Determined Contributions (NDCs). These include national laws, support measures, and economic incentives to achieve the global climate targets (United Nations, 2016). Germany, being one of the countries committed to this, is already aiming for climate neutrality by 2045 - five years earlier than the agreed global target for CO₂ neutrality (Federal Ministry for Economic Affairs and Climate Action 2021). In order to achieve this goal, German climate policy is focusing in particular on the massive expansion of renewable energies. For example, the electricity sector is to be converted to at least 80% renewable energy sources by 2030. The Renewable Energy Sources Act ('Erneuerbare Energien Gesetz') (Federal

Ministry of Justice and Consumer Protection, 2014) is one of the most important legal foundations for the expansion of electricity grids and storage capacities. The urgency to develop alternative energy sources became apparent with the energy crisis in 2022, triggered by the war in Ukraine and the loss of Russian gas supplies. Rising energy prices put considerable pressure on German politicians and forced them to act (Konopelko et al. 2023). As a result, support measures were increased and regulatory processes simplified in order to promote the expansion of solar and wind power significantly. This included the promotion of plug-in solar devices for self-consumption of electricity (Federal Ministry for Economic Affairs and Climate Action 2021).

A plug-in solar device, also known as a balcony power plant or 'mini photovoltaic system', converts sunlight into climate-friendly household electricity. Technically, it is 'a device consisting of a solar system or several solar systems, an inverter, a connection cable and a plug for connection to the final circuit of an end consumer' (Federal Ministry of Justice and Consumer Protection, 2025). Unlike conventional photovoltaic systems, the use of a plug-in solar device does not require a large area but can be installed as a small system on balconies, terraces, or other external wall

✉ Khanh Nguyen
khanh.nguyen@uni-bayreuth.de

¹ Chair of General Business Administration, University of Bayreuth, Universitaetsstrasse 30, 95447 Bayreuth, Germany

² University of Bayreuth, Bayreuth, Germany

surfaces. This means that tenants in apartment buildings in urban areas in particular, can install the solar modules and generate their own (green) electricity without having to use large areas (Valdivia-Sisniegas 2023). The installation of plug-in solar devices is also comparatively simple and can be done by the user, meaning that professional installation is not necessary (Gögelein et al. 2024). Connection to the domestic grid is just as simple. In the simplest case, only a plug is inserted into an existing socket. The electricity produced can then be used directly. How much electricity a plug-in solar device can generate depends on the location and the performance of the solar system (Valdivia-Sisniegas 2023). If the solar modules are optimally aligned, a standard 800-watt balcony power plant can generate approx. 500–600 kWh of green electricity per year and is therefore able to cover approx. 20% of the electricity consumption of a two-person household with an average electricity consumption of 2000 kWh per year (Solar storage systems research group HTW Berlin, 2024). The electricity generation costs from the solar system are significantly lower than the conventional electricity procurement costs (Fraunhofer 2024). The fact that plug-in solar devices are comparatively inexpensive, have a useful life of 20 to 30 years, and are subsidized by the state through tax breaks, makes switching to renewable energy particularly attractive to many private households from a financial perspective (Federal Environment Agency, 2025). According to the Federal Network Agency and its market master data register, more than 800,000 plug-in solar devices have already been installed on German balconies and terraces since the beginning of 2025. Compared to the previous year, the number of systems has thus doubled (Market master data register, 2025). At the international level, however, there is still potential for plug-in solar devices to penetrate the market. There is high demand in both the USA (Gerber et al. 2025) and Hungary (Molnár and Szép 2025), but grid-related challenges and regulatory hurdles are significantly hindering adoption. In Austria, on the other hand, plug-in solar devices are enjoying great popularity as part of the general photovoltaic boom, which is why thousands of mini-photovoltaic systems have already been installed on balconies and in gardens in the capital of Vienna (Pallinger 2024).

In the context of the increasing demand for plug-in solar devices, the following question is posed: Which influencing factors determine the adoption of plug-in solar devices and contribute to specifically promoting their use in the future? As far as we know, there have been no studies on the adoption of the technology on the German market. In the international context, Molnár and Szép (2025) have examined the adoption of plug-in solar devices for the Hungarian market using the Unified Theory of Acceptance and Use of Technology (UTAUT2).

Our study is part of the research field on the use of photovoltaic systems. We focus on mini-photovoltaic systems and examine the factors influencing the intention to use them. In doing so, we are contributing to the field of research that has only been scientifically investigated to a limited extent to date. In addition to the technical aspects, we also consider economic and ecological factors that lead to the intention to use, in order to obtain a more comprehensive overall picture. We also analyze the importance of these factors for different user groups, in order to gain differentiated insights into the adoption of plug-in solar devices. This understanding can help policymakers and industry representatives to develop more targeted promotional measures to further drive uptake and thus the energy transition.

Our paper is structured as follows: Firstly, the development of plug-in solar devices in Germany will be outlined. The subsequent presentation of the theoretical foundations of technology adoption is then followed by a review of prior research on the acceptance of solar devices. Based on these insights, the conceptual framework is introduced, and the hypotheses are developed. The subsequent methodology section describes the sample, data collection process, and study design in detail. The results section reports the findings of the PLS-SEM and PLS-MGA analyses. Finally, the paper discusses the theoretical and practical implications before concluding with a summary of the main results, a critical reflection on the study's limitations, and directions for future research.

2 Theoretical background and literature review

2.1 The development of plug-in solar devices in Germany

Photovoltaic systems facilitate electricity generation with zero CO₂ emissions, thereby contributing significantly to the energy transition (Best et al. 2019; Shakeel et al. 2023; Paramita et al. 2024). Plug-in solar devices are a subcategory of this technology, characterized by their small footprint, manageable installation costs, and comparatively low purchase price (Gögelein et al. 2024). This leads to shorter payback periods compared to conventional roof systems, meaning a plug-in solar device can pay for itself in just three to ten years. Additionally, after a year or two, these devices generate as much energy as is required for their production and disposal (Federal Environment Agency, 2025; Solar storage systems research group HTW Berlin, 2024). From economic and ecological perspectives, plug-in solar devices are an efficient alternative for the decentralized generation of electricity (Fraunhofer 2024).

Despite their advantages, the spread of plug-in solar devices in Germany was restricted for a long time due to the institutional and regulatory hurdles (VDE Association for Electrical, Electronic & Information Technologies, 2017). It was not until 2021, when the federal government recognized their potential for generating electricity for personal use in densely populated urban areas, that administrative hurdles were removed, grid connection procedures were simplified, and financial incentives were created (Federal Ministry for Economic Affairs and Climate Action 2021). Political reforms (Federal Ministry for Economic Affairs and Energy, 2024) and technological product developments (Spaeth et al. 2023) have contributed to a growing share of self-consumption in solar electricity generation. Consequently, the number of registered plug-in solar devices in Germany grew to nearly one million by early 2025 (Market master data register, 2025). This technology has been particularly successful in urban households with limited or no access to their own roof space (Valdivia-Sisniegas 2023), evolving from a niche technology to a viable alternative for renewable electricity generation.

2.2 Theoretical foundations of technology adoption

The field of technology adoption research has been significantly influenced by psychological theories concerning human behavior. Among the most influential behavioral models are the Theory of Reasoned Action (TRA) by Fishbein and Ajzen (1975) and the Theory of Planned Behavior (TPB) by Ajzen (1985). The TRA explains behavioral intention and, consequently, behavior by assuming that attitude toward behavior and subjective norm are decisive factors (Fishbein and Ajzen 1975). The TPB extends the approach by incorporating perceived behavioral control, which is defined as the subjective perception of ease or difficulty in executing the behavior (Ajzen 1985).

In contrast to behavior-oriented perspectives, diffusion and technology acceptance models emphasize the perception and evaluation of innovation characteristics as key determinants of adoption. These include the Innovation Diffusion Theory (IDT) (Rogers 2003), the Technology Acceptance Model (TAM) (Davis 1989), and the Unified Theory of Acceptance and Use of Technology (UTAUT/UTAUT2) (Venkatesh 2003, 2012).

Rogers' IDT conceptualizes the adoption of an innovation as a process by which it is spread through various communication channels within a social system over time. The rate of adoption is influenced by the perceived attributes of the innovation: relative advantage, compatibility, complexity, trialability, and observability (Rogers 2003).

In contrast, the TAM by Davis (1989) focuses on individual cognitive evaluations of the technological attributes.

The behavioral intention is determined by the attitude toward using, perceived usefulness, and perceived ease of use (Davis 1989).

However, when technologies are understood as socio-technical systems, decisions about adoption go beyond technological perceptions and also include social influences, organizational, and facilitating conditions. The UTAUT approach by Venkatesh et al. (2003) integrates these individual, social, and contextual determinants into a unified framework. The key factors to be considered are performance expectancy, effort expectancy, social influence, and facilitating conditions for examining the behavioral intention and the use behavior. To provide a more comprehensive explanation of technology acceptance in the consumer use context, Venkatesh et al. (2012) expanded the original model to include hedonic motivation, price value, and habit in UTAUT2.

While these models differ in their emphasis, they share the assumption that adoption decisions are shaped by a combination of cognitive evaluations, social influences, and contextual conditions. These theoretical perspectives provide the conceptual foundation for analyzing consumer adoption behavior of photovoltaic systems.

2.3 Empirical evidence on household solar photovoltaic adoption

Research on plug-in solar devices has been addressing technical performance (Tian et al. 2023; Valdivia-Sisniegas 2023; Gögelein et al. 2024), economic efficiency (Spaeth et al. 2023; Seme et al. 2024), and environmental sustainability (Wirth 2025). However, there is a lack of research on the behavioral determinants of adoption. To address this gap, it is recommended that the extant literature on the adoption of privately used photovoltaic systems be consulted, as these systems have a similar technological basis.

In the context of TRA and TPB, the adoption of photovoltaic systems is influenced by individual motives such as the pursuit of social status, self-sufficiency, and financial benefits. However, high costs, expenses, and risks associated with solar systems have a negative influence on the attitude towards photovoltaics (Korcaj et al. 2015; Jacksohn et al. 2019; Le and Tran 2024). Additionally, studies demonstrate that the attitude towards renewable technologies is influenced by green attributes like ecological beliefs and knowledge of renewable energies (Palm and Tengvard 2011; Düştegör et al. 2018).

Empirical studies applying Rogers' IDT to the adoption of photovoltaics have identified cost considerations as a central determinant. As demonstrated by Qureshi et al. (2017) in the context of Pakistan and Simpson and Clifton (2017) with regard to Western Australia, financial aspects have been

identified as key drivers. However, Simpson and Clifton (2017) demonstrate that for early adopters, technical performance and environmental considerations are more decisive than economic motives. Similarly, Kumar et al. (2024), using structural equation modeling in the Indian context, conclude that perceived technical and ecological benefits foster adoption, whereas high upfront costs and insufficient financial incentives hinder it.

Various studies have been conducted on the interaction between users and photovoltaics, drawing upon the TAM. Empirical findings indicate that perceived usefulness and perceived ease of use significantly influence attitude formation (Ahmad et al. 2017; Tsaur and Lin 2018; Bouaguel and Alsulimani 2022). In addition, environmental awareness strengthens attitudes toward adoption, reflecting the relevance of solar modules' renewable energy potential (Tsaur and Lin 2018).

When photovoltaic adoption is conceptualized within a broader socio-technical framework, the UTAUT/UTAUT2 is frequently applied. Molnár and Szép (2025) have provided one of the few empirical studies examining the technological acceptance of plug-in solar devices. Focusing on the Hungarian market, their results indicate that all examined determinants, performance expectancy, social influence, facilitating conditions, hedonic motivation, and price value, significantly influence behavioral intention, whereas effort expectancy does not show a significant effect. The effort required for installation and use is not a critical factor, suggesting that the technology is perceived as uncomplicated and user-friendly. The authors have emphasized that the existing infrastructure, the expected performance, and the price-performance ratio are particularly decisive for adoption (Molnár and Szép 2025). In relation to conventional photovoltaic systems, Roy and Mohapatra (2022) report positive effects of performance expectancy, effort expectancy, social influence, and hedonic motivation on behavioral intention. While Aggarwal et al. (2019) emphasize social beliefs and effort expectancy, Bektı et al. (2022) highlight the importance of price value within UTAUT2.

Finally, recent studies have increasingly employed a combination of the aforementioned models to achieve a more comprehensive explanation of acceptance behavior (Alam et al. 2021; Wolske et al. 2017; Anjum and Subhan 2024). This approach mirrors the multi-stage and systemic nature of technology acceptance.

3 Conceptual framework and hypotheses development

3.1 Conceptual framework

Using the theoretical findings from previous research on large-scale photovoltaic systems as a foundation, we have

developed a conceptual framework that considers the unique characteristics of plug-in solar devices. Compared to conventional photovoltaic systems, plug-in systems require less financial and practical effort, making the technology more accessible and consumer-oriented, where individual evaluation is essential to the purchase decision.

In accordance with the technology adoption research, we conceptualize attitude as a pivotal construct that links the perceived characteristics of the technology with behavioral intention. However, it is important to note that the decision to purchase a product is not solely determined by cognitive evaluations of its technological characteristics. Instead, it is influenced by a complex interplay of social and contextual factors. Given the contemporary designation of plug-in solar devices as green technologies, environmental factors are recognized as significant influencing elements.

Accordingly, the proposed framework integrates individual evaluations, social influences, and environmental factors to explain the intention to use plug-in solar devices. The hypotheses developed in the following section are predicated on this structure.

3.2 Attitude

Attitude (ATT) is generally understood as the evaluation of behavior that results from personal beliefs on the one hand and the expected consequences of the action on the other (Fishbein and Ajzen 1975; Davis 1989). In the context of research on sustainable behavior, attitude has emerged as a consistent predictor of usage decisions. Empirical studies in the areas of green consumption (Sreen et al. 2018; Kamalanon et al. 2022), sustainable mobility (Haustein and Jensen 2018; Moons and Pelsmacker 2015), and the adoption of photovoltaic systems (Sun et al. 2020; Kesari et al. 2021; Fatoki 2022) have been consistent in suggesting that a positive attitude is related to the intention to use.

However, it should be noted that a positive attitude does not necessarily lead to an intention to use or to actual behavior. Research has demonstrated the presence of discrepancies between attitude and intention, as well as between intention and behavior. This suggests that positive evaluations may not necessarily result in the formation of concrete intentions to act, thereby remaining unfulfilled (Sheeran and Webb 2016). This discrepancy is particularly pronounced in the domain of sustainable products and technologies, where contextual and structural constraints, such as high costs, limited access to reliable information, and infrastructural requirements, impede the translation of environmentally friendly attitudes into actual purchasing decisions (Peattie 2010; Claudy et al. 2013; Echegaray and Hansstein 2017).

The findings from research on the adoption of photovoltaic systems suggest that not all information influences

the implementation process equally. As demonstrated by Goodarzi et al. (2021), the dissemination of general, non-individualized information has been shown to positively influence attitudes toward photovoltaic systems. However, this information does not appear to have a significant impact on the actual adoption of these systems. Conversely, the translation of positive attitudes into concrete actions is more likely to be facilitated by specific and credible information from independent sources.

These findings imply that the relationship between attitude and intention remains salient, yet its strength is contingent on contextual factors. Consequently, attitude should be understood more as a basis for evaluation, whose behavioral relevance depends on the presence of conducive, structural, and informational conditions.

Based on the extant behavior-oriented models and the studies enumerated, the following hypothesis is postulated for the present study, notwithstanding the discussed attitude-intention gap: The attitude toward plug-in solar devices has a positive effect on the intention to use.

3.3 Performance expectancy

Performance expectancy (PE) is defined as the extent to which an individual believes that the utilization of a technology will assist them in achieving personal or task-related objectives and enhancing performance outcomes (Venkatesh 2003). Within the UTAUT, performance expectancy functions as an expectancy of use of the technology. Consequently, it is conceptualized as a direct determinant of behavioral intention.

According to Fishbein and Ajzen (1972), expectancy of use is a central predictor of cognitive attitude formation. Consequently, performance expectancy can be comprehended beyond its role in UTAUT as an anticipated outcome of action that serves as the cognitive basis for attitudes toward a technology. Empirical studies support this relationship, demonstrating that the perceived instrumental benefits of using technology are strongly associated with a more positive attitude toward the technology in question (Park et al. 2007; Rana et al. 2017; Dwivedi et al. 2019). Correlations of a similar nature have been observed in connection with renewable energy technologies. In these cases, expectations of functional and performance-related benefits have been shown to contribute to a positive evaluation of these technologies (Aggarwal et al. 2019; Roy and Mohapatra 2022; Ahn et al. 2016).

In light of the theoretical considerations and relevant empirical findings, the following hypothesis is formulated: Performance expectancy has a positive effect on attitude toward plug-in solar devices.

3.4 Effort expectancy

Effort expectancy (EE) describes the degree to which a person believes that the use of the technology is easy to learn and implement. Users tend to prefer technologies that are perceived as intuitive, easy to understand, and low in complexity (Venkatesh 2003).

Beyond its role as a predictor of behavioral intention within the UTAUT framework, effort expectancy can also be understood as a cognitive evaluation of anticipated usage effort. Technologies that are perceived as easy to use are associated with lower cognitive effort and fewer anticipated barriers to use, which contributes to a more favorable evaluative attitude toward the technology. This assertion is corroborated by empirical evidence. For instance, Rana et al. (2017) and Dwivedi et al. (2019) demonstrate that effort expectancy exerts a direct effect on attitude and an indirect effect on behavioral intention, which is mediated by attitude. This finding indicates that perceived ease of use plays a significant role in the cognitive evaluation of technologies.

With regard to the plug-in devices, the evaluation of said devices could depend on the perceived complexity of commissioning and maintenance. Technologies that are expected to function without professional installation and enable the generation of electricity through a simple plug-in connection are therefore likely to be perceived as comparatively user-friendly (Gögelein et al. 2024).

Based on this, we formulate the following hypothesis: Effort expectancy has a positive effect on attitude toward plug-in solar devices.

3.5 Social influence

Social influence (SI) is defined as the degree to which an individual perceives that important others believe he or she should use the new system (Venkatesh 2003). In the absence of prior experience with an unfamiliar technology, uncertainty can emerge. The provision of informative support by trusted individuals has been demonstrated to reduce uncertainty and perceived risk, which in turn affects attitudes toward the technology (Thakur and AlSaleh 2019; Bo and Ma'rof 2024). In this context, studies such as those by Kim and Srivastava (2007) and Bo and Ma'rof (2024) demonstrate that trust in the social environment encompasses reviews and testimonials on social networks.

Beyond the realm of information mechanisms, social influence also operates through normative pressures, such as conformity, social belonging, and the aspiration for social acknowledgment (Hamari and Koivisto 2015). The observable utilization of a technology within a social or spatial context can serve as 'social proof', thereby exerting a positive influence on the technology's perceived value.

Empirical studies on the adoption of photovoltaic systems demonstrate that the visibility of solar systems enhances individuals' self-perception and intention to utilize them (Graziano and Gillingham 2015; Rode and Müller 2019).

The integration of both informative and normative mechanisms indicates that social influence has the capacity to influence the development of attitudes towards technology. Therefore, the following hypothesis is proposed: Social influence has a positive effect on attitude toward plug-in solar devices.

3.6 Sustainability expectancy

Since plug-in solar devices are a sustainable technology for generating and using green electricity, previous studies have suggested that an ecological dimension should be included in the acceptance model (Shahzad et al. 2022; Neves et al. 2025; Ahn et al. 2016). Being consistent with prior research on perceived environmental benefits (Korcaj et al. 2015) and green innovations (Chen et al. 2006), we operationalized sustainability expectancy (SE) as the degree to which an individual perceives that adoption of a renewable energy technology will lead to significant environmental benefits.

Perceived environmental benefits can activate moral beliefs and prosocial values, thereby promoting a more positive attitude (Hamari et al. 2016). Additionally, the perceived environmental friendliness of a product can serve as a unique selling point, indicating higher quality or superior value for money (Peattie 2010). In the context of solar energy, perceived collective environmental benefits significantly contribute to opinions about photovoltaic systems (Korcaj et al. 2015), and environmental protection motives are often cited as key drivers of adoption (Palm and Tengvard 2011; Corbett et al. 2022).

Overall, expected sustainability outcomes are an important factor in attitudes toward plug-in solar devices. We therefore propose the following hypothesis: Sustainability expectancy has a positive effect on attitude toward plug-in solar devices.

3.7 Pro-environmental behavior

In contrast to sustainability expectancy, which refers to technology-specific expectations regarding environmental performance, pro-environmental behavior (PEB) represents a general behavioral disposition. This awareness is accompanied by a heightened environmental consciousness and ecological commitment, encompassing deliberate, voluntary actions aimed at minimizing environmental degradation and fostering a sustainable lifestyle (Kollmuss and Agyeman 2002). Individuals who possess a strong environmental awareness and commitment to sustainability actively seek

opportunities to engage in environmental protection (Hinds and Sparks 2008; Verplanken 2018). This encompasses the integration of sustainable technologies into daily living. Research in this area indicates that pro-environmental behavior has a positive effect on the intention to use sustainable technologies (Laureti and Benedetti 2018; Vorobeve et al. 2022; Adeel et al. 2024). In the context of solar energy, personal environmental awareness has been shown to significantly increase the likelihood of using photovoltaic systems (Stikvoort et al. 2020; Ghosh and Satya Prasad 2024).

Given the technological underpinnings and environmental advantages of plug-in solar devices, it is reasonable to hypothesize that eco-conscious behavior will positively influence the intention to use such devices. In consideration of the aforementioned points, the following hypothesis is hereby proposed: Pro-environmental behavior has a positive effect on the intention to use plug-in solar devices.

3.8 Price value

Price value (PV) is defined as the cognitive compromise between the perceived benefits of a technology and its associated costs. In instances where the estimated benefits exceed the costs, this has been demonstrated to positively influence the intention to use the technology (Venkatesh 2012). Empirical studies have demonstrated that price value exerts a significant influence on the intention to utilize technologies, particularly those that offer functional, monetary, and utilitarian benefits (Tamilmani et al. 2018).

In the context of sustainable technologies, ecological aspects are also increasingly being included in cost-related assessments. Research conducted by Khazaei (2019) and Vafaei-Zadeh et al. (2022) indicates that when consumers evaluate the price-performance ratio of electric vehicles, they consider not only personal and functional criteria but also environmental criteria, such as the reduction of CO₂ emissions. In relation to the adoption of photovoltaic systems, Lau et al. (2020) and Bektı et al. (2022) demonstrate that environmental factors, including sustainable energy consumption and long-term energy savings, play a substantial role in the positive evaluation of cost-effectiveness. Based on this, we formulate the following hypothesis: Price value has a positive effect on the intention to use plug-in solar devices.

To synthesize the theoretical argumentation conceptually, Table 1 summarizes the central constructs and their definitions, whereas Table 2 provides a comprehensive overview of the hypotheses derived from this study. Figure 1 integrates the derived causal relationships into a closed model structure. This research model provides the conceptual foundation for the subsequent empirical investigation.

Table 1 Theoretical definition of model constructs

Construct	Abbr.	Definition
Performance expectancy	PE	Performance expectancy is defined as the degree to which an individual believes that using the system will help him or her to attain gains in job performance (Venkatesh et al., 2003).
Effort expectancy	EE	Effort expectancy is defined as the degree of ease associated with the use of the system (Venkatesh et al., 2003).
Social influence	SI	Social influence is defined as the degree to which an individual perceives that important others believe he or she should use the new system (Venkatesh et al., 2003).
Sustainability expectancy	SE	The degree to which an individual perceives that adoption of a renewable energy technology will lead to significant environmental benefits. (Chen et al. 2006; Korcaj et al. 2015)
Attitude	ATT	An individual's positive or negative feelings about performing the target behaviour (Fishbein and Ajzen 1975; Davis 1989).
Pro-environmental behavior	PEB	Pro-environmental behavior mean a behavior that consciously seeks to minimize the negative impact of one's actions on the natural and built world (Kollmuss and Agyeman 2002).
Price value	PV	A consumer's cognitive tradeoff between the perceived benefits of the applications and the monetary cost of using them (Venkatesh et al., 2012).
Behavioral intention	BI	Behavioral intention is defined as a measure of the strength of one's intention to perform a specific behaviour (Fishbein and Ajzen 1975).

Table 2 Model hypotheses

H1	Performance expectancy has a positive effect on attitude toward plug-in solar devices.	PE → ATT (+)
H2	Effort expectancy has a positive effect on attitude toward plug-in solar devices.	EE → ATT (+)
H3	Social influence has a positive effect on attitude toward plug-in solar devices.	SI → ATT (+)
H4	Sustainability expectancy has a positive effect on attitude toward plug-in solar devices.	SE AT → T (+)
H5	The attitude toward plug-in solar devices has a positive effect on the intention to use.	ATT → BI (+)
H6	Pro-environmental behavior has a positive effect on the intention to use plug-in solar devices.	PEB → BI (+)
H7	Price value has a positive effect on the intention to use plug-in solar devices.	PV → BI (+)

4 Methodology

4.1 Sample and data collection

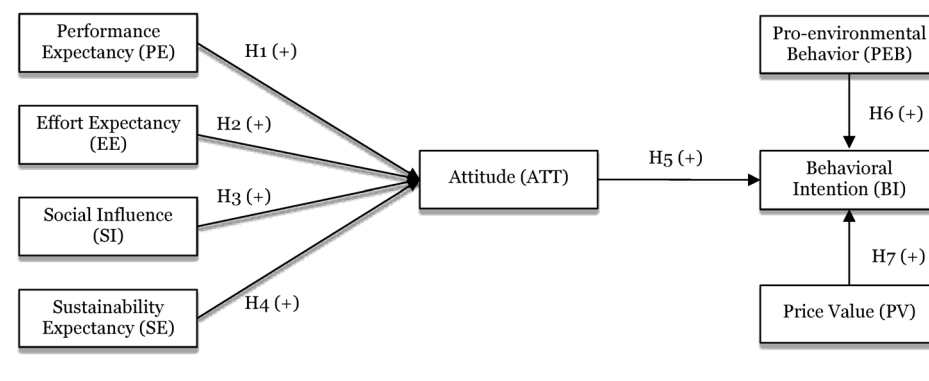
To empirically test the proposed model, a cross-sectional survey design was utilized. We collected the data through an online survey platform called LimeSurvey, targeting individuals living in Germany with varying levels of interest in plug-in solar devices. In principle, anyone over the age of eighteen could take part in the study. Participants were recruited via social media platforms. We also posted our questionnaire in social media forums dedicated to the use of photovoltaic systems. The participation was voluntary and

anonymous. The participants were informed that there were no correct or incorrect answers in completing the questionnaire. The online survey was administered in January 2025.

The questionnaire was structured in three sections. At the beginning, the technology of plug-in solar devices was introduced briefly to introduce the participants to the topic and ensure that everyone started from the same technical basis. In order to avoid any potential distortions due to prior information, the functionality was presented in a neutral manner. Subsequently, participants were asked whether they owned such a plug-in solar device. Those who did not were further asked to indicate whether they were generally not interested in adopting one or whether they intended to purchase one in the future. Participants expressing purchase intention were then requested to specify the anticipated time frame of adoption (within the next few months, within 6 to 12 months, within 1 to 2 years, or in more than two years). Most indicated either a near-term (approx. 36%) or a long-term purchase period (32%). Table 3 shows the purchase periods of the interested respondents.

The second part of the survey contained the construct measurement items. The questionnaire concluded with demographic questions.

A total of 398 responses were obtained. To ensure the quality of the data and limit the potential methodological errors, we integrated attention questions according to the recommendations of Hair et al. (2018). Participants who

Fig. 1 Research model**Table 3** Planning periods for the purchase of a plug-in solar device

Time Horizon	Soon In the next months	Short-term In 6–12 months	Medium-term In 1–2 years	Long-term In > 2 years
Interested (N=110)	39	18	18	35

answered these control questions incorrectly were excluded as part of the data cleansing process, as were people with incomplete questionnaires, a much faster than average processing time, or conspicuous response patterns that indicated arbitrary answers (Hair et al. 2018). After data cleansing, we had 376 fully analyzable data sets at our disposal. Of these, 111 said they already owned a plug-in solar device (owners), 110 said they were interested and had plans to buy one (interested), and 139 said they would not use or buy one (rejecters). With regard to the reasons given by them, around 49% stated lack of space or lack of suitable space as the main reason. Other reasons given were a lack of knowledge and experience of the technology (19%), investment costs being too high (14%), and owning a large solar system, which is why an additional smaller system seems superfluous (10%). A total of 16 respondents did not select any of the three options, indicating that they were not allocated to any of the groups.

To ensure a required minimum sample for the main groups (owners, interested and rejecters), we did a post-hoc power analysis using G*Power (Faul et al. 2009). This indicated that the smallest subgroup size (interested, $N=110$) exceeded the minimum size of 85 to detect medium effects of 0.15 with statistical power of 80% at a significance level of 5%.

In terms of the demographic data of our total sample of 376 participants, just under 65% were male. The average age was 41 years. Around 45% had a university degree. Over 72% were in permanent employment. In terms of monthly net income, just under 57% earned more than €2,000, with the majority earning between €2,001 and €3,000.

However, a detailed look at the three subgroups indicated clear differences. The group of owners of plug-in solar devices had demographic characteristics that were largely in line with the results of the study by the Solar storage systems research group HTW Berlin (2022) on the characteristics of German plug-in solar device users: In our sample, 90% of users were male, the average age was 48 and just under 47% had an academic degree. In addition, around 76% were in permanent employment. In terms of income, around 55% had a monthly net income of over €3,000.

Although the interested group is characterized by a comparatively higher proportion of women (40%), the majority remained male. With an average age of 40 years, the group was younger but had the highest proportion of university graduates of all three groups (approx. 51%). 75% were in permanent employment. The majority also earned between €2,001 and €3,000 per month.

The rejecter group showed a proportion of women of 48%, which was even higher than among the interested group. The average age was 36, making it the youngest of the three groups. The proportion of people with an academic degree was around 38%, which was lower than the proportion of the owners (47%) and the interested (51%). The high proportion of students in the group was striking at around 30%, as was reflected in the income: 43% of the rejecters group had a monthly net income of no more than €2,000.

Table 4 summarizes the demographic data of our sample.

4.2 Measurement items

All constructs were operationalized using items derived from prior validated studies and adapted to the context of plug-in solar devices. The items were measured reflectively using a five-point Likert scale ranging from 1 ('strongly disagree') to 5 ('strongly agree'). The constructs of performance expectancy (PE), effort expectancy (EE), and price value (PV) were measured using items derived from Venkatesh et al. (2003). Social influence (SI) and Behavioral Intention (BI) were also adapted from Venkatesh et

Table 4 Sample demographics

Demographics	Specifications	Complete		Owners		Interested		Rejecters	
		<i>N</i> =376		<i>N</i> =111		<i>N</i> =110		<i>N</i> =139	
Counts		Counts	%	Counts	%	Counts	%	Counts	%
Sex	Male	244	64.9	100	90.1	66	60.0	72	51.8
	Female	130	34.6	10	9.0	44	40.0	66	47.5
	Other	2	0.5	1	0.9	-	-	1	0.7
Age	19–29 years	116	30.9	5	4.5	33	30.0	73	52.5
	30–39 years	64	17.0	17	15.3	26	23.6	18	12.9
	40–49 years	76	20.2	45	40.5	18	16.4	13	9.4
	≥50 years	120	31.9	44	39.6	33	30.0	35	25.2
Highest educational attainment	Graduate degree	169	44.9	52	46.8	56	50.9	53	38.1
	High school diploma, A-Level	63	16.8	12	10.8	16	14.5	35	25.2
	Technical/community college	116	30.9	37	33.3	32	29.1	42	30.2
	Other	28	7.4	10	9.1	6	5.5	9	6.5
Occupation	(Self) Employed	269	71.5	84	75.7	82	74.5	92	66.2
	Student	64	17.0	1	0.9	21	19.1	41	29.5
	Pensioners	26	6.9	13	11.7	5	4.5	4	2.9
	Other	17	4.5	13	11.7	2	1.8	2	1.4
Monthly net income (€)	<1,000	48	12.8	3	2.7	14	12.7	25	18.0
	1,000–2,000	66	17.6	10	9.0	21	19.1	34	24.5
	2,001–3,000	90	23.9	23	20.7	24	21.8	38	27.3
	3,001–4,000	60	16.0	26	23.4	20	18.2	13	9.4
	>4,001	64	17.0	35	31.5	14	12.7	15	10.8
	No specification	48	12.8	14	12.6	17	15.5	14	10.1

al. (2003). In the context of renewable energies, the scales were supplemented by the studies of Jain et al. (2022) for SI and Ali et al. (2020) for BI. For measuring the participants' attitude toward plug-in solar devices (ATT), we adapted the scales from Ahmad et al. (2017). The measures for sustainability expectancy (SE) were operationalized from Korcaj et al. (2015). For the measurement of pro-environmental behavior (PEB), we adapted the scales from Mancha and Yoder (2015) and Lucarelli et al. (2020).

Following a translation-back-translation procedure, we conducted a pretest with twenty individuals to enhance the comprehensibility and the reliability of the measurement items. Based on the received feedback, minor linguistic refinements were implemented to enhance clarity for the main survey.

Table 5 presents the list of the measurement items, accompanied by their means and standard deviations (SD) and references.

4.3 Data analysis

To test the proposed hypotheses, we employed partial least squares structural equation modeling (PLS-SEM). The method has been demonstrated to be appropriate for explaining variance in key endogenous constructs (Hair et al. 2022) and for examining structural differences across

groups by leveraging nonparametric resampling methods (Matthews et al. 2018).

The complete analyses were executed with SmartPLS4, using the conventional path weighting scheme (Ringle et al. 2024). Bootstrapping with 5000 subsamples was employed to test the significance of the path coefficients. Following established guidelines (Hair et al. 2022), we applied a two-stage approach, first evaluating the reflective measurement model and subsequently assessing the structural model.

Reliability and convergent validity were examined using Cronbach's alpha (CA), composite reliability (CR), and average variance extracted (AVE). Discriminant validity was assessed using the heterotrait-monotrait ratio (HTMT). Multicollinearity was evaluated using variance inflation factors (VIF).

In order to identify group differences in users' adoption intention, a multigroup analysis in partial least squares structural equation modeling (PLS-MGA) was employed (Cheah et al. 2023). In this context, a finite mixture partial least squares approach (FIMIX-PLS) was conducted to address unobserved heterogeneity. Prior to conducting the multigroup comparison, measurement invariance was assessed using the measurement invariance of composite models procedure (MICOM) (Henseler et al. 2016). Group differences in structural paths were examined using a non-parametric permutation test (NPT) (Klesel et al. 2022).

Table 5 Constructs and items

Constructs and items			Mean (SD)	References
PE	PE1	I would find plug-in solar devices useful for generating sustainable electricity.	4.505 (0.838)	Venkatesh et al. (2003)
	PE2	Using a plug-in solar device lets me use electricity directly.	4.239 (0.923)	
	PE3	I provide myself with electricity by using a plug-in solar device.	4.460 (0.805)	
EE	EE1	I have enough time and energy to install and use a plug-in solar device.	3.710 (1.306)	Venkatesh et al. (2003)
	EE2	It would be easy for me to install and use a plug-in solar device.	4.210 (1.001)	
	EE3	Learning how to install and use a plug-in solar device is easy for me.	4.149 (1.094)	
SI	SI1	People who are important to me think that I should use a plug-in solar device.	2.612 (1.222)	Venkatesh et al. (2003), Jain et al. (2022)
	SI2	People who influence my behavior think that I should use a plug-in solar device.	2.556 (1.210)	
	SI3	Using a plug-in solar device would create a positive impression of me among other people.	2.976 (1.154)	
SE	SE1	I find that with a plug-in solar device system; I protect the environment.	4.138 (0.867)	Korcay et al. (2015)
	SE2	The operation of a plug-in solar device system is environmentally friendly.	3.785 (1.031)	
	SE3	I save natural resources with a plug-in solar device.	3.750 (1.001)	
ATT	ATT1	Using a plug-in solar device is a good idea.	4.311 (0.921)	Ahmad et al. (2017)
	ATT2	Overall, I think I will enjoy solar technology as a source of electricity in my house.	4.035 (1.097)	
	ATT3	I like the idea of using a clean source of electricity in my house.	4.298 (0.993)	
PEB	PEB1	I try to reduce my carbon footprint.	3.665 (1.000)	Mancha and Yoder (2015), Lucarelli et al. (2020)
	PEB2	I intend to engage in environmentally friendly behavior.	3.293 (1.174)	
	PEB3	I try to be as environmentally friendly as possible.	3.707 (1.072)	
	PEB4	I turn off lights/fans/electrical appliances when not in use.	4.144 (0.984)	
PV	PV1	The plug-in solar device is reasonably priced.	3.420 (1.026)	Venkatesh et al. (2012)
	PV2	The plug-in solar device is a good value for the money.	3.761 (1.014)	
	PV3	At the current price, the plug-in solar device provides a good value.	3.931 (1.060)	
BI	BI1	I plan to install/I have a plug-in solar device.	3.761 (1.355)	Venkatesh et al. (2003), Ali et al. (2020)
	BI2	I am planning to install/I have installed solar electricity panels for my house.	4.066 (1.136)	
	BI3	I intend to use/I use a plug-in solar device to power my house with solar electricity.	3.731 (1.207)	
	BI4	I will consider using/I use a plug-in solar device.	3.880 (1.280)	

5 Results estimation

5.1 Measurement model

The evaluation of the indicator reliability revealed significant factor loadings, which exceeded the threshold value of 0.70 (Hair et al. 2022), assuming a sufficiently high reliability of the individual indicators. Assessing the internal consistency reliability, all constructs demonstrated values exceeding the recommended threshold of 0.70 for both CA

and CR (Hair et al. 2022). The results indicated adequate internal consistency among the constructs. In consideration of the convergent validity assessment, the AVE values obtained exceeded the recommended threshold of 0.50 (Hair et al. 2022). The results of the reliability and convergent validity tests are summarized in Table 6. Assessing the discriminant validity, the HTMT values (see Table 7) were below the recommended threshold of 0.85 (Henseler et al. 2015; Franke and Sarstedt 2019), assuming the absence of critical correlations between the constructs.

Table 6 Assessment of reliability and convergent validity

Data set	Construct	Item	Loadings	CA	CR	AVE
Complete <i>N</i> =376	ATT	ATT1	0.904	0.863	0.868	0.784
		ATT2	0.871			
		ATT3	0.882			
	BI	BI1	0.909	0.899	0.905	0.770
		BI2	0.828			
		BI3	0.836			
		BI4	0.932			
	EE	EE1	0.875	0.852	0.863	0.771
		EE2	0.855			
		EE3	0.903			
	PE	PE1	0.861	0.729	0.803	0.636
		PE2	0.723			
		PE3	0.803			
	PEB	PEB1	0.816	0.821	0.935	0.637
		PEB2	0.715			
		PEB3	0.879			
		PEB4	0.774			
	PV	PV1	0.887	0.879	0.882	0.805
		PV2	0.912			
		PV3	0.892			
	SE	SE1	0.810	0.807	0.807	0.723
		SE2	0.863			
		SE3	0.875			
	SI	SI1	0.877	0.762	0.765	0.683
		SI2	0.881			
		SI3	0.711			

Table 7 Assessment of discriminant validity

Data set	Construct	ATT	BI	EE	PE	PEB	PV	SE	SI
Complete <i>N</i> =376	ATT								
	BI	0.736							
	EE	0.392	0.653						
	PE	0.680	0.578	0.520					
	PEB	0.469	0.259	0.091	0.194				
	PV	0.629	0.658	0.569	0.697	0.131			
	SE	0.678	0.467	0.254	0.490	0.590	0.441		
	SI	0.602	0.491	0.341	0.439	0.301	0.491	0.415	

5.2 Structural model

A thorough evaluation of multicollinearity in the structural model revealed that none of the VIF values for the predictor latent variables exceeded the stringent threshold value of 3 (Hair et al. 2022), assuming no critical multicollinearity between the constructs.

The adjusted R^2 values of 0.523 for ATT and 0.496 for BI indicated a moderate explanatory power. The SRMR value of 0.086 was slightly above the commonly suggested threshold of 0.08 (Hu and Bentler 1998).

In the context of hypothesis testing, the bootstrapping results indicated for hypothesis H1 a significant relationship between PE and ATT ($\beta=0.336$, $p<0.001$) with a

moderate effect of $f^2=0.169$. Consequently, H1 was not rejected. Hypothesis H2, which examined the influence of EE on ATT, was not significant and was therefore rejected. In terms of hypothesis H3, there was a significant but small effect ($f^2=0.099$) between SI and ATT ($\beta=0.239$, $p<0.001$). Consequently, H3 was not rejected. In consideration of the impact of SE on ATT in hypothesis H4, the findings indicated a significant influence ($\beta=0.344$, $p<0.001$) with a moderate effect size ($f^2=0.203$). Therefore, H4 was not rejected.

Turning to the analysis of BI, H5 is examined first. A significant positive relationship between ATT and BI ($\beta=0.467$, $p<0.001$) was exhibited, with a moderate effect size ($f^2=0.248$). Thus, H5 was not rejected. With regard to hypothesis H6, there was a significant impact of PV on BI

($\beta=0.328, p<0.001$) with a moderate effect size ($f^2=0.146$). Consequently, H6 was not rejected. For hypothesis H7, there was no significant influence of PEB on BI. Thus, H7 was rejected.

Finally, in the context of indirect effects, the findings indicated that PE, SI, and SE exert indirect influences on BI via ATT.

Table 8 summarizes the evaluation of the PLS-SEM, including the significance of the path coefficients, VIF-values, and adjusted R^2 .

5.3 Multi-group analysis results

5.3.1 FIMIX-PLS

In order to examine whether the predefined group classification of owners, interested, and rejecters, adequately captures potential heterogeneity in the sample, we performed a finite mixture PLS (FIMIX-PLS) (Sarstedt et al. 2017). The results suggested a three-segment solution, as indicated by the lowest values of the model quality indicators Akaike Information Criterion (AIC4), Bayes Information Criterion (BIC), and Consistent Akaike Information Criterion (CAIC), as illustrated in Table 9. Only AIC3 indicated an alternative solution. According to Sarstedt et al. (2011), the final number of segments should be determined by the segment solution in which AIC4 and BIC both favor the same segment model. Consequently, we posit that the three-segment solution is methodologically sound.

5.3.2 Measurement model results per group

The assessment of the measurement model for the owner group indicated satisfactory indicator reliability, internal consistency, convergent validity, and discriminant validity (Hair et al. 2022; Henseler et al. 2015; Franke and Sarstedt 2019).

For the interested group, two factor loadings (PE2=0.668; SI4=0.695) showed values slightly below the recommended threshold of 0.70. However, CR and AVE of both constructs exceeded the recommended cutoffs, indicating adequate reliability and convergent validity. CA for PE (0.699) was marginally below 0.70 but considered acceptable given the satisfactory CR values (Hair et al. 2022). Discriminant validity was confirmed, as all HTMT values were below the recommended threshold (Henseler et al. 2015; Franke and Sarstedt 2019).

Similarly, in the rejecters group, most factor loadings exceeded 0.70, with three indicators (BI1=0.600; PE2=0.686; PEB=0.656) slightly below the threshold. Nonetheless, CR, CA, and AVE met the established criteria, supporting the reliability and validity of the constructs (Hair

Table 8 Assessing the structural model

Data set	Relationship	Std. beta	Std. error	t stat.	p values	CI bias corr.		VIF	f^2	Adj. R^2
						2.5%	97.5%			
Complete N=376	PE	0.336	0.058	5.814	0.000	0.213	0.442	1.412	0.169	0.523
	EE	0.064	0.046	1.405	0.160	-0.029	0.150	1.235	0.007	
	SI	0.239	0.038	6.293	0.000	0.166	0.316	1.227	0.099	
	SE	0.344	0.048	7.198	0.000	0.252	0.441	1.237	0.203	
	ATT	0.467	0.052	8.902	0.000	0.363	0.569	1.760	0.248	0.496
	PV	0.328	0.049	6.669	0.000	0.226	0.417	1.471	0.146	
	PEB	0.010	0.042	0.229	0.818	-0.076	0.089	1.241	0.000	
Indirect effects										
	PE $\diamond$	0.157	0.031	5.077	0.000	0.098	0.220			
	EE $\diamond$	0.030	0.023	1.326	0.185	-0.012	0.076			
	SI $\diamond$	0.112	0.023	4.942	0.000	0.073	0.160			
	SE $\diamond$	0.161	0.030	5.427	0.000	0.109	0.226			

Table 9 Fit indices for the one- to four-segment solutions

Criteria	Number of segments			
	1	2	3	4
AIC3	1617.915	1372.596	1306.308	1301.316
AIC4	1626.915	1391.596	1335.308	1340.316
BIC	1644.281	1428.258	1391.266	1415.570
CAIC	1653.281	1447.258	1420.266	1454.570

et al. 2022). HTMT values further confirmed discriminant validity (Henseler et al. 2015; Franke and Sarstedt 2019).

The assessment indicates that the measurement models satisfy all essential reliability and validity criteria, thus establishing a robust foundation for subsequent multigroup analyses. Tables A1 and A2 in the 8. summarize the assessment results for each subgroup.

5.3.3 MICOM

To ensure the PLS-MGA results, we assessed measurement invariance using MICOM and its three-step procedure (Henseler et al. 2016; Cheah et al. 2023).

Firstly, we established configural invariance by employing the same set of indicators across all groups, which were equally parameterized and estimated (Henseler et al. 2016). This included the consistent treatment of the indicators and the handling of the data, as well as the establishment of a uniform PLS-algorithm setting for estimation (Hair et al. 2022).

Secondly, compositional invariance was assessed using the permutation test implemented in MICOM. To control family-wise error inflation in multigroup comparisons, we applied a Šidák correction to the nominal significance level (Cheah et al. 2023). This resulted in an adjusted confidence level of 98.31%. Except for ATT in the comparison between interested and rejecters, the correlations between composite scores were not significantly different (see Table A3 in 8.). In combination with configural invariance, partial measurement invariance was therefore established for all constructs except ATT in this specific group comparison. Consequently, structural path coefficients involving ATT cannot be validly compared between the interested and the rejecters.

Finally, to assess full measurement invariance, the equality of composite means and variances must be established. However, given that the majority of the composites' equality of mean values and variances across the three groups did not yield all non-significant differences, full invariance was not supported.

However, since the present PLS-MGA focuses exclusively on comparing structural path coefficients rather than latent means or variances, the establishment of configural and compositional invariance is sufficient (Henseler et al.

2016). Thus, partial measurement invariance is considered adequate for valid structural group comparisons.

5.3.4 Structural model results per group

5.3.4.1 Owners The structural model results for the owner group indicated significant positive impacts of PE ($\beta=0.265$, $p=0.025$), EE ($\beta=0.197$, $p=0.047$), and SE ($\beta=0.439$, $p<0.001$) on ATT. While the effects of PE ($f^2=0.088$) and EE ($f^2=0.061$) were small, SE demonstrated a moderate effect on ATT ($f^2=0.338$). ATT, in turn, significantly influenced BI ($\beta=0.559$, $p<0.001$) with a moderate effect size ($f^2=0.241$). The explained variance indicated moderate explanatory power for ATT (adj. $R^2=0.594$) and BI (adj. $R^2=0.466$).

5.3.4.2 Interested The structural model's evaluation for the interested group demonstrated significant positive influences of PE ($\beta=0.261$, $p=0.003$), SE ($\beta=0.427$, $p<0.001$), and SI ($\beta=0.257$, $p<0.001$) on ATT. The effect sizes of PE ($f^2=0.097$) and SI ($f^2=0.098$) were small, whereas SE exhibited a moderate effect ($f^2=0.303$). With regard to BI, PEB ($\beta=0.331$, $p<0.001$), PV ($\beta=0.270$, $p=0.002$), and ATT ($\beta=0.245$, $p=0.024$) all showed significant positive effects. The corresponding effect sizes were small (PEB: $f^2=0.114$; PV: $f^2=0.106$; ATT: $f^2=0.059$). The adjusted R^2 indicated a moderate explanatory power for ATT (adj. $R^2=0.411$) and BI (adj. $R^2=0.351$).

5.3.4.3 Rejecters The structural model of the rejecter group demonstrated significant positive impacts of PE ($\beta=0.292$, $p=0.001$), SE ($\beta=0.317$, $p<0.001$), and SI ($\beta=0.358$, $p<0.001$) on ATT. The effect size of PE was small ($f^2=0.142$), whereas the effects of SE ($f^2=0.173$) and SI ($f^2=0.230$) were moderate. For the second dependent variable, ATT ($\beta=0.456$, $p<0.001$) and PV ($\beta=0.175$, $p=0.050$) exerted positive effects on BI. While ATT showed a moderate effect size ($f^2=0.220$), the effect of PV was small ($f^2=0.037$). The explanatory power for ATT (adj. $R^2=0.505$) and BI (adj. $R^2=0.312$) was both moderate.

Table 10 provides an overview of the assessment of the group-specific structural models.

5.4 Assessment of pairwise comparison using NPT

We employed a non-parametric permutation-based test (NPT) to compare the specific path coefficients between the groups (Klesel et al. 2022). For pairwise comparisons, at least partial measurement invariance must be present

Table 10 Assessment of structural models

Data set	Relationship	Std. beta	Std. error	t stat.	p values	CI bias corr.		VIF	f ²	Adj. R ²
						2.5%	97.5%			
Owners N=111	PE →	ATT	0.265	0.118	2.247	0.044	0.510	2.032	0.088	0.594
	EE →	ATT	0.197	0.100	1.984	-0.007	0.388	1.624	0.061	
	SE →	ATT	0.439	0.083	5.264	0.277	0.604	1.459	0.338	
	SI →	ATT	0.081	0.058	1.391	-0.035	0.195	1.219	0.014	
	PEB →	BI	0.131	0.087	1.509	-0.046	0.291	1.385	0.024	0.466
Indirect effects	PV →	BI	0.079	0.094	0.832	-0.117	0.255	2.012	0.006	
	ATT →	BI	0.559	0.098	5.681	0.326	0.722	2.495	0.241	
	PE →	BI	0.148	0.070	2.125	0.025	0.303			
	EE →	BI	0.110	0.063	1.755	0.002	0.256			
	SE →	BI	0.246	0.069	3.579	0.124	0.396			
Interested N=110	SI →	BI	0.045	0.033	1.373	-0.017	0.114			
	PE →	ATT	0.261	0.087	2.986	0.090	0.425	1.233	0.097	0.411
	EE →	ATT	0.011	0.083	0.127	-0.178	0.158	1.313	0.000	
	SE →	ATT	0.427	0.072	5.895	0.271	0.554	1.061	0.303	
	SI →	ATT	0.257	0.063	4.115	0.124	0.371	1.189	0.098	
Indirect effects	PEB →	BI	0.331	0.100	3.293	0.114	0.420	1.512	0.114	0.351
	PV →	BI	0.270	0.086	3.142	0.106	0.569	1.090	0.106	
	ATT →	BI	0.245	0.108	2.257	0.023	0.397	1.608	0.059	
	PE →	BI	0.064	0.042	1.525	0.004	0.163			
	EE →	BI	0.003	0.022	0.119	-0.038	0.050			
Rejecters N=139	SE →	BI	0.104	0.049	2.141	0.016	0.208			
	SI →	BI	0.063	0.033	1.902	0.007	0.138			
	PE →	ATT	0.292	0.084	3.465	0.122	0.454	1.255	0.142	0.505
	EE →	ATT	0.026	0.076	0.341	-0.178	0.141	1.029	0.001	
	SE →	ATT	0.317	0.074	4.262	0.174	0.464	1.209	0.173	
Indirect effects	SI →	ATT	0.358	0.063	5.667	0.233	0.481	1.159	0.230	
	PEB →	BI	0.049	0.075	0.646	-0.154	0.169	1.164	0.003	0.312
	PV →	BI	0.175	0.089	1.963	-0.013	0.335	1.224	0.037	
	ATT →	BI	0.456	0.083	5.510	0.296	0.613	1.403	0.220	
	PE →	BI	0.133	0.043	3.103	0.062	0.232			
Indirect effects	EE →	BI	0.012	0.035	0.337	-0.079	0.067			
	SE →	BI	0.144	0.044	3.268	0.070	0.247			
	SI →	BI	0.163	0.044	3.722	0.089	0.263			
	ATT →	BI	0.163	0.044	3.722	0.089	0.263			

Table 11 Assessment of pairwise comparison using NPT

Relationship			Pairwise Comparison	Path Coefficient Difference	Permutation Test Šidák's <i>p</i> -value adjustment 0.01695
EE	→	ATT	Owners vs. Interested	0.187	0.155
			Owners vs. Rejecters	0.171	0.127
			Interested vs. Rejecters	(− 0.015)	(0.881)
PE	→	ATT	Owners vs. Interested	0.004	0.982
			Owners vs. Rejecters	−0.028	0.853
			Interested vs. Rejecters	(− 0.032)	(0.815)
SE	→	ATT	Owners vs. Interested	0.013	0.911
			Owners vs. Rejecters	0.123	0.304
			Interested vs. Rejecters	(0.110)	(0.348)
SI	→	ATT	Owners vs. Interested	− 0.176	0.048
			Owners vs. Rejecters	− 0.276	0.003
			Interested vs. Rejecters	(− 0.100)	(0.292)
PEB	→	BI	Owners vs. Interested	− 0.199	0.146
			Owners vs. Rejecters	0.083	0.337
			Interested vs. Rejecters	0.282	0.011
PV	→	BI	Owners vs. Interested	− 0.191	0.231
			Owners vs. Rejecters	−0.097	0.436
			Interested vs. Rejecters	0.095	0.428
ATT	→	BI	Owners vs. Interested	0.314	0.066
			Owners vs. Rejecters	0.103	0.432
			Interested vs. Rejecters	(− 0.211)	(0.070)

according to the MICOM procedure (Henseler et al. 2016; Chin and Dibbern 2010). In order to control for family-wise error inflation across multiple comparisons, a Šidák correction was applied to the significance level (Cheah et al. 2023).

The NPT results are summarized in Table 11. Path comparisons for constructs without partial measurement invariance are reported in brackets and were not considered further in this analysis.

The results indicated no significant differences for most path coefficients across the groups. However, a significant difference was observed between owners and rejecters for the path from SI to ATT = −0.276 ($p=0.003$). Furthermore, the comparison between interested and rejecters revealed a significant difference in the impact of PEB on BI (diff=0.282, $p=0.011$).

6 Discussion and implications

6.1 Theoretical implications

While performance expectancy has been shown to exert a significant positive influence on attitude formation across all three groups, the corresponding effect sizes of the owners ($f^2=0.088$), and the interested ($f^2=0.097$) were small. Our findings are therefore not inconsistent with other studies in the field of renewable energies and technology acceptance

(e.g., Aggarwal et al. 2019; Roy and Mohapatra 2022; Ahn et al. 2016) but rather point to a context-dependent assessment of performance expectancy. Plug-in solar devices constitute a scaled-down application of conventional photovoltaic technology, whose core functionality is widely well-known and socially familiar. In consideration of this, Rogers' IDT suggests that the relevance of certain determinants for adoption may shift during the diffusion phases (Rogers 2003). Relative advantage, such as performance expectancy, is particularly influential during early adoption stages but may diminish in importance once the instrumental benefits of the technology become widely recognized. Our findings demonstrate that performance expectancy continues to exert a statistically significant influence, but other contextual or value-related factors may have become more salient, especially for the owners and interested. Conversely, the effect size of the rejecter group was in the upper range of small effect ($f^2=0.142$), approaching medium magnitude. Consequently, this group requires a higher level of functional safety in order to engage with plug-in solar devices.

Although only the owners exhibited a positive significant relationship between effort expectancy and the attitude towards plug-in solar devices, the relationship was only statistically significant ($p=0.047$), with no practical relevance ($f^2=0.061$). Therefore, we assume that effort expectancy has no relevant impact on the attitude across all three groups. The study by Molnár and Szép (2025), which examined the intention to use balcony power plants in Hungary, came to

a similar conclusion. Molnár and Szép (2025) argue that plug-in solar devices do not require professional installation and are ready to use immediately after connection. The perceived effort required to use them is therefore comparatively low. In contrast to conventional, large-scale photovoltaic systems, plug-in solar devices are characterized not only by their small footprint but also by their ease of installation and use (Gögelein et al. 2024). These low-threshold requirements could mean that effort expectancy is less of an influencing factor.

The study revealed that all three groups held the perception that plug-in solar devices were a form of green technology. The ecological expectations of the use of the technology are based on environmentally friendly energy generation, characterized by low pollutant emissions and efficient use of resources (Chen et al. 2006; Korcaj et al. 2015). The fact that the perceived environmental benefits have a positive effect on the formation of attitudes towards plug-in solar devices is consistent with studies on conventional photovoltaic systems, according to which the environmental motive is essential for the adoption of the technology (Korcaj et al. 2015; Palm and Tengvard 2011; Corbett et al. 2022). In the context of sustainable technologies, our findings fit in with the research that, in addition to technical product characteristics, sustainability-related product characteristics are also decisive for the choice of technology.

With regard to social influence, both the interested and rejecter groups showed a significant positive relationship with attitude. Unlike owners, interested and rejecters do not (yet) own a plug-in solar device, which means that they have no personal experience with the technology and may therefore attach great importance to the opinions of those around them in order to reduce their uncertainties (Tscherning and Mathiassen 2010). The pairwise group comparison between owners and rejecters supports this assumption and shows that rejecters place a significantly higher value on the social influence factor compared to owners. An alternative explanation for the relevance of social influence in the attitude formation of interested and rejecters could lie in the sustainability focus of the technology, which means that aspects such as social desirability and the public visibility of sustainable action must be taken into account (Hamari and Koivisto 2015). Accordingly, a positive attitude could result not only from the functional benefits of the technology, but also from presenting oneself as particularly environmentally friendly in order to gain social recognition or demonstrate ('green') affiliation (Graziano and Gillingham 2015; Rode and Müller 2019).

In consideration of the relationship between attitude and intention, we were able to determine a significant result for all three groups. In the area of adoption of photovoltaic systems, our results on plug-in solar devices are in line with

the findings of Sun et al. (2020), Kesari et al. (2021), and Fatoki (2022). Considering the effect size, however, our results demonstrated a differentiated picture. For owners ($f^2=0.241$) and rejecters ($f^2=0.220$), we were able to determine a moderate effect size. Contrary to expectations, there was only a small effect for interested ($f^2=0.059$). Based on this, we assume a weakened form of the attitude-intention gap for this group. Given that the interested group is generally interested in purchasing a plug-in solar device and is considering installation at least in the short to medium term, a stronger link between positive attitude and intention would theoretically be expected. However, as with Peattie (2010), Claudy et al. (2013), and Echegaray and Hansstein (2017), attitude does not appear to be the driving factor for the intention to use green technology. Rather, contextual factors come to the fore.

We have integrated the construct of pro-environmental behavior into our study, as it has been identified in various studies on sustainable technologies as a relevant predictor of usage intention (Vorobeve et al. 2022; Adeel et al. 2024; Laureti and Benedetti 2018). In our study, however, only the interested group demonstrated a significant positive correlation between pro-environmental behavior and the intention to use. Despite the relatively small effect size, its relevance became particularly salient at the pairwise group comparison: In contrast to the rejecters, the interested group attributed a significantly stronger influence to pro-environmental behavior on their intention to use plug-in solar devices. In combination with the results on sustainability expectancy, this indicates that the group not only acknowledges the sustainability-related advantages of these devices but also views them as a means of actively engaging in environmental protection (Verplanken 2018; Hinds and Sparks 2008).

In the context of the cognitive tradeoff between associated costs and perceived benefits, a significant correlation between price value and the intention to use plug-in solar devices could not be determined among the group of owners. Significant effects were found for the interested and rejecters, but the effect size for the rejecter group was small ($f^2=0.037$), meaning only statistical significance, but not practical relevance. Whereas the findings for the interested group indicated an awareness of the price-performance ratio of plug-in solar devices. In view of their general environmentally-oriented attitude, it is concluded that sustainable criteria such as long-term energy savings and environmentally friendly energy consumption play a central role in their cost-benefit analysis alongside functional criteria. Our result is thus in line with previous studies on price value and solar modules, which also emphasize the importance of sustainability-related benefit considerations (Lau et al. 2020; Bektı et al. 2022).

6.1.1 Practical implications

The findings of our study have several practical implications for promoting plug-in solar devices. It has been demonstrated that sustainability characteristics, in particular sustainability expectations and within the interested group, pro-environmental behavior, have been identified as decisive factors in the adoption process. Consequently, advertising strategies should prioritize the promotion of environmental benefits. Transparent communication that credibly conveys the individual contribution to sustainability and climate protection without resorting to greenwashing can increase the likelihood of plug-in solar devices being used. Concrete measures could include sustainability certifications, ecological seals of approval, or publicly visible indicators of CO₂ savings that explicitly highlight the ecological added value of plug-in solar devices and strengthen the environmentally oriented intention to use them.

In order to address the group of rejecters who refrain from adoption due to technological concerns or cost-related considerations, targeted information and communication measures focusing on functionality and reliability can help to close remaining knowledge gaps and reduce uncertainties. In this context, easily accessible and far-reaching channels such as social media and influencer marketing could be particularly effective in addressing previously hesitant target groups. Studies show that social media and influencer marketing are already proving promising in various areas such as clothing, nutrition, and health (Gomes et al. 2022; Byrne et al. 2017). Given the high social relevance of the topic, the sustainability aspect of solar technology could represent high potential for advertising communication (Vilkaite-Vaitone 2024).

In accordance with the findings, which indicate that the rejecter group attaches great importance to social influence, the establishment of interactive and easily accessible platforms that facilitate exchange between existing and potential users could build trust and break down barriers to acceptance. Previous research shows that the source of information, the timing of its delivery, and the manner of its presentation have a significant impact on the effectiveness of communication about sustainability-related technologies (Goodarzi et al. 2021).

7 Conclusion

The aim of our study was to investigate the factors influencing the adoption of plug-in solar devices. In light of the heterogeneity of experience with plug-in solar devices, we differentiated between three groups: the owners, the interested, and the rejecters. We conducted a PLS-MGA to derive varied insights into the adoption process of plug-in solar devices.

While the results for the owners largely align with the overall findings, which indicate that technical aspects such as performance expectancy and effort expectancy tend to be less influential compared to sustainability-related factors, a more differentiated analysis reveals additional insights. In terms of pro-environmental behavior, the interested group appears to perceive the adoption of plug-in solar devices as an opportunity to further extend their sustainable lifestyle. In contrast, rejecters seem to be more strongly influenced by technological concerns and social opinions than the other two groups.

The group-specific results, therefore, underline that the technology adoption process for sustainable technologies is not homogeneous but shaped by distinct expectations. Promoting sustainable technologies consequently requires strategies that both activate sustainability-oriented motivations and reduce technology-related skepticism. Considering these two dimensions may contribute to broader societal acceptance and support the transition toward more sustainable energy systems.

8 Limitations and suggestions for future research

The present study has focused on the German market, yet it is crucial to consider the general sustainability attitudes of the German population with regard to limitations. The concept of sustainability has emerged as a prominent subject in both political discourse and societal discourse, underscoring the heightened sensitivity and relevance of this issue (Venghaus et al. 2022). In nations where sustainability issues do not carry comparable weight, the emphasis could instead be placed on other factors, for example, the technical or the economic requirements of technology.

In consideration of the financial aspect, price value has been included in the study. However, subsequent research could focus on consumers' willingness to pay for plug-in solar devices. A segmentation of willingness to pay according to different user groups could assist in the initiation of targeted political support measures.

Furthermore, the present study concentrated on the determinants of attitude formation and the predictive components of usage intention, while other factors such as political influence or subsidies were disregarded. Subsequent research could build upon this investigation by exploring the impact of external factors, such as political measures, on the intention to use.

Appendix

Table 12 Assessment of reliability and convergent validity

Data set	Construct	Item	Loadings	CA	CR	AVE
Owners <i>N</i> =111	ATT	ATT1	0.888	0.797	0.817	0.712
		ATT2	0.771			
		ATT3	0.867			
	BI	BI1	0.757	0.808	0.806	0.637
		BI2	0.830			
		BI3	0.729			
		BI4	0.868			
	EE	EE1	0.869	0.866	0.907	0.785
		EE2	0.887			
		EE3	0.902			
	PE	PE1	0.877	0.735	0.766	0.652
		PE2	0.739			
		PE3	0.801			
	PEB	PEB1	0.891	0.878	0.900	0.729
		PEB2	0.801			
		PEB3	0.887			
		PEB4	0.833			
	PV	PV1	0.887	0.910	0.919	0.847
		PV2	0.942			
		PV3	0.932			
	SE	SE1	0.865	0.870	0.873	0.793
		SE2	0.902			
		SE3	0.905			
	SI1	SI1	0.823	0.791	0.796	0.705
		SI2	0.880			
		SI3	0.814			
Interested <i>N</i> =110	ATT	ATT1	0.795	0.721	0.736	0.640
		ATT2	0.766			
		ATT3	0.837			
	BI	BI1	0.842	0.812	0.828	0.631
		BI2	0.762			
		BI3	0.720			
		BI4	0.845			
	EE	EE1	0.748	0.813	0.882	0.718
		EE2	0.878			
		EE3	0.907			
	PE	PE1	0.848	0.699	0.735	0.592
		PE2	0.668			
		PE3	0.781			
	PEB	PEB1	0.767	0.824	0.836	0.653
		PEB2	0.822			
		PEB3	0.825			
		PEB4	0.816			
	PV	PV1	0.809	0.807	0.824	0.720
		PV2	0.892			
		PV3	0.843			
	SE	SE1	0.792	0.740	0.744	0.656
		SE2	0.809			
		SE3	0.828			
	SI	SI1	0.885	0.737	0.740	0.662
		SI2	0.848			
		SI3	0.695			
Rejecters <i>N</i> =139	ATT	ATT1	0.916	0.897	0.898	0.829
		ATT2	0.892			
		ATT3	0.923			

Table 12 (continued)

Data set	Construct	Item	Loadings	CA	CR	AVE
	BI	BI1	0.857	0.830	0.869	0.671
		BI2	0.600			
		BI3	0.886			
		BI4	0.899			
	EE	EE1	0.815	0.786	0.803	0.698
		EE2	0.865			
		EE3	0.825			
	PE	PE1	0.871	0.719	0.843	0.618
		PE2	0.686			
		PE3	0.791			
	PEB	PEB1	0.847	0.756	0.784	0.571
		PEB2	0.721			
		PEB3	0.656			
		PEB4	0.786			
	PV	PV1	0.815	0.771	0.773	0.687
		PV2	0.859			
		PV3	0.811			
	SE	SE1	0.746	0.756	0.772	0.672
		SE2	0.852			
		SE3	0.856			
	SI	SI1	0.844	0.782	0.816	0.685
		SI2	0.822			
		SI3	0.815			

Table 13 Assessment of Discriminant Validity using HTMT

Data set	Construct	ATT	BI	EE	PE	PEB	PV	SE	SI
Owners N=111	ATT								
	BI	0.834							
	EE	0.612	0.620						
	PE	0.829	0.725	0.755					
	PEB	0.577	0.492	0.283	0.353				
	PV	0.819	0.596	0.553	0.737	0.324			
	SE	0.802	0.631	0.382	0.653	0.621	0.594		
Interested N=110	SI	0.499	0.342	0.323	0.484	0.371	0.327	0.433	
	ATT								
	BI	0.602							
	EE	0.291	0.693						
	PE	0.465	0.564	0.485					
	PEB	0.719	0.491	0.109	0.212				
	PV	0.330	0.426	0.512	0.653	0.179			
Rejecters N=139	SE	0.676	0.416	0.177	0.236	0.665	0.131		
	SI	0.559	0.400	0.456	0.275	0.282	0.515	0.256	
	ATT								
	BI	0.628							
	EE	0.119	0.406						
	PE	0.587	0.399	0.271					
	PEB	0.448	0.271	0.099	0.198				
	PV	0.507	0.458	0.172	0.611	0.141			
	SE	0.641	0.415	0.117	0.487	0.573	0.489		
	SI	0.611	0.445	0.146	0.373	0.272	0.444	0.366	

Table 14 Assessment of Measurement Invariance using MICOM

Groups	Con-struct	Compositional Invariance			Partial Measure- ment Invariance Established	Composite mean values and variances				Full Mea- surement Invariance Established
		c	c _{1,69%}	p value		Equal Mean Value Diff	p value	Equal Variances Diff	p value	
Owners vs. Interested	ATT	0.999	0.992	0.455	Yes	0.007	0.962	0.500	0.185	Yes
	BI	0.994	0.972	0.361	Yes	0.297	0.025	0.181	0.680	-
	EE	0.991	0.895	0.360	Yes	0.862	0.000	-0.798	0.007	-
	PE	0.988	0.949	0.348	Yes	0.395	0.002	-0.207	0.790	-
	PEB	0.996	0.985	0.161	Yes	-0.192	0.304	0.385	0.049	-
	PV	1.000	0.994	0.857	Yes	0.752	0.000	0.196	0.367	-
	SE	1.000	0.995	0.757	Yes	0.150	0.263	0.490	0.020	-
	SI	0.998	0.966	0.679	Yes	0.195	0.145	0.134	0.439	Yes
Owners vs. Rejecters	ATT	1.000	0.999	0.228	Yes	0.795	0.000	-0.608	0.004	-
	BI	0.999	0.997	0.308	Yes	1.388	0.000	-0.864	0.000	-
	EE	0.993	0.986	0.146	Yes	1.193	0.000	-1.063	0.000	-
	PE	0.994	0.981	0.250	Yes	0.757	0.000	-0.776	0.006	-
	PEB	0.988	0.318	0.613	Yes	0.016	0.409	0.432	0.016	-
	PV	1.000	0.998	0.832	Yes	1.252	0.000	0.199	0.174	-
	SE	0.997	0.994	0.087	Yes	0.397	0.001	0.335	0.051	-
	SI	0.996	0.986	0.218	Yes	0.617	0.000	0.202	0.211	-
Interested vs. Rejecters	ATT	0.999	0.999	0.035	-	0.837	0.000	-1.089	0.000	-
	BI	0.999	0.994	0.395	Yes	1.317	0.000	-1.066	0.000	-
	EE	0.990	0.875	0.633	Yes	0.501	0.000	-0.265	0.083	-
	PE	0.994	0.945	0.503	Yes	0.491	0.000	-0.609	0.005	-
	PEB	0.987	0.881	0.471	Yes	0.118	0.246	0.087	0.744	Yes
	PV	0.999	0.985	0.771	yes	0.764	0.000	-0.022	0.898	-
	SE	0.994	0.985	0.167	Yes	0.282	0.030	-0.150	0.472	-
	SI	0.989	0.980	0.078	Yes	0.450	0.000	0.069	0.682	-

Funding Open Access funding enabled and organized by Projekt DEAL.

Declarations

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Adeel HB, Sabir RI, Shah Nawaz M, Zafran M (2024) Adoption of environmental technologies in the hotel industry: development of sustainable intelligence and pro-environmental behavior. *Discover Sustain* 5:1
- Aggarwal AK, Syed AA, Garg S (2019) Factors driving Indian consumer's purchase intention of roof top solar. *Int J Energy Sect Manage* 13(3):539–555
- Ahmad S, Mat Tahar R, Cheng JK, Yao L (2017) Public acceptance of residential solar photovoltaic technology in Malaysia. *PSU Res Rev* 1(3):242–254
- Ahn M, Kang J, Hustvedt G (2016) A model of sustainable household technology acceptance. *Int J Consumer Stud* 40(1):83–91
- Ajzen I (1985) From Intentions to Actions: A Theory of Planned Behavior. In: Kuhl J, Beckmann J (eds) *Action Control: From Cognition to Behavior*. Springer Series in Social Psychology. Springer, Berlin, Heidelberg, pp 11–39
- Alam SS, Ahmad M, Othman AS, Shaari ZBH, Masukujjaman M (2021) Factors affecting photovoltaic solar technology usage intention among households in Malaysia: model integration and empirical validation. *Sustainability* 13(4):1773
- Ali S, Poulova P, Akbar A, Javed HMU, Danish M (2020) Determining the influencing factors in the adoption of solar photovoltaic

- technology in Pakistan: a decomposed Technology Acceptance Model approach. *Economics* 8(4):108
- Anjum A, Subhan M (2024) Examining public intentions and attitudes toward solar rooftop panel adoption in Indian residences: an integration of TPB, DOI and UTAUT. *Kybernetes*. <https://doi.org/10.1108/k-01-2024-0080>
- Bekti DBM, Prasetyo YT, Redi AANP, Budiman AS, Mandala IMPL, Putra AR, Persada SF, Nadlifatin R, Young MN (2022) Determining factors affecting customer intention to use rooftop solar photovoltaics in Indonesia. *Sustainability* 14(1):280
- Best R, Burke PJ, Nishitaten S (2019) Understanding the determinants of rooftop solar installation: evidence from household surveys in Australia. *Australian J Agric Res Econ* 63(4):922–939
- Bo D, Ma'rof AA (2024) Understanding User Attitude towards AI Agents: The Roles of Perceived Competence, Trust in Technology, and Social Influence. *Int J Acad Res Bus Social Sci* 14:12
- Bouaguel W, Alsulimani T (2022) Understanding the factors influencing consumers' intention toward shifting to solar energy technology for residential use in Saudi Arabia using the Technology Acceptance Model. *Sustainability* 14(18):11356
- Byrne E, Kearney J, MacEvilly C (2017) The role of influencer marketing and social influencers in public health. *Proc Nutr Soc*. <https://doi.org/10.1017/S0029665117001768>
- Cheah J-H, Amaro S, Roldán JL (2023) Multigroup analysis of more than two groups in PLS-SEM: A review, illustration, and recommendations. *J Bus Res* 156:113539
- Chen Y-S, Lai S-B, Wen C-T (2006) The Influence of Green Innovation Performance on Corporate Advantage in Taiwan. *J Bus Ethics* 67(4):331–339
- Chin WW, Dibbern J (2010) An Introduction to a Permutation Based Procedure for Multi-Group PLS Analysis: Results of Tests of Differences on Simulated Data and a Cross Cultural Analysis of the Sourcing of Information System Services Between Germany and the USA. In: Esposito Vinzi V, Chin WW, Henseler J, Wang H (eds) *Handbook of Partial Least Squares*. Springer Berlin Heidelberg, Berlin, Heidelberg, pp 171–193
- Claudy MC, Peterson M, O'Driscoll A (2013) Understanding the Attitude-Behavior Gap for Renewable Energy Systems Using Behavioral Reasoning Theory. *J Macromarketing* 33(4):273–287
- Corbett CJ, Hershfield HE, Kim H, Malloy TF, Nyblade B, Partie A (2022) The role of place attachment and environmental attitudes in adoption of rooftop solar. *Energy Policy* 162:112764
- Davis FD (1989) Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Q* 13(3):319
- Düştęğör D, Sultana N, Felemban N, Al Qahtani D (2018) A smarter electricity grid for the Eastern Province of Saudi Arabia: perceptions and policy implications. *Utilities Policy* 50:26–39
- Dwivedi YK, Rana NP, Jeyaraj A, Clement M, Williams MD (2019) Re-examining the Unified Theory of Acceptance and Use of Technology (UTAUT): Towards a Revised Theoretical Model. *Inform Syst Front* 21(3):719–734
- Echegaray F, Hansstein FV (2017) Assessing the intention-behavior gap in electronic waste recycling: the case of Brazil. *J Clean Prod* 142:180–190
- Fatoki O (2022) Determinants of Intention to Purchase Photovoltaic Panel System: An Integration of Technology Acceptance Model and Theory of Planned Behaviour. *Int J Energy Econ Policy* 12(3):432–440
- Faul F, Erdfelder E, Buchner A, Lang A-G (2009) Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods* 41(4):1149–1160
- Federal Environment Agency (2025) *Steckersolargeräte reduzieren eigene Stromkosten - auch für Mieter*innen*, available at: <https://www.umweltbundesamt.de/umwelttipps-fuer-den-alltag/heizen-bauen/balkonkraftwerk-steckersolargerat#wie-sie-mit-balkon-solaranlagen-umweltfreundlich-strom-erzeugen>
- Federal Ministry of Justice and Consumer Protection (2014) *Gesetz Gesetz zur grundlegenden Reform des Erneuerbare-Energien-Gesetzes und zur Änderung weiterer Bestimmungen des Energiewirtschaftsrechts*
- Federal Ministry of Justice and Consumer Protection (2025) *Erneuerbare-Energien-Gesetz vom 21. Juli 2014 (BGBl. I S. 1066), das zuletzt durch Artikel 1 des Gesetzes vom 21. Februar 2025 (BGBl. 2025 I Nr. 52) geändert worden ist*
- Federal Ministry for Economic Affairs and Energy (2024) *Gesetz zur Änderung des Erneuerbare-Energien-Gesetzes und weiterer energiewirtschaftsrechtlicher Vorschriften zur Steigerung des Ausbaus photovoltaischer Energieerzeugung*
- Federal Ministry for Economic Affairs and Climate Action (2021) Federal Climate Action Act of 12 December 2019 (Federal Law Gazette I, p. 2513), as last amended by Article 1 of the Act of 15 July 2024 (Federal Law Gazette I 235)
- Fishbein M, Ajzen I (1972) Attitudes and Opinions. *Ann Rev Psychol* 23(1):487–544
- Fishbein M, Ajzen I (1975) Belief, attitude, intention and behavior: An introduction to theory and research, Addison-Wesley series in social psychology. Addison-Wesley, Reading, Mass
- Franke G, Sarstedt M (2019) Heuristics versus statistics in discriminant validity testing: a comparison of four procedures. *Internet Res* 29(3):430–447
- Fraunhofer ISE (2024) *Photovoltaic Plants with Battery Cheaper than Conventional Power Plants*, available at: <https://www.ise.fraunhofer.de/en/press-media/press-releases/2024/photovoltaic-plant-s-with-battery-cheaper-than-conventional-power-plants.html>
- Gerber DL, Ginsberg-Klemmt A, Stoler L, Shackelford J, Meier A (2025) Barriers to balcony solar and plug-in distributed energy resources in the United States. *Energies* 18(8):2132
- Ghosh A, Satya Prasad VK (2024) Evaluating the influence of environmental factors on household solar PV pro-environmental behavioral intentions: A meta-analysis review. *Renew Sustain Energy Rev* 190:114047
- Gögelein D, von Schwerin M, Herbolt V (2024) PV system installation assessment based on power measurement for balcony power plant applications. *IEEE J Photovoltaics* 14(4):571–582
- Gomes MA, Marques S, Dias Á (2022) The impact of digital influencers' characteristics on purchase intention of fashion products. *J Global Fashion Mark* 13(3):187–204
- Goodarzi S, Masini A, Aflaki S, Fahimnia B (2021) Right information at the right time: Reevaluating the attitude-behavior gap in environmental technology adoption. *Int J Prod Econ* 242:108278
- Graziano M, Gillingham K (2015) Spatial patterns of solar photovoltaic system adoption: the influence of neighbors and the built environment. *J Econ Geogr* 15(4):815–839
- Hair JF, Babin BJ, Anderson RE, Black WC (2018) *Multivariate data analysis*, 8th ed. Cengage Learning, Boston
- Hair JF, Hult GTM, Ringle CM, Sarstedt M (2022) *A primer on partial least squares structural equation modeling (PLS-SEM)*, Third edition. SAGE Publications Incorporated, Thousand Oaks
- Hamari J, Koivisto J (2015) Working out for likes: An empirical study on social influence in exercise gamification. *Comput Hum Behav* 50:333–347
- Hamari J, Sjöklint M, Ukkonen A (2016) The sharing economy: Why people participate in collaborative consumption. *J Association Inform Sci Technol* 67(9):2047–2059
- Haustein S, Jensen AF (2018) Factors of electric vehicle adoption: A comparison of conventional and electric car users based on an extended theory of planned behavior. *Int J Sustainable Transp* 12(7):484–496
- Henseler J, Ringle CM, Sarstedt M (2015) A new criterion for assessing discriminant validity in variance-based structural equation modeling. *J Acad Mark Sci* 43(1):115–135

- Henseler J, Ringle CM, Sarstedt M (2016) Testing measurement invariance of composites using partial least squares. *Int Mark Rev* 33(3):405–431
- Hinds J, Sparks P (2008) Engaging with the natural environment: The role of affective connection and identity. *J Environ Psychol* 28(2):109–120
- Hu L, Bentler PM (1998) Fit indices in covariance structure modeling: Sensitivity to underparameterized model misspecification. *Psychol Methods* 3(4):424–453
- Jacksohn A, Grösche P, Rehman K, Schröder C (2019) Drivers of renewable technology adoption in the household sector. *Energy Econ* 81:216–226
- Jain NK, Bhaskar K, Jain S (2022) What drives adoption intention of electric vehicles in India? An integrated UTAUT model with environmental concerns, perceived risk and government support. *Res Transp Bus Manag* 42:100730
- Kamalanon P, Chen J-S, Le T-T-Y (2022) Why Do We Buy Green Products? An Extended Theory of the Planned Behavior Model for Green Product Purchase Behavior. *Sustainability* 14(2):689
- Kesari B, Atulkar S, Pandey S (2021) Consumer Purchasing Behaviour towards Eco-Environment Residential Photovoltaic Solar Lighting Systems. *Global Bus Rev* 22(1):236–254
- Khazaei H (2019) The Influence of Personal Innovativeness and Price Value on Intention to Use of Electric Vehicles in Malaysia. *Eur Online J Nat Social Sci* 8(3):483–494
- Kim YA, Srivastava J (2007) Impact of social influence in e-commerce decision making, in Gini, M., Kauffman, R.J., Sarppo, D., Delarocas, C. and Dignum, F. (Eds.), *Proceedings of the ninth international conference on Electronic commerce, 19 08 2007 22 08 2007, Minneapolis MN USA*, ACM, New York, NY, USA, pp. 293–302
- Klesel M, Schubert F, Niehaves B, Henseler J (2022) Multigroup analysis in information systems research using PLS-PM. *ACM SIGMIS Database* 53(3):26–48
- Kollmuss A, Agyeman J (2002) Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environ Educ Res* 8(3):239–260
- Konopelko A, Kostecka-Tomaszewska L, Czerewacz-Filipowicz K (2023) Rethinking EU countries' energy security policy resulting from the ongoing energy crisis: Polish and German standpoints. *Energies* 16(13):5132
- Korcaj L, Hahnel UJ, Spada H (2015) Intentions to adopt photovoltaic systems depend on homeowners' expected personal gains and behavior of peers. *Renew Energy* 75:407–415
- Kumar P, Gupta S, Dagar V (2024) Sustainable energy development through non-residential rooftop solar photovoltaic adoption: Empirical evidence from India. *Sustain Dev* 32(1):795–814
- Lau L-S, Choong Y-O, Wei C-Y, Seow A-N, Choong C-K, Senadjki A, Ching S-L (2020) Investigating nonusers' behavioural intention towards solar photovoltaic technology in Malaysia: the role of knowledge transmission and price value. *Energy Policy* 144:111651
- Laureti T, Benedetti I (2018) Exploring pro-environmental food purchasing behaviour: An empirical analysis of Italian consumers. *J Clean Prod* 172:3367–3378
- Le NTT, Tran KT (2024) Predicting the intention to install solar photovoltaic panels in emerging market: the role of consumer innovativeness, knowledge, and support for government incentives. *J Open Innov Technol Mark Complex* 10(4):100423
- Lucarelli C, Mazzoli C, Severini S (2020) Applying the theory of planned behavior to examine pro-environmental behavior: the moderating effect of COVID-19 beliefs. *Sustainability* 12(24):10556
- Mancha RM, Yoder CY (2015) Cultural antecedents of green behavioral intent: An environmental theory of planned behavior. *J Environ Psychol* 43:145–154
- Market master data register (2025) Overview of current units, available at: <https://www.marktstammdatenregister.de/MaStR/Einheit/Einheiten/OeffentlicheEinheitenuebersicht>
- Matthews L, Hair J, Matthews R (2018) PLS-SEM: The Holy Grail for Advanced Analysis. *Mark Manage J* 28:1
- Molnár L, Szép T (2025) Technology acceptance of balcony solar systems in Hungary – exploring influencing factors in a late-adopter country. *Manage Environ Quality: Int J* 36(2):329–350
- Moons I, de Pelsmacker P (2015) An extended decomposed theory of planned behaviour to predict the usage intention of the electric car: a multi-group comparison. *Sustainability* 7(5):6212–6245
- Neves C, Oliveira T, Cruz-Jesus F, Venkatesh V (2025) Extending the unified theory of acceptance and use of technology for sustainable technologies context. *Int J Inf Manage* 80:102838
- Pallinger J (2024) Der Boom von Balkonkraftwerken ist ungebrochen, *Der Standard*, 11 April, available at: <https://www.derstandard.at/story/3000000215356/der-boom-von-balkonkraftwerken-ist-ungebrochen>
- Palm J, Tengvard M (2011) Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden. *Sustainability: Sci Pract Policy* 7(1):6–15
- Paramita D, Hartono B, Utomo DS, Arini HM, Mulyani YP, Rizqianwan A, Banjar Nahor KM, Spanellis A, Beltran M, Adrin HN, Baroroh DK, Tjahjono B (2024) Exploring factors influencing intention and actual usage in household solar PV adoption. *Cleaner Respons Consum* 15:100242
- Park J, Yang S, Lehto X (2007) Adoption of mobile technologies for Chinese consumers, No. 8
- Peattie K (2010) Green Consumption: Behavior and Norms. *Annu Rev Environ Resour* 35(1):195–228
- Qureshi TM, Ullah K, Arentsen MJ (2017) Factors responsible for solar PV adoption at household level: A case of Lahore, Pakistan. *Renew Sustain Energy Rev* 78:754–763
- Rana NP, Dwivedi YK, Lal B, Williams MD, Clement M (2017) Citizens' adoption of an electronic government system: towards a unified view. *Inform Syst Front* 19(3):549–568
- Ringle CM, Wende S, Becker J-M (2024) SmartPLS 4. SmartPLS, Bönningstedt
- Rode J, Müller S (2019) I spot, i adopt! A discrete choice analysis on peer effects in solar photovoltaic system adoption of households. *SSRN Electron J*
- Rogers EM (2003) Diffusion of innovations, 5th edn. Free Press, New York
- Roy S, Mohapatra S (2022) Problems of adoption of solar power and subsequent switching behavior: an exploration in India. *Int J Energy Sect Manage* 16(1):78–94
- Sarstedt M, Becker J-M, Ringle CM, Schwaiger M (2011) Uncovering and Treating Unobserved Heterogeneity with FIMIX-PLS: Which Model Selection Criterion Provides an Appropriate Number of Segments? *Schmalenbach Bus Rev* 63(1):34–62
- Sarstedt M, Ringle CM, Hair JF (2017) "Treating Unobserved Heterogeneity in PLS-SEM: A Multi-method Approach." In: Latan H, Noonan R (eds) *Partial Least Squares Path Modeling*. Springer International Publishing, Cham, pp 197–217
- Seme S, Strojansk L, Simonic E, Sredensek K (2024) Balcony solar photovoltaic plug-and-play systems. *Renew Energies Environ Power Qual J* 2:276–282
- Shahzad M, Qu Y, Rehman SU, Zafar AU (2022) Adoption of green innovation technology to accelerate sustainable development among manufacturing industry. *Journal of Innovation & Knowledge* 7(4):100231
- Shakeel SR, Yousaf H, Irfan M, Rajala A (2023) Solar PV adoption at household level: insights based on a systematic literature review. *Energy Strategy Rev* 50:101178
- Sheeran P, Webb TL (2016) The Intention–Behavior Gap. *Soc Pers Psychol Compass* 10(9):503–518

- Simpson G, Clifton J (2017) Testing Diffusion of Innovations Theory with data: Financial incentives, early adopters, and distributed solar energy in Australia. *Energy Res Social Sci* 29:12–22
- Solar storage systems research group HTW Berlin (2024) Plug solar simulator, available at: <https://solar.htw-berlin.de/rechner/stecker-solar-simulator/>
- Solar storage systems research group HTW Berlin (2022) Use of plug-in solar devices 2022, available at: <https://solar.htw-berlin.de/studien/nutzung-steckersolar-2022/>
- Spaeth U, Popp A, Fechtner H, Cichon A, Schmuelling B (2023) Self-consumption Optimization of Balcony Solar Systems Using a Load-controlled Battery Storage, in *2023 10th International Conference on Power and Energy Systems Engineering (CPESE)*, 08.09.2023–10.09.2023, Nagoya, Japan, IEEE, pp. 378–382
- Sreen N, Purbey S, Sadarangani P (2018) Impact of culture, behavior and gender on green purchase intention. *J Retailing Consumer Serv* 41:177–189
- Stikvoort B, Bartusch C, Juslin P (2020) Different strokes for different folks? Comparing pro-environmental intentions between electricity consumers and solar prosumers in Sweden. *Energy Res Soc Sci* 69:101552
- Sun P-C, Wang H-M, Huang H-L, Ho C-W (2020) Consumer attitude and purchase intention toward rooftop photovoltaic installation: The roles of personal trait, psychological benefit, and government incentives. *Energy Environ* 31(1):21–39
- Tamilmani K, Rana N, Dwivedi Y, Sahu GP and and, Roderick S (2018) *Exploring the role of 'price value' for understanding consumer adoption of technology: a review and meta-analysis of UTAUT2 based empirical studies*
- Thakur R, AlSaleh D (2019) Impact of Cognition, Affect, and Social Factors on Technology Adoption. *Int J Technol Mark* 13(2):1
- Tian X, Wang J, Ji J (2023) Performance prediction of a curved-type solar balcony combined with the flexible PV/T system during the non-heating season. *Energy Convers Manag* 292:117402
- Tsaur R-C, Lin Y-H (2018) Exploring the consumer attitude of building-attached photovoltaic equipment using revised Technology Acceptance Model. *Sustainability Basel* 10(11):4177
- Tscherning H, Mathiassen L (2010) The role of social networks in early adoption of mobile devices. In: Pries-Heje J, Venable J, Bunker D, Russo NL, DeGross JI (eds) *Human benefit through the diffusion of information systems design science research IFIP advances in information and communication technology*. Springer, Heidelberg, pp 52–70
- United Nations (2016) *The Paris Agreement*, available at: https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf
- Vafaei-Zadeh A, Wong T-K, Hanifah H, Teoh AP, Nawaser K (2022) Modelling electric vehicle purchase intention among Generation Y consumers in Malaysia. *Res Transp Bus Manag* 43:100784
- Valdivia-Sisniegas RH (2023) Increasing PV solar collection using the upper edges in balconies. *J Phys Conf Ser* 2600(4):42009
- VDE Association for Electrical, Electronic & Information Technologies (2017) *Installation of low-voltage systems* No. VDE 0100–551:2017-02, available at: <https://www.vde-verlag.de/normen/0100364/din-vde-0100-551-vde-0100-551-2017-02.html>
- Venghaus S, Henseleit M, Belka M (2022) The impact of climate change awareness on behavioral changes in Germany: changing minds or changing behavior? *Energy Sustain Soc* 12:1
- Venkatesh V, Morris MG, Davis GB (2003) User acceptance of information technology: toward a unified view. *MIS Quarterly* 27(3):425
- Venkatesh T and Xu (2012) Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology. *MIS Q* 36(1):157
- Verplanken B (2018) Promoting sustainability: towards a segmentation model of individual and household behaviour and behaviour change. *Sustain Dev* 26(3):193–205
- Vilkaite-Vaitone N (2024) From likes to sustainability: how social media influencers are changing the way we consume. *Sustainability Basel* 16(4):1393
- Vorobeva D, Scott IJ, Oliveira T, Neto M (2022) Adoption of new household waste management technologies: the role of financial incentives and pro-environmental behavior. *J Clean Prod* 362:132328
- Wirth H (2025) *Recent Facts about Photovoltaics in Germany*, available at: <https://www.pv-fakten.de/>
- Wolske KS, Stern PC, Dietz T (2017) Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories. *Energy Res Social Sci* 25:134–151

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.