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# Technology acceptance of household-scale solar PV systems in Hungary and in Poland – a comparative analysis using UTAUT2

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ABSTRACT

This study examines the determinants of household intention to adopt residential solar photovoltaic (PV) systems in two coal-dependent regions of the European Union – Northern Hungary and Poland's Śląskie Voivodeship, thereby addressing the limited theoretical and comparative evidence that is available about late-adopter, fossil-fuel-intensive contexts. The novelty of the research lies in the application of an extended Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) model to the persuasion stage of the diffusion of innovations. This integrates additional constructs (compatibility, education, personal innovativeness, and cost perceptions) to capture the contextual and socio-technical specificities of household energy decisions. Data were collected through an online survey in 2025 among potential adopters aged 30–59 (N = 353). Structural equation modeling (SEM) using SmartPLS was employed to assess the drivers of adoption intention and compare effects across the two regions. The findings show that performance expectancy, price value, hedonic motivation, facilitating conditions, education, and personal innovativeness significantly shape adoption intention, though their importance varies between Hungary and Poland. Social influence, compatibility, and perceived costs do not significantly affect intention in either region. These results reveal that households in coal-intensive areas remain highly sensitive to institutional support structures, technological benefits, and individual predispositions. The study advances theoretical work by contextualizing the UTAUT2 framework within early-stage renewable energy adoption in post-communist coal+ regions. From a practice perspective, it demonstrates that policies that enhance procedural clarity, subsidy stability, and access to installers can strengthen households' willingness to adopt solar PV, supporting a more equitable and accelerated energy transition.

## 1. Introduction

Household electrification is a key component of the broader energy transition, reflecting a strengthening global trend toward cleaner and more efficient energy use. Across the world, households are replacing traditional appliances and systems with modern, electric alternatives associated with higher efficiency and lower emissions. As households electrify, their electricity consumption increases significantly, leading to a fundamental shift in their overall energy mix. This rising demand for electricity is often met not only through the grid but also through decentralized renewable energy systems such as rooftop solar panels. These technologies are widely available, their social acceptance is high [1], and their affordability and other socioeconomic benefits make them highly attractive to households. Households with solar photovoltaic (PV) systems are more energy-conscious and, as prosumers, become more informed about energy issues and more supportive of environmental activities and movements. They change and rationalize their energy use patterns with the help of smart meters [2]. As a result, both the social engagement in energy systems and the need to participate in energy policy-making are growing [3] – as Szulecki writes, they are becoming *"political agents in a changing environment"* [4, p. 13].

Many factors influence a household's decision to switch fuels and adopt new technologies. Rogers [5] outlines five stages in the innovation adoption process: knowledge, persuasion, decision, implementation, and confirmation. Each stage involves distinct behaviors that may be shaped by direct or indirect interventions or incentives. During the

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persuasion stage, household acceptance of renewable energy is often hindered by a range of behavioral and other barriers [6]. To explore the current landscape of solar PV adoption, Shakeel et al. [7] conducted a systematic literature review of 146 studies, summarizing the methodologies and analytical approaches that were used. The review identified 127 distinct factors influencing adoption, categorized into eight groups: economic, environmental, personal, social, demographic, technical, market-related, and regulatory. Notably, the authors found that only 21% of the reviewed studies were grounded in theoretical frameworks. Twenty-one different theories or models were identified, e.g., Rogers' innovation diffusion model, the theory of planned behavior, the unified theory of acceptance and the use of technology (UTAUT and UTAUT2). UTAUT2's main objective is to identify and assess the key factors influencing individuals' behavioral intention to use and their actual use of technology. Building on the work of Shakeel et al. [7], we have identified eight studies [8–15] that employed UTAUT or UTAUT2 to investigate the adoption of various energy technologies to explain technology acceptance and use in consumer contexts. The UTAUT2 model, along with these eight papers, will be presented in more detail in *Section 3*.

This study fits into the research strand listed here. It concentrates on the persuasion stage of the diffusion process, during which individuals enhance their understanding of a technology, assess its potential benefits and drawbacks, and form either a positive or negative attitude toward its adoption [5,16]. It describes a comparison of the technology acceptance of household-scale solar PV systems[1] in two Member States of the European Union, namely Hungary and Poland. These countries have several similarities that make them suitable for comparative analysis. Both Poland and Hungary belong to Central and Eastern Europe, and as a result of their similar historical and post-communist industrial legacy, the GDP per capita of both is below the European Union average, and economic growth still takes priority over sustainable development [18,19]. They are often characterized as populist and as favoring traditional energy systems. As a consequence, the latter have made only limited progress in aligning their policies with the goals of the European Union's climate agenda [19], and they are also lagging behind in advancing the energy transition. According to the World Economic Forum [20], the Energy Transition Index score is 65.4 for Hungary (23rd in the global ranking, which includes 118 countries) and 59.9 for Poland (43rd) in 2025.

The analysis focuses on two regions: Śląskie Voivodeship (Silesia in English) in Poland, and Northern Hungary. Both of them are labelled as "*coal+ regions*" by the European Union, according to the 'Initiative for Coal Regions in Transition' launched in 2017 [21]. The program supports coal, peat, lignite, and oil shale regions in transitioning to a low-carbon economy, targeting 36 NUTS2[2]-regions associated with at least 100 jobs in fossil fuel extraction. By doing so, the European Union acknowledges that these regions face greater challenges in the energy transition due to their high fossil fuel dependency [21].

In both regions (Silesia and Northern Hungary), the energy transition poses a threat in terms of the potential loss of industries and jobs, primarily due to the still-dominant role of coal. Northern Hungary is home to a lignite-fired power plant and a coal mine, and >2000 jobs depend on solid fossil fuels [22]. Silesia is the largest hard coal mining region in Europe, where mining has historically played a crucial role in regional development. The region employs 80% of Poland's mining sector workforce, comprising 89,000 workers as of 2020. In some cities, coal-related jobs account for up to 50% of total employment [23].

Despite these difficulties, the energy transition is underway, and there are encouraging signs in terms of the uptake of household-scale solar PV systems. More information is now available about their distribution, but less is known about the factors that influence residents' intention to buy and install such systems, as well as the magnitude of these impacts. In this study, the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) model is employed to gain a deeper understanding of residents' motivations and intentions.

Shakeel et al. [7] identify eight research gaps in the area of solar PV adoption at household level: 1) methodological problems, 2) weak theoretical foundation, 3) lack of consideration of the adoption stage of the technology (differences can be determined between early- and late-adopter countries), 4) understanding of potential for co-adoption, 5) lack of information about market-related factors, 6) lack of stakeholder analysis, 7) lack of comparative studies, 8) weak attention to the role of national culture. This study focuses on the last two research gaps and contributes to the literature in at least four ways. First, it has been identified that citizens generally accept rooftop, household-scale solar PV systems in Poland and Hungary [24], but the factors influencing households' decision-making processes, as well as the magnitude of these impacts, remain unclear. Second, most research examines a single country, providing a single-country case study; comparative analyses are rare. The current article compares two countries that not only share similar economic and social characteristics but, as both are members of the European Union, must also meet climate targets within the same framework. Third, in constructing the model and selecting the influencing factors, we took into account the energy culture of the two countries under review. Fourth, to our knowledge, UTAUT2 has never been used to examine the situation with household-scale solar systems in these two countries. Deeper knowledge about people's intentions and the main drivers of technology acceptance may support the decision-making process and help create an efficient policy framework.

The remainder of this paper is organized as follows. *Section 2* provides the policy background that frames the study. *Section 3* presents the theoretical background, including the evolution of technology acceptance theories, the application of UTAUT2 to solar PV adoption, and the justification for the additional constructs incorporated into the extended model. *Section 4* develops the research hypotheses and introduces the conceptual model. *Section 5* describes the research procedure, sample, and measurement instruments. *Section 6* reports the empirical results, including the preliminary analyses, measurement model assessment, and structural model evaluation. Finally, *Section 7* delivers the discussion, theoretical and practical implications, limitations, future research directions, and concluding remarks.

## 2. Policy background

Photovoltaic electricity potential in Europe ranges from 700 to 2000 kWh/kWp, depending on geographical location. In Hungary, the value is around 1050 to 1350 kWh/kWp; in Poland, it is slightly lower, ranging from 900 to 1200 kWh/kWp. These numbers put these two countries roughly in the middle of the field [25].

In 2023, in Poland, the share of renewable energy sources in gross final energy consumption was 16.56%, with 25.79% in gross final electricity consumption, and in Hungary, it was 17.12% and 19.54%, respectively [26]. Like other EU Member States, both Poland and Hungary revised their renewable energy targets in 2024. In the proposed update of the National Energy and Climate Plan to 2030, Poland targets a 32.6% share of renewable energy sources in 2030 [27], while Hungary specifies 30% [28]. In both countries, new solar power plants are expected to make the most significant contributions to these goals. Poland expects to have at least 29 GW of installed PV capacity in 2030, and Hungary 12 GW [29,30]. However, the number of prosumers in each country already varies considerably. While Poland foresees 2 million prosumers by 2030 [31], Hungary expects 200,000 [32]. Here, we note that this latter target was in fact already achieved in 2023, but the 2024 update of the National Energy and Climate Plan foresees further expansion [30].

[1] *By this, we mean power plants that are connected to a low-voltage system with an interconnection capacity of<50 kVA at any given connection point* [17].

[2] *Nomenclature of territorial units for statistics - basic regions (for regional policies)*

In both countries, the solar market has experienced significant growth over the last few years, driven by the decreasing cost of solar PV systems, incentives, and favorable geographical locations. After 2020, the deployment of these systems accelerated further, driven by newly adopted energy strategies, the coronavirus pandemic (COVID-19), the energy crisis of 2021–2022, Russia's full-scale invasion of Ukraine, emerging energy security concerns, and digitalization. Regarding Poland, growing environmental awareness, especially regarding poor air quality, may be mentioned as well [33].

Hungary reached its first 1 MW of total installed solar PV capacity in 2010, whereas Poland achieved this in 2009 [40]. In 2024, Poland surpassed Hungary in both total solar electricity production (17,340 GWh vs. 9136 GWh) and total installed solar PV capacity (21,200 MW vs. 7551 MW). However, Hungary had achieved a significantly larger share of solar energy in its electricity mix (19.48% compared to Poland's 8.9%) and more solar PV capacity per capita (0.79 kW vs. 0.58 kW). Household-scale solar PV systems accounted for 12,735 MW in Poland and 2690 MW in Hungary, with 1543,942 registered prosumers in Poland and 256,471 in Hungary. The share of households with household-scale solar PV systems reached 6.2% in Hungary, whereas in Poland, 14% of single-family homes had PV micro-installation as of 2022 (Table 1). In the following, the main drivers (compensation mechanisms and support schemes) of this great expansion are presented in more detail.

In both countries, the net-metering accounting system has been in place for a long time (and remains in place for older installations). In Poland, this includes prosumers who connected their installations to the grid by March 31, 2022. With net-metering, surplus energy is fed into the grid, and a prosumer with a 2–10 kW micro-installation can *"take back"* up to 80% of this energy free of charge when their demand exceeds their self-production. In addition, prosumers are exempt from paying a distribution fee [38]. In Hungary, the net-metering introduced in 2007 was slightly different. It involved the yearly netting of electricity volumes fed into and withdrawn from the grid [41,42]. For prosumers, this accounting process was guaranteed from the start of their installation; however, calls for its revision were on the agenda as early as 2019. The end of net metering (for new installations) was announced by the government in August 2023.

In both countries, one reason for the change is the revision of EU legislation (Directive (EU) 2019/944), which states that *"Member States that have existing schemes that do not account separately for the electricity fed into the grid and the electricity consumed from the grid, shall not grant new rights under such schemes after 31 December 2023"* [43]. It also adds: *"In any event, customers subject to existing schemes shall have the possibility at any time to opt for a new scheme that accounts separately for the electricity fed into the grid and the electricity consumed from the grid as the basis for calculating network charges"* [43].

In Poland, prosumers who have installed PV micro-installations since April 1, 2022, are billed under the new net-billing system, according to which surplus energy fed into the grid is billed at market price. The introduction of this new billing system for prosumers has reduced interest in PV micro-installations [44]. Moreover, since July 1, 2024, net-billing in Poland requires that surplus energy be billed according to hourly prices on the Day-Ahead Market for prosumers whose PV systems came online after that date, rather than the previously applicable average monthly prices from the wholesale market [45]. Additionally, for PV installations connected to the grid from August 1, 2024, onwards, investing in an energy storage system is mandatory. According to Tomczyk and Łapniewska [44], due to favorable regulations and additional incentives, such as public subsidies and thermal insulation tax relief, the payback period for an investment in a PV micro-installation (4.40 kW) in central Poland averages around four years.

In Hungary, as of 8 September 2023, for new installations (whose application was not submitted by 7 September 2023), the option of net metering billing is no longer available, and users are now subject to so-called gross metering [46]. Gross metering involves separate metering and billing: electricity consumed from and exported to the grid is measured and paid for independently (including grid fees), with the latter invoiced separately at a rate of HUF 5/kWh [47]. This compensation mechanism has a significant impact on the payback period of an average household system, estimated at approximately 7 years for net metering and 15–20 years for gross metering.

Table 2 compares the compensation mechanisms in the two examined countries.

In both examined regions (Silesia and Northern Hungary), there is still huge potential for further solar installations. While in Silesia, the installed capacity of PV panels reached 914 MW (74.5 kW/km$^2$) in 2022, in Northern Hungary, it was 239.5 MW (17.83 kW/km$^2$) [34,35,48,49]. In Northern Hungary, 5.7%, and in Silesia, 4.14% of occupied dwellings have solar panels (both regions fall below the national average regarding this indicator). While in Silesia, the high urbanization rate and underdeveloped electricity network primarily slow down installations, in Northern Hungary, barriers typically include outdated building structures and high energy poverty. In the following, we present the situations in more detail.

In Silesia, 93% of dwellings with solar panels are single-family buildings, which dominate rural areas. Hence, the lowest saturation of PV installations occurs in urban municipalities, where collective housing buildings predominate. However, this solution would be particularly relevant to this voivodeship, which has the highest urbanization rate in Poland. In the northern and western parts of the region, the poor condition of the power grid makes it difficult to connect new PV installations [48]. Additionally, in the northern part, insulation levels may be approximately 10% lower than in the southern part due to varying

**Table 1**
PV systems in 2024 in Hungary and Poland: main statistics.

| | Hungary | Poland |
|---|---|---|
| **Total population (million)** | 9.58 | 36.62 |
| **GDP per capita (current prices, EUR)** | 21,570 | 22,560 |
| **Electricity production from solar energy (GWh)** | 9136 | 17,340 |
| **Share of solar energy in electricity production (%)** | 19.48 | 8.90 |
| **Total solar PV capacity (MW)** | 7551 | 21,200 |
| **Solar PV capacity per capita (kW)** | 0.79 | 0.58 |
| **Household-scale solar PV capacity (MW)** | 2690 | 12,735 |
| **Number of prosumers** | 256,471 | 1543,942 |
| **Share of households with household-scale solar PV systems (%)** | 6.2 | 14 |

Sources: [34–39].

**Table 2**
Overview of compensation mechanisms for household self-consumption in Hungary and Poland (for installations connected after 7 September 2023 in Hungary and after 31 March 2022 in Poland).

| | Metering and billing arrangement | Feed-in tariff | Retail rate (excluding taxes, levies, and other charges) | |
|---|---|---|---|---|
| | | | Energy fee | System charges |
| **Hungary** | Separate metering and billing | Static, fixed | Static | T-tariff and D-tariff; static |
| **Poland** | Net billing | Monthly average price until July 2024, then dynamic hourly market price, VAT also levied on credited amount | Static, variable Time of Use, dynamic, depending on the supply contract | T-tariff: static D-tariff: static/ Time of Use |

Note: T and D indicate whether the tariff applies to the use of the transmission or distribution system.
Source: Authors' compilation based on [46, p. 6].

weather conditions. Moreover, the entire region is struggling with the problem of severe air pollution, which further hinders the conditions for capturing solar radiation [50].

In Northern Hungary, the number of household-scale solar PV systems per 1000 inhabitants is 48.2, which is significantly higher than the national average (30.9 in 2024) [34], but their spatial distribution is concentrated in only a few mid-size cities. Several factors hinder the diffusion of social practices, technologies, and knowledge related to solar PV systems [51]. Among these, the low energy efficiency of the building stock definitely stands out. A significant proportion of dwellings are in poor condition: 93.9% of them were built before 2000, and their energy efficiency is generally very low. Their outdated electric systems and weak building structure make installations difficult. Another problem is energy poverty, which is defined in terms of vulnerability in Hungary. The Hungarian Energy Efficiency Act defines a 'household to be supported' as a vulnerable household whose annual energy expenditure, covering the heating of the dwelling to 20 °C and the provision of hot water, exceeds 25% of the household's annual income [52, p. 10]. The scale of the problem is illustrated by the fact that a total of 151 municipalities (24.8% of all municipalities) in Northern Hungary are at risk of energy poverty [22]. The related villages are home to just over 275,000 people (25% of the region's population). Szép and Tóth found that in Hungary, the distribution of solar PV systems is most strongly influenced by the education level of the inhabitants, the size and the age of dwellings, their spatial location, as well as built-up areas and population size [53]. These indicators are particularly unfavorable in areas affected by energy poverty. Typically, these vulnerable social groups are headed by less-educated adults, a significant proportion of whom live in rural peripheral areas in buildings that were constructed before 1980, whose walls are often made of adobe or other poor-quality mixed masonry. These are characterized by low energy efficiency and overcrowding [51]. Together, these factors mean that these households remain stuck at the bottom of the energy ladder, and, without targeted assistance, the energy transition and the adaptation of technologies using modern renewable energy sources will remain out of reach for them [54].

## 3. Theoretical background

Research on technology acceptance and innovation diffusion has progressed through a series of theoretical developments, each contributing to a more comprehensive understanding of how individuals evaluate and adopt new technologies. This study builds on this evolution by applying an extended version of UTAUT2 to examine households' intention to adopt residential solar PV systems in Hungary and Poland.

### *3.1. Evolution of technology acceptance theories*

Early theories of technology acceptance, including the Theory of Reasoned Action (TRA) and the Theory of Planned Behavior (TPB), conceptualized behavioral intention as a function of attitudes, subjective norms, and perceived behavioral control [8]. These models laid the foundation for understanding adoption behavior but were limited in explaining technology-specific perceptions.

The Technology Acceptance Model (TAM) advanced the field by introducing perceived usefulness and perceived ease of use as core drivers of adoption. TAM and its extensions became widely used in information systems research; however, they remained confined to individual-level perceptions and did not fully incorporate social or contextual factors [55]. Other frameworks – such as the Motivational Model (MM) [55], the combined TAM–TPB model (C-TAM-TPB), the Model of PC Utilization (MPCU) [56], Innovation Diffusion Theory (IDT) [57], and Social Cognitive Theory (SCT) [58] – contributed additional insights, but often in a fragmented manner.

To synthesize these theoretical strands, Venkatesh et al. developed the Unified Theory of Acceptance and Use of Technology (UTAUT) [59]. UTAUT integrates the central determinants of earlier theories into four core constructs – performance expectancy, effort expectancy, social influence, and facilitating conditions – while incorporating key moderators such as age, gender, and experience. Unlike earlier models, UTAUT offers a unified structural explanation of behavioral intention and consistently accounts for a larger share of variance than its predecessors.

Recognizing the increasing significance of consumer technologies, Venkatesh et al. later introduced UTAUT2 [60], which expands UTAUT by adding hedonic motivation, price value, and habit. These constructs capture emotions, financial considerations, and behavioral routines that are particularly relevant to household decision-making. UTAUT2 has since been applied extensively in studies of emerging technologies such as digital banking, smart metering, electric vehicles, conditionally automated vehicles, and solar PV systems [13,61].

Fig. 1 illustrates the progression from early attitudinal models to more integrative frameworks such as UTAUT and UTAUT2. This theoretical evolution highlights a shift from narrow cognitive perspectives to comprehensive, multidimensional explanations of technology adoption, forming the foundation for the present study.

### *3.2. UTAUT2 in the context of solar PV adoption*

Household decisions regarding the adoption of solar PV systems involve evaluating multiple functional, social, emotional, and contextual factors – many of which align closely with the UTAUT2 constructs. Solar PV adoption often entails expectations about economic and performance benefits, ease of use, social or neighborhood influences, and the availability of support and information, reflecting the core elements of UTAUT2.

Prior studies that have applied UTAUT2 to energy-related innovations such as electric vehicles and smart metering have shown that performance expectancy, effort expectancy, social influence, and facilitating conditions are robust predictors of adoption intention [13,61]. Research that specifically examines solar PV adoption similarly identifies these constructs as influential, though the relative importance of each varies across contexts [8–15]. For example, performance expectancy is frequently linked to cost savings and energy independence, while social influence is amplified in settings where visible diffusion patterns encourage peer imitation.

Despite these insights, two gaps remain in the literature. First, UTAUT2 has seldom been applied in cross-country analyses of household solar PV adoption in Central and Eastern Europe – regions with distinct energy transition trajectories. Second, many studies extend UTAUT2 by integrating context-specific variables such as environmental beliefs, awareness of subsidies, perceived quality, or cost perceptions, suggesting that additional determinants may be necessary to fully explain household decision-making about PV systems.

To address these gaps, the present research applies an extended UTAUT2 model adapted to the characteristics of residential solar PV adoption in Hungary and Poland.

### *3.3. Justification for additional constructs in the extended model*

To capture the unique aspects of household energy decisions, four additional constructs – compatibility, education, personal innovativeness, and costs – were incorporated into the conceptual model. These variables are well established in the innovation-diffusion and renewable energy literature and complement the UTAUT2 framework.

*Compatibility*, derived from Innovation Diffusion Theory, refers to the extent to which a technology aligns with users' values, experiences, and lifestyle. In residential solar PV adoption, compatibility includes the perceived alignment with household energy use patterns, environmental

 

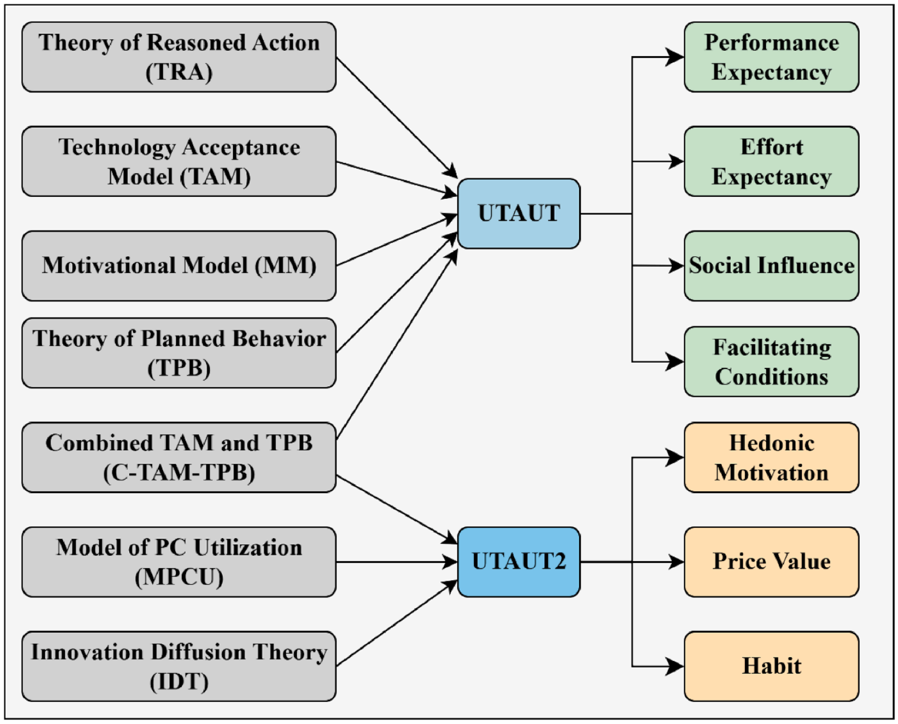


**Fig. 1.** Evolution of technology acceptance theories.
Source: Authors' construction based on Venkatesh et al. [62,63]

values, and the physical characteristics of the home. Prior research (e.g. [57]) identifies compatibility as a strong predictor of renewable energy adoption.

*Education* shapes individuals' capacity to understand technological options, evaluate costs and benefits, and interpret technical information. Higher levels of education are linked to greater awareness and acceptance of renewable energy technologies. Including education acknowledges its role in informed decision-making regarding solar PV adoption [8].

*Personal innovativeness* reflects an individual's predisposition to adopt new technologies early [12]. Given that solar PV systems are still perceived as emerging energy solutions in many regions, innovativeness can significantly influence adoption attitudes and reduce perceived risks.

*Cost perceptions* – including installation expenses, expected energy savings, and awareness of financial incentives – are central to decisions about solar PV. Prior studies [9,10,14] show that perceived costs can strongly facilitate or hinder adoption, often more so than environmental or social considerations.

Together, these four constructs enhance the explanatory capacity of the extended UTAUT2 model by capturing psychological, socio-demographic, economic, and contextual elements relevant to household energy technology adoption.

## 4. Hypotheses development

Drawing on the extended UTAUT2 framework and the additional constructs outlined above, this section presents the hypotheses that guide the empirical investigation. Each hypothesis is supported by a theoretical rationale and evidence from prior studies on technology and renewable energy adoption.

### 4.1. UTAUT2 constructs

*Performance expectancy* refers to the degree to which individuals believe that solar PV systems will deliver beneficial outcomes, such as reduced electricity costs or increased energy independence. Prior studies consistently identify performance expectancy as a strong predictor of adoption in energy and technology domains [13,61].

- *H1: Performance expectancy positively influences households' intention to adopt solar PV energy systems.*

*Effort expectancy* captures perceptions of the ease of understanding, installing, or using solar PV systems [9–14]. Lower perceived complexity tends to strengthen adoption intention, particularly for technologies perceived as technically demanding.

- *H2: Effort expectancy positively influences households' intention to adopt solar PV energy systems.*

*Social influence* reflects perceptions that significant others – such as family, friends, or neighbors – support or expect solar PV adoption. Given the visibility of rooftop panels, social diffusion plays a substantial role in PV adoption decisions [8–15].

- *H3: Social influence positively influences households' intention to adopt solar PV energy systems.*

*Price value* measures the perceived trade-off between the benefits of solar PV and the financial investment required. High perceived value increases the likelihood of adoption [9,14,64].

- *H4: Price value positively influences households' intention to adopt solar PV energy systems.*

*Hedonic motivation* refers to the enjoyment or satisfaction derived from using a technology, such as the sense of autonomy or environmental responsibility associated with generating clean energy [9,12–14, 64].

- *H5: Hedonic motivation positively influences households' intention to adopt solar PV energy systems.*

*Facilitating conditions* encompasses the availability of information, resources, support, and infrastructure enabling solar PV adoption. Strong facilitating conditions reduce uncertainty and increase adoption readiness [14].

- *H6: Facilitating conditions positively influence households' intention to adopt solar PV energy systems.*

*Habit* describes automatic tendencies formed through prior experience with similar technologies. Although household-level experience with solar PV is limited, related routines (e.g., using smart energy devices) may influence adoption intention [14].

- *H7: Habit positively influences households' intention to adopt solar PV energy systems.*

### *4.2. Additional constructs*

*Compatibility* describes the perceived fit between solar PV systems and individuals' values, lifestyle, and existing energy practices. Rooted in innovation diffusion theory, compatibility is widely recognized as a key predictor of renewable energy adoption.

- *H8: Compatibility positively influences households' intention to adopt solar PV energy systems.*

*Education* enhances individuals' ability to interpret technical and financial information, leading to more favorable evaluations of renewable energy technologies.

- *H9: Education positively influences households' intention to adopt solar PV energy systems.*

*Personal innovativeness* reflects the tendency to adopt new technologies earlier than others. More innovative individuals exhibit greater openness and reduced perceived risk, strengthening adoption intention.

- *H10: Personal innovativeness positively influences households' intention to adopt solar PV energy systems.*

*Cost perceptions* play a fundamental role in renewable energy decisions. High installation costs or low expected financial returns can discourage adoption, while favorable cost assessments encourage it.

- *H11: Costs positively influence households' intention to adopt solar PV energy systems.*

### *4.3. Conceptual model*

The eleven hypotheses derived above together form the basis of the conceptual model guiding this study. Building on the extended UTAUT2 framework, the model positions households' intention to adopt solar PV systems as the dependent variable and includes both UTAUT2 constructs and additional context-specific variables as direct predictors. This structure reflects the assumption – widely supported in prior research on energy technology adoption – that household decision-making is shaped by a combination of cognitive evaluations, social influences, emotional responses, economic considerations, and individual characteristics.

The UTAUT2 constructs represent the core technology-related mechanisms expected to drive adoption. Performance expectancy and effort expectancy capture the perceived utility and ease associated with solar PV systems, forming the primary cognitive pathway toward intention. Social influence and facilitating conditions account for interpersonal and contextual effects, recognizing that household adoption is embedded in the broader social and infrastructural environment. Hedonic motivation and habit capture the experiential and behavioral dimensions of technology engagement, while price value reflects financial assessments relative to benefits. Together, these constructs represent the foundational elements of UTAUT2 and are hypothesized to directly influence adoption intention.

The additional constructs – compatibility, education, personal innovativeness, and costs – extend the model to reflect characteristics unique to household energy decisions. Compatibility introduces the notion of lifestyle and value alignment, recognizing that adoption is more likely when solar PV use aligns with existing practices. Education captures differences in cognitive capacity and information-processing skills relevant to evaluating complex energy technologies. Personal innovativeness reflects individual openness to new technologies and willingness to engage with novel solutions. Finally, explicit cost perceptions address financial considerations that are particularly salient in the context of solar PV investments. These constructs complement the UTAUT2 components by incorporating lifestyle, socio-demographic, psychological, and economic factors known to influence renewable energy adoption.

In the conceptual model (Fig. 2), all eleven constructs are specified as direct antecedents of households' intention to adopt solar PV systems. This configuration enables a comprehensive evaluation of the relative influence of technology-related, contextual, psychological, and financial factors. It also provides a basis for examining potential differences across the two country samples included in the study. The resulting framework reflects an integrative, multidimensional approach to understanding solar PV adoption in residential settings.

## 5. Method

### *5.1. Research procedure and sample*

The target group of the research was defined as potential solar PV users aged 30–59 living in Northern Hungary and Silesia, Poland. Potential users were identified as individuals who (1) live in privately owned properties suitable for solar panel installation, (2) do not currently possess such a system, and (3) are considered household decision-makers in matters related to energy. We chose this age group because the main target group for solar panels consists of people in their 30 s, 40 s, and 50 s who own property, have a stable income, think long-term, and are environmentally conscious [65].

Since precise data on the size and composition of this target group were not available, it was not possible to draw a representative sample in a single step. In such cases, the most appropriate approach is the so-called double sampling procedure [66]. In the first stage, a representative sample (quota-sampled by gender, age, and settlement type) was drawn from the general population aged 30–59, to whom only screening and demographic questions were addressed. In the second stage, the survey was continued exclusively among respondents who met the screening criteria and therefore belonged to the defined target group. The responses obtained in this way theoretically reflect the characteristics of the entire population of potential solar PV users.

Data were collected through professional online panels, a task commissioned to SEDO Research Ltd. in the first quarter of 2025. The company maintains a pre-recruited and continuously updated database of potential respondents who voluntarily participate in social and market research. Panel members were invited to take part in the study via email, and participation was entirely voluntary. Before accessing the questionnaire, all respondents were informed about the purpose of the study, data protection measures, and their right to withdraw at any time. Data collection followed the double-sampling procedure described above. In the first stage, invitations were sent to a representative sample of panel members aged 30–59 living in the target regions (Northern Hungary and Silesia, Poland). These individuals completed a brief

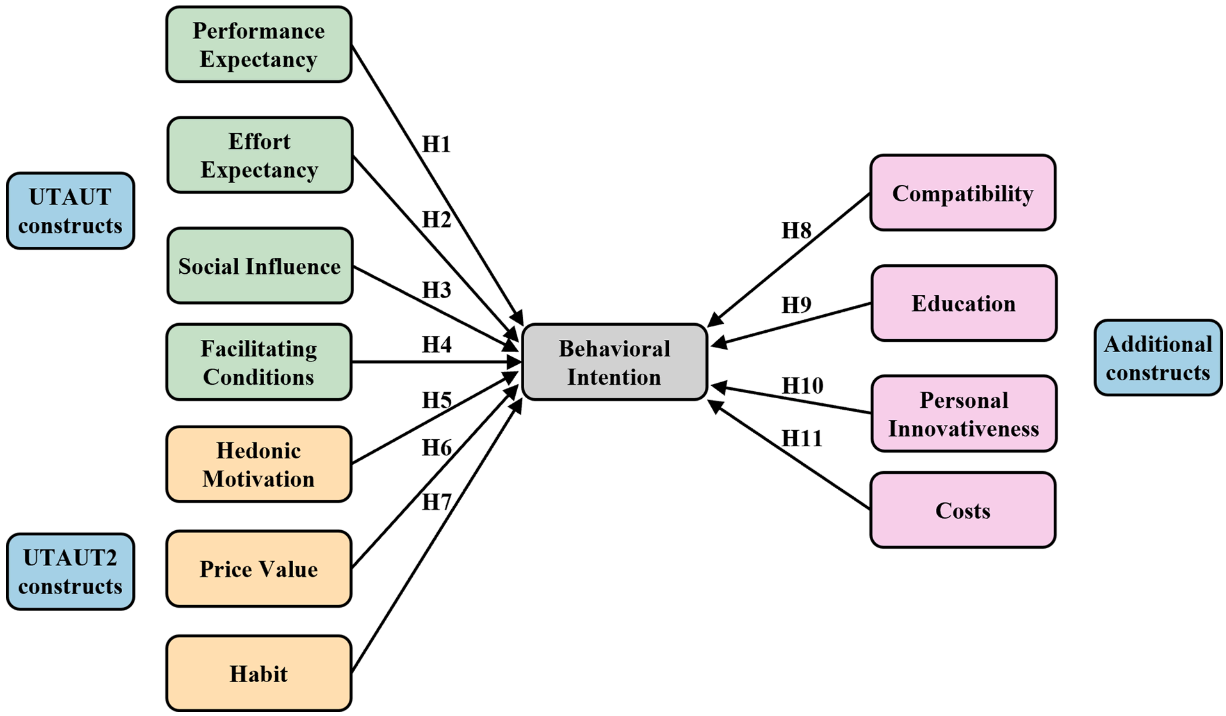


**Fig. 2.** Conceptual model.
Source: Authors' construction

screening questionnaire to assess their eligibility based on property ownership, suitability of residence for PV installation, and their decision-making role in household energy matters. Only respondents meeting these criteria were invited to complete the full questionnaire in the second stage.

Data quality was ensured through multiple mechanisms, including built-in attention-check items, response time monitoring, and consistency validation. Incomplete or inconsistent responses were excluded from the final dataset. After data collection, the responses were exported from the online platform and processed using statistical software. Data were thoroughly validated to ensure coding accuracy, verify completeness, and identify missing values. This careful handling of the data enhanced the reliability of the dataset and strengthened the rigor of the analytical framework.

Statistical analyses were performed in SPSS, while the research hypotheses were tested using partial least squares structural equation modeling (PLS-SEM) in SmartPLS. SEM was selected because the model included multiple latent constructs with interrelated paths, requiring simultaneous estimation of measurement and structural relationships. PLS-SEM was deemed appropriate given the study's prediction-oriented objective, moderate sample size, and the potential non-normal distribution of the data. This method is also well-suited to models that combine reflective and formative constructs, as commonly found in technology adoption research. Overall, PLS-SEM provided a robust analytical framework for assessing the theoretical model and identifying the determinants of households' intentions to adopt solar PV systems.

The structural and measurement relationships specified in the research model can be expressed in the following system of equations, which represent the general form of the partial least squares structural equation model (PLS-SEM).

Measurement equations:

$$PE = \beta_1^{PE}\cdot PE_1 + \beta_2^{PE}\cdot PE_2 + \beta_3^{PE}\cdot PE_3 + \beta_4^{PE}\cdot PE_4 + \beta_5^{PE}\cdot PE_5 + \beta_6^{PE}\cdot PE_6 + \zeta_{PE},$$

$$EE = \beta_1^{EE}\cdot EE_1 + \beta_2^{EE}\cdot EE_2 + \beta_3^{EE}\cdot EE_3 + \beta_4^{EE}\cdot EE_4 + \zeta_{EE},$$

$$SI = \beta_1^{SI}\cdot SI_1 + \beta_2^{SI}\cdot SI_2 + \beta_3^{SI}\cdot SI_3 + \beta_4^{SI}\cdot SI_4 + \zeta_{SI},$$

$$PV = \beta_1^{PV}\cdot PV_1 + \beta_2^{PV}\cdot PV_2 + \beta_3^{PV}\cdot PV_3 + \beta_4^{PV}\cdot PV_4 + \beta_5^{PV}\cdot PV_5 + \zeta_{PV},$$

$$HM = \beta_1^{HM}\cdot HM_1 + \beta_2^{HM}\cdot HM_2 + \beta_3^{HM}\cdot HM_3 + \beta_4^{HM}\cdot HM_4 + \zeta_{HM},$$

$$FC = \beta_1^{FC}\cdot FC_1 + \beta_2^{FC}\cdot FC_2 + \beta_3^{FC}\cdot FC_3 + \beta_4^{FC}\cdot FC_4 + \zeta_{FC},$$

$$HB = \beta_1^{HB}\cdot HB_1 + \beta_2^{HB}\cdot HB_2 + \beta_3^{HB}\cdot HB_3 + \zeta_{HB},$$

$$CM = \beta_1^{CM}\cdot CM_1 + \beta_2^{CM}\cdot CM_2 + \beta_3^{CM}\cdot CM_3 + \zeta_{CM},$$

$$ED = \beta_1^{ED}\cdot ED_1 + \beta_2^{ED}\cdot ED_2 + \beta_3^{ED}\cdot ED_3 + \beta_4^{ED}\cdot ED_4 + \beta_5^{ED}\cdot ED_5 + \beta_6^{ED}\cdot ED_6 + \beta_7^{ED}\cdot ED_7 + \beta_8^{ED}\cdot ED_8 + \zeta_{ED},$$

$$PI = \beta_1^{PI}\cdot PI_1 + \beta_2^{PI}\cdot PI_2 + \beta_3^{PI}\cdot PI_3 + \zeta_{PI},$$

$$CO = \beta_1^{CO}\cdot CO_1 + \beta_2^{CO}\cdot CO_2 + \beta_3^{CO}\cdot CO_3 + \beta_4^{CO}\cdot CO_4 + \beta_5^{CO}\cdot CO_5 + \zeta_{CO},$$

$$BI = \beta_1^{BI}\cdot BI_1 + \beta_2^{BI}\cdot BI_2 + \beta_3^{BI}\cdot BI_3 + \beta_4^{BI}\cdot BI_4 + \zeta_{BI}.$$

Structural equation:

$$BI = \beta_{PE}\cdot PE + \beta_{EE}\cdot EE + \beta_{SI}\cdot SI + \beta_{PV}\cdot PV + \beta_{HM}\cdot HM + \beta_{FC}\cdot FC + \beta_{HB}\cdot HB + \beta_{CM}\cdot CM + \beta_{ED}\cdot ED + \beta_{PI}\cdot PI + \beta_{CO}\cdot CO + \zeta_{BI}$$

where
*PE:* Performance Expectancy
*EE:* Effort Expectancy
*SI:* Social Influence
*PV:* Price Value
*HM:* Hedonic Motivation
*FC:* Facilitating Conditions
*HB:* Habit
*CM:* Compatibility
*ED:* Education

*PI:* Personal Innovativeness
*β*: Coefficients
*ζ*: Errors

No control variables were included in the structural model, as the primary objective of the analysis was to test the hypothesized relationships among the latent constructs derived from the extended UTAUT framework. Nevertheless, information on several demographic variables (e.g., age, gender, education, settlement type) was collected as part of the survey. These may serve as potential control variables in future research. This decision was made to maintain model parsimony and focus the analysis on the theoretical relationships of interest.

The composition of the cleaned Hungarian ($n_h$ = 200) and Polish ($n_p$ = 153) samples is presented in Table 3.

The methodological solutions applied in the research ensure the generalizability of the findings to the entire target population, while the sample sizes of the Hungarian and Polish subsamples separately also meet the minimum sample size requirements for PLS-SEM analysis, as recommended by Kock and Hadaya [67].

### 5.2. Research instruments

The questionnaire was specifically developed to test the conceptual model and the proposed hypotheses. The instrument consisted of three clearly distinguishable parts.

The first included demographic and screening questions designed to identify eligible respondents. Participants were asked about their gender, age, place of residence (county and settlement type), and whether they met the predefined screening criteria: (1) living in a privately owned property suitable for solar PV system installation, (2) not yet owning such a system, and (3) being the decision-maker in the household regarding these matters.

The second part of the questionnaire comprised 53 items and two control questions. The conceptual model includes 12 constructs, each operationalized through 3–8 measurement items. For most constructs, validated scales from prior literature were applied. Respondents were asked to evaluate the items on a seven-point Likert scale, ranging from 1

**Table 3**
Composition of Hungarian and polish samples.

| | Hungarian sample ($n_H$=200) | |
|---|---|---|
| Gender | Male | 50.0% |
| | Female | 50.0% |
| Age | 30–39 | 31.0% |
| | 40–49 | 35.5% |
| | 50–59 | 35.5% |
| Type of settlement | City with county status | 11.5% |
| | Town | 29.5% |
| | Village | 59.0% |
| Education | Primary education | 6.0% |
| | Post-secondary. non-tertiary education | 31.0% |
| | Upper secondary education | 33.5% |
| | Bachelor's degree or equivalent | 18.0% |
| | Master's degree or equivalent | 9.5% |
| | Doctoral degree or equivalent | 0.5% |
| | Prefer not to answer | 1.5% |
| | **Polish sample ($n_P$=153)** | |
| Gender | Male | 56.2% |
| | Female | 43.8% |
| Age | 30–39 | 30.7% |
| | 40–49 | 40.5% |
| | 50–59 | 28.8% |
| Type of settlement | Village | 0.7% |
| | Town with up to 50,000 inhabitants | 34.6% |
| | Town with from 50,000 to 100,000 inhabitants | 21.6% |
| | City with over 100,000 inhabitants | 43.1% |
| Education | Primary or lower secondary education | 0.7% |
| | Basic vocational education | 7.2% |
| | Upper secondary education | 35.9% |
| | Bachelor's degree | 15.7% |
| | Master's degree | 40.5% |

**Table 4**
Constructs and measurement items.

| Constructs (Source) | | Measurement items | |
|---|---|---|---|
| PE | Performance Expectancy [68] | PE1 | I think solar PV systems are an environmentally friendly technology. |
| | | PE2 | I think solar PV systems will be beneficial in my daily life. |
| | | PE3 | In my opinion, a solar PV system is a technology that is easy to use. |
| | | PE4 | In my opinion, using a solar PV system will save on electricity usage where I live. |
| | | PE5 | I have become partially independent from the service provider. |
| | | PE6 | A solar PV system can cover my family's basic needs regarding electricity consumption. |
| EE | Effort Expectancy [68] | EE1 | A solar PV system can be easily installed in my house. |
| | | EE2 | A solar PV system will work well with my household appliances. |
| | | EE3 | Solar PV systems are easy to maintain. |
| | | EE4 | It is easy for me to understand how solar PV systems work with household appliances in my residence. |
| SI | Social Influence [69] | SI1 | I always consult my friends, colleagues, and influencers (vloggers, technical experts, etc.) about their experiences before deciding to buy. |
| | | SI2 | If my friends, colleagues, and influencers (vloggers, technical experts, etc.) have good experience with solar PV systems, I will consider having one as well. |
| | | SI3 | I have heard from friends, colleagues, and influencers (vloggers, technical expert, etc.) that I should consider using a solar PV system. |
| | | SI4 | I will share information about sustainable products with my friends and family members. |
| PV | Price Value [69] | PV1 | Solar PV systems have become more affordable. |
| | | PV2 | A government subsidy would strengthen my intent to buy a solar PV system. |
| | | PV3 | Even the gross metering system for solar PV systems strengthens my intent to install a solar PV system. |
| | | PV4 | A solar PV system would reduce my electricity bill. |
| | | PV5 | The financial viability of a solar home system is important. |
| HM | Hedonic Motivation [68] | HM1 | I would be satisfied to be the first to use a solar PV system in my neighborhood. |
| | | HM2 | I love trying new products before others. |
| | | HM3 | The purchase/installation of solar PV systems in my residence is something that makes me satisfied. |
| | | HM4 | Purchasing/installing solar PV systems at my residence will be a pleasant experience. |
| FC | Facilitating Conditions [70] | FC1 | I have the knowledge and resources necessary to consider a solar PV system. |
| | | FC2 | I can get help from others when I have difficulties using solar PV system. |
| | | FC3 | I have sufficient area at my residence on which a solar PV system may be installed. |
| | | FC4 | Having reliable technical support is important for solar PV systems. |
| HB | Habit (Compiled by the authors) | HB1 | I would pay more attention to the timing of household activities. |
| | | HB2 | I would read tips to optimize my electricity consumption. |
| | | HB3 | I would change my habits to maximize my self-consumption. |
| CM | Compatibility [70] | CM1 | Solar PV technology is compatible with our culture. |
| | | CM2 | Solar PV technology is compatible with our values. |

(*continued on next page*)

**Table 4** (*continued*)

| Constructs (Source) | | Measurement items | |
|---|---|---|---|
| | | CM3 | Using solar PV technology, I will look environmentally conscious. |
| ED | Education (Compiled by the authors) | ED1 | I have always been interested in new technologies. |
| | | ED2 | I have always been interested in renewable energy sources. |
| | | ED3 | I am an experimenter. |
| | | ED4 | I feel that my educational background has equipped me with the necessary skills to effectively use technology. |
| | | ED5 | I believe that my level of education positively influences my ability to learn new technologies. |
| | | ED6 | I often seek additional educational opportunities to enhance my technological skills. |
| | | ED7 | I think my formal education is relevant to my current use of technology. |
| | | ED8 | I have access to resources that support my ongoing education in technology-related fields. |
| PI | Personal Innovativeness [71] | PI1 | If I heard that the solar PV installation process had become less bureaucratic, I would be interested enough to try it. |
| | | PI2 | Compared to my friends, I seek out a lot of information about solar PV installation services. |
| | | PI3 | I would purchase a new solar PV installation service even if no one in my circle of friends had tried one before. |
| CO | Costs [72] | CO1 | Installation costs are very high. |
| | | CO2 | There are major price and quality differences between European and non-EU (e.g., Chinese) products. |
| | | CO3 | Need to spend money for training purposes. |
| | | CO4 | Cost and benefits do not justify. |
| | | CO5 | Uncertainty about end-of-life costs (collection, processing, and discarding or recycling). |
| BI | Behavioral Intention [68] | BI1 | I have the resources (money, time, effort) necessary to have a solar PV system installed. |
| | | BI2 | I want to utilize free energy from the sun for my electricity needs. |
| | | BI3 | I would love to try to use solar PV technology. |
| | | BI4 | I am interested in using a solar PV system if given more information. |

(“*strongly disagree*") to 7 (“*strongly agree*”). To ensure data quality, two attention-check questions were included, each requiring respondents to select a specific response option. Participants who failed either of these checks were excluded from the analysis.(Table 4)

The third and final part of the questionnaire consisted of additional demographic questions designed to characterize the sample in more detail. This included items on educational attainment, occupation, income, marital status, dwelling size, type of property, number of household members, ownership status, and condition of the building.

To ensure the validity and reliability of the survey instrument, a comprehensive multi-stage validation procedure was implemented. In the first phase, content validity was established through an expert review. A panel of scholars in educational research and behavioral sciences evaluated the questionnaire to verify that the items accurately reflected the intended constructs and that the adaptations from the UTAUT framework were appropriate. The original English questionnaire was translated into Hungarian and Polish using the standard forward–backward translation procedure [73]. Two independent bilingual experts produced forward translations, which were reconciled into a consensus version. Each version was then back-translated into English by a translator unfamiliar with the original instrument. Discrepancies were discussed and resolved by the research team to ensure conceptual and semantic equivalence and cultural appropriateness across all language versions. A pilot study was then conducted with a small sample of households (20 in total) from the target population to assess the clarity of wording, internal consistency, and overall structure. Respondents' feedback informed minor revisions to enhance comprehensibility and alignment with the research objectives. The finalized questionnaires were subsequently administered to the samples. This systematic validation process – combining expert evaluation, rigorous translation, and pilot testing – strengthened the robustness of the measurement instrument and reinforced the credibility of the study's empirical results.

## 6. Results

### 6.1. Preliminary analysis results

#### 6.1.1. Descriptive analysis results

Descriptive statistics were calculated for all measurement items to examine the distributions and central tendencies of the observed variables in both national samples. Table 5 presents the means, standard deviations, skewness, and kurtosis values for each indicator for Hungarian and Polish respondents. The results indicate that the mean values are generally above the midpoint of the seven-point Likert scale, suggesting positive perceptions of solar PV adoption across most constructs. The skewness and kurtosis values fall within the acceptable range ($\pm 2$), confirming that the data do not substantially deviate from normality and are suitable for further analysis using PLS-SEM.

#### 6.1.2. Common method bias test

Variance Inflation Factor (VIF) values were used to assess potential common method bias. All VIF values are well below the common threshold of 5. The highest VIF values observed are around 5.867 for CM1, 5.737 for PE4, and 5.726 for HM4, all in the Polish sample (Table 6). While these values are slightly above 5, they are still generally considered acceptable. This suggests that multicollinearity is not a significant concern in this study and the regression coefficients are likely to be stable.

### 6.2. Measurement model analysis

#### 6.2.1. Reliability and convergent validity

We used factor loadings, Cronbach's alpha, composite reliability, and average variance extracted (AVE) to assess model validity and reliability. Table 7 displays the results of the latter tests for all constructs in the Hungarian and Polish samples. All factor loadings exceed 0.6, confirming the model's validity and indicating that the items are strongly related to their respective constructs. Reliability results indicate excellent internal consistency for nearly all constructs across both samples, with Cronbach's alphas ranging from 0.8 to 0.9. Similarly, Composite Reliability (CR) values are above 0.7, further supporting the reliability of the constructs. The results also demonstrate that AVEs exceed 0.5, indicating good convergent validity for most constructs. However, the *cost* construct is associated with AVE values below 0.5 in both countries, suggesting that the related items may not strongly converge on a single construct. Overall, the findings indicate that both the Hungarian and Polish samples demonstrate good validity and reliability.

#### 6.2.2. Discriminant validity

Discriminant validity evaluates if constructs differ from one another. The Fornell-Larcker criterion and Heterotrait-Monotrait (HTMT) ratio of correlations are two popular approaches to such an evaluation.

For discriminant validity to be supported with the Fornell-Larcker criterion, the square root of each construct's AVE must be larger than its correlations with every other construct (the off-diagonal entries in the

**Table 5**
Descriptive statistics.

| Constructs | Item code | Hungarian sample | | | | Polish sample | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | M | SD | Skew | Kurt | M | SD | Skew | Kurt |
| Performance Expectancy | PE1 | 5.960 | 1.198 | −0.967 | 0.037 | 5.725 | 1.501 | −1.153 | 0.645 |
| | PE2 | 6.040 | 1.279 | −1.472 | 1.897 | 5.288 | 1.735 | −0.759 | −0.419 |
| | PE3 | 5.745 | 1.244 | −0.77 | −0.3 | 5.405 | 1.475 | −0.815 | 0.132 |
| | PE4 | 6.090 | 1.375 | −1.873 | 3.257 | 5.477 | 1.744 | −0.995 | 0.022 |
| | PE5 | 5.580 | 1.589 | −0.993 | 0.119 | 5.242 | 1.698 | −0.729 | −0.257 |
| | PE6 | 5.585 | 1.467 | −0.882 | −0.041 | 5.235 | 1.712 | −0.907 | 0.113 |
| Effort Expectancy | EE1 | 5.525 | 1.453 | −0.631 | −0.74 | 4.961 | 1.838 | −0.708 | −0.466 |
| | EE2 | 5.810 | 1.405 | −1.316 | 1.384 | 5.131 | 1.783 | −0.637 | −0.592 |
| | EE3 | 5.195 | 1.373 | −0.451 | −0.361 | 4.889 | 1.672 | −0.455 | −0.612 |
| | EE4 | 5.430 | 1.482 | −0.892 | 0.22 | 5.203 | 1.64 | −0.657 | −0.385 |
| Social Influence | SI1 | 4.460 | 1.851 | −0.301 | −0.9 | 4.294 | 1.909 | −0.187 | −1.078 |
| | SI2 | 4.560 | 1.73 | −0.305 | −0.865 | 4.405 | 1.985 | −0.29 | −1.153 |
| | SI3 | 4.805 | 1.784 | −0.501 | −0.752 | 4.124 | 2.113 | −0.076 | −1.408 |
| | SI4 | 5.085 | 1.736 | −0.703 | −0.496 | 4.902 | 1.831 | −0.531 | −0.866 |
| Price Value | PV1 | 4.280 | 1.57 | −0.268 | −0.406 | 4.275 | 1.804 | −0.248 | −0.884 |
| | PV2 | 5.505 | 1.716 | −1.057 | 0.197 | 4.588 | 1.945 | −0.469 | −0.938 |
| | PV3 | 5.575 | 1.627 | −1.185 | 0.716 | 4.248 | 1.847 | −0.314 | −0.876 |
| | PV4 | 6.050 | 1.348 | −1.659 | 2.436 | 5.000 | 1.788 | −0.581 | −0.606 |
| | PV5 | 5.880 | 1.391 | −1.469 | 1.79 | 5.660 | 1.651 | −1.175 | 0.488 |
| Hedonic Motivation | HM1 | 4.330 | 2.05 | −0.241 | −1.157 | 4.137 | 1.97 | −0.22 | −1.075 |
| | HM2 | 4.230 | 2.022 | −0.189 | −1.172 | 4.569 | 1.802 | −0.434 | −0.744 |
| | HM3 | 5.295 | 1.668 | −0.713 | −0.416 | 4.693 | 1.875 | −0.467 | −0.808 |
| | HM4 | 5.525 | 1.572 | −0.983 | 0.181 | 4.627 | 1.802 | −0.493 | −0.581 |
| Facilitating Conditions | FC1 | 4.810 | 1.761 | −0.572 | −0.543 | 4.477 | 1.843 | −0.363 | −0.926 |
| | FC2 | 5.155 | 1.745 | −0.83 | −0.142 | 4.634 | 1.708 | −0.441 | −0.624 |
| | FC3 | 5.995 | 1.301 | −1.566 | 2.479 | 4.948 | 1.912 | −0.691 | −0.608 |
| | FC4 | 6.165 | 1.219 | −1.683 | 2.45 | 5.418 | 1.715 | −1.02 | 0.143 |
| Habit | HB1 | 5.400 | 1.659 | −1.036 | 0.342 | 4.641 | 1.801 | −0.433 | −0.727 |
| | HB2 | 4.945 | 1.827 | −0.702 | −0.526 | 5.438 | 1.525 | −0.737 | −0.241 |
| | HB3 | 5.265 | 1.732 | −0.996 | 0.11 | 5.131 | 1.588 | −0.657 | −0.219 |
| Compatibility | CM1 | 5.580 | 1.394 | −1.004 | 0.715 | 4.948 | 1.638 | −0.626 | −0.316 |
| | CM2 | 5.715 | 1.423 | −1.082 | 0.552 | 5.072 | 1.602 | −0.683 | −0.198 |
| | CM3 | 5.720 | 1.375 | −1.205 | 1.076 | 5.026 | 1.709 | −0.522 | −0.67 |
| Education | ED1 | 5.515 | 1.543 | −0.932 | 0.183 | 5.150 | 1.529 | −0.693 | 0.205 |
| | ED2 | 5.535 | 1.566 | −0.974 | 0.167 | 4.895 | 1.667 | −0.575 | −0.282 |
| | ED3 | 4.855 | 1.664 | −0.409 | −0.632 | 4.346 | 1.636 | −0.344 | −0.468 |
| | ED4 | 4.875 | 1.748 | −0.514 | −0.757 | 4.817 | 1.652 | −0.564 | −0.373 |
| | ED5 | 4.960 | 1.753 | −0.628 | −0.654 | 5.216 | 1.455 | −0.746 | 0.322 |
| | ED6 | 4.560 | 1.88 | −0.445 | −0.938 | 4.863 | 1.577 | −0.392 | −0.424 |
| | ED8 | 5.060 | 1.718 | −0.689 | −0.486 | 4.882 | 1.473 | −0.457 | −0.274 |
| Personal Innovativeness | PI1 | 5.160 | 1.743 | −0.926 | 0.053 | 5.314 | 1.624 | −0.725 | −0.256 |
| | PI2 | 4.355 | 1.854 | −0.234 | −1.001 | 4.523 | 1.751 | −0.262 | −0.865 |
| | PI3 | 4.995 | 1.817 | −0.749 | −0.444 | 4.725 | 1.679 | −0.428 | −0.501 |
| Costs | CO1 | 5.960 | 1.186 | −1.165 | 0.919 | 5.150 | 1.559 | −0.781 | 0.235 |
| | CO2 | 5.370 | 1.485 | −0.833 | 0.251 | 5.131 | 1.512 | −0.491 | −0.414 |
| | CO3 | 3.805 | 1.776 | −0.126 | −0.958 | 4.039 | 1.576 | −0.055 | −0.499 |
| | CO4 | 4.665 | 1.714 | −0.49 | −0.566 | 4.314 | 1.583 | −0.177 | −0.469 |
| | CO5 | 4.840 | 1.605 | −0.553 | −0.337 | 4.673 | 1.673 | −0.366 | −0.579 |
| Behavioral Intention | BI1 | 3.120 | 1.888 | 0.441 | −1.045 | 4.458 | 1.933 | −0.314 | −1.037 |
| | BI2 | 5.835 | 1.428 | −1.286 | 1.161 | 5.255 | 1.579 | −0.815 | 0.122 |
| | BI3 | 5.950 | 1.459 | −1.551 | 1.812 | 5.098 | 1.669 | −0.682 | −0.268 |
| | BI4 | 5.470 | 1.61 | −0.993 | 0.189 | 4.967 | 1.648 | −0.564 | −0.265 |

relevant row and column). As shown in Tables 8 and 9, the Fornell-Larcker criterion is met, indicating that the constructs are largely distinct.

The HTMT ratio is a more conservative indicator of discriminant validity (Tables 10 and 11). HTMT values of <0.90 (or in some cases, 0.85) are indicative of good discriminant validity. Values greater than this imply a lack of discriminant validity.

Most HTMT values are below 0.90, indicating good discriminant validity. However, the PE-EE value (0.899) is very close to the threshold, which may raise concerns about the discriminant validity between *performance expectancy* and *effort expectancy*. The Polish sample is associated with a number of HTMT values above 0.90, suggesting serious problems with discriminant validity. In particular, BI-CM (0.926), BI-ED (0.931), BI-FC (0.922), PI-BI (1.004), PV-BI (0.932), FC-EE (0.930), PI-ED (0.922), PV-FC (0.970), and PV-PE (0.893) are problematic. The value of 1.004 for PI-BI is of particular concern, indicating that *personal innovativeness* and *behavioral intention* are not well-differentiated constructs in the Polish sample.

### 6.3. Structural model analysis

#### 6.3.1. Path coefficients

Figs. 3 and 4 present the results of the hypothesis testing, showing the path coefficients, t-statistics, p-values, and conclusions for the direct effects of each construct on *behavioral intention* for the Hungarian and Polish samples. Next, we present the results, comparing both samples to highlight their similarities and differences.

*Performance expectancy* exhibits a significant positive relationship with intention in Hungary, with a P-value of 0.006, whereas this relationship is not significant in the Polish case. This suggests that perceived benefits and the effectiveness of solar PV systems are stronger motivators for Hungarians than for Polish households. Furthermore, *effort*

**Table 6**
Variance inflation factor (VIF).

| Constructs | Item code | Hungarian sample | Polish sample |
|---|---|---|---|
| Behavioral Intention | BI1 | 1.103 | 1.564 |
| | BI2 | 3.607 | 2.857 |
| | BI3 | 4.320 | 3.699 |
| | BI4 | 2.194 | 2.202 |
| Compatibility | CM1 | 3.193 | 5.867 |
| | CM2 | 2.959 | 5.537 |
| | CM3 | 2.330 | 2.280 |
| Costs | CO1 | 1.121 | 1.671 |
| | CO2 | 1.152 | 1.425 |
| | CO3 | 1.427 | 1.445 |
| | CO4 | 1.605 | 1.782 |
| | CO5 | 1.581 | 2.145 |
| Education | ED1 | 5.268 | 3.123 |
| | ED2 | 4.582 | 2.484 |
| | ED3 | 2.470 | 2.487 |
| | ED4 | 4.042 | 2.906 |
| | ED5 | 3.833 | 3.472 |
| | ED6 | 2.610 | 3.414 |
| | ED8 | 2.171 | 2.765 |
| Effort Expectancy | EE1 | 2.007 | 2.373 |
| | EE2 | 1.880 | 3.554 |
| | EE3 | 2.188 | 2.999 |
| | EE4 | 2.039 | 2.609 |
| Facilitating Conditions | FC1 | 1.850 | 2.493 |
| | FC2 | 1.766 | 1.926 |
| | FC3 | 2.025 | 2.702 |
| | FC4 | 1.935 | 1.417 |
| Habit | HB1 | 2.187 | 1.472 |
| | HB2 | 2.409 | 2.310 |
| | HB3 | 2.594 | 2.753 |
| Hedonic Motivation | HM1 | 1.995 | 3.208 |
| | HM2 | 2.131 | 2.350 |
| | HM3 | 3.602 | 5.164 |
| | HM4 | 2.808 | 5.726 |
| Performance Expectancy | PE1 | 2.090 | 1.943 |
| | PE2 | 3.981 | 4.338 |
| | PE3 | 2.326 | 2.721 |
| | PE4 | 2.537 | 5.737 |
| | PE5 | 2.416 | 5.196 |
| | PE6 | 2.529 | 4.327 |
| Personal Innovativeness | PI1 | 2.022 | 1.642 |
| | PI2 | 2.347 | 1.927 |
| | PI3 | 1.971 | 2.140 |
| Price Value | PV1 | 1.553 | 2.522 |
| | PV2 | 1.836 | 2.744 |
| | PV3 | 1.980 | 2.803 |
| | PV4 | 2.536 | 3.009 |
| | PV5 | 2.855 | 1.706 |
| Social Influence | SI1 | 1.880 | 2.140 |
| | SI2 | 2.629 | 3.303 |
| | SI3 | 2.257 | 3.280 |
| | SI4 | 1.829 | 1.887 |

*expectancy* has a significant negative relationship with *behavioral intention* in the Hungarian sample, whereas it shows no relationship in Poland, indicating that for some, perceived ease might paradoxically reduce adoption intention, possibly due to a misunderstanding of the technology's value or the perception of a lack of challenge.

Interestingly, the relationship between *social influence* and *behavioral intention* is not supported in either sample. This suggests that peer pressure or others' opinions do not significantly affect solar PV system adoption intentions in either country. *Price value* supports behavior in Poland but not in Hungary, highlighting that financial considerations are more influential for Polish households. The influence of *hedonic motivation* is supported in Hungary but not in Poland, implying that the pleasure or satisfaction derived from using solar PV systems is a stronger driver for Hungarians. Similarly, the relevance of *facilitating conditions* is supported in Hungary but not in Poland, indicating that the availability of infrastructure and support systems is a key factor for Hungarians.

Regarding *habit*, the relationship is significant and negative in Hungary but not in Poland. Similar to *effort expectancy*, pre-existing habits appear to hinder adoption intention in Hungary overall. *Compatibility* is not supported in either country, suggesting that perceived consistency between solar PV systems and existing values and lifestyles does not influence adoption intention. *Education* shows a significant relationship in Poland but not in Hungary, suggesting that interest in new technologies is a stronger driver for Polish households. Likewise, *personal innovativeness* is supported for Poland but not for Hungary, indicating that a willingness to try new technologies is more important for Polish households. Lastly, *costs* are not a significant factor in either country, suggesting that the perceived financial burden does not significantly deter adoption intention in either context (Table 12).

### 6.3.2. Structural model assessment

Table 13 provides the R-squared and Q-squared values for *behavioral intention* for each sample. The results show that the model explains 67.3% of the variance in behavioral intention in Hungary and has good predictive relevance. In the Polish case, the model explains 84.7% of the variance, indicating excellent predictive relevance.

Overall, the $R^2$ and $Q^2$ values suggest that the proposed model is robust in explaining and predicting *behavioral intention* across both countries, with particularly strong predictive power in the Polish sample.

### 6.3.3. Effect sizes

Table 14 shows the f2 effect sizes, which indicate the relative importance of each independent variable. Effect sizes are usually categorized as no effect (< 0.02), small (0.02–0.15), medium (0.15–0.35), and large (> 0.35). Most significant paths across both samples have small effect sizes. Accordingly, these factors statistically influence *behavioral intention,* but their individual contributions to explaining its variance are modest. For example, in Hungary, *performance expectancy, effort expectancy, hedonic motivation, facilitating conditions*, and *habit* all have small effects. In Poland, *price value, education, personal innovativeness*, and *compatibility* are also associated with small effects. This suggests that behavioral intention is influenced by numerous small factors acting in concert, rather than a few dominant ones.

### 6.3.4. Multi-group analysis

Table 15 presents the results of the multi-group analysis, which directly compares the path coefficients between the Hungarian and Polish samples. A significant p-value (< 0.05) indicates a statistically significant difference in the relationship between the two countries.

The findings show noteworthy cross-country variation in the determinants of *behavioral intention* to adopt solar PV systems. *Education* has a significantly stronger positive effect on behavioral intention in Poland than in Hungary ($p = 0.032$), indicating that educational level is a more effective predictor of adoption intention among Polish consumers. Conversely, *effort expectancy* has a significantly stronger negative effect on behavioral intention in Hungary than in Poland ($p = 0.026$), suggesting that ease-of-use perceptions may dampen rather than stimulate adoption intention in the Hungarian context. *Facilitating conditions* strongly support *behavioral intention* in Hungary ($p = 0.043$), but not in Poland, highlighting the stronger role of conducive infrastructure and resources in shaping intentions among Hungarian consumers. Additionally, *habit* proves to be a limiting factor of *behavioral intention* in Hungary ($p = 0.024$), whereas its influence is nonsignificant in Poland. These results underscore the need for context-specific approaches to promoting the adoption of solar PV systems across diverse national environments.

### 6.3.5. Robustness check

A robustness check was conducted to confirm the stability and validity of the model estimates. Using the original dataset, 5000 bootstrap subsamples were generated to re-estimate the model parameters. The bootstrapping procedure yielded consistent results. Moreover, the path coefficients and significance levels obtained from the bootstrap analysis

**Table 7**
Measurement model.

| Constructs | Item code | Hungarian sample | | | | Polish sample | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Factor loading | Cronbach's alpha | Composite Reliability (CR) | Average Variance Extracted (AVE) | Factor loading | Cronbach's alpha | Composite Reliability (CR) | Average Variance Extracted (AVE) |
| Performance Expectancy | PE1 | 0.735 | 0.908 | 0.929 | 0.687 | 0.770 | 0.941 | 0.954 | 0.775 |
| | PE2 | 0.915 | | | | 0.914 | | | |
| | PE3 | 0.815 | | | | 0.846 | | | |
| | PE4 | 0.837 | | | | 0.932 | | | |
| | PE5 | 0.825 | | | | 0.907 | | | |
| | PE6 | 0.835 | | | | 0.903 | | | |
| Effort Expectancy | EE1 | 0.843 | 0.855 | 0.901 | 0.695 | 0.852 | 0.909 | 0.937 | 0.787 |
| | EE2 | 0.854 | | | | 0.921 | | | |
| | EE3 | 0.826 | | | | 0.895 | | | |
| | EE4 | 0.810 | | | | 0.878 | | | |
| Social Influence | SI1 | 0.674 | 0.852 | 0.892 | 0.675 | 0.814 | 0.884 | 0.919 | 0.740 |
| | SI2 | 0.841 | | | | 0.888 | | | |
| | SI3 | 0.892 | | | | 0.905 | | | |
| | SI4 | 0.863 | | | | 0.831 | | | |
| Price Value | PV1 | 0.714 | 0.861 | 0.900 | 0.643 | 0.857 | 0.884 | 0.916 | 0.689 |
| | PV2 | 0.754 | | | | 0.865 | | | |
| | PV3 | 0.795 | | | | 0.855 | | | |
| | PV4 | 0.857 | | | | 0.885 | | | |
| | PV5 | 0.878 | | | | 0.669 | | | |
| Hedonic Motivation | HM1 | 0.803 | 0.879 | 0.916 | 0.732 | 0.891 | 0.910 | 0.937 | 0.788 |
| | HM2 | 0.813 | | | | 0.816 | | | |
| | HM3 | 0.925 | | | | 0.915 | | | |
| | HM4 | 0.877 | | | | 0.925 | | | |
| Facilitating Conditions | FC1 | 0.773 | 0.819 | 0.878 | 0.644 | 0.867 | 0.845 | 0.896 | 0.685 |
| | FC2 | 0.741 | | | | 0.817 | | | |
| | FC3 | 0.845 | | | | 0.883 | | | |
| | FC4 | 0.847 | | | | 0.736 | | | |
| Habit | HB1 | 0.846 | 0.875 | 0.921 | 0.796 | 0.738 | 0.809 | 0.887 | 0.726 |
| | HB2 | 0.924 | | | | 0.881 | | | |
| | HB3 | 0.905 | | | | 0.926 | | | |
| Compatibility | CM1 | 0.926 | 0.895 | 0.935 | 0.827 | 0.952 | 0.917 | 0.948 | 0.859 |
| | CM2 | 0.925 | | | | 0.947 | | | |
| | CM3 | 0.877 | | | | 0.880 | | | |
| Education | ED1 | 0.885 | 0.924 | 0.938 | 0.686 | 0.862 | 0.930 | 0.944 | 0.706 |
| | ED2 | 0.872 | | | | 0.817 | | | |
| | ED3 | 0.799 | | | | 0.816 | | | |
| | ED4 | 0.849 | | | | 0.834 | | | |
| | ED5 | 0.791 | | | | 0.855 | | | |
| | ED6 | 0.819 | | | | 0.859 | | | |
| | ED8 | 0.777 | | | | 0.837 | | | |
| Personal Innovativeness | PI1 | 0.873 | 0.850 | 0.909 | 0.769 | 0.818 | 0.820 | 0.893 | 0.736 |
| | PI2 | 0.890 | | | | 0.865 | | | |
| | PI3 | 0.867 | | | | 0.888 | | | |
| Costs | CO1 | 0.519 | 0.688 | 0.754 | 0.389 | 0.700 | 0.763 | 0.828 | 0.492 |
| | CO2 | 0.832 | | | | 0.739 | | | |
| | CO3 | 0.516 | | | | 0.685 | | | |
| | CO4 | 0.548 | | | | 0.594 | | | |
| | CO5 | 0.646 | | | | 0.774 | | | |
| Behavioral Intention | BI1 | 0.430 | 0.798 | 0.875 | 0.651 | 0.757 | 0.864 | 0.908 | 0.712 |
| | BI2 | 0.900 | | | | 0.870 | | | |
| | BI3 | 0.930 | | | | 0.910 | | | |
| | BI4 | 0.863 | | | | 0.832 | | | |

**Table 8**
Fornell-Larcker criterion – Hungarian sample.

| | BI | CM | CO | ED | EE | FC | HB | HM | PE | PI | PV | SI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BI | 0.807 | | | | | | | | | | | |
| CM | 0.689 | 0.909 | | | | | | | | | | |
| CO | 0.291 | 0.321 | 0.624 | | | | | | | | | |
| ED | 0.612 | 0.672 | 0.197 | 0.828 | | | | | | | | |
| EE | 0.576 | 0.707 | 0.154 | 0.565 | 0.833 | | | | | | | |
| FC | 0.654 | 0.661 | 0.154 | 0.717 | 0.701 | 0.803 | | | | | | |
| HB | 0.310 | 0.515 | 0.390 | 0.443 | 0.377 | 0.302 | 0.892 | | | | | |
| HM | 0.706 | 0.726 | 0.299 | 0.621 | 0.657 | 0.592 | 0.463 | 0.856 | | | | |
| PE | 0.653 | 0.679 | 0.233 | 0.496 | 0.805 | 0.618 | 0.388 | 0.633 | 0.829 | | | |
| PI | 0.686 | 0.745 | 0.301 | 0.737 | 0.651 | 0.653 | 0.499 | 0.757 | 0.583 | 0.877 | | |
| PV | 0.698 | 0.746 | 0.227 | 0.599 | 0.761 | 0.672 | 0.403 | 0.720 | 0.802 | 0.691 | 0.802 | |
| SI | 0.436 | 0.474 | 0.154 | 0.539 | 0.441 | 0.494 | 0.385 | 0.485 | 0.435 | 0.527 | 0.504 | 0.822 |

**Table 9**
Fornell-Larcker criterion – polish sample.

| | BI | CM | CO | ED | EE | FC | HB | HM | PE | PI | PV | SI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BI | 0.844 | | | | | | | | | | | |
| CM | 0.825 | 0.927 | | | | | | | | | | |
| CO | 0.430 | 0.391 | 0.701 | | | | | | | | | |
| ED | 0.835 | 0.743 | 0.415 | 0.840 | | | | | | | | |
| EE | 0.761 | 0.760 | 0.258 | 0.756 | 0.887 | | | | | | | |
| FC | 0.789 | 0.735 | 0.401 | 0.801 | 0.814 | 0.827 | | | | | | |
| HB | 0.727 | 0.758 | 0.452 | 0.646 | 0.670 | 0.701 | 0.852 | | | | | |
| HM | 0.805 | 0.798 | 0.370 | 0.735 | 0.733 | 0.771 | 0.628 | 0.888 | | | | |
| PE | 0.778 | 0.813 | 0.357 | 0.675 | 0.819 | 0.719 | 0.720 | 0.785 | 0.880 | | | |
| PI | 0.848 | 0.769 | 0.430 | 0.809 | 0.760 | 0.778 | 0.727 | 0.738 | 0.732 | 0.858 | | |
| PV | 0.816 | 0.799 | 0.344 | 0.719 | 0.788 | 0.834 | 0.717 | 0.806 | 0.815 | 0.746 | 0.830 | |
| SI | 0.684 | 0.618 | 0.377 | 0.653 | 0.662 | 0.688 | 0.625 | 0.706 | 0.646 | 0.616 | 0.755 | 0.860 |

**Table 10**
Heterotrait-Monotrait ratio of correlations (HTMT) – Hungarian sample.

| | BI | CM | CO | ED | EE | FC | HB | HM | PE | PI | PV | SI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BI | | | | | | | | | | | | |
| CM | 0.796 | | | | | | | | | | | |
| CO | 0.361 | 0.241 | | | | | | | | | | |
| ED | 0.715 | 0.721 | 0.278 | | | | | | | | | |
| EE | 0.677 | 0.799 | 0.214 | 0.630 | | | | | | | | |
| FC | 0.795 | 0.763 | 0.340 | 0.838 | 0.837 | | | | | | | |
| HB | 0.346 | 0.577 | 0.362 | 0.465 | 0.430 | 0.353 | | | | | | |
| HM | 0.824 | 0.800 | 0.260 | 0.676 | 0.738 | 0.689 | 0.517 | | | | | |
| PE | 0.740 | 0.750 | 0.237 | 0.529 | 0.899 | 0.709 | 0.435 | 0.697 | | | | |
| PI | 0.850 | 0.849 | 0.271 | 0.828 | 0.759 | 0.784 | 0.561 | 0.870 | 0.660 | | | |
| PV | 0.821 | 0.840 | 0.238 | 0.658 | 0.869 | 0.786 | 0.472 | 0.811 | 0.891 | 0.805 | | |
| SI | 0.460 | 0.508 | 0.183 | 0.551 | 0.493 | 0.543 | 0.446 | 0.509 | 0.469 | 0.554 | 0.561 | |

**Table 11**
Heterotrait-Monotrait ratio of correlations (HTMT) – polish sample.

| | BI | CM | CO | ED | EE | FC | HB | HM | PE | PI | PV | SI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BI | | | | | | | | | | | | |
| CM | 0.926 | | | | | | | | | | | |
| CO | 0.447 | 0.371 | | | | | | | | | | |
| ED | 0.931 | 0.801 | 0.396 | | | | | | | | | |
| EE | 0.856 | 0.829 | 0.240 | 0.821 | | | | | | | | |
| FC | 0.922 | 0.836 | 0.420 | 0.901 | 0.930 | | | | | | | |
| HB | 0.860 | 0.872 | 0.506 | 0.736 | 0.775 | 0.848 | | | | | | |
| HM | 0.903 | 0.868 | 0.356 | 0.798 | 0.797 | 0.877 | 0.720 | | | | | |
| PE | 0.862 | 0.876 | 0.343 | 0.719 | 0.881 | 0.809 | 0.819 | 0.840 | | | | |
| PI | 1.004 | 0.886 | 0.452 | 0.922 | 0.877 | 0.932 | 0.887 | 0.846 | 0.833 | | | |
| PV | 0.932 | 0.884 | 0.350 | 0.794 | 0.880 | 0.970 | 0.852 | 0.884 | 0.893 | 0.879 | | |
| SI | 0.771 | 0.675 | 0.390 | 0.702 | 0.725 | 0.784 | 0.748 | 0.775 | 0.697 | 0.704 | 0.836 | |

closely matched those derived from the original sample. These findings indicate that the model is robust and that the estimated relationships are stable across resamples.

## 7. Discussion and conclusion

### *7.1. Discussion*

The paper describes an examination of the determinants of household intentions to adopt residential solar PV systems in two coal-dependent regions of Central and Eastern Europe – Silesia in Poland and Northern Hungary – using an extended UTAUT2 model enriched with the variables of compatibility, education, personal innovativeness, and cost perceptions. The comparative results reveal both shared and divergent patterns across the two national contexts.

Across both samples, social influence and compatibility did not significantly predict adoption intention, suggesting that neither peer networks nor perceived lifestyle fit play a defining role in PV-related decisions, despite the high visibility of rooftop solar systems, as noted in previous research [8–15]. In neither country did cost perceptions significantly deter adoption, indicating that households may not perceive the initial financial burden as prohibitive, echoing the finding that perceived economic benefits often outweigh cost concerns in PV uptake [24].

Hungarian households were strongly influenced by performance expectancy, hedonic motivation, facilitating conditions, and habit. The significance of facilitating conditions underscores the importance of institutional stability and infrastructural support – an issue frequently highlighted in the Hungarian energy-policy context [74,75]. The negative effects of effort expectancy and habit suggest that routinized energy-use practices and perceptions of procedural simplicity may reduce motivation, as trivializing the technology may lead to underestimating its value.

Polish households exhibited a different motivational structure: price value, education, and personal innovativeness significantly shaped adoption intention. These findings align with previous evidence showing the centrality of financial incentives, energy literacy, and openness to experimentation in Polish renewable technology adoption

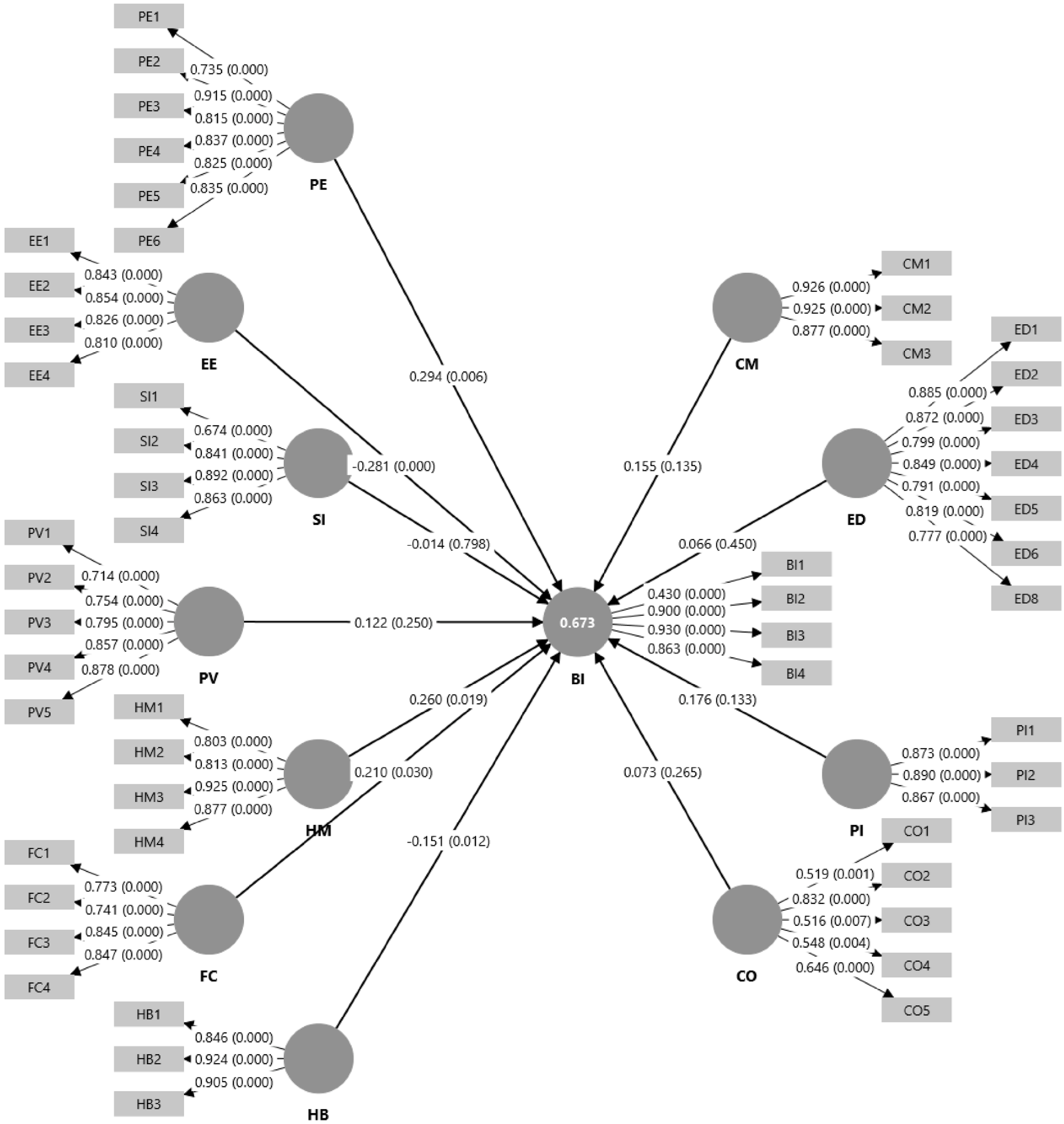


**Fig. 3.** Final path model and coefficients: Hungarian sample.

[33,76–82]. The strong role of education reflects the region's large supply of technically skilled labor and the prevalence of engineering competencies in Silesia [83,84].

Taken together, the results confirm that PV adoption intentions are shaped by multidimensional and context-dependent factors, supporting earlier insights into energy cultures and national differences within Central and Eastern Europe [18,19,85,86].

### *7.2. Theoretical implications*

This study makes several contributions to the theoretical understanding of household energy-technology adoption, particularly within the framework of UTAUT2.

First, by applying and extending UTAUT2 in two coal-dependent European regions, the research demonstrates that the relative importance of UTAUT2 predictors varies substantially across socio-institutional contexts. While performance expectancy and hedonic motivation align with core UTAUT2 assumptions in the Hungarian sample, price value and education play more central roles in the Polish sample. This divergence suggests that the UTAUT2 model is sensitive to contextual energy cultures [18], and national policy environments [19], offering empirical support for calls to integrate cultural and structural factors into technology-acceptance research.

Second, the incorporation of education and personal innovativeness highlights the value of integrating innovation-diffusion constructs into UTAUT2 in order to capture household-level technological decision-making [5,16]. The strong effects of education and innovativeness in Poland indicate that cognitive capacity and the predisposition toward experimentation remain underexplored but theoretically important determinants in energy-technology adoption [87]. Future theoretical models should further formalize these constructs.

Third, the study shows that facilitating conditions remain a critical predictor in environments characterized by regulatory volatility, contributing to the theoretical understanding of how institutional

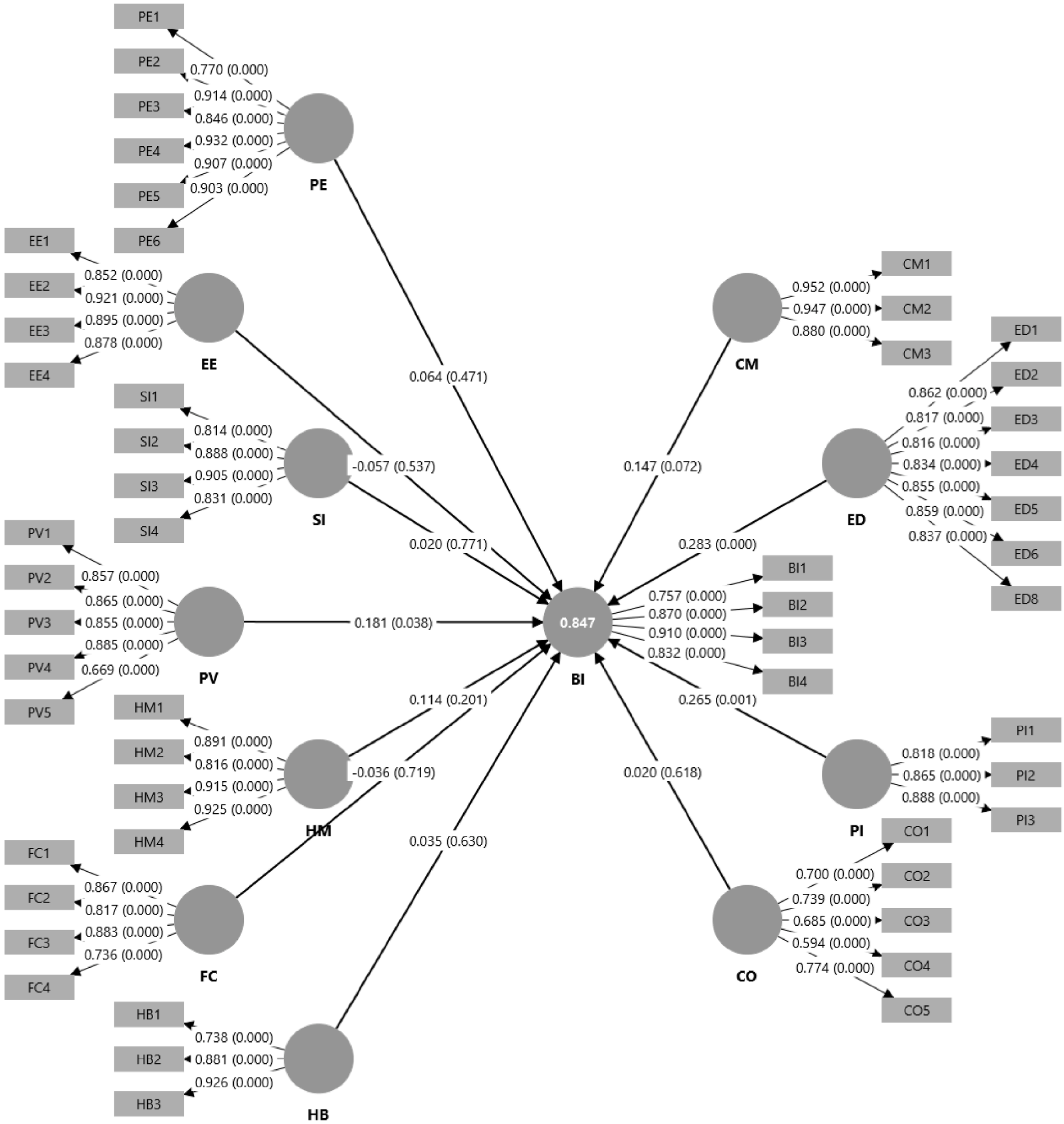


**Fig. 4.** Final path model and coefficients: polish sample.

uncertainty shapes perceived behavioral control in energy transitions [74,75]. This supports expanding UTAUT2 to account for macro-level governance stability [88].

Finally, the lack of influence of social influence and compatibility challenges the emphasis in earlier PV-adoption research on the effect of peer effects and lifestyle alignment [7,24]. It suggests that social imitation may decline in regions where PV adoption is already high, or energy decisions are driven by pragmatic and technical considerations rather than social norms.

### *7.3. Practical and managerial implications*

The findings yield region-specific guidance for policymakers, energy agencies, and installers seeking to accelerate residential PV adoption.

#### *7.3.1. Implications for Poland*

Since price value strongly predicts behavioral intention, deploying financial instruments remains crucial. Policymakers should maintain or expand targeted subsidies, tax deductions, and low-interest financing schemes that have already proven effective [44,33,76–78]. The strong influence of education and personal innovativeness indicates that informational campaigns should emphasize technical aspects, system performance, and long-term energy independence, particularly appealing to Silesia's technologically skilled population [83,84]. Programs that support techno-literacy – such as digital platforms, interactive tools, and consultations – could further empower households with relevant competencies.

**Table 12**
Direct effects on behavioral intention.

| Hypo-theses | Path | Hungarian sample | | | | Polish sample | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Path coefficient | t-statistics | p-value | Conclusion | Path coefficient | t-statistics | p-value | Conclusion |
| H1 | Performance Expectancy → behavioral Intention | 0.294 | 2.737 | 0.006 | Supported | 0.064 | 0.721 | 0.471 | Not supported |
| H2 | Effort Expectancy → Behavioral Intention | −0.281 | 3.802 | 0.000 | Supported | −0.057 | 0.617 | 0.537 | Not supported |
| H3 | Social Influence → Behavioral Intention | −0.014 | 0.256 | 0.798 | Not supported | 0.020 | 0.292 | 0.771 | Not supported |
| H4 | Price Value → Behavioral Intention | 0.122 | 1.151 | 0.250 | Not supported | 0.181 | 2.072 | 0.038 | Supported |
| H5 | Hedonic Motivation → Behavioral Intention | 0.260 | 2.343 | 0.019 | Supported | 0.114 | 1.279 | 0.201 | Not supported |
| H6 | Facilitating Conditions → Behavioral Intention | 0.210 | 2.175 | 0.030 | Supported | −0.036 | 0.360 | 0.719 | Not supported |
| H7 | Habit → Behavioral Intention | −0.151 | 2.510 | 0.012 | Supported | 0.035 | 0.481 | 0.630 | Not supported |
| H8 | Compatibility → Behavioral Intention | 0.155 | 1.495 | 0.135 | Not supported | 0.147 | 1.797 | 0.072 | Not supported |
| H9 | Education → Behavioral Intention | 0.066 | 0.756 | 0.450 | Not supported | 0.283 | 3.789 | 0.000 | Supported |
| H10 | Personal Innovativeness → Behavioral Intention | 0.176 | 1.504 | 0.133 | Not supported | 0.265 | 3.352 | 0.001 | Supported |
| H11 | Costs → Behavioral Intention | 0.073 | 1.114 | 0.265 | Not supported | 0.020 | 0.498 | 0.618 | Not supported |

**Table 13**
Structural model assessment ($R^2$ and $Q^2$ measures).

| Constructs | Hungarian sample | | | Polish sample | | |
|---|---|---|---|---|---|---|
| | $R^2$ | $R^2$ Adjusted | $Q^2$ | $R^2$ | $R^2$ Adjusted | $Q^2$ |
| Behavioral Intention | 0.673 | 0.654 | 0.581 | 0.847 | 0.835 | 0.806 |

**Table 14**
Effect sizes ($f^2$ measures).

| Path | Hungarian sample | | Polish sample | |
|---|---|---|---|---|
| | f2 | Effect size | f2 | Effect size |
| Performance Expectancy → Behavioral Intention | 0.068 | Small | 0.005 | No effect |
| Effort Expectancy → Behavioral Intention | 0.062 | Small | 0.004 | No effect |
| Social Influence → Behavioral Intention | 0.000 | No effect | 0.001 | No effect |
| Price Value → Behavioral Intention | 0.011 | No effect | 0.035 | Small |
| Hedonic Motivation → Behavioral Intention | 0.068 | Small | 0.019 | No effect |
| Facilitating Conditions → Behavioral Intention | 0.045 | Small | 0.002 | No effect |
| Habit → Behavioral Intention | 0.043 | Small | 0.003 | No effect |
| Compatibility → Behavioral Intention | 0.004 | No effect | 0.125 | Small |
| Education → Behavioral Intention | 0.021 | Small | 0.028 | Small |
| Personal Innovativeness → Behavioral Intention | 0.026 | Small | 0.108 | Small |
| Costs → Behavioral Intention | 0.013 | No effect | 0.002 | No effect |

### 7.3.2. *Implications for Hungary*

The significance of facilitating conditions points to the need for stable, transparent, and predictable regulatory frameworks. Frequent policy changes, such as the suspension of net metering, increase uncertainty and erode trust [74,75]. Clear communication, streamlined administrative procedures, and guaranteed grid-connection timelines could improve adoption readiness. The role of hedonic motivation and performance expectancy suggests that communication campaigns should highlight not only economic benefits but also the symbolic and experiential values of PV adoption, such as autonomy, modernity, and environmental stewardship. Installers and local governments may leverage these themes to enhance perceived desirability.

**Table 15**
Multi-group analysis.

| Relationship | Difference (Hungary – Poland) | p-value |
|---|---|---|
| Performance Expectancy → Behavioral Intention | 0.230 | 0.051 |
| Effort Expectancy → Behavioral Intention | −0.224 | 0.026* |
| Social Influence → Behavioral Intention | −0.034 | 0.350 |
| Price Value → Behavioral Intention | −0.059 | 0.336 |
| Hedonic Motivation → Behavioral Intention | 0.146 | 0.152 |
| Facilitating Conditions → Behavioral Intention | 0.246 | 0.043* |
| Habit → Behavioral Intention | −0.186 | 0.024* |
| Compatibility → Behavioral Intention | 0.009 | 0.475 |
| Education → Behavioral Intention | −0.216 | 0.032* |
| Personal Innovativeness → Behavioral Intention | −0.089 | 0.269 |
| Costs → Behavioral Intention | 0.053 | 0.245 |

Note: *Differences are significant in the relationships between the two countries ($P < 0.05$).

### 7.3.3. *Cross-country insights*

Since cost perceptions did not significantly deter adoption in either region, messaging should go beyond addressing financial barriers to emphasize reliability, long-term energy security, and system performance. Tailored communication strategies should be developed for each region, reflecting their distinct motivational structures [19].

## 7.4. *Limitations and future research recommendations*

This study has three main limitations. First, it focuses on two coal-dependent regions within Central and Eastern Europe, limiting the generalizability of the findings to other sociotechnical environments and energy cultures. Future studies should include multiple coal regions or extend the comparison to non-coal regions to broaden the analytical scope. Second, the questionnaire lacked open-ended questions, limiting the depth of qualitative insight into household attitudes. Future research could apply mixed-methods designs or in-depth interviews to contextualize quantitative findings. Third, the analysis relies on cross-sectional data, limiting the ability to draw inferences about temporal changes in adoption intentions. Longitudinal studies could capture dynamic adjustment processes as regulatory frameworks and energy-market conditions evolve.

Additional future research directions include integrating measures of trust in institutions, perceived policy stability, or environmental concern, which may increase explanatory power in contexts with volatile energy governance [89]. Cross-cultural extensions of UTAUT2 could also formalize how energy culture influences the salience of technological, social, or financial drivers.

### *7.5. Conclusion*

The study described here applied an extended UTAUT2 model to examine the determinants of household solar PV adoption intentions in Silesia (Poland) and Northern Hungary. The results reveal distinct national patterns: Polish intentions are shaped primarily by financial considerations, education, and personal innovativeness, whereas Hungarian intentions are influenced by performance expectancy, hedonic motivation, facilitating conditions, and habit. Social influence, compatibility, and cost perceptions were not significant in either context. These findings highlight the importance of tailoring policy and communication strategies to regional motivations and institutional environments. The study contributes to theoretical discussions on improving the contextualization of UTAUT2 in energy transitions and provides actionable guidance for policymakers seeking to support household-scale PV adoption.

## CRediT authorship contribution statement

**László Molnár:** Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tekla Szép:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization. **Mohammad M. Jaber:** Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Alicja Dańkowska:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Hanna-Mari Husu:** Writing – review & editing, Supervision.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Tekla Szep reports financial support was provided by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences. Acknowledgement to the CIRCLETECH project (101079354) funded by the Horizon Europe programme of the European Commission. Other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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