Shamon *et al.*
Energy, Sustainability and Society (2025) 15:48
https://doi.org/10.1186/s13705-025-00547-7

Energy, Sustainability
and Society

RESEARCH Open Access

Solar energy on all suitable roof areas? Homeowners' acceptance of government subsidies and smart energy services in Germany

Hawal Shamon[1*], Frauke Meyer[2], Gianmarco Aniello[1] and Wilhelm Kuckshinrichs[3]

Abstract

Background Photovoltaic (PV) systems are nowadays a central pillar in the expansion of renewable energy in Germany. Nevertheless, further significant growth in renewable energy will be needed in the future to meet the national emission reduction targets set by the German government. Homeowners play a crucial role in the expansion of PV capacity. In a discrete choice experiment, we empirically examine the impact of a large number of dimensions on homeowners' PV adoption, including attributes that have received less attention in the literature so far, such as the included (smart energy) services, government subsidies, and forms of financing.

Results Our results show that increasing levels of smart energy services for PV systems increase respondents' valuation of smart energy services, while increasing the access rights of the contractual partner has a negative impact on the valuation. The latter negative effect is mitigated by an element of co-determination. Furthermore, our results point to the importance of government subsidies as a measure to increase PV adoption. Participants preferred one-time (or continuous) payments over continuous (or one-time) payments when government grants amounted to 40% (or 10%) of the investment cost; they were indifferent between both forms when subsidies amounted to 20% of the investment cost. Homeowners clearly preferred loan financing to self-financing only at an effective interest rate of 1.03%, as opposed to 3.53%. This result indicates a limited effectiveness of this subsidy measure, which is designed to overcome the problem of high investment costs from a conceptual point of view. Our results also show that homeowners are not so heterogeneous when it comes to the importance they attach to certain attributes related to PV adoption. Decisions were made independent of socio-demographic characteristics, but are related in some cases to the homeowners' value orientations and risk inclination.

Conclusions Homeowners are more likely to adopt smart energy services when they are involved in the typically automated processes through decision prompts. Financial factors are of pivotal role. There is a need to tailor financing strategies, as preferences for subsidy schemes vary with the level of financing. In addition, low-interest loans are ineffective in reducing the high upfront costs of PV deployment. Smart energy services have great potential, but there are also some caveats.

*Correspondence:
Hawal Shamon
h.shamon@fz-juelich.de
[1] Institute of Climate and Energy Systems – Jülich Systems Analysis (ICE-2), Forschungszentrum Jülich GmbH, Jülich, Germany
[2] Institute of Energy and Climate Research – System Analysis and Technology Evaluation (IEK-STE), Jülich, Germany
[3] Corporate Development – National and International Relations (UE-NIB), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

Background

Germany will need an annual PV expansion of about 23 GW (by 2030) or 20 GW (by 2040), plus an additional 15 GW per year for replacement installations in the medium term (cf. [1, 2]), to meet the targets of the *Renewable Energy Sources Act* (Erneuerbare-Energien-Gesetz, [3]) and, ultimately, Germany's national emission reduction goals. Homeowners living in owner-occupied detached, semi-detached, or terraced houses (in the focus of this study) offer a large untapped expansion potential for PV. Of the 11.6 million households living in owner-occupied detached, semi-detached, or terraced houses in 2018 [4], only 1.4 million (i.e., 12.1%) generated income from feeding electricity into the grid in 2020 [5], even though investments in residential PV systems can yield attractive financial returns [6–9]. The importance of this group of actors for the expansion of PV capacity in Germany is also reflected in the ambitions of the previous coalition government to use all suitable roof surfaces for solar energy ([10], p. 57).

A number of studies conducted in different countries have identified motives and barriers in the PV adoption process (e.g., [11–25]). One important bottom line is that financial barriers in the form of high capital costs hinder the various non-financial factors favoring PV adoption (such as considerations of self-sufficiency, environmental concerns, a person's desire to express their environmental awareness, or a person's general interest in technology for symbolic reasons). According to Balcombe et al. [15], despite the provision of feed-in tariffs, capital costs are the most significant barrier. In fact, empirical studies of households that are equipped with PV systems underscore the importance of financial aspects by showing that financial aspects have played a very central role in the adoption of PV systems (cf. for example, [26–28]). Other empirical studies have reported that some of their examined households rejected microgeneration installations because of financial considerations after starting the adoption process (e.g., [12, 14]). Last but not least, our own preparatory research conducted as part of an online survey of 300 homeowners (241 of them without PV systems and 59 with PV systems) in Germany in 2019 ([29], p. 55–57) supports the conclusion that high upfront costs are a bottleneck in the diffusion of PV systems in Germany. When asked in an open question what disadvantages (multiple disadvantages could be mentioned) the 241 homeowners without a PV system saw in purchasing a PV system for their household, 42% of the responses to the open question referred to "high acquisition or initial costs". Compared to the second most frequently mentioned category, "effort involved in installing the system" (8%), this is a clear indication of a fundamental problem in the diffusion of photovoltaics systems in Germany. In this respect, subsidy payments are seen as an effective measure to increase the uptake of microgeneration energy technologies [3, 13, 30], even if they are controversial from an economic point of view (e.g., [31]).

In the case of Germany and its ambitious expansion targets, subsidies are likely to continue to play an important role in PV adoption in the future. According to Rogers [32], financial aspects and resource scarcity are at the forefront of the adoption decisions of the late majority and laggards in a diffusion process. Although PV module prices have fallen significantly over the past four decades, the average selling price of a PV system with a rated output of 10–100 kWp has remained relatively unchanged since 2012 (cf. [1]).

The German subsidy landscape is sufficiently differentiated with respect to PV installations. The German *Renewable Energy Sources Act* provides for feed-in tariffs. Feed-in tariffs minimize investor risk by requiring electricity supply companies to purchase and pay for electricity generated from renewable energy sources at a fixed price and by shortening payback periods. In addition, state-owned banks (e.g., KfW) and regional banks (e.g., NRW.Bank) offer homeowners advantageous low-cost solar loans for the installation of PV systems, providing an alternative to high lump-sum payments at relatively low borrowing costs. Thus, low-cost solar loans conceptually contribute to resolving the conflict identified by Jager [17] between high upfront costs at the time of purchase and delayed revenues and/or cost savings from the operation of the PV system [Art. 4 para. 3 3].

Given the portfolio of different existing subsidy measures in Germany, the low PV diffusion among households in owner-occupied single-family, two-family, or terraced single-family homes is surprising. Therefore, our first research objective is to examine how homeowners value different subsidy measure alternatives that could be used by the German government to support a PV expansion to a 215 GW installed capacity in 2030 [Art. 4 para. 3 3] [3]. To our knowledge, little is known about homeowners' preferences for different subsidy schemes. Published studies on PV adoption have elicited homeowners' (stated) preferences for individual subsidy measures, e.g., feed-in tariffs of varying size [16, 33], investment grants of varying size and timing [33] or for various more general purchase premiums [3, 34], leaving out the theoretically important alternative of low-interest loans.

At the same time, the planned massive expansion of renewables carries the risk of increasing intermittency. Empirical evidence suggests that prosumers do not necessarily adjust their electricity consumption significantly to the production level of their PV system (cf. e.g., [13, 35, 36]). The digitalization of electricity grids enables automated demand-side flexibility options that can counteract fluctuating electricity production, which is why it is considered necessary for a successful energy transition in Germany (e.g., [29]). The digitalization of electricity grids involves the combination of classical energy technologies (for generation, storage, and consumption) with information and communication technologies (ICT), so-called smart energy products. Smart energy products, in turn, form the basis for the development of new smart energy services [29, 37], such as data-based remote maintenance of PV systems or grid-friendly remote control of PV systems coupled with battery energy storage systems (hereafter referred to as BES), e.g., to reduce peak demand.

However, the widespread adoption of grid-friendly smart energy services associated with PV installations is likely to be hampered by the need for homeowners to invest additional funds in battery energy storage. In addition, research in the smart meter context has shown that privacy concerns prevent households from adopting smart meters [38–42]; an issue that should also be relevant in the PV context, as smart energy services imply that consumer data are transferred to the PV provider as a contractual partner. Another barrier to overcome is that some services are designed to automate processes and take place outside of the homeowner's control. This loss of control is another serious barrier to the adoption of smart energy services, as studies have shown (e.g., [38–40]). In short, smart energy services send at least three signals that can be perceived in opposite ways from the homeowner's perspective. Homeowners are attracted to smart energy services because of the level of service they offer, but privacy concerns and opaque automated processes, especially if they are beyond the homeowner's control, cause them to avoid smart energy services.

In the present study, we contribute to previous research that has found that homeowners require significant financial compensation to accept remote monitoring and control or sharing of usage and personal data by a service provider [41], especially when the data are shared with third parties [43]. Our research contributes to the existing literature by examining the extent to which the features of co-determination can overcome the challenges posed by automated processes, as well as the question of whether or not 'maximizing self-sufficiency' is a more appealing goal than 'maximizing revenue from electricity sale'.

In the upcoming "Methods" section, we will describe the survey and the discrete choice experiment (hereafter referred to as DCE). In addition to the attributes that directly address our main research questions (i.e., *government subsidies, financing forms, and included (smart energy) services*), we aligned the selection of attributes with the results of our preliminary study from 2019 ([29], pp. 55–57) and included additional attributes (such as *investment costs*, *expected annual nominal return*, *degree of self-sufficiency*, and *CO_2 savings*) in order to arrive at a more realistic purchase decision from the perspective of homeowners. In doing so, we provide subjects with a standardized frame of reference (the choice set with its particular alternatives of attribute-level combinations) for decision-making (cf. also [44]), which reduces the risk of uncertainty among laypersons regarding the benefits of PV systems (cf. [19]). In the following two sections, we first present and then discuss the results of our study. In the final section, we will draw some conclusions.

Methods

Data

We defined the target population for our online survey as homeowners who live in an owner-occupied property in Germany. Owners of apartments in apartment buildings were excluded because of the need to make a collective decision on PV installations. We commissioned a commercial survey institute to draw a quota sample of ($n=$) 700 target persons from an online access panel in August 2020 (quota: household size). Of these, ($n_1=$) 250 persons were supposed to live in a household with PV installation and ($n_2=$) 450 persons were supposed to live in a household without PV installation. We retrieved the quota scheme from b4p 2019 [45].

At the beginning of our survey, we used several screening questions to exclude respondents from the survey who reported that their household members lived in a) an apartment; b) a rented house; or c) a residential property that they did not own (at least in part), or d) a property where they were not involved in energy-related decisions.

In addition, we included attention check items in the questionnaire to screen and exclude respondents who responded carelessly (cf. [46]). In this study, we focus on the gross sample of 450 ($=n_2$) homeowners who reported living in a detached, semi-detached, or terraced house that is (at least partially) owned by the respondent and not equipped with a PV system (average age 55 years (SD = 12.32), 52% male, and 42% have a university entrance qualification). Within this subsample, we restrict our analyses to these 382 ($=n_{2a}$) household members (on average 55 years old (SD = 12.01), 52% male, and 41% with a high school diploma) who reported that they had not decided against the purchase of a PV system before the survey (cf. Table 1). Thus, our analysis is based on respondents who could reasonably be faced with a decision to adopt PV for their home.

Survey

The subject of the survey was electricity, mobility, and heat in the household sector. The survey consisted of a

Table 1 Distribution of household sizes according to quota plan (in %)

Household size	Quota plan[a]	Gross sample ($n=700$)	With PV ($n_1=250$)	Without PV ($n_2=450$)	Analytical sample ($n_{2a}=382$)
1 person	12	12	7	15	14
2 persons	44	46	38	51	49
3 persons	19	18	20	17	18
4 persons and more	25	24	34	18	19

[a] Data taken from b4p 2019 [45] show the distribution of household sizes in Germany for people aged 25 and over, who own either a detached single-family house or a semi-detached house. This resulted in 6,850 cases, representing an estimated German population of 16.02 million

standardized questionnaire and of two separate DCEs, i.e., one that was designed for ($n_1=$) 250 households without PV installation and another one designed for ($n_2=$) 450 households with PV installation.[1] The median time taken to complete the survey was 23 min for the ($n_2=$) 450 participants.

Discrete choice experiment

In the present DCE, we exposed study participants to 12 choice sets after an introductory page (cf. Table 4 in the Appendix). Each choice set consisted of three unlabeled alternatives and a no-choice option (see Fig. 1). We described the unlabeled alternatives by nine attributes (see Fig. 1), while the attribute levels varied between two and seven (see Table 2). The combination of attribute levels across the three unlabeled alternatives and participants varied according to a randomized design with minimal overlap (shortcut method), which ensured a balanced representation of attribute levels and increased precision in the estimation of the main effects [47].

The no-choice option can be thought of as representing the status quo choice, such as "I would continue to use my current long-distance service provider" [47]. Its inclusion is necessary to align a DCE with utility maximization and demand theory ([48], p. 440) and allows for a more realistic choice situation in the hypothetical setting of a DCE (cf. e.g., [49]). Previous methodological research has concluded that forced choices (i.e., not offering a no-choice option) can produce biased or incomplete results that lead to incorrect conclusions (e.g., [50, 51]). Accordingly, the inclusion of a no-choice option is considered an important measure to mitigate the hypothetical bias in DCEs (cf. [52], Part II).

Attributes and hypotheses We selected the attributes according to our research objectives and other attributes that we considered relevant in order to mimic a realistic purchasing decision (cf. Section Background). In addition to the *technical system* (i.e., PV vs. PV-BES), which forms the basis of our investigation, we used both financial and non-financial aspects to describe the particular technical system presented as an alternative. Specifically, we used four financial attributes (*investment cost*, *yearly nominal return*,[2] *government subsidies*, and *form of financing*), which allow us to examine the relationship between the different gradations of each of the financial attributes and homeowners' purchase intentions. Given the assumption of diminishing *positive* marginal utility of money in the theory of economic preferences (e.g., [53]), we expect that homeowners generally have stronger preferences for lower investment costs, higher government subsidies as well as higher yearly nominal returns (e.g., [14, 17, 30, 54]). Regarding the *form of financing*, two alternative expectations are plausible. Considering only the cost of credit, it is reasonable to expect that homeowners have a stronger preference for self-financing than for credit financing. However, since homeowners may also be under budget constraints (especially as a result of buying a house) or have the intention to invest their budget in alternative (possibly more profitable) investments, it is also reasonable to expect that they will prefer credit financing at low interest rates to self-financing or credit financing at high interest rates.

In addition, we used two attributes that include both financial and non-financial aspects: *self-sufficiency potential* and *included (smart energy) services*.[3] The *self-sufficiency potential* primarily captures aspirations for autarky, whether due to a desire to become independent

[1] Both DCEs have a different thematic focus. Each respondent answered only one DCE (depending on whether he or she lived in a household with or without a PV installation) and the standardized survey. Due to word limitations, the DCE for homeowners with PV installation is not presented in this manuscript.

[2] Although, from an economic point of view, financial performance indicators should reflect all cash flows, we have deliberately refrained from including any subsidy payments in the description of the attribute "annual nominal return". The aim of discrete choice experiments is to quantify the effect of each attribute on respondents' decisions in isolation. Linking the two attributes by stating that the reported annual nominal rate of return includes subsidy payments that would contradict this goal. Our nominal rate of return can therefore be understood as a kind of partial rate of return.

[3] In the DCE, we referred to this attribute as "included services" instead of "smart energy services included". We feared that the latter term was not yet widely used in the population, so that different interpretations by respondents could not be ruled out. However, the chosen level clearly expresses that we are investigating smart energy services.

Please compare the following offers carefully and check the offer that you would purchase for your home. If you would not purchase any of the offers for your home, please check the option on the right.

Technical system	PV system	PV system with battery storage	PV system	I would not purchase any of these offers
Supplier	Supra-regional energy supply company	Online merchant	Online merchant	
Investment costs (includes purchase and installation costs)	€15,000	€15,000	€20,000 €	
Expected yearly nominal return (*As a result of the sale of self-produced electricity and reduced consumption costs for electricity of an energy provider) over 20 years (considering age-related power loss)	2%	2%	6%	
Government subsidies (*If government subsidies is offered, it will be paid to you immediately <u>after installation</u> of the PV system.)	One-time investment grant of 10% (corresponds to €1,500)	Continuous investment grant of €220 for 20 years	No investment grant	
Form of financing (*All figures refer to investment costs, independent of potential investment grants received <u>after installation</u>.)	Self-financing	Credit financing Annual percentage rate: 3,53% Credit period: 10 years Residual debt after 10 years: €0	Self-financing	
Self-sufficiency potential (*Expected share of annual household electricity consumption covered by self-produced electricity (also called self-sufficiency rate).)	20%	40%	40%	
Included free services by the provider	Graphic visualization of the amount of electricity generated by the PV system and the current electricity consumption (in increments of one minute).	Remote supervision of PV system and battery storage for maintenance and repair purposes.	Graphic visualization of the amount of electricity generated by the PV system and the current electricity consumption (in increments of one minute).	
Yearly CO_2 savings in the German energy production (*Yearly CO_2 emissions per capita were 7,900 kg in Germany in 2019.)	Savings of 5,000 kg	Savings of 490 kg	Savings of 490 kg	
	o	**o**	**o**	**o**

Notes: * This text appeared when participants clicked on the respective information button [i], a so-called mouseover, located at the respective attribute on the decision screens.

Fig. 1 Example of a choice task

of energy providers, to protect against power outages, and/or rising electricity prices in the future (e.g., [14, 15, 18, 30, 55]).[4] Hence, we expect homeowners to prefer higher levels of self-sufficiency, regardless of the specific reason. The *included (smart energy) services* represent a multifaceted attribute that is expected to affect homeowners' preferences in various ways, with potentially conflicting outcomes.

First, smart energy services can vary in the level of the service degree (i.e., the content and scope) and thus offer different levels of convenience to homeowners. From this perspective, we expect that homeowners have stronger preferences for included *(smart energy)* services with high (compared to low) service levels, as they offer more value for the same investment cost. At the same time, the provision of higher service levels, especially in the context of smart energy services, may require homeowners to grant more extensive access rights to their smart energy products (in this study, PV and PV-BES) to contractual partners (e.g., PV providers) or third parties (e.g., smart service providers or grid operators). Since individuals have a basic need for orientation and control [56, 57], the less a smart energy service allows homeowners to control the processes (e.g., with an element of co-determination), the more one can expect the granting of extensive access rights to undermine homeowners' preferences for included (smart energy) services.

Finally, we included two non-financial attributes, namely *supplier* and *CO_2 savings*. With respect to *supplier*, we aim to examine the impact of respondents' trust in different types of suppliers that offer PV systems. We expect that homeowners prefer to purchase PV or PV-BES from offline rather than online suppliers, as physical stores are considered "touchpoints for building credibility and trustworthiness and developing durable relationships with consumers" ([58], p. 555). Even though not all PV(-BES) providers have physical stores, as in the retail segment, where PV(-BES) could be presented (e.g., in showrooms), offline providers allow homeowners to visit the provider in person (several times, if necessary), to convince themselves of the provider's credibility on site, and to build up a relationship of trust based on personal interaction. With this in mind, we expect homeowners to prefer offline providers to online providers. Furthermore, PV(-BES) can be considered a long-term investment, at least when it comes to economic viability considerations of PV(-BES) systems. For the sake of simplicity, a period of 20 years is usually assumed, based on the payment period of the feed-in tariff in Germany, which is being paid over 20 years and also the remaining year ([59], p. 307). In this respect, we expect the continuity of a business to be an important factor for homeowners when deciding whether to purchase a system.

The perception that ownership succession is not always resolved can result in owner-operated businesses disappearing from the market over time. Similarly, owner-managed businesses are not as financially robust as large corporations and may struggle to survive economic downturns. From this point of view, we assume that homeowners prefer larger companies as suppliers. On the other hand, supra-regional utilities in Germany may struggle with an image that they have not necessarily been pioneers of a sustainable energy transition, but they have instead clung to conventional generation technologies for far too long. Against this backdrop, it is reasonable to expect that homeowners will prefer public utilities and local, owner-operated companies over supra-regional utilities. Last but not least, given the high level of environmental awareness in Germany, which has even increased in recent years (cf. e.g., [60, 61]), we expect CO_2 savings to be an important attribute of PV and PV-BES, with homeowners preferring higher to lower CO_2 savings.

Levels We applied a conditional display design for the attributes *investment costs*, *government subsidies*, *self-sufficiency potential*, and *included services* based on the attribute *technical system* (cf. Table 2). The range of levels of these four attributes differed between PV systems and PV-BES according to plausibility considerations, while we intended to cover a wide range of investment cost levels covering PV and BES systems in a wide range of sizes up to 20 kW_p. 20 kW_p systems were not widespread at the time of the study but may become more relevant in the future. As a matter of fact, the German government extended the limit for exemption of EEG-levy on self-consumed electricity for systems of 10 kW_p up to 30 kW_p in 2021 ([62], p. 3163). In addition, BES enables homeowners to achieve higher levels of self-sufficiency than PV systems do and provides companies with the opportunity to offer homeowners other smart energy services. Accordingly, the self-sufficiency rates and CO_2 saving levels also reflect the wide variation in system sizes that is implicitly assumed. For the attributes of *government subsidies* and *form of financing*, we have specified conditional levels based on the level of *investment costs* in the given alter-

[4] In the context of the current German regulations, the self-sufficiency potential attribute indirectly addresses financial issues from an economic point of view. The higher the level of self-sufficiency, the more profitable a PV system is. However, for respondents who have not yet considered a PV system for their household, or who have not yet acquired detailed knowledge of the regulatory background, this mediating effect is very likely not to be pronounced. 246 respondents (i.e., 64% of the analytical sample) indicated in the questionnaire that they had never considered buying, renting, or leasing a PV system for their household, so we assume that most respondents did not associate higher economic viability with this attribute.

Table 2 Attributes and levels in the DCE

Attribute	Level
1. Technical system	1. PV system 2. PV system and battery storage
2. Supplier	1. Local owner-managed company 2. Online merchant 3. Supra-regional energy supply company 4. Public utility
3. Investment costs (includes purchase and installation costs)	1. €10,000[a] 2. €15,000 3. €20,000 4. €25,000 5. €30,000 6. €35,000[b]
4. Expected yearly nominal return over 20 years (considering age-related power loss) (As a result of the sale of self-produced electricity and reduced consumption costs for electricity of an energy provider)	1. 0% 2. 2% 3. 4% 4. 6% 5. 8% 6. 10%
5. Government subsidies (If government subsidies is offered, it will be paid to you immediately after installation of the PV system.)	1. No investment grant 2. One-time payment, 10% (€< <**X**> >)[b] 3. One-time payment, 20% (€< <**X**> >) 4. One-time payment, 40% (€< <**X**> >)[a] 5. Yearly payment of (€< <**X**> >* 0.74%[c]) over 20 years[b] 6. Yearly payment of (€< <**X**> >* 1.47%[c]) over 20 years 7. Yearly payment of (€< <**X**> >* 2.95%[c]) over 20 years[a]
6. Form of financing of total purchase and installation costs (All figures refer to investment costs, independent of potential investment grants received after installation.)	1. Self-financing 2. Credit financing Annual percentage rate: 1,03% Monthly rate: €< <**X**> > Credit period: 10 years Residual debt after 10 years: €0 3. Credit financing Annual percentage rate: 3,53% Monthly rate: €< <**X**> > Credit period: 10 years Residual debt after 10 years: €0
7. Self-sufficiency potential of the system (Expected share of annual household electricity consumption covered by self-produced electricity (also called self-sufficiency rate).)	1. 20%[a] 2. 40% 3. 60% 4. 80%[b]
8. Included free services by the provider[+]	1. Graphic visualization of the amount of electricity generated by the PV system and the current electricity consumption (in increments of one minute).[a] 2. Remote supervision of PV system for maintenance and repair purposes. Necessary maintenance and repair works are executed upon consultation.[a] 3. Remote supervision of PV system for maintenance and repair purposes. Necessary maintenance and repair work are executed without your assistance.[a] 4. Graphic visualization of the amount of electricity generated by the PV system, the charge status of the battery storage, and the current electricity consumption (in increments of one minute).[b] 5. Remote supervision of PV system and battery storage for maintenance and repair purposes.[b] 6. Remote control of PV system and battery storage to maximize the self-sufficiency rate.[b] 7. Remote control of PV system and battery storage to maximize revenues from electricity sales.[b]
9. Yearly CO_2 savings in the German energy production (Yearly CO_2 emissions per capita were 7,900 kg in Germany in 2019.)	1. Savings of 490 kg 2. Savings of 5,000 kg 3. Savings of 10,000 kg

[+] Attribute was a labeled included service rather than an included smart energy service for reasons described in FN3

[a] Attribute levels only used in combination with attribute 1.1 PV system

[b] Attribute levels only used in combination with attribute 1.2 PV system and battery storage

<<X> >: conditional amount depending on the investment cost presented in the alternative

Table 2 (continued)

[c] For the DCE, we calculated specific absolute cost levels for each investment cost to be presented to respondents. Due to space limitations, this table presents percentages that allow for the recalculation of close approximations for the amounts presented to DCE participants. Table 5 in the Appendix provides the actual amounts used in this study

native. For example, if the cost of a particular alternative investment is shown as €20,000, a one-time investment grant of 20% is shown as €4,000 and a loan at 1.03% APR is shown as €175 per month. The effective annual percentage rate of level 2 (i.e., 1.03%) was based on the nominal annual percentage rate (i.e., 1.02%) of the 10-year loans offered by the KfW Program 270 to solvent homeowners in February 2020.[5]

For the *government subsidies*, we have included a fixed annual payment over 20 years as an alternative to the one-time investment grant. Using a nominal discount rate of 4.04%,[6] the sum of these discounted annual payments is just below the value of the corresponding one-time grant.[7] This allows us to compare whether respondents prefer a one-time grant or a continuous annual payment of the same discounted nominal amount and to assess whether the respondents implicitly discount the future cash flows at a rate above our benchmark (i.e., 4.04%).

We designed the different smart energy services levels for PV and PV-BES after screening existing smart energy services. The smart energy services used in this study vary in terms of the service level degree (i.e., *graphical visualization, remote supervision, remote control*), the implicit level of automated processes and third-party access rights (i.e., *none* in the case of graphic visualization, *moderate* in the case of remote supervision, *extended* access rights in the case of remote control) as well as the measures intended to compensate for any negative effects of automated processes and extended access rights (i.e., *executed upon consultation, maximize the self-sufficiency rate, maximize revenues from electricity sales*).

The lowest level of CO_2 savings was chosen as the "zero reference" in order to be able to compare the effects of relatively extreme CO_2 savings with a situation of marginal savings. The German Environment Agency published a net avoidance factor per kWh of energy provided by photovoltaic systems for 2018 as 627 g CO_2 eq/kWh ([64], p.33). Accordingly, the lowest level in CO_2savings corresponds to a feed-in of 798 kWh, the middle level to a feed-in of 8,143 kWh, and the highest level to a feed-in of 16,287 kWh into the grid in 2018. Applied to the size of the PV system, this corresponds to a feed-in rate of 20% for a 4 kWp system with an average production of 4,000 kWh, or an 80% feed-in rate for a 10 (or 20) kWp system with an average electricity production of 10,000 (or 20,000) kWh per year in Germany in 2018.

Standardized questionnaire

The questionnaire included survey items measuring respondents' value orientations and risk inclination, as well as survey items measuring respondents' sociodemographic characteristics (i.e., gender, age, education, residence in East or West Germany) and disposable household income (cf. Table 6 in the Appendix).

Value orientation Values function as "guiding principles in the life of a person or group" ([65], p. 664) and are used by individuals as criteria "to select and justify actions and to evaluate people (including the self) and events" ([66], p. 1). In this study, we measured the importance that respondents attached to three different values (i.e., *universalism-nature*, *self-direction-action*, *security-personal*) by using a refined version of the revised Portrait Values Questionnaire [67].[8] The value *universalism-nature* reflects how important a person considers the protection of the environment to be, while *self-direction-action* includes the importance a person attaches to autonomy of action, and *security-personal* captures the strength of an individual's longing for personal security. We expect that these personal values are related to the importance a respondent attaches to certain attributes in the DCE.

We measured each of the three values using three survey items describing the motivation of a fictitious third person. We asked our respondents how similar they thought the person in the description was to them and provided a fully verbalized six-point scale with response options ranging from not like me at all, not like me, little like me, somewhat like me, like me, very much like me for their responses. Not providing an exit option allowed us to average respondents' responses to the three items for each value in the analysis.

[5] Detailed information about the KfW's 270 Program can be found on the KfW website [64].

[6] 4.04% resulting from the interaction of the inflation rate and the real discount rate, which are both set at 2%.

[7] A yearly payment of €147 is equivalent to €2,941 in nominal terms over twenty years. Discounting the annual payments at a rate of 4.04% yields a net present value of €1,991 which is just below the corresponding one-time grant of €2,000.

[8] In total, the PVQ-R comprised 19 values with 57 items. In this study, we focus on the values mentioned in the main text above.

Risk inclination Risk inclination reflects a person's tendency to take risks with regard to actions or new technological developments. We measured risk inclination using an item battery on innovation readiness, based on Lin's work [68]. Our item battery contained four survey items, each measuring a slightly different aspect of respondents' willingness to innovate with respect to new technological developments. In one of the items, we asked respondents to indicate the extent to which the statement "I am willing to take risks." applies to them using an endpoint verbalized seven-point scale ranging from "strongly disagree" to "strongly agree". This survey item is used to measure homeowners' risk inclination.

Socio-demographics The following socio-demographic characteristics which were requested in the questionnaire are used for the analyses (cf. "Methods of analysis" section): gender (male/female), region of residence (East/West Germany), age, educational attainment (ISCED score grouped into three categories: low: 1, 2, 3/medium: 4, 5, 6/high: 7, 8) ([69], p. 5), and monthly disposable household income (grouped into three categories: less than €3,000/€3,000-€4,999/ €5,000 or more).

Methods of analysis

DCEs enable estimations in terms of utility or willingness to pay. The latter is attractive because it informs political and economic decision-makers about the monetary value that people attach to public or private goods or services. Thus, it can be used for pricing. In the case of private goods such as PV systems that are provided by companies, we consider it critical that scientific analysis has a potential impact on pricing. Therefore, in this study, we prefer the estimation in terms of utility.

We applied a hierarchical bias estimation procedure implemented in the Sawtooth software according to Orme [72] to analyze respondents' decisions in the 12 choice sets. Hierarchical bias estimation calculates a mean-centered utility value, called *part-worth utility*, for each level of an attribute at the respondent level [70]. *Part-worth utilities* sum up to zero due to the underlying effect coding of the levels of one attribute.

Averaging the (respondent-specific) part-worth utilities of a particular attribute level across all respondents enables us to compare different levels of an attribute in terms of the average utility they generate across all respondents (e.g., the utility of level 1 of a particular attribute is higher than the utility of level 4 of that attribute). In the following, we will analyze the average part-worth utilities of a particular attribute level across all respondents, referring to them as *level part-worth*. Level part-worths are intervallically scaled, which means that we can compare the increase or decrease in part-worths between two levels of different attributes, but we cannot directly compare the absolute part-worth of one level of one attribute (A) to the absolute part-worth of one level of another attribute (B) (e.g., level 2 of attribute A with a presumed part-worth of 10 is equally preferred to level 2 of attribute B with a presumed part-worth of 10), nor can we relate the absolute values of the part-worths of two levels of an attribute to each other (e.g., level 2 with a presumed part-worth of 30 yields three times the utility of level 1 with a presumed part-worth of 10) [71].

In addition, we will analyze the relative importance—also called *attribute importance*—of each of the examined nine attributes, which are calculated for each respondent. Looking at the attribute importance allows us to rank and compare the examined attributes according to the importance they played in the decision-making process across all participants for a particular DCE.

We will compare *level part-worths* (cf. "Level part-worths" section) and *averaged attribute importance*[9] (cf. "Mean attribute importance" section) using statistical significance tests, which in non-probabilistic samples serve as a pragmatic criterion for distinguishing important from unimportant effects or differences [72]. In doing so, we will use a variant of the Sidak correction test proposed by [73]—with $p\prime = 1 - (1 - p)^{\sqrt{m}}$, where m is the number of pairwise comparisons conducted between the levels of each attribute [74, 75]—to account for the multiple pairwise comparisons of *level part-worths* and *attribute importance* in the significance level of our t-tests for comparing means [74–76].

In addition, we will examine the relationships between various respondent characteristics measured in the online questionnaire (cf. "Standardized questionnaire" section) and each of the nine attributes using ordinary least squares (OLS) regression models in an explorative manner (cf. "Determinants of attribute importance" section). This is because the *average attribute importance* ratios conceal possible individual differences in the importance respondents attach to an attribute when making decisions.

Results

Level part-worths

Figure 2 shows the level part-worths for each level of the nine attributes along with the standard deviations. In Table 7 of the Appendix, panels *a* to *i* show the results of the pairwise t-tests for the level part-worths of different

[9] The mean attribute importance of each of the nine attributes is obtained by averaging each of the nine attribute importance ratios across all respondents.

levels of a given attribute (cf. "Methods of analysis" section).

As can be seen in Fig. 2, the level part-worth of PV-BES is higher than the level part-worth of PV alone. However, this difference is not significant ($p\prime = .060$) as shown in Table 7 (panel a). Regarding *supplier*, we find that the level part-worth is highest for a public utility, followed by a local owner-managed company, and a supra-regional energy supply company, while an online merchant is the least preferred option among our respondents (cf. Figure 2). As can be seen in Table 7 (panel *b*), the difference in level part-worth is insignificant between a public utility and a local owner-managed company, while all other differences in level part-worths are significant ($p\prime <0.001$).

In addition, we observe that level part-worths decrease monotonically with increasing *investment costs*, while level part-worths increase monotonically with increasing *yearly nominal rates of return*. The differences in the level part-worth of all pairwise comparisons of investment cost levels and *yearly nominal return* levels, respectively, are significant ($p\prime < .001$), except for the difference in the level part-worth between a nominal rate of return of four and six percent ($p\prime = .172$).

Regarding *government subsidies*, we find that the level part-worth is larger when grants are paid than when no grant is paid. We also find that the level part-worth ratio increases monotonically with increasing monetary grant value in each of the two broader grant classes (one-time grants and continuous grants). As can be seen in Table 7 (panel e) in the Appendix, results regarding the question whether respondents prefer one-time grants to continuous grants are mixed. The level part-worths of one-time payments are larger than the level part-worths of continuous yearly payments if grants amount to the corresponding 40% ($p\prime < .001$) of the investment costs, but they are significantly smaller if grants amount to only 10% ($p\prime < .001$). The level part-worths of one-time payments are statistically indifferent to the level part-worths of continuous yearly payments if it amounts to 20% ($p\prime = .196$).

With respect to the *form of financing*, each of the two credit financing options has a larger level part-worth than the self-financing option, with the highest level part-worth at an interest rate of 1.03% (cf. Figure 2). As can be seen in Table 7 (panel f) in the Appendix, the level part-worth of the low-interest loan (1.03%) is significantly larger than both the level part-worth of the high-interest loan (3.53%) and the level part-worth of self-financing ($p\prime < .001$). At the same time, the difference between the high-interest loan and the self-financing option is insignificant ($p\prime = .181$).

Furthermore, Fig. 2 shows that the level part-worth increases monotonically and intuitively as a consequence of the increasing *self-sufficiency potential* and as a consequence of the increasing *CO_2 savings* per year. The paired t-tests (Table 7, panels *g* and *i*) between the levels of the *self-sufficiency potential* and the levels of CO_2 savings are all significant ($p\prime < .001$).

In terms of the *included services* for PV systems, the level part-worth of level 3 (supervision and automatic maintenance service) is significantly smaller than the level part-worth of level 2 (maintenance after consultation) ($p\prime < .001$). The level part-worth of level 3 (supervision and automatic maintenance service) is also significantly smaller than the level part-worth of level 1 (mere visualization) ($p\prime < .001$), while the level part-worth of level 2 (maintenance after consultation) is statistically indifferent to the level part-worth of level 1 (mere visualization) ($p\prime = .758$). For PV-BES, the level part-worth of level 4 (mere visualization) is significantly higher than that of level 5 (remote supervision) ($p\prime = .002$) and than that of level 6 (remote control for the purpose of maximizing the self-sufficiency rate) ($p\prime < .001$). However, level 4 (mere visualization) yields a significantly smaller level part-worth than level 7 ($p\prime < .001$). At the same time, the level part-worths of level 5 (remote supervision) and level 6 (remote control for the purpose of maximizing the self-sufficiency rate) are statistically insignificant ($p\prime = .120$), while the level part-worth of level 7 (remote control to maximize revenues from energy sales) is significantly larger than both the level part-worth of level 5 (remote supervision) and the level part-worth of level 6 (remote control for the purpose of maximizing the self-sufficiency rate) ($p\prime < .001$).

Mean attribute importance

Figure 3 shows the attribute importance of the nine attributes that were examined in this study, which add up to 100 percent. The most important attribute is *investment costs* with 23.8 percent, the least important is *form of financing* with 5.4 percent. Except for three of the 36 pairwise mean comparisons of attribute importance, all other pairwise comparisons yield significant differences ($p\prime < 0.05$).[10] In general, financial aspects are on average relatively more important than non-financial aspects in the decision process to purchase a PV system (with or without battery storage). In particular, the four financial aspects (*investment costs*, *government subsidies*, *yearly nominal return*, and *form of financing*) sum up to 51.9

[10] The three insignificant differences in attribute importance refer to the following pairwise comparisons: ***self-sufficiency potential*** vs. ***supplier type*** ($p = 0.98$), ***self-sufficiency potential*** vs. ***CO_2 savings*** ($p = 0.177$), ***supplier type*** vs. ***CO_2 savings*** ($p = 0.479$).

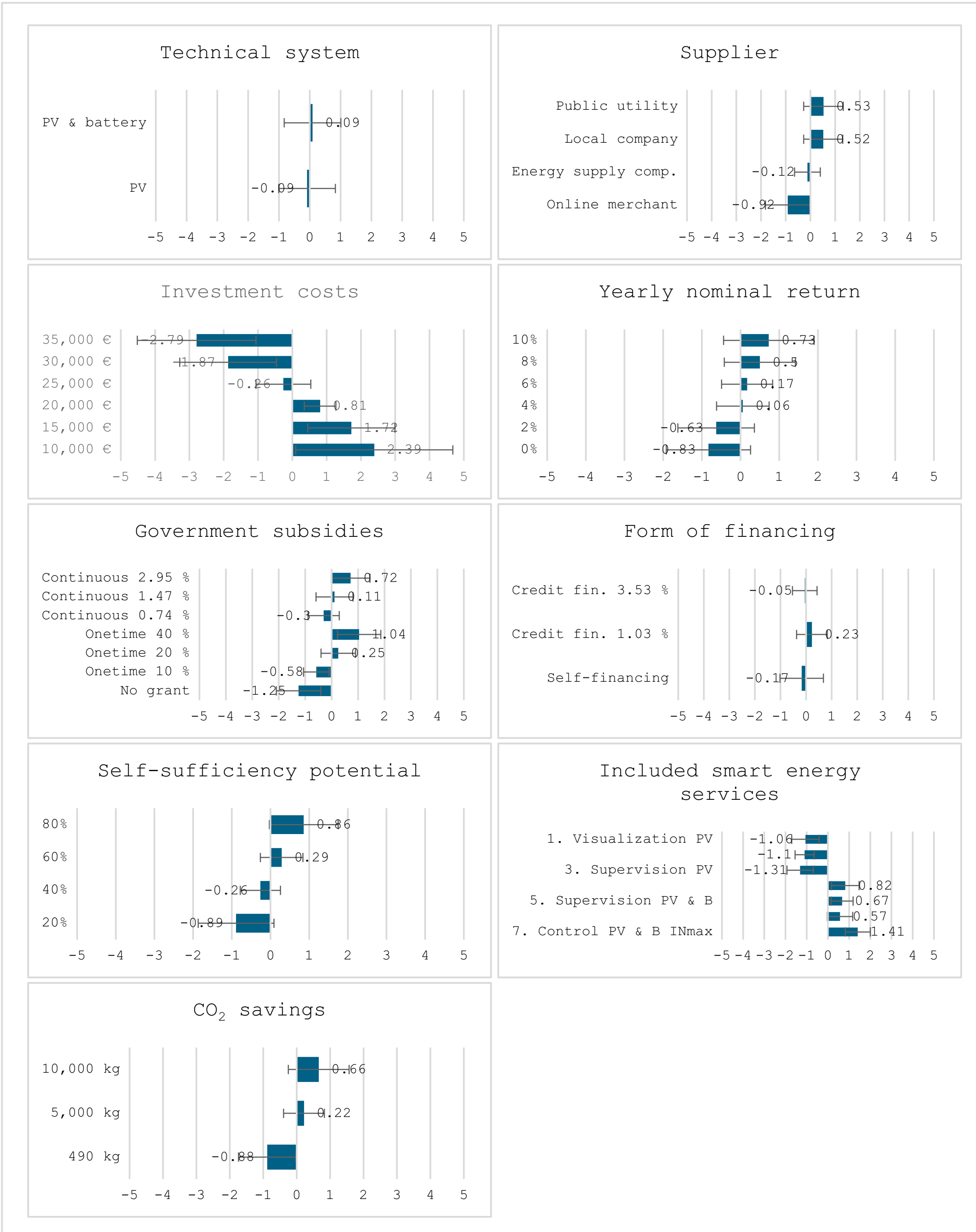


Fig. 2 Level part-worths. Level part-worth (x-axis) and standard deviations (whiskers) by attribute and level. Analysis based on data of 382 participants

percent, while the three non-financial attributes (*supplier*, *CO_2 savings*, and *technical systems*) amount to 24.1 percent. The two mixed attributes (*self-sufficiency potential* and *included services*) add up to 23.8 percent.

Determinants of attribute importance

Table 3 presents the results of nine OLS regression models. In each model, the individual attribute importance of the respective attribute constitutes the dependent

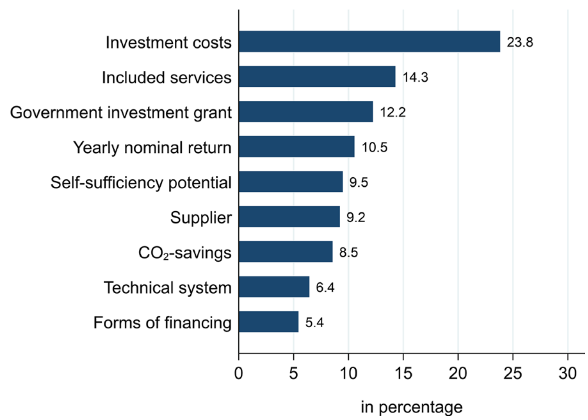


Fig. 3 Mean importance of attributes in the decision process. Analysis based on data of 382 participants. Attributes ordered according to their average relative importance

variable.[11] Overall, the average importance attached to the nine attributes is largely independent of socio-demographic characteristics. Exceptions are that survey participants ascribe less importance to the *self-sufficiency potential* of a PV system ($p<0.05$). In addition, respondents currently living in eastern Germany attach more importance to the *self-sufficiency potential* of a PV system than respondents living in western Germany ($p<0.05$). On the other hand, the amount of CO_2 savings is considered less important to respondents in eastern than to those in western Germany ($p<0.01$).

In addition, older respondents attach on average significantly less importance to the attribute of *yearly nominal return* ($p<0.05$) and *self-sufficiency potential* ($p<0.05$). Moreover, a high compared to a low level of education is negatively related to the role of *government subsidies* ($p=0.036$, cf. notes of Table 3).

The values *self-direction-action* and *security-personal* have no effect on the importance attached to any of the nine attributes.[12] However, a higher score on the *universalism-nature* value is associated with less importance attached to *investment costs* ($p<0.05$) and more importance attached to the types of *included services* ($p<0.05$) and to the amount of *CO_2 savings* ($p<0.05$).[13] Furthermore, a higher risk taking is negatively associated with the importance attached to *investment costs* ($p<0.001$). At the same time, we find that homeowners who take risks attach more importance to (expected) *yearly nominal returns* and *financing options.*

Discussion

In line with the literature (e.g., [14, 15]), financial aspects, especially the initial investment costs, are the most important dimension with respect to the adoption of PV and PV-BES systems. Non-monetary aspects such as CO_2 savings, technological, and even pure self-sufficiency aspirations seem to play a minor role when these are detached from financial motivations by means of the DCE setting. However, comparing the importance of different attributes should always be done with some caution because the resulting attribute importance may also be influenced by design aspects of a DCE. These include not only large discrepancies in the number of levels chosen for different attributes but also in the range between the smallest and the largest levels. In this study, the number of attribute levels varied considerably, from two to seven, whereas attributes with a higher number of levels tend to be given more importance in the decision-making process in DCEs.

This may at least partly explain, for example, why *CO_2 savings* and *forms of financing* (each with its three levels) as well as the *technical system* (with its two levels) yielded smaller attribute importance scores than the other attributes in this study that varied from four to seven levels (cf. "Mean attribute importance" section). Overall, however, these design considerations do not affect the analyses on the determinants of attribute importance (cf. "Determinants of attribute importance" section), as each of these attribute-specific analyses is meaningful in its own right.

Interestingly, *smart energy services* are the second most important factor in the purchase decision. Our results indicate two opposing effects on respondents' valuation of smart energy services. On the one hand, improving the quality of smart energy services has a positive effect on respondents' valuation of services; on the other hand, granting access rights to the contractual partner has a negative effect on valuation. These counteracting effects were both observed among the smart energy services that we designed specifically for stand-alone PV installations (i.e., levels 1–3 of attribute 8) and among the specific smart energy services that we presented for PV-BES

[11] Figure 4 in the Appendix shows the distributions of the individual attribute importance for each of the nine attributes.

[12] Although one might hypothesize that a stronger orientation toward the value of *self-direction-action* would increase the importance respondents attach to the attribute of the *self-sufficiency potential*, since this attribute involves personal energy autonomy, we do not find this relationship in our study. Similarly, higher financial burdens could reduce the feeling of personal security, while increased energy autonomy could positively influence personal security. In our data, however, we do not find a relationship between the value *security-personal* and the importance attached to financial attributes or the *self-sufficiency potential.*

[13] In Table 8 in the Appendix, we also report estimates of the same model but without the self-direction-action and security-personal values. In this model, universalism-nature is positively related to the importance attached to whether it is a PV system with or without battery storage, but no longer to the types of included services.

Table 3 Determinants of attribute importance: OLS regression results

	Technical system	Supplier	Investment costs	Yearly nominal return	Government subsidies	Form of financing	Self-sufficiency potential	Included services	CO_2savings
Male[a]	0.051 (0.475)	−0.239 (0.594)	0.789 (1.285)	1.183 (0.642)	−0.331 (0.454)	0.249 (0.431)	−1.358* (0.531)	−0.482 (0.369)	0.138 (0.754)
East-Germany[b]	0.205 (0.489)	−0.561 (0.607)	1.447 (1.562)	−0.759 (0.752)	0.160 (0.582)	0.019 (0.513)	1.600* (0.639)	0.108 (0.463)	−2.219** (0.702)
Age	0.001 (0.019)	0.031 (0.020)	0.056 (0.049)	−0.057* (0.024)	0.033 (0.019)	0.003 (0.019)	−0.048* (0.020)	0.009 (0.014)	−0.028 (0.029)
ISCED low (1, 2, 3)[c]	−0.953 (0.684)	−0.107 (1.052)	−4.642 (2.683)	0.712 (1.386)	1.342 (0.943)	0.990 (0.880)	1.803 (1.059)	0.547 (1.008)	0.309 (1.011)
ISCED high (7,8)[c]	0.331 (0.532)	0.366 (0.619)	−1.573 (1.294)	0.678 (0.789)	−0.698 (0.473)	0.262 (0.467)	−0.427 (0.598)	0.379 (0.391)	0.681 (0.751)
Income less than 3,000 €[d]	0.522 (0.529)	0.781 (0.610)	−0.054 (1.387)	0.061 (0.642)	0.070 (0.538)	−0.703 (0.441)	−0.738 (0.546)	0.055 (0.380)	0.005 (0.709)
Income 5,000 € or more[d]	0.137 (0.654)	−0.052 (0.830)	−1.050 (1.665)	0.694 (1.054)	0.215 (0.595)	−0.164 (0.604)	−0.745 (0.775)	0.254 (0.467)	0.710 (1.022)
Self-direction-action	−0.056 (0.342)	0.162 (0.408)	0.975 (0.941)	−0.147 (0.488)	0.284 (0.357)	−0.186 (0.301)	−0.246 (0.389)	−0.530 (0.281)	−0.257 (0.486)
Security-personal	0.087 (0.299)	−0.023 (0.344)	−0.862 (1.011)	0.314 (0.449)	−0.127 (0.339)	0.475 (0.278)	−0.199 (0.384)	0.118 (0.261)	0.217 (0.479)
Universalism-nature	0.394 (0.232)	0.062 (0.249)	−1.462* (0.647)	0.122 (0.346)	−0.202 (0.222)	−0.061 (0.198)	0.017 (0.230)	0.387* (0.179)	0.744* (0.319)
Risk inclination	0.204 (0.156)	0.155 (0.206)	−2.073*** (0.375)	0.469* (0.206)	0.054 (0.155)	0.326** (0.122)	0.110 (0.168)	0.341** (0.111)	0.415 (0.256)
Constant	3.334 (2.211)	5.842* (2.404)	33.720*** (5.808)	10.076*** (3.031)	10.479*** (2.078)	3.143 (2.202)	14.793*** (2.565)	13.037*** (1.683)	5.576 (3.460)
R^2	0.025	0.018	0.127	0.067	0.031	0.042	0.066	0.060	0.068

OLS estimates. N = 349. Robust standard errors in parentheses. *$p<0.05$, **$p<0.01$, ***$p<0.001$ (tested with a two-tailed test); 33 respondents had to be disregarded of the analysis due to item-nonresponse in the income variable.

[a] Reference category: female

[b] Reference category: West Germany

[c] Reference category: medium (5, 6)

[d] Reference category: €3,000–€4,999. F-test results for differences between ISCED category "low (1, 2, 3)" and "high (7, 8)": technical system: $F(1,337) = 2.64, p = .105$, supplier: $F(1,337) = 0.17, p = .677$, investment costs: $F(1,337) = 1.19, p = .277$, yearly nominal return: $F(1,337) = 0.00, p = .981$, government subsidies: $F(1,337) = 4.41, p = .036$, form of financing: $F(1,337) = 0.61, p = .434$, self-sufficiency potential: $F(1,337) = 3.80, p = .052$, included services: $F(1,337) = 0.02, p = .875$, CO_2 savings: $F(1,337) = 0.10, p = .747$. F-test results for differences between Income category "less than €3,000" and "more than €5,000": technical system: $F(1,337) = 0.28, p = .595$, supplier: $F(1,337) = 0.91, p = .342$ investment costs: $F(1,337) = 0.33, p = .567$, yearly nominal return: $F(1,337) = 0.34, p = .562$, government subsidies: $F(1,337) = 0.05, p = .831$, form of financing: $F(1,337) = 0.72, p = .395$, self-sufficiency potential: $F(1,337) = 0.00, p = .994$, included services: $F(1,337) = 0.17, p = .680$, CO_2 savings: $F(1,337) = 0.48, p = .490$

(i.e., levels 4–7 of attribute 8). Our findings corroborate the existing literature [41, 43]. Comparing levels 7 and 6 shows that homeowners value smart energy services more when granting access rights to a contractual partner is linked to monetary compensation derived from maximizing electricity sales revenue. Homeowners value maximizing the self-sufficiency rate (level 6) similarly to the remote supervision of the PV system and battery storage for maintenance and repair purposes (level 5). We interpret this finding in the sense that homeowners primarily associate autonomy with maximizing self-sufficiency rather than financial compensation.

At the same time, our findings complement those of Richter and Pollitt [42] and von Loessl [44]. Comparing levels 2 and 3 shows that the negative effects of granting access rights to the contractual partner can be mitigated if the business model addresses homeowners' fears about losing control. For example, it could provide them with an element of co-determination by asking for their consent before performing a service, rather than performing the service automatically.

As expected, we find that with respect to the design of government subsidies, participants prefer higher grants to lower grants for both one-time and ongoing grants. We also observe a moderating effect on preferences for one-time and continuous grants. As long as the government grants an amount to 40% of the investment costs, homeowners prefer one-time grants paid immediately after installation to continuous payments over 20 years. However, if subsidies amount to 20% of the investment costs, survey participants are indifferent between one-time and continuous payments.

When the government subsidy was 10% of the investment cost, the surveyed homeowners preferred a continuous payment over 20 years to a one-time payment. In this context, it is important to note that we assumed a nominal discount rate of 4.04%, so that the sum of the discounted annual payments is just below the value of the corresponding one-time grant (cf. FN [7]). This allows us to make a direct comparison between the grants.

Our results also show that low-interest loans present an attractive measure from homeowners' point of view. Study participants preferred taking up a low-interest loan (set at 1.03% APR with a 10-year term in this study) over financing the technology via a high-interest loan (set at 3.53% APR with a 10-year term) or self-financing; whereas, they were indifferent between taking up the high-interest loan and financing the technology out of their own funds. This means that low-interest loans have limited effectiveness. The interest rate must be low enough to make the subsidy attractive to homeowners. The interest rate of 1.03% used in our study for the low-interest loan was based on the KfW bank loan for solvent homeowners valid in February 2020. The effective interest rate for the KfW bank loan (No. 270) is currently (March 2025) 3.76%, which is higher than the hypothetical interest rate of 3.53% we used for Level 3 at the time of the survey. It is therefore questionable to what extent the current KfW interest rate will accelerate adoption. To make matters worse, this form of financing is given the lowest priority for decision-making in this study. Even though the comparability of the importance of the attributes may be somewhat affected by the different number of levels for the nine characteristics, this last position is still meaningful. These results do not paint a particularly optimistic picture of the German financing landscape, where subsidized loans are used to overcome the challenge of high upfront costs of PV deployment. Despite all these findings regarding homeowners' preferences for government subsidy programs, it should be noted that, from the perspective of economic liberalism, subsidies, and more generally support programs, raise several issues and market distortions. From the perspective of climate advocates, market distortions in favor of renewable technologies may be desirable, as they aim to reduce the price of PV systems for homeowners, and thus increase the demand. On the other hand, support schemes (e.g., feed-in tariffs) neither directly subsidize the desirable public good (i.e., CO_2 emission reduction) nor penalize the negative externality (CO_2). Conversely, the various support schemes and their interaction with electricity prices do not have a neutral impact on end-user profitability and optimal system sizing. In this context, low-interest loans may encourage the adoption of BES [8]. A combination of low feed-in tariffs and high retail tariffs may incentivize the adoption of smaller, less cost-effective PV systems due to economies of scale [77]. Investment grants, on the other hand, tend to favor the installation of larger PV systems [77]. Finally, as the discount rate assumed by households may be a critical factor in the investment decision to adopt PV and BES, according to Aniello et al. [8], it could be considered by policymakers to optimize the level and timing of subsidy payments. In addition, subsidy schemes may raise concerns about distributional equity (e.g., between homeowners and renters), while in the case of somewhat inelastic supply, the gains from subsidies may be (partly) captured by suppliers, who may raise their prices accordingly. With regard to low-interest loans, there are problems at the implementation level in practice in Germany. Commercial banks may reject applications for low-interest loans from homeowners willing to install solar panels without further explanation. To develop solutions for a successful energy transition in the future, social science research should focus on the problems and underlying mechanisms at their implementation level.

Another finding of this study is that, in a statistical sense, participants valued PV installations and PV-BES equally. This is an interesting result because battery energy storage may have fallen out of favor among some homeowners in Germany in recent years due to concerns about their environmental impact during production and disposal. In other words, our findings do not suggest widespread rejection of BES among homeowners. Finally, our findings suggest that homeowners prefer public utilities as well as local, owner-managed companies to supra-regional energy supply companies and online merchants. This is interesting insofar as homeowners might view supra-regional energy supply companies as custodians of conventional energy generation technologies. The reduced preference for online merchants may be due to a lack of personal interaction, which is better suited to building trust between individuals (cf. e.g., [58, 78, 79]). To overcome the drawbacks of a lack of personal interaction and to build trust, online merchants can try to introduce institutional safeguards such as feedback systems and escrow services [80].

In this study, we also addressed heterogeneity issues by examining how respondents' socio-demographic characteristics, values, and risk propensity affect the importance homeowners attach to different attributes. The level of importance attached to most attributes is largely independent of socio-demographic characteristics. However, there are notable exceptions. Respondents currently living in eastern Germany attach more importance to the self-sufficiency potential of a PV system. This could be due to the fact that in the East of Germany, trust in government institutions or companies to ensure a stable electricity supply is lower as a result of the experience with a particularly vulnerable energy system in the former GDR [81]. On the other hand, CO_2 savings were considered less important by respondents in eastern Germany than in western Germany. This could be explained by the delayed public discourse on environmental protection in the states of the former GDR. In East Germany, environmental protection did not enter the broad public discourse until after reunification in 1989, while in West Germany it began as early as the late 1960s [82]. This is also consistent with Meyer et al. [83], who find that respondents in eastern Germany have significantly less positive environmental attitudes, willingness, and behavior than respondents in western Germany.[14] Companies operating in eastern Germany are well advised to promote PV installations with battery storage while emphasizing the increased self-sufficiency potential of such installations.

Our findings on the association between *universalism-nature* and the amount of *CO_2 savings* are consistent with the literature on the relationship between general environmental values and pro-environmental behaviors (e.g., [84, 85]), as *CO_2 savings* reflect the positive environmental effects of a PV(-BES) system. The more important the nature-oriented value orientation is for homeowners, the less their investment decisions regarding PV systems are influenced by simple economic calculations, and the more they are influenced by deep-rooted environmentalism, as reflected in the potential to reduce CO_2 emissions. Our findings also suggest that homeowners who are willing to take risks attach greater importance to smart energy services, possibly because they are generally more open to innovations and less concerned about data security issues and third-party access rights. This may cause them to value the included services more and therefore attach a greater importance to this attribute.

Finally, we find that homeowners who are willing to take risks attach greater importance to (expected) *yearly nominal returns* and *forms of financing*. One possible explanation for this pattern is that risk-inclined individuals are less concerned about the level of initial investment costs but rather eager to earn returns. In this case, credit financing serves as a means to an end, i.e., to achieve the returns. Conversely, a lack of risk inclination in the field of new technologies increases homeowners' desire to examine the financial risks associated with purchasing a PV system more closely.[15] They care, however, less about the expected returns, since these returns contain an element of uncertainty.

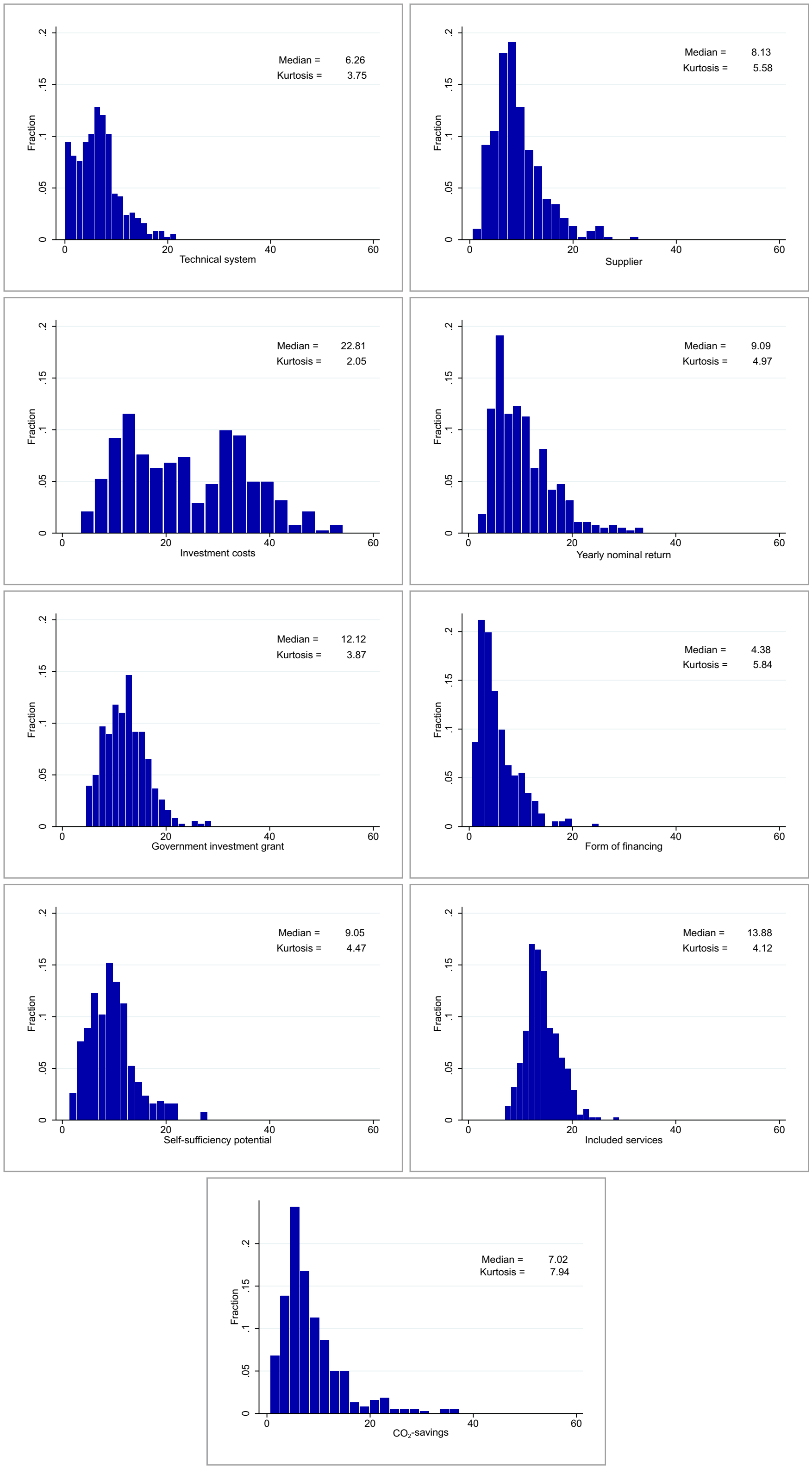
Investment costs, in turn, are fixed and—in the view of a risk-averse homeowner—thus need to be kept as low as possible to minimize the financial loss in case the newly installed technology performs worse than expected. In order to motivate the less risk-inclined part of the population, too, it is crucial to decrease investment costs. This can be achieved, e.g., by funding research projects to reduce the costs of PV installations in the medium term or by providing immediate *government subsidies* (while at the same time communicating that this is a direct reduction of the investment costs). The risk-tolerant part of the population will undoubtedly benefit from the facilitation of smart energy services. This should, on the one hand, be strongly promoted—to reach the risk-tolerant homeowners, and, on the other hand, kept strictly optional—in order not to lose the risk-averse homeowners.

Another strategy to address risk-aversion is considering alternative business models. Rental and lease of systems are already concrete alternative business models which allow homeowners to circumvent investment costs and reduce operating risks, yet they require households to commit to a long contract as well as long-term payments. A further alternative business model could consist of utility-owned PV installations, by which owners of buildings allow utility (or other) companies to install, operate, and own PV systems on their rooftops in exchange for cheap electricity and/or a monthly lease payment. Business models of utility-owned rooftop PV installations are already emerging in other countries [87] and might entail additional co-benefits in terms of grid operation efficiency and grid integration of distributed generation [88]. With respect to the German case, a new regulation[16] favoring such alternative business models could eliminate all investment costs and operational risks for households, while guaranteeing them a stream of incoming payments, thereby increasing the appeal of rooftop PV to a larger share of the homeowner population (e.g., low-income, risk-averse, elderly). Given its characteristics,

[14] For this study, Meyer F et al. [84] analyzed data on environmental attitudes, willingness, and behaviors of the International Social Survey Programme (ISSP) of the waves 1993, 2000, and 2010. East German residents have a significantly less environmentally friendly attitude, willingness, and behavior in each year, except for their behavior in 1993 and their attitude in 2000. Preisendörfer [83], on the other hand, found behaviors and attitudes of respondents in East Germany to be more positive for some and more negative for other items.

[15] Additionally, risk inclinations may also be related across different domains of life, in this case risk inclinations towards new technologies and towards financial risks. T. Dohmen et al. [87] show that pairwise correlations of risk inclinations in the domains career, sports and leisure, car driving, health, and financial matters are all around 0.5 and highly significant.

[16] This kind of business model exists in Germany too, but it is usually offered only in the case of large rooftop surfaces (e.g., above 800 m^2), whereas it is not economically viable for the supplier to rent small rooftops of detached houses.



Notes: The higher the variance of a distribution, the more heterogonous respondents are with respect to the importance they attach to a particular attribute.

Fig. 4 Distribution of individual level attributes importance ($n = 382$)

Table 4 Information provided to respondents as Introduction to Discrete Choice Experiment (placed on a separate questionnaire before the first choice set)

Thank you for your answers so far
We would now like to ask you to imagine that you alone can decide whether to invest in a photovoltaic system with or without battery storage for your household
In the following, we will present various offers for photovoltaic systems with and without battery storage several times in a row. The offers may differ in the following points:
- the provider of the system,
- the investment costs (including purchase and installation costs of the system)
- the expected annual nominal return on investment over 20 years (taking into account age-related performance losses)
- any state investment subsidies that will be paid to you after installation of the system,
- the form of financing,
- the self-supply potential of the system,
- the free service included from the provider and
- the savings in annual CO_2 emissions in German electricity production resulting from your purchase
Please compare the offers thoroughly and select the offer that you would purchase for your own home

utility-owned rooftop PV installations could be easily extended to apartment buildings (incl. renter-occupied ones). The involved utility companies or other (smart) energy organizations (e.g., aggregators, renewable energy communities, etc.) might include small investors, thereby allowing broader citizen participation in the energy transition. Finally, it is clear that having companies specialized in owning and managing PV installations might significantly reduce transaction costs, as well as installation costs due to economies of scale, professional expertise, and a higher degree of market power in comparison with single households. Therefore, adopting this business model might even improve the overall cost-efficiency of the energy transition.

In summary, the heterogeneity analyses show that only a few specific socio-demographic characteristics influence how homeowners approach an investment decision to purchase a PV system. Future DCE-based studies should further examine homeowner heterogeneity in order to identify motivating and hindering characteristics among homeowners. It would also be interesting to examine the robustness of two findings in this study. Firstly, men compared to women were found to attach less importance to the self-sufficiency potential of a PV system even though controlling in the analysis for participants' orientation to the value Self-direction-action. This finding points to the possibility that other factors than one's orientation to the value Self-direction-action drive the difference between men and women in attaching importance to the self-sufficiency potential. Secondly, researchers might investigate more deeply why a high compared to a low education level is negatively related to the role of *government subsidies* even though we controlled for participants' household income and orientation to the value nature.

Regarding the aspects that could be addressed in future studies, the limitations of DCEs in general and in this study should be kept in mind. DCEs allow eliciting stated (in contrast to observed) purchasing decisions of target persons. The extent to which the findings obtained in DCEs can be generalized to the real purchasing behavior of the target persons is generally associated with uncertainties. The closer the DCE is designed to reality, the higher the probability that the results can also be transferred to real purchasing decisions. In this study, we attached great importance to presenting participants with a realistic purchase decision. We did this by offering respondents a non-option, by presenting homeowners with key parameters for an investment decision, i.e., investment costs, potential savings, and expected return, and by trying to cover the respective attribute level ranges as realistically as possible in a nuanced

Table 5 Yearly payments over 20 years presented to participants of the DCE as a function of system specific investment costs and investment grants

		Attribute 3: Investment costs (in €)									
		PV					**PV-BES**				
		10,000	**15,000**	**20,000**	**25,000**	**30,000**	**15,000**	**20,000**	**25,000**	**30,000**	**35,000**
Attribute 5: Government subsidies	Level 5	–	–	–	–	–	€110	€147	€184	€221	€258
	Level 6	€147	€221	€295	€369	€443	€221	€295	€369	€443	€590
	Level 7	€295	€443	€590	€738	€886	–	–	–	–	–

Table 6 Questions used for heterogeneity analysis

Gender

What is your gender?
Answer options:
Female, Male, Non-binary

Region

Which region is your house located in?
Answer options:
Baden-Württemberg, Bayern, Berlin, Brandenburg, Bremen, Hamburg, Hessen, Mecklenburg-Vorpommern, Niedersachsen, Nordrhein-Westfalen, Rheinland-Pfalz
Saarland, Sachsen-Anhalt, Sachsen, Schleswig–Holstein, Thüringen

Age

How old are you?
Answer option:
I am ____ years old

Household income

If you add up the combined net income of your household from all members of the household and from all sources, how high is the monthly income of your household after tax?
→ Please consider all available types of income for the household, for example monthly salary, income from self-employment, occupational pension, state pension, rental income, and universal credit (after deduction of taxes and social security contributions) as well as other benefit payments (e.g., working tax credits, child benefits, disability living allowance, pension credit)
Answer option:
__________ Euros (an amount rounded to 500 or 1,000 Euros is sufficient)

Values

Here we briefly describe some people. Please read each description and think about how much each person is or is not like you. Please mark how much the person in the description is like you

It is important to % him_her%, …

Self-direction-action

1. to make %his/her% own decisions about %his/her% life
2. to plan %his/her% activities independently
3. to be free to choose what %he/she% does by himself

Security-personal

1. it is very important to him to avoid disease and protect his health
2. to be personally safe and secure
3. to avoid all dangers

Universalism-nature

1. to care for nature
2. to take part in activities to defend nature
3. to protect the natural environment from destruction or pollution

Answer options for each of the nine items:
not like me at all, not like me, little like me, somewhat like me, like me, very much like me

Risk inclination

In general, what is your stance on new technological developments? Please indicate in how far the following statement applies to you: I am willing to take risks
Answer option:
7-point scale with "does not apply at all" to "completely applicable"

The expressions % him_her% and %his/her% reflect so-called fillers in online surveys that were used to replace the respective filler for male (female) respondents with him and his (her and her), respectively

manner. This came at the cost of the simplicity of the DCE design in this study. The presented DCE is complex since there is a high discrepancy in the number of attribute levels across the attributes and there are a few conditional display restrictions that were supposed to prevent illogical and/or implausible restrictions from being presented. A high discrepancy in the number of attribute levels will lead to the so-called number-of-level effect as respondents will attach a higher level of importance to attributes with "many" levels than to attributes with "few" levels (cf. [89]). A potential number-of-level effect in this study would be of greater importance for the comparison of mean attribute scores (cf. "Mean attribute importance" section) than for the analyses regarding the determinants of attribute importance (cf. "Determinants of attribute importance" section) that were carried out separately

Table 7 Panel a to i: Paired t-test results: Level part-worths

	Difference in means	Standard error diff	t-value	p-value	p-value Sidak
a. Technical system					
PV–PVB	−0.089	0.047	−1.88	0.060	0.060
b. Supplier					
Local comp–Online merch	1.440	0.078	18.38	< 0.001	< 0.001
Local comp–En supply comp	0.635	0.054	11.84	< 0.001	< 0.001
Publ utility–Online merch	1.450	0.076	19.14	< 0.001	< 0.001
Publ utility–En supply comp	0.646	0.058	11.1	< 0.001	< 0.001
Local comp–Publ utility	−0.011	0.062	−0.17	0.862[a]	1.000
Online merch–En supply comp	−0.805	0.053	−15.18	< 0.001[a]	< 0.001
c. Investment costs					
10.000 €–15.000 €	0.666	0.073	9.11	< 0.001	< 0.001
15.000 €–20.000 €	0.913	0.061	14.85	< 0.001	< 0.001
20.000 €–25.000 €	1.076	0.055	19.59	< 0.001	< 0.001
25.000 €–30.000 €	1.608	0.054	29.81	< 0.001	< 0.001
30.000 €–35.000 €	0.915	0.051	17.89	< 0.001	< 0.001
d. Yearly nominal return					
0–2%	−0.200	0.041	−4.91	< 0.001	< 0.001
2–4%	−0.698	0.048	−14.63	< 0.001	< 0.001
4–6%	−0.106	0.059	−1.79	0.037	0.172
6–8%	−0.333	0.047	−7.15	< 0.001	< 0.001
8–10%	−0.229	0.048	−4.81	< 0.001	< 0.001
e. Government subsidies					
No grant—One-time 10%	−0.673	0.051	−13.11	< 0.001	< 0.001
One-time 10%–One-time 20%	−0.824	0.043	−19.20	< 0.001	< 0.001
One-time 20%–One-time 40%	−0.790	0.053	−14.84	< 0.001	< 0.001
No grant—Contin. 0.74%	−0.952	0.045	−21.33	< 0.001	< 0.001
Contin. 0.74%–Contin. 1.47%	−0.41	0.046	−8.95	< 0.001	< 0.001
Contin. 1.47%–Contin. 2.95%	−0.609	0.044	−13.98	< 0.001	< 0.001
One-time 10%–Contin. 0.74%	−0.279	0.039	−7.25	< 0.001	< 0.001
One-time 20%–Contin. 1.47%	0.134	0.059	2.27	0.012	0.196
One-time 40%–Contin. 2.95%	0.316	0.053	5.92	< 0.001	< 0.001
f. Form of financing					
Self–Credit 1.03%	−0.399	0.072	−5.6	< 0.001[a]	< 0.001
Self–Credit 3.53%	−0.118	0.064	−1.85	0.065[a]	0.181
Credit 1.03%–Credit 3.53%	0.280	0.034	8.15	< 0.001[a]	< 0.001
g. Self-sufficiency potential					
20–40%	−0.626	0.052	−11.35	< 0.001	< 0.001
40–60%	−0.545	0.042	−12.75	< 0.001	< 0.001
60–80%	−0.572	0.048	−12.02	< 0.001	< 0.001
h. Included services					
PV standalone					
Visual PV–Superv PV	0.046	0.043	1.06	0.146[a]	0.758
Visual PV–Superv PV (Auto)	0.257	0.053	4.87	< 0.001[a]	< 0.001
Superv PV–Superv PV (Auto)	0.211	0.044	4.81	< 0.001[a]	< 0.001
PV and battery storage					
Visual PVB–Superv PVB	0.156	0.041	3.81	< 0.001[a]	0.002
Visual PVB 4–Control Suff 6	0.257	0.054	5.01	< 0.001[a]	< 0.001
Visual PVB 4–Control Rev 7	−0.588	0.054	−10.86	< 0.001[a]	< 0.001
Superv PVB–Control Suff	0.101	0.046	2.2	0.014[a]	0.120

Table 7 (continued)

	Difference in means	Standard error diff	*t*-value	*p*-value	*p*-value Sidak
Superv PVB–Control Rev	−0.744	0.048	−15.55	< 0.001[a]	< 0.001
Control Suff–Control Rev	−0.846	0.042	−20.31	< 0.001[a]	< 0.001
i. CO_2 savings					
490–5.000 kg	−1.109	0.060	−18.35	< 0.001	< 0.001
5.000–10.000 kg	−0.437	0.066	−6.62	< 0.001	< 0.001

Differences in means and standard errors, t-values and p-values of paired t-tests. Additionally, we report the *p*-values corrected by a variant of the Sidak correction for dependent tests proposed by Tukey, Ciminera, and Heyse (1985) $p\prime = 1 - (1 - p)^{\sqrt{m}}$, where *m* is the number of pairwise comparisons conducted between the levels of each attribute (Lüpsen 2020, Blakesley et al. 2009). Degrees of freedom for each t-test: 381

[a] P-values of two-sided t-tests. All other p-values of one-sided tests

Table 8 Determinants of attribute importance: OLS regression results (excluding Self-direction-action and Security-personal)

	Investment costs	Included services	Government subsidies	Yearly nominal return	Self-sufficiency potential	Supplier	CO_2 savings	Technical system	Form of financing
Male[a]	0.850 (1.217)	−0.514 (0.355)	−0.232 (0.441)	1.206* (0.601)	−1.113* (0.501)	−0.314 (0.546)	−0.006 (0.703)	−0.041 (0.442)	0.165 (0.401)
East-Germany[b]	1.594 (1.482)	0.223 (0.442)	0.269 (0.551)	−0.703 (0.705)	1.524* (0.608)	−0.626 (0.571)	−2.247*** (0.656)	0.116 (0.465)	−0.151 (0.473)
Age	0.056 (0.048)	0.003 (0.014)	0.026 (0.018)	−0.051* (0.024)	−0.039 (0.020)	0.031 (0.019)	−0.025 (0.027)	−0.007 (0.018)	0.005 (0.019)
ISCED low (1, 2, 3)[c]	4.366 (2.437)	−0.695 (0.910)	−1.239 (0.953)	−0.207 (1.248)	−1.736 (0.978)	−0.277 (0.980)	−0.502 (1.026)	1.121 (0.664)	−0.832 (0.795)
ISCED high (7,8)[c]	3.132 (2.561)	−0.470 (0.962)	−1.903 (0.977)	0.424 (1.353)	−2.186* (1.060)	0.040 (1.065)	0.259 (1.158)	1.406 (0.762)	−0.702 (0.844)
Income Less than 3,000 €[d]	0.273 (1.315)	0.004 (0.377)	−0.237 (0.517)	−0.134 (0.603)	0.873 (0.526)	−0.853 (0.575)	−0.266 (0.676)	−0.401 (0.507)	0.741 (0.426)
Income 5,000 € or more[d]	−0.723 (1.686)	0.315 (0.484)	−0.109 (0.665)	0.554 (1.057)	0.242 (0.793)	−0.988 (0.851)	0.645 (1.002)	−0.428 (0.701)	0.492 (0.612)
Universalism-nature	−1.410* (0.553)	0.256 (0.153)	−0.124 (0.191)	0.161 (0.299)	−0.114 (0.197)	0.113 (0.214)	0.670* (0.291)	0.385* (0.180)	0.062 (0.175)
Risk inclination	−2.065*** (0.358)	0.341*** (0.103)	0.082 (0.142)	0.483* (0.195)	0.116 (0.157)	0.127 (0.187)	0.387 (0.235)	0.180 (0.144)	0.348** (0.115)
Constant	29.752*** (4.896)	12.427*** (1.513)	12.532*** (1.885)	10.616*** (2.497)	13.410*** (1.927)	7.590*** (1.815)	6.265* (2.542)	3.381* (1.598)	4.029* (1.777)
R^2	0.124	0.047	0.024	0.067	0.054	0.021	0.065	0.024	0.041

OLS estimates. $N = 349$. Robust standard errors in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. 33 respondents had to be disregarded of the analysis due to item-nonresponse in the income variable

[a] Reference category: female

[b] Reference category: West Germany

[c] Reference category: medium (5, 6)

[d] Reference category: 3,000 €–4,999 €

for each of the attributes and do not imply a comparison across attributes. At the same time, it should be noted that attribute importance scores are also affected by the chosen range of attribute levels, which in turn also affects the size of regression coefficients (cf. [90]). In light of this, it is generally preferable to avoid over-generalizing the results of DCEs. Instead, they should be limited to the specific conditions of a DCE. The design complexity with respect to the conditional display restrictions may be an issue relevant to the efficiency of the estimation. Future studies should therefore reexamine (elements of) this study in the context of a less complex design.

Conclusions

Overall, the study highlights the central role of financial factors, the need for tailored funding strategies, and the potential of alternative business models to overcome investment barriers. Non-monetary aspects such as CO_2 savings or self-sufficiency are irrelevant unless they are linked to financial benefits. This is especially true for households with a low environmental awareness. In addition, in East Germany, self-sufficiency is more highly valued, whereas CO_2 savings are less so.

With regard to state subsidies, the preference for one or the other form of subsidy (continuous vs. one-time grant) depends on the amount of the subsidy. In addition to the preferences of homeowners, the administrative burden and the associated administrative costs are likely to play a significant role for the state when choosing the form of subsidy. Low-interest loans are only attractive if the subsidized interest rates are low enough. This measure will not effectively address the problem of high capital costs. At this point, alternative business models (leasing or utility-owned PV) are the solutions to investment barriers under certain circumstances.

Smart energy services have great potential, but there are some reservations. While a higher level of service is appreciated, a loss of control (e.g., through data access for contractors) is viewed negatively. In addition to monetary compensation, homeowners should be involved in the usually automated processes by means of decision queries. This will increase their acceptance of smart energy services.

Appendix

See Fig. 4 and Tables 4, 5, 6, 7, 8.

Acknowledgements

When writing the manuscript, the author used DeepL Write to check grammar and spelling and to make minor improvements to readability and style. After using this tool, the author checked the content and edited it where necessary. He takes full responsibility for the content of the publication.

Author contributions

H.S. and G.A. conceptualized the survey and discrete choice experiment. H.S. and F.M. conducted the analyses and wrote the main manuscript text. F.M. and H.S. prepared figures and tables. G.A. wrote parts of the manuscript and reviewed the manuscript. W.K. reviewed the survey and the manuscript.

Funding

Open Access funding enabled and organized by Projekt DEAL. This study was conducted within the framework of the Virtual Institute "Smart Energy" (VISE). The VISE is funded by the European Regional Development Fund (EFRE) and by the federal state of North Rhine-Westphalia (EFRE-0600037). The authors declare no financial interest or relationship.

Data availability

The survey data used for the analysis in this study are available upon request from the authors, provided that disclosure does not violate data protection regulations.

Declarations

Ethics approval and consent to participate

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 6 May 2024 Accepted: 25 September 2025
Published online: 13 November 2025

References

1. Wirth H (2025) Aktuelle Fakten zur Photovoltaik in Deutschland: Fraunhofer ISE2025. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf. Accessed 05 Mar 2025.
2. von Wirth T, Gret-Regamey A, Moser C, Stauffacher M (2016) Exploring the influence of perceived urban change on residents' place attachment. J Environ Psychol 46:67–82. https://doi.org/10.1016/j.jenvp.2016.03.001
3. EEG (2023) Erneuerbare-Energien-Gesetz 4(3). https://www.gesetze-im-internet.de/eeg_2014/BJNR106610014.html. Accessed 30 Nov 2024.
4. DESTATIS (2020) Bautätigkeit und Wohnungen - Bestand an Wohnungen - Fachserie 5 - Reihe 3. Wiesbaden: DESTATIS. https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Wohnen/Publikationen/Downloads-Wohnen/bestand-wohnungen-2050300207004.pdf;jsessionid=5218274CC3C3E9A038F9AE95A09CE752.live742?__blob=publicationFile. Accessed 13 Apr 2022.
5. DESTATIS (2022) 2,2 Millionen Photovoltaik-Anlagen in Deutschland installiert. Pressemitteilung Nr. N 037 vom 21. Juni 2022. https://www.destatis.de/DE/Presse/Pressemitteilungen/2022/06/PD22_N037_43.html. Accessed 19 Mar 2023.
6. Bergner J, Quasching V (2019) Sinnvolle Dimensionierung von Photovoltaikanlagen für Prosumer. Version 1.2 (März 2019): Hochschule für Technik und Wirtschaft Berlin. https://solar.htw-berlin.de/studien/dimensionierung-von-pv-anlagen/. Accessed 04 Jun 2022.
7. Wirth H (2022) Aktuelle Fakten zur Photovoltaik in Deutschland: Fraunhofer ISE2022. www.pv-fakten.de. Accessed 04 Feb 2022.
8. Aniello G, Shamon H, Kuckshinrichs W (2021) Micro-economic assessment of residential PV and battery systems: the underrated role of financial and fiscal aspects. Appl Energy 281:115667. https://doi.org/10.1016/j.apenergy.2020.115667
9. Kuckshinrichs W, Ball CS, Aniello G (2023) Levelized profits for residential PV-battery systems and the role of regulatory and fiscal aspects in Germany. Energy Sustain Soc 13(1):10. https://doi.org/10.1186/s13705-023-00390-8
10. SPD, GRÜNEN BD, FDP (2021) Koalitionsvertrag 2021 - 2025: Mehr Fortschritt wagen - Bündnis für Freiheit, Gerechtigkeit und Nachhaltigkeit. https://www.spd.de/fileadmin/Dokumente/Koalitionsvertrag/Koalitionsvertrag_2021-2025.pdf. Accessed 02 Mar 2022.
11. Palm A (2017) Residential solar photovoltaics deployment: barriers and drivers in space. Doctoral dissertation, Lund University. https://portal.research.lu.se/en/publications/fd0f2599-fb5d-4987-bdc9-c0312f47170d. Accessed 04 Mar 2022.
12. Palm J (2018) Household installation of solar panels—motives and barriers in a 10-year perspective. Energy Policy 113:1–8. https://doi.org/10.1016/j.enpol.2017.10.047
13. Palm J, Eidenskog M, Luthander R (2018) Sufficiency, change, and flexibility: critically examining the energy consumption profiles of solar PV prosumers in Sweden. Energy Res Soc Sci 39:12–18. https://doi.org/10.1016/j.erss.2017.10.006
14. Palm J, Tengvard M (2011) Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden. Sustain Sci Pract Policy 7(1):6–15. https://doi.org/10.1080/15487733.2011.11908061
15. Balcombe P, Rigby D, Azapagic A (2013) Motivations and barriers associated with adopting microgeneration energy technologies in the UK.

Renew Sustain Energy Rev 22:655–666. https://doi.org/10.1016/j.rser.2013.02.012
16. Islam T, Meade N (2013) The impact of attribute preferences on adoption timing: the case of photo-voltaic (PV) solar cells for household electricity generation. Energy Policy 55:521–530. https://doi.org/10.1016/j.enpol.2012.12.041
17. Jager W (2006) Stimulating the diffusion of photovoltaic systems: a behavioural perspective. Energy Policy 34(14):1935–1943. https://doi.org/10.1016/j.enpol.2004.12.022
18. Korcaj L, Hahnel UJJ, Spada H (2015) Intentions to adopt photovoltaic systems depend on homeowners' expected personal gains and behavior of peers. Renew Energy 75:407–415. https://doi.org/10.1016/j.renene.2014.10.007
19. Rai V, Beck AL (2015) Public perceptions and information gaps in solar energy in Texas. Environ Res Lett 10(7):074011. https://doi.org/10.1088/1748-9326/10/7/074011
20. Rai V, Reeves DC, Margolis R (2016) Overcoming barriers and uncertainties in the adoption of residential solar PV. Renew Energy 89:498–505. https://doi.org/10.1016/j.renene.2015.11.080
21. Wolske KS, Stern PC, Dietz T (2017) Explaining interest in adopting residential solar photovoltaic systems in the United States: toward an integration of behavioral theories. Energy Res Soc Sci 25:134–151. https://doi.org/10.1016/j.erss.2016.12.023
22. Parkins JR, Rollins C, Anders S, Comeau L (2018) Predicting intention to adopt solar technology in Canada: the role of knowledge, public engagement, and visibility. Energy Policy 114:114–122. https://doi.org/10.1016/j.enpol.2017.11.050
23. Alipour M, Salim H, Stewart RA, Sahin O (2020) Predictors, taxonomy of predictors, and correlations of predictors with the decision behaviour of residential solar photovoltaics adoption: a review. Renew Sustain Energy Rev 123:109749. https://doi.org/10.1016/j.rser.2020.109749
24. Poier S (2021) Towards a psychology of solar energy: analyzing the effects of the Big Five personality traits on household solar energy adoption in Germany. Energy Res Soc Sci 77:102087. https://doi.org/10.1016/j.erss.2021.102087
25. Scheller F, Graupner S, Edwards J, Weinand J, Bruckner T (2022) Competent, trustworthy, and likeable? Exploring which peers influence photovoltaic adoption in Germany. Energy Res Soc Sci 91:102755. https://doi.org/10.1016/j.erss.2022.102755
26. Rai V, Sigrin B (2013) Diffusion of environmentally-friendly energy technologies: buy versus lease differences in residential PV markets. Environ Res Lett 8(1):014022. https://doi.org/10.1088/1748-9326/8/1/014022
27. Dharshing S (2017) Household dynamics of technology adoption: a spatial econometric analysis of residential solar photovoltaic (PV) systems in Germany. Energy Res Soc Sci 23:113–124. https://doi.org/10.1016/j.erss.2016.10.012
28. Simpson G, Clifton J (2017) Testing diffusion of innovations theory with data: financial incentives, early adopters, and distributed solar energy in Australia. Energy Res Soc Sci 29:12–22. https://doi.org/10.1016/j.erss.2017.04.005
29. Shamon H et al. (2021) Smart Energy in Haushalten: Technologien, Geschäftsmodelle, Akzeptanz und Wirtschaftlichkeit. Schriften des Forschungszentrums Jülich Reihe Energie & Umwelt. Vol. 541. Jülich: Forschungszentrum Jülich GmbH Zentralbibliothek.
30. Balcombe P, Rigby D, Azapagic A (2014) Investigating the importance of motivations and barriers related to microgeneration uptake in the UK. Appl Energy 130:403–418. https://doi.org/10.1016/j.apenergy.2014.05.047
31. Bezdek RH, Sparrow FT (1981) Solar subsidies and economic efficiency. Energy Policy 9(4):289–300. https://doi.org/10.1016/0301-4215(81)90005-7
32. Rogers EM (2003) Diffusion of innovations. Free Press, New York
33. Petrovich B, Carattini S, Wüstenhagen R (2021) The price of risk in residential solar investments. Ecol Econ 180:106856. https://doi.org/10.1016/j.ecolecon.2020.106856
34. Hille SL, Curtius HC, Wüstenhagen R (2018) Red is the new blue – The role of color, building integration and country-of-origin in homeowners' preferences for residential photovoltaics. Energy Build 162:21–31. https://doi.org/10.1016/j.enbuild.2017.11.070
35. Peters AM, van der Werff E, Steg L (2019) Mind the gap: the implications of not acting in line with your planned actions after installing solar photovoltaics. Front Psychol. https://doi.org/10.3389/fpsyg.2019.01423
36. Bhushan N, Steg L, Jans L, Albers C (2021) Does installing photovoltaic panels affect daily electricity usage patterns? A generalized additive model approach. Energy Clim Change 2:100052. https://doi.org/10.1016/j.egycc.2021.100052
37. Chasin F, Paukstadt U, Gollhardt T, Becker J (2020) Smart energy driven business model innovation: an analysis of existing business models and implications for business model change in the energy sector. J Clean Prod 269:122083. https://doi.org/10.1016/j.jclepro.2020.122083
38. Paukstadt U, Becker J (2021) From energy as a commodity to energy as a service—a morphological analysis of smart energy services. Schmalenbach J Bus Res 73(2):207–242. https://doi.org/10.1007/s41471-021-00111-x
39. Balta-Ozkan N, Davidson R, Bicket M, Whitmarsh L (2013) Social barriers to the adoption of smart homes. Energy Policy 63:363–374. https://doi.org/10.1016/j.enpol.2013.08.043
40. Pepermans G (2014) Valuing smart meters. Energy Econ 45:280–294. https://doi.org/10.1016/j.eneco.2014.07.011
41. Wilson C, Hargreaves T, Hauxwell-Baldwin R (2017) Benefits and risks of smart home technologies. Energy Policy 103:72–83. https://doi.org/10.1016/j.enpol.2016.12.047
42. Richter L-L, Pollitt MG (2018) Which smart electricity service contracts will consumers accept? The demand for compensation in a platform market. Energy Econ 72:436–450. https://doi.org/10.1016/j.eneco.2018.04.004
43. Wunderlich P, Veit DJ, Sarker S (2019) Adoption of sustainable technologies: a mixed-methods study of German households. MIS Q 43(2):673–692. https://doi.org/10.25300/misq/2019/12112
44. von Loessl V (2023) Smart meter-related data privacy concerns and dynamic electricity tariffs: evidence from a stated choice experiment. Energy Policy 180:113645. https://doi.org/10.1016/j.enpol.2023.113645
45. Shamon H, Dülmer H, Giza A (2022) The factorial survey: the impact of the presentation format of vignettes on answer behavior and processing time. Sociol Methods Res 51(1):396–438. https://doi.org/10.1177/0049124119852382
46. Gesellschaft für integrierte Kommunikationsforschung (GIK) (2019) https://gik.media/best-4-planning/. Accessed 21 Feb 2022.
47. Shamon H, Berning CC (2020) Attention check items and instructions in online surveys: boon or bane for data quality? Surv Res Methods 14(1):55–77. https://doi.org/10.18148/srm/2020.v14i1.7374
48. Sawtooth (2021) CBC Questionnaires and Design Strategy. https://sawtoothsoftware.com/help/lighthouse-studio/manual/hid_web_cbc_designs_1.html. Accessed 14 Jul 2021.
49. Hanley N, Mourato S, Wright RE (2001) Choice modelling approaches: a superior alternative for environmental valuatioin? J Econ Surv 15(3):435–462. https://doi.org/10.1111/1467-6419.00145
50. Kamakura W, Haaijer R, Wedel M (2001) The no—choice alternative in conjoint choice experiments. Int J Market Res 43(1):1–12. https://doi.org/10.1177/147078530104300105
51. Dhar R, Simonson I (2003) The effect of forced choice on choice. J Mark Res 40(2):146–160
52. Penn JM, Hu W, Cox LJ (2019) The effect of forced choice with constant choice experiment complexity. J Agr Resource Econ 44(2):439–455
53. Haghani M, Bliemer MCJ, Rose JM, Oppewal H, Lancsar E (2021) Hypothetical bias in stated choice experiments: part II. Conceptualisation of external validity, sources and explanations of bias and effectiveness of mitigation methods. J Choice Model 41:100322. https://doi.org/10.1016/j.jocm.2021.100322
54. Waugh FV (1935) The marginal utility of money in the United States from 1917 to 1921 and from 1922 to 1932. Econometrica 3(4):376–399. https://doi.org/10.2307/1905630
55. Islam T (2014) Household level innovation diffusion model of photo-voltaic (PV) solar cells from stated preference data. Energy Policy 65:340–350. https://doi.org/10.1016/j.enpol.2013.10.004
56. Wittenberg I, Matthies E (2016) Solar policy and practice in Germany: how do residential households with solar panels use electricity? Energy Res Soc Sci 21:199–211. https://doi.org/10.1016/j.erss.2016.07.008
57. Epstein S (1990) Cognitive-experiential self-theory. In: Barone DF, Hersen M, Van Hasselt VB (eds) Handbook of personality: theory and research. The Guilford Press, New York
58. Grawe K (2014) Neuropsychotherapie. Hogrefe, Göttingen
59. Nosi C, Pucci T, Melanthiou Y, Zanni L (2022) The influence of online and offline brand trust on consumer buying intention. EuroMed Journal

of Business ahead-of-print 17(4):550–567. https://doi.org/10.1108/EMJB-01-2021-0002
60. BGBl I (2000) Nr. 13. pp 305–309. https://www.bgbl.de/xaver/bgbl/start.xav?start=%2F%2F*%5B%40attr_id%3D%27bgbl100s0305.pdf%27%5D#/switch/tocPane?_ts=1760081378618
61. Hartmann J, Preisendörfer P (2021) Development and structure of environmental worries in Germany 1984–2019. Z Soziol 50(5):322–337. https://doi.org/10.1515/zfsoz-2021-0022
62. Rubik F, Müller R, Harnisch R, Holzhauer B, Schipperges M, Geiger S (2020) Environmental Awareness in Germany 2018 - Results of a representative survey. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). https://www.umweltbundesamt.de/en/publikationen/environmental-awareness-in-germany-2018. Accessed 24 Feb 2022.
63. BGBl I (2020) Nr. 65. pp 3138–3205. https://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&start=%2F%2F%2A%5B%40attr_id=%27bgbl120s3206.pdf%27%5D#/switch/tocPane?_ts=1760103005784
64. KfW 2020 Erneuerbare Energien - Standard (270) Strom erzeugen für ein nachhaltiges Energiesystem. https://www.kfw.de/inlandsfoerderung/Unternehmen/Energie-Umwelt/F%C3%B6rderprodukte/Erneuerbare-Energien-Standard-(270). Accessed 15 Dec 2020.
65. Umweltbundesamt (2019) Emissionsbilanz erneuerbarer Energieträger - Bestimmung der vermiedenen Emissionen im Jahr 2018. http://www.umweltbundesamt.de/publikationen/emissionsbilanz-erneuerbarer-energietraeger. Accessed 06 Feb 2020.
66. Schwartz SH, Cieciuch J, Vecchione M, Davidov E, Fischer R, Beierlein C et al (2012) Refining the theory of basic individual values. J Pers Soc Psychol 103(4):663–668. https://doi.org/10.1037/a0029393
67. Schwartz SH (1992) Universals in the content and structure of values: theoretical advances and empirical tests in 20 countries. Adv Exp Soc Psychol 25:1–65. https://doi.org/10.1016/S0065-2601(08)60281-6
68. Beierlein CE, Davidov D, Behr J, Cieciuch Z, László R, Latcheva S et al. (2013) German version of the Portrait Values Questionnaire, revision 3 (PVQ-R3). Unpublished manuscript.
69. Lin CA (1998) Exploring personal computer adoption dynamics. J Broadcast Electron Media 42(1):95–112
70. Dülmer H, Jagodzinski W, Siegers P. Classification Scheme for the Modified Education Variable of the EVS 1999/2000, mimeo. 2008.
71. Sawtooth (2022) Estimating Part-Worth Utilities. https://sawtoothsoftware.com/help/lighthouse-studio/manual/id_cvaestimate.html. Accessed 17 Mar 2022.
72. Orme BK (2020) Getting started with conjoint analysis: strategies for product design and pricing research. Research Publishers LLC, Manhattan Beach
73. Shamon H, Dülmer H (2014) Raising the question on "who should get what?" again: on the importance of ideal and existential standards. Soc Justice Res 27(3):340–368. https://doi.org/10.1007/s11211-014-0217-3
74. Tukey JW, Ciminera JL, Heyse JF (1985) Testing the statistical certainty of a response to increasing doses of a drug. Biometrics 41(1):295–301. https://doi.org/10.2307/2530666
75. Blakesley RE, Mazumdar S, Dew MA, Houck PR, Tang G, Reynolds CF 3rd et al (2009) Comparisons of methods for multiple hypothesis testing in neuropsychological research. Neuropsychology 23(2):255–264. https://doi.org/10.1037/a0012850
76. Lüpsen H (2019) Multiple Mittelwertvergleiche - parametrisch und nichtparametrisch -sowie α-Adjustierungen mit praktischen Anwendungen mit R und SPSS. Cologne: Regionales Rechenzentrum (RRZK). http://www.uni-koeln.de/~a0032/statistik/texte/mult-comp.pdf. Accessed 05 Mar 2019.
77. Abdi H (2007) The Bonferonni and Šidák corrections for multiple comparisons. In: Salkind NJ (ed) Encyclopedia of measurement and statistics. Sage, Thousand Oaks
78. Hartner M, Mayr D, Kollmann A, Haas R (2017) Optimal sizing of residential PV-systems from a household and social cost perspective: a case study in Austria. Sol Energy 141:49–58. https://doi.org/10.1016/j.solener.2016.11.022
79. Benedicktus RL (2008) Psychological distance perceptions and trust beliefs for Internet-only and hybrid retailers: implications for marketers. Florida State University, Tallahassee
80. Grabner-Kräuter S (ed) (2004) Building consumer trust in online markets. Springer, Berlin
81. Pavlou PA, Gefen D (2004) Building effective online marketplaces with institution-based trust. Inf Syst Res 15(1):37–59. https://doi.org/10.1287/isre.1040.0015
82. Shin H, Trentmann F (2019) Energy shortages and the politics of time: resilience, redistribution and `normality' in Japan and East Germany, 1940s–1970s. In: Brewer JJ, Fromer N, Trentmann F (eds) Scarcity in the modern world: history, politics, society and sustainability. Bloomsbury, New York, pp 1800–2075
83. Preisendörfer P (1999) Umweltbewußtsein und Umweltverhalten im West-Ost-Vergleich. Umwelteinstellungen und Umweltverhalten in Deutschland: Empirische Befunde und Analysen auf der Grundlage der Bevölkerungsumfragen „Umweltbewußtsein in Deutschland 1991–1998". VS Verlag für Sozialwissenschaften, Wiesbaden.
84. Meyer F, Shamon H, Vögele S (2022) Dynamics and heterogeneity of environmental attitude, willingness and behavior in Germany from 1993 to 2021. Sustainability 14(23):16207. https://doi.org/10.3390/su142316207
85. Katz-Gerro T, Greenspan I, Handy F, Lee H-Y (2017) The relationship between value types and environmental behaviour in four countries: universalism, benevolence, conformity and biospheric values revisited. Environ Values 26(2):223–249. https://doi.org/10.3197/096327117X14847335385599
86. Steg L, de Groot JIM (2012) Environmental values. In: Clayton S (ed) The oxford handbook of environmental and conservation psychology. Oxford University Press, Oxford
87. Dohmen T, Falk A, Huffman D, Sunde U, Schupp J, Wagner GG (2011) Individual risk attitudes: measurement, determinants, and behavioral consequences. J Eur Econ Assoc 9(3):522–550. https://doi.org/10.1111/j.1542-4774.2011.01015.x
88. Shen B, Kahrl F, Satchwell AJ (2021) Facilitating power grid decarbonization with distributed energy resources: lessons from the United States. Annu Rev Environ Resour 46(1):349–375. https://doi.org/10.1146/annurev-environ-111320-071618
89. Barbose G, Satchwell AJ (2020) Benefits and costs of a utility-ownership business model for residential rooftop solar photovoltaics. Nat Energy 5(10):750–758. https://doi.org/10.1038/s41560-020-0673-y
90. Verlegh PWJ, Schifferstein HNJ, Wittink DR (2002) Range and number-of-levels effects in derived and stated measures of attribute importance. Mark Lett 13(1):41–52. https://doi.org/10.1023/A:1015063125062

Publisher's Note