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Intentions to adopt photovoltaic systems depend on homeowners' expected personal gains and behavior of peers

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ABSTRACT

Photovoltaic (PV) system adoption in Germany is mainly driven by a feed-in tariff that guarantees a financial return on investment. To promote adoption in the future absence of this tariff, we explored further motives of homeowners relevant to PV system purchase intention. A sample of 200 homeowners who did not own a PV system participated in an online-survey. Only few homeowners actually planned to adopt a PV system. However, basic willingness to adopt a PV system was high, whereas willingness to pay was low - hinting at a potentially growing market with falling prices. Using path analysis, we show that the subjective norm (i.e. peer behavior and expectations) and the attitude towards PV were strong predictors of purchase intention. Attitude towards PV systems was mainly based on aspirations of social status, autarky, and financial gains, whereas costs, efforts, and risks associated with PV systems were detrimental to attitude. We conclude that to promote further adoption, energy storage systems that increase financial savings and autarky need to be improved and marketed. Furthermore, institutionalized tests of PV systems and labels need to be introduced to reduce risk perceptions among homeowners willing to adopt a PV system.

1. Introduction

Globally, the prevalent method of producing electricity and heat is the burning of fossil fuels [4]. The drawbacks of this *modus operandi* are manifold and lead to growing concerns worldwide [23].

One solution is the use of renewable energies, which reduces pollution, dependence on energy imports, and the waste of fossil fuel resources [26]. It also has the potential to mitigate climate change [4].

Unlike the fossil fuels market, the renewable energy market is open to individuals who want to become electricity producers – especially in the case of residential photovoltaic (PV[1]) systems. Germany, at the end of 2012, had 1.3 million PV systems connected to the grid with a combined capacity of 32 GWp [10,11]. Approximately 90% of these systems were small-scale systems (<30 kWp) purchased by homeowners – accounting for about 45% of total PV capacity [5].

This widespread adoption of PV has been attributed to the German Renewable Energy Act (Erneuerbare-Energien-Gesetz, [12,30]). This Act not only guarantees PV system owners the option to feed the electricity produced by renewable energy systems into the grid, but also a price (feed-in tariff) above market value[2] for every kWh fed in. Location and capacity of new PV installations need to be registered with the federal grid agency (Bundesnetzagentur) to be eligible for the feed-in tariff [12]. The tariff is determined the day the PV system is connected to the grid and fixed for 20 years. Thus, the Renewable Energy Act made PV systems a financially sensible investment, even in the early days when they were expensive and otherwise unprofitable. It kicked off PV system development, and resulted in price reductions not only for PV modules, but also for other components required for a PV system, and for labor cost of installations [27]. Compared to other policy

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[1] Within the scope of this study we focused on PV system adoption due to its versatility. PV produces electricity that can be fed into the grid or partially consumed on site – unlike heat produced by solar thermal or geothermal systems. For many homeowners, PV may be preferable to wind energy for three reasons: 1) it is scalable to the building size and the financial means of the homeowner, 2) it requires little to no maintenance, and 3) it does not change the home's appearance as drastically.

[2] The market value is the price at which electricity is sold at the European Energy Exchange EEX in Leipzig, Germany. The price for baseload power in 2014 was set at 42.12€ per MWh (approx. .04€ per kWh; [16]). Domestic consumers buy electricity from utilities at a price of up to .29€ per kWh [17], which includes various taxes, grid costs, the Renewable Energy Act levy, and other smaller concessions.

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Nomenclature

Alphabetical symbols

N	sample size
n	sub-sample size
p	measure of statistical significance
r	correlation coefficient (Spearman correlation)
R^2	measure of explained variance

Greek symbols

α	Cronbach's α (measure of internal consistency of a scale)
β	standardized regression weight
χ^2	chi-square (measure of model fit)

Abbreviations

df	degrees of freedom
GFI	goodness of fit index (measure of model fit)
GWp	gigawatt peak (measure of maximum power production capacity)
kWh	kilowatt hour
kWp	kilowatt peak (measure of maximum power production capacity)
M	mean value
PV	photovoltaic
RMSEA	root mean square error of approximation (measure of model fit)
SD	standard deviation
SRMR	standardized root mean square residual (measure of model fit)
TPB	Theory of Planned Behavior

instruments, such as quotas or auctions, "feed-in tariffs are by far the most effective policy instruments" ([30], p. 36).

Currently, the feed-in tariff for new installations lies below the consumer price of electricity and further reductions are planned for the coming years [13]. This means that consuming the electricity produced by one's own PV system leads to savings (approx. .29€ per kWh) that are higher than the potential profit earned if the energy was fed into the grid (feed-in tariff: .13€ per kWh for residential PV systems that are smaller than 10 kWp and were connected to the grid in April 2014). Accordingly, the feed-in tariff, which had been credited with attracting investments in PV systems [30], is losing relevance. Thus, the German PV market is becoming more similar to the markets of other countries raising the question: What can stimulate future PV adoption in Germany and elsewhere?

1.1. Adoption of innovation

The adoption of PV systems has been researched in different settings and by using various methods – of which we will present a selection. For an overview of factors determining innovation adoption in general we recommend Rogers' *Diffusion of Innovations* [35].

In California, for example, PV system diffusion in one's street and zip code area predicted further adoption [7], showing that the decision to adopt is subject to peer behavior. Not only does peer behavior offer social learning possibilities, it also sets a norm.

In Hong Kong, the barriers in the adoption of PV systems were high purchase price, long payback periods, inadequate infrastructure, and lack of incentives [45]. Apart from affordability, respondents remarked that grid operators should be obliged to feed the power produced into the grid. Zhang and colleagues (2012) emphasize the role of legislation in incentivizing, but also regulating the market, thus providing security for the investors.

In the Netherlands, a lack in PV adoption was reported even though "grants covered about 90% of the costs of a PV system", showing that financial incentives are not sufficient to promote adoption ([24], p. 1936). Jager [24] stressed the importance of campaigns and forums for discussion to inform potential adopters of the benefits of PV adoption and to reduce the perception of barriers.

In Austria, environmental protection motives, although prevalent among farmers and "reported to be very important in the [PV adoption] decision making process", failed to predict PV system adoption among said farmers ([9], p. 99). To many, the involvement of the trusted *cooperative society of farmers* (Maschinenring) and role models who had already adopted PV systems, offered the security needed to decide upon this large investment.

From a project developer's point of view, investments in large-scale PV systems were mainly dependent on the feed-in tariff and the policy risk, which both differ between European nations [29]. It was found that policy risk translates into monetary costs, as does the duration of administrative processes. Stable political conditions and fast approvals or rejections of PV project proposals can therefore compensate for lower feed-in tariffs.

Outside the realm of PV system adoption, studies on the adoption of solar thermal systems, combined heat and power systems, and even the adoption of energy-saving behavior produced results, which were useful for the present study. Solar thermal systems served as a status symbol for homeowners in Germany [43]. A desire to become energy independent was one motive to take part in a field test of combined heat and power systems [18]. Energy saving behavior could be increased by informing homeowners about average energy consumption in one's neighborhood, but not by informing about the environmental or financial benefits of saving energy [32]. Evidently, pro-environmental behavior and product purchase can be motivated by non-environmental motives.

All in all, the adoption of PV systems is not solely dependent on its environmental benefit, or its price. Policy, infrastructure, incentives, knowledge of the subject matter, and the social context also play a role and need to be considered. In the present study we aimed at integrating these findings and empirically test the claims.

1.2. Predicting purchase behavior

Asking homeowners what it would take for them to purchase a PV system is easy, whereas getting useful answers to this question is difficult, for multiple reasons (see Ref. [42], for an overview): There are many options to improve PV systems as these systems have many attributes. On the one hand, PV systems are designed to save fossil fuels by converting solar radiation into electricity. On the other hand, PV systems are expensive and their production is energy intensive. As none of these attributes is primary, it is difficult to identify what attributes need to be changed to make PV systems more attractive in general (cf. [41]).

Improving one attribute of PV systems might not change homeowners' intentions to purchase the system because objective specifications do not directly translate into subjective perceptions (cf. [14]).

Furthermore, people are often unaware of (or unwilling to admit) what affects their behavior. In a study on energy-saving behavior, participants stated they would save energy for financial and environmental reasons (cf. [32]). However, information about financial or environmental benefits mailed to households did not reduce energy consumption, whereas the mere presentation of average energy consumption within their own community — the *norm* — did.

Social desirability, the tendency to reply as expected (by society or the interviewer) also affects data collection. This may result for instance in over-emphasis of environmental protection as the reported reason for behavior change or adoption of innovation (cf. [44]).

With these potential pitfalls in mind, we did not only ask homeowners for motives to purchase PV systems, but also collected data on how various attributes of PV systems were being perceived. Based on the perceptions and using psychological behavior models, we statistically inferred what factors influence attitudes and purchase intention concerning PV. We then compared these factors to the self-reported motives for PV adoption.

1.2.1. Theory of Planned Behavior

Due to the high price, involved effort, and uncertainties in outcomes, a PV system purchase can be considered a complex behavior. Nonetheless, it is a behavior that can be analyzed using standard psychological models. We started out with the *Theory of Planned Behavior* (TPB [1]) as our prediction model, which we extended by adding factors specific to the perception of various attributes of PV systems.

The TPB [1] is one of the most widely used behavior prediction models in psychological research (cf. [2]), with applications in various realms such as environmental behavior [39], purchasing [34], and financial investment decisions [15].

The TPB posits that *behavior* is preceded by a *behavioral intention*, which is in turn determined by the *attitude*, *subjective norm*, and *perceived behavioral control* — see Fig. 1.

The *attitude* is the result of a general appraisal of a behavior [1]. It depends on the personal conviction that a behavior will have certain consequences and the expected probability and evaluation of these consequences. The appraisal may result in approval or disapproval of the behavior based on the individual's perception of utility associated with it. Section 1.2.2 contains the potential precursors of attitude towards PV.

According to Ajzen [1], the *subjective norm* is the perceived social pressure that demands a certain behavior. It consists of both a descriptive and an injunctive norm. The descriptive norm is the perceived peer behavior, whereas the injunctive norm is the perceived expectations from peers. Together, the perceptions of what the reference group does and what behavior is expected from us, lead to the formation of a norm. People are more or less inclined to adhere to the norm depending on how important the reference group is to them. For instance, it was shown that the initial adoption of PV systems in one's community leads to higher future adoption rates among members of the community [7,24,35].

The *perceived behavioral control* is the individual's belief in his or her ability to show the behavior in question [1]. If a person does not believe to be capable of performing a behavior, no behavioral intention will be formed. The less resources, such as time, money, or knowledge, a person believes to have, the lower the perceived behavioral control of this person will be. In the case of PV, a homeowner needs to be in control of, for example, a suitable roof, and resources to finance a PV system. These factors were also reported to be the main barriers in the PV adoption process (cf. [25,45]).

Due to constraints in the observation of actual purchasing behavior, we concentrated on the behavioral intention, i.e. purchase intention. Although there remains a gap between intention and behavior [20], knowing intentions is valuable because the execution of the behavior is more likely the stronger the intention is [1].

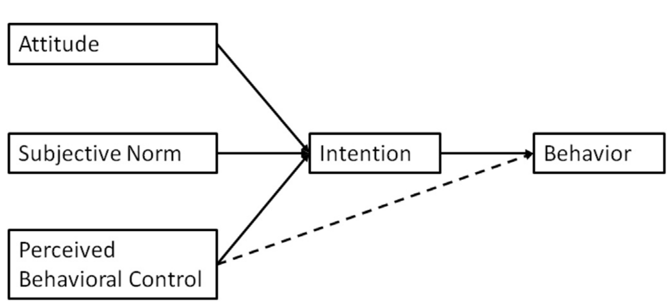

Fig. 1. The Theory of Planned Behavior by Ajzen [1].

1.2.2. Precursors of attitude towards PV

Innovations are adopted when a relative advantage is expected from them, be it financial profit or social prestige for example [35]. Thus, we expanded the TPB by adding five specific benefits (potential relative advantages) and one overall cost factor to explain the attitude a person holds towards PV. By collecting data on perceptions rather than motives, we wanted to avoid socially desirable answers.

PV system purchase is not only environmentally driven; non-environmental concerns may play a role [28]. The specific benefits we chose were (1) environmental, (2) economic, (3) autarky, (4) financial, and (5) social status benefits. The underlying motives of these benefits are either collective (1 & 2), resulting in a benefit for the community, or they are individual (3–5), resulting in a benefit for the individual homeowner only. We also added (6) perceived overall cost to our model because cost is a primary attribute of PV systems [41]. The model is displayed in Fig. 2.

1.2.2.1. Collective benefits. PV systems potentially yield positive outcomes for everybody sharing the environment [4]. The same pertains for the economic benefit, which accrues for everybody within the nation by increasing domestic production while reducing energy imports and the adverse effects on the economy through pollution [26].

1.2.2.2. Individual benefits and costs. Motivation to invest in a PV system also stems from benefits the individuals expect for themselves. The autarky benefit is concerned with individual energy independence for the homeowner gained through PV (cf. [18]). Although homeowners with a PV system still depend on the grid, they nonetheless associate the production of electricity with independence [24,25]. The financial benefit means either profit through the sale of electricity, or savings in utility bills through own-consumption. Related to but different from the subjective norm (see Section 1.2.1), the social status benefit is concerned with improving one's standing in the community by exceeding the norm — i.e. sticking out in a positive way. As Rogers ([35], p. 215) put it: "Undoubtedly one of the important motivations for almost any individual to adopt an innovation is the desire to gain social status." The subjective norm in contrast is concerned with adhering to a norm — i.e. not sticking out in a negative way (cf. [32]).

Perceived overall cost consists of monetary and non-monetary costs, i.e. efforts and risks associated with PV systems [29,30].

We collected data on how beneficial and costly homeowners perceive PV systems to be because the objective costs and benefits of PV systems do not guide behavior; the subjective perceptions of these do.

1.3. Research questions

With the current study, we aimed to identify how homeowners' perceptions of PV systems affect their intention to purchase such a

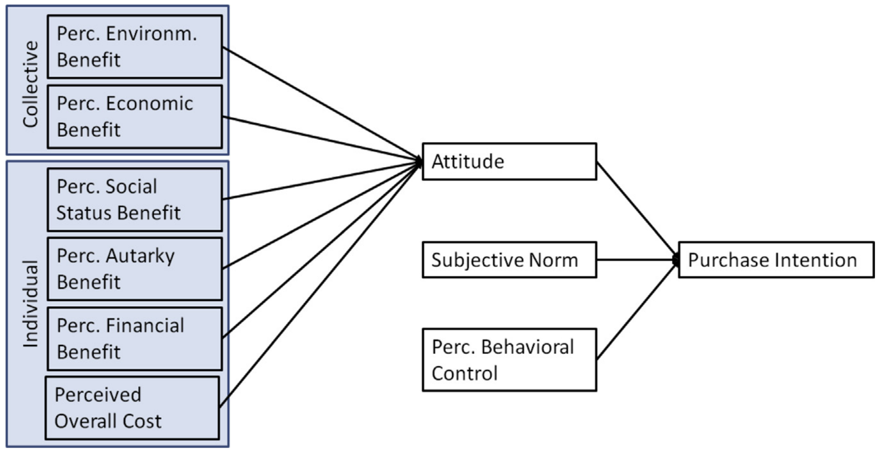

Fig. 2. PV purchase prediction model based on the Theory of Planned Behavior [1] extended to include potential precursors of attitude, which are either individual or collective.

system. Based on the Theory of Planned Behavior [1], we assessed the relative weights of attitude, subjective norm, and perceived behavioral control regarding the intention to purchase a PV system. Next, we determined the relevance of perceived benefits and costs of PV systems for the attitude towards PV. We aimed to find an answer to the question "Why do homeowners want a PV system?" by combining standard psychological prediction models with aspects specific to PV purchase.

2. Material and methods

Sample: 200 homeowners (77 female), who did not own a PV system, completed our online-survey in February 2013. Their mean age was 43 years ($SD = 9.8$). Monthly income was not disclosed by 13% of our participants. Of the remaining, 12.5% made up to 2000€, 21.5% up to 3000€, 29.5% up to 4000€, 13% up to 5000€, and 10.5% made more than 5000€. 41.5% lived in rural areas, whereas 32.5% were small-, and 26.5% were big-city dwellers. Participants were recruited and financially compensated via a market research company.

Procedure: Participants received an email containing a link to the online-questionnaire. All materials were presented to participants in German. In the beginning, participants read a paragraph on PV systems, their history, and workings – as not to confuse PV with solar thermal systems. The questionnaire continued with assessing perceptions and beliefs regarding PV systems as follows.

Measurements: The questionnaire was standardized with a predominantly closed answer format. The items measured participants' perceptions of and beliefs about PV systems on a 6-point scale (1: *does not apply* to 6: *fully applies*). It is indicated in the following paragraphs if another scale or answer format was used. See Tables 1 and 2 for an overview.

Purchase Intention constituted the main dependent variable. Participants indicated their intention by agreement to the statement "I plan to install a PV system within 3 years".

Attitude was comprised of 3 items ($\alpha = .92$) covering expected utility, rationality ("… a PV system is a sensible decision"), and the hedonic value of a PV system (cf. [1]).

Subjective Norm was comprised of 7 items ($\alpha = .91$), three of which concerned the descriptive norm, i.e. behavior of peers (e.g. "Many people in my community own a PV system"), and four the injunctive norm, i.e. felt obligation (e.g. "People expect me to install a PV system") (cf. [1]).

Perceived Behavioral Control was comprised of 5 items ($\alpha = .58$) concerned with the homeowner's ability to purchase a PV system, e.g. the suitability of location, roof, and financial situation (e.g. "Financing a PV system is possible for me") (cf. [1]).

Perceived Overall Costs was comprised of 3 items ($\alpha = .78$) covering the expected financial costs, risks, and efforts of installing a PV system (e.g. "I find a PV system harbors too many risks").

Perceived Specific Benefits were measured with sub-scales for perceived environmental ($\alpha = .89$; e.g. "I find, with a PV system I protect the environment"), economic ($\alpha = .90$), autarky ($\alpha = .84$), financial ($\alpha = .87$), and social status ($\alpha = .87$) benefits. These sub-scales were tested in a pilot study [25].

Willingness to Adopt was measured by agreement to the statement "I would like to install a PV system" and participants indicated their *willingness to pay* by stating the price they would be willing to pay for a PV system.

Explicit Purchase Motives were measured by agreement to statements (e.g. "Environmental protection is an argument in favor of a PV system"). The statements covered the motives

Table 1
Sub-scale and item overview for purchase intention, attitude, subjective norm, and perceived behavioral control.

Sub-scale	*M*	*SD*
Purchase intention		
I plan to install a PV system within the next 3 years	2.51	1.54
Attitude ($\alpha = .92$)	3.81	1.29
I find a PV system gives me a good feeling	3.77	1.35
…a PV system is a sensible decision for me	3.69	1.43
…a PV system is very useful to me	3.96	1.41
Subjective norm ($\alpha = .91$)	2.11	1.05
Many people who are important to me would find it good if I installed a PV system	2.48	1.57
Many people in my community would find it good if I installed a PV system	2.47	1.42
People expect me to install a PV system	1.49	1.01
I feel obligated to install a PV system	1.70	1.21
Many people who are important to me own a PV system	1.92	1.30
For people in my situation it is common to install a PV system	2.05	1.32
Many people in my community own a PV system	2.65	1.37
Perceived behavioral control ($\alpha = .58$)	4.63	.99
My house is suitable for the installation of a PV system (not shaded by trees, chimneys, other buildings etc.)	4.65	1.64
Financing a PV system is possible for me	3.62	1.87
I could install a PV system if I wanted to	4.50	1.75
Getting a permit to install a PV system is possible (no historic building)	4.76	1.69
I can decide what happens on my rooftop	5.62	.99

Notes: $N = 200$; 6-point scale from 1: *does not apply* to 6: *fully applies*.

Table 2
Sub-scale and item overview for the predictors of attitude.

Sub-scale	*M*	*SD*
Environmental ($\alpha = .89$)	4.47	1.13
I find with a PV system I protect the environment	4.63	1.25
…with a PV system I improve air quality	4.22	1.37
…the operation of a PV system is environmentally friendly	4.69	1.18
…I save natural resources with a PV system	4.34	1.39
Economic ($\alpha = .90$)	3.95	1.15
I find with a PV system I promote craftsmanship in Germany	4.18	1.22
…PV systems are an important export good for the German economy	3.87	1.48
…with a PV system I take part in the creation and securing of jobs in Germany	3.83	1.36
…with a PV system I support Germany as a Research and Development location	4.02	1.38
Social ($\alpha = .87$)	3.56	1.11
I find a PV system shows that I accept social responsibility	3.68	1.50
…my friends and family like PV systems	3.73	1.45
…PV system owners have a higher social status	2.96	1.45
…a PV system on my roof will be well liked in my community	3.73	1.37
…a PV system will improve my standing in the community	3.10	1.35
…a PV system shows that I am concerned about the environment	4.14	1.37
Financial ($\alpha = .87$)	3.71	1.12
I find a PV system serves as a financial provision for old age	3.59	1.43
…a PV system is a secure financial investment	3.67	1.35
…with a PV system I can produce the amount of electricity I need	3.94	1.42
…a PV system is profitable	3.66	1.31
…the initial cost will be recouped	3.70	1.39
Autarky ($\alpha = .84$)	4.31	1.14
I find I can compensate for rising electricity prices with a PV system	4.21	1.48
…a PV system allows me to secure part of my energy provision	4.91	1.16
…a PV system gives me more control over my electricity provision	4.10	1.37
…a PV system enables me to become independent of energy providers	4.01	1.49
Perceived overall costs ($\alpha = .78$)	3.56	1.17
I find a PV system harbors too many risks	3.10	1.41
…the costs attached to PV systems are too high	4.26	1.40
…a PV system demands too much effort from me	3.32	1.42

Notes: $N = 200$.

environmental protection, economic development of Germany, individual energy independence, financial profit, and social status.

Analysis: Path analysis was employed using AMOS (IBM SPSS Statistics 20).

3. Results

Purchase intentions among the participants were low, considering only 10 of the 200 participants stated they were planning "to install a PV system within 3 years" (value of 6 on a 6-point scale) – see Table 4 for a complete distribution. Attitudes were positive on average ($M = 3.81$; $SD = 1.29$). Subjective norms as perceived by homeowners were weak ($M = 2.11$; $SD = 1.05$), whereas perceived behavioral control was high ($M = 4.63$; $SD = .99$) – see Table 1.

3.1. Model fit

The path analysis showed a good model fit (GFI = .95; SRMR = .054; RMSEA = .096; $\chi^2/df = 2.84$; $df = 19$). To increase the fit, we allowed for a covariation of the constructs subjective norm and perceived social status benefit, as they both concern one's standing in the community in different ways. For a full display of the model estimates, see Fig. 3.

3.2. Prediction of purchase intention

In accordance with our model, a large portion of the variance of purchase intention ($R^2 = .42$) was explained by the subjective norm ($\beta = .37$), attitude ($\beta = .35$), and perceived behavioral control ($\beta = .17$), the latter playing a minor role in comparison. In other words, the more people in the reference group appear to adopt a PV system and the more positive one appraises PV systems, the higher the intention to purchase one – provided the homeowner feels capable of purchasing.

3.3. Prediction of attitude

More than two thirds of the variance of attitude towards PV ($R^2 = .68$) were explained by perceived social status ($\beta = .28$), autarky ($\beta = .25$), financial ($\beta = .20$), and environmental ($\beta = .15$) benefits on the one hand and the perceived overall cost ($\beta = -.18$) on the other.

Perceived individual benefits were crucial for the prediction of attitude towards PV. The more homeowners perceived PV systems to increase their social status, autarky, and financial profit, and the lower the perceived overall cost associated with PV, the more positive their attitude towards PV systems was.

Perceived environmental benefit ($\beta = .15$) did explain variance in attitude, although weaker compared to the individual motives. The perceived economic benefit of PV systems played no role in explaining variance in attitude ($\beta = .02$).

3.4. Purchase motives expressed by participants

There was a discrepancy between statistically inferred precursors of attitude towards PV systems (see sections above) and the purchase motives expressed by our participants. We presented five motives for PV system purchase, analogous to the sub-scales that measured the five perceived benefits, and asked our participants to assess the relevance of each. On average, autarky was ranked first and social motives came in last – see Table 3 for an overview.

Table 3
Self-reported relevance of motives to purchase a PV system.

Rank	Purchase motive	*M*	*SD*
1	Autarky	4.75	1.40
2	Environmental	4.40	1.50
3	Financial	3.78	1.55
4	Economy	3.53	1.47
5	Social	2.89	1.68

Notes: $N = 200$, 1: *does not apply* to 6: *fully applies*.

3.5. Willingness to adopt and pay

In addition to participants' PV system purchase intention that was low, we inquired about their willingness to adopt a PV system using the item "I would like to install a PV system". One in four (24%) affirmed this statement by assessing a value of 6 on a 6-point. Table 4 displays the full distribution. We found no correlation of willingness to adopt with age ($r = -.07$; $p = .32$) or income ($r = -.09$; $p = .26$). However, we found a negative correlation between purchase intention and age ($r = -.22$; $p = .002$), but no correlation with income ($r = .03$; $p = .67$).

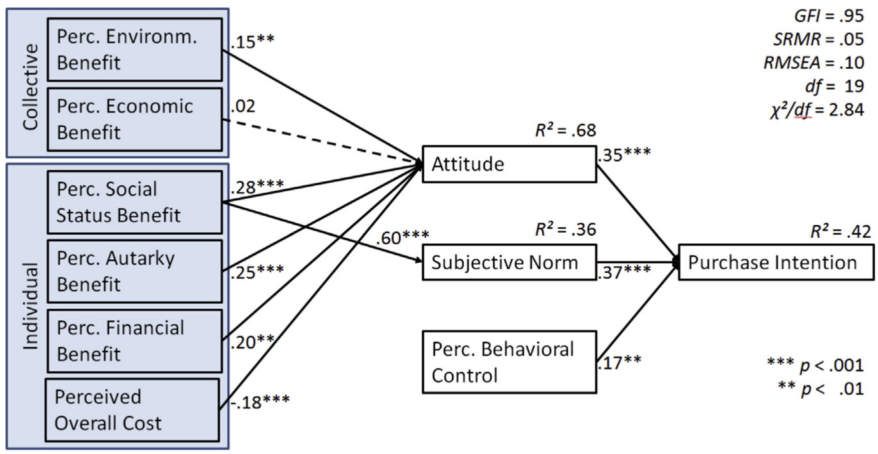

Fig. 3. Model estimates based on path analysis for the prediction of purchase intention and attitude towards PV. *Notes*: correlations, as well as error terms are not displayed for reasons of better legibility. Regression weights are standardized β-weights.

Table 4
Willingness to adopt compared to intention to purchase a PV system.

	Willingness to adopt "I would like to install a PV system."		Purchase intention "I plan to install a PV system within 3 years."	
	n	%	*n*	%
1 *does not apply*	22	11.0	75	37.5
2	25	12.5	36	18.0
3	22	11.0	38	19.0
4	32	16.0	24	12.0
5	51	25.5	17	8.5
6 *fully applies*	48	24.0	10	5.0

Notes: $N = 200$.

Willingness to pay for PV systems was also given, but very heterogeneous among participants. One third of our sample (33%) was not willing to pay for a PV system. There were multiple peaks in the distribution of purchase prices the participants were willing to pay, most prominently at 5000€ (12.5% of our sample) and 10000€ (13.5%). For a better overview, we aggregated the data in increments of 5000€ – see Table 5 for details. The older the participants were, the lower their willingness to pay was ($r = -.199$; $p = .005$). There was no correlation between income and willingness to pay neither including all participants ($r = -.01$; $p = .89$) nor including only participants willing to pay for a PV system ($r = -.03$; $p = .73$).

4. Discussion

We found factors that influence homeowners' attitudes towards PV systems and purchase intentions. This allows conclusions about how to promote further adoption, be it by increasing homeowners' benefits or by removing adoption barriers. Although the observation of actual purchase behavior was beyond the scope of this study, the explanation of purchase intentions as the precursor of actual purchase behavior offers valuable insights into homeowners' thoughts on PV adoption.

Table 5
Willingness to pay for a PV system.

Willingness to pay (€)	Number of indications	Percent
No willingness (0)	66	33.0
1–5000	65	32.5
5001–10000	30	15.0
10001–15000	13	6.5
15001–20000	15	7.5
>20000	11	5.5
Total	200	100.0

Notes: $N = 200$; Values in Euro – for Dollar values multiply by 1.35 (exchange rate February 2013). Free answers were aggregated in 5000€ increments for a better overview.

4.1. Predicting purchase intention

PV purchase intentions can be partially predicted and explained using the Theory of Planned Behavior [1], which takes into consideration the general appraisal (i.e. attitude) of PV systems, the behavior of peers (i.e. subjective norm), and the feeling of being able to purchase and install a PV system (i.e. perceived behavioral control). In addition we extended the Theory of Planned Behavior to explain the abstract attitude by collecting data on how homeowners perceive PV systems on various cost and benefit dimensions.

On average, attitudes towards PV systems were positive. Subjective norms, however, were weak, meaning that our participants on average neither observed a lot of PV adoption in their communities, nor did they feel socially obligated to adopt a PV system. The perceived behavioral control was high on average, which means that our participants felt capable of adopting a PV system if they wanted to.

In line with the Theory of Planned Behavior, attitudes towards PV systems partially explained purchase intentions. We dug deeper to find what the attitudes towards PV were based on – see Section 4.2.

The subjective norm was strong in predicting purchase intentions: Perceiving that the reference group adopts PV systems and sensing the expectation for oneself to do so as well, resulted in a higher intention to purchase a PV system. Perceiving low adoption rates resulted in lower purchase intentions. This effect may not only be based on social pressure, but also on opportunities to learn from role models, which reduces uncertainties [7,9]. Social influence should therefore not be underestimated as a factor in the adoption of PV systems.

The perceived behavioral control was a weaker predictor in comparison. Most homeowners reported to be capable of adopting a PV system if they wanted to. Considering that the most often reported barrier impeding PV adoption is lack of resources such as money or a suitable roof [25,45], this was not an intuitive result. This can have two reasons. First, the importance of perceived behavioral control may increase when analyses are based on data related to actual purchase behavior, instead of purchase intentions. Second, Welsch and Kühling ([43], p.171) may be right in saying “When reference persons are included, income becomes insignificant”.

4.2. Precursors of attitude

The attitude towards PV systems is an important predictor of purchase intention. However, it is an abstract concept based on non-defined utility, sensibility, and hedonic value. Thus, from the start we aimed to explain what the basis of attitude was. On six scales homeowners could assess PV systems on one cost and five benefit dimensions. We then analyzed the relationship between these perceived costs and benefits to their attitudes towards PV systems.

In our study, attitudes towards PV systems mainly depended on personal gains expected by homeowners. Our model explained two thirds of the variance in attitudes showing that homeowners in our sample were only partially environmentally-motivated in their PV purchase intention, but mainly driven by aspirations of social status, autarky, and financial profit (see also Refs. [18,43]). Perceived environmental benefit and overall cost of PV systems did play a minor role, whereas perceived economic benefit did not. This method of having homeowners assess PV systems instead of merely asking them to state purchase motives, allowed us to reduce the effect of social desirability, as evident in the high predictive value of perceived social status benefit.

Social status is an important motive in the adoption of any innovation [35]. However, when asked directly, our participants did not agree. This demonstrates the aforementioned difficulty in identifying motives of PV purchase by merely asking the potential adopter. It is apparent that especially when it comes to social status and norm implications regarding behavior, people are either unable or unwilling to assess the influence of peers or the social context in general on their own behavior (see also Ref. [32]).

The social context has an effect on behavior and even on the choice of products. The concept of *conspicuous consumption* proposes that people purchase specific products to signal their wealth and status to others [3]. This concept was expanded to *conspicuous conservation*, where these behaviors and products also benefit the environment [21]. The rationale: the more you can afford, the more resources you must have. The more visible and distinct a product is, the better it serves as a signal (see also Ref. [38]).

Autarky was identified to be a strong motive to purchase a PV system among the homeowners in our sample. Our statistical analyses showed a strong relationship between perceived autarky benefits and attitudes towards PV systems. Furthermore, homeowners explicitly named autarky as the number one motive to purchase a PV system. Autarky can be approximated using three means: increasing power production, reducing consumption, and storing surplus. Thus, homeowners may be motivated to reduce their power consumption to achieve their goal of energy independence – as every kWh saved is another step towards autarky. Batteries can efficiently store electricity produced during the day for consumption in the evening hours. We claim that the installation of batteries constitutes a step towards autarky and may make PV systems more attractive (cf. [18]).

Individual financial profit can not only be achieved through selling electricity, but also through savings by consuming the electricity produced instead of feeding it into the grid. Batteries are one way to increase consumption on site, direct use is another. There are smart appliances (e.g. washing machines) that automatically turn on when the PV system produces a lot of electricity during daytime. Charging electric vehicles (cars and scooters) can further increase the share of electricity consumed on site. Own-consumption will become a profitable option for homeowners and small businesses, even in the absence of smart appliances, batteries, or feed-in tariffs – which would mean feeding surplus electricity into the grid at market value [37].

Perceived overall cost – which comprises costs, efforts, and risks associated with PV system installations – may be reduced by lowering prices of PV modules, facilitating the administrative process (information search, forms, loans etc.), and by introducing standards. Especially standards increase reliability and predictability of products, while reducing risk (which in turn reduces costs [30]). To guide investment decisions, there is a need for an institution that tests PV module quality and awards labels (cf. [36]). For solar thermal systems this institution (*Solar Keymark*) already exists and could be emulated for PV systems.

Perceived environmental benefits were associated with attitudes towards PV systems. This association, however, was weaker than expected, although homeowners explicitly named it the second strongest motive to purchase. Social desirability may have influenced this explicit (direct) assessment of purchase motives. Nevertheless, increasing the perceived environmental benefits of PV can improve attitudes towards PV systems. This can be done by reducing the environmental harm (that stems from the production and disposal of PV systems) through recycling. In crystalline PV cells, more than 90% of the silicon and glass in modules could technically be recycled [27]. Furthermore, producing a PV module from recycled silicon reduces energy demand by 70% [6].

In our study, the perceived economic benefit for Germany did not explain variance in attitudes towards PV systems. Deeming the diffusion of PV systems as beneficial to the national job market and gross domestic product did not affect the general appraisal of PV systems. In Germany, this concept of national economic benefit may be perceived as unrelated to PV purchase intentions. However, the economic benefit may be associated with PV systems and valued more strongly by homeowners in other nations, such as the United States, where the economic benefits of renewable energies are emphasized [8].

4.3. Social desirability

There was a high acquiescence in the willingness to adopt a PV system, however, only 5 percent of the participants agreed to the stronger item on actually planning to adopt a PV system within 3 years. Considering the past diffusion of PV systems outlined in the introduction [10,11], the reported purchase intentions seem realistic.

Social factors dominated both predictions of purchase intentions and attitudes towards PV systems; the subjective norm being the strongest predictor of purchase intentions, perceived social status benefit being the strongest predictor of attitude towards PV systems. Participants rated the social motive least relevant for a PV purchase decision, whereas our path analysis results showed perceived social status benefit to be a strong predictor of attitude towards PV systems. This discrepancy between expressed purchase motives and statistically inferred motives was also found in a PV adoption study among Austrian farmers [9], and in adoption studies regarding electric vehicles and local energy systems [33]. Participants are either unaware of the strong social forces guiding their behavior or they reply in a socially desirable manner, claiming to aspire after environmental protection and presenting (or even viewing) themselves as uninterested in status. That is why we did not rely on direct, i.e. explicit, reasons reported by our participants, but also inferred motives by analyzing perceptions of PV systems and attitudes.

4.4. Willingness to adopt and pay

We found that there is a broad willingness to adopt PV systems and a basic willingness of German homeowners to also pay for PV systems (cf. [22]). One third of our sample, however, indicated to be willing to pay between 100€ and 5000€ only. Considering the many people willing to purchase, but unwilling to pay more than 5000€, offering affordable PV system bundles could serve and open up a wider customer base. These bundles should include PV modules, inverter, wiring, and installation. We do not call for cheaper modules, but for an optimized and thus more economical PV system in this lower price range.

Purchase intention, willingness to adopt, and willingness to pay, counter-intuitively, were independent of income. Purchase intention and willingness to pay were only correlated with age, whereas the more general willingness to adopt was not. The older the participants were, the less likely they were to intend to purchase a PV system and the less they were willing to pay. Older people may refrain from purchasing a PV system because it has implications for a period of 20 years.

4.5. Limitations of the current study

We recruited our participants via a market research company. As these participants were not randomly recruited, but already members of a panel, self-selection cannot be ruled out. However, all of the participants were homeowners and thus potential adopters of PV systems, whose opinions are valuable in determining what affects purchase intentions regarding PV systems.

Purchase intention was assessed by one item only. However, this was an item specific to the behavior in question (see *Principle of Compatibility* [19]). A large part of the sample was willing to adopt a PV system, whereas only ten participants (of 200) were planning to do so within 3 years. Considering the 1.3 million PV systems already installed, this is a realistic share and thus a useful item. The effect of social desirability was low, if existent at all.

An issue with assessing perceived behavioral control was the heterogeneity of the sub-scale we used to measure the construct, which resulted in low reliability. However, barriers in PV adoption are manifold and independent of each other (financial means, roof size, permits etc.), so we decided to create a broad instead of a narrow and more internally consistent scale.

5. Conclusion and policy implications

In our study, PV system purchase intentions among homeowners depended on individual gains and very strongly on the social context. Policy and PV industry can make use of these influences to increase purchase intentions, and thus adoption.

To improve attitudes, we recommend the sale of PV systems combined with energy storage and management systems. First, this will increase consumption on site and result in reduced utility bills – a financial benefit. Second, it may increase a sense of autarky among homeowners, as their dependence on electricity providers is reduced. PV or battery system installation may be coupled with training on reducing energy consumption in the household to further increase the benefit for homeowners and the environment. A collateral benefit of storing electricity is the reduced feed-in during peak hours, taking the load off the grid. In this vein, to stabilize the grid, the German Government has already put financial support of energy storage systems in place [10,11].

To reduce perceived overall cost, which includes perceived risks and effort, we propose the introduction of standards and accompanying labels. Homeowners invest time and effort in the information search and decision making. In addition there are risks due to unknown product quality. Labels can improve information search and reduce risks [36]. Reduced risk translates into predictability and reduced monetary costs [30].

Subjective norms, as they are based on perceptions, can be increased by informing homeowners about nationwide PV system adoption rates. Even if uncommon in someone's neighborhood or region, national PV adoption can contribute to the subjective norm, as direct observation of adoption is not necessary [32].

All in all, cost is only an issue in the absence of value. The primary question should not be how to reduce cost, but how to create a value to offset it. Our findings offer starting points for industry to follow both strategies. Policy should be aimed at providing security and supporting further research and development.

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