Joint Discussion Paper
Series in Economics

by the Universities of

Aachen · Gießen · Göttingen
Kassel · Marburg · Siegen

ISSN 1867-3678

No. 02-2024

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How to get photovoltaics on the roofs? Empirical evidence on the public support for a residential solar mandate in Germany

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How to get photovoltaics on the roofs? Empirical evidence on the public support for a residential solar mandate in Germany

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January 2024

This study evaluates whether a residential solar mandate in the case of roof renovation is a useful complement to economic incentives for further photovoltaics (PV) adoption. Analyzing determinants affecting PV ownership and installation intentions among single-family homeowners, as well as factors influencing support for a solar mandate and perceptions of its effectiveness, our empirical results, based on a survey of German utility customers, show that a residential solar mandate is a rather unpopular policy measure among homeowners. However, a solar mandate addresses two important factors which, according to our results, increase the willingness to install PV: firstly, the perception that the personal environment expects more PV, and secondly, an upcoming roof renovation. Both social desirability and a favorable time window can be institutionalized through a solar mandate. In terms of support for a solar mandate, we find that the perceived effectiveness of such a mandate has a strong influence on homeowner support. Perceived effectiveness, in turn, is closely related to perceived cost savings and perceived environmental benefits of PV. Based on these results, we conclude that an active information policy regarding the environmental and cost implications of PV expansion is essential to increase the acceptance of a solar mandate.

JEL classification: D12, Q42, Q48, Q58

Keywords: Photovoltaics, solar mandate, empirical analysis, public support, effectiveness

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1. Introduction

The global expansion of photovoltaics (PV) has predominantly been driven by economic incentives. As of the year 2021, about 130 countries had implemented feed-in tariffs or feed-in premiums to promote both large and small-scale renewable electricity generation (REN21, 2022). A more recent trend involves the supplementary introduction of solar mandates, which necessitate property owners to install PV systems on suitable rooftops, mostly applicable to new buildings and in some cases also to existing buildings. Typically, solar mandates are limited to specific building uses (e.g., office buildings, factory buildings, supermarkets, apartment complexes) and minimum sizes. Solar mandates have already been implemented in some European countries such as Greece, Italy, Austria, Germany, Belgium[1], and outside Europe in California (USA)[2], and in Tokyo (Japan)[3].

In Germany, photovoltaics is envisioned to play a key role in the transition of the energy system. The Renewable Energy Act (Erneuerbare-Energien-Gesetz, § 4) outlines the ambitious goal of adding 22 gigawatts (GW) of PV capacity annually, with the ultimate aim of archiving an installed capacity of 215 GW by the year 2030. Assessments of the existing building stock indicate that approximately 79 GW of PV capacity can be installed on existing residential buildings (Claußner et al., 2020). Nonetheless, a mere 11 % of residential roofs were equipped with PV systems in 2020.[4] Developing these roofs for PV use has the potential to ensure that natural areas and agricultural lands are not needed for PV generation purposes, and thereby to mitigate negative impacts of large-scale PV installations on the landscape and the environment.

At present, there is no solar mandate in place at the federal level in Germany. As stipulated in the Coalition Agreement of the current government, the introduction of such a mandate is proposed for mandatory application in new commercial buildings and as a standard requirement for residential buildings (Bundesregierung, 2021). While solar mandates have been instituted in nine out of sixteen federal states and some municipalities, only four federal states have hitherto implemented solar mandates specifically for residential buildings. The latter is a subject of considerable debate. While proponents argue that it could accelerate the expansion of photovoltaics and usefully complement existing economic incentives, critics of such a requirement fear that the associated costs could discourage roof renovations and adversely affect the acceptance of photovoltaics, thereby undermining the goals of the energy transition in general.

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[1] https://api.solarpowereurope.org/uploads/SPE_Note_Solar_Mandates_in_Europe_4103dcc90d.pdf. Last accessed on 25 May 25 2023.

[2] https://www.energy.ca.gov/sites/default/files/2022-12/CEC-400-2022-010_CMF.pdf, Last accessed on 13 July 2023.

[3] https://www.pv-magazine.com/2022/12/16/tokyo-introduces-mandatory-pv-requirements-for-new-buildings-homes/. Last accessed on 25 May 2023.

[4] https://www.eupd-research.com/89-prozent-des-solarpotenzials-noch-ungenutzt/. Last accessed on 26 May 2023.

The objective of our analysis is to evaluate whether a residential solar mandate in the event of roof renovation is a useful complement to economic incentives for further PV adoption. To this end, we first analyze the determinants that influence PV ownership (Model 1) and PV installation intentions (Model 2) of single-family homeowners. We then examine the factors that explain homeowners' support for a residential solar mandate (Model 3) and their perceptions of its effectiveness (Model 4). The empirical results in this study are based on data from a survey conducted among electricity customers of an energy supplier in the metropolitan area of Cologne, Germany. Notably, there was no residential solar mandate in effect in the study area at the time of the survey.

We find that a residential solar mandate is a rather unpopular policy measure among homeowners. Nevertheless, it addresses two important factors that increase the willingness to install a PV system: A solar mandate institutionalizes the social desirability of roof use for the generation of PV electricity and thus addresses an important factor that explains the willingness to install in our analysis, namely the perception that the personal environment expects further PV adoption. In addition, we show that an upcoming roof renovation increases the likelihood of a high intention to install PV. This window of opportunity could be better exploited with a residential solar mandate. In addition, our analysis shows that the belief that a PV system is a good investment is very important for the ownership of such a system. We conclude that it does not exempt the legislature from regulating market conditions in such a way that surplus electricity that cannot be used in households is appropriately remunerated - whether through private aggregators or feed-in tariffs, for example. The results of our analysis should also raise awareness of the fact that a solar mandate harbors the risk that homeowners may be financially overburdened in the event of a roof renovation. Regarding support for a solar mandate, we see that the perceived effectiveness of such a mandate has a strong influence on homeowners' support. In turn, perceived effectiveness is closely related to the perceived cost savings and perceived environmental benefits of photovoltaics. Based on these findings, we believe that an active information policy regarding the environmental and cost implications of PV expansion is essential to increase the acceptance of a solar mandate.

Our study confirms results from previous research on PV adoption (e.g., Best and Chareunsy, 2022; Ruokamo et al., 2023; Wolske et al., 2017), which identified a relevant set of attitudinal variables toward photovoltaics. Furthermore, we show that controlling for risk preferences, patience, key building characteristics, and disposable financial assets improves the understanding of solar PV adoption decisions. With regard to research on the public acceptance of climate policy measures (e.g., Bergquist et al., 2022; Eliasson and Jonsson, 2011; Lam, 2015), we find that a separate analysis of support and perceived effectiveness contributes to a better understanding of the role of technology-related factors, socio-psychological factors and political orientation.

The article is structured as follows. Section 2 first reviews the relevant literature on PV investment decisions and climate policy acceptance, on which our analysis is based. The sample structure, variables, and methodology are explained in section 3. The results are presented in section 4. Section 5 concludes with a discussion of the results and a brief outlook on future research.

2. Literature review

The research question guiding our study is based on two distinct research strands in empirical economics: research on household investment behavior and research on the public acceptance of climate policies. With respect to private investment in PV systems, our study is based on the following findings: In their comprehensive literature review, Alipour et al. (2020) illustrate the complexity associated with investment decisions in photovoltaics. In total, the authors identify 333 potentially relevant factors that can explain attitudes toward PV, general willingness to invest, specific investment intentions, and PV adoption. To narrow down the set of relevant explanatory factors, we rely mainly on factors identified in studies on the real investment behavior of homeowners (e.g., Jacksohn et al., 2019; Arnold et al., 2022; Best and Chareunsy, 2022; Ruokamo et al., 2023) and on homeowners' intentions to invest in photovoltaics (e.g., Korcaj et al., 2015; Wolske et al., 2017; Petrovich et al., 2019; Ruokamo et al., 2023; Schelly and Letzelter, 2020).

The individual perception of economic benefits or relative advantages of a PV installation has been found to be particularly important (Best et al., 2019; Jacksohn et al., 2019; Klein and Deissenroth, 2017; Korcaj et al., 2015). Environmental concerns and technology affinity play a role, however it is not clear to which extent (Jacksohn et al., 2019; Ruokamo et al., 2023; Schelly and Letzelter, 2020; Wolske et al., 2017). Peer effects and social norms have been shown to foster investment in photovoltaics (Bollinger and Gillingham, 2012; Petrovich et al., 2019) as well as trust in PV companies (Schelly and Letzelter, 2020; Wolske et al., 2017). Furthermore, existing studies find that aesthetic perceptions of PV panels play an important role to expand the consumer base for rooftop photovoltaics (Corbett et al., 2022; Hille et al., 2018; Petrovich et al., 2019). Building characteristics have been rather approximated in existing empirical analysis (e.g., number of bedrooms, square footage) and indicate that bigger homes have more likely a PV system installed than smaller ones (Arnold et al., 2022; Best et al., 2019; Jacksohn et al., 2019; Ruokamo et al., 2023). High electricity expenses (Best et al., 2019) as well as the use of an electric vehicle (Lyu, 2023) or an heat pump (Ruokamo et al., 2023) have been shown to impact the decision to purchase PV systems. Finally, evidence on the role of traditional sociodemographic indicators like age, gender, education and income is mixed (Best and Chareunsy, 2022; Korcaj et al., 2015; Ruokamo et al., 2023). Best et al. (2019) and Petrovich et al. (2019) emphasize the role of capital constraints and wealth.

With regard to climate policies, a solar mandate might be seen as a typical regulatory push measure with high upfront costs and a high degree of coercion for the individual. However, the real cost intensity depends on other regulations, in Germany on the Renewable Energy Act, which, at least so far, has followed the rationale that an investment in a PV system should generate a modest return over a period of 20 years. In this context, we assume that distributive effects and thus perceptions of fairness are not directly related to a solar mandate, but to the Renewable Energy Act. The degree of coercion depends on the specific design of the solar mandate (e.g., does it set specific requirements for roof utilization, how is compliance controlled, how is non-compliance sanctioned).

In conceptualizing our study, we build on the findings of three overview studies. The first major overview study was conducted by Drews and van den Bergh (2015). They identify three general categories for factors influencing climate policy support: first, socio-psychological factors and climate change perceptions including individual values, political orientation and environmental awareness; second, the design of climate policies including the perceived effectiveness and fairness; and third, contextual factors such as social norms, the wider economic and geographical context. Bumann (2021) arrives at a similar assessment in her evaluation of empirical studies using survey data as input. She concludes "that public support for climate policies is rather a matter of climate change beliefs and party identification, and not primarily a question of socio-demographic background." Both overview studies, however, only indicate tendencies about the relevance of explanatory factors. A study by Bergquist et al. (2022) used econometric methods in a meta-analysis to quantitatively estimate the relevance of different explaining factors. They examined 15 determinants by synthesizing 51 studies across 33 countries and conclude that among all factors, the perceived fairness and effectiveness of a climate policy are the most important determinants. Determinants addressing climate change evaluations have medium impact followed by psychological factors including self-transcendent values, trust in relevant institutions and political identification. Demographic variables showed only weak or close to zero effects (Bergquist et al., 2022).

3. Data and methodology

3.1 Survey design and data collection

Survey items were jointly developed with input from marketing and customer relations practitioners associated with three collaborating German utilities. Subsequently, a pilot study was conducted with 481 customers of a regional utility in Kassel, Germany, between November 2022 and March 2023. Following the analysis of the pilot study results, the questionnaire underwent a thorough review and revision. The final data used in the analysis is derived from a convenience sample of an online survey conducted by the University of Kassel in cooperation with a regional utility between May and July 2023. To supplement the survey data, billed electricity consumption information from the utility for the year 2022 was included in the analysis. The survey targeted customers in the city of Cologne and the surrounding area, a rather urbanized region in the German federal state of North Rhine-Westphalia. In total, 130,281 customers of the utility were invited to participate by personal e-mail.[5] Written consent was obtained from all participants before the questionnaire was started, and participants were made aware that their participation in the survey is completely anonymous and voluntary.

In total. 4,729 respondents completed the questionnaire, of whom 2,029 lived in rental housing (42.9 %), 1,779 lived in their own house (37.6 %), 871 lived in their own apartment (18.4 %), and 50 lived in other types of housing (1.1 %). For the purpose of our analysis, we focus on homeowners because we believe they would be most directly affected by a solar mandate. Due to missing responses to several optional questions, the final data set was reduced to a total of 1,334 homeowners, of which 368 (28 %) owned a PV system and 966 (72 %) did not. The sample specifically includes household decision-makers, defined as individuals with at least some role in purchasing and investment decisions within the household. The representativeness of our sample with respect to homeowners in Germany can only be approximated. A comparison with data from the 2022 Mikrozensus, the largest German household survey in official statistics, shows that single-person households, low-income households, and respondents between the ages of 25 and 45 years are underrepresented in our sample (see Appendix 1).

3.2 Variables

The variables selected for our analysis were adapted from various studies and supplemented with some variables based on the advice of cooperating practitioners (see Table 1).

[5] The customers had to have an e-mail address on file and have been customers for at least one year. Excluded were deviating bill recipients (i.e., customers living elsewhere), customers in dunning process or with complaints in the last year as well as VIP customers and employees. According to the reporting of the mail program, 121,708 of the e-mails were delivered, 63,252 customers opened the mail and 7,578 clicked on the link.

Table 1: Description of dependent and explanatory variables

Variable	Definition	Adapted from
Dependent variables		
PV ownership	Dummy variable equals one if the respondent stated that a solar PV system is installed on the household's rooftop.	
Intention to install PV	Dummy variable equals one if the respondent stated that it is rather or very likely that a PV system will be installed on the household's rooftop within the next 5 years.	Best et al. (2019)
Support for solar mandate	Dummy variable equals one if the respondent answered "rather" or "very" to the question "How much do you support the legal obligation for homeowners to install a PV system in case their roof is renovated, provided that the roof is suitable for this?".	Engler et al. (2021)
Perceived effectiveness of solar mandate	Dummy variable equals one if the respondent answered "More positive than negative effects" or "Only positive effects" to the question "What effects do you expect from such a solar mandate regarding climate protection?" and zero if respondent answered "Only negative effects", "More negative than positive effects", "Neither positive nor negative effects".	Kallbekken and Sælen (2011)
Personal attitudes toward photovoltaics		
Perceived return advantage	Dummy variable equals one if the respondent rather or totally agreed with the statement "By investing in a PV system, a good return can be achieved.".	Wolske et al. (2017)
Perceived cost hedging	Dummy variable equals one if the respondent rather or totally agreed with the statement "A PV system can protect against rising electricity costs.".	Wolske et al. (2017)
Perceived environmental benefit	Dummy variable equals one if the respondent rather or totally agreed with the statement "A PV system contributes to environmental and climate protection.".	Franceschinis et al. (2017)
Perceived autarky effect	Dummy variable equals one if the respondent rather or totally agreed with the statement "A PV system makes you less dependent on energy companies.".	Korcaj et al. (2015)
Trust in PV installer	Dummy variable equals one if the respondent rather or totally agreed with the statement "PV installers are trustworthy.".	Wolske et al. (2017)
Aesthetic perception	Dummy variable equals one if the respondent rather or totally agreed with the statement "Roofs with PV systems are just as nice as roofs without.".	Petrovich et al. (2019)
Social desirability of PV expansion	Dummy variable equals one if the respondent rather or totally agreed with the statement "My environment (e.g., family, friends and acquaintances) expects more PV systems to be installed.".	Korcaj et al. (2015) Curtius et al. (2018)
PV in neighborhood	Dummy variable equals one if respondent answered "'A minority", "About half", "A majority" or "All" and zero if respondent answered "None" to the question "How many of your neighboring houses have a PV system on the roof?".	Own
Building characteristics and electricity use		
Roof towards south	Dummy variable equals one if the roof is directed to the south.	Own
Roof renovation required	Dummy variable equals one if the respondent stated that a roof renovation is likely required within the next 10 years and zero if the respondent answered "Over 10 to 20 years", "In over 20 years", "Don't know".	Own

Heat pump	Dummy variable equals one if the respondent stated the use of a heat pump for room heating purposes.	Own
Electric vehicle	Dummy variable equals one if the respondent stated the use of an electric vehicle.	Own
Grid power purchase above median	Dummy variable equals one if a households billed electricity consumption in 2022 was higher than the sample median of 2,727 kWh.	Own
Control variables		
Risk taking	Dummy variable equals one if the respondent answered “rather willing to take risks” or “very willing to take risks” to the question “How willing are you personally to take risks?	Falk et al. (2018)
Patience	Dummy variable equals one if the respondent answered “rather willing” or “very willing” to the question “How much are you willing to give up something that benefits you today in order to benefit more in the future?”.	Falk et al. (2018)
Altruism	Dummy variable equals one if the respondent answered “rather willing” or “very willing” to the question “How much are you willing to give to a good cause without expecting anything in return?”.	Falk et al. (2018)
Environmental awareness	Shortened NEP-scale. Index variable that ranges between six and thirty, with higher values indicating a higher degree of environmental awareness. To construct this measure, the respondents were asked to indicate to what extent they agree with the following six statements: “Humans have the right to modify the natural environment to suit their needs,” “Humans are severely abusing the planet,” “Plants and animals have the same right to exist as humans,” “Nature is strong enough to cope with the impacts of modern industrial nations,” “Humans were meant to rule over the rest of nature,” and “The balance of nature is very delicate and easily upset.”	Ziegler (2017)
Conservative	Dummy variable equals one if the respondent rather or totally agreed with the statement “I identify myself with conservatively oriented politics”.	Ziegler (2017)
Liberal	Dummy variable equals one if the respondent rather or totally agreed with the statement “I identify myself with liberally oriented politics”.	Ziegler (2017)
Social	Dummy variable equals one if the respondent rather or totally agreed with the statement “I identify myself with liberally oriented politics”.	Ziegler (2017)
Ecological	Dummy variable equals one if the respondent rather or totally agreed with the statement “I identify myself with ecologically oriented politics”.	Ziegler (2017)
Age	The respondent’s age in years.	
Female	Dummy variable equals one if the respondent identifies as a woman.	
Academic education	Dummy variable equals one if the respondent’s highest level of education is at least an advanced technical college certificate or a high school diploma.	
Household size	Number of persons living in the household	
Equivalized net household income (1,000)	Weighted net monthly household income with the weights 1 for the first adult, 0.5 for every additional adult and child over 14 years of age, and 0.3 for every child under 14 years of age, divided by 1,000.	Feldman (2010) Horsfield (2014)
EUR 30,000 available without credit	Dummy variable equals one if the respondent answered “yes” to the question “Are you currently able to make a purchase or investment of EUR 30,000 without taking out a loan?”.	Petrovich et al. (2019)

The following considerations guided the final selection of variables. Our dependent variables are PV ownership, the intention to install PV, the support for a solar mandate and the perception of the environmental effectiveness of such a mandate. The literature offers a number of more or less specific ways to operationalize investment intentions in photovoltaics. Compared to other studies that asked respondents in more general terms whether they had considered purchasing a PV system (Ruokamo et al., 2023) or whether they were interested in talking to a PV installer (Wolske et al., 2017), we asked respondents to indicate the likelihood of installing a PV system within the next five years (*intention to install PV*). Since we are interested in the interplay between ongoing investment dynamics and a residential solar mandate, we have chosen to ask for five years which is a much longer time period than the specified time period of 12 months in a comparable study by Best et al. (2019). The variable *support for solar mandate* is based on comparable items in a study of climate policy acceptance by Engler et al. (2021), the variable *perceived effectiveness of solar mandate* is based on Kallbekken and Sælen (2011).

Our main explaining variables cover two categories: First, personal attitudes toward phovoltaics and second, building characteristics and electricity use. The first category comprises seven variables: the first two variables address economic aspects of rooftop PV, namely, to what extent the purchase of a PV system is seen as a worthwhile financial investment (*perceived return advantage*) and to what extent it is believed that owning a PV system can protect against rising electricity costs (*perceived cost hedging*). The third variable addresses the perceived positive impact on the environment and the climate (*perceived environmental benefit*). The fourth variable represents an assessment of the contribution of rooftop PV to the independence from electricity suppliers (*perceived autarky effect*). The fifth variable asks for an aesthetic evaluation of roofs with photovoltaics compared to roofs without (*aesthetic perception*). The last two variables deal with the perception of social norms: an injunctive social norm is addressed by asking to what extent the social environment of respondents expects more PV systems to be installed (*social desirability of PV expansion*), and a descriptive norm addressing the perceived status quo of the prevalence of PV systems in the neighborhood (*PV in neighborhood*).

Concerning building characteristics and energy use, we included five variables into our analysis: The orientation of the roof to the south (*roof towards south*), which due to the radiation conditions in Germany lead to greater economic efficiency of PV systems. In addition, it makes little sense to install a PV system if the roof is due for renovation in the foreseeable future. Therefore, we consider whether respondents subjectively believe that their roof will need to be renovated in the next 10 years (*roof renovation required*). Since a larger part of the electricity generated by a PV system can usually be used by the user when electricity consumption is high, we included the use of a *heat pump* and an *electric car* as well as the real grid purchase (*grid power purchase above median*) as additional explanatory variables in our models for PV ownership and the intention to install PV.

For household investment decisions related to sustainability, it has been shown to be a useful approach to control for risk-taking, patience, altruism, and environmental awareness (e.g., Engler et al., 2023; Fischer et al., 2021; Groh and Ziegler, 2022; Gutsche et al., 2021). For environmental awareness we use a shortened form of the New Environmental Paradigm (NEP) scale (Dunlap et al., 2000) as used in many econometric studies for Germany (e.g., Engler et al., 2021; Ziegler, 2021). To depict a possible influence of basic ideological attitudes, we also control for political preferences. Following Ziegler (2017), we measure the respondents' political identification using four dummy variables indicating to what extent a person identifies with conservative, liberal, social and ecological politics.

In addition to the standard sociodemographic control variables of *age*, *female*, *academic education*, *household size,* and *income,* all models include an indicator of disposable monetary assets. Based on an item used by Petrovich et al. (2019), we asked whether the person is able to make an investment in the amount of EUR 30,000, which is a comfortable budget for a typical PV and battery storage system.

3.3 Econometric models

We use four binary probit models to conduct our analysis. In our models, the marginal effects are the effect of a one-unit change in an explanatory variable on the estimated likelihood that an individual owns a PV system (Model 1), intends to install a PV system (Model 2), and supports a solar mandate (Model 3). The equivalent one-unit changes for dummy coded variables represent the discrete change effects instead of the average marginal effects. We decided to include the perceived effectiveness of a solar mandate as an explanatory variable in Model 3, because it usually has a large positive effect on the likelihood of support (e.g., Eliasson and Jonsson, 2011; Kallbekken and Sælen, 2011; Lam, 2015). In addition, we present in Model 4 the factors that influence the perceived effectiveness of the solar mandate. Robustness checks were performed with additional variables (i.e., affinity for technology interaction (ATI), urban / rural, duration of residence) and other suitable model specifications (i.e., ordered probit models, multinomial probit model, see Table A. 4 and A.5 in the Appendix) and confirmed the robustness of our results.

Because we have cross-sectional data, we can only analyze individual perceptions at one point in time. This is particularly relevant to the interpretation of the PV ownership model because it represents a decision made in the past. We are assuming that owning and using a PV system will have influenced attitudes towards photovoltaics, and that the attitudes we measured in our survey do not necessarily reflect attitudes at the time of purchase.

4. Results

4.1 Descriptive statistics

Table A.1 in the Appendix presents summary statistics of our sample, including all variables used in the econometric analysis. In the following, we provide some contextual information about our sample to facilitate the interpretation of our estimation results.

Homeowners with PV: Our sample includes homeowners who installed a PV system between 1993 and 2023, under very different technical, legal, and economic conditions. One might expect that the sample primarily includes PV owners who installed their systems during peak times, i.e., in the years 2009 to 2012, when market conditions made double-digit returns on PV systems easily achievable. However, this is not the case. The majority of PV owners surveyed (68.8 %) installed their system between 2019 and 2023, only 14.8 % installed their system between 2009 and 2012 (N=365). The average PV system size is 8.2 kWp, which is in line with our expectations and representative of a typical PV system on a single-family home in Germany. 72.3 % of the PV systems have south-facing panels, 44.8 % have west-facing panels and 37.3 % have east-facing panels.

Homeowners without PV: In order to get an idea of how much respondents have already dealt with photovoltaics, we asked them to place themselves in a decision phase regarding a possible investment in a PV system based on a classification by Scheller et al. (2021). We find that 14 % of the homeowners in our sample have not yet considered installing a PV system at all. 32.1 % say they have thought about buying a PV system but have not yet taken any action. 29.3 % have already gathered information about the technical and economic conditions for operating a PV system (e.g., on the internet, from family and friends). 15.4 % have gathered offers from PV installers and 9.2 % have decided for or against a system. As expected, the willingness to install PV increases as the decision phase progresses. The largest quantitative jump occurs between the first and second stage from 5.9 % to 32.3 % as depicted in Table 2.

Table 2: Decision stage and intention to install PV among homeowners without PV (N=966)

Decision stage	% (#)	Intention to install PV
Stage 1: The installation of a PV system has not yet been an issue.	14.0 % (135)	5.9 %
Stage 2: The installation of a PV system has been considered, but nothing has been done.	32.1 % (310)	32.3 %
Stage 3: Information about the technical and economic conditions for the operation of a PV system has been obtained (e.g. on the Internet, from family and friends).	29.3 % (283)	47.3 %
Stage 4: Offers from PV installers have already been obtained.	15.4 % (149)	58.4 %
Stage 5: A decision for or against a PV system has already been made.	9.2 % (89)	52.8 %

Table 3 provides a first impression of how PV ownership and the intention to install PV are related to support for a solar mandate and the perceived environmental effectiveness of such a mandate.

Table 3: Support of solar mandate and perceived effectiveness among subgroups

	N	Support of solar mandate	Perceived effectiveness of solar mandate
All homeowners	1.334	37.6 %	57.3 %
Homeowners without PV	966	32.2 %	54.8 %
Low intention to install PV[1]	590	24.9 %	48.3 %
High intention to install PV[2]	376	43.6 %	64.9 %
Homeowners with PV	368	51.6 %	64.1 %

Notes: [1] Intention to install PV = 0 [2] Intention to install PV = 1

Overall support for a solar mandate among homeowners is rather low at 37.6 %.[6] Homeowners with low intentions to install PV in the next 5 years show the lowest support at 24.9 %, while homeowners who have installed PV in the past show the highest support at 51.6 %. The levels of perceived effectiveness in terms of climate protection are higher across all groups, although a comparable pattern emerges.

Table 4: Support for and perceived effectiveness of solar mandate

		Support for solar mandate		
		Low[1]	High[2]	Total
Perceived effectiveness of solar mandate	Low[3]	40.1 % (535)	2.5 % (34)	42.7 % (569)
	High[4]	22.3 % (298)	35.0 % (467)	57.3 % (765)
	Total	62.4 % (833)	37.6 % (501)	100.0 % (1,334)

Notes: [1] Support for solar mandate = 0 [2] Support for solar mandate = 1
[3] Perceived effectiveness of solar mandate = 0 [4] Perceived effectiveness of solar mandate = 1

Table 4 shows the relationship between perceived effectiveness of a solar mandate and its support. 40.1 % of respondents believe a solar mandate is neither effective nor worth supporting, while 35 % believe it is effective and support it. 22.3 % of respondents believe a solar mandate would be effective in protecting the climate, but do not support it. A small minority of 2.5 % of respondents believes that a solar mandate would not be effective but do support it.

[6] This contrasts especially with high approval of a solar mandate among tenants in our sample: 70.7 % of the 2,029 surveyed tenants support a solar mandate for residential buildings, and 75.9 % consider it effective for climate protection. However, this is not further discussed due to the scope of this study.

4.2 PV ownership and the intention to install PV

Table 5 presents the estimation results for PV ownership and the intention to install PV. The expectation that a PV system will provide a good return on investment has a strong influence on owning a PV system. Furthermore, trust in PV installers and the perception that roofs with photovoltaics are just as visually appealing as roofs without photovoltaics increase the likelihood that a person will own a PV system. We can also measure a neighborhood effect. Our indicators for building characteristics and energy use are all statistically significant for PV ownership, and the effects are in the expected direction. A south-facing roof and the use of a heat pump or an electric car increase the probability of PV ownership. The need for roof renovation and an above-average use of grid electricity make PV ownership less likely.

Regarding the intention to install a PV system, only the perceived social desirability of further PV expansion is significant among the attitudes towards photovoltaics; the expectation of a good return is only weakly significant, as is a neighborhood effect. A south-facing roof increases the likelihood of planning to install a PV system, as does an upcoming roof renovation. Surprisingly, high electricity consumption and the use of a heat pump or an electric car are not statistically significant. The intention to install a PV system is also influenced by risk tolerance, patience and political preferences. Finally, the ability to invest EUR 30,000 without taking out a loan plays an important role.

A solar mandate addresses two factors that we find in our analysis to increase the willingness to install PV. First, it would institutionalize the social desirability of PV expansion. Depending on the design of the solar mandate, one would have to justify not wanting to comply with this obligation. Second, it would address the increased willingness to install PV when renovating a roof and could lead to better exploitation of this window of opportunity. If a solar mandate results in a PV system becoming a standard feature of homes in the future, individual factors such as risk-taking preferences and patience will become irrelevant. Similarly, the role of political preferences in the willingness to install may then diminish, as trust in PV installers may no longer be a determining factor in owning a PV system.

However, our analysis should also draw attention to two problems associated with a solar mandate. Our results regarding the effect of the availability of EUR 30,000 suggest that there is a risk that people may subjectively feel or objectively be overburdened financially by a combined investment in roof insulation, new roofing, and the installation of a PV system. In addition, the important role of expected returns for actual PV ownership should sensitize to the fact that a solar mandate does not exempt the legislator from setting economic incentives in such a way that an investment in such a system remains economically viable.

Table 5: Estimated average marginal and discrete effects from Models 1 and 2

	Model 1: PV ownership	Model 2: Intention to install PV
Perceived return advantage	**0.208*** (0.032)**	**0.087* (0.045)**
Perceived cost hedging	0.027 (0.030)	0.043 (0.038)
Perceived environmental benefit	**0.060* (0.035)**	0.060 (0.044)
Perceived autarky effect	0.031 (0.028)	0.046 (0.035)
Trust in PV installer	**0.134*** (0.026)**	0.012 (0.035)
Aesthetic perception	**0.061*** (0.022)**	0.019 (0.030)
Social desirability of PV expansion	0.012 (0.022)	**0.088*** (0.030)**
PV in neighborhood	**0.090*** (0.024)**	**0.056* (0.033)**
South facing roof	**0.042** (0.021)**	**0.077*** (0.028)**
Roof renovation required	**-0.113*** (0.027)**	**0.138*** (0.036)**
Heat pump	**0.219*** (0.041)**	0.040 (0.056)
Electric vehicle	**0.274*** (0.037)**	0.060 (0.058)
Grid power purchase above median	**-0.088*** (0.021)**	0.024 (0.029)
Risk taking	-0.022 (0.024)	**0.079** (0.035)**
Patience	-0.013 (0.024)	**0.107*** (0.031)**
Altruism	0.024 (0.024)	0.046 (0.032)
Environmental awareness	**0.006** (0.003)**	-0.002 (0.004)
Conservative	0.007 (0.024)	0.010 (0.032)
Liberal	-0.024 (0.023)	**-0.063** (0.030)**
Social	-0.013 (0.025)	**-0.060* (0.034)**
Ecological	-0.029 (0.026)	**0.081** (0.036)**
Age	-0.000 (0.001)	**-0.007*** (0.001)**
Female	**-0.070*** (0.024)**	**-0.096*** (0.032)**
Academic education	-0.004 (0.023)	0.042 (0.030)
Household size	0.003 (0.009)	0.007 (0.012)
Equivalized net household income (1,000)	0.011 (0.007)	**0.017* (0.009)**
EUR 30,000 available without credit	0.015 (0.023)	**0.113*** (0.031)**
N	1334	966

*Robust standard errors in parenthesis, * p<0.10, ** p<0.05, *** p<0.01. Statistically significant effects in bold*

4.3 *Support for and perceived effectiveness of solar mandate*

Table 6 shows the results for the support of a solar mandate and its perceived environmental effectiveness.

Table 6: Estimated average marginal and discrete effects for Models 3 and 4

	Model 3: Support for solar mandate	Model 4: Perceived effectiveness of solar mandate
Perceived effectiveness of solar mandate	**0.445*** (0.024)**	
PV ownership	**0.071*** (0.024)**	-0.023 (0.029)
Perceived return advantage	0.032 (0.026)	0.035 (0.033)
Perceived cost hedging	0.011 (0.032)	**0.125*** (0.036)**
Perceived environmental benefit	-0.016 (0.044)	**0.197*** (0.044)**
Perceived autarky effect	-0.028 (0.028)	-0.013 (0.031)
Trust in PV installers	**0.071*** (0.024)**	**0.116*** (0.028)**
Aesthetic perception	**0.054** (0.023)**	-0.009 (0.026)
Social desirability of PV expansion	**0.068*** (0.022)**	0.031 (0.026)
PV in neighborhood	-0.007 (0.027)	0.024 (0.029)
Risk taking	0.011 (0.025)	-0.034 (0.029)
Patience	0.035 (0.023)	**0.068** (0.027)**
Altruism	0.039 (0.024)	0.026 (0.027)
Environmental awareness	0.002 (0.003)	**0.008** (0.004)**
Conservative	**-0.043* (0.025)**	**-0.070** (0.028)**
Liberal	**-0.046** (0.023)**	-0.041 (0.026)
Social	0.010 (0.026)	0.031 (0.029)
Ecological	**0.115*** (0.029)**	**0.204*** (0.033)**
Age	0.000 (0.001)	-0.001 (0.001)
Female	-0.025 (0.025)	**-0.056** (0.028)**
Academic education	0.014 (0.023)	-0.033 (0.026)
Household size	**0.016* (0.009)**	-0.004 (0.011)
Equivalized net household income (1,000)	**0.013* (0.007)**	-0.001 (0.008)
EUR 30,000 available without credit	0.012 (0.023)	0.023 (0.027)
N	1334	1334

*Robust standard errors in parenthesis, * p<0.10, ** p<0.05, *** p<0.01. Statistically significant effects in bold*

In Model 3, the perceived environmental effectiveness has by far the greatest influence on support for a solar mandate. Other relevant factors are PV ownership, trust in PV installers, aesthetic aspects and the social desirability of PV expansion in one's own social environment. It is also plausible that people who identify with liberal politics are more likely to oppose a solar mandate, while people who identify with ecological politics are more likely to support it. The picture is somewhat different when we look at the factors that determine whether respondents consider a solar mandate to be an effective climate protection measure in Model 4. Ceteris paribus, two environmental protection-related factors play an important role: the perception that PV systems contribute to environmental and climate protection, and environmental awareness. We think that this result underlines the need for an active information policy to increase the acceptance of a solar mandate. Key information on the environmental impact of PV systems should be made easily accessible to the public, e.g. how long it takes PV systems in Germany to pay back the energy required to produce the systems, what proportion of Germany's electricity demand is met by PV electricity, but also where problems are expected with the supply of PV electricity.

A second important finding concerns the role of PV's perceived protection against rising electricity costs. The perception that PV effectively protects against rising electricity costs increases the likelihood that a solar mandate will be perceived as effective in protecting the climate. In other words, respondents believe that a relevant environmental impact depends on the cost benefits of photovoltaics. This also calls for an active information policy on the individual and economic costs of PV expansion. This also calls for an active information policy on the individual and economic costs of PV expansion. Trust in the implementing actors plays a role not only in the overall support of a solar mandate, but also in the perception of its environmental effectiveness. With regard to political preferences, it can be stated that conservative voters in particular are skeptical about the environmental effectiveness of a solar mandate, whereas such a mandate fits in well with the ideas of ecologically oriented voters.

5. Conclusions and policy implications

The primary objective of our study is to assess whether a mandate to install PV on residential buildings in the event of roof renovation is a useful complement to existing economic instruments. To this end, we analyzed data from a survey of electricity customers of a German utility and examined the factors that explain PV ownership and willingness to install PV, as well as support for a solar mandate and its perceived environmental effectiveness. Our survey was conducted in the second quarter of 2023, at a time when PV construction in the study region[7] and in Germany was greatly accelerated in response to the war in Ukraine and the associated sharp price increases and price fluctuations for electricity in Germany.

[7] The additional installed PV capacity in Cologne is 4.8 MW in 2020, 7.2 MW in 2021, 10.7 MW in 2022 and 30 MW in 2023.

First, we see that almost half of the surveyed homeowners who do not yet own a PV system are in a pre-decision phase regarding PV, indicating that there is still a relevant target group that can be activated for further PV installations. Second, we see that a solar mandate is unpopular with homeowners. Overall, 37.6 % of homeowners surveyed support a solar mandate, and even among homeowners who already have a PV system, only 51.6 % support it. Third, our analysis suggests that a solar mandate is sensibly linked to factors that increase the willingness to install PV, namely the social desirability of PV expansion and roof renovation as a window of opportunity. A standardization of processes as a result of a solar mandate might ensure that investing in a PV system depends no longer on the willingness to take risks. Patience, political preferences and the trust in PV installers on the part of the investing homeowners. Fourth, based on the findings, we recommend that the introduction of a solar mandate must in any case be accompanied by an active information policy on the environmental benefits and cost impact of photovoltaic expansion. Finally, it seems that a solar mandate, at least in the short and medium term, can only be a supplement to the Renewable Energy Act. Since the return motive plays such an important role for PV ownership, we consider it essential and due to unstable market conditions quite challenging that the legislator must succeed in continuously adapting the economic framework for PV investments so that an investment does not become economically unprofitable.

For further research, we suggest the following aspects to be considered. Since our dataset is not representative of homeowners in Germany, a further study with representative data would be desirable. The analysis could be expanded to include additional explanatory factors, such as knowledge of subsidies for PV electricity (Palm and Lantz, 2020) or the migration background of the respondents (Best, 2023; Groote et al., 2016). From a research perspective, we believe that it is important that future analyses in the field of renewable energy investments systematically control for available financial assets, buildings characteristics as well as risk tolerance and patience in order to limit the problem of omitted variable bias.

Acknowledgements

This study was conducted as part of the OwnPV-Outlook research project funded by the German Federal Ministry for Economic Affairs and Climate Action (grant number: 03EI1031B). We would like to thank our project partners for fruitful discussions in the course of designing the survey, the cooperating utilities for their professional handling of customer outreach, and Gunnar Gutsche for his helpful comments on earlier versions of the manuscript.

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Appendix

Table A.1: Sociodemographic characteristics

Owner-occupied households in Mikrozensus 2022[a]			Sample		
	N in thousands	%		N	%
Total households	16,503		Total households	1,334	
Household size			Household size		
1 person	4 094	24.8	1 person	166	12.4
2 persons	6 861	41.6	2 persons	662	49.6
3 persons	2 471	15.0	3 persons	211	15.8
4 and more persons	3 076	18.6	4 and more persons	295	22.1
Move-in year			Move-in year		
Before 1999	7 709	46.7	Before 1999	582	43.6
1999-2008	3 585	21.7	1999-2008	335	25.1
2009-2018	3 737	22.6	2009-2018	311	23.3
2019 and after	1 472	8.9	2019 and after	106	7.9
Net monthly household income from ... to below ... Euro			Net monthly household income from ... to below ... Euro		
Less than 2,000	3,007	18.2	Less than 2,000	55	4.1
2,000 – 3,000	3,533	21.4	2,000 – 3,000	171	12.8
3,000 – 4,000	3,142	19.0	3,000 – 4,000	231	17.3
4,000 and more	6,819	41.3	4,000 and more	877	65.7
Main income earner aged ... to under ... years			Respondent aged ... to under ... years		
Below 25	118	0.7	Below 25	0	0
25 – 45	3 146	19.1	25 – 45	112	8.4
45 - 65	7 301	44.2	45 - 65	701	52.5
65 and older	5 937	36.0	65 and older	521	39.1

[a] The Mikrozensus is the largest annual household survey of official statistics in Germany. With around 810,000 people in around 370,000 private households and shared accommodation, around 1 % of the population in Germany is surveyed.

Table A.2: Summary statistics

Variables	Mean				Min	Max
	All	Homeowner with PV	Homeowner without PV			
			High intention to install PV	Low intention to install PV		
Support of solar mandate	.38	.52	.44	.25	0	1
Perceived efficacy of solar mandate	.57	.64	.65	.48	0	1
Perceived return advantage	.20	.40	.20	.08	0	1
Perceived cost hedging	.76	.88	.83	.65	0	1
Perceived environmental benefit	.86	.94	.91	.78	0	1
Perceived autarky effect	.75	.85	.81	.64	0	1
Trust in PV installer	.27	.45	.23	.18	0	1
Aesthetic perception	.64	.75	.65	.56	0	1
Social desirability	.50	.60	.58	.38	0	1
PV in neighborhood	.79	.86	.81	.73	0	1
South facing roof	.57	.64	.59	.51	0	1
Roof renovation required	.16	.09	.26	.14	0	1
Heat pump	.10	.21	.09	.05	0	1
Electric vehicle	.13	.30	.11	.05	0	1
Grid power purchase above median	.50	.44	.56	.50	0	1
Risk taking	.26	.31	.34	.18	0	1
Patience	.59	.67	.71	.47	0	1
Altruism	.63	.70	.69	.54	0	1
Environmental awareness	24.46	24.87	24.70	24.06	6	30
Conservative	.33	.31	.31	.35	0	1
Liberal	.38	.36	.36	.40	0	1
Social	.63	.65	.64	.61	0	1
Ecological	.61	.66	.70	.51	0	1
Age	61.38	60.32	58.94	63.66	25	102
Female	.28	.21	.23	.35	0	1
Academic education	.57	.64	.63	.49	0	1
Household size	2.58	2.71	2.74	2.40	1	20
Equivalized net household income (1,000)	3.30	3.62	3.53	2.95	0.14	12.5
EUR 30,000 available without credit	.55	.63	.63	.45	0	1
Number of observations	1,334	368	376	590		

Table A.3: Correlation matrix (p < 0.05)*

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) PV ownership	1.00														
(2) Intention to install PV		1.00													
(3) Support of solar mandate	0.179*	0.195*	1.00												
(4) Perceived effectiveness of solar mandate	0.085*	0.163*	0.562*	1.00											
(5) Perceived return advantage	0.303*	0.173*	0.160*	0.121*	1.00										
(6) Perceived cost hedging	0.166*	0.196*	0.207*	0.264*	0.209*	1.00									
(7) Perceived environmental benefit	0.148*	0.167*	0.220*	0.302*	0.139*	0.385*	1.00								
(8) Perceived autarky effect	0.140*	0.179*	0.124*	0.156*	0.148*	0.456*	0.261*	1.00							
(9) Trust in PV installer	0.243*	0.06	0.221*	0.181*	0.205*	0.145*	0.149*	0.118*	1.00						
(10) Aesthetic perception	0.143*	0.095*	0.150*	0.119*	0.118*	0.195*	0.206*	0.179*	0.139*	1.00					
(11) Social desirability of PV expansion	0.123*	0.191*	0.227*	0.184*	0.162*	0.212*	0.230*	0.143*	0.142*	0.113*	1.00				
(12) PV in neighborhood	0.109*	0.093*	0.04	0.04	0.062*	0.05	0.03	0.04	0.01	0.04	0.062*	1.00			
(13) Roof towards south	0.086*	0.084*	-0.01	0.01	0.060*	0.058*	0.04	0.04	0.059*	0.02	-0.01	0.04	1.00		
(14) Heat pump	0.211*	0.081*	0.02	0.02	0.04	0.063*	0.01	0.05	0.05	0.05	0.02	0.04	0.03	1.00	
(15) Electric vehicle	0.300*	0.121*	0.146*	0.102*	0.110*	0.112*	0.114*	0.107*	0.079*	0.068*	0.116*	0.05	-0.01	0.100*	1.00
(16) Grid power purchase above median	-0.070*	0.06	-0.01	-0.01	-0.03	-0.00	-0.04	0.03	-0.01	0.00	0.02	0.115*	-0.01	0.072*	0.05
(17) Risk taking	0.069*	0.174*	0.05	0.01	0.152*	0.077*	0.04	0.082*	0.04	-0.04	0.03	0.00	-0.00	0.084*	0.106*
(18) Patience	0.092*	0.235*	0.206*	0.200*	0.160*	0.216*	0.188*	0.179*	0.073*	0.120*	0.168*	0.00	0.01	0.085*	0.079*
(19) Altruism	0.090*	0.151*	0.203*	0.180*	0.079*	0.160*	0.217*	0.130*	0.106*	0.02	0.137*	0.03	0.057*	0.01	0.069*
(20) Environmental awareness	0.064*	0.077*	0.204*	0.234*	0.02	0.157*	0.258*	0.129*	0.056*	0.142*	0.148*	0.00	0.066*	-0.02	0.02
(21) Conservative	-0.02	-0.04	-0.182*	-0.188*	-0.05	-0.114*	-0.107*	-0.094*	-0.04	-0.098*	-0.103*	-0.01	0.03	-0.00	-0.04
(22) Liberal	-0.02	-0.04	-0.104*	-0.097*	0.03	-0.03	-0.03	-0.02	-0.02	-0.061*	0.00	-0.04	-0.04	0.02	0.03
(23) Social	0.02	0.03	0.213*	0.219*	0.04	0.110*	0.180*	0.084*	0.101*	0.126*	0.114*	0.01	-0.03	-0.01	0.03
(24) Ecological	0.072*	0.192*	0.356*	0.362*	0.082*	0.211*	0.315*	0.168*	0.115*	0.157*	0.231*	0.02	-0.00	0.02	0.109*
(25) Age	-0.056*	-0.186*	-0.03	-0.03	-0.04	-0.075*	0.01	-0.121*	0.01	-0.107*	0.01	-0.119*	-0.01	-0.086*	-0.064*
(26) Female	-0.097*	-0.120*	-0.04	-0.02	-0.070*	-0.03	-0.01	-0.01	0.00	0.02	-0.03	-0.00	0.04	-0.05	-0.090*
(27) Academic education	0.084*	0.135*	0.101*	0.04	0.079*	0.04	0.058*	0.05	0.081*	0.04	0.101*	0.02	-0.02	0.092*	0.119*
(28) Household size	0.063*	0.129*	0.077*	0.04	0.04	0.083*	0.00	0.074*	0.03	0.054*	0.094*	0.083*	-0.00	0.115*	0.133*
(29) Equivalized net household income	0.116*	0.172*	0.074*	0.02	0.086*	0.083*	0.085*	0.107*	0.03	-0.064*	0.064*	0.00	0.00	0.086*	0.159*
(30) EUR 30,000 available without credit	0.095*	0.178*	0.099*	0.072*	0.076*	0.072*	0.087*	0.060*	0.058*	-0.02	0.068*	0.02	-0.00	0.05	0.102*

Variables	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)
(16) Grid power purchase above median	1.00														
(17) Risk taking	0.00	1.00													
(18) Patience	-0.058*	0.191*	1.00												
(19) Altruism	-0.02	0.125*	0.261*	1.00											
(20) Environmental awareness	-0.054*	-0.04	0.206*	0.222*	1.000										
(21) Conservative	-0.02	0.03	-0.102*	-0.087*	-0.231*	1.000									
(22) Liberal	0.00	0.158*	0.01	0.02	-0.144*	0.215*	1.000								
(23) Social	-0.05	-0.01	0.154*	0.243*	0.222*	-0.255*	-0.081*	1.000							
(24) Ecological	-0.074*	0.061*	0.226*	0.290*	0.359*	-0.250*	-0.079*	0.466*	1.000						
(25) Age	-0.062*	-0.02	-0.093*	0.04	-0.078*	0.054*	0.105*	0.086*	0.032	1.000					
(26) Female	-0.065*	-0.141*	-0.03	0.03	0.177*	-0.085*	-0.055*	0.041	0.050	-0.088*	1.000				
(27) Academic education	-0.02	0.143*	0.158*	0.122*	-0.013	-0.015	0.109*	0.113*	0.177*	-0.033	-0.061*	1.000			
(28) Household size	0.162*	0.056*	0.071*	0.00	0.035	-0.037	-0.034	-0.014	0.042	-0.400*	-0.126*	0.023	1.000		
(29) Equivalized net household income	0.02	0.208*	0.077*	0.106*	-0.069*	0.070*	0.182*	-0.074*	0.062*	-0.005	-0.088*	0.281*	-0.176*	1.000	
(30) EUR 30,000 available without credit	-0.065*	0.166*	0.134*	0.110*	-0.022	0.056*	0.101*	0.030	0.138*	0.164*	-0.132*	0.198*	-0.083*	0.356*	1.000

Table A.4: Results of ordered probit models. The dependent variables are coded as 3-alternative ordinal variables with the lowest and highest two categories of the original variable combined.

Estimated average marginal and discrete effects on the estimated probability of Y = 3	Intention to install PV	Support for solar mandate	Perceived effectiveness of solar mandate
Perceived effectiveness of solar mandate		**0.446*** (0.023)**	
PV ownership		**0.072*** (0.024)**	-0.011 (0.030)
Perceived return advantage	**0.159*** (0.033)**	0.025 (0.027)	0.046 (0.034)
Perceived cost hedging	0.044 (0.030)	0.011 (0.030)	**0.117*** (0.035)**
Perceived environmental benefit	**0.102*** (0.038)**	-0.025 (0.037)	**0.142*** (0.039)**
Perceived autarky effect	**0.047* (0.028)**	**-0.043* (0.026)**	-0.003 (0.031)
Trust in PV installers	**0.060** (0.028)**	**0.055** (0.024)**	**0.114*** (0.029)**
Aesthetic perception	**0.044* (0.024)**	0.026 (0.021)	**-0.045* (0.026)**
Social desirability of PV expansion	**0.060** (0.024)**	**0.040* (0.021)**	0.020 (0.027)
PV in neighborhood	**0.091*** (0.027)**	0.016 (0.025)	0.024 (0.030)
South facing roof	**0.068*** (0.023)**		
Roof renovation required	**0.065** (0.030)**		
Heat pump	**0.151*** (0.042)**		
Electric vehicle	**0.196*** (0.036)**		
Grid power purchase above median	**-0.041* (0.023)**		
Risk taking	0.024 (0.029)	-0.010 (0.023)	-0.048 (0.030)
Patience	**0.073*** (0.025)**	**0.047** (0.022)**	0.044 (0.028)
Altruism	0.028 (0.025)	0.012 (0.022)	0.016 (0.028)
Environmental awareness	0.005 (0.003)	0.004 (0.003)	0.005 (0.003)
Conservative	0.008 (0.024)	**-0.040* (0.023)**	**-0.059** (0.027)**
Liberal	-0.033 (0.024)	**-0.056*** (0.022)**	**-0.063** (0.027)**
Social	**-0.045* (0.026)**	0.014 (0.024)	0.009 (0.029)
Ecological	0.044 (0.027)	**0.121*** (0.027)**	**0.193*** (0.033)**
Age	**-0.006*** (0.001)**	0.000 (0.001)	0.000 (0.001)
Female	**-0.117*** (0.026)**	0.014 (0.023)	-0.028 (0.029)
Academic education	0.031 (0.024)	-0.004 (0.021)	-0.038 (0.027)
Household size	0.008 (0.012)	**0.018* (0.010)**	0.004 (0.012)
Equivalized net household income (1,000)	**0.019** (0.008)**	**0.014** (0.007)**	0.002 (0.008)
EUR 30,000 available without credit	**0.060** (0.025)**	0.006 (0.022)	0.022 (0.027)
N	966	1334	1334

*Robust standard errors in parenthesis, * p<0.10, ** p<0.05, *** p<0.01. Statistically significant effects in bold*

Table A.5: Results of the multinomial probit model

Estimated average marginal and discrete effects	PV owners	Potential adopters	Non-adopters
Perceived return advantage	**0.219*****	-0.041	**-0.177*****
	(0.032)	(0.030)	**(0.032)**
Perceived cost hedging	0.022	0.025	-0.047
	(0.030)	(0.033)	(0.032)
Perceived environmental benefit	0.052	0.026	**-0.078***
	(0.036)	(0.039)	**(0.040)**
Perceived autarky effect	0.024	0.022	-0.046
	(0.028)	(0.030)	(0.030)
Trust in PV installer	**0.131*****	**-0.060****	**-0.071*****
	(0.026)	**(0.026)**	**(0.027)**
Aesthetic perception	**0.061*****	-0.013	**-0.047***
	(0.022)	(0.025)	**(0.026)**
Social desirability of PV expansion	0.011	**0.062****	**-0.073*****
	(0.022)	**(0.024)**	**(0.025)**
PV in neighborhood	**0.089*****	0.003	**-0.091*****
	(0.024)	(0.029)	**(0.029)**
South facing roof	**0.039***	**0.038***	**-0.078*****
	(0.021)	**(0.023)**	**(0.024)**
Roof renovation required	**-0.115*****	**0.177*****	**-0.063****
	(0.027)	**(0.034)**	**(0.031)**
Heat pump	**0.219*****	**-0.068***	**-0.150*****
	(0.041)	**(0.035)**	**(0.041)**
Electric vehicle	**0.271*****	**-0.093*****	**-0.177*****
	(0.037)	**(0.032)**	**(0.037)**
Grid power purchase above median	**-0.090*****	**0.067*****	0.023
	(0.021)	**(0.023)**	(0.024)
Risk taking	-0.025	**0.065****	-0.039
	(0.024)	**(0.029)**	(0.029)
Patience	-0.017	**0.077*****	**-0.060****
	(0.024)	**(0.026)**	**(0.026)**
Altruism	0.025	0.028	**-0.054****
	(0.024)	(0.026)	**(0.027)**
Environmental awareness	**0.006****	-0.004	-0.002
	(0.003)	(0.003)	(0.003)
Conservative	0.005	0.005	-0.010
	(0.024)	(0.026)	(0.026)
Liberal	-0.023	-0.029	**0.052****
	(0.023)	(0.024)	**(0.025)**
Social	-0.012	-0.037	**0.050***
	(0.025)	(0.028)	**(0.028)**
Ecological	-0.031	**0.081*****	**-0.049***
	(0.026)	**(0.029)**	**(0.029)**
Age	-0.000	**-0.005*****	**0.006*****
	(0.001)	**(0.001)**	**(0.001)**
Female	**-0.073*****	**-0.048***	**0.121*****
	(0.024)	**(0.027)**	**(0.028)**
Academic education	-0.004	0.029	-0.025
	(0.022)	(0.025)	(0.025)
Household size	0.002	0.003	-0.005
	(0.009)	(0.010)	(0.010)
Equivalized net household income (1,000)	**0.012***	0.007	**-0.019****
	(0.007)	(0.008)	**(0.008)**
EUR 30,000 available without credit	0.011	**0.076*****	**-0.087*****
	(0.023)	**(0.026)**	**(0.026)**
N	1334	1334	1334

*Robust standard errors in parenthesis, * p<0.10, ** p<0.05, *** p<0.01. Statistically significant effects in bold*

Notes: The dependent variable is a nominal variable that can take on three mutual exclusive values: 1 = PV owner; 2 = potential adopter (Intention to install PV = 1); 3 = non-adopter (Intention to install PV = 0).