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Meta-analysis of the role of equity dimensions in household solar panel adoption

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Abstract

If some households are less likely to be able to participate in solar panel adoption due to socio-economic or demographic characteristics, then inequity can exist. We use meta-regressions to analyse links between research characteristics and dimensions of equity including gender, economic distributions, renting, education, and ethnicity. We find that studies assessing actual solar panel uptake rather than intentions are less likely to analyse gender influences. Cross-sectional studies are more likely to include analyses of economic distributions and renting impacts but are less likely to assess policy variables. We also investigate links between research characteristics and prior findings. Significant influences of equity on solar panel uptake are 17 percentage points (p.p.) and 10 p.p. less likely to be found with regard to education and ethnicity, respectively, in household-level studies compared to aggregated studies. Our paper encourages more frequent analysis of equity aspects, coverage of a broader range of equity aspects, and analysis that incorporates both equity and policy variables. For research questions on household equity, we suggest using data on actual solar-panel uptake at the household level.

Keywords: education; equity; ethnicity; household; meta-analysis; solar

1. Introduction

This paper investigates the social drivers for adoption of household solar panels through meta-analysis. Solar photovoltaic (PV) energy has begun to make a meaningful contribution to climate change mitigation, and by broadening household adoption, it can have a further impact. Expected growth to over 100 million households relying on rooftop solar panels by 2030 is an indicator of the vast global potential for renewable energy expansion (IEA, 2022). Broadened understanding of social drivers can aid in policy formulation, allowing for more targeted policies to be devised.

The global relevance of our meta-analysis starts to become apparent in Figure 1. We include 157 articles which cover 45 countries, spanning each main continent. Our covered countries account for approximately 72% of the global population (World Bank, 2022). This global perspective can build on insights from solar-uptake studies of single countries (Best et al., 2021; Hansen et al., 2022; Petrovich et al., 2019). Figure 1 indicates that studies frequently assess populous countries (e.g. India and the U.S.) and countries with high proportional solar uptake (e.g. Australia). Meta-analysis can also inform future studies of many more countries.

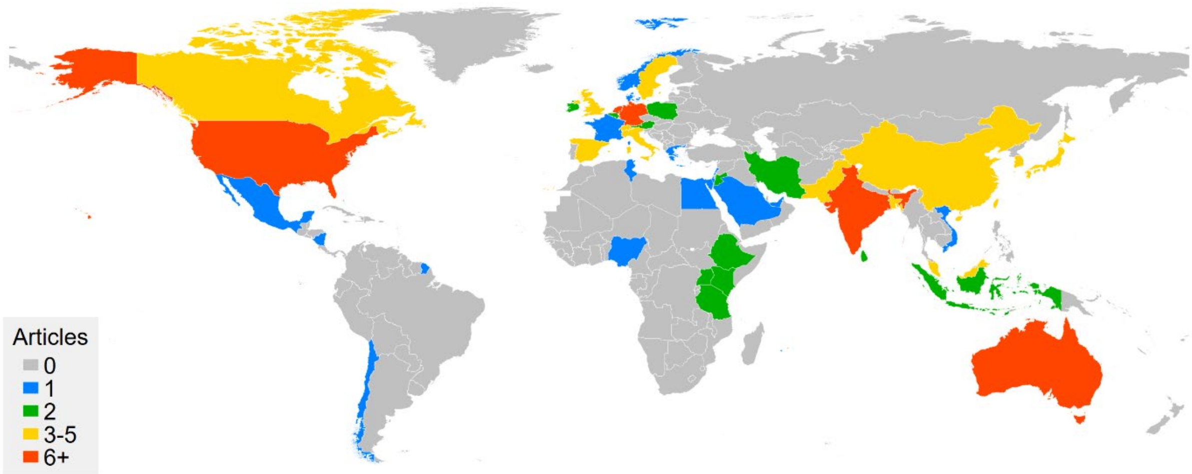

Figure 1. The number of articles which cover each country in our meta-analysis. The shape file for the construction of the map is from the World Bank (2022).

There is a strong motivation to promote the equitable adoption of solar panels across different household types for social reasons (Carley and Konisky, 2020). This stems from the potential for solar panels to reduce energy-related expenditure and insecurity (Best and Sinha, 2021). These are increasingly important issues following the onset of the COVID-19 pandemic and the recent elevation in energy prices and cost of living pressure (Graff and Carley, 2020; Memmott et al., 2021). However, energy transitions can perpetuate existing inequality (Borenstein, 2022; Carley and Konisky, 2020), such as when solar panel uptake is mostly pursued by higher-income households that can afford the initial installation costs. To improve the outcomes for disadvantaged households, it is crucial for policy approaches to be based on an enhanced understanding of equitable household adoption (O'Shaughnessy, 2021). Focus on household equity is a crucial complement, alongside other solar studies focusing on profit or unequal exchange across countries (D'Adamo et al., 2022; Roos, 2022).

A major challenge in the construction of equitable policies is that there are many relevant factors in the solar context. Policies to promote solar panel uptake have been popular, and attempts to target low- and middle-income households can be effective (O'Shaughnessy et al., 2021). These and other policies face the risk of creating trade-offs related to efficiency and equity (Best et al., 2021; Borenstein, 2022). For instance, policymakers may consider ceasing support for household solar to re-direct attention to more cost-effective utility-scale operations. However, such a policy shift may "lock in" inequality since early uptake was primarily by higher-income households (O'Shaughnessy, 2022). Past studies have also found that peer influences are an important non-policy determinant of household energy outcomes (Bollinger and Gillingham, 2012; Hansen et al., 2022; Petrovich et al., 2019). In addition, political participation has been identified as a contributor (Mildenberger et al., 2019). Environmental perceptions and other preferences are further motivations (Gillingham and

Tsvetanov, 2019). Economic factors were found to be the main driver in some studies (Jacksohn et al., 2019), especially for more recent adopters (Palm, 2020).

Building more equitable solar adoption policies could be possible with a better understanding of the multi-dimensional nature of equity. By analysing 167 studies from 157 papers, our meta-regressions show which study types investigate numerous equity dimensions, and we also explore possible reasons for the findings of prior research. For example, the findings of prior research could be influenced by different types of analysis, such as analysis based on the use of household surveys, or by the different contexts of data aggregated at regional levels. A further complication is the correlation between many of the equity dimensions. We therefore assess the links between different equity dimensions. These approaches take a different path compared to valuable literature reviews describing and categorising types of variables and methods (Alipour et al., 2021, 2020). Our approach also diverges from a meta-study of intentions, which makes the important recommendation that future studies should seek to follow comparable procedures (Schulte et al., 2022). Examining the impacts of different methodological approaches also has great potential in meta-analysis (Busch and Lewandowski, 2018).

We base our study on an existing framework designed for the broader context of energy transitions in general (Carley et al., 2018). The framework breaks down aspects of vulnerability in energy transitions into themes and specific measures, such as the proportion of populations with socioeconomic or demographic characteristics. We select this framework due to its broad coverage of equity dimensions and the recognition of equity as a multi-dimensional construct. We apply this framework by analysing multiple socio-economic and demographic measures from the framework. From the longer list of measures that are relevant for energy transitions, we select the dimensions that are most relevant for solar panel adoption, as evident in the variables that have been assessed in prior solar adoption studies

(Alipour et al., 2020). We analyse a broad range of equity aspects in the socio-demographic and economic categories, including education, ethnicity, income, and wealth (Best et al., 2021; O'Shaughnessy et al., 2021; Sunter et al., 2019). We also analyse equity related to other important dimensions, i.e., gender and renting status (Zander, 2020).

2. Method and data

2.1 Conceptual definitions

We define solar PV as any system that produces electricity from solar panels. The study focuses on solar PV in the context of domestic installations, which are typically mounted on rooftops or integrated within residential buildings.

We define uptake as the installation and subsequent use of a solar PV system. We define determinants to include socio-demographic or economic characteristics (income, age, etc.) that have been hypothesised to be either directly or indirectly related to solar PV uptake.

2.2 Eligibility criteria

For inclusion, studies had to meet the following eligibility criteria:

(1) Studies were included if they assessed the determinants of solar PV uptake in correlational analyses or as explanatory variables for solar PV uptake with a focus on domestic installations. We defined specific keywords to identify relevant studies that we also integrated into our initial search strategy (detailed below in sub-section 2.4).

(2) Studies were included if they fulfilled the statistical criteria for inclusion in a meta-analysis: we included studies reporting descriptive statistics for purposes of comparing solar and non-solar adopters with testing for statistical significance, and studies employing

regression including structural equation modelling and stated preference-based studies (e.g., discrete choice experiments).

(3) The included studies were reported in English.

(4) The included studies were peer-reviewed articles. We also excluded conference papers because many conference submissions were subsequently published as journal articles. We excluded other grey literature (book chapters, reports) that did not undergo a peer review process.

2.3 Exclusion criteria

We excluded studies in case they did not meet the required eligibility criteria.

In the first step, we defined specific exclusion criteria that we also integrated into our initial search strategy (detailed below).

(1) Installations other than solar PV. Studies were excluded if they focused on solar installations other than solar PV, including solar hot water, hybrid energy installations (e.g., hybrid turbine-PV or solar-biogas systems, hybrid solar-geothermal systems), and large-scale installations (e.g., solar plants). We also excluded studies on specific applications or technologies, such as solar heat pumps, solar inverters, solar feeders, solar heating, and solar cooling/refrigeration technologies. Furthermore, studies were excluded if they primarily examined the uptake of household appliances connected to solar PV systems (e.g., cooking/lighting applications, home battery and storage systems). We excluded studies on passive houses and those primarily discussing solar potential rather than solar uptake.

(2) Focus not on the determinants of solar PV uptake. Excluding studies which did not focus on determinants of PV is consistent with eligibility criteria (1) in sub-section 2.2, which states that studies are included when they assess determinants of PV. We also excluded

studies primarily concerned with developing algorithms or simulations to predict optimal solar power usage, as well as studies on load modelling.

We subsequently conducted a further manual analysis of articles and used additional exclusion criteria:

(3) Irrelevant variables or those that are relevant in other contexts. Studies were excluded if they did not assess variables related to the uptake of solar PV or if solar PV adoption was not included as a dependent variable. Examples are studies that examined solar PV adoption as an "antecedent" or as an independent variable to then test impacts on other outcomes (e.g., retail electricity rates). Studies assessing the "income bias" of PV adopters were not included, as they measure income differences (Darghouth et al., 2022; O'Shaughnessy et al., 2021).

(4) Data not suited for inclusion in a meta-analysis. Studies were also excluded if they did not fulfil the statistical criteria for inclusion in a meta-analysis. Examples include prior reviews and meta-analyses (we separately inspected these publications to ensure that no studies were missing from our search, as detailed below), studies offering descriptive statistics with no tests for statistical significance, studies that ranked outcomes as "best/worst", case studies that discussed the impacts of policies or the experiences of specific countries, regions or neighbourhoods but without offering datasets, qualitative studies based on interview data, focus group discussions, and surveys with open-ended questions that predominantly required textual input.

(5) Studies on forecasting. We excluded studies forecasting adoption, as these studies were based on assumptions about variables such as external factors (e.g., policy implementation), customer groups and behavioural intentions. We excluded agent-based models, which are predominantly based on hypothetical scenarios and simulations.

(6) Studies were excluded if their primary focus was on economic analysis, environmental analysis, analysis of the technical performance of solar PV systems, or analysis of engineering-related or technical aspects of solar PV.

Notably, some articles reported on multiple studies that employed different methods for each study. In these cases, we examined every study within the respective article considering the above-mentioned inclusion and exclusion criteria. If we found more than one eligible study per article, this study was treated as a separate study for the purpose of the meta-analysis (see sub-section 2.5). Analyses with different control sets in a single paper were counted as only one study when using the same general method.

2.4 Search strategies

To identify relevant studies, we used three different search strategies: (1) a search of the Scopus database, (2) a backwards/forwards search for further studies using the reference lists of the identified studies, and (3) a search of existing reviews.

We developed an initial string to identify relevant studies in the Scopus database. The data included in this article include all articles indexed in Scopus through 05 April 2022, the date when we downloaded the dataset for further analysis. We refined our search strategy through various iterations while carefully monitoring that each step would not lead to the removal of relevant studies.

Search string 1: TITLE ("rooftop" OR "home" OR "homeowner*" OR "home owner*" OR "residential" OR "household*" OR "domestic") AND TITLE ("PV" OR photovoltaic OR "photo-voltaic" OR solar) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")).

This basic search string resulted in 2,855 results, but a further manual inspection showed that the results contained too many irrelevant articles. We therefore defined a second search string to explicitly integrate the exclusion criteria discussed above in sub-section 2.3:

Search string 2: (TITLE ("rooftop" OR "home" OR "homeowner*" OR "home owner*" OR "residential" OR "household*" OR "domestic") AND TITLE ("PV" OR photovoltaic OR "photo-voltaic" OR solar) AND NOT TITLE ("water" OR "wind*" OR "turbine*" OR "plant*" OR "pump*" OR "inverter*" OR "feeder" OR "therm*" OR "geotherm*" OR "biogas*" OR "wastewater" OR "sewage" OR "batter*" OR "storage" OR "vehicle" OR "heat*" OR "cool*" OR "air condition*" OR "refrigerat*" OR "cook*" OR "light*" OR "potential" OR "passive")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")).

The second search string yielded 1,320 results. In another iteration, we refined this search string to also exclude studies on algorithms/simulations to predict optimal solar power usage, as well as studies on load modelling. We therefore defined a third search string to explicitly model the exclusion criteria:

Search string 3: (TITLE ("rooftop" OR "home" OR "homeowner*" OR "home owner*" OR "residential" OR "household*" OR "domestic") AND TITLE ("PV" OR photovoltaic OR "photo-voltaic" OR solar) AND NOT TITLE ("water" OR "wind*" OR "turbine*" OR "plant*" OR "pump*" OR "inverter*" OR "feeder" OR "therm*" OR "geotherm*" OR "biogas*" OR "wastewater" OR "sewage" OR "batter*" OR "storage" OR "vehicle" OR "heat*" OR "cool*" OR "air condition*" OR "refrigerat*" OR "cook*" OR "light*" OR "potential" OR "passive")) AND NOT TITLE-ABS-KEY ("algorithm*" OR "load*" OR "simulat*") AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")).

The final search yielded 832 articles. We subsequently removed two duplicates, leaving 830 articles for a further manual analysis (described below in sub-section 2.5).

2.5 Data extraction and manual analyses

We downloaded articles indexed in Scopus through 05 April 2022. We downloaded all available bibliometric information, including the author name(s), title, abstract, keywords, publication details, digital object identifier (doi), and full text of the article. In the first step, two of the authors separately inspected the title and abstract of each record to decide whether the article should become part of the meta-analysis based on the inclusion and exclusion criteria above. The initial inter-rater agreement was high (>99%), with disagreement regarding only five records, which were all initially retained and then further inspected in a second step. In total, the manual check identified 144 records that could possibly meet the criteria for the meta-analysis.

In a second step, all three authors further inspected the full text of the article of the 144 records, with a specific focus on the data, methods and results to ascertain whether the articles would meet the statistical criteria for inclusion in the meta-analysis, as detailed above in sub-section 2.2. Of the 144 records, 81 were retained.

To ensure that our Scopus search did not miss any records (which can happen due to the nature of keyword searches), we ran a comprehensive backwards and forwards search on the 81 articles in our sample. The forwards search retrieved 1,188 unique journal publications, while the backwards search led to 673 unique journal publications. In total, 1,679 unique journal publications were identified while conducting the backwards and forwards search (273 of these publications had already been included in our initial sample of 832 articles). A further round of manual inspection of these articles and examination of their data, methods and results allowed us to find an additional relevant 70 new papers.

In the last step, we inspected literature review articles that were identified through the steps above. We carried out this step to identify any articles that we might have potentially missed. Three literature review articles are cited in this article, and an exploration of the references of these articles yielded another 6 articles. Therefore, our total sample consists of 157 articles. Note that ten articles featured two distinct studies, each of which met the inclusion criteria. We included those studies as separate studies for purposes of analysis, such that the total sample for meta-analysis consists of 167 studies. The process is shown in Figure 2.

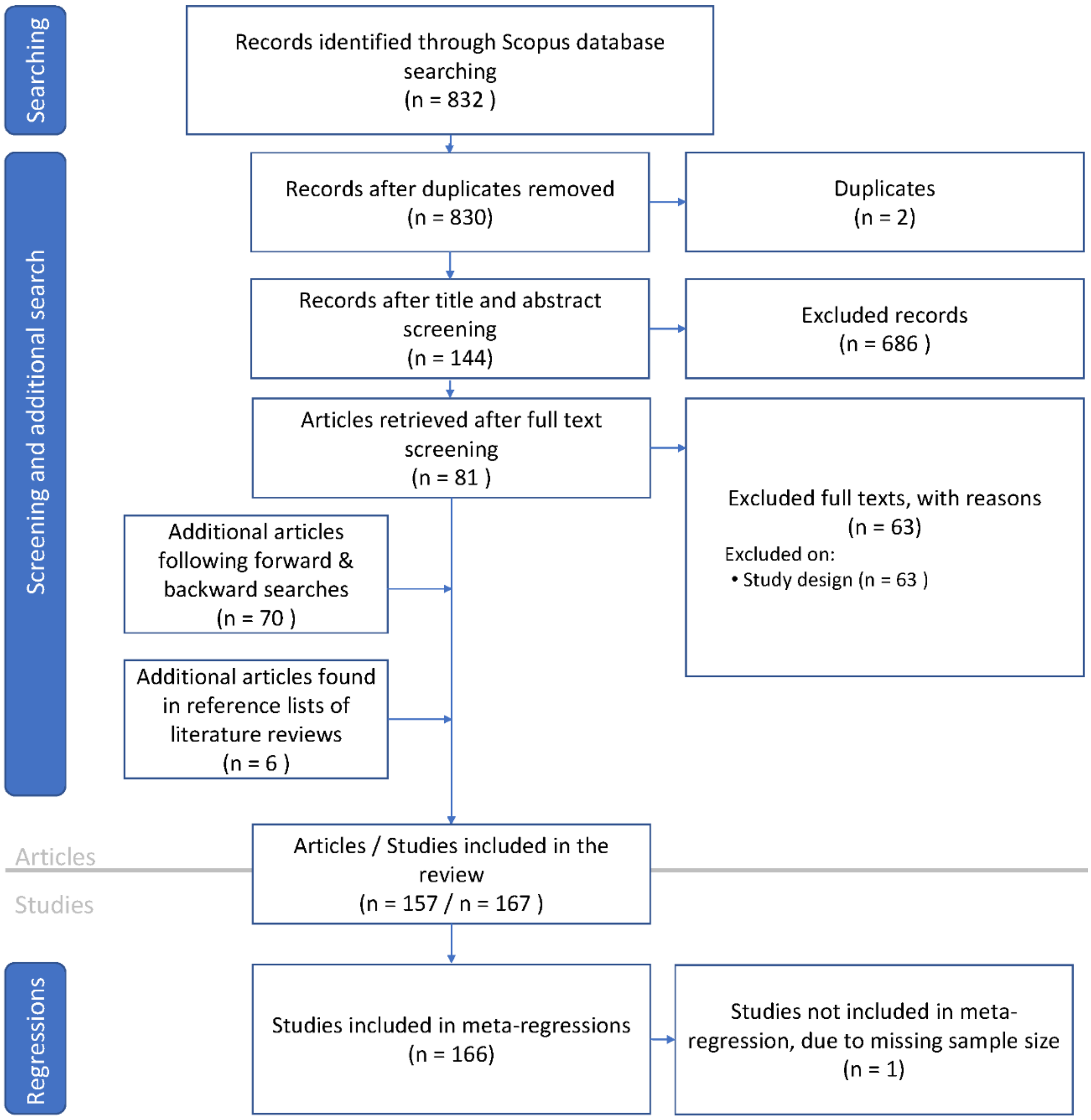

Figure 2. Flow diagram for our search and screening process based on the ROSES flow diagram for systematic reviews (Haddaway et al., 2018; Ivanova et al. 2020).

2.6 Equity aspects in our study

Figure 3 shows that equity aspects are assessed by a minority of the 167 studies from our search criteria. Approximately 25% of studies explicitly mention equity, equality, or justice in the text. Variables for income or capital distributions, which allow for different impacts for different parts of the distribution, such as a solar uptake peak for middle-income households (Bondio et al., 2018), are measured in only 16% of studies. Ethnicity is assessed in 21% of studies. An explanatory variable distinguishing between owners and renters is used in 21% of studies. Gender influences are measured with an explanatory variable in 23% of studies. Explicit explanatory variables for education are included more often than other aspects. Gender or renting variables are more likely to be included in cross-sectional studies compared to those incorporating temporal analysis. Gender is the only equity dimension that is more likely to be assessed by household-level studies compared to aggregated analysis.

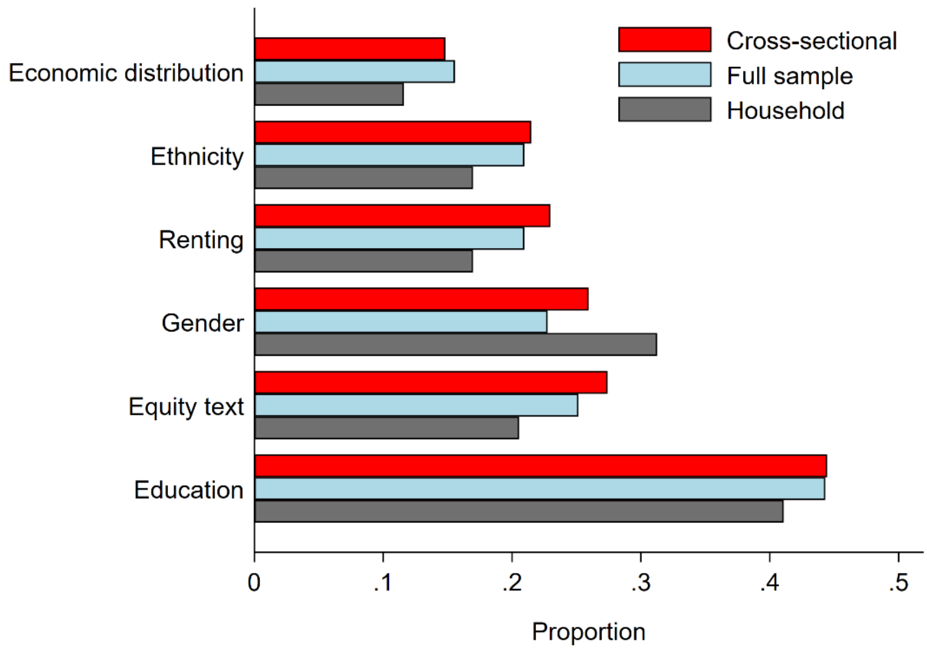

Figure 3. The proportion of studies assessing each of six dimensions of equity. The full sample includes 167 studies, with 135 being cross-sectional studies and 112 using household-level data.

The correlations between binary variables for the inclusion of equity dimensions in the 167 studies in our analysis are shown with a heatmap (Figure 4). Darker shading indicates higher correlations. There are no strong concentrations of high correlations across a single column or row, suggesting that there is a risk that the understanding of one equity dimension could be influenced by the lack of analysis of other related dimensions. This risk is pronounced when recalling Figure 3, which showed that only a minority of studies assessed each equity dimension.

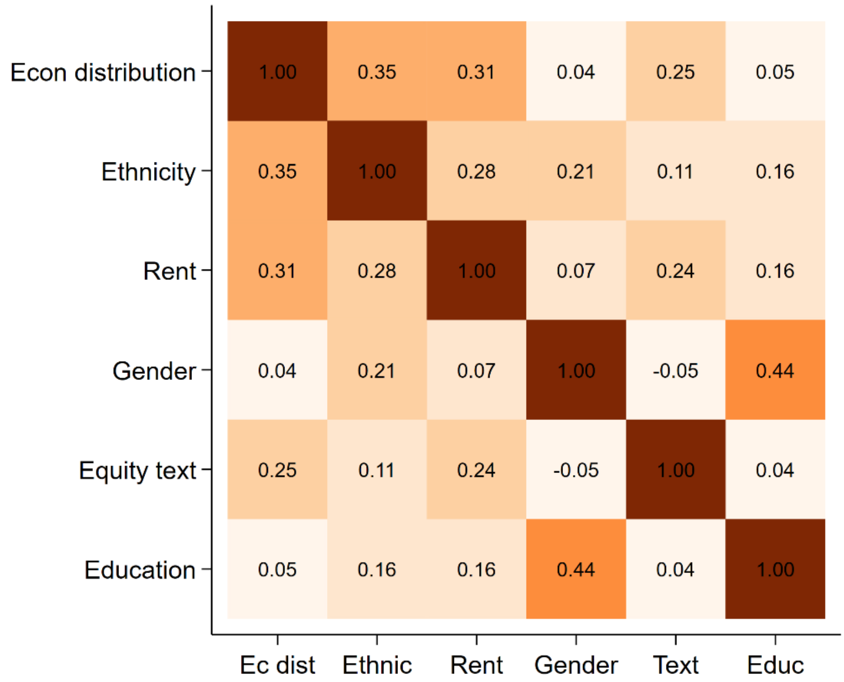

Figure 4. Correlation matrix heatmap based on binary variables equal to one when a study includes each equity dimension. This heatmap covers 167 studies.

2.7 Explanatory variables

We assess research characteristics as explanatory variables including five binary classifications. Studies may use household-level data or area-aggregated data such as for census tracts or ZIP codes. Aggregation might sometimes be appropriate (Darghouth et al., 2022), although there is a risk that aggregated findings will not correspond to household relationships for aspects that vary across areas (Banzhaf et al., 2019; Best and Chareunsy, 2022; Tidemann et al., 2019). Studies can also focus on intentions (Schulte et al., 2022), as opposed to actual uptake. Another aspect relates to time: most solar uptake studies are cross-sectional (Alipour et al., 2021), although panel investigations are also used. Findings may differ across country types so we use groups for the Organisation for Economic Co-operation and Development (OECD) and other countries. We also account for occupant age, one of the most assessed variables (Alipour et al., 2020), as studies controlling for age are likely to have research questions on socio-demographic issues.

We also assess other characteristics of studies, including some numerical aspects. We measure the size of studies with the natural log of the sample size. Underlying studies tend to have smaller sample sizes when they use cross-sections, household-level data, intentions rather than actual solar-panel uptake, and for analysis of non-OECD countries. The number of years since 2022 that each paper was published is also included to understand the impact of publication age on research choices and outcomes.

2.8 Meta-regressions

Our first main analytical contribution is investigating the link between research characteristics and the inclusion of equity dimensions in prior solar research. We use equity dimensions from a broad framework introduced in prior research (Carley et al., 2018), and produce Z scores from meta-regressions based on logit models. The dependent variables relate to binary variables for when equity dimensions are included in a prior study on solar panel adoption. One of these binary variables equals one when a study mentions “equity”, “equality”, or “justice” in the text. We treated the word “just” as equivalent to “justice” in usage such as “just access” or “just distribution” but not when “just” is a synonym for “only”. The other dependent variables require prior studies to include an explicit variable for the equity dimension when explaining solar panel uptake. We initially assess economic distributions, ethnicity, renting, gender, and education. We then assess three other variables for policy, environmental concern, and peer effects.

The logit model in equation (1) applies separately for each dependent variable. In each case, the dependent variable gives the log of the odds of a study including the equity dimension in its analysis. The odds are given as the probability (*p*) of including the equity dimension divided by the complement. The right-hand side of equation (1) shows the explanatory variables for our logit regressions, which are the characteristics of the studies. There are binary variables for cross-sectional studies (*C*), household-level data (*H*), actual solar panel uptake (*A*), coverage of OECD countries (*O*), and inclusion of age (*G*) as an explanatory variable. Continuous variables include the log of sample size (*S*) and the number of years since publication (*Y*). The use of logit models means that the binary nature of the dependent variable is explicitly considered, as opposed to the use of linear probability models.

$$log[\frac{p}{1-p}] = \beta_0 + \beta_1 C + \beta_2 S + \beta_3 H + \beta_4 A + \beta_5 Y + \beta_6 O + \beta_7 G \quad (1)$$

Our second main analytical contribution involves assessing the extent to which research characteristics influence the findings of past solar research. These findings include significant, nonsignificant, or omitted with regard to the impact of an equity dimension on solar panel uptake. Significant coefficients are split into positive and negative categories when assessing the role of education in solar panel uptake. Significance includes *p*-values up to 0.1. With multiple unordered categories, we use a multinomial logit model. Marginal effects are displayed from these models to show the impact of research characteristics on research outcomes.

3. Results

3.1 The link between research characteristics and inclusion of equity dimensions

Our meta-regressions indicate that there are strongly significant influences of numerous characteristics in explaining whether a solar adoption study assesses various equity dimensions. These influences are summarised in a heatmap of the Z scores for six logit meta-regressions (Figure 5). Darker shading indicates higher Z scores, with values above 1.645 being statistically significant at the 10% level and values above 2.58 being significant at the 1% level. All significant coefficients are positive except one; thus, we show absolute values to simplify the shading. The full table of coefficients and standard errors is presented in the Supplementary material (Table A.1).

Cross-sectional studies are more likely to assess four equity dimensions based on statistical significance in four cases (Z scores above 1.645 in Figure 5). A larger sample size may facilitate broader analysis, including economic distributions ("Econ") and ethnicity, as shown by high Z scores for explaining the investigation of these dimensions. Studies of actual uptake, compared to intentions, are more likely to explicitly analyse the issue of property rights constraints for renters. Studies that control for the age of household respondents, as a proxy for research questions related to socio-demographic issues, are positively linked with the assessment of five equity dimensions. These results are similar when using a sample of 127 studies that are in journals with a score of one or above based on the Scimago Journal and Country Rank (SJR) from 2020.

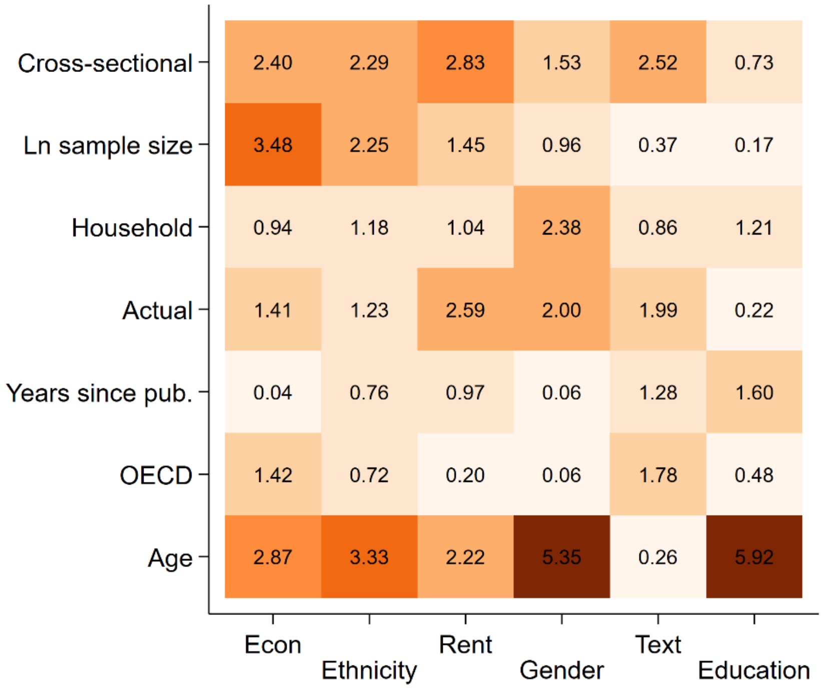

Figure 5. Heatmap for the Z scores (absolute values) from six meta-regression logit models. The explanatory variables are on the vertical axis. The binary dependent variables in the six logit models are on the horizontal axis (Econ=economic distributions). Darker shading indicates higher Z scores.

It is also interesting to note which characteristics were not significantly associated with consideration of each of the six equity dimensions. Even though the household level is the most appropriate for equity analysis, there is only one significant link, with household studies being more likely to assess gender influences. Temporal or spatial patterns do not appear to be pronounced, as the time since publication or the country under study tend to have nonsignificant links to inclusion of equity dimensions. One exception is that studies of countries belonging to the OECD tend to mention equity in the textual discussion.

Solar studies are less likely to include a policy variable when they use cross-sectional and actual solar uptake data, based on the meta-regression in column (1) of Table 1. The first of these links for cross-sectional contexts is particularly strong, with a *p*-value of 0.000. There is also a negative coefficient for the household-data variable. While this negative relationship is not statistically significant, with a *p*-value of 0.14, it is far from being positive and significant. These results in Table 1 can be interpreted as implying that policy analysis has related more to effectiveness or efficiency by assessing changes over time (i.e. not cross-sectional analysis) rather than equitable household distribution (as the household variable is not positive and significant but nearly significantly negative).

Table 1 also shows which study types assess environmental concern as a driver of solar panel uptake. Environmental concern relates to inter-generational equity, as solar uptake can enhance future environmental outcomes. In column (2), we find negative influences of both sample size and studies using actual solar-panel uptake data for the outcome of studies assessing environmental concerns. This means that greater confidence about the influence of environmental concern on solar panel uptake could be gained if future studies use larger sample sizes and data on actual solar panel uptake. We also find that studies of OECD countries are more likely to assess environmental concern as a driver of solar-panel uptake, all else equal. This means that there might be potential for more future studies of non-OECD countries to consider environmental concern.

In column (3), we assess which studies assess peer effects as drivers of solar uptake. We find negative influences from cross-sectional studies and the use of actual solar data. The results give an intuitive interpretation that panel studies are more likely to assess peer effects, as the temporal dimension allows for one peer to later affect another.

Table 1. Logit coefficients for meta-regressions explaining whether studies include variables for policy, environmental concern, or peer effects

Research characteristic	(1) Policy	(2) Environmental	(3) Peer effects
Cross-sectional (yes=1)	-2.354***	-0.061	-1.266**
	(0.584)	(0.526)	(0.523)
Ln sample size	-0.114	-0.171*	-0.078
	(0.096)	(0.093)	(0.085)
Household (yes=1)	-0.769	-0.543	0.094
	(0.521)	(0.460)	(0.447)
Actual uptake (yes=1)	-0.911*	-1.704***	-1.096**
	(0.535)	(0.487)	(0.445)
Years since publication	0.058	0.057	0.056
	(0.059)	(0.055)	(0.052)
OECD (yes=1)	0.469	1.228***	0.473
	(0.460)	(0.435)	(0.392)
Age control (yes=1)	0.029	0.797**	0.301
	(0.382)	(0.361)	(0.338)
Pseudo R^2	0.157	0.136	0.067

Notes: ***, ** and * represent statistical significance at the 1%, 5% and 10% levels, respectively. The coefficients from three logit models are shown. Standard errors are in brackets below the coefficients. There are 167 studies based on 157 papers. One paper does not specify the sample size meaning that there are 166 observations for each column.

3.2 Impacts of research characteristics on equity findings in past solar research

3.2.1 Shaping the understanding of education-based equity

Studies using household-level data are less likely to find positive and significant impacts of education on solar panel uptake (Figure 6). The probability of studies finding significant positive links from education to solar panel uptake is approximately 17 percentage points (p.p.) lower for studies using household-level data (compared to aggregated data) in the main results (H1 in Figure 6). Similar outcomes are observed in robustness tests, such as when restricting the sample to only regression studies (H2) or including income as an additional explanatory variable (H3) to account for the correlation between income and education.

Other significant coefficients exist for country groups and the temporal aspect. Education is less likely to be a positive and significant explanator for solar uptake in OECD countries. This result might be related to the greater variation in education in non-OECD countries, on average, compared to OECD countries, where most people generally have an opportunity to finish high school. OECD countries being less likely to find positive education influences on solar uptake is the least robust of the relationships in Figure 6, with statistical significance only at the 10% level. Table A.2 also has evidence that cross-sectional and older studies are more likely to find that education is positive and significant in explaining solar panel uptake.

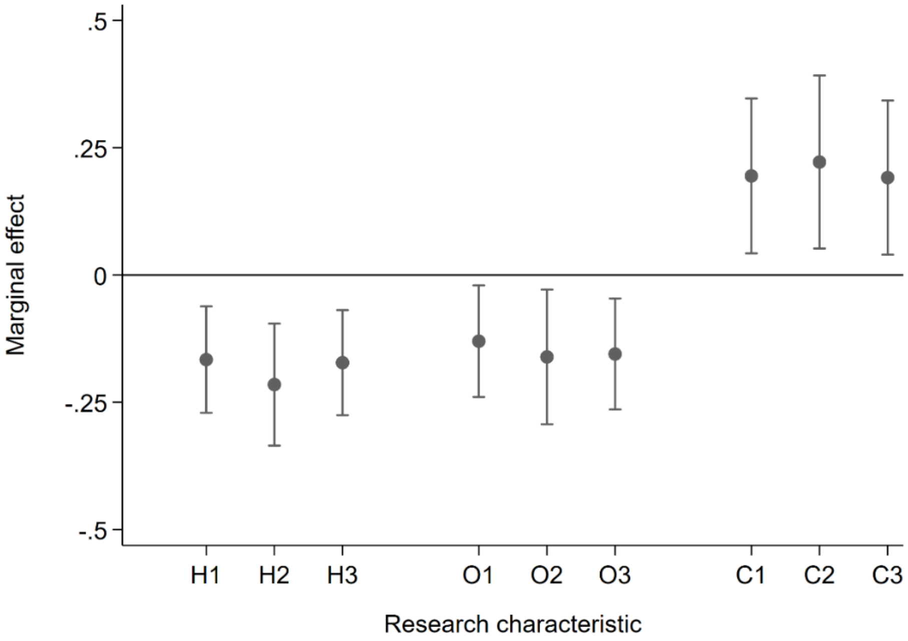

Figure 6. The influence of three key research characteristics on the likelihood of finding positive and significant influences of education on solar panel uptake. The marginal effects are from a multinomial logit model. Point estimates and 90% confidence intervals are shown. H=household-level data; O=OECD; C=cross-sectional. H1 is from the main meta-regression, while H2 and H3 are from robustness tests. The full results for the main meta-regression with other explanatory variables are shown in the Supplementary material (Table A.2).

3.2.2 The influence of the study type on the ethnicity findings

Examining ethnicity, Figure A.1 splits the full sample of 167 studies into household-level or aggregated studies. In both cases, most studies do not control for ethnicity. However, there is a difference when comparing significant or nonsignificant influences of ethnicity on solar panel uptake. Most aggregated studies that assess ethnicity find a significant link, whereas over half of the corresponding household-level studies do not.

Some study types have different probabilities of finding that ethnicity has a significant influence on solar panel uptake, even when controlling for multiple characteristics in the meta-regression in Table 2. The probability of studies finding a significant link between ethnicity and solar panel uptake is on average 10 p.p. lower for household-level studies (compared to studies using data at aggregated levels). There is also a positive link between a larger sample size and the probability of finding significant ethnicity impacts. We also add a binary variable for U.S. studies, given that ethnicity is a major issue in U.S. research, as supported by the negative and significant coefficient in the omitted column. A similar analysis for the gender dimension reveals that most characteristics have insignificant coefficients.

Table 2. The role of research characteristics in the outcomes of research on the influence of ethnicity on solar panel adoption

Research characteristic	Significant	Nonsignificant	Omitted
Ln sample size	0.022**	–0.022**	0.000
	(0.009)	(0.010)	(0.012)
Household (yes=1)	–0.103*	0.149***	–0.046
	(0.053)	(0.048)	(0.067)
Actual uptake (yes=1)	0.074	0.068	–0.142*
	(0.083)	(0.043)	(0.085)
Years since publication	0.010	–0.007	–0.003
	(0.007)	(0.006)	(0.009)
OECD (yes=1)	–0.053	–0.030	0.083
	(0.069)	(0.055)	(0.077)
US study (yes=1)	0.076	0.191***	–0.267***
	(0.048)	(0.046)	(0.053)
Age control (yes=1)	0.066	0.161***	–0.226***
	(0.047)	(0.053)	(0.058)

Notes: ***, ** and * represent statistical significance at the 1%, 5% and 10% levels, respectively. The marginal effects from a multinomial logit model are shown, indicating the probability that each of the three outcomes (significant, nonsignificant, omitted) of the influence of ethnicity on solar panel uptake is observed. Standard errors are in brackets below the marginal effects. There are 167 studies based on 157 papers. One paper does not specify the sample size; thus, here, we have 166 observations. The pseudo R^2 is 0.330. The results are similar if an extra variable for cross-sectional versus panel studies is included. This variable is omitted from the main results since all six panel studies that include an ethnicity variable find it to be significant, leading to large standard errors for this variable.

4. Discussion and conclusions

4.1 Contributions

The first contribution of this study is a systematic understanding of the characteristics of studies which analyse equity and related issues. We show that some approaches have been more commonly used to assess equity. For example, cross-sectional studies have been more likely to assess most equity dimensions, including economic distributions, ethnicity, and renting. However, cross-sectional studies have been less likely to include a policy variable. This can be interpreted as a barrier to equitable policy formulation since studies may consider policy or equity but rarely both. The absence of equitable policy research is evident with only 7 of 167 studies including both a policy variable and a variable for economic distributions, with none also using household-level data.

Another example of characteristics of studies analysing equity relates to the distinction between actual and intended uptake of solar panels. Studies using actual data for solar uptake were more likely to include analysis of the distinction between renting and owning homes but there was an absence of positive and significant relationships for most other equity dimensions. Another concerning finding is that studies assessing actual solar-panel uptake have been less likely to include a policy variable. This means that it will be difficult for policymakers to assess the actual impacts of policies across a broad range of contexts.

A second contribution of this study is to show how much research characteristics can influence the understanding of equity. For example, household-level studies are less likely to find significant equity impacts, including a lower chance of finding positive and significant influences of education on solar-panel uptake. The magnitude, in this case, is major at around 17 percentage points. Another example is that household-level studies are less likely to find significant influences of ethnicity on solar panel uptake with a magnitude of 10 percentage points.

4.2 Policy implications

Greater understanding of equity for household energy technologies is important for policy processes given the links between politics, policy, and technology (Pahle et al., 2022; Schmidt and Sewerin, 2017). This importance is evident as policymakers have increasingly considered approaches to enhance equity, such as targeting low-income households. There are many alternatives to this targeting. Policymaker choices on which type of group to target can be substantially enhanced with an improved understanding of equity in solar panel adoption.

One key policy implication from this paper is that policymakers should be careful when considering targeted policies based on education or ethnicity. Our meta-regressions showed that links from education and ethnicity to solar panel uptake are very sensitive to research characteristics, especially the distinction between household or aggregated data. Household-level data may be most appropriate for informing potential policies related to household investments such as solar panels. In contrast, aggregated area-level data may be suitable when considering area-level investments such as electricity transmission grids.

A second key policy implication is that much more research is needed to support equitable policy development. Our analysis reveals that the minority of studies that consider equity tend to not consider policy. Our meta-regressions revealed an explanation for this tendency, as cross-sectional studies are more likely to analyse equity but less likely to analyse policy. Past solar research with policy analysis has also tended to be based on aggregated data or intentions, whereas understanding actual household distributions will be important in contributing to equitable policy development.

Policymakers may be able to achieve greater equity in solar panel uptake by targeting other variables such as economic distributions or renting. However, our analysis showed that very few solar-uptake studies have considered economic distributions, and even fewer have also analysed policies. This implies that future research on the links between economic distributions, policies, and solar-panel uptake may be highly useful.

4.3 Limitations and future directions

Some limitations apply to the use of meta-analysis in general and relate to the underlying studies assessed. For example, underlying studies with small samples might be less reliable. However, our Stata code includes a robustness test showing similar results when dropping 22 studies with sample sizes of 200 or below. Other issues with underlying studies may also affect our meta-analysis results, such as where studies finding significant results are more likely to be published. However, solar uptake is driven by a wide range of factors, so solar studies will generally have a mix of significant and non-significant coefficients.

Specific limitations for our meta-analysis relate to the number of studies to analyse and the choices of prior research. Smaller numbers of studies contribute to less precise results, meaning that caution is required when interpreting and generalising results. However, our sample of 166 prior studies is larger than many prior meta-studies across various fields. Meta-analysis is also inappropriate for assessing factors that have only been analysed in a very small number of prior studies. For example, we are unable to provide a meta-analysis on the role of political participation. Limitations exist concerning economic distributions, which constrain the scope of our study. The small amount of prior analysis limits the potential to understand whether prior results for economic distributions are sensitive to research choices.

Our analysis encourages more frequent analysis of equity aspects in future research on the drivers of household solar panel adoption. In addition, we suggest that a broader range of equity dimensions should be assessed. Covering more equity dimensions is important because equity dimensions are correlated, leading to a risk that the understanding of equity could be impacted by omitting key dimensions. We also suggest that additional consideration be given to the methodology. Our analysis motivates further analysis using household-level data. Incorporating temporal aspects and considering non-OECD countries represent further fruitful research pathways.

Our results showing varying ethnicity findings based on methodology also encourage more research. For example, future studies could include further analysis with household-level data, larger samples, and coverage of more countries. Nuances likely exist, and ethnicity differences might lead to variations in solar uptake only in some specific cases. For instance, research can consider public-sector housing where specific analysis can focus on rental contexts (Best, 2022). Area-level effects may also exist, such as lower access to grid infrastructure for areas with ethnic minorities (Brockway et al., 2021), which could influence household solar adoption.

If future studies follow comparable methods with similar data formats there would be less need for analysis explaining the influences of research characteristics on research outcomes. However, this is unlikely to occur in practice, as there is diversity in methods, data, and researcher preferences. Our meta-analysis shows how research characteristics can influence results substantially.

Extensions are possible in multiple directions. Extending meta-analysis across a range of economic variables could complement this study on social drivers. Future meta-analysis can consider the link between equity dimensions and solar adoption over time, as more panel-data studies are conducted. Future meta-analysis could also consider other variables, such as political orientation or participation, if more studies consider related influences. Given our analytical approach, there is also potential for our research to be relevant for future energy studies that go beyond solar panel adoption. Strong links between solar panels and electric vehicle investment (Kaufmann et al., 2021) suggest one additional area to which our analysis can apply.

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