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Hide and seek: The supply and demand of information for household solar photovoltaic investment

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ABSTRACT

Buildings provide an ideal platform for solar photovoltaics (PV) towards sustainable development goals, and the decision to invest in PV lies predominantly with building owners. Information delivery is critical for the diffusion of innovations, and this study aims to improve the quality of information for household PV investors in Sweden. A User Journey Mapping approach is applied with a combination of semi-structured interviews and a review of online solar calculators. The results show that despite a rapid growth in the quantity of information there is still a gap between demand and supply due to the lack of clarity and trustworthiness of information. This is clearly demonstrated in the review of online calculators, which show a high variance in results. Payback time, for example, ranged from 7 to 18 years for a single test case. The information gap can be closed by creating neutral, non-commercial online information sources that focus on transparency and education where household investors can validate supplier offers and analyses. The PV industry risks eroding trust in the market, which will likely slow adoption by the early majority and hinder sustainability goals.

1. Introduction

Solar photovoltaics (PV) are poised to become one of the primary sources of renewable energy due to the abundance of solar radiation on earth and the rapidly falling costs of PV technology (IEA, 2021). A unique feature of PV is the ease of scaling – i.e. similar equipment used in utility scale power plants is also used in distributed systems. Buildings provide an ideal platform for solar energy capture given that no land use change is required and the energy is used directly where it is generated, creating what is typically called a prosumer. The technical potential of rooftop solar PV could make a notable contribution to electricity demands, for example up to 22% in the European Union (Defaix et al., 2012) and 38.6% in the United States (Gagnon et al., 2016).

The decision of whether solar PV is installed on all of these rooftops lies predominantly with the building owners. Technology adoption is often described using Roger's diffusion of innovation (DoI) model (Rogers, 2003) involving five stages of decision making – knowledge, persuasion, decision, implementation, and confirmation, and has been expanded to include a phase for initial interest (Broers et al., 2019; Wilson et al., 2018; Wolske et al., 2017), as shown in Fig. 1.

The entry point to decision making is attributed to the individual's level of innovativeness, e.g. do they seek out new technologies or wait for social norms to decide for them? The decision process can also be triggered by a specific event, such as a roof renovation or new subsidy. Moving through the model involves increasingly focused information gathering regarding the suitability of the technology. The knowledge gaining stage can involve personal searches for information, advice from professionals, or experiences from peers. At the opinion-forming phase, detailed information about the specific decision is collected, for example a quotation and potential financing. External factors related to the decision can also be considered, such as changes in building value or non-economic benefits. Once all information is considered, the decision is made and if accepted will progress to implementation and the experience of owning the technology. This experience can then be fed back into the social network (dashed line) and the decision process of others. The DoI model also assumes that not all decision makers will enter or proceed through the model at the same time or speed. Rogers describes five categories of individuals based on their interest/willingness to adopt new technology; innovators, early adopters, early majority, late majority, and laggards.

Behavioral research on PV adoption has covered all aspects of the DoI model, including; motives and barriers (Kowalska-Pyzalska, 2018;

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Palm, 2018; Rai et al., 2016; Schelly, 2014), information channels (Palm and Eriksson, 2018; Rai and Beck, 2015; Reeves et al., 2017), conditions for acceptance (Korcaj et al., 2015; Rai and Sigrin, 2013; Scarpa and Willis, 2010), and the peer effects from those who have adopted (Bollinger and Gillingham, 2012; Graziano et al., 2019; Palm, 2017; Rai and Robinson, 2013).

Environmental values and/or a high level of innovativeness often initiates interest, however the inability to test a technology prior to adoption is a barrier (Rogers, 2003). The influence of peers works to increase adoption, either through passive observation of other rooftops, a unique feature of PV amongst energy efficiency devices (Bollinger and Gillingham, 2012; Graziano et al., 2019), or more importantly a confirmation of satisfaction from trusted peers within a social network (Mundaca and Samahita, 2020; Palm, 2017). Peer effects are a positive influence throughout the decision making process (Palm, 2017), however the strongest influence on the final decision is most often financial (Fleiβ et al., 2017; Kastner and Stern, 2015; Newell and Siikamäki, 2013; Sommerfeld et al., 2017) particularly when shifting from early adopters to the early majority (Simpson and Clifton, 2017).

Simple payback time is the most salient economic metric for household investors, where the mean acceptable time to consider adopting is about eight years (Dong and Sigrin, 2019). The long payback time barrier has been overcome by access to various forms of financing and third party contracts, where the owner has little-to-no upfront cost, thereby experiencing savings immediately, but sacrificing some of the lifetime value with the financier (Drury et al., 2012; O'Shaughnessy et al., 2021).

Historically, homeowners have been labeled economically irrational in evaluating the benefits of and adopting energy efficiency technologies (Hausman, 1979), the so called energy efficiency paradox or gap (Jaffe and Stavins, 1994). This is where engineering economics suggests an energy efficient product should be preferred, however consumers do not adopt it at the expected rate. Due to the high level of complexity, the size or even real presence of the gap is debated (Gillingham and Palmery, 2014). For example, it is possible that simple engineering economics does not capture the full set of features of a product, or that there are hidden non-economic costs, which would make the model incomplete in describing consumer decision making. The gap can also be partially explained by market forces, such as imperfect or costly information (Howarth and Andersson, 1993), or behavioral, such as risk aversion under uncertainty (Greene, 2011; Hassett and Metcalf, 1993). Owners can also have the option to delay adoption and take advantage of future technological improvements, incorporating a time component to the model (Ansar and Sparks, 2009; Bauner and Crago, 2015; Van Soest and Bulte, 2001).

When these factors are taken together, the "irrational" gap between engineering economic calculations and empirical technology adoption can be at least partially explained (Allcot and Greenstone, 2012; Gillingham et al., 2009). Schubert and Stadelmann (2015) suggest that information access is the main limiting factor, and that product labels, such as the EU Energy Label or the US EnergyGuide, provide the engineering economics in a manner that allows for more rational decision making. These combinations of information delivery with consumer response provides behavioral research avenues for increasing PV adoption in the built environment.

A particularly difficult challenge for a PV investor is the need to predict future performance through the generation of technical and economic metrics. The long-term nature of PV investment means it is easier to hide misleading information. For example, if it is assumed that electricity prices (and thus the value of PV savings) will increase by 3% over the lifetime of the system, and this does not come to bear, it could be many years before the owner realizes their returns will not be as good as expected. This is an issue of information asymmetry, where a complex product is not fully understood by the customer, potentially leading to sub-optimal adoption rates (Collins and Curtis, 2017) or enabling sellers to mislead customers into a sale (Mauritzen, 2020). The asymmetry problem extends beyond individual buyers/sellers as it can degrade the quality of goods in the market over time (Akerlof, 1970; Rommel et al., 2016).

With traditional energy consuming durables (e.g. appliances, automobiles), labeling campaigns have sought to improve energy literacy and increase the adoption of efficient technologies with mixed success (Brounen and Kok, 2011; Davis and Metcalf, 2014; Howarth et al., 2000; Newell and Siikamäki, 2013). Creating a universal label for PV systems is more difficult due to the considerable differences in generation performance by location, both regionally and locally. For example, the same PV system could produce 50% less energy if placed on one side of a roof versus another, even though it is the same owner and building. Of course, labeled equipment also varies to some degree depending on usage (e.g. fuel efficiency as a function of driving style), however these are typically related to the user's behavior which often has more immediate feedback.

Experiences purchasing PV are rare (possibly once or twice in a lifetime) and are not immediately intuitive for those without experience. The experience of trusted peers offers an important proxy and increases general trust in the technology (Mundaca and Samahita, 2020; Palm, 2017; Rai and Robinson, 2013), but this is not a substitute for a personalized performance analysis. Standardized performance calculations could substitute standardized labels, however understanding the variables that drive the calculations relies on educating potential PV investors to reduce information asymmetry and uncertainty. This is particularly challenging given the need to be not only financially literate, but also informed on energy consumption, production, and have the cognitive ability capable of assessing options and making decisions (Blasch et al., 2021).

Given the importance of information flow in technology adoption, the costs of uncertainty and the potential risks from asymmetry, it is critical to assess and improve the flow and quality of PV information in the market. Previous work has described the types and sources of information user's value and the subsequent gaps in the market, however the authors are not aware of any studies describing the quality of PV information being supplied from the household PV investor's perspective. Using the Swedish market as an example, this study aims to improve the quality of solar PV information availability for household investors through the following sub-objectives:

- Identify the customer's needs, barriers, motives, and misconceptions
- Define the quality of information currently available
- Specify promising methods to serve the customer's needs for solar PV information

The Swedish PV market is relatively small by global standards, but installations are predominantly made on buildings and are growing rapidly (Lindahl et al., 2020). For many years, interest in solar energy

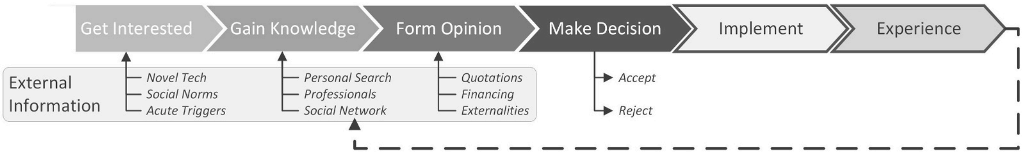

Fig. 1. Diffusion of Innovation model (with adaptations).

has been high and the typical signatures of innovation diffusion have been present (Mundaca and Samahita, 2020; Palm, 2016). The lack of information, particularly trustworthy information online, was identified as a barrier by Palm (2018) and Palm and Eriksson (2018). Since then many websites have been created by commercial, third party, and government actors to inform building owners about their solar energy potential and the steps towards procuring PV for their roofs. Of particular interest are solar calculators that provide rapid techno-economic analyses similar to installer quotations. This study builds on the work of Palm and Eriksson (2018) by analyzing the development of information delivery to non-expert, household PV investors.

2. Methodology

This study uses a user-centered design approach where User Journey Mapping (UJM) is used to frame the demand and supply of solar PV information. UJM, also known as Customer Journey Mapping, is a design technique that visualizes a user's process and interaction with a service or a product (Diana et al., 2009; Segelström, 2009).

While UJM can vary by product or service, there are five common elements: the user, scenario and expectations (i.e. goal and context), journey phases, actions and mindsets, and opportunities to improve. In this case, the users are building owners/managers who are aiming to install (or at least decide about the suitability of) a PV system (i.e. the scenario). The expectations, actions and mindset of the users are found through semi-structured interviews, labeled here as "information demand." By mapping out several users' actions and decisions towards a goal, an understanding for expectations, experience, relationships, and the most important touchpoints towards a final action or decision are created. The ability for online information sources to meet the user's demands, i.e. information supply, informs the final portion of UJM and this study's objective, opportunities to improve.

The scope is limited to PV system performance, i.e. energy production, interaction with the building, and the subsequent economic outcome. This is a limited area within the entire scope of information delivery, with the focus placed on the knowledge gain and opinion forming phases of the DoI model. Performance and cost are also the main quantified variables when forming an opinion and comparing offers, as opposed to subjective aspects such as aesthetics or pride of ownership, even though these are often strong motives to adopt.

2.1. *Information demand*

In determining demand for information, 28 semi-structured interviews are conducted with decision makers in three ownership categories; villas (n = 12), multi-family homes (n = 9), and professional property managers at firms owning residential rental properties (n = 7). All interviewees have investigated solar PV for their properties but only some have adopted, as shown in Table 1. The villa and multi-family home (MFH) representatives were recruited via social media and housing organization newsletters, while property management firms were contacted directly. The non-professional interviewees were offered a free energy consultation by the authors for their buildings related to solar energy after the interview, which was accepted by six parties.

Of the 28 interviewees, 23 are male and five are female. The average age is 54.4 years with the oldest being 89 and the youngest 39. Despite calls for participation being broadcast nationally, the majority of respondents (n = 24) are located within the Stockholm metropolitan region. Stockholm is Sweden's largest city and has the third highest absolute installation rate of PV (Lindahl et al., 2020). While specific income information was not collected, the interviewees are self-described as either professionals (n = 25) or pensioners, and include a wide range of occupations, for example; executive, investment advisor, engineer, and of course property managers. There are a lack of statistics in Sweden on the demographics of PV adopters, making it difficult to understand the representativeness of the sample, however previous homeowner surveys/interviews (Mundaca and Samahita, 2020; Palm, 2017, 2018; Palm and Eriksson, 2018) and interviews with MFH representatives (Muyingo, 2015) have similar demographics.

Table 1
Interviewees by property type and ownership of PV.

	Villas	MFH	Professional	Total
With PV	5	2	6	12
Without PV	7	7	1	16
Total	12	9	7	28

The interview structure is informed by the UJM methodology, with the purpose to follow the user's information gathering and decision processes towards buying or not buying PV. To capture the user's actions and mindset, opening questions are formed from five thematic areas – motives to own a PV system, triggers that lead to the investigation, actions taken during the process, contact points, and barriers. There is also a timing dimension, i.e. journey phases, broken into three periods – before, during, and after the installation; except for those without PV who only experience the before phase. Interviewees are asked an opening question and are free to describe their own process, which can be followed by additional questions to pull out critical aspects (e.g. timing). The opening and following questions are listed by thematic area in Table 2. Interviews are conducted in Swedish via video chat (due to the COVID-19 pandemic), recorded, transcribed, and the selected responses translated into English by the authors.

Results are organized by thematic areas and filtered to include points directly related to information searching as it applies to the "gain knowledge" and "form opinion" stages of the DoI model. Results are examined qualitatively and cross-referenced with previous literature through the lens of information demand to qualify the findings and identify novel perspectives.

2.2. *Information supply*

Online information supply and quality is tested using publicly available information channels with a focus on techno-economic calculators. All known online solar calculators in Sweden (as of April 2020) are reviewed for information supply, including PV sellers (n = 8), commercial third parties (n = 3) and governments (n = 3). At the time of testing, all of the websites were free to use, however some required that contact information be provided in order to receive the results. Two sample homes from the Stockholm region are tested in ten of the calculators, seven from PV sellers and three from third parties. Only 10 calculators could be directly compared due to incompatible information being presented or lack of geographical coverage. The results for energy production and economic outcomes are compared from the user's viewpoint of shopping for a PV system.

The selected homes are represented in Fig. 2, where the neighborhood location, home orientation, and load data and shown. The choice of homes is arbitrary insofar as they needed to be in an area covered by as many calculators as possible, however these specific homes are chosen due to their close proximity (to control for irradiation) and identical

Table 2
Interview questions by thematic area.

Thematic Area	Opening and Following Questions
Motives	What motivated you to invest in PV from the beginning?
Triggers	Describe when you first started thinking about investing in PV. What information are you looking for? And when?
Activities	What steps did you take to find information about PV?
Contact Points	Where, who, and through which channel(s) did you contact when searching for information?
Barriers	When on the journey did you feel reluctant to invest in PV? What was the cause?

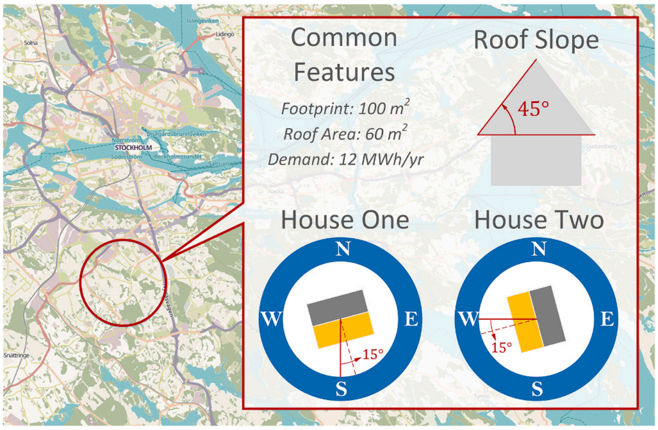

Fig. 2. Target buildings' location, orientation, and load data.

construction. This makes it possible to test the output from the tools for different cases while controlling for as many variables as possible. Likewise, the specific locations (i.e. addresses) are not critical to the results and is omitted to protect privacy.

The homes are identical in construction with 1.5 stories, an approximate footprint of 110 m^2, and are assumed to have identical electricity demand of 12,000 kWh/year, a common value for Swedish homes using electric heating systems, i.e. heat pumps without cooling (Statistics Sweden, 2013). Each has 60 m^2 of suitable roof area for PV tilted at 45° with House One's roof facing 15° east of south (165° azimuth) and House Two's facing 15° south of west (255° azimuth). The roofs suitable for PV are colored yellow in Fig. 2 [base map from (OSM, 2021)]. The houses are within 200 m of each other, meaning the only difference between them is orientation.

3. What investors want

3.1. Motives

The most common motivation for installing solar PV revealed by all investor groups is a good economic outcome. Two other secondary performance benefits were mentioned concerning the environment and self-sufficiency.

The exact meaning of "good economic outcome" varied, with the majority referring to payback time as their main metric, even the professional managers, and a few others referring to return on investment. Villa owners most often mentioned specific payback times, claiming 5–10 years was acceptable. Villa Owner no.6 who has PV, summarizes the economic motivation: "In just 7 years the investment paid off. If you compare to your alternatives, this is a great investment - nothing else is as attractive."

Property managers generally accepted longer payback times, highlighting instead the non-economic aspects of PV. Manager no.4 captures this sentiment: "We do not need very short payback times, we have a long-term outlook. It can even be 17 years." Property managers also mentioned the need to meet regulatory goals, become industry leaders, and position their firms/brands as environmentally positive. This is in contrast to villa owners and MFH representatives, who are not subject to the same regulations. As Villa Owner no.4 states, "it is politically correct to say you are 'environmentally conscious,' but for me it is about money." For MFH it can even be a legal issue, as mentioned by MFH Representative no.9: "PV must be financially profitable. It is written [in the bylaws] for a housing cooperative to benefit its members' finances, so the environment does not come as a priority."

The observed motivations for installing PV are familiar; they correspond to previous interviews in Sweden (Muyingo, 2015; Palm, 2018; Palm and Tengvard, 2011; Warneryd and Karltorp, 2020) and are similar to motives observed in other countries (Dong and Sigrin, 2019; Sommerfeld et al., 2017). It is noteworthy, however, that economic aspects are the most prominent, a sign that PV may be moving towards the early majority of adopters in Sweden (Simpson and Clifton, 2017).

3.2. Triggers

The triggers reported by all interviewees can be divided into three main categories; advertisements, internal factors, and external factors. Advertisements include offers received from a PV seller or educational material from an organization; including housing associations, government agencies, and industry groups. However, for villa owners and MFH associations, other related renovations, i.e. internal factors, are a more acute trigger. Several respondents mentioned a new roof installation and a few mentioned electric vehicle purchases.

For property managers, the search for PV was triggered by external political and public opinion pressure, which for them leads to energy performance standards that are much easier to meet with PV. Manager no.4 summarizes the situation well: "In 2015, we did not have any PV, but we saw that our colleagues had installed. It was a defenseless economy then. However our owner is the municipality, and now they have adopted a strategy that expects us as a building company to reduce our CO_2 emissions."

3.3. Activities and contact points

There is a stark difference between amateur and professional homeowners when it comes to information searching. Most of the professionals now have their own PV competence or hire an engineering consultant to evaluate their buildings. Given the larger scale and frequency of their installations, this cost can be justified. For individual villa owners or MFH representatives, much of the work must be done on their own, and will be the focus for this chapter.

Information is both pushed and pulled to the homeowners. The pushing largely comes from activist neighbors or advertisements from environmental or solar industry groups and PV suppliers. More relevant here is the active pull of information, which is primarily done by searching the internet and contacting providers for quotations.

Both villa owners and MFH representatives provided a diverse list of contact points they collect information from. General information is collected from semi-neutral third parties, mainly solar or building industry expos, government websites, and community members. When personal, detailed analysis is needed, the vast majority relied on private companies to provide calculations, usually through quotations. Being able to discuss personal situations with a professional is tantamount to a consultation, however several respondents mentioned issues of trust regarding their calculations. Villa Owner no.2 states, "This winter it has been dark most of the time, I feel unsure of the figures that suppliers give in the average solar time for panel. Feels like wishful thinking." Villa Owner no.12 confirms, "It's hard to buy an assumption about what I can get out of it [PV generation], which is based on a dream scenario."

One MFH representative mentioned that they would like to have an outside consultant review their quotes, stating that they don't know what to look for. This is analogous to the situation online, where users do not have the time or expertise to parse out good information. Villa Owner no.4 reflects this sentiment well: "There is too much information online and it is too difficult to find the 'right' answer."

3.4. Barriers

As mentioned in chapter 3.1, the respondents cited self-sufficiency as a motivation for having PV. This is not particularly new (Juntunen and Martiskainen, 2021), however it is noteworthy the level they were aware of the interaction between PV, their building, and the grid. Investors are generally aware that during a sunny day, most PV generation is sold to the grid due to low loads in the home, and during winter there is very little generation relative to summer as well as their building demand. Some think about this in a purely technical aspect, as Villa Owner no.12 put it, “PV is not an optimal product for our family. We may consider installing panels later, so we have an external battery to capture energy when we are not using it.” MFH cooperatives have a similar challenge due to the apartments often having independent electricity meters, meaning the PV generation can only service communal loads. As MFH Representative no.7 states, “it does not pay to give electricity only to the property, for example the laundry room.”

This statement ties into the economic portion of self-consumption and self-sufficiency. There is a belief that selling to the grid is economically undesirable and should be avoided, as MFH Representative no.7 stated, “When we sell we get the electricity trading price [wholesale market]. That’s not so much bang for the buck if we need to sell back.” MFH Representative no.3 confirms, " 90% [of the PV generation] should be consumed in your own facility for it to be profitable.” This leads many to think about battery storage as a necessary part of the system. Even with their 50% investment subsidy, stationary batteries at their current price have marginal economic performance in Sweden, restricting their attraction to innovators or early-adopters. This leads most investors to the conclusion that because PV and batteries do not pay off, then PV alone will also not pay off. The self-consumption issue is heterogeneous amongst building types due to the policies around prosumer support (Lindahl et al., 2020). On top of the market price, most prosumers earn a tax credit on sales that nearly eliminates the penalty for low self-consumption, but since the program relies on the taxation system, it can be complicated for some actors to benefit from it.

Another common barrier to adoption is the uncertainty around technical and economic performance. The majority of contact points for respondents were PV suppliers who are generally the only source for a personalized analysis of their home/building. Finding trustworthy information and installers to compare offers was found to be a common challenge, which is consistent with Palm and Eriksson (2018) for Sweden and is a theme noted in other countries (Rai and Robinson, 2013; Scheller et al., 2020; Tanaka et al., 2017). This barrier is being lowered by the development of online solar calculators and a platform for finding and rating installers analogous to other industries (e.g. Angie’s List), however the internet tended to be more of a liability than an asset to information supply. MFH Representative no.4’s comment captures this best: “The internet [calculators] does not give real numbers, we do not trust this at all. Therefore, we do not get a credible picture.”

4. What investors get

The online solar calculators can be divided into three main types; manual input, solar maps, and a manual/map hybrid. Manual input asks the user to directly enter or select values such as roof area, pitch, orientation, etc. that are used for calculating solar production. Solar maps are geographical information system (GIS) databases where the solar irradiation is pre-calculated using 3D building geometry data, which can then be used to determine PV production. Manual/map hybrids are the most common type where the user’s inputs are aided by a map, for example by allow them to graphically select the roof area and orientation.

All of the websites investigated for the study are listed in Table 3. For the calculators that are compared quantitatively, the inputs used for each house are also given. In the case of Hybrid style sites, the roof area is usually selected by drawing on a satellite image, leading to small discrepancies between the homes. From a strict view of calculation comparisons, the differences in area could be seen as an unacceptable inaccuracy. However, it is more relevant here to test the tools as a user would, which results in discrepancies due to the user interface. The larger differences are due to the calculators using a horizontal footprint (areas closer to 40 m^2) or those considering the roof’s inclination (areas closer to 60 m^2). The roof areas from fortum.se are predefined, include the entire roof area (regardless of its suitability for PV), and is not editable by the user, hence the reason why areas are doubled in this case.

Aside from area selection, the websites vary with input style. Many use graphical inputs without numerical confirmation, for example using “south” or “west” to denote orientation instead of degrees. Some also use ranges to help users estimate their values, such as a 31°–60° slope. In all cases where direct input is not available, the closest possible input to the known conditions of each house are used. Where “NA” is listed at kraftringen.se, the user provides a graphical input for the azimuth but does not receive numerical confirmation. For variables where “No In” is listed, the websites do not have an input. Some sites have additional inputs not listed here, for example the selection of different module types or roof material. In these cases, the most neutral PV modules offered that balance efficiency and cost are selected, as well as a tile roof.

If online solar calculators are built to inform investors during the opinion forming phase, it is reasonable to assume that most aim to answer the question – do I want a PV system on my house? To answer this question, there is a lot of supporting information that needs to be provided, for example; how much PV should I have? How much will it cost? How much will it save? The following sections compare the information provided in answering these questions.

4.1. Key performance indicators

The presentation form and key performance indicator (KPI) selection of the results varies considerably with each calculator. Graphical and/or user-experience design is outside the scope of this study, so focus is placed on *what* information is presented rather than *how* it is present. In Fig. 3, a list of all found KPIs are categorized by type with a stacked column showing frequency of use by provider type. Here it can be seen that upfront system cost and annual generation are nearly ubiquitous. System size (in various forms) is also reported in all of the calculators aside from the government websites, which do not recommend specific PV systems. This makes the government provided tools difficult to compare with commercial websites, which is discussed further in Chapter 5.

The general information delivery for the PV sellers and third parties is structured as followed;

- a recommended system size (by panel count or area),
- a quote for the total cost (varying by inclusion of subsidy),
- annual electricity generation, and
- annual money saved from the subsequent generation.

It can be noted that the economic benefits of PV are focused much more on savings versus investment KPIs. However, the costs and benefits tend to be shown separately, leaving the user to calculate the net lifecycle savings on their own. In the websites that do present lifecycle savings (i.e. net value), only one calculator from a third party applies discounting to calculate net present value. By far the most common investment metric is simple payback time, which appears in eight of the fourteen calculators; double that of the next most common, internal rate of return.

Given that motives for adopting solar PV are often environmental, it is interesting that all of the calculators place a high emphasis on economic results and none of the PV sellers provide greenhouse gas (GHG) savings. Instead, they focus on what the solar energy can be used for, e.g. cooking, laundry, or distance in an electric vehicle, to make the results relatable to everyday life. While useful, this can also enhance the rebound effect, where users increase energy consumption following an efficiency or PV investment and negate a portion of the energy savings

Table 3
Websites investigated and input parameters used in quantitative comparison.

Website			House One				House Two			
Address	Owner	Style	Area (m^2)	Azimuth (deg)	Slope (deg)	Elec. Use (MWh/yr)	Area (m^2)	Azimuth (deg)	Slope (deg)	Elec. Use (MWh/yr)
eon.se/solceller/solcellskalkyl	Seller	Direct	40–60	South	31–60	12	40–60	West	31–60	12
fortum.se/privat/solceller	Seller	Hybrid	114	−15	45	12	120	75	45	12
gosol.se/solcellskalkylator	Seller	Direct	41–60	South	31–60	10–15	41–60	West	31–60	10–15
hemsol.se	3rd Party	Hybrid	61	−15	45	12	59	−15	45	12
solceller.kraftringen.se	Seller	Hybrid	NA	NA	31+	No In	NA	NA	31+	No In
solcellskollen.se	3rd Party	Direct	NA	South	45	12	NA	West	45	12
solkollen.nu/test	3rd Party	Hybrid	57	South	45	No In	61	West	45	No In
sveasolar.com/se/solcellskalkylator	Seller	Hybrid	41	South	45	12	41	West	45	12
telgeenergi.se/privat/solceller	Seller	Direct	60	No In	No In	12.2	60	No In	No In	12.2
vattenfall.se/solceller	Seller	Hybrid	44	South	31+	No In	44	West	31+	No In
otovo.se	Seller	Hybrid	–	–	–	–	–	–	–	–
gi.karlstad.se/solkartan/#	Govt.	Map	–	–	–	–	–	–	–	–
energiradgivningen.se/solkartan	Govt.	Map	–	–	–	–	–	–	–	–
energimyndigheten.se/fornybart/solelportalen	Govt.	Direct	–	–	–	–	–	–	–	–

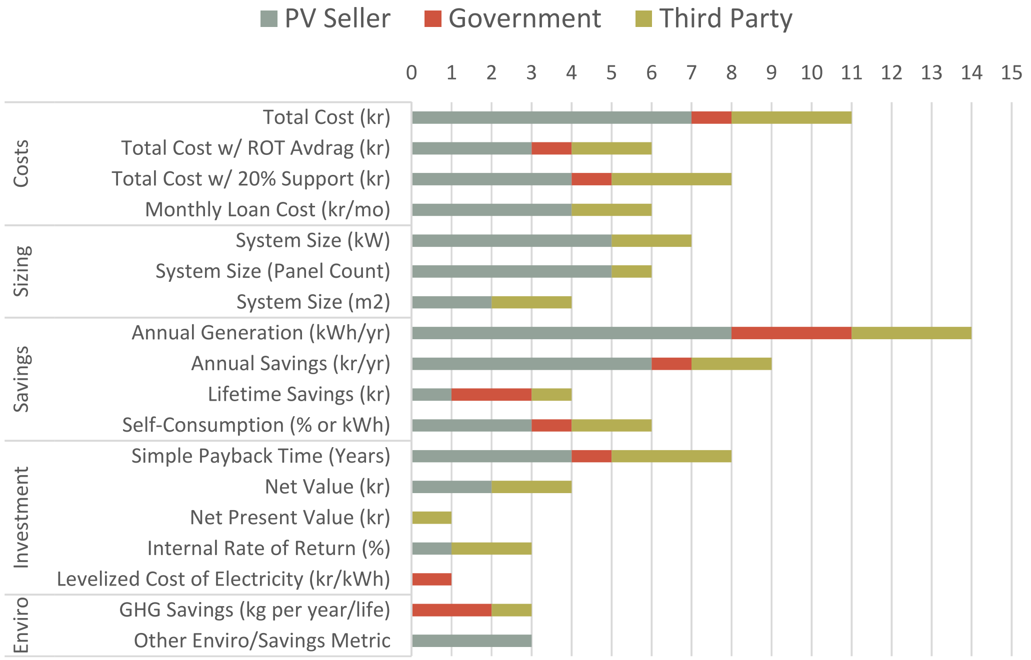

Fig. 3. Instances of KPI by provider type (14 sites in total).

(Deng and Newton, 2017; Qiu et al., 2019). Surprisingly, one website uses an airplane trip, which is a completely different energy form[1] (electricity vs. petroleum fuel). This analogy is most likely meant to invoke thoughts of a high climate impact activity; however, it could also trigger a negative spillover by suggesting the user is has moral license to take a guilt-free holiday as a reward for installing solar panels (Sorrell et al., 2020).

4.2. *Calculator results*

A selection of results from the calculators for the south facing roof are given in Fig. 4 comparing the system size, generation, installation cost, and economic benefits. Marker shapes represent the provider type, which is only PV Sellers (round) and Third Parties (diamond), while the colors individualize. To increase the number of comparisons, some KPIs have been derived from the information provided by the tools (for example, calculating system capacity in kW_p when only panel count and power rating are provided).

The specific values in Fig. 4 are not important, but rather the broad range of results found for a single house. Recommended systems range from 6.9 to 10.3 kW_p in size, producing 4280 kWh/yr to 10,000 kWh/yr (equivalent to 36%–83% of annual demand). Much of this difference in

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[1] It is worth noting that Sweden is also the birthplace of the “flight shame” social movement with the aim of reducing the environmental impact of aviation, although it is unknown if a direct connection is intended here by the site’s designers.

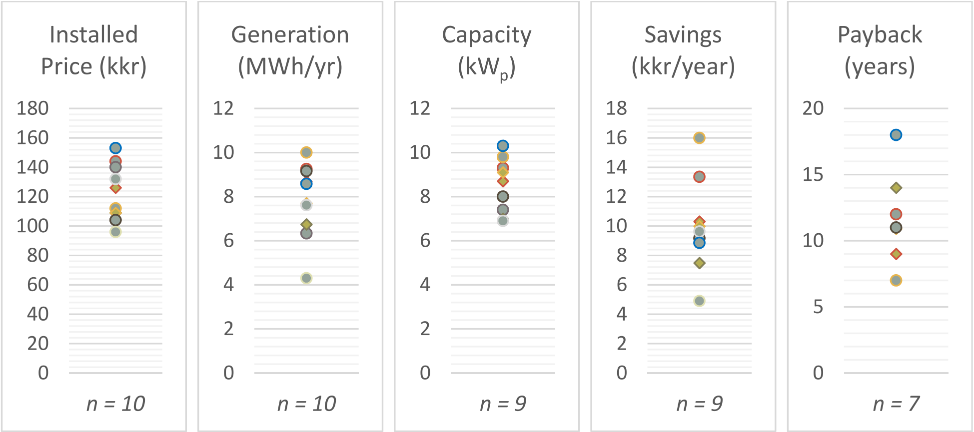

Fig. 4. Select techno-economic results from online solar calculators.

sizing is due to the methods for collecting and processing available roof area – some calculators rely on user input versus pre-defined areas, some assume the full selected area is available, and some reduce the area by a fixed percentage. Subsequently, the annual generation is also a function of system sizing, but also differences in productivity that are shown in Fig. 5 and discussed later in this section. Regardless of the method used to define available roof area, a common approach of all tools is to fill that area as much as possible with PV.

For some KPIs, the differences in technical parameters directly translate to differences in economic outcomes. The potential cost ranges from 96 to 153 thousand kronor (kkr), again influenced by system size but also specific price. Perhaps the widest range of results can be found in annual savings, where the highest value is more than three times larger than the smallest. While this is in part due to the size and generation, the wider gap in saving as compared to generation highlights the differences in electricity price assumptions. This is also reflected in the payback times, influenced by both installation price and annual savings, where the shortest time is seven years and the longest is 18 years.

To remove the influence of system sizing and roof area assumption on the results, the annual yield (i.e. specific generation, in kWh/kW_p) and specific installation price (in kr/W_p) are shown in Fig. 5. It is important to note that these values are not given to users directly by any of the calculators, and it is unlikely that most household investors would have the knowledge or motivation to compare results in this way without previous experience or education in solar PV systems.

Yield ranges from 836 to 1145 kWh/kW_p with an average of 975 kWh/kW_p. The most common yield in the Stockholm region is 810 kWh/kW_p (Schelin, 2019), so given that the south facing roof has a nearly optimal orientation for the location it is expected that yield should be higher than average. 1145 kWh/kW_p, however, would place it as one of the most productive systems in Sweden even though the solar irradiation in Stockholm is approximately 10% lower than the sunniest region (SMHI, 2014). Specific prices range from 14.3 to 19.2 kr/W_p with an average of 16.9 kr/W_p. Variations in price is less surprising given that providers offer different products with varying levels of quality and performance. In some calculators, users can even select between different modules to compare how aesthetics and efficiency affect price. However, given that specific price is not presented directly in any calculator, it is more difficult for investors to compare results from different providers.

Comparing results between the south- and west-facing roofs in Fig. 6

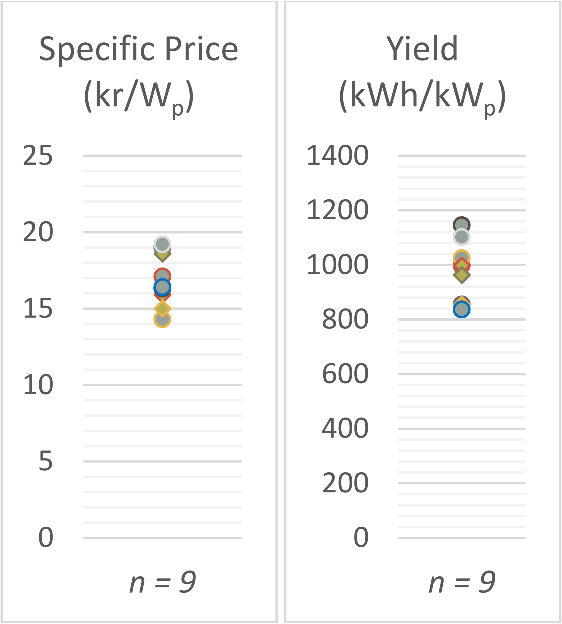

Fig. 5. Specific prices and yield from select online solar calculators.

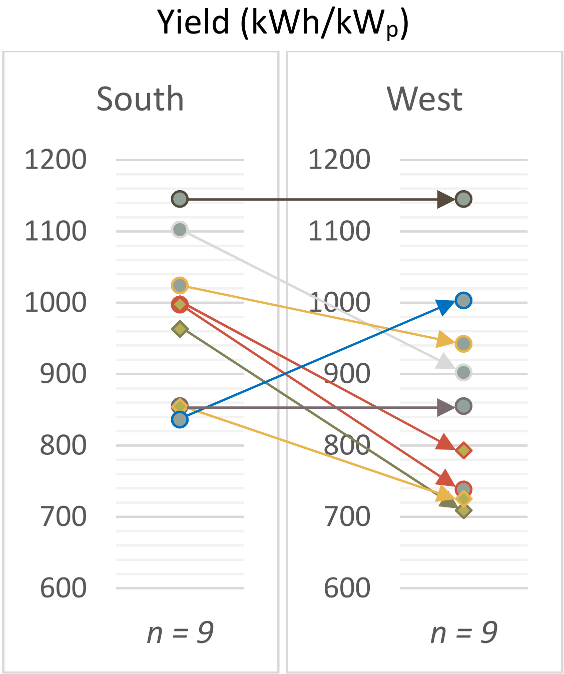

Fig. 6. Yield comparison between the south- and west-facing roofs.

provides additional insight into the calculators' assumptions and methods. The variance for the western roof is comparable to the southern and production declines are between a reasonable 15%–25%. Surprisingly, two of the calculators show no difference in yield and one calculator actually shows an increase. The calculator showing an increase is most likely a software bug, however the calculators showing no reduction for a roof that should have approximately 20% less yield could be considered misleading, particularly given that they ask the user for roof orientation as an input. One additional calculator not shown here does not ask for orientation as an input, and therefore also shows the same yield for any given area.

5. Discussion

Generally speaking, the rapid growth of online information sources is a positive development in response to previously identified barriers (Palm and Eriksson, 2018). The high-level overview presented here, however, demonstrates that more information may not necessarily lead to more informed decision making. The inconsistency in results make comparing quotes/analyses nearly impossible for the average household investor. Even for the authors who have considerable experience in the field, deconstructing the methods and assumptions of each calculator was challenging or impossible with the limited information provided.

One potential solution is a standardized method of analysis within the PV industry. It is relatively easy to manipulate boundary conditions without the customer's full understanding, allowing several sites to present what should be considered a best possible outcome. One recent project aimed to produce such a standard (Stridh and Larsson, 2017), however it focused on levelized cost of energy as the main KPI, which does not take into consideration savings and revenues (i.e. economic benefits) that most investors ask for. Another issue is the changing prices over time, both for PV systems and electricity prices. Therefore, any harmonization within the industry would require regular updating.

In the near term, the practicality and feasibility of industry standards is questionable. To establish standards would require the agreement of many stakeholders on boundary conditions that have a high uncertainty about a long-term future. This is not impossible to overcome, but would likely take time to craft and implement. As mentioned above, the standards would require maintenance as new information updates the expectations about the future, but this is also not an impassable barrier. Perhaps the most challenging aspect is that neither industry nor government will be motivated to threaten the PV industry's rapid growth. Most stakeholders would likely agree that more PV is generally good, so if standards were enforced there is a chance they could just codify optimistic outlooks rather than provide a balanced analysis for investors.

Another solution is non-commercial or third party calculators. There are already several commercial third parties with online calculators, but as the results above show, their results are as equally varied as the PV sellers. This could be due to their own need to monetize their calculators by providing sales leads, which is harder to do with less optimistic assumptions. It is worth noting, however, that the most conservative result did come from a third-party calculator.

Ideally, a calculator would be provided by a third party with a high level of trust that does not directly profit from PV sales. The Swedish Energy Agency's website dedicated to solar energy education does offer a calculation tool with several positive aspects, such as sliders for easy input changes and explanations of what reasonable inputs should be (Swedish Energy Agency, 2021). However, it is difficult for the average household investor to personalize it or validate installer offers due to the PV productivity being input in annual yield (kWh/kW_p). No other solar calculators or maps provide this value to users directly, meaning they must understand how to make the calculation themselves. Another government provided online tool are solar maps, which allow users to find their building and see how much solar radiation is available on the roof. It requires more expertise to convert this value into an annual PV yield than what the commercial tools provide, therefore a gap remains in the market for a truly neutral application that can benchmark commercial PV analyses.

In addition to the source of information, the form or quality of information delivery is also of importance. It is already known that potential PV investors in Sweden have heterogeneous needs for information (Palm and Eriksson, 2018), therefore information delivery must cater to diverse needs. For example, the use of nudging versus boosting, i.e. heuristic (System 1) versus contemplative (System 2) decision making (DellaValle and Sareen, 2020). Boosting in particular requires careful presentation of information such that it enhances users' cognitive abilities rather than taxing them. This is a common challenge with decisions under uncertainty, and the methods of communicating probabilities have significant influence on individual's ability to choose wisely, particularly in a rare, unfamiliar event like a PV investment (Hertwig et al., 2011; Tubau et al., 2019).

It should be asked then if there is any harm caused by the current status of information supply for household PV investors? Given the rapid growth in PV installations in Sweden, particularly in buildings, information asymmetry is not harming the quantity of PV systems in the market as has for other energy products (Collins and Curtis, 2017). For example, LEED certified buildings are well documented to underperform expectations (Hu, 2021; Scofield, 2009), leading to public criticism (Swearingen, 2014), yet claims of energy savings continues (Scofield and Cornell, 2019). What is less certain is if this is harming the quality of PV systems in the market. If unrealistic expectations are placed on the economic performance, suppliers will be incentivized to provide lower quality products that can meet installation price targets (Mauritzen, 2020; Rommel and Sagebiel, 2017). Given that the quality of a PV module or inverter is impossible to distinguish from casual observation, and will likely not reveal itself for several years, investors have very little ability to judge if the product they have received will perform as well or as long as advertised. If/when quality deficiencies arise, trust erodes which can then negatively influence the number of new installations (Liu et al., 2018). Similar to other "green" building products/systems, future work is needed to empirically confirm any trends in PV quality.

Overly positive economic outcomes are also easy to overestimate through either optimistic generation or electricity prices. If PV investors are tracking their systems closely, then after two or three years they would begin to observe the deviating trends and are likely to share this information with other potential investors. This negative influence on PV's reputation would likely be revealed faster than quality issues, potentially creating a gap between the early adopters and early majority (Simpson and Clifton, 2017). Although the data is still sparse, reports of underperforming systems are beginning to emerge, suggesting this latter risk to the PV industry may become more acute (Kovacs, 2019).

The potential for trust degradation to occur is only speculative at this point, however the conditions are in place. Today the vast majority of PV owners in Sweden only receive a single quotation, often using a firm recommended from a trusted peer (Falkenström and Johansen, 2020; Kovacs, 2019). In this case, the solar calculators can act as tools for confirmation bias, i.e. demonstrating quantitatively the performance expectations owner's expect and/or want to hear, rather than supporting informed, independent decisions. Without conflicting messages, unrealistic expectations are free to spread. There is little messaging in the market to suggest that PV isn't a good choice, with payback times of 7–10 years being colloquially stated as "typical" for most villas (Redaktionen Stordåhd, 2021) even though that outcome is optimistic given the results shown here and elsewhere (Sommerfeldt and Madani, 2017). It is easy to imagine a point in the near future where a number of unsatisfied customers are highlighted in the media and undermine the trust of an industry that has over-promised and under-delivered. This is when the long-term harm would be revealed.

6. Conclusions and policy implications

This article has taken a user-centric approach to describe the current demand and supply of information for potential household PV investors in Sweden. The results show that household investors are becoming more sophisticated in their informational needs, however the gaps in information supply found by Palm and Eriksson (2018) remain despite the rapid increase in online information sources. The example homes tested by online PV calculators reveals that the information being provided is high on quantity but not necessarily quality, with high variance in the techno-economic performance and system recommendations. While third party tools from government agencies exist, their form is not compatible with commercial offerings reducing their effectiveness as an arbiter of information. As it is today, most online calculators are marketing tools aiming to attract customers to the brand, collect contact information, and then build a relationship through dialog.

Two potential solutions have been discussed; the creation of industry standards and a neutral, authoritative information source. At a systemic level, standardizing calculation methods would help reduce uncertainty and differentiate suppliers based on quality and price. This could be achieved through industry organization, but similar consumer protection standards around building simulations have come through government regulation. The main challenge however, is that both industry and government stakeholders are motivated to grow the PV industry, and given the lack of an immediate threat to PV investors (i.e. the harm reveals itself over time), standards are unlikely to provide a timely solution.

A neutral information source is more likely given that the Swedish Energy Agency is already committed to providing PV investors with timely information, including their own calculator, is already in place. Therefore, future work to improve their calculator for nudging and boosting is the most promising pathway to solving the information problem for PV investors. A relatively quick and easy improvement would be to update the inputs and/or outputs of their calculator to be more compatible with commercial offerings, where users could directly enter and/or compare the results they receive in offers. This would act as a benchmarking tool from a trusted authority.

A more ambitious, and in our view necessary, improvement would be a revised calculator design that takes into account aspects of nudging and boosting. Unlike other energy efficiency products, the performance and benefits of PV systems do not as easily permit the simple labeling typically used to educate investors/consumers. Therefore, online calculators should adopt educational features so that PV investors are more empowered. Two critical aspects that should be included are results personal to the user (Khosrowpour et al., 2016) and dynamic/interactive feedback (Beck et al., 2017). Serious games are another approach that have proven effective at closing information gaps (Rai and Beck, 2017).

Regardless of who provides the information, the techno-economic analyses commonly communicated with potential PV investors suffer from lack of accuracy, transparency, and certainty. Therefore, we suggest rethinking and restructuring the communication methods and strategies around education rather than marketing, which can also be the subject of future work. We propose not only developing web-based, personal, and interactive tools, but using them for experimentation to understand the most effective user experiences and communication methods for PV. For example, how to balance motives (self-sufficiency, economy, and environment) and when/how to present information for the desired cognitive strategy (nudge vs. boost). Such studies could help inform policy on a balance between economic and behavioral interventions (Loewenstein and Chater, 2017) and even improve direct communication through traditional sales channels.

Regardless of the information source, future communication strategies should focus on transparency and honesty in order to avoid the risk of trust erosion. Solar PV technology plays a pivotal role in achieving national and international climate goals as well as Sustainable Development Goals. If the PV industry over-promises and under-delivers, it could hinder the long-term progress towards a highly electrified and sustainable future society.

CRediT authorship contribution statement

Nelson Sommerfeldt: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft. **Ida Lemoine:** Methodology, Investigation, Data curation, Writing – review & editing. **Hatef Madani:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Akerlof, G.A., 1970. The market for “lemons”: quality uncertainty and the market mechanism. Q. J. Econ. 84, 488–500. https://doi.org/10.2307/1879431.

Allcot, H., Greenstone, M., 2012. Is there an energy efficiency gap? J. Econ. Perspect. 26, 3–28. https://doi.org/10.1257/jep.26.1.3.

Ansar, J., Sparks, R., 2009. The experience curve, option value, and the energy paradox. Energy Pol. 37, 1012–1020. https://doi.org/10.1016/j.enpol.2008.10.037.

Bauner, C., Crago, C.L., 2015. Adoption of residential solar power under uncertainty: implications for renewable energy incentives. Energy Pol. 86, 27–35. https://doi.org/10.1016/j.enpol.2015.06.009.

Beck, A.L., Lakkaraju, K., Rai, V., 2017. Small is big: interactive trumps passive information in breaking information barriers and impacting behavioral antecedents. PLoS One 12, 1–16. https://doi.org/10.1371/journal.pone.0169326.

Blasch, J., Boogen, N., Daminato, C., Filippini, M., 2021. Empower the consumer! energy-related financial literacy and its implications for economic decision making. Econ. Energy Environ. Policy 10. https://doi.org/10.5547/2160-5890.10.2.JBLA.

Bollinger, B., Gillingham, K., 2012. Peer effects in the diffusion of solar. Mark. Sci. 31, 900–912. https://doi.org/10.1287/mksc.1120.0727.

Broers, W.M.H., Vasseur, V., Kemp, R., Abujidi, N., Vroon, Z.A.E.P., 2019. Decided or divided? An empirical analysis of the decision-making process of Dutch homeowners for energy renovation measures. Energy Res. Soc. Sci. 58, 101284. https://doi.org/10.1016/j.erss.2019.101284.

Brounen, D., Kok, N., 2011. On the economics of energy labels in the housing market. J. Environ. Econ. Manag. 62, 166–179. https://doi.org/10.1016/j.jeem.2010.11.006.

Collins, M., Curtis, J., 2017. Identification of the Information Gap in Residential Energy Efficiency: How Information Asymmetry Can Be Mitigated to Induce Energy Efficiency Renovations (No. 558). ESRI.

Davis, L.W., Metcalf, G.E., 2014. Does Better Information Lead to Better Choices? Evidence from Energy-Efficiency Labels.

Defaix, P.R., van Sark, W.G.J.H.M., Worrell, E., de Visser, E., 2012. Technical potential for photovoltaics on buildings in the EU-27. Sol. Energy 86, 2644–2653. https://doi.org/10.1016/j.solener.2012.06.007.

DellaValle, N., Sareen, S., 2020. Nudging and boosting for equity? Towards a behavioural economics of energy justice. Energy Res. Soc. Sci. 68, 101589. https://doi.org/10.1016/j.erss.2020.101589.

Deng, G., Newton, P., 2017. Assessing the impact of solar PV on domestic electricity consumption: exploring the prospect of rebound effects. Energy Pol. 110, 313–324. https://doi.org/10.1016/j.enpol.2017.08.035.

Diana, C., Pacenti, E., Tassi, R., 2009. Visualtiles: communication tools for (service) design. In: Clatworthy, S., Nisula, J.-V., Holmlid, S. (Eds.), ServDes.2009 - DeThinking Service, ReThinking Design, pp. 65–76. Oslo.

Dong, C., Sigrin, B., 2019. Using willingness to pay to forecast the adoption of solar photovoltaics: a “parameterization + calibration” approach. Energy Pol. 129, 100–110. https://doi.org/10.1016/j.enpol.2019.02.017.

Drury, E., Miller, M., Macal, C.M., Graziano, D.J., Heimiller, D., Ozik, J., Perry IV, T.D., 2012. The transformation of southern California's residential photovoltaics market through third-party ownership. Energy Pol. 42, 681–690. https://doi.org/10.1016/j.enpol.2011.12.047.

Falkenström, J., Johansen, K., 2020. Köpprocessen Vid Köp Av Solceller I Sverige (The Purchasing Process of PV Systems in Sweden). Luleå tekniska universitet.

Fleiß, E., Hatzl, S., Seebauer, S., Posch, A., 2017. Money, not morale: the impact of desires and beliefs on private investment in photovoltaic citizen participation initiatives. J. Clean. Prod. 141, 920–927. https://doi.org/10.1016/j.jclepro.2016.09.123.

Gagnon, P., Margolis, R., Melius, J., Phillips, C., Elmore, R., 2016. Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment (NREL/TP-6A20-65298).

Gillingham, K., Palmery, K., 2014. Bridging the energy efficiency gap: policy insights from economic theory and empirical evidence. Rev. Environ. Econ. Pol. 8, 18–38. https://doi.org/10.1093/reep/ret021.

Gillingham, K., Newell, R.G., Palmer, K., 2009. Energy efficiency economics and policy. Annu. Rev. Resour. Econ. 1, 597–620. https://doi.org/10.1146/annurev.resource.102308.124234.

Graziano, M., Fiaschetti, M., Atkinson-Palombo, C., 2019. Peer effects in the adoption of solar energy technologies in the United States: an urban case study. Energy Res. Soc. Sci. 48, 75–84. https://doi.org/10.1016/j.erss.2018.09.002.

Greene, D.L., 2011. Uncertainty, loss aversion, and markets for energy efficiency. Energy Econ. 33, 608–616. https://doi.org/10.1016/j.eneco.2010.08.009.

Hassett, K.a., Metcalf, G.E., 1993. Energy conservation investment: do consumers discount the future correctly? Energy Pol. 21, 710–716. https://doi.org/10.1016/0301-4215(93)90294-P.

Hausman, J., 1979. Individual discount rates and the purchase and utilization of energy-using durables. Bell J. Econ. 10, 33–54. https://doi.org/10.2307/3003318.

Hertwig, R., Barron, G.M., Weber, E.U., Erev, I., 2011. Decisions from experience and the effect of rare events in risky choice. SSRN Electron. J. 15, 534–539. https://doi.org/10.2139/ssrn.1301100.

Howarth, R.B., Andersson, B., 1993. Market barriers to energy efficiency. Energy Econ. 15, 262–272. https://doi.org/10.1016/0140-9883(93)90016-K.

Howarth, R.B., Haddad, B.M., Paton, B., 2000. The economics of energy efficiency: insights from voluntary participation programs. Energy Pol. 28, 477–486. https://doi.org/10.1016/S0301-4215(00)00026-4.

Hu, M., 2021. 2019 energy benchmarking data for LEED-certified buildings in Washington, D.C.: simulation and reality. J. Build. Eng. 42, 102475. https://doi.org/10.1016/j.jobe.2021.102475.

IEA, 2021. Net Zero by 2050. Paris.

Jaffe, A.B., Stavins, R.N., 1994. The energy paradox and the diffusion of conservation technology. Resour. Energy Econ. https://doi.org/10.1016/0928-7655(94)90001-9.

Juntunen, J.K., Martiskainen, M., 2021. Improving understanding of energy autonomy: a systematic review. Renew. Sustain. Energy Rev. 141, 110797. https://doi.org/10.1016/j.rser.2021.110797.

Kastner, I., Stern, P.C., 2015. Examining the decision-making processes behind household energy investments: a review. Energy Res. Soc. Sci. 10, 72–89. https://doi.org/10.1016/j.erss.2015.07.008.

Khosrowpour, A., Xie, Y., Taylor, J.E., Hong, Y., 2016. One size does not fit all: establishing the need for targeted eco-feedback. Appl. Energy 184, 523–530. https://doi.org/10.1016/j.apenergy.2016.10.036.

Korcaj, L., Hahnel, U.J.J., Spada, H., 2015. Intentions to adopt photovoltaic systems depend on homeowners' expected personal gains and behavior of peers. Renew. Energy 75, 407–415. https://doi.org/10.1016/j.renene.2014.10.007.

Kovacs, P., 2019. Besiktningar Av Mindre Solcellsanläggningar I Drift (Examination of Small PV Installations in Operation).

Kowalska-Pyzalska, A., 2018. What makes consumers adopt to innovative energy services in the energy market? A review of incentives and barriers. Renew. Sustain. Energy Rev. 82, 3570–3581. https://doi.org/10.1016/j.rser.2017.10.103.

Lindahl, J., Dahlberg-Rosell, M., Oller-Westerberg, A., 2020. National Survey Report of PV Power Applications in Sweden 2019.

Liu, Y., Hong, Z., Zhu, J., Yan, J., Qi, J., Liu, P., 2018. Promoting green residential buildings: residents' environmental attitude, subjective knowledge, and social trust matter. Energy Pol. 112, 152–161. https://doi.org/10.1016/j.enpol.2017.10.020.

Loewenstein, G., Chater, N., 2017. Putting nudges in perspective. Behav. Publ. Pol. 1, 26–53. https://doi.org/10.1017/bpp.2016.7.

Mauritzen, J., 2020. Are solar panels commodities? A Bayesian hierarchical approach to detecting quality differences and asymmetric information. Eur. J. Oper. Res. 280, 365–382. https://doi.org/10.1016/j.ejor.2019.07.001.

Mundaca, L., Samahita, M., 2020. What drives home solar PV uptake? Subsidies, peer effects and visibility in Sweden. Energy Res. Soc. Sci. 60, 101319. https://doi.org/10.1016/j.erss.2019.101319.

Muyingo, H., 2015. Organizational challenges in the adoption of building applied photovoltaics in the Swedish tenant-owner housing sector. Sustainability 7, 3637–3664. https://doi.org/10.3390/su7043637.

Newell, R.G., Siikamäki, J.V., 2013. Nudging Energy Efficiency Behavior: the Role of Information Labels. https://doi.org/10.1016/j.yexmp.2014.03.001. No. 19224).

OSM, 2021. Open Street Map [WWW Document]. URL. https://www.openstreetmap.org/.

O'Shaughnessy, E., Barbose, G., Wiser, R., Forrester, S., Darghouth, N., 2021. The impact of policies and business models on income equity in rooftop solar adoption. Nat. Energy 6, 84–91. https://doi.org/10.1038/s41560-020-00724-2.

Palm, A., 2016. Local factors driving the diffusion of solar photovoltaics in Sweden: a case study of five municipalities in an early market. Energy Res. Soc. Sci. 14, 1–12. https://doi.org/10.1016/j.erss.2015.12.027.

Palm, A., 2017. Peer effects in residential solar photovoltaics adoption—a mixed methods study of Swedish users. Energy Res. Soc. Sci. 26, 1–10. https://doi.org/10.1016/j.erss.2017.01.008.

Palm, J., 2018. Household installation of solar panels – motives and barriers in a 10-year perspective. Energy Pol. 113, 1–8. https://doi.org/10.1016/j.enpol.2017.10.047.

Palm, J., Eriksson, E., 2018. Residential solar electricity adoption: how households in Sweden search for and use information. Energy. Sustain. Soc. 8, 1–9. https://doi.org/10.1186/s13705-018-0156-1.

Palm, J., Tengvard, M., 2011. Motives for and barriers to household adoption of small-scale production of electricity : examples from Sweden. Sustain. Sci. Pract. Pol. 7, 6–15.

Qiu, Y., Kahn, M.E., Xing, B., 2019. Quantifying the rebound effects of residential solar panel adoption. J. Environ. Econ. Manag. 96, 310–341. https://doi.org/10.1016/j.jeem.2019.06.003.

Rai, V., Beck, A.L., 2015. Public perceptions and information gaps in solar energy in Texas. Environ. Res. Lett. 10 https://doi.org/10.1088/1748-9326/10/7/074011.

Rai, V., Beck, A.L., 2017. Play and learn: serious games in breaking informational barriers in residential solar energy adoption in the United States. Energy Res. Soc. Sci. 27, 70–77. https://doi.org/10.1016/j.erss.2017.03.001.

Rai, V., Robinson, S. a, 2013. Effective information channels for reducing costs of environmentally- friendly technologies: evidence from residential PV markets. Environ. Res. Lett. 8, 014044 https://doi.org/10.1088/1748-9326/8/1/014044.

Rai, V., Sigrin, B., 2013. Diffusion of environmentally-friendly energy technologies: buy versus lease differences in residential PV markets. Environ. Res. Lett. 8 https://doi.org/10.1088/1748-9326/8/1/014022.

Rai, V., Reeves, D.C., Margolis, R., 2016. Overcoming barriers and uncertainties in the adoption of residential solar PV. Renew. Energy 89, 498–505. https://doi.org/10.1016/j.renene.2015.11.080.

Reeves, D.C., Rai, V., Margolis, R., 2017. Evolution of consumer information preferences with market maturity in solar PV adoption. Environ. Res. Lett. 12 https://doi.org/10.1088/1748-9326/aa6da6.

Rogers, E.M., 2003. Diffusion of Innovations, fifth ed. Free Press.

Rommel, K., Sagebiel, J., 2017. Preferences for micro-cogeneration in Germany: policy implications for grid expansion from a discrete choice experiment. Appl. Energy 206, 612–622. https://doi.org/10.1016/j.apenergy.2017.08.216.

Rommel, J., Sagebiel, J., Müller, J.R., 2016. Quality uncertainty and the market for renewable energy: evidence from German consumers. Renew. Energy 94, 106–113. https://doi.org/10.1016/j.renene.2016.03.049.

Scarpa, R., Willis, K., 2010. Willingness-to-pay for renewable energy: primary and discretionary choice of British households ' for micro-generation technologies. Energy Econ. 32, 129–136. https://doi.org/10.1016/j.eneco.2009.06.004.

Schelin, E., 2019. Photovoltaic System Yield Evaluation in Sweden. Mälardalen University.

Scheller, F., Doser, I., Sloot, D., McKenna, R., Bruckner, T., 2020. Exploring the role of stakeholder dynamics in residential photovoltaic adoption decisions: a synthesis of the literature. Energies 13, 6283. https://doi.org/10.3390/en13236283.

Schelly, C., 2014. Residential solar electricity adoption: what motivates, and what matters? A case study of early adopters. Energy Res. Soc. Sci. 2, 183–191. https://doi.org/10.1016/j.erss.2014.01.001.

Schubert, R., Stadelmann, M., 2015. Energy-using durables - why consumers refrain from economically optimal choices. Front. Energy Res. 3, 1–13. https://doi.org/10.3389/fenrg.2015.00007.

Scofield, J.H., 2009. Do LEED-certified buildings save energy? Not really. Energy Build. 41, 1386–1390. https://doi.org/10.1016/j.enbuild.2009.08.006.

Scofield, J.H., Cornell, J., 2019. A critical look at "Energy savings, emissions reductions, and health co-benefits of the green building movement. J. Expo. Sci. Environ. Epidemiol. 29, 584–593. https://doi.org/10.1038/s41370-018-0078-1.

Segelström, F., 2009. Communicating through visualizations: service designers on visualizing user research. In: Clatworthy, S., Nisula, J.-V., Holmlid, S. (Eds.), ServDes.2009 - DeThinking Service, ReThinking Design, pp. 175–185. Oslo.

Simpson, G., Clifton, J., 2017. Testing Diffusion of Innovations Theory with data: financial incentives, early adopters, and distributed solar energy in Australia. Energy Res. Soc. Sci. 29, 12–22. https://doi.org/10.1016/j.erss.2017.04.005.

SMHI, 2014. Annual Global Horizontal Solar Radiation [WWW Document]. http://www.smhi.se/klimatdata/meteorologi/stralning/normal-globalstralning-under-ett-ar-1.2927. (Accessed 24 September 2015).

Sommerfeld, J., Buys, L., Vine, D., 2017. Residential consumers' experiences in the adoption and use of solar PV. Energy Pol. 105, 10–16. https://doi.org/10.1016/j.enpol.2017.02.021.

Sommerfeldt, N., Madani, H., 2017. Revisiting the techno-economic analysis process for building-mounted, grid-connected solar photovoltaic systems: Part two - Application. Renew. Sustain. Energy Rev. 74, 1394–1404. https://doi.org/10.1016/j.rser.2017.03.010.

Sorrell, S., Gatersleben, B., Druckman, A., 2020. The limits of energy sufficiency: a review of the evidence for rebound effects and negative spillovers from behavioural change. Energy Res. Soc. Sci. 64, 101439. https://doi.org/10.1016/j.erss.2020.101439.

Statistics Sweden, 2013. Yearbook of Housing and Building Statistics 2012. Stockholm.

Stordåhd, Redaktionen, 2021. Ny Undersökning: Var Femte Vill Installera Solpaneler under 2021. New survey: One-fifth want to install PV during 2021) [WWW Document]. Sven. Fastigh. URL. https://www.svenskfastighetsutveckling.se/2021/05/19/ny-undersokning-var-femte-vill-installera-solpaneler-under-2021/.

Stridh, B., Larsson, D., 2017. Investeringskalkyl För Solceller (Investment Calculations for Solar PV) - 2017:02. Energimyndigheten (Swedish Energy Agency).

Swearingen, A., 2014. LEED-certified Buildings Are Often Less Energy-Efficient than Uncertified Ones [WWW Document]. Forbes. URL. https://www.forbes.com/sites/realspin/2014/04/30/leed-certified-buildings-are-often-less-energy-efficient-than-uncertified-ones/.

Swedish Energy Agency, 2021. Solelkalkylen (PV Calculator) [WWW Document]. URL. https://www.energimyndigheten.se/fornybart/solelportalen/vad-kostar-det/solelkalkyl/.

Tanaka, K., Sekito, M., Managi, S., Kaneko, S., Rai, V., 2017. Decision-making governance for purchases of solar photovoltaic systems in Japan. Energy Pol. 111, 75–84. https://doi.org/10.1016/j.enpol.2017.09.012.

Tubau, E., Rodríguez-Ferreiro, J., Barberia, I., Colomé, À., 2019. From reading numbers to seeing ratios: a benefit of icons for risk comprehension. Psychol. Res. 83, 1808–1816. https://doi.org/10.1007/s00426-018-1041-4.

Van Soest, D.P., Bulte, E.H., 2001. Does the energy-efficiency paradox exist? Technological progress and uncertainty. Environ. Resour. Econ. 18, 101–112. https://doi.org/10.1023/A:1011112406964.

Warneryd, M., Karltorp, K., 2020. The role of values for niche expansion: the case of solar photovoltaics on large buildings in Sweden. Energy. Sustain. Soc. 10 https://doi.org/10.1186/s13705-020-0239-7.

Wilson, C., Pettifor, H., Chryssochoidis, G., 2018. Quantitative modelling of why and how homeowners decide to renovate energy efficiently. Appl. Energy 212, 1333–1344. https://doi.org/10.1016/j.apenergy.2017.11.099.

Wolske, K.S., Stern, P.C., Dietz, T., 2017. Explaining interest in adopting residential solar photovoltaic systems in the United States: toward an integration of behavioral theories. Energy Res. Soc. Sci. 25, 134–151. https://doi.org/10.1016/j.erss.2016.12.023.