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Innovators, followers and laggards in home solar PV: Factors driving diffusion in Finland

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ABSTRACT

Generating electricity from solar energy is a way for households to participate in the ongoing transition to decarbonized and more decentralized energy systems. A large empirical literature has examined the drivers and barriers associated with household solar PV adoption. An emerging strand of this literature investigates what distinguishes earlier adopters from later adopters and non-adopters. However, there is yet limited understanding of the differences between earlier and later adopters, as few papers have applied formal statistical models to compare different customer segments. The present study addresses this gap. We examine how the factors that influence household solar PV choices differ between earlier adopters, potential adopters – households that have considered installing solar PV but have not yet done so – and non-adopters. We analyze these choices using rich data from a household-level survey conducted in Finland. The findings show that the adoption of solar PV is linked to a multitude of socio-demographic and financial factors and personal motivations. There are clear differences in the motives and perceptions of adopters, potential adopters, and non-adopters. Accounting for such differences between customer segments will help to better design and target public policy instruments and marketing campaigns that aim to incentivize and nudge households toward solar PV investments.

1. Introduction

Household energy consumption has a considerable role in climate change mitigation and energy security (see e.g., [1]). Home solar energy generation is a way to both reduce carbon emissions and enable households to be active participants in the green energy transition. By having their own micro-generation households can shield themselves against volatile electricity prices in an increasingly renewables-based power system. Moreover, distributed smaller-scale generation enhances energy security by reducing dependence on imported fuels, the supply of which can be affected by cartel operations or geopolitical instabilities. However, the diffusion of home solar photovoltaic (PV) systems remains slow, and policymakers and utility companies are actively looking for ways to increase installation rates. Identifying and understanding the factors that motivate household solar PV adoption is key for developing effective policy measures and marketing campaigns.

A substantial empirical literature has examined the drivers of and barriers to household solar PV adoption. Most studies only differentiate two groups, adopters and non-adopters (see, e.g., [2–9] and an extensive review by Alipour et al. [10]). However, adoption of a new technology does not happen simultaneously in society. Rogers' [11] diffusion of innovations theory predicts that people who adopt an innovation early have different characteristics and motivations than those who adopt later. Empirical understanding of the differences between earlier and later adopters remains limited. Few papers have applied the diffusion of innovations theory to data and investigated what distinguishes earlier adopters of home solar PV from later adopters and non-adopters [12]. This gap in knowledge points to a need for research that accounts for differences between earlier adopters and those who decide to delay investment. Understanding these differences can have considerable implications for policy and marketing strategies, by helping policymakers, utility companies and installers identify new market segments and predict areas and groups ripe for adoption.

The objective of this paper is to empirically assess how the

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characteristics and attitudes that influence household solar PV decision-making differ between early adopters, later adopters, and non-adopters. To answer this research question, we carried out a household survey that was designed to elicit information on whether a household had already adopted solar PV or was considering installing solar PV later, as well as a rich set of household characteristics and attitudinal and motivational factors. Respondents were classified as early adopters, potential adopters, or non-adopters on the basis of their answer to the survey question "Have you considered purchasing a solar PV system?". To interpret our results in relation to Rogers' [11] diffusion of innovations framework and compare earlier versus later adopters, we consider potential adoption as a proxy for later adoption. Through this lens, our analysis provides novel results on socio-demographic dimensions and stated attitudes and motivations that predict earlier adoption versus later adoption of home solar PV.

Our results also point to the importance of choosing appropriate statistical methods in the empirical diffusion of innovation research. We apply the multinomial logit choice modeling approach to analyze differences between the three distinct groups of respondents. Using the multinomial logit approach allows simultaneously examining all the factors potentially connected to households' solar PV decisions and to assess the *marginal impacts* of specific variables on the likelihood of being an earlier adopter, a later adopter, or a non-adopter. The results reveal that predictions from simple, separate statistical tests of differences in variable means, used in some earlier consumer segment comparisons, can err and differ from predictions obtained when simultaneously accounting for all the variables potentially driving adoption.

Our research provides new insights into the factors linked to household solar PV decisions and informs the development of cost-effective policies and marketing strategies directed at individuals most likely to decide to install solar PV. Differentiating those considering solar PV adoption from those more reluctant to invest could help policymakers, utility companies and installers to better target information campaigns, subsidy programs, and marketing campaigns.

The paper is organized as follows. Section 2 presents previous literature on earlier and later adopters and summarizes the solar PV landscape in Finland. The survey and modeling approach are discussed in Section 3. Section 4 shows and discusses the results, and Section 5 concludes the paper.

2. Earlier and later adopters in solar PV diffusion

2.1. Diffusion of innovations theory and empirics

Not everybody adopts an innovation at the same time. Rogers' [11] diffusion of innovations framework provides a classical context for analyzing earlier and later adopters. Rogers divides adopters into five categories based on how early they adopt relative to other people, referred to as "innovators", "early adopters", "the early majority", "the late majority" and "laggards". Rogers proposes profiles for each adopter category based on personal and socio-economic characteristics as well as attitudes to innovation attributes and information channels. According to Rogers, innovators have higher social status and more financial resources than adopters in the other categories. Innovators are also venturesome and willing to try new technologies at some risk. Early adopters have similar characteristics, but they adopt new technologies after more careful consideration. Both innovators and early adopters are opinion-leaders among their peers in terms of new technologies. The early majority in turn are cautious in making decisions. Adopters in this category may be more price-sensitive than earlier adopters and adopt a new technology once it is used relatively widely. The late majority and the laggards are skeptical and conservative toward new technologies. Moore [13] introduced the concept of a "chasm" between innovators/early adopters and the early majority, which may prevent an innovation from diffusing through a market. The chasm refers to different personality traits and expectations for the innovation among early adopters and the early majority.

Empirical studies on the differences between earlier and later adopters of residential solar energy remain scarce. Palm [12] provides a systematic review of this research. His review points out that few papers have focused on the differences between earlier and later adopters as such (see e.g., [14]), although the topic has been touched upon in conjunction with other main foci. Palm [12] also analyzed differences in adoption motives between the earliest and somewhat later adopters of residential PV systems in Sweden, focusing on how the relationship between environmental concern and PV adoption has evolved over time. He finds that the relationship between environmental concern and PV adoption is somewhat weaker in the latter years than in the middle years in the sample.

Sigrin et al. [15] explored differences in the attitudinal and socio-economic characteristics of early and more recent adopters, as well as of adopters and non-adopters. Comparing the group-wise mean responses, they concluded that protecting the environment was less of a motivation for more recent than for early adopters, whereas protecting against future electricity price increases was more important for recent adopters. They also found that recent adopters were less educated than early adopters and had more centrist beliefs on political, social and economic issues. The authors conclude that recent adopters appear to install PV for different reasons than early adopters.

Palm [16] compared motives and barriers for PV adoption in two waves of interviews. She concluded that there had been a shift in households' reasons for installing PV: households in the first interview set were motivated mainly by environmental motives and technophilia, whereas households in the second interview set emphasized economic motives. Both samples were too small ($N = 20$ and $N = 43$) to generalize the findings to larger sets of households.

De Groote et al. [5] studied whether the importance of factors explaining PV adoption changed over time as PV subsidies became less generous. They found that income, having a college or university degree as well as a white collar or public-sector occupation have a significant effect on PV adoption in the earlier period but not in the latter. The influence of environmental awareness in turn appeared to become more important in the second period. Overall, De Groote et al. concluded that the determinants of PV adoption were relatively robust over time.

Reeves et al. [17] compared adopter characteristics and information search in two adjacent markets, one mature and the other young. Neighborhood peer effects operated similarly in the two markets, whereas respondents in the more mature market were less likely to value information from roofing contractors than their counterparts in the younger market. Overall, the importance of information from trustworthy local utility companies increased as the adoption of solar PV spread.

Haas et al. [18] surveyed adopters and potential adopters, with the latter group defined on the basis of membership of a renewable energy association. Haas et al. concluded that environmental factors were the dominant motivation for adoption in both groups. Financial incentives were emphasized more by adopters than by potential adopters, while potential adopters were more likely to prioritize lower electricity costs in their investment decision.

The intrapersonal nature of technology diffusion has received relatively little attention. Scheller et al. [19] used focus group discussions to explore the influence of stakeholders on adoption decisions throughout a three-stage decision-making process. Stakeholders closest to the decision-makers in terms of emotional and spatial proximity had the largest influence on decision-making throughout the stages.

2.2. Residential solar PV in Finland

While Finland is located in Northern Europe, the annual full-load hours for solar PV are quite similar to those in Northern Germany. Generation potential varies between seasons, though, with higher potential in the spring and summer months [20]. Small-scale grid-connected solar power capacity has been growing fast recently. While the capacity was 27 MW in 2016, in 2018 it was already 120 MW, and installations have continued to grow, reaching around 390 MW in 2021 [21]. Grid-connected detached houses and summer cottages form a substantial share of the total capacity. The exact number of residential households with an on- or off-grid solar PV system is not reported in the official statistics. We estimate that at the time of data collection in 2018, the Finnish PV market had just reached the early adopter stage with an approximately 2.5 % diffusion rate. This approximation is based on an average household having a PV system size of 4.9 kW, 120 MW of installed capacity, and 1 million potential locations for on-grid systems. Despite this substantial growth, overall residential solar PV capacity in Finland remains modest.

Finland aims to be carbon-neutral by 2035. Increasing the share of renewables in energy production is imperative for reaching this goal, and Finland's Energy and Climate Strategy seeks to exploit the potential of solar PV, in particular in the residential sector, to boost the share of renewables. The conflict in Ukraine has highlighted the role of energy security and solar PV can be part of the solution in replacing Russian imports. Designing policies to promote further growth in solar PV calls for an understanding of the determinants of solar PV adoption.

Residential solar PV investment is supported through several channels. Most support is non-monetary, such as information provision. Monetary incentives are provided through a tax credit that allows households to deduct part of the solar PV installation costs from their income tax liability (a maximum of € 2250 a year) [22]. The most important determinants of the payback period of the investment are the size of the PV system and whether the PV system is connected to the grid or not. Grid connection is important then excess electricity can be sold back to the grid. Sizing the PV system so that most of the electricity is for personal consumption is typically the most economical choice.

Then factors associated with household solar PV system adoption in Finland have only been addressed in one previous study, which differs from ours in that it used a qualitative, interview-based approach [23]. The purpose of the study was to obtain an understanding of the experiences of Finnish pioneer households ($N = 28$), an aim quite different from our objective of statistically discerning generalizable results on how the factors that influence household solar PV decision-making differ between earlier adopters, potential adopters, and non-adopters.

3. Empirical setting and approach

3.1. Survey design

We carried out a survey of Finnish households in May 2018. The survey was designed to elicit data explaining **households' decision or intention to adopt solar PV** and included items on general technology adoption behavior, environmental attitudes, perceptions of technology characteristics and economic benefits, sources of information, perceptions of solar energy and solar PV systems as well as personal and home characteristics. Survey items were developed based on diffusion of innovations framework by Rogers [11], previous empirical literature, e.g., [9,14,24–26], and co-design with experts in the Finnish solar PV market. We will describe the survey items in more detail in Section 3.2. A pilot study was carried out to test the survey and to ensure that the survey items were understandable and credible to respondents. The pilot round was quantitative and was carried out by means of an internet survey by Webropol in March 2018, with employees of the distribution company Caruna Oy as participants. We approached 309 individuals and received 95 responses to the pilot study.

The final survey was in the form of an online survey by Webropol. Invitations to complete the survey were emailed to 10,670 residential customers of the largest distribution system operator in Finland, Caruna Oy, living in homes where installing a solar PV system is possible (detached and semi-detached houses). The survey was sent to all Caruna Oy customers who had already installed a grid-connected solar power system and whose email address was available, a total of 1328 customers, and to a random sample of 9342 Caruna Oy customers whose municipalities and home characteristics matched those of the adopters. Respondents were incentivized to participate by offering a chance to win a prize in a lottery.

We received 1554 responses, which implies an overall response rate of 14.6 %. The response rate was higher for solar PV system adopters than for other households (35.8 % vs. 11.5 %). The difference may be explained by greater involvement with the topic among adopters. Overall, the response rate was quite low, and the sample collected may thus suffer from nonresponse bias. There are several possible reasons for the low response rate. The selected survey mode (online survey) may have affected the response rate. The low response rate may also reflect the observation that households do not find an energy-related survey topic very interesting [27].

For the analysis, we excluded 61 respondents with missing observations for some explanatory variables (income, household size, property age, and a binary variable describing employment or education/expertise related to energy). In addition, we excluded 31 respondents living in terraced houses and 85 respondents who answered the survey based on their holiday home. The final sample comprises 1377 fully completed surveys, of which 436 were from solar PV owners.

Table 1 presents descriptive statistics for the final sample and for the corresponding Finnish population. The respondents are representative of the corresponding Finnish population in terms of household size and age. The respondents' ages are between 24 and 86 years. The respondents are on average more educated and have higher income levels. In terms of the rural-urban dimension of home location, sparsely populated areas and small population centers are slightly overrepresented. The group of respondents also has a higher share of males than the population overall, which is what one would expect in that potential survey respondents were contacted based on customer information from the electricity distribution company and male household

Table 1
Descriptive statistics of the respondents and the corresponding Finnish population.

	Respondents ($N = 1377$)	Corresponding Finnish population (N = 1,870,360)[a]
Sociodemographic characteristics		
	Average	
Age (years)	54.4	53.3
Household size	2.8	2.94
	Percent	
Gender		
Female	22.9	48.6
Male	77.1	51.4
Household's income (gross, €/month)		
<2000	3.3	12.9
2000–3999	20.5	27.3
4000–5999	30.2	26.1
6000–7999	20.3	17.9
>8000	23.0	15.8
Education		
University or applied sciences degree	64.1	37.3
Community type (urban – rural characterization)		
Town or city	62.0	54.8
Sparsely populated area or small population center	38.0	45.2
Home type		
Detached or semidetached single-family house	96.6	100
Farmhouse	3.4	NA

[a] The corresponding Finnish population includes individuals who are between 22 and 85 years old and live in detached or semidetached houses.

members are more often those who sign the contract with the distributor.

3.2. Survey variables and links to previous literature

Our main empirical analysis applies a multinomial logit model of individuals' adoption decisions [28,29]. The dependent variable in the empirical analysis is the adoption intention or adoption decision elicited by the following question: "Have you considered purchasing a solar PV system?". Respondents were presented with three answers: "No", "Yes", and "I already have a solar PV system". Respondents were classified as non-adopters if they chose "No", potential adopters if they chose "Yes" and adopters if they chose "I already have a solar PV system". The categories relate to Rogers' more detailed categories as follows: the adopters include mainly innovators, the potential adopters both early adopters and early majority individuals and the non-adopters mainly late-majority individuals and laggards.

The survey allowed us to elicit a rich set of variables to explore as predictors of the intention or decision to adopt. The selection of variables was based on Rogers' [11] adopter typology (see Section 2) and previous PV adoption literature, which has mostly focused on comparing adopters and non-adopters. Table 2 summarizes the variables, grouping them in accordance with the taxonomy of PV adoption predictors presented in Alipour et al. [10]. The following sections discuss the variables in more detail.

3.2.1. Sociodemographic variables

The sociodemographic variables in our survey include respondent's **age**, **gender**, **income**, level of **education**, **household size** and an indicator for **rural location**. The empirical literature on the effects of these characteristics on PV adoption is not conclusive [10]. Some studies have found that older people are less likely to adopt [3,6,9], whereas some have found no significant effect [5]. Some studies have shown that adoption probability increases with education level [6,25], while the opposite has also been documented [5]. Income may have an important role in the adoption decision since solar power systems have a relatively high initial investment cost, and De Groote et al. [5] and Kwan [6], for example, found a positive association with income. On the other hand, Willis et al. [30] found a negative association with income for several renewable technologies, including PV. Some previous studies have suggested that male residents are more likely to adopt [3,5]. Larger households may be more likely to adopt as they generally have higher electricity consumption [5,31]. Finally, urban and rural areas may differ in terms of marketing, permit processes and space available, and previous studies have shown that solar technologies are often first adopted in rural areas [6,10]. In terms of differences between earlier and later adopters, Rogers' [11] adopter typology proposes that sociodemographic characteristics differentiate earlier and later adopters in that earlier adopters have better income and higher education than later adopters. Sigrin et al. [15] found that recent adopters were less educated than early adopters, whereas earlier and later adopters did not differ significantly with respect to age or income.

3.2.2. Home characteristics

Home characteristics are likely to affect the adoption decision [10], and we include several of these characteristics in our empirical analysis. **House area** documents the heated square meters, which we hypothesize to reflect energy consumption. **House age** may be linked to energy and technical standards or roof condition [4,32]. Previous studies have found house size to correlate positively with adoption and house age negatively [4,5]. **Farmhouse** is an indicator for a house that is part of an agricultural holding. To investigate whether using electricity for heating predicts PV adoption, we include indicators for electricity-based heating modes common in Finland: **direct electric heat**, **water-circulating heating system** powered by electricity (a system that circulates hot water), and **heat pump**. We expect electricity-powered heating to be

Table 2
Variable definitions and summary statistics.

Dependent variable	Percent	N = 1377
Non-adopter	27.1	
Potential adopter	41.2	
Adopter	31.7	

Explanatory variables	Description	Mean	SD
Sociodemographic characteristics			
Age	Respondent's age	54.42	12.73
Female (1 if yes)	Respondent is female	0.23	0.42
Income (8 categories)	Household's monthly gross income (1 < 2000€, 2 = 2000€–3999€, 3 = 4000€–5999€, 4 = 6000–7999€, …, 8 > 14,000€)	3.62	1.59
Higher education	Respondent has an applied sciences or university degree	0.64	0.48
Household size	Number of individuals in the household	2.77	1.25
Rural location (1 if yes)	Respondent lives in the countryside or in a small village	0.38	0.49
Home characteristics			
House area (metric)	Size of the house in square meters	164.69	81.11
House age	Age of the house	38.46	30.89
Farmhouse (1 if yes)	The house is part of an agricultural holding	0.03	0.18
Direct electric heating (1 if yes)	Heating mode is direct electric heating	0.40	0.49
Water-circulating heating (1 if yes)	Heating mode is a hot water circulation system powered by electricity	0.06	0.24
Heat pump (1 if yes)	Heating mode involves a heat pump (ground source heat pump, exhaust air heat pump, or air-to-water heat pump)	0.24	0.43
Energy efficiency upgrade (1 if yes)	Energy efficiency improvement(s) have been conducted in the house after year 2000	0.46	0.50
Attitudes to new technologies			
Prefers widely used (1 if yes)[a]	"I prefer purchasing devices that are widely used"	0.50	0.50
Values user experience (1 if yes)[a]	"I only purchase devices of which there is user experience information available"	0.53	0.50
Interest in testing (1 if yes)[a]	"Testing new devices is interesting"	0.63	0.48
Values reliability (1 if yes)[a]	"I may not purchase a useful device, if it is not reliable enough"	0.86	0.35
Dislikes complexity (1 if yes)[a]	"I may not purchase a useful device, if it is complicated"	0.60	0.49
Diy type person (1 if yes)[a]	"I am a do-it-yourself type person"	0.56	0.50
Attitudes to the environment			
Env. important (1 if yes)[a]	"When purchasing a new device I always pay attention to its environmental attributes"	0.62	0.49
Env. exaggerated (1 if yes)[a]	"Environmental problems associated with energy production (emissions and climate change) are exaggerated"	0.19	0.39
Attitudes to economic factors and solar PV attributes			
Price is important (1 if yes)[a]	"The price is the most important characteristic when I purchase devices"	0.45	0.50
Elec. prices increase (1 if yes)[a]	"The price of electricity will increase significantly in the near future"	0.64	0.48
Solar PV is expensive (1 if yes)[a]	"Solar power systems are too expensive"	0.74	0.44
Should be subsidized (1 if yes)[a]	"Investment subsidies should be levied on residential solar power systems"	0.78	0.42
Long payback time (1 if yes)[a]	"The payback time of a solar PV system is too long"	0.70	0.46

(continued on next page)

Table 2 (*continued*)

Explanatory variables	Description	Mean	SD
Increases resale value (1 if yes)[a]	"A solar power system increases the resale value of a home"	0.77	0.42
System is high maintenance (1 if yes)[a]	"A solar power system requires a lot of work"	0.10	0.30
System is ugly (1 if yes)[a]	"Solar power systems are ugly"	0.11	0.32
Information			
Peers (1 if yes)	The individual knows someone who has a solar power system	0.41	0.49
Expert (1 if yes)	Education or occupation is related to energy	0.23	0.42
Information is insufficient (1 if yes)[a]	"There is not enough usable information on solar power system available for households"	0.44	0.50

[a] Variable is based on a 5-point Likert scale item with responses from 1 = strongly disagree to 5 = strongly agree. The variable takes the value 1 if the respondent chose 4 = somewhat agree or 5 = strongly agree, and 0 otherwise.

positively correlated with PV adoption, as PV may generate significant electricity cost savings for such households. Variable **energy efficiency upgrade** captures remodels that aim at energy savings, such as adding heat insulation or window or heating system replacement. Energy efficiency improvements can also be interpreted as a proxy for environmental awareness, similarly to De Groote et al. [5] and Mills and Schleich [31].

3.2.3. *Attitudes to new technologies*

A key prediction from the diffusion of innovations literature is that personal attitudes toward new technologies and risk-taking differentiate earlier and later adopters [11]. The survey approach allowed us to elicit data on respondents' attitudes, which we measured through several Likert-scale agreement questions. Responses ranged across a five-point scale from "strongly disagree", "disagree somewhat", "neither agree nor disagree", "agree somewhat" to "strongly agree". An opt-out response "prefer not to say" was also included. These responses were then transformed into dichotomous indicators that take the value 1 if the respondent chose "agree somewhat" or "strongly agree" and 0 otherwise.

Respondents were asked to rate the following statements on attitudes to new technologies, with the associated dichotomous indicators used in the analysis presented in parentheses:

- I prefer purchasing devices that are widely used by other households (**prefers widely used**).
- I only purchase devices with user experience information (**values user experience**).
- Testing new devices is interesting (**interest in testing**).
- I may not purchase a useful device if it is not sufficiently reliable (**values reliability**).
- I may not purchase a useful device if it is complicated to use (**dislikes complexity**).
- I am a do-it-yourself type person (**diy type person**).

3.2.4. *Attitudes to the environment*

While some previous papers control for environmental preferences, researchers typically use proxies such as hybrid vehicle ownership or voting choices (see e.g., [3,5,6,12]). Some survey-based studies on the drivers of home solar PV adoption have explored stated environmental attitudes. Sun et al. [33] found that ecological lifestyle and warm glow were associated with rooftop solar installation intentions. Rai and Beck [34] also found that stated environmental concern predicted intentions to install solar and Mundaca and Samahita [35] that a variable summarizing the respondent's environmental attitude was associated with a higher likelihood to adopt. We follow the stated environmental attitudes approach and measure respondents' environmental attitudes through the following items, again with the associated dichotomous indicators presented in parentheses:

- When purchasing a new device, I always pay attention to its environmental attributes (**env. important**).
- Environmental problems associated with energy production (emissions and climate change) are exaggerated (**env. exaggerated**).

Empirical literature on the environmental attitudes of earlier and later adopters is not conclusive. Palm [16] and Sigrin et al. [15] found that earlier adopters emphasize environmental aspects more than later adopters, and the results in Palm [12] are in line with these findings. Haas et al. [18] found that environmental factors are important motives in both groups, whereas in De Groote et al. [5] the proxy for environmental awareness was more important in the later period examined.

3.2.5. *Attitudes to economic factors and solar PV attributes*

Previous studies show that financial factors are important in solar power system adoption processes [8,9,36]. In addition, Rogers [11] argues that financial factors are more important for later than for early adopters. Long [37] found that electricity price increases are associated with investment in energy conservation. Sigrin et al. [15] considered the importance of protecting against future electricity price increases, which they found to be more important for recent adopters than for earlier adopters. Haas et al. [18] found that potential adopters were more likely than adopters to consider a lower electricity bill as an important PV investment motive. Simpson and Clifton [8] emphasized that financial incentives act both as a means to increase the affordability of solar systems and as a 'cue to action' for people considering installing solar.

We included questions on the importance of device price when considering purchasing new devices and on the perception of future electricity prices:

- Price is the most important characteristic when I purchase new devices (**price is important**).
- The price of electricity will increase significantly in the future (**electricity prices increase**).

Respondents' attitudes to investment costs, solar PV subsidies and payback times were measured through the following items, with the associated dichotomous indicators presented in parentheses:

- Solar power systems are too expensive (**solar PV is expensive**).
- Investment subsidies should be levied on residential solar power systems (**should be subsidized**).
- The payback time of a solar power system is too long (**long payback time**).

Faiers and Neame [14] found that the additional value of solar PV on house resale value and the appearance of the system may affect the adoption decision. Perceptions on the ease of use may also be important. We measure these attitudes to solar PV attributes through the following items, with the associated dichotomous indicators presented in parentheses:

- A solar power system increases the resale value of a home (**increases resale value**).
- A solar power system requires a lot of work (**system is high maintenance**).
- Solar power systems are ugly (**system is ugly**).

3.2.6. *Information*

Finally, previous studies have found that peers with PV systems have a positive influence on PV adoption [2,3,7,35,38–40]. Direct contact with a friend or a neighbor, for example, who has adopted a solar power system facilitates the exchange of information and may reduce the complexity of the decision-making process and encourage adoption [25,41]. Noll et al. [40] stress paying attention to the correlations between variables capturing peer effects and socio-demographic characteristics in empirical studies. A strength of the multinomial logit approach used in this paper in this respect is that it allows the marginal impact of an increase in a specific variable on the likelihood of adoption to be assessed.

Rogers' [11] adopter typology also proposes that wide coverage media are more important sources of information for earlier adopters than for later adopters. Later adopters in turn may place a higher value on local, interpersonal information channels. Somewhat contrary to this hypothesis, Reeves et al. [17] find that respondents in a less mature market were more likely to value information from local roofing contractors than their counterparts in a more mature market. Overall, previous literature indicates that information has an important role in solar PV adoption decisions and that consumers are looking for trustworthy content [17,19,34,38,40–45].

We consider three variables related to information and peer effects. **Peers** indicates whether the respondent knows someone who has a solar PV system and **expert** whether the respondent's education or occupation are energy-related. **Information is insufficient** summarizes responses to the Likert item "There is not enough usable information on solar power system available for households".

3.3. Differences between potential adopters and early adopters

A key prediction from the diffusion of innovations literature is that the attitudes and demographics of early adopters and the rest that follow them differ [11]. Before proceeding with the multinomial logit analysis, we simply tested the differences between early adopters and potential adopters by conducting a series of Student's *t*-tests where the null hypothesis was that the means of early adopters (survey respondents who already have a solar PV system) equal those of potential adopters (survey respondents who answered "Yes" to the question "Have you considered purchasing a solar PV system?"). This approach has been used in an analysis comparing adopters and non-adopters with earlier and more recent adopters by Sigrin et al. [15]. Table 3 shows the results.

Table 3
Comparison of means of potential adopters and adopters.

H0: $\mu_{potential} = \mu_{adopter}$	Potential adopter	Adopter			*P*-value	95 % CI	
Unequal var. assumed	Mean μ	Mean μ	t	df	Two-tailed	Lower	Upper
Sociodemographic characteristics							
Age	51.09	57.23	−7.956	938	0.000***	−7.655	−4.625
Female (1 if yes)	0.24	0.15	3.645	995	0.000***	0.042	0.139
Income (8 categories)	3.79	3.63	1.533	951	0.126	−0.044	0.358
Higher education	0.69	0.59	3.042	910	0.002**	0.033	0.153
Household size	2.99	2.68	3.831	996	0.000***	0.155	0.481
Rural location (1 if yes)	0.37	0.49	−3.787	921	0.000***	−0.180	−0.057
Home characteristics							
House area (metric)	167.45	177.28	−1.704	810	0.089	−21.166	1.496
House age	38.85	37.29	0.808	903	0.419	−2.232	5.354
Farmhouse (1 if yes)	0.04	0.05	−0.995	861	0.320	−0.038	0.012
Direct electric heating (1 if yes)	0.41	0.40	0.239	939	0.811	−0.054	0.069
Water-circulating heating (1 if yes)	0.06	0.07	−0.183	928	0.855	−0.034	0.028
Heat pump (1 if yes)	0.25	0.29	−1.559	913	0.119	−0.010	0.011
Energy efficiency upgrade (1 if yes)	0.57	0.71	−4.921	974	0.000***	−0.207	−0.089
Attitudes to new technologies							
Prefers widely used (1 if yes)	0.50	0.45	1.581	938	0.114	−0.012	0.113
Values user experience (1 if yes)	0.55	0.47	2.503	934	0.012*	0.017	0.142
Interest in testing (1 if yes)	0.66	0.72	−1.845	956	0.065	−0.112	0.003
Values reliability (1 if yes)	0.87	0.84	1.411	890	0.159	−0.012	0.076
Dislikes complexity (1 if yes)	0.60	0.56	1.586	928	0.113	−0.012	0.112
Diy type person (1 if yes)	0.61	0.59	0.479	933	0.632	−0.046	0.076
Attitudes to the environment							
Env. important (1 if yes)	0.61	0.69	−2.755	960	0.006**	−0.142	−0.024
Env. exaggerated (1 if yes)	0.16	0.18	−0.602	922	0.548	−0.062	0.033
Attitudes to economic factors and solar PV attributes							
Price important (1 if yes)	0.49	0.37	3.608	950	0.000***	0.051	0.174
Elec. prices increase (1 if yes)	0.65	0.70	−1.547	954	0.122	−0.104	0.012
Solar PV is expensive (1 if yes)	0.80	0.68	4.400	855	0.000***	0.068	0.178
Should be subsidized (1 if yes)	0.81	0.79	0.925	916	0.355	−0.026	0.074
Long payback time (1 if yes)	0.75	0.70	1.999	906	0.046*	0.001	0.113
Increases resale value (1 if yes)	0.77	0.90	−5.449	998	0.000***	−0.169	−0.080
System is high maintenance (1 if yes)	0.08	0.04	3.081	994	0.002*	0.017	0.077
System is ugly (1 if yes)	0.15	0.08	3.810	1001	0.000***	0.037	0.115
Information							
Peers (1 if yes)	0.44	0.49	−1.498	933	0.134	−0.110	0.015
Expert (1 if yes)	0.27	0.24	1.215	956	0.225	−0.021	0.088
Information is insufficient (1 if yes)	0.48	0.40	2.405	946	0.016*	0.014	0.138

*, **, and *** indicate significance at the 0.05, 0.01, and 0.001 levels, respectively.

The results suggest that energy efficiency upgrades – also a proxy for environmental awareness – are more common among early adopters. Early adopters are also more likely than potential adopters to state that they consider environmental attributes when purchasing new devices (env. important). These findings suggest that environmental awareness may be a motivation for early adopters of residential solar PV. Potential adopters are more likely to value user experience than early adopters. Attitudes to economic factors and solar PV attributes differ among potential adopters and early adopters. Potential adopters state more often than early adopters that device price is the most important characteristic driving purchase decisions, and that solar PV is expensive and has a long payback time. Potential adopters are less likely than early adopters to state that solar PV increases house resale value. Potential adopters more often find that solar PV systems require a lot of work (system is high maintenance) and are ugly. Finally, potential adopters are more likely than early adopters to state that there is insufficient information on solar power system available for households. Taken together, these findings suggest that economic considerations, lack of information and esthetic aspects may be deterring solar PV adoption in Finland.

However, a simple differences-in-means comparison of the variables of interest does not condition on background variables, and conclusions about the extent to which potential adopters are motivated by different prompts than early adopters may be misguided. As Table 3 shows, potential adopters and early adopters differ in terms of their sociodemographic background characteristics. Potential adopters are on average younger than early adopters, are more often female, have university or applied sciences education (higher education) more often, and are less likely to live in rural locations. Further, a differences-in-means comparison does not provide information on how important the different variables are in terms of predicting the likelihood that an individual is a non-adopter, potential adopter or early adopter. To control for differences in background variables, we next turn to a multinomial logit model of adoption decisions. This approach allows us to disentangle the importance of the stated attitudes and motivations as factors explaining the likelihood of adopting early, possibly later, or not at all, from those of the different background variables. The analysis also shows that while by and large the variables whose means in the potential adopter and earlier adopter groups differ statistically significantly also predict the likelihood that an individual is a potential adopter or an earlier adopter, this parallel does not hold in all cases.

3.4. Modeling adoption decisions

We utilize the multinomial logit model to analyze individuals' adoption decisions [28,29]. The multinomial logit model posits the following conditional choice probability for individual n adopting choice j:

$$P_{nj} = \frac{exp(\beta_j x_n)}{1 + \sum_{k=1}^{J} exp(\beta_k x_n)} \; for \; j = 0, \ldots, J, \tag{1}$$

where x_n is a vector of explanatory variables and β_j the corresponding vector of estimated parameters for choice j. The idiosyncratic error is assumed to be independently and identically distributed (IID) and an extreme value one (EV1) type. Because the choice probabilities sum to one, only J parameter vectors are needed to determine the $J+1$ probabilities (for the reference choice $J = 0$, the vector $\beta_0 = 0$). In our case, the multinomial logit model has three possible outcomes: earlier adopter, potential adopter, and non-adopter. We present the results as average marginal effects.

We assess marginal effects to investigate how the choice probability changes when an explanatory variable changes by one unit. The marginal effects (ME) are calculated as follows:

$$\text{ME} = \frac{\partial P_{nj}}{\partial x_n} = P_{nj}\left(\beta_j - \sum_{k=0}^{J} P_{nk}\beta_k\right) = P_{nj}\left(\beta_j - \overline{\beta}\right), \tag{2}$$

where the parameter estimates β_j and choice probabilities P_{nj} enter every marginal effect. The standard errors (SEs) of the MEs are derived with the delta method. In our application, the marginal effects describe the effect of a unit change in an explanatory variable on the likelihood that an individual is an earlier adopter, a potential adopter or non-adopter.

4. Results and discussion

This section discusses the empirical results from the multinomial logit model. Table 4 presents the results following the classification of the explanatory variables presented in Section 3.2 (see also Table 2). The multinomial logit model performs quite well: the McFadden Pseudo R^2 is 0.19. Overall, the model captures several statistically significant factors explaining the decision to install solar PV, to consider installing solar PV later or not to even consider installing solar PV. Put differently, these are factors in respect of earlier adopters, potential adopters, and non-adopters differ. Appendix A presents the results from a binomial logit model where the dependent variable takes the value 1 if the respondent already owns a solar PV system (adopter) and 0 if the respondent does not own a solar PV system (non-adopter). The likelihood of solar PV adoption is explained by the same variables in both models (that is, the variables are statistically significant factors explaining the outcome that an individual already has solar PV, with the same sign).

4.1. Sociodemographic characteristics

We first discuss the sociodemographic variables, reproducing the marginal effects (MEs) displayed in Table 4 in parentheses. **Age** somewhat increases the likelihood of being an earlier adopter (0.53 %***) or a non-adopter (0.21 %**) but decreases the likelihood of being a potential adopter (−0.74 %***). Potential adopters are thus likely slightly younger than those who have already installed a solar PV system or do not even consider installing one. Previous literature is inconclusive on the effect of age on solar PV adoption [5,6,9]. Our findings do not confirm Rogers' [11] proposition that innovators are typically younger.

Regarding the role of gender in the adoption decision, the data do not reveal whether the decision is made at the household level or by the respondent. Thus, the variable **female** may not correctly capture decisions made by women. While the results suggest that female respondents are less likely to be early adopters and more likely to be non-adopters than male respondents, there is a caveat. As such, the finding is in line with previous evidence that male residents are more likely to adopt solar PV (see e.g., [3,5]).

Higher **income** is associated with a higher likelihood of being a potential adopter (1.7 %*) and a lower likelihood of being a non-adopter (−1.9 %**). However, the marginal effects are quite small. Income has no statistically significant association with being an early adopter, which diverges from some earlier results that have found that higher income is associated with a higher likelihood of adoption [5,6]. On the other hand, current income is also only a proxy for overall financial resources.

Respondents living in **rural** areas in turn are significantly more likely to be earlier adopters than those living in more urban areas (13.1 %***) and significantly less likely to be non-adopters (that is, not even considering solar PV adoption at the time of our survey, with an ME of −11.1 %***). Higher distribution tariffs in rural areas allow for higher cost savings from own generation, which may explain these findings. There is no statistically significant difference in the likelihood of being a potential adopter between those living in rural versus more urban areas.

Contrary to Rogers' [11] theory, **high education** (here, applied sciences or university degree) decreased the likelihood of being an earlier adopter (–7.3 %***). However, highly educated respondents were more likely to be potential adopters (6.8 %**) than respondents with lower education. Household characteristics not observed in the data may be behind these findings. For example, highly educated

Table 4
Results of the multinomial logit model.

	Non-adopter		Potential adopter		Adopter	
Variable	ME	SE	ME	SE	ME	SE
Age	0.0021**	0.0010	−0.0074***	0.0012	0.0053***	0,0011
Female	0.0561**	0.0287	0.0467	0.0339	−0.1028***	0,0288
Income	−0.0188**	0.0081	0.0169*	0.0092	0.0019	0.0083
Higher education	0.0044	0.0234	0.0681**	0.0279	−0.0725***	0.0256
Household size	−0.0027	0.0109	0.0037	0.0124	−0.0010	0.0116
Rural location	−0.1106***	0.0222	−0.0199	0.0272	0.1305***	0.0248
House area	−0.0007***	0.0002	0.0003*	0.0002	0.0004**	0.0002
House age	0.0002	0.0004	0.0009*	0.0005	−0.0010**	0.0004
Farmhouse	−0.0731	0.0661	0.0098	0.0768	0.0634	0.0691
Direct electric heating	−0.0897***	0.0242	0.0255	0.0315	0.0642**	0.0291
Water-circulating heating	−0.0251	0.0439	−0.0245	0.0553	0.0496	0.0519
Heat pump	−0.0771***	0.0280	0.0001	0.0363	0.0770**	0.0339
Energy efficiency upgrade	−0.0919***	0.0230	0.0030	0.0276	0.0890***	0.0248
Prefers widely used	0.0400*	0.0224	−0.0235	0.0267	−0.0165	0.0238
Values user experience	0.0340	0.0228	0.0183	0.0272	−0.0523**	0.0245
Interest in testing	−0.0758***	0.0236	−0.0016	0.0279	0.0773***	0.0246
Values reliability	0.0429	0.0307	0.0117	0.0385	−0.0545	0.0353
Dislikes complexity	0.0117	0.0234	0.0064	0.0275	−0.0181	0.0246
Diy type person	−0.0570**	0.0229	0.0435	0.0273	0.0134	0.0244
Env. important	−0.0593**	0.0235	−0.0224	0.0276	0.0817***	0.0243
Env. exaggerated	0.0680**	0.0291	−0.0608*	0.0328	−0.0072	0.0296
Price is important	0.0309	0.0221	0.0515*	0.0264	−0.0824***	0.0237
Elec. prices increase	−0.0762***	0.0228	−0.0024	0.0267	0.0786***	0.0235
Solar PV is expensive	0.0059	0.0302	0.0974***	0.0360	−0.1033***	0.0337
Should be subsidized	−0.0584**	0.0271	0.0657**	0.0315	−0.0073	0.0289
Long payback time	−0.0622**	0.0307	0.0181	0.0354	0.0440	0.0303
Increases resale value	−0.1523***	0.0282	−0.0338	0.0317	0.1860***	0.0258
System is high maintenance	0.1393***	0.0375	−0.0165	0.0442	−0.1229***	0.0393
System is ugly	0.1242***	0.0370	−0.0432	0.0403	−0.0810**	0.0355
Peers	−0.1028***	0.0217	0.0367	0.0261	0.0661***	0.0235
Expert	−0.0570**	0.0272	0.1187***	0.0321	−0.0617**	0.0263
Information is insufficient	−0.0281	0.0221	0.0804***	0.0263	−0.0523**	0.0234
LL	−1213.46					
LL(0)	−1491.83					
McFadden Pseudo R2	0.19					
AIC	2558.9					
N	1377					
k (# of parameters)	66					

*, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

respondents could live in more energy efficient homes or have moved to their home more recently than respondents with lower education. There is no statistically significant relationship with being a non-adopter. These findings differ somewhat from findings by Sigrin et al. [15], who found that later adopters were less educated than earlier adopters. Note that other things being equal, **household size** has no statistically significant association with the likelihood of adoption even though household size differs statistically significantly in the groups of potential adopters and early adopters (see Table 3).

4.2. Home characteristics

Regarding **house area**, our findings are similar to earlier literature from Davidson et al. [4] and De Groote et al. [5]: the likelihoods of both earlier and later solar PV adoption increase with the heated floor area of the home, although the increase is small in magnitude (MEs of 0.04 %** and 0.03 %*). The likelihood of non-adoption in turn decreases with area (ME –0.07%***). As electric heating is common, the heated floor area reflects the overall electricity consumption of the household. **House age** decreases the likelihood of being an earlier adopter and increases the likelihood of being a potential adopter (MEs −0.10 %** and 0.09 %*), although for being a potential adopter the ME is significant only at the 10 % level. The MEs are also quite small in magnitude. Qualitatively this finding is in line with earlier literature [4,5] and reasonable in that newer houses may be more amenable to solar PV installation in terms of roof condition and technical standards.

Respondents in houses where the primary heating mode is **direct electric heating** or a **heat pump** technology are substantially more likely to be early adopters (MEs 6.4 %** and 7.7 %**) than respondents with other heating modes, and less likely to be non-adopters (MEs −9.0 %** and −7.7 %**). This finding is in line with expectations, since own solar power generation can provide more substantial cost savings in these houses than in houses where the primary heating mode is, say, district heating or oil boiler heating. The results suggest that electricity-powered water heating as the primary heating mode does not affect the likelihood of adoption, but this finding could be due to a lack of statistical power - only a small share of respondents had water heating (see Table 2). In addition, having an electricity-based primary heating mode does not statistically significantly affect the probability of considering solar PV at the time of the survey. The results for **energy efficiency updates** are similar: respondents who have carried out energy efficiency upgrades are significantly more likely to be earlier adopters (ME 8.9 %***) and less likely to be non-adopters (ME –9.2 %***).

Importantly, the predictions from the simple differences-in-means comparison in Table 3 and the multinomial logit results in Table 4 differ. In terms of means, potential adopters and earlier adopters differ statistically significantly only with respect to the energy efficiency upgrades undertaken, whereas the multinomial logit analysis suggests that several variables in this group are associated with the likelihood of being a potential or earlier adopter.

4.3. Attitudes to new technologies

Overall, the Likert-scale variables measuring attitudes to new technologies are not very strong predictors of earlier or later adoption in our study. The variables **values reliability** and **dislikes complexity** are not statistically significant factors predicting solar PV adoption behavior. The variable **prefers widely used** increases the probability of being a non-adopter but is only statistically significant at the 10 % level (ME 4.0 %*). If anything, this finding is consistent with the conjecture that non-adopters are more likely to prefer purchasing only devices that are already widely used than earlier or later adopters [11]. Respondents who **value user experience information** about new technologies before adoption are also less likely to be among the earlier adopters of solar PV systems (ME –5.2 %**). This is also in line with Rogers' [11] characterization. We find no statistically significant associations between valuing user information and being a later adopter or a non-adopter.

As one would expect, the probability of being an earlier adopter is higher for those with **interest in experimenting with new technologies** (ME of 7.7 %***) while the probability of being a non-adopter is lower (−7.6 %***). The variable has no statistically significant link with being a potential adopter. The predictions from the differences-in-means comparison and the multinomial logit model diverge here in that there is no statistically significant difference in the stated interest in experimenting with new technologies in the groups of potential adopters and earlier adopters. Respondents who describe themselves as a **do-it-yourself** type person are less likely to be non-adopters than others (ME −5.7 %**), but the variable is not a statistically significant predictor of being an earlier or later adopter.

4.4. Attitudes to the environment

Individuals who generally consider eco-friendliness when making technology purchasing decisions are more likely to adopt solar PV (**env. important**: ME 8.2 %***). Interestingly, variable **env. important** does not have a significant association with being a potential adopter. Agreeing on the claim that environmental problems caused by energy production (emissions and climate change) are exaggerated (variable **env. exaggerated**) is associated with a higher likelihood of non-adoption (6.8 %**) and a lower likelihood of being a potential adopter (−6.1 %*). These findings are in line with those in Palm's [12] review, which suggests that earlier adopters find environmental aspects more important than (actual and potential) later adopters, as well as with recent results by Sun et al. [33] finding that an ecological lifestyle and a warm glow are positively associated with rooftop solar installation intentions and by Mundaca and Samahita [35] finding that environmentalism increases the likelihood of adoption. Again, a differences-in-means comparison (see Table 3) would predict differently in that there is no statistically significant difference in the propensity to state that environmental problems are exaggerated in the groups of potential adopters and earlier adopters.

4.5. Attitudes to economic factors and solar PV attributes

Respondents for whom **device price** is the most important characteristic driving purchase decisions are significantly less likely to be earlier adopters (−8.2 %***) and more likely to be potential adopters (5.2 %*). Furthermore, respondents who expect **electricity prices** to increase in the future are significantly more likely to be earlier adopters (7.9 %***). Thus, adopters may be protecting themselves from higher future electricity prices. This is not detected by the differences-in-means comparison in Table 3, which finds no statistically significant difference in the propensity of respondents in the potential adopter and earlier adopter groups to expect that electricity prices will increase.

As one might expect, respondents who find solar PV systems **too expensive** are less likely to be earlier adopters (−10.3 %**). On the other hand, respondents who agreed with this statement are more likely to be potential adopters than those who did not agree (ME is 9.7 %**). Respondents who agreed with the statement that **investment subsidies** should be levied on residential solar PV are less likely to be non-adopters than those who did not agree with the statement (−5.8 %**) but more likely to be potential adopters (6.6 %***). A possible explanation for this association is that respondents who are not even considering solar PV would not benefit from a subsidy, whereas those who are considering adoption would. Here too the predictions from the differences-in-means comparison in Table 3 diverge in that there are no statistically significant differences in the views on investment subsidies in the potential adopter and earlier adopter groups. More counterintuitively, the perception that the **payback time** is long is associated with a lower likelihood of being a non-adopter (–6.2 %**) but has no significant association with being an earlier or potential adopter. It is likely that earlier and potential adopters are better informed about the payback time than non-adopters, which may be reflected in the finding.

The perception that solar PV **increases home resale value** is significant both statistically and in magnitude: respondents who agree with this statement are 18.6 % more likely than those who do not agree to be earlier adopters and 15.2 % less likely to be non-adopters (both MEs are statistically significant at the 1 % level). These findings are in line with earlier results, for example, by Faiers and Neame [14].

The perceptions that solar PV requires a **lot of work** and that solar PV **systems are ugly** are both associated with a lower likelihood of being an earlier adopter (MEs −12.3 %*** and −8.1 %**) and, symmetrically, a higher likelihood of being a non-adopter (MEs 13.9 %*** and 12.4 %***). Neither item has a statistically significant association with being a potential adopter.

4.6. Information

Having **peers** who have a solar PV system is associated with a higher likelihood of being an earlier adopter and a lower likelihood of being a non-adopter (MEs 6.6 %*** and −10.3 %***), which is in line with findings from earlier research [2,3,7,35,39–41,46]. There is no statistically significant association between this variable and the likelihood of being a potential adopter. In contrast, an energy-related education or occupation, captured by the variable **expert**, is associated with a higher likelihood of a respondent being a potential adopter (ME 11.9 %***) and a lower likelihood of being a non-adopter (ME –5.7 %**). More surprisingly, respondents with an energy-related education or occupation are less likely than others to be earlier adopters (ME –6.2 %**). This finding could stem from well-informed consumers postponing their solar power investment decisions, perhaps to wait for the investment cost to decrease in the future. Finally, respondents who agree with the statement that the **information** on solar PV systems available to households **is insufficient** are more likely than others to be potential adopters (ME 8.0 %***) and less likely to be earlier adopters (ME –5.2 %**). This finding implies that inadequate information may slow down the adoption process. The finding is in line with the results from previous literature that information has a positive association with the likelihood of adoption [44] and intentions toward solar adoption [34].

5. Conclusion

This research examines how factors driving household solar PV decision-making differ between earlier adopters, later adopters, and non-adopters, with survey respondents' stated adoption intentions as a proxy for later adoption. Rogers' [11] theory that different groups of adopters each have different characteristics and roles in the adoption process has been hugely influential in shaping diffusion of innovations research, yet few empirical studies have examined what prompts earlier home solar PV adopters versus those who delay investment. Our findings empirically demonstrate that there are differences in the factors explaining the likelihood of being an earlier adopter, potential (later) adopter, and a non-adopter in home solar PV. The results are largely in line with Rogers' framework when it comes to how attitudes toward the environment and new technologies relate to the timing of adoption. Adopters (primarily equivalent to innovators in Rogers' typology) were motivated by environmental attributes of the technology and interest in trying new technologies. They valued user experience and put less weight on investment costs than potential adopters and non-adopters. In terms of sociodemographic characteristics, the predictors of being an adopter differed somewhat from Rogers' hypotheses, whereas the predictors for being a potential adopter (early adopters and early majority in Rogers' typology) mostly support Rogers' typology. Younger age, higher education, and higher income each increased the likelihood of being a potential adopter.

Our results are also a reminder of the importance of methods. The multinomial logit approach used has been designed specifically to assess the importance of all the different factors driving discrete consumer decisions. The approach produced results that differ somewhat from simple one-by-one comparisons of explanatory variable means, which has been the method used in previous studies of earlier versus later home solar PV adoption. In relation to the empirical literature primarily interested in what drives home solar PV adoption, our results confirm previous findings that peer effects are enabling factors and that information deficits are barriers to adoption. Somewhat surprisingly, energy-related education or employment was linked to postponing adoption in our survey data. This result may stem from an expectation that home PV system prices will decrease as the technology matures. The perception that electricity prices will increase in future in turn motivated adoption.

An important policy implication of the results is that improving the availability of relevant and trustworthy technical and economic information and accounts of user experiences could support the adoption of solar PV. This conjecture is also supported by previous research (see e.g., [2,19,35,40,42,45]). Such interventions could take the form of local or regional energy counseling for households, development of online tools, and educational games (see Rai and Beck [42] for an interesting example). Our results also indicate that misperceptions about the environmental effects of energy supply or the effort required by home solar PV could hamper adoption. Providing accurate information on the environmental impacts of the energy sector and the role of solar PV in reducing greenhouse gas emissions, and on the ease of use of home solar PV after installation, could also be effective interventions.

Perceptions that solar PV systems are expensive and that they should be subsidized were associated with delayed adoption. However, the survey data did not allow an assessment of the significance of actual solar PV system prices or subsidies as barriers to or enablers of home solar PV uptake. More research is needed to disentangle the importance of subsidies from that of accurate information and to determine the applicability of subsidies as a policy intervention in the Finnish context. The economic viability of home solar PV is also in transition, which implies that the effectiveness of subsidy interventions could fade rapidly. Solar system prices in the Finnish market have been decreasing in recent years, and electric vehicles, which allow households to store electricity from solar PV, have become more common. In terms of targeting policy interventions and marketing campaigns to those likely to consider solar PV adoption, by differentiating those unlikely to invest from potential adopters, our results indicate that younger, people with a university or applied sciences degree and higher-income households are more likely to be potential adopters.

Although the results on the factors related to solar PV adoption seem mostly intuitive, there are some limitations to our study. First, adopters' responses may have been biased toward justifying the choice they had made, rendering them overly positive regarding solar PV. Thus, responses to the attitudinal questions may have been driven by the adoption decision already taken. On the other hand, the data collected in the survey enabled us to carry out an econometric analysis with a rich set of background variables and, importantly, with relatively equal shares of early adopters, potential adopters, and non-adopters. The presence of respondents from all adoption categories mitigates the potential "early adopter bias" discussed by Edling and Danks [47]. Second, the external validity of the results is limited due to the possible nonresponse bias and selection bias discussed in Section 3.1. The sample population is not as representative of the relevant Finnish population as a random sample would have been. In particular, the share of solar PV adopters in our sample was higher than that in the market overall. The results are also specific to a context with certain building and energy infrastructure, electricity market, climate, and economic profitability conditions for solar PV. However, the findings are informative for other areas with similar characteristics, for example the Nordic countries, which are part of the same electricity market as Finland, share the same climate, and in many ways have similar infrastructure.

Finally, this study is cross-sectional. A follow-up survey at a different point in time would be an interesting topic for future study. A second survey wave would allow an examination of temporal dimensions of solar PV adoption, tracing changes in energy policy, markets, and consumer attitudes and motivations over time (see Sovacool et al. [48]). For example, electricity prices surged in Europe, including Finland, in 2022. As a consequence, the economic profitability of grid-connected home solar PV has likely increased. Both average electricity prices and price variability have increased markedly, and substantial, continuous media attention has made the increase salient. These unanticipated market changes provide price variation that could help better understand the importance of economic factors as drivers of home solar PV uptake.

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.

Data availability

The authors do not have permission to share data.

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Appendix A. Binomial logit model results

As an alternative specification, we focused on two possible outcomes: already have installed a solar PV system (adopter) or have not installed a solar PV system (non-adopter). In the binomial logit (BL) model, the choice probability is of the form

$$P_n(j=1) = \frac{exp(\beta_1 x_n)}{1 + exp(\beta_1 x_n)}. \tag{A1}$$

The BL model performs quite well, with a McFadden Pseudo R^2 of 0.18. Overall, the model captures several statistically significant factors explaining solar PV adoption. Table A1 presents the results as average marginal effects.

Table A1
Results of the binomial logit model.

	Adopter	
Variable	ME	SE
Age	0.0052***	0.0011
Female	−0.1035***	0.0288
Income	0.0026	0.0084
High education	−0.0668***	0.0256
Household size	−0.0026	0.0116
Rural location	0.1311***	0.0247
House area	0.0003*	0.0002
House age	−0.0011**	0.0004
Farmhouse	0.0650	0.0691
Direct electric heating	0.0691**	0.0290
Water-circulating heating system	0.0542	0.0520
Heat pump	0.0784**	0.0338
Energy efficiency upgrade	0.0921***	0.0247
Prefers widely used	−0.0160	0.0238
Values user experience	−0.0521**	0.0245
Interest in testing	0.0778***	0.0246
Values reliability	−0.0571	0.0352
Dislikes complexity	−0.0190	0.0246
Diy type person	0.0138	0.0244
Env. important	0.0825***	0.0244
Env. exaggerated	−0.0073	0.0298
Price important	−0.0806***	0.0237
Elec. prices increase	0.0786***	0.0236
Solar PV is expensive	−0.0987***	0.0337
Should be subsidized	−0.0045	0.0289
Long payback time	0.0444	0.0303
Increases resale value	0.1890***	0.0257
System is high maintenance	−0.1359***	0.0382
System is ugly	−0.0790**	0.0360
Peers	0.0671***	0.0235
Expert	−0.0619**	0.0261
Information is insufficient	−0.0517**	0.0235
LL	−707.29	
LL(0)	−860.43	
McFadden Pseudo R2	0.18	
AIC	1480.6	
N	1377	
k (# of parameters)	33	

*, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

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