Journal of Cleaner Production 378 (2022) 134417

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

The future adoption of community shared solar: An unlabeled choice experiment in Guangdong, China

Zhenyu Tan [a], Deyu Li [b,c], Tong Xu [b,*]

[a] Department of Land Economy, University of Cambridge, Cambridge, United Kingdom
[b] Centre for Environment, Energy and Natural Resource Governance, Department of Land Economy, University of Cambridge, Cambridge, United Kingdom
[c] Department of Human Geography and Spatial Planning, Utrecht University, Utrecht, the Netherlands

ARTICLE INFO

Handling Editor: Zhifu Mi

Keywords:
Community shared solar
Energy policy
Technology diffusion
User
China

ABSTRACT

Community shared solar (CSS) program has great potentials in contributing to the complete decarbonization of the power sectors worldwide. Few research have focused on its potential diffusion from the user perspective. This paper fills the gap by conducting a survey-based unlabeled choice experiment in the Guangdong Province, China to investigate the determinants of potential users' willingness to participate in CSS programs. We analyzed the survey data using a random parameter logit model. Our results show that users are more likely to participate in CSS programs with lower upfront payment, trialability, shorter payback period, a public utility as provider and larger impact on climate change mitigation. However, they are likely to accept longer payback period in CSS programs with higher participation rate because of the potential benefit from interpersonal communication. Users' previous knowledge of CSS programs and income will also increase their willingness to participate in CSS programs with higher upfront payment. Our results provide important implications for designing policies and business models to promote the distributive renewable energy in China.

1. Introduction

The net-zero transition to limit global warming to 2 °C goal of the Paris Agreement by 2050 requires the acceleration of the development of new, and the deployment of existing clean energy technologies to replace fossil fuels (IEA, 2020). Solar photovoltaic technology (PV) played and will continue to play an important role in this transition (IEA, 2020). Despite the significant cost reduction and unexpected deployment over the last two decades, further upscaling of solar energy still faces challenges such as the high cost of financing and the grid integration (Creutzig et al., 2017). In this context, community solar energy has great potential in advancing the decarbonization of power sectors.

Community shared solar (CSS) are one type of distributed solar PV power plants built on-site or off-site communities to provide electricity or financial benefits through the net energy metering to those households participated in the programs (Chan et al., 2017; Michaud, 2015; Feldman et al., 2015). Fig. 1 demonstrates how CSS programs work, and Fig. 2 provides a general picture of CSS programs. Various forms of community solar projects emerged over the years including utility-sponsored community solar, and community solar operated by special purpose entities, like community energy cooperatives (Funkhouser et al., 2015; Bauwens et al., 2016; Korjonen-Kuusipuro et al., 2017).

Recent literature has emphasized the importance of an user perspective or public participation in understanding the net-zero energy transitions (Schot et al., 2016; Chilvers et al., 2021). There exist technological, financial, and policy factors affecting the users' participation in CSS programs, and can be grouped into three main categories: the characteristics of CSS programs, the communication channels, and the effects of social systems (Augustine and McGavisk, 2016; Awad and Gül, 2018; Cai et al., 2019; Chan et al., 2018; Feldman et al., 2015; Hess and Lee, 2020; Michaud, 2015; Wang, 2014; Xu and Cao, 2020). However, most existing studies on the diffusion of CSS programs do not quantitatively include all three categories.

The rapid growth of solar PV deployment in China since 2010 resulted from various demand pull policies aimed at creating and sustaining domestic market (Yap et al., 2022). However, most solar panels are installed in centralized solar PV power plants. Although the National Energy Administration of China started to promote distributed solar energy projects (i.e. solar PV power plant with capacity smaller than 20 MW) since 2014 (National Energy Administration, 2014b), and allowed market-oriented trading in 2017 (National Energy Administration,

* Corresponding author.
E-mail address: tx224@cam.ac.uk (T. Xu).

https://doi.org/10.1016/j.jclepro.2022.134417
Received 20 May 2022; Received in revised form 17 September 2022; Accepted 28 September 2022
Available online 7 October 2022

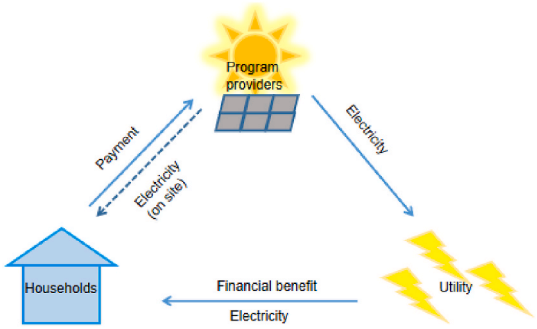

Fig. 1. Demonstration of CSS programs.

2017), distributed solar PV only accounts for 35% of total installed capacity of solar PV in China in 2021 (National Energy Administration, 2022). Furthermore, most centralized solar PV projects locate in the western regions far away from consumption centers in eastern regions, creating challenges in grid integration and long-distance transmission of electricity (Gao and Rai, 2019).

CSS program has the potential in further increasing the penetration rate of distributed solar energy in China. However, few studies focused on its potential diffusion in China. The recent published 14th Five Year Plan of Modern Energy System emphasized the development of distributed solar energy (National Development and Reform Commission, 2022). It is therefore important to conduct an ex-ante analysis of factors that might affect people's willingness to participate in CSS programs in China. The rest of the paper is organized as follows. Section 2 reviews the existing literature on diffusion of community solar energy. Section 3 introduces the research area and the methodology of our experiment. Section 4 shows the results from the econometric analysis based on the survey data. We discusses the implications of our results in section 5 and conclude in section 6.

2. Literature review

2.1. The theory of the diffusion of innovations

Rogers's theory of the diffusion of innovations (2003) introduced four key components of diffusion. First, five characteristics of a specific technological innovation jointly influence diffusion speed: relative advantages, trialability, compatibility, complexity, and observability. The second element is the communication channel, which represents all means, including mass media, interpersonal communication channels, and the Internet, to deliver information from one individual to another so that people alter or keep their attitude toward the innovation; both verbal and nonverbal communication, which conveys information for observation and imitation, are significant in decision making. The third element is time, which is involved in diffusion through the innovation-decision process, the adopter categorization, and the adoption rate, which is the relative speed of adoption. The last element, the social system, is the group of interrelated units that pursue a mutual goal, and the structure of a system affects the adoption in various ways. In addition, the characteristics of decision-making adopters also matter in the diffusion of innovations.

2.2. Empirical research on the diffusion of distributed solar PV (DPV)

Existing research on the drivers of the diffusion of distributed solar PV (DPV) mostly focused on four groups of factors: 1) characteristics of DPV projects; 2) communication channels; 3) social systems; 4) characteristics of adopters. First, Yuan et al. (2011) and D'Agostino et al. (2011) theorized that the high cost and technology deficiencies might hinder the adoption of individual DPV in China. These theories should be considered along with the fact that International Renewable Energy Agency (2020) said solar PV costs fell 82% between 2010 and 2019. Fleiβ et al. (2017) identified that the low cost of a solar PV system and continuous subsidies were the main drivers of the diffusion of DPV in Australia. Qureshi et al. (2017) found that a long payback period impacted the diffusion of individual DPV; however, Schelly (2014) found that, in Wisconsin, U.S., people did not consider the payback period of individual DPV because they regarded that the adoption was to purchase future electricity using present money and it was a lifestyle instead of an investment. As for CSS, Augustine and McGavisk (2016), Hoffman and High-Pippert (2014), and Bovarnick and Johnson (2019) identified that the complexity of CSS programs, high upfront payments, long payback periods, and limited financial incentives were barriers to CSS diffusion. Chan et al. (2017, 2018) and Chang et al. (2017) noted that a PAYG structure and a monthly-payment plan might increase the participation rate by enhancing financial availability and flexibility.

Second, peer effects from communications and imitation were found important to the formation of the adoption decision of individual solar PV (Rai and Beck, 2015; Schelly, 2014; Islam, 2014; Rai and Robinson, 2013). Without necessary information obtained through communication channels, people would not be aware of related products and then adopt them (Yuan et al., 2011; Qureshi et al., 2017). Specifically, Islam (2014) took the adoption rate as a proxy of the imitation effect and found that nonverbal communication by observing people changed people's attitudes toward the attributes of solar PV and eventually persuaded them to adopt solar PV. Moreover, peer effects would be strengthened as the number of adopters increased (Rai and Robinson, 2013). Direct marketing from providers is also important to induce adoption decisions (Rai et al., 2016).

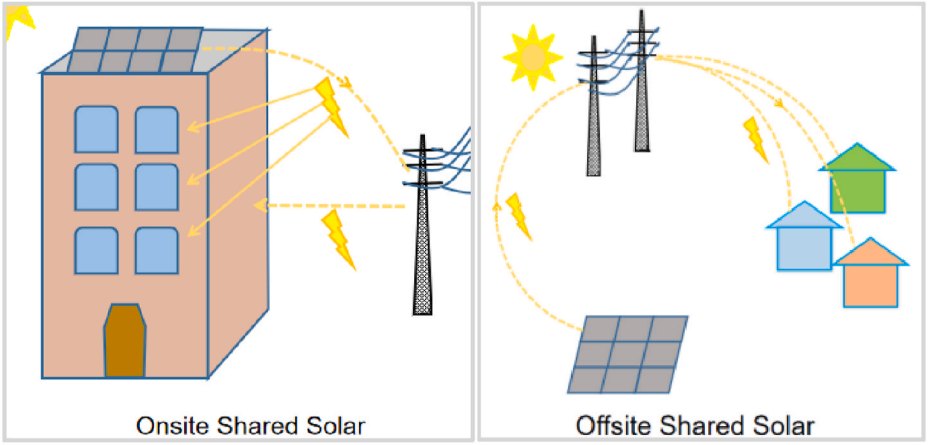

Fig. 2. General pictures of CSS programs.

Similar findings about CSS included that people would not adopt it when they were unfamiliar with it (Chang et al., 2017; Bovarnick and Johnson, 2019; Feldman et al., 2015; Koch and Christ, 2018). Therefore, communications and education about CSS could reduce barriers to accepting unfamiliar CSS programs (Horváth and Szabó, 2018; Koch and Christ, 2018), and these processes could be accelerated by social media (Chan et al., 2018).

Third, unlike the consensus on the effect of communication channels, the literature has not reached an agreement on the influence of the social system. Koch and Christ (2018), Bashiri and Alizadeh (2018), Rai and Beck (2015), and Yuan et al. (2011) found that individuals' desire to manage air pollution encouraged them to utilize individual DPV. However, this function of social norms was not significant in Islam (2014) and Fleiβ et al. (2017). Different results were also found about the effect of social structure. Ferster et al. (2020) proved that interactions within a social system promote a collective decision on the adoption of solar energy, while Vasseur and Kemp (2015) found that individuals did not feel social pressure to adopt solar energy when making an independent decision. Social trust also affects the adoption of DPV. Abdullah et al. (2017) found that respondents distrusted the provider, a third party of the SHS, and thus rejected adopting that provider's solar PV; they preferred the government to supply solar products. By contrast, Lee et al. (2018) found that small solar power stations run by private corporations were more attractive than those run by the government.

Lastly, existing research also covered the effect of individual characteristics, but conclusions were variable. Bashiri and Alizadeh (2018) and Vasseur and Kemp (2015) found a weak trend toward the younger adopting individual DPV, whereas Schelly (2014), whose sample's average age was 60, found that willingness to adopt solar PV became stronger as the age increased; Kwan (2012) found middle-aged people are more likely to adopt individual DPV. As for the education level, Islam (2014) rejected the hypothesis that solar PV adopters had higher education levels, but Sardianou and Genoudi (2013) accepted this hypothesis, which coincided with Rogers's theory (2003) that early adopters tend to be better-educated. Regarding income, Kwan (2012) found that the medium-income group would be more likely to adopt solar PV at home, while Vasseur and Kemp (2015) showed that adopters tended to have higher income. In addition, Bashiri and Alizadeh (2018) found that being female and having a larger family size positively affected the willingness to adopt individual DPV, but Sardianou and Genoudi (2013) found that gender was not a significant variable in explaining the adoption of renewable energy.

2.3. The research gap

Existing literature, such as Fleiβ et al. (2017), Abdullah et al. (2017), and Vasseur and Kemp (2015), focus on the characteristics of distributed solar PV, the communication channels, or the effects of social systems separately. Including all three elements would be advantageous in investigating the diffusion. Individuals are aware of innovations only after communication channels deliver information to them, and the social system shapes individuals' behavior patterns (Rogers, 2003). Some studies, such as Chan et al. (2018), Koch and Christ (2018), and Hoffman and High-Pippert (2014), following Rogers's theory, cover three key elements with qualitative insights. In addition, few research focused on the willingness of users to participate in CSS programs in China. This study endeavors to address the research gap by quantitatively investigating how the factors covered in Rogers's three elements affect the willingness of users to participate in CSS programs in China.

3. Methodology

3.1. Research area

We chose Guangdong Province in China to conduct our survey. Guangdong is the most developed province locating in southern China. Although the size of Guangdong is only 2% of China's size, it is home eight percent of the Chinese population, 11 percent of China's GDP, 17 percent of R&D investment, and 13 percent of public budget (National Bureau of Statistics, 2020). However, the electricity consumption in Guangdong is higher than that of other provinces of China, and the share of electricity from renewable source is lower than national average (National Bureau of Statistics, 2021). Despite the abundant solar energy potential in Guangdong (National Energy Administration, 2014c), only 3% of China's total solar PV capacity locates in Guangdong (National Energy Administration, 2022). Nevertheless, the share of distributed solar energy in Guangdong is 50 percent, higher than the national average. Therefore, the upscaling of solar energy through community shared solar in Guangdong can provide important policy implications that can be extrapolated to other provinces in China.

3.2. Choice experiment design

We chose a choice experiment (Louviere et al., 2000), which can observe people's reactions in different scenarios that CSS program were introduced into China, was designed for this research. We chose an unlabeled design (De Bekker-Grob et al., 2010) to draw people's attention to the attributes of the CSS program. In each task of the choice experiment, respondents were asked to select their most preferred option among three hypothetical CSS programs, plus an opt-out option meaning respondents were not willing to participate in any of the hypothetical CSS programs.

3.2.1. Attributes and levels

It is important to simplify the hypothetical CSS program. Atkinson et al. (2018) suggested that the hypothetical goods had to be easily understandable to reduce respondents' cognitive burden. Moreover, people's familiarity with a hypothetical good can also reduce the hypothetical bias (Atkinson et al., 2018). Therefore, in our hypothetical CSS programs, participants would pay an upfront payment for the 25-year subscription of PV panels, which is similar to purchasing SHSs with 25-year average operating life (Jordan and Kurtz, 2013). Participants received the right to use the PV panels, but these remained owned by the program provider, who is responsible for any necessary maintenance.

Attributes and levels were selected from the reviewed literature, daily practice, and consultation with an expert in energy policy; a focus group discussion of five individuals was conducted to enhance the validity of this selection. The selected attributes, their explanations, and their levels are summarized in Table 1. Particular considerations when designing the attributes deserve explanation: Firstly, the effects of financial benefits, such as subsidies and feed-in tariffs (FITs), are reflected in the payback period (Fleiβ et al., 2017) to reduce respondents' cognitive burden. Secondly, the participation rate, as a proxy of the intensity of any form of communication, was selected to represent the effect of the communication channel. The efficiency of this proxy was shown in Islam (2014) when it was used to represent imitation effects. In addition, in a society with the Internet, online discussion could be easily accessed. Thus, in a hypothetical scenario, the more participants in a CSS program, the easier it would be for people to gain information from other participants, reducing the uncertainty of adoption. Consequently, participation rate can be included in the utility function of the random utility theory (McFadden, 1974), because participants who reduce their uncertainty are more likely to prefer to participate. Thirdly, no other attribute was included, to ensure simplicity: the complexity of the task increases with the number of attributes, and programs with excessive attributes may be too challenging to be understood, causing biases in respondents' answers (Louviere et al., 2008).

The costs took the prices of SHSs as references because no CSS data in China was available. The price of the SHS was about 10000 RMB/kW (Shiften, 2020; GuangfuBJX, 2018). The capacity of SHS usually ranges

Table 1
Attributes and their levels with descriptions.

Attributes	Levels	Attribute descriptions
Upfront payment (RMB)	2000 50000 100000 150000	The cost for the participation in the CSS program.
Payback period (years)	5 12.5 25 26	The time that the CSS program needs to generate a positive net present value (NPV), which is the discounted difference between the upfront payment and the financial benefit generated through the participation.
Trialability	Yes No	If participants can leave the program with proper refunds at any time.
Participation rate	0% 2.5% 5% 12.5%	The percentage of people who have participated in the CSS program in a community.
Reduction of CO_2 (tons/year)	200 5000 10000 20000	The amount of CO_2 emissions reduced by the program per year.
Program provider	a public utility a company a non-profit organization	The program provider which provides and manages the program.

from 5 kW to 15 kW, with an average of about 10 kW, and the smallest capacity is 0.2 kW (Wang, 2020). Hence, levels of the upfront payment were achieved. The shortest payback period was set at 5 years, which is the shortest payback period among the existing CSS programs in America (Beavers et al., 2013). The other three levels of the payback period represent that a CSS program has a relatively long payback period, a zero NPV, and a negative NPV respectively, given that no literature has recorded the longest payback period. Trialability has two levels: Yes and No.

The participation rate ranges from 0% to 12.5%. Rogers (2003) introduced the concept of critical mass, which is a situation where the number of people adopting an innovation is enough so that the diffusion becomes self-sustaining. After the adoption rate reached the threshold of critical mass, which is usually between 5% and 20%, social norms such as pressure on nonadopters and imitation of common behavior can dominate further adoption. Therefore, critical mass may cause an illusion in the analysis of other factors. Thus, the participation rate could not be set higher than 20%. In this case 12.5%, which is the average number of 5% and 20%, was arbitrarily selected to represent a strong communication channel, while 5%, 2.5%, and 0% represented moderate and weak communication channels.

The largest possible amount of reduction of CO2 emissions is 20,000 tons/year because the largest scale of DPV is limited to 20 MW (National Energy Administration, 2014a), and a solar PV system at a 1 MW scale can reduce about 1000 tons of CO2 per year in China according to Chinese Certificated Emission Reduction (*Tanjiaoyi, 2016*). The remaining levels were selected to represent the amount of the reduction of CO2 emissions of CSS programs at smaller scales. Since the CSS program can be provided by a local public utility, a business, or a non-profit corporation (Coughlin et al., 2011), these were set as three levels.

3.2.2. Choice sets

80 choice sets were created by a fractional orthogonal design (Louviere et al., 2000). This was accomplished by the mixed-level orthogonal design, which was efficient for detecting both main effects and interaction effects, in *Lighthouse Studio* (Sawtooth Software, 2020). The design created 8 blocks of choice sets and each has 10 tasks. A dominance test was designed as a choice set, as suggested by Atkinson et al. (2018), to test if respondents seriously answered the survey, and to prevent the impact of random selection and fatigue bias. This test includes a dominating program with the lowest upfront payment, the shortest payback period, and the largest avoided CO_2 emissions in a task. Any individual who fails to select a dominating program may misunderstand the task and will be excluded from the final sample, enhancing the validity of the collected data (Lancsar and Louviere, 2006). Table 2 is a translated version in English of an example of a choice task presented in the questionnaire.

If there are three available 25-year CSS programs, namely, Program A, Program B, and Program C, which one would you like to participate in? Please pay attention to the family budget and choose the program only if you are willing to pay the corresponding amount in the realistic scenario, or choose "Nonparticipation".

3.2.3. Questionnaire materials and survey administration

Following Mangione's (1995) recommendations on surveys, 8 versions of the questionnaire were created, each of which included one block of choice sets. Each version of the questionnaire was the same except for the section on the choice experiment. One version of the questionnaires and its translated version in English may be found via the links in the Appendix.

Before fielding the survey, two pilot studies were conducted. Firstly, 12 individuals, who were convenient samples with different education levels, finished the survey and provided feedback on the questionnaire. Accordingly, the framing in the survey was revised to ensure the choice experiment was understandable with the given information. The survey was revised again after the second pilot study involving 71 households collected by *Questionnaire Star* (WJX, 2020). 55 of them completed the survey, and they spent less time on the survey (110 s on average) than respondents in the first pilot study (about 5 min). Moreover, 54.55% of them failed the dominance test, meaning that many respondents did not seem to be seriously completing the questionnaire. Therefore, a small amount of e-cash was attached to the questionnaire as further incentive.

The final version of the questionnaire had several procedures, as shown in Fig. 3. In the first section, respondents were told the purpose of this survey, the estimated time (5 min) to complete the survey, and a chance to receive some e-cash. They were also told that a complex experiment would be provided, followed by a question asking if they were willing to continue the questionnaire. Only those choosing 'Yes' continued to answer two questions about their attitudes to air pollution and climate change, which aimed to involve them in the choice experiment. The second section started with a 'cheap talk' (Ladenburg and Olsen, 2014) and an example of choice tasks. The 'cheap talk' briefly introduced CSS and explained six attributes and how to finish choice tasks. The participation rate was stressed to represent the opportunity for people to require necessary information from other participants. Participants were told that using a TV for 10 h generates 1000 g of CO_2 on average, so that they had a sense of the amount of CO_2. Furthermore, they were told the differences between individual DPV and the CSS program. After the example of tasks, they were asked how much they had understood about the attributes and the choice experiment, and whether they could continue the questionnaire. Only respondents who

Table 2
An example of the choice task (English translation).

	Program A	Program B	Program C	D Nonparticipation
Upfront payment	50000 RMB	150000 RMB	2000 RMB	
Payback period	12.5 years	5 years	26 years	
Trialability	Yes	Yes	No	
Participation rate	12.5%	0%	5%	
CO_2 Reduction	20,000 tons	20,000 tons	10,000 tons	
Program provider	Public Utility	Non-profit Organization	Company	

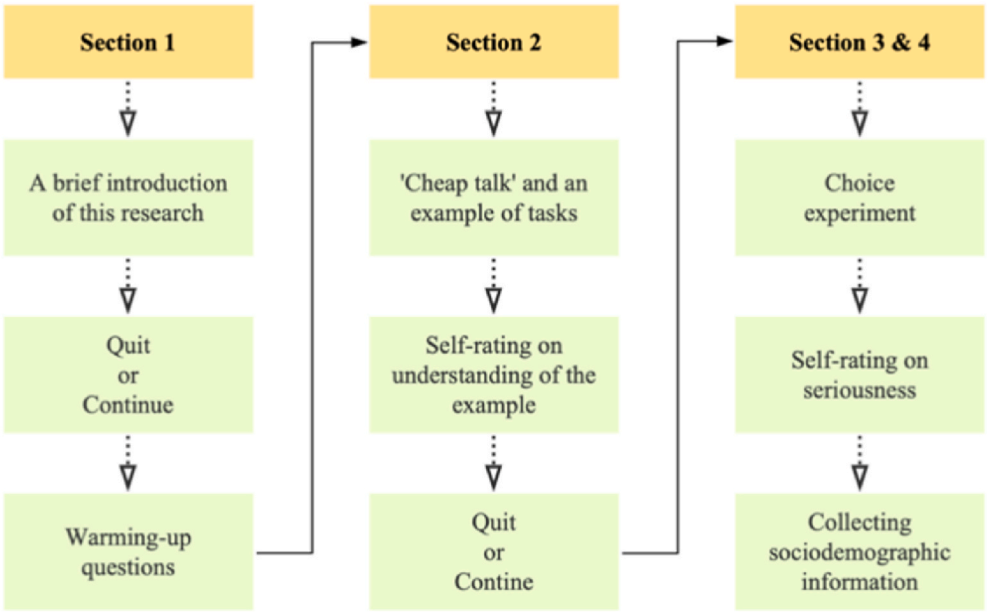

Fig. 3. The procedures of the questionnaire.

chose to continue could participate in the choice experiment, which was in the third section. Each task in the third section reminded respondents to bear their family budget in mind through an 'opt-out reminder' (Ladenburg and Olsen, 2014), which instructed them to choose the opt-out option if they were not willing to pay for CSS in a real context. Moreover, respondents were asked how serious they were when participating in the choice experiment at the end of the third section. The last section collected respondents' attitudes toward solar power and personal characteristics.

3.3. Data collection

3.3.1. Sampling strategy

The survey was conducted using a Chinese online platform called Questionnaire Star, from 24th June to 2nd July 2020. This platform can send questionnaires to more than 6.2 million registered users, who have different vocations, most of whom are under 40 years old. Sampling services were purchased so that 8 versions of questionnaires were randomly sent to different respondents in Guangdong. Each respondent received a random version and could not answer any other versions of the questionnaire.

3.3.2. Response analysis

564 completed questionnaires were collected. 392 respondents confirmed that they understood how to finish the choice experiment, and they seriously considered all attributes when making choices by choosing the largest two Likert scales. These 392 respondents passed the dominance test, and the average time they spent on the questionnaire was over 6 min (383 s), which is more than the average time that people spent in the second pilot study. Therefore, it could be concluded that the these 392 respondents' answers could be used for the analysis. The overall completion rate of the questionnaire is 69.5%, higher than the reliable completion rate of the choice experiment about 31% in academic work (Kontoleon and Yabe, 2003). Each version has similar submissions and completion rate, as listed in Table 3. Therefore, the attrition will not be affected by the version of the questionnaire.

3.3.3. Sample representativeness

The demographic representativeness of the sample are summarized in Table 4. The representativeness of the sample is modest, and some deviations from the data of Guangdong must be noticed. Our respondents are mostly under 40 and well-educated. This might limit the policy implications drawn from this research. Early adopters tend to have higher income and education levels (Rogers, 2003). Similar pattern has been noticed in the earlier adopter of electric vehicles (Meelen et al., 2019). Therefore, our results can still help provide advice for the formative phase in the diffusion of CSS (Wilson, 2012). With sufficient caution, the result will be discussed in section 5.

3.4. Econometric model

3.4.1. Theoretical foundation

The Random Utility Model (RUM) is a suitable model for this research because rational people's choices are based on utility (McFadden, 1974). In this case, RUM assumes individual n's utility ($\mathbf{U}_{nj}$) is divided into a deterministic utility ($\boldsymbol{V}_{nj}$) and a stochastic utility (ϵ) as shown in Equation (1). The deterministic utility $\boldsymbol{V}_{nj}$ is observable, and it represents an individual's observable component of utility gains from option j (j = Program A, Program B, Program C, or the opt-out option) (McFadden, 1974).

$$\boldsymbol{U}_{nj} = \boldsymbol{V}_{nj} + \epsilon_{nj} \tag{1}$$

Furthermore, assuming the individual n's deterministic utility (Vnj) is a linear combination of utility gained from attributes $\boldsymbol{Xj}$ of option j, and assuming preference heterogeneity exists (McFadden and Train, 2000), Equation (1) can be written as:

Table 3
The completion rate of the different versions of the questionnaire.

Versions	1	2	3	4	5	6	7	8
Total submissions (564)	69	76	66	72	65	65	72	79
Valid submissions (392)	46	56	43	50	44	46	49	58
Completion rate (%)	66.67	73.37	65.15	69.44	67.69	70.77	68.06	73.42

Table 4
Descriptive statistics of respondent characteristics N = 392.

	Samples	2018 Guangdong census data*
Location of respondents		
Eastern Guangdong	31.63%	15.32%
Western Guangdong	11.22%	14.28%
Pearl River Delta	51.79%	55.53%
Northern Guangdong	5.36%	14.87%
Age		
0–20	–	17.18% (0–14)
20–29	48.72%	
30–39	38.78%	74.2% (14–64)
40–49	6.63%	Detailed percentages of age intervals are not available.
50–59	3.32%	
60+	–	8.62% (64+)
Family Income(yuan)		
lower than 5000	4.85%	
5000–9999	24.23%	8979.79 (Average family income)
10000–49999	56.12%	
50000–89999	6.63%	
90000–12999	4.08%	
130000+	4.08%	
Education		
Primary school(=6 years)	0.00%	25.00%
Middle High school (=9 years)	1.28%	46.00%
High school(=12 years)	6.38%	24.00%
University degree(=16 years)	85.46%	4.60%
Master degree and higher(≈18 years)	6.89%	0.40%
Gender		
Male	51.15%	52.18%
Female	48.85%	47.82%
Previously knew about CSS		
Yes	52.81%	
No	47.19%	
Household size		
Mean	3.93	3.18
Standard Deviation	1.17	–
Attitudes to air quality and climate change[a]		
Air pollution in the city is serious	3.04	–
Global warming is severe	4.33	–
Solar PV can help to mitigate the climate change problem	4.02	–

*Note: Source: Guangdong Statistics Bureau at: http://tjnj.gdstats.gov.cn:8080/tjnj/2019/directory.html (accessed: 6 July 2020).

[a] On the 1–5 Likert scale, where 1 = strongly disagree and 5 = strongly agree. Average values are reported.

$$\boldsymbol{Unj} = (\beta+\eta n)\mathbf{X}j + \epsilon nj \quad (2)$$

Where **β** is the vector of coefficients of attributes ***Xj*** and **η**n is the vector of individual n's random factors. It does not assume the unrealistic independent from irrelevant alternatives characteristic (McFadden and Train, 2000). The probability that j is chosen can be estimated with Stata 15.0 if coefficients in **β** are assumed to have independently identically normal distribution.

In terms of coding, continuous variables were coded at their levels. Effect coding was used for the two categorical variables (trialability and the type of CSS provider) to detect both main effects and interaction effects and prevent the misinterpretation of the coefficients of categorical variables (Bech and Gyrd-Hansen, 2005). An alternative-specific-constant (ASC) that captures information not explained by the attributes was generated. This ASC equaled 1 when Program A, B, or C was selected, and 0 when respondents chose not to participate any of the program.

3.4.2. Random parameter logit model

First, the main effects of the selected attributes were examined by including only these selected attributes as regressors. All attributes were significant at the 1% significance level. The coefficient of the upfront payment was assumed to be a constant to obtain normally distributed marginal WTPs.

The WTP for each attribute can be derived through Equation (3) where β_{xk} and $\beta_{payment}$ represent the estimated coefficients of kth attribute x and the upfront payment, respectively (Atkinson et al., 2018).

$$WTPxk = -(\beta xk/\beta payment) \quad (3)$$

To investigate the interaction effects of these attributes, all two-way interaction effects were introduced into the model following the backward selection. Lastly, all significant variables together with individual characteristics were put into the model to check if personal characteristics affected the willingness to participate and people's perception of those attributes. The characteristics of respondents were introduced into the model through their products with the ASC and with two attributes (the upfront payment and the payback period) which had higher relative importance. The Relative Importance (RI) of an attribute in a choice reflects people's sensitiveness of the change of the attribute (Orme, 2010). RI was obtained using market simulations in the software Lighthouse Studio.

Particularly, income intervals were asked in surveys, but the variable, Income, took average values (7,500, 30,000, 70,000, and 110,000) of 4 middle-income intervals, and took 5000 and 130,000 to represent the lowest- and the highest-income intervals respectively, to create a continuous variable avoiding excessive interaction terms. Following the backward selection, and based on the t-statistics, McFadden R2, AIC, and BIC, the final model with 1000 Halton draws were obtained. In addition, diagnostic tests were conducted to prove the robustness of the model specification, and there were no omitted variables and no severe multicollinearity.

Table 5
Random parameter logit model.

Variable	Coefficients	Standard error
	Non-random parameters in the utility function	
Upfront Payment (in RMB 10,000)	−0.149***	0.009
Company	−0.110***	0.034
	Random parameters in the utility function	
Payback Period	−0.076***	0.006
Trialability	0.451***	0.037
Participation Rate	0.011	0.013
CO_2 Reduction	0.110***	0.038
Public Utility	0.280***	0.037
ASC	3.406***	0.290
	Two-way interaction parameters in the utility function	
Payback Period × Participation Rate	0.001*	0.001
	Interaction terms between parameters and personal information	
Known × ASC	1.322***	0.369
Known × Upfront Payment	0.039***	0.009
Income × Upfront Payment	0.005***	0.001
	Derived standard deviations of parameter distributions	
SD: Payback Period	0.077***	0.005
SD: Participation Rate	0.054***	0.009
SD: CO_2 Reduction	0.356***	0.060
SD: Trialability	0.481***	0.042
SD: Public Utility	0.379***	0.047
SD: ASC	2.595***	0.213
Observations	15680	
McFadden's pseudo R^2	0.11975	
AIC	8078.544	
BIC	8216.426	

***P < 0.01, **P < 0.05, *P < 0.1.

4. Results

Table 5 summarizes the results of our regression model. All coefficients of attributes except for Company and Upfront Payment have a random distribution. Among interaction terms, only Payback Period × Participation Rate was significant at the 10% significance level. Among demographic variables, only the previous awareness of CSS (denoted as Known) significantly increased the willingness to participate. In addition, the awareness of CSS and income have significant influence on people's preferences for the upfront payment. The McFadden R^2 of the final model is around 0.12, indicating that the model is moderately fit. It is acceptable according to existing studies (Can and Alp, 2012; Mazzanti, 2001).

According to the model, the coefficients of Upfront Payment and Payback Period are negative as expected. They indicate respondents prefer lower costs and shorter payback periods. The coefficient of the Company is negative while the coefficient of Public Utility is positive. These results indicate that compared to programs provided by a non-profit organization, respondents are less willing to participate in a company-led program, and more willing to participate in a CSS program led by public utility. The coefficients of CO_2 Reduction and Trialability, and ASC are positive. Respondents prefer the CSS program, which brings much carbon emissions saving and allows them to try. The large and positive coefficient of ASC means that respondents are willing to participate in a CSS program. The coefficient of Participation Rate is positive but not significant, whereas the interaction term, Payback Period × Participation Rate, is significantly positive. This indicates that the percentage of participants (when under 12.5%) does not directly encourage participation, but as the participation rate increases, people's willingness to participate in a program with a certain payback period increases given all else unchanged. In terms of the awareness of CSS, respondents having heard of CSS are more willing to choose a hypothetical CSS program. The coefficients of Known × Upfront Payment and Income × Upfront Payment are positive meaning that the awareness of CSS and a higher income reduce disutility caused by the upfront payment of CSS programs.

The RI and the WTP are used to reflect the magnitude of effects of attributes as shown in Table 6. The upfront payment is the most important attribute that respondents would consider, followed by the payback period. The other four attributes have less importance.

5. Discussions

5.1. Discussions of results

Our result shows that respondents do not prefer a high upfront payment of CSS programs, indicating that the high upfront payment is a barrier to adoption, especially among lower income groups. This finding is in line with the conclusions of the previous literature (e.g. Chan et al., 2018; Augustine and McGavisk, 2016; Vasseur and Kemp, 2015). Moreover, the highest relative influence of high upfront payment shows that cost is the most important attribute affecting people's willingness to participate in CSS programs, which is similar to the conclusions of Yuan et al. (2011) and Qureshi et al. (2017).

Besides the cost, long payback period is another barrier to adopting CSS. This barrier can be interpreted in two dimensions according to Schelly (2014) and Fleiβ et al. (2017). First, Schelly (2014) recorded that solar PV adopters regarded the cost of the adoption as a bill in the future. If an individual participates in a CSS program before the break-even point of the investment, it means that a participant pays the electricity bill before electricity consumption. Therefore, the observed unfavorable long payback period means that respondents do not wish to pay for future electricity too early with present money, even if electricity is generated from clean energy. Second, Fleiβ et al. (2017) found that the return on investment drove people to adopt distributed solar energy. While CSS programs may provide participants with financial benefits after the payback period, the unfavorable long payback period means that respondents do not want to wait for the net present value of their participation to become positive.

Following the interpretation of the effects of the upfront payment and the payback period, the meaning that their interaction is insignificant could be explained. The result shows that influences of the upfront payment and the payback period on the possibility to adopt CSS are independent: any change of one hardly alters respondents' preference for the other. Therefore, when the upfront payment of a CSS program is fixed, respondents may be more willing to adopt CSS with a shorter payback period. Similarly, keeping the payback period and all else unchanged, respondents may increase the probability to adopt CSS if they could pay less. Respondents' revealed preference shows that there exists a trade-off between the upfront payment and the payback period. This result could be more meaningful combining findings in Schelly (2014) and Fleiβ et al. (2017). Respondents felt a utility level of having cheaper electricity bills in future. Also, at the same utility level, respondents may invest more in a program when the time for the NPV to turn positive becomes shorter. This relationship between the upfront payment and the payback period has not been researched before, and this finding could probably help to design a feasible financial structure for a CSS program.

Another interesting finding of the interaction effect is that the positive effect of interpersonal communication is indirect. It only moderates the negative impact of payback period. This is different from the study of Rai and Robinson (2013) which found a direct contribution of communications and imitation to the adoption of individual distributed solar energy. More participation implies that more information may be conveyed through mass media, interpersonal communications, and the Internet. The higher participation rate reduces the uncertainty of a CSS program and increases participants' utility by compensating for uncertainty brought by a long payback period, thus the willingness to adopt CSS increases. However, the participation rate itself does not directly increase the willingness to adopt, so the information delivered through the communication channel may be insufficient to alter people's behavior and encourage their imitation. This shows that the participation rate may not reach the threshold of critical mass; people's decision-making may mainly depend on objective consideration of characteristics. The adoption rate of CSS cannot take off when the participation rate is less than 12.5%: the diffusion cannot self-sustain, so the promotion of CSS is necessary.

The aforementioned indirect and moderating effect of interpersonal communication implies that it is important to include the interaction of the communication channel and characteristics of CSS to reveal the mechanism of how communication channel functions. Existing literature (such as Rai and Robinson, 2013; Ozaki, 2011) also found the effectiveness of the communication channel in changing people's perceptions of certain characteristics of DPV. However, additional caution is necessary when interpreting the participation rate. The participation rate can also be perceived as a source of social pressure. In the choice experiment, its meaning is stressed that it represents how easily people can require any necessary information from existing participants.

Table 6
Relative importance and mean willingness to pay with 95% confidence intervals.

Attributes	Relative Importance	Mean WTPs (in 10 thousand RMB)	95% confidence intervals	
Upfront Payment	28.92%	–	–	–
Payback Period	26.15%	−0.51/year	−0.59	−0.43
Trialability	13.48%	3.03	2.54	3.51
Participation Rate	11.48%	0.08/1%	−0.09	0.24
CO_2 Reduction	10.15%	0.74/ton	0.24	1.24
Program Provider	9.82%	–	–	–
Provider (public utility)	–	1.88	1.39	2.37
Provider (company)	–	−0.74	−1.19	−0.29
ASC	–	22.85	19.04	26.66

Moreover, the participation rate was set at a relatively low level to avoid a critical mass. Thus, the effect of the participation rate can mainly represent the effect of the communication channel.

Trialability positively affects the adoption decision, and it is the third most important attribute affecting respondents' decisions. People are willing to pay 30,300 RMB more for a CSS program with trialability compared to the one without trialability. Trialability is preferred because respondents are allowed to reconsider during the participation. Before people fully accept an innovation, they are faced with uncertainty (Rogers, 2003). Thus, the chance to affirm the capability of generating benefits increases the willingness to adopt CSS. In a real CSS program, participants can only confirm the program generates benefits for them after their participation, and a confirmation reduces the risk of them making a wrong family investment. This is similar to the conclusion of Chang et al. (2017) that a PAYG structure attracted individuals, especially medium- and low-income households, to participate in CSS programs.

People prefer a CSS program that reduces more CO_2 emissions. The social norm that guides people to protect the environment may help the adoption of CSS. Literature such as Koch and Christ (2018) and Rai and Beck (2015) also showed people's environmental concerns persuaded them to adopt individual DPV. However, this environmental norm is not as important as the ability to reduce CO_2 emissions ranks penultimate in terms of RI (10.15%). This is similar to the finding in a survey (Fleiβ et al., 2017) in Australia that people cared about the environment, but this concern did not determine the adoption of individual DPV. This value-action gap has been documented by literature (Howell, 2013), which means even if people attach importance to the amount of reduced CO_2 emissions, other factors have a more powerful influence on the decision on the adoption or not. Therefore, it can be concluded that social norms are less important in decision-making. However, there exists heterogeneity in responses to carbon emission reductions. Some people value the ability to reduce CO_2 emissions more than others. Therefore, it is better to include public education about environmental issues in the promotion of CSS so that more people attach importance to carbon emission reductions.

Respondents would distinguish the program provided by different entities, though they do not attach much importance (9.82%) to the program provider. On average, respondents prefer a public utility-led CSS program, then a program led by a non-profit organization. They dislike the program run by a company compared. This finding is similar to the conclusion of Abdullah et al. (2017), which suggested that the government should lead the promotion of distributed solar energy in Pakistan.

The education level of respondents is not significant to affect people's willingness to adopt CSS in this study. It contradicts Rogers's (2003) theory that early adopters are more likely to be well educated. Although Islam (2014), in a study with 298 individuals, has the same finding that the education level does not matter in the adoption of solar PV, our result might be due to the fact that our respondents are mainly well-educated. In existing literature, Sardianou and Genoudi's (2013) finds that a better education background encourages the adoption of renewable energies within a sample, of which the majority do not possess a bachelor's degree. Other studies, such as Kwan (2012), Bashiri and Alizadeh (2018) and Yuan et al. (2011), with larger sample sizes, also found a significant effect on education levels. Future studies should include balanced sample to further investigate the impact of education on the diffusion of CSS in China.

The awareness of CSS would significantly increase individuals' willingness to participate in CSS programs. This is in line with existing findings that the lack of awareness of CSS hinders people's decisions to participate (Horváth and Szabó, 2018; Koch and Christ, 2018). Awareness of CSS can also reduce respondents' disutility caused by the upfront payment. Therefore, at the beginning of the diffusion of CSS, when the participation rate is low and the imitation effect among people is still weak, relevant education about CSS may be crucial. Additionally, CSS should be promoted to everyone regardless of education level. After gaining enough understanding of CSS, not only is individuals' willingness to participate enhanced, but also they are willing to accept a higher upfront payment. The necessity of education about the characteristics of CSS and the mechanism of a CSS program has been proven in America, and its effect to persuade people is obvious (Chan et al., 2018).

Age and gender are insignificant in our results. Rogers (2003) provided a generalization that early adopters are not distinct from later adopters in age. This is common in the diffusion of innovations, and this may apply to CSS. Although some literature (e.g. Schelly, 2014; Kwan, 2012) claimed age mattered in the adoption of individual DPV because, within their sample, age is related to wealth, and the older have greater purchasing power, in our sample, respondents' purchasing power is not directly determined by age. However, due to the age structure of the sample skewed to the young age, future research should expand the sample to further investigate the role of age in the adoption of CSS program in China.

5.2. Implications for policy

With sufficient cautiousness, advice about introducing CSS into well-developed cities in China for policymakers can be provided. For young citizens with higher income and education levels, a welcome program should feature a low cost, a short payback period. It should allow participants to leave with appropriate refunds at any time. Therefore, reducing the cost through economies of scale, learning-by-doing (Nemet, 2006), and efficient management, which avoids resource waste, should be conducted for cost-saving (Stanton and Kline, 2016). Low-interest loans may be feasible to reduce both providers' and individuals' total costs in CSS (Bovarnick and Johnson, 2019). Lower upfront cost may be possible by allowing a half-panel subscription (Chan et al., 2018). In addition, a community purchase program that recruits a large number of households at the same time may not only reduce the upfront payment but also increase the participation rate (Bovarnick and Johnson, 2019).

Also, within the government budget, necessary subsidies and feed-in tariffs (FITs) can accelerate the payback procedure, and thus, stable financial support should be implemented (Fleiβ et al., 2017). However, the declining financial support for solar PV in China may increase the uncertainty of CSS programs. Thus, stable policies about CSS should be issued in advance of the implementation. In addition, the provider should care about the trade-off between the payment and the payback period when designing the financial structure of a CSS program. The effectiveness of the PAYG structure and the monthly-payment plan is worth a trial, because they may reduce uncertainty directly. Moreover, learning from the situation in America and issuing necessary legislation and policies may be an effective way to reduce the uncertainty of CSS (Feldman et al., 2015; Chan et al., 2018).

The design of a CSS program should account for the relationship between the scale of CSS programs and the ability to reduce CO2 emissions and cost; thus the program should not be on a small scale. Moreover, a larger-scale program allows more participants, which may enhance the communication between adopters and potential adopters. An online platform for communication about CSS may be helpful, because those descriptions, pictures, and videos about CSS from adopters may bring imitation effects. In addition, providing a publicly-accessible online database illustrating the features and performance of CSS and participants' satisfaction with CSS may facilitate individuals to search and learn about CSS by themselves and increase trust in CSS programs (Carmichael, 2019). The acceptable scale of the program should be identified when designing a CSS program. Furthermore, the prioritized provider is the public utility, so the state-owned grid should take responsibility to design, provide and manage CSS programs. However, if a company, or a non-profit organization that can manage a CSS program, attempts to lead a program, the government should help to encourage people to trust the program provider. A possible measure to

assure individuals that a company or a non-profit organization is trustworthy is to endorse power purchase agreements (Chang et al., 2017). The government can contract services out to a company or a non-profit organization, or partner with them, with a clear statement that these entities run the service on behalf of the government (Coughlin et al., 2011).

The design of CSS programs should be easily understandable. The high cost of education of CSS has been proved in its implementation in America (Feldman et al., 2015), so it should avoid arrangements that are difficult to understand. Promotion of the CSS program is necessary before the critical mass happens. It may be more effective when focusing on the high-income group at the beginning of the diffusion of CSS. Education about CSS should cover the performance of PV panels, the payment scheme, the profitability, and the mechanism of CSS (Chang et al., 2017). What is more, the environmental benefit of CSS and the challenge to mitigate climate change should also be taught to the public. In addition to the advice provided above, many other related methods to accelerate the diffusion of CSS can be learned from the existing CSS programs.

First, it is more difficult to manage electricity supply and demand when CSS programs are connected to the grid. The unstable power generation from solar PV systems has an impact on the operation of the grid. Second, the deployment of CSS requires an extra cost in infrastructure and inevitably hurts the benefits of some stakeholders. Third, constructing an accurate and resilient billing structure is time-consuming and costly. And fourthly, without corresponding legislation and policies, the implementation can be difficult and its development is slow. These are typical barriers to the diffusion of CSS which organizations have been trying to solve. For example, modelling households' electricity consumption patterns, deploying well-performing energy storage devices and superior grid-connected inverters, and increasing the efficiency of self-consumption of electricity may help mitigate the impact of connecting solar PV to the grid (Xu and Cao, 2020; Awad and Gül, 2018). People also find that CSS programs have economies of scale and thus costs are eventually reduced (Feldman et al., 2015). Some program providers developed widely acceptable and applicable business models in America (Coughlin et al., 2011). In terms of legal and political support, it has been proved that grants for the application of shared solar, the trading permission of community solar, and legislation of community net energy metering help the implementation of CSS in America (Augustine and McGavisk, 2016; Michaud, 2015).

6. Conclusions

The community shared solar (CSS) project has great potentials in decarbonizing the power sector in China. Building on the theory of innovation diffusion by Rogers (2003), this research investigates the factors that may affect electricity users' willingness to participate in CSS programs. We conducted a choice experiment via online surveys among a small group of households in Guangdong, China. We mainly asked in the survey the preference of respondents among three hypothetical CSS programs with different features. We analyzed the 392 validated response using a random parameter logit model. Our results show that high upfront payment and long payback period were main barriers of the users' willingness to participate in CSS program. Furthermore, respondents showed higher interest in a CSS program with an opt-out option, operated by public utility and larger environment benefits. They tended to accept longer payback period in CSS program with higher participation rate. The income and the knowledge of users about CSS increase their willingness to participate in CSS program with higher upfront payment. Our results can help designing better policies and business models for promoting community shared solar projects in China.

CRediT authorship contribution statement

Zhenyu Tan: initiated the study, collected data, performed the statistical analysis, and drew the figures, drafted the manuscript, All authors contributed to the interpretation of the results and revision of the manuscript. **Deyu Li:** provided feedback and edited the manuscript, All authors contributed to the interpretation of the results and revision of the manuscript. **Tong Xu:** initiated the study, All authors contributed to the interpretation of the results and revision of the manuscript, provided feedback and edited the manuscript.

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

Data will be made available on request.

Acknowledgement

This research was funded by the China Scholarship Council. We would like to thank Prof. Laura Diaz Anadon for her suggestions and modifications. We are grateful to Dr. Silas S. Brown for assistance with writing revision.

Appendix

Links to questionnaires:
https://www.wjx.cn/hj/3ovued2nce2qxkgboqh59g.aspx (Chinese).
https://www.wjx.cn/hj/jmobiso6iuolqxflmoncbw.aspx (English).
In case of server shutdown or other problems, both of the above URLs have also been saved in the Internet Archive Wayback Machine (web.archive.org) as of July 2022.

References

Abdullah, Zhou, D., Shah, T., Jebran, K., Ali, S., Ali, A., Ali, A., 2017. Acceptance and willingness to pay for solar home system: Survey evidence from northern area of Pakistan. Energy Reports 3, 54–60. https://doi.org/10.13891/j.cnki.mer.2015.06.003.

Atkinson, G., Braathen, N.A., Groom, B., Mourato, S., 2018. Cost-benefit analysis and the environment: further developments and policy use. Available at: https://www.oecd-ilibrary.org/environment/cost-benefit-analysis-and-the-environment_9789264085169-en. (Accessed 6 July 2020).

Augustine, P., McGavisk, E., 2016. The next big thing in renewable energy: shared solar. Electr. J. 29 (4), 36–42. Available at: https://linkinghub.elsevier.com/retrieve/pii/S104061901630029X. (Accessed 6 July 2020).

Awad, H., Gül, M., 2018. 'Optimisation of community shared solar application in energy efficient communities'. Sustain. Cities Soc. 43 (2018), 221–237. Available at: https://linkinghub.elsevier.com/retrieve/pii/S2210670718305821. (Accessed 6 July 2020).

Bashiri, A., Alizadeh, S.H., 2018. 'The analysis of demographics, environmental and knowledge factors affecting prospective residence'. Available at: https://linkinghub.elsevier.com/retrieve/pii/S1364032117312376. (Accessed 6 July 2020).

Bauwens, T., Gotchev, B., Holstenkamp, L., 2016. What drives the development of community energy in Europe? The case of wind power cooperatives. Energy Res. Social Sci. 13, 136–147.

Beavers, D., McGuckin, J., Sweet, E., 2013. Community shared solar: review and recommendations for Massachusetts models. Available at: https://www.mass.gov/files/documents/2016/08/nv/community-shared-solar-model-frameworks-032813.pdf. (Accessed 6 July 2020).

Bech, M., Gyrd-Hansen, D., 2005. 'Effects coding in discrete choice experiments'. Health Econ. 14 (10), 1079–1083. https://doi.org/10.1002/hec.984. Available at: (Accessed 6 July 2020).

Bekker-Grob, De, E, W., Hol, L., Donkers, B., Van Dam, L., Habbema, J.D.F., Leerdam, Van, M, E., Kuipers, M.D., Essink-Bot, M.L., Steyerberg, E.W., 2010. 'Labeled versus unlabeled discrete choice experiments in health economics: an application to colorectal cancer screening'. Value Health 13 (2), 315–323. Available at: https://linkinghub.elsevier.com/retrieve/pii/S1098301510603786. (Accessed 6 July 2020).

Bovarnick, B., Johnson, L., 2019. 'Research review on residential solar access: barriers and solutions for low and moderate income communities. Available at: https://cbey.yale.edu/sites/default/files/2019-10/Barriers%20and%20Solutions%20LMI%20Solar_FINAL_0.pdf. (Accessed 12 July 2022).

Cai, Xiang, et al., 2019. 'Business models of distributed solar photovoltaic power of China: the business model canvas perspective'. Sustainability 11.16, 4322. https://doi.org/10.3390/su11164322. Available at: (Accessed 12 July 2022).

Can, Ö., Alp, E., 2012. 'Valuation of environmental improvements in a specially protected marine area: a choice experiment approach in Göcek Bay, Turkey'. Sci. Total Environ. 439, 291–298. https://doi.org/10.1016/j.scitotenv.2012.09.002. Available at: (Accessed 6 July 2020).

Carmichael, R., 2019. 'Behaviour change, public engagement and Net Zero. A report for the Committee on Climate Change' Available at and. https://www.theccc.org.uk/publications/. (Accessed 4 September 2022). http://www.imperial.ac.uk/icept/publications/.

Chan, G., Evans, I., Grimley, M., Ihde, B., Mazumder, P., 2017. 'Design choices and equity implications of community shared solar'. Electr. J. 30 (9), 37–41. https://doi.org/10.1016/j.tej.2017.10.006. Available at: (Accessed 6 July 2020).

Chan, G., Grimley, M., Arnold, E., Evans, I., Herbers, J., Hoffman, M., Ihde, B., Mazumder, P., Jordan, M., Neuman, N., Streitz, R., 2018. Community shared solar in Minnesota: learning from the first 300 megawatts. Available at: https://conservancy.umn.edu/handle/11299/201626. (Accessed 6 July 2020).

Chang, V., Goldenberg, C., Hoskins, J., Lassiter, S., Li, Z., Nakatani, E., Oluwafemi, S., Safford, H., 2017. Solar gardens in the Garden State: community solar recommendations for New Jersey. Available at: http://wws.princeton.edu/sites/default/files/content/WWS%20591d%20Solar%20Report%202017.pdf. (Accessed 6 July 2020).

Chilvers, J., Bellamy, R., Pallett, H., Hargreaves, T., 2021. A systemic approach to mapping participation with low-carbon energy transitions. Nat. Energy 6 (3), 250–259.

Coughlin, J., Grove, J., Irvine, L., Jacobs, J.F., Phillips, S.J., Moynihan, L., Wiedman, J., 2011. 'Guide to community solar: utility, private, and non-profit project development'. Available at: https://digitalscholarship.unlv.edu/cgi/viewcontent.cgi?article=1040&context=renew_pubs. (Accessed 6 July 2020).

Creutzig, F., Agoston, P., Goldschmidt, J.C., Luderer, G., Nemet, G., Pietzcker, R.C., 2017. The underestimated potential of solar energy to mitigate climate change. Nat. Energy 2 (9), 1–9.

D'Agostino, A.L., Sovacool, B.K., Bambawale, M.J., 2011. 'And then what happened? A retrospective appraisal of China's Renewable Energy Development Project (REDP)'. Renew. Energy 36 (11), 3154–3165. https://doi.org/10.1016/j.renene.2011.03.017. Available at: (Accessed 6 July 2020).

Feldman, D., Brockway, A.M., Ulrich, E., Margolis, R., 2015. 'Shared Solar. Current Landscape, Market Potential, and the Impact of Federal Securities Regulation' (No. NREL/TP-6A20–63892). National Renewable Energy Lab. (NREL), Golden, CO (United States. Available at: https://www.nrel.gov/docs/fy15osti/63892.pdf. (Accessed 6 July 2020).

Ferster, B., Brownson, J.R., Macht, G.A., 2020. Catalyzing community-led solar development by enabling cooperative behavior: insights from an experimental game in the United States. Energy Res. Social Sci. 63, 101408 https://doi.org/10.1016/j.erss.2019.101408. (Accessed 6 July 2020).

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. Available at: (Accessed 6 July 2020).

Funkhouser, E., Blackburn, G., Magee, C., Rai, V., 2015. Business model innovations for deploying distributed generation: the emerging landscape of community solar in the US. Energy Res. Social Sci. 10, 90–101.

Gao, X., Rai, V., 2019. Local demand-pull policy and energy innovation: evidence from the solar photovoltaic market in China. Energy Pol. 128, 364–376.

Guangdong Statistics Bureau, 2020. Guangdong statistical yearbook in 2019. Available at: http://tjnj.gdstats.gov.cn:8080/tjnj/2019/directory.html. (Accessed 6 July 2020).

GuangfuBJX, 2018. Available at: http://hy.bjx.com.cn/ask/116.shtml. (Accessed 6 July 2020).

Hess, D., Lee, D., 2020. 'Energy decentralization in California and New York: conflicts in the politics of shared solar and community choice'. Renew. Sustain. Energy Rev. 121 (2020), 109716 https://doi.org/10.1016/j.rser.2020.109716. Available at: (Accessed 6 July 2020).

Hoffman, S., High-Pippert, A., 2014. 'Sharing the sun: attitudes, early adopters and community solar projects'. Available at: https://ir.stthomas.edu/cas_polisci_pub/1/. (Accessed 6 July 2020).

Horváth, D., Szabó, R.Z., 2018. Evolution of photovoltaic business models: overcoming the main barriers of distributed energy deployment. Renew. Sustain. Energy Rev. 90, 623–635. https://doi.org/10.1016/j.rser.2018.03.101. Available at: (Accessed 6 July 2020).

Howell, R.A., 2013. It's not (just)"the environment, stupid!" Values, motivations, and routes to engagement of people adopting lower-carbon lifestyles'. Global Environ. Change 23 (1), 281–290. https://doi.org/10.1016/j.gloenvcha.2012.10.015. Available at: (Accessed 4 September 2022).

IEA, 2020. Clean energy innovation. IEA, Paris. https://www.iea.org/reports/clean-energy-innovation.

International Renewable Energy Agency, 2020. Renewable power generation costs in 2019. Available at: https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019. (Accessed 12 July 2022).

Islam, T., 2014. 'Household level innovation diffusion model of photo-voltaic (PV) solar cells from stated preference data'. Energy Pol. 65, 340–350. https://doi.org/10.1016/j.enpol.2013.10.004. Available at: (Accessed 6 July 2020).

Jordan, D.C., Kurtz, S.R., 2013. 'Photovoltaic degradation rates—an analytical review'. Prog. Photovoltaics Res. Appl. 21 (1), 12–29. Available at: http://doi.wiley.com/10.1002/pip.1182. (Accessed 6 July 2020).

Koch, J., Christ, O., 2018. Household participation in an urban photovoltaic project in Switzerland: exploration of triggers and barriers. Sustain. Cities Soc. 37, 420–426. https://doi.org/10.1016/j.scs.2017.10.028. Available at: (Accessed 6 July 2020).

Kontoleon, A., Yabe, M., 2003. Assessing the impacts of alternative 'opt-out'formats in choice experiment studies: consumer preferences for genetically modified content and production information in food (online) available at: https://pdfs.semanticscholar.org/5345/0ec62f4d8725e79b4ccbee38d9745fd82322.pdf. (Accessed 6 July 2020).

Korjonen-Kuusipuro, K., Hujala, M., Pätäri, S., Bergman, J.P., Olkkonen, L., 2017. The emergence and diffusion of grassroots energy innovations: building an interdisciplinary approach. J. Clean. Prod. 140, 1156–1164.

Kwan, C.L., 2012. 'Influence of local environmental, social, economic and political variables on the spatial distribution of residential solar PV arrays across the United States'. Energy Pol. 47, 332–344. https://doi.org/10.1016/j.enpol.2012.04.074. Available at: (Accessed 6 July 2020).

Ladenburg, J., Olsen, S.B., 2014. 'Augmenting short cheap talk scripts with a repeated opt-out reminder in choice experiment surveys'. Resour. Energy Econ. 37, 39–63. https://doi.org/10.1016/j.reseneeco.2014.05.002. Available at: (Accessed 6 July 2020).

Lancsar, E., Louviere, J., 2006. Deleting 'irrational'responses from discrete choice experiments: a case of investigating or imposing preferences? Health Econ. 15 (8), 797–811. Available at: https://pubmed.ncbi.nlm.nih.gov/16615039/. (Accessed 6 July 2020).

Lee, H.J., Huh, S.Y., Yoo, S.H., 2018. 'Social preferences for small-scale solar photovoltaic power plants in South Korea: a choice experiment study'. Sustainability 10 (10), 3589. Available at: http://www.mdpi.com/2071-1050/10/10/3589. (Accessed 6 July 2020).

Louviere, J., Hensher, D., Swait, J., Adamowicz, W., 2000. Stated Choice Methods: Analysis and Applications. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511753831. (Accessed 6 July 2020).

Louviere, J.J., Islam, T., Wasi, N., Street, D., Burgess, L., 2008. Designing discrete choice experiments: do optimal designs come at a price? J. Consum. Res. 35 (2), 360–375. https://doi.org/10.1086/586913. Available at: (Accessed 6 July 2020).

Mangione, T.W., 1995. Mail Surveys: Improving the Quality (Vol. 40). Sage.

Mazzanti, M., 2001. 'Discrete choice models and valuation experiments an application to cultural heritage. Available at: https://pdfs.semanticscholar.org/50bb/670d620f98ac15b36dc60a203998f415bc31.pdf?_ga=2.268717560.804947455.1594513228-1103001394.1582467564. (Accessed 6 July 2020).

McFadden, D., 1974. Conditional logit analysis of qualitative choice behavior. Available at: https://eml.berkeley.edu/reprints/mcfadden/zarembka.pdf. (Accessed 6 July 2020).

McFadden, D., Train, K., 2000. 'Mixed MNL models for discrete response'. J. Appl. Econom. 15 (5), 447–470. https://doi.org/10.1002/1099-1255(200009/10)15:5<447::AID-JAE570>3.0.CO;2-1. Available at: (Accessed 6 July 2020).

Meelen, T., Truffer, B., Schwanen, T., 2019. Virtual user communities contributing to upscaling innovations in transitions: the case of electric vehicles. Environ. Innov. Soc. Transit. 31, 96–109.

Michaud, G., 2015. 'Community shared solar in Virginia: political and institutional barriers and possibilities. Politics, Bureaucracy & Justice 5 (1).

National Bureau of Statistics, 2020. China statistical yearbook in 2020. Available at: http://www.stats.gov.cn/tjsj/ndsj/2020/indexch.htm. (Accessed 12 July 2022).

National Bureau of Statistics, 2021. China statistical yearbook in 2021. Available at: http://www.stats.gov.cn/tjsj/ndsj/2021/indexch.htm. (Accessed 12 July 2022).

National Development and Reform Commission, 2022. "14th Five-Year Plan" modern energy system planning. Available at: https://www.ndrc.gov.cn/xwdt/tzgg/20220 3/P020220322583239614565.pdf, 2022.

National Energy Administration, 2014a. Notice of the national energy administration on further implementation of policies concerning distributed photovoltaic power generation. Available at: http://zfxxgk.nea.gov.cn/auto87/201409/t20140904_1837.htm. (Accessed 6 July 2020).

National Energy Administration, 2014b. The thirteenth five-year Plan of energy development. Available at: http://www.nea.gov.cn/135989417_14846217874961n.pdf. (Accessed 6 July 2020).

National Energy Administration, 2014c. How is solar energy distributed in China? Available at: http://www.nea.gov.cn/2014-08/03/c_133617073.htm. (Accessed 17 May 2022).

National Energy Administration, 2017. Notice on carrying out the pilot project of distributed generation market-oriented transactions. Available at: http://zfxxgk.nea.gov.cn/auto87/201711/t20171113_3055.htm. (Accessed 12 July 2022).

National Energy Administration, 2022. Construction and operation of solar photovoltaic power plants in 2021. http://www.nea.gov.cn/2022-03/09/c_1310508114.htm. (Accessed 9 March 2022).

Nemet, G.F., 2006. 'Beyond the learning curve: factors influencing cost reductions in photovoltaics'. Energy Pol. 34 (17), 3218–3232. https://doi.org/10.1016/j.enpol.2005.06.020. Available at. (Accessed 6 July 2020).

Orme, B., 2010. 'Interpreting the results of conjoint analysis'. Getting Started with Conjoint Analyis 2, 77–88. Available at. https://www.sawtoothsoftware.com/download/techpap/interpca.pdf. (Accessed 6 July 2020).

Ozaki, R., 2011. 'Adopting sustainable innovation: what makes consumers sign up to green electricity?'. Bus. Strat. Environ. 20 (1), 1–17. Available at. https://www.

infona.pl/resource/bwmeta1.element.wiley-bse-v-20-i-1-bse650. (Accessed 6 July 2020).
Qureshi, T.M., Ullah, K., Arentsen, M.J., 2017. 'Factors responsible for solar PV adoption at household level: a case of Lahore, Pakistan'. Renew. Sustain. Energy Rev. 78, 754–763. Available at. https://www-sciencedirect-com.ezp.lib.cam.ac.uk/science/article/pii/S136403211730521X. (Accessed 6 July 2020).
Rai, V., Beck, A.L., 2015. 'Public perceptions and information gaps in solar energy in Texas' *Environmental Research Letters, 10*(7), 074011 Available at. https://iopscience.iop.org/article/10.1088/1748-9326/10/7/074011. (Accessed 6 July 2020).
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 (1), 014044. Available at. https://iopscience.iop.org/article/10.1088/1748-9326/8/1/014044. (Accessed 6 July 2020).
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. Available at. (Accessed 6 July 2020).
Rogers, E.M., 2003. Diffusion of Innovations. Simon and Schuster, New York.
Sardianou, E., Genoudi, P., 2013. 'Which factors affect the willingness of consumers to adopt renewable energies?'. Renew. Energy 57, 1–4. https://doi.org/10.1016/j.renene.2013.01.031. Available at: (Accessed 6 July 2020).
Sawtooth Software, 2020. Lighthouse Studio (9.8.1). [Computer program]. Available at. https://www.sawtoothsoftware.com/index.php?option=com_content&view=article&id=657#latest-version. (Accessed 6 July 2020).
Schelly, C., 2014. 'Residential solar electricity adoption: what motivates, and what matters? A case study of early adopters'. Energy Res. Social Sci. 2, 183–191. https://doi.org/10.1016/j.erss.2014.01.001. Available at. (Accessed 6 July 2020).
Schot, J., Kanger, L., Verbong, G., 2016. The roles of users in shaping transitions to new energy systems. Nat. Energy 1 (5), 1–7.
Shiften, 2020. Photovoltaic power generation [equipment price] How much does it cost to install a set of 10kW household solar pv in Dongguan? Available at: http://www.zghzst.com/news/122.html. (Accessed 6 July 2020).
Stanton, T., Kline, K., 2016. 'The ecology of community solar gardening: a 'companion planting' guide' *nrri* 16–07. Available at. https://www.researchgate.net/publication/331330472_The_Ecology_of_Community_Solar_Gardening_A_%27Companion_Planting%27_Guide. (Accessed 6 July 2020).
Tanjiaoyi, 2016. Available at. http://www.tanjiaoyi.com/article-19186-1.html. (Accessed 6 July 2020).
Vasseur, V., Kemp, R., 2015. 'The adoption of PV in The Netherlands: a statistical analysis of adoption factors'. Renew. Sustain. Energy Rev. 41, 483–494. https://doi.org/10.1016/j.rser.2014.08.020. Available at. (Accessed 6 July 2020).
Wang, K., 2014. 'Prospects, problems and suggestions for distributed photovoltaic power generation'. Aanhui Sci. Technol. 4 (2014) https://doi.org/10.3969/j.issn.1007-7855.2014.04.019. Available at. (Accessed 12 July 2022).
Wang, S., 2020. Solarbe. Available at. http://wenku.solarbe.com/p-21202.html. (Accessed 6 July 2020).
Wilson, C., 2012. Up-scaling, formative phases, and learning in the historical diffusion of energy technologies. Energy Pol. 50, 81–94.
Wjx, 2020. *Questionnaire star* service. Available at. https://www.wjx.cn. (Accessed 6 July 2020).
Xu, J., Cao, Q., 2020. 'Research on the status and application of distributed photovoltaic grid-connected power generation in China'. Energy and Conservation 2020 (6). https://doi.org/10.16643/j.cnki.14-1360/td.2020.06.021. Available at. (Accessed 12 July 2022).
Yap, X.S., Truffer, B., Li, D., Heimeriks, G., 2022. Towards transformative leapfrogging. Environ. Innov. Soc. Transit. 44, 226–244.
Yuan, X., Zuo, J., Ma, C., 2011. 'Social acceptance of solar energy technologies in China—end users' perspective'. Energy Pol. 39 (3), 1031–1036. https://doi.org/10.1016/j.enpol.2011.01.003. Available at. (Accessed 6 July 2020).