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Social Preferences for Small-Scale Solar Photovoltaic Power Plants in South Korea: A Choice Experiment Study

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Abstract: To reduce greenhouse gas emissions, the South Korean government plans to expand the installation of small-scale solar photovoltaic (SPV) power plants, which do not occupy large spaces and have a smaller environmental impact than large-scale SPV power plants. This article applies a choice experiment to evaluate quantitatively the value given by people to the attributes of the installation of small-scale SPV power plants. To reflect the preference heterogeneity of South Korean people, a Bayesian estimation of a mixed-logit model is successfully performed. According to the results, South Korean people consider the electricity bill, the operating body, and the installation location as being more important than other attributes. The respondents prefer small-scale SPV power plants that are located in residential areas, have a large scale of installation, are operated by a private corporation and produce electricity for self-consumption. For these attributes, the South Korean people are willing to pay an additional electricity bill of South Korean won (KRW) 4286/month, KRW 3712/kW, KRW 2885/month and KRW 3731/month, respectively. The results provide meaningful implications regarding the aspects of installation on which the government should focus. In addition, the results can be utilized in policy making and decision making related to the installation of small-scale SPV power plants.

Keywords: renewable energy; stated preference technique; discrete choice model; willingness to pay; heterogeneity

1. Introduction

The most common way to produce electricity is to use fossil fuels, such as coal or oil. However, the use of fossil fuels emits large amounts of greenhouse gases (GHGs), the cause of climate change. South Korea is the fifth-largest emitter of GHGs among the Organization for Economic Co-operation and Development (OECD) countries. Between 2000 and 2013, its GHG emissions increased by 39 percent, ranked second after Turkey among the OECD countries [1]. In addition, the rate of carbon dioxide (CO_2) emissions from coal combustion was the highest in the OECD countries in 2013 compared with 1990 [2]. Therefore, as discussed at the 2015 United Nations Climate Change Conference, the South Korean government decided to reduce its GHG emissions by 37% by 2030 compared with the business-as-usual level [3].

The development and dissemination of alternative energy sources is a major option for reducing GHG emissions. Accordingly, the South Korean government plans to expand the electricity supply by replacing some of the fossil fuels with renewable sources, such as solar energy. For example, it is planning to increase the ratio of renewable electricity generation in the total power generation from 7%

in 2016 to 20% by 2030 and to supply more than 95% of new generation capacity with clean energy, such as solar and wind power [4]. This would increase the total capacity of the solar photovoltaic (SPV) power plants from 5.7 GW in 2017 to 36.5 GW by 2030.

To install a considerable number of SPV panels, large spaces are required. However, it is difficult to secure such large spaces in South Korea, because forest areas occupy about 70% of the entire country and the population density is high. Large-scale SPV power plants installed in mountainous areas can cause negative environmental damage, such as damage to forests and ecosystems, and encroach on the natural scenery [5]. On the other hand, small-scale SPV power plants can be installed in a relatively small space, such as on roofs of residences or buildings, and cause less environmental damage. Therefore, a small-scale SPV power plant is a realistic alternative in some countries, like South Korea. If the use of small-scale SPV power plants is expanded, the following positive effects are expected. First, the GHG emissions will be reduced. Second, the amount of air pollutants, which are the cause of fine dust, will be diminished. Third, unnecessary power transmission facilities will decrease, because power generation and consumption can be performed simultaneously [6,7]. Finally, the dependence on energy imports will be reduced and the uses of domestic energy increased.

For these reasons, several countries are expanding the installation of small-scale SPV power plants. In the case of South Korea, the government of Seoul City is planning to supply SPV power plants to one million households by 2022, an amount that is equivalent to the capacity of a nuclear power plant (1 GW). Therefore, new rental apartments will be required to install small-scale SPV power plants from 2018, and small-scale SPV power plants will be installed in all public buildings and schools unless there are safety problems [8]. The city of Busan also plans to increase its rate of renewable electricity generation compared with the total electricity consumption to 30% by 2030. Thus, it is expanding its SPV energy self-reliant villages by installing small-scale SPV power plants on top of old residences and ships [9]. As an international example, the Japanese government has been implementing the Net-Zero Energy House (ZEH), a zero-energy housing project, since 2012. This project aims to reduce energy consumption through SPV power generation and improved insulation performance. To that end, the majority of new residences will be built as ZEHs by 2020 [10]. In the U.S., California has set a goal of reducing carbon emissions by 40 percent by 2030 and supplying 50 percent of its electricity to renewable energy. In addition, new residences will have to install SPV energy from 2020 [11].

As the interest in renewable energy has increased, many related studies have been published. In general, there are many papers that studied SPV power in many countries. Most studies have assessed the economic feasibility, financial evaluation, government incentives, environmental value and negative environmental impact of SPV energy e.g., [5,12–19]. Furthermore, there are papers on consumption, optimal price and the offering strategy problem that can be considered in SPV market e.g., [20–22] and evaluating relationship between renewable energy and citizens' life quality from an economic standpoint e.g., [23,24].

However, as a countermeasure to reduce the negative environmental impacts of large-scale SPV power plants, research on small-scale SPV power plants is underway, but the number of such studies in the literature applying stated preference (SP) methods is very small. In the literature, many studies have evaluated the willingness to pay (WTP) for expanding large-scale renewable energy. In the SP methods applied in this study, contingent valuation (CV) e.g., [25–29] and choice experiment (CE) e.g., [30–32] are representative.

Few studies have analyzed the social preference for small-scale SPV power plant installation at the level of detailed attributes, focusing on the quantitative estimation of the public's WTP. Therefore, this study aims to analyze the social preferences of the detailed attributes of installing small-scale SPV power plants in South Korea and to quantitatively predict public acceptance of small-scale SPV power plants through simulation of virtual small-scale SPV power plants. This allows you to set policy priorities for various types of small-scale SPV power plants. The results of this study can be used as the basis for the policy formulation, as public attitude is crucial for a successful renewable energy project. The results of the study will also provide meaningful insights to enhance the public acceptance and reliability of policies when increasing the number of small-scale SPV power plants. The rest of the study is composed of three sections. Section 2 is devoted to explaining the methodology adopted in the study. Section 3 presents and discusses the results. The final section contains the conclusions and related policy implications of this study.

Current Issues Regarding Small-Scale Solar Photovoltaic Power Plants

At the 2015 United Nations Climate Change Conference in Paris (COP21), countries have submitted their Intended Nationally Determined Contributions (INDCs) to indicate their emissions reduction commitments. The reduction targets for each country are considered to be quite challenging [3,33–36]. As part of the efforts to achieve such reduction target, many countries are concentrating on expanding renewable energy through government incentive schemes such as Emission Trading System (ETS) or Feed-In Tariff (FIT) and Feed-In Premium (FIP). In case of ETS, about 39 countries around the world, including the EU, are running ETS, and the United States, Japan, and China are only implemented in some regions. Some countries, including Mexico, Chile, and Brazil, are considering introducing the system [37]. The FIT was in effect in 60 countries in 2014, and FIP, which improved FIT, has recently been applied to ease the increase in electricity bill and the development of biased energy [38–42].

Among renewable energies, SPV energy is expected to play an important role in expanding renewable energy voluntarily based on ETS, FIT, and FIP. This is because SPV power is simple to install and it takes shorter time to operate than other renewable power sources. In addition, the rate of decline in SPV power generation costs was 60% between 2010 and 2015, the highest among other energy generation costs. It is expected that the cost will continue to decline and it will be competitive with the fossil fuel power generation [43]. Price competitiveness is expected to have a positive impact on small-scale SPV power generation.

From a long-term perspective, small-scale SPV industries need to be informed about the public's acceptance of small-scale SPV power plants because they can contribute significantly to the voluntary supply of SPV power. The current SPV-related policy, which is sporadic and focused only on supply expansion, should be improved, as it would be a huge financial burden to implement a government policy on installation of small-scale SPV power plants. In addition, it is necessary to predict in advance the extent to which the public will support a small-scale SPV power plant with specific characteristics for voluntary dissemination. Therefore, the main goal of this study is to obtain policy implications for small-scale SPV power plant installations in the future by quantitatively analyzing the social preference for installing small-scale SPV power plants to reflect current issue.

2. Methodology

2.1. Survey Design and Data Collection: A Choice Experiment

To analyze the social preferences for installing small-scale SPV power plants, it is necessary to conduct a survey of the public's preferences regarding their installation. In this study, we use the CE approach, a representative SP method, to analyze the social preferences for small-scale SPV power plant installation. The CE presents respondents with several product (or service) alternatives, consisting of attributes and levels related to the target goods, and then asks them to choose their preferred alternative among them.

To design an appropriate CE questionnaire, we need to select the attributes and levels of small-scale SPV power plant installation. The selected attributes and levels are obtained through an extensive literature review and consultation with experts in the energy sector. As shown in Table 1, the five attributes selected are the installation location, installation scale, operating body, use of the electricity produced and additional electricity bills.

First, the installation location of small-scale SPV power plants can be divided into residence, city and suburb. Residence is assumed to be a home, and in cities small-scale SPV power plants can be installed on the rooftops of buildings. In suburbs, small-scale SPV power plants can be installed on forest, idle land or the roofs of livestock pens. Second, the installation scale was limited to a maximum of 150 kW; the larger the scale, the more electricity can be produced. The installation scale attributes are set at 30 kW (the scale that can be installed on the roof of a residence), 80 kW (the scale that can be installed on the roof of buildings) and 150 kW (the scale that can be installed on forest or idle land). Third, the operation can be divided into individual, corporation and government, and the ownership of the electricity produced lies with the operating entity. Fourth, the detailed level of electricity use produced is self-consumption or sales. Finally, the price attribute is set as the monthly electricity bill per household that is additionally paid. Compared with conventional coal-fired power plants, renewables have a high cost of power generation; thus, the electricity bill could rise if the proportion of small-scale SPV power plants increases. Therefore, in this study, the level of price attributes is considered by referring to Lim et al. [18], who investigated the WTP for the expansion of renewable energy facilities. There are four levels of 1000, 3000, 6000 and 10,000 KRW/month. The attributes and their levels are summarized in Table 1. It is assumed that the levels of possible attributes other than these five attributes, which may affect respondents' preference, are the same in all the alternatives.

Table 1. Descriptions and levels of the five chosen attributes.

Attributes	Descriptions	Levels
Installation location	Installation location of small-scale photovoltaic power plants	Level 1: Not selected [1] Level 2: Residence Level 3: City Level 4: Suburb
Installation scale	Installation scale of small-scale photovoltaic power plants (limit installation scale to 150 kW)	Level 1: Not selected [1] Level 2: 30 kW Level 3: 80 kW Level 4: 150 kW
Operation	Small-scale photovoltaic power plants can be operated by an individual, corporation or government, and ownership of the electricity generated from small-scale photovoltaic power plants belongs to the operating entity	Level 1: Not selected [1] Level 2: Individual Level 3: Corporation Level 4: Government
Electricity use	Choose to consume or sell electricity generated by small-scale photovoltaic power plants	Level 1: Not selected [1] Level 2: Self-consumption Level 3: Sales
Price	Monthly additional electricity bill per household for installation of small-scale photovoltaic power plants (unit: South Korean won)	Level 1: KRW 0 [1] Level 2: KRW 1000 Level 3: KRW 3000 Level 4: KRW 6000 Level 5: KRW 10,000

Notes: [1] indicates the current level of each attribute. USD 1.0 was approximately equal to KRW 1167.7 at the time of the survey.

The CE question consists of three alternatives. One is alternative C, which represents the present state (status quo), and the other two are composed of different attribute levels for small-scale SPV power plant installation. There is a total of $4^3 \times 3^1 \times 5^1$ possible choice alternatives in combination with the suggested attributes and their levels. However, it is not possible to ask the respondents to choose among all these possible alternatives in the survey. Thus, a minimum set of alternatives is derived through the orthogonal main-effects design, and a total of 16 alternative sets are extracted. In fact, we randomly mix 16 alternative sets into eight alternative sets with two alternatives. For the convenience of the respondents, we split the respondents into two groups and survey only four alternative sets per group. The respondents are directed to choose their preferred alternative among the three within the alternative set. Figure 1 is an example of an alternative set presented to the respondents.

	Alternative A	Alternative B	Alternative C
Installation location	Residence	City	Not selected
Installation scale	30 kW	150 kW	Not selected
Operation	Individual	Corporation	Not selected
Electricity use	Self-consumption	Sales	Not selected
Price	KRW 1000	KRW 6000	KRW 0
Check with √ only the one alternative that you prefer among A, B or C (the status quo).	□ A	□ B	□ C

Figure 1. An example of the choice experiment.

The actual fieldwork was conducted by a professional polling firm (Research Prime) for one month in June 2016. To improve the reliability of the SP data, the survey respondents were limited to the household owners and their spouses who have the actual burden of electricity bill payment and who are aged from 20 to 65 years. The sample of the survey consists of 600 South Korean households, which were selected according to the purposive quota sampling to obtain a similar ratio to the actual population in South Korea. In addition, face-to-face surveys were conducted to ensure a better understanding of various attributes and to provide sufficient information to raise the response rates. In this study, we examine the number of respondents to gender, family size, age and monthly average household income. Information on respondents' characteristics is summarized in Table 2. The distribution of respondents' characteristics in Table 2 is very similar to that of actual Korean population at the time of the survey [44], which indicates that the samples were adequately drawn.

Table 2. Characteristics of the survey respondents.

Variables		Number of Sample (Ratio %)
Gender	Male	300 (50.0%)
	Female	300 (50.0%)
Family size	1–2	151 (25.2%)
	3–4	399 (66.5%)
	5–6	50 (8.3%)
Age (years)	20–29	23 (3.8%)
	30–39	124 (20.7%)
	40–49	208 (34.7%)
	50–59	180 (30.0%)
	60–69	65 (10.8%)
Monthly household income	Less than KRW 3 million	112 (18.7%)
	KRW 3–4 million	148 (24.7%)
	KRW 4–5 million	137 (22.8%)
	KRW 5–6 million	83 (13.8%)
	More than KRW 6 million	120 (20.0%)
Total		600 (100%)

2.2. The Model Specifications

The collected SP data are analyzed using a discrete choice model (DCM) based on random utility models. DCMs have been used for many years in marketing analyses to assess consumer preferences for different product attributes [45,46]. They have also been used in the fields of energy and environment [47,48] due to their wide applicability. In this study, the CE data obtained through the survey is inherently discrete characteristics, as respondents choose the one alternative that gives them the highest utility among the various alternatives. Therefore, the DCM is suitable as an analytical model for this study because it can jointly evaluate the trade-offs by considering several important attributes. In the DCM, the utility (U_{nj}) that the decision maker n obtains from alternative j consists of the deterministic utility (V_{nj}) and the random utility (ε_{nj}). Respondents choose the alternative that would give them the highest utility. Thus, the probability that respondent n would choose alternative j is the case that the utility of alternative j would be greater than the utility of any other alternatives [49,50], which is expressed as follows:

$$\begin{aligned} P_{nj} &= \Pr\left(U_{nj} > U_{ni}, \forall i \neq j\right) \\ &= \Pr\left(V_{nj} + \varepsilon_{nj} > V_{ni} + \varepsilon_{ni}, \forall i \neq j\right) \\ &= \int_{\varepsilon} I\left(\varepsilon_{ni} - \varepsilon_{nj} < V_{nj} - V_{ni}, \forall i \neq j\right) f(\varepsilon_n) d\varepsilon_n \end{aligned} \quad (1)$$

In Equation (1), various forms of DCM are derived depending on how the probability distribution of the unobserved portion of utility $f(\varepsilon_n)$ is assumed. For a typical standard multinomial logit model, it is assumed that all respondents have a homogeneous preference structure. In addition, standard logit model follows unrealistic independent from irrelevant alternatives (IIA) characteristic that the ratio of the choice probability of the two alternatives in the choice set is not affected by the presence of other alternatives. To overcome these limitations, this study uses a mixed logit model that reflects the heterogeneity of respondents' preferences. Several recent studies have identified the existence of preference heterogeneity for renewable energy technologies [51–53], which should be considered in developing sophisticated policies. Therefore, it is necessary to consider heterogeneity in respondents' preference for installing of small-scale SPV power plants. Mixed logit model is very appropriate for this research purpose. The mixed logit model assumes that the coefficient vector β_n, which is the value given by the respondent to each attribute, follows a specific probability distribution for the population and that the probability density function is $f(\beta)$. The mixed logit model also allows more accurate analysis of respondents' preferences by assuming different probability distributions for each attribute [54].

In the mixed logit model, the utility U_{njt} that respondent n derives from an alternative j within the choice set t is expressed [49,54] as:

$$U_{njt} = V_{njt} + \varepsilon_{njt} = \beta_n{}' X_{njt} + \varepsilon_{njt}\,,\ \beta_n \sim N(b, W) \quad (2)$$

where U_{nj} is the utility that respondent n obtains from alternative j, V_{nj} is the representative utility that relates the observed factors to the respondent's utility, and ε_{nj} is a disturbance that is the unobserved portion of utility. X_{njt} is also a vector consisting of attributes related to alternative j within choice set t. β_n is the vector that represents the coefficient of attributes and follows a probability distribution with an average of b and a variance of W. Assuming ε_{njt} as a random disturbance with a distribution of i.i.d. extreme value, the choice probability is derived [54] as:

$$P_{nj} = \int \left(\frac{e^{\beta_n' x_{nj}}}{\sum_i e^{\beta_n' x_{ni}}} \right) f(\beta) d\beta \quad (3)$$

After assuming a specific distribution for each coefficient, the likelihood function is derived as:

$$L(y_n|\beta_n) = \prod_{t=1}^{T} \frac{\exp(\beta_n' x_{jt})}{\sum_{k=1}^{J} \exp(\beta_n' x_{kt})} \tag{4}$$

y_n refers to a vector that collects all of the alternatives that each respondent n chooses from the tth set of alternatives.

On the other hand, it is difficult to compare the relative value of attributes from the coefficient estimates based on the mixed logit model, since they represent the marginal contribution to the utility of each attribute with different units. Therefore, it is necessary to calculate the *MWTP* from the estimated results. *MWTP* means the amount that a respondent is willing to pay to keep his or her utility the same as before when the quantity or quality of the attribute changes by one unit. Assuming that the deterministic utility (V_{nj}) consists of an alternative price attribute ($x_{j,price}$) and any other attribute (x_{jk}) except for it, the *MWTP* for each attribute can be calculated as:

$$MWTP_{x_{jk}} = -\frac{\partial U_{nj}/\partial x_{jk}}{\partial U_{nj}/\partial x_{j,price}} = -\frac{\beta_k}{\beta_{price}} \tag{5}$$

In addition, when respondents choose an alternative, each attribute has a different relative importance (*RI*) to the decision. If the part worth of each attribute is calculated, the *RI* of each attribute can be obtained as shown in the following Equation (6). The part worth of attribute k can be obtained by multiplying the minimum level minus the maximum level of attribute k by the coefficient of β_k of attribute k.

$$RI_K = \frac{part - worth_K}{\sum_k part - worth_k} \times 100 \tag{6}$$

3. Results and Discussion

3.1. Estimation Results: Social Preferences for Installing Small-Scale SPV Power Plants

For the analysis of respondents' preference for small-scale SPV power plant installation, the utility that respondent n obtains when s/he chooses alternative j is specified as:

$$\begin{aligned} U_{nj} = {} & ASC_{A,n} + \beta_{n1} d_{\text{Residence}} + \beta_{n2} d_{City} + \beta_{n3} d_{Suburb} + \beta_{n4} x_{scale} + \beta_{n5} d_{Individual} + \beta_{n6} d_{Corporation} \\ & + \beta_{n7} d_{Government} + \beta_{n8} d_{Self-consumption} + \beta_{n9} d_{Sales} + \beta_{n10} x_{\text{Price}} + \varepsilon_{nj} \end{aligned} \tag{7}$$

In Equation (7), $d_{\text{Residence}}$, d_{City} and d_{Suburb} are the dummy variables representing residence, city and suburb in the installation location attribute, respectively. x_{Scale} is the variable representing the installation scale attribute. $d_{Individual}$, $d_{Corporation}$ and $d_{Government}$ are the dummy variables meaning individual, corporation and government in the operation attribute, respectively. $d_{Self-consumption}$ and d_{Sales} are the dummy variables indicating self-consumption and sales in the electricity use attribute, respectively. The 'not selected' level is set to the base for all the dummy variables. Finally, x_{Price} means the additional electricity bill.

As mentioned above, the mixed logit model has the advantage that researchers can assign a specific distribution to each coefficient based on the characteristics of the variables [54]. This study assumes that all the parameters follow a normal distribution. The Bayesian method is used to estimate the model. The Bayesian estimation method has the advantage of being able to solve the global optimization problem and the initial value problem compared with the conventional maximum likelihood estimation [55–57]. The estimated coefficients, as well as the median *MWTP* and average *RI* derived from them, are shown in Table 3. The mean and standard deviation of all the estimated parameters are significant at the 1% or 5% level.

Table 3. Estimation results of the mixed logit model.

Variables [1]		Assumed Distribution	Mean of the Estimate, b	Standard Deviation of Estimate, $\sqrt{W}$	Median $MWTP$ [3]	Average RI (%) [4]
ASC [2]		Normal	4.8036	19.7203	-	-
Installation location	Residence	Normal	3.2706 **	48.6588 **	4286 KRW/month	9.72
	City	Normal	2.7939 **	51.5031 **	4171 KRW/month	10.16
	Suburb	Normal	−3.4755 **	19.1387 **	−2714 KRW/month	7.39
Installation scale	Installation scale (unit: kW)	Normal	5.3991 **	27.4433 **	3712 KRW/kW	11.88
Operation	Individual	Normal	3.1616 **	22.5141 **	2811 KRW/month	7.70
	Corporation	Normal	5.4051 **	32.1585 **	2885 KRW/month	10.71
	Government	Normal	3.3647 **	39.4655 **	1344 KRW/month	9.77
Electricity use	Self-consumption	Normal	5.5952 **	32.0638 **	3731 KRW/month	10.43
	Sales	Normal	1.0202 *	16.4477 **	2070 KRW/month	5.63
Additional electricity bill (unit: KRW/month)		Normal	−0.6751 **	1.4623 **	-	16.61

Notes: [1] The variables are defined in Table 1. [2] ASC refers to alternative-specific constants that represent dummies for the respondents choosing alternative A. ** and * indicate statistical significance at the 1% and 5% levels, respectively. [3] The *MWTP* is calculated based on 2000 values drawn from the distribution of the estimated coefficient, and the median of the 2000 *MWTP* observations is presented. [4] The *RI* of each attribute is calculated based on 2000 values drawn from the distribution of the estimated coefficient, and the mean of the 2000 *RI* observations is presented.

First, the *RI* of small-scale SPV power plant installation (the last column in Table 3) shows that respondents regard the additional electricity bills as the most important consideration when installing a small-scale SPV power plant. When comparing the category of attributes, it is shown that the operating body (28.18%) and installation location (27.26%) are considered to be similar in importance, followed by additional electricity bills (16.61%) and electricity use (16.06%). On the other hand, the *RI* of the scale of installation is relatively low, 11.88%, indicating that the respondents do not consider it as an important attribute in the process of small-scale SPV power plant installation. Because small-scale SPV power plants are installed in the living environment of the public, there is a considerable visual impact. Therefore, the respondents' interest in how the small-scale SPV power plants operate and where they are installed will have greatly influenced their choices.

Next, it is necessary to examine the respondents' preferences and *MWTP* for individual attributes. For the installation location, all the parameters except for parameter d_{Suburb} are positive. This result indicates that the respondents do not prefer suburbs as the location for installing small-scale SPV power plants. This is very interesting, as the majority of small-scale SPV power plants are currently located in suburban areas in the case of South Korea. The public's interest in safe and clean energy has increased over the last decade. As a result, the public's preference for renewable energy, such as solar energy, has increased, and thus members of the public have a positive view of the installation of small-scale SPV power plants in densely populated residential and city areas. In addition, the government's support for and promotion of renewable energy may help to encourage people to think that SPV power plants are no longer obnoxious facilities. For their preferred installation location, the respondents are willing to pay an additional electricity bill of KRW 4286/month.

The sign of the parameter estimate for the installation scale is also positive. Since the amount of electricity production is proportional to the scale of a power plant, the result of a positive parameter is predictable. As the installation scale grows by 1 kW, the respondents indicate that they are willing to pay an additional electricity bill of KRW 3712/month.

The sign of the parameter is positive for all the operating bodies, and the corporation attribute showed the largest value among them. Looking at the structure of South Korea's power industry, the state-run Korea Electric Power Corp. has integrated control over the field of transmission, distribution and sales. It does not seem that the respondents trust the current energy governance, mainly operated by a few public corporations. Therefore, the operation attribute is interpreted as reflecting a preference for private corporations rather than the government. The respondents would be willing to pay an additional electricity bill of KRW 2885/month if the operating entity was a private corporation.

All the parameters of attributes in electricity use are also positive. In particular, the mean of the estimate shows that self-consumption is about five times higher than sales, which means that self-consumption is preferred to selling the renewable electricity produced. These results indicate that the institutional expansion of energy prosumers (a compound word for a producer and a consumer) and the promotion of small-scale distributed power have improved the social acceptance of energy self-consumption. Therefore, the respondents are willing to pay an additional electricity bill of KRW 3731/month when they consume their own electricity.

Finally, we examine the standard deviation of the estimates. For installation locations, the standard deviation of residences and cities are relatively higher than those for other attributes. This means that the distribution of the respondents' preferences is broader than that of other attributes and that the WTP distribution is also broad. Therefore, an increase in the electricity bill based on changing the installation location will be controversial compared with the manipulation of other attributes. The standard deviation for the government is also relatively high compared with individuals and corporations within the operation attributes. This means the respondents have different attitudes toward the government in operating small-scale SPV power plants from individuals or private corporations. There is a wide distribution of the respondents' preference for sales in the attributes of the electricity produced. That is, the electricity produced is likely to be less controversial in paying an additional electricity bill for self-consumption than for sales. On the other hand, we can see that the consumer preferences for other attributes are relatively consistent.

3.2. Simulations: Scenario Analysis of Future Small-Scale SPV Power Plant Installation

This section deals with possible scenarios for future small-scale SPV power plant installation. Based on the estimation results, we can predict how the public acceptance of a hypothetical small-scale SPV power plant installation will change due to variations in the levels of some attributes, such as the installation location and electricity bill. Next, we reflect the possible increase in the electricity bill for each scenario and simulate its impact on the level of public acceptance. First, the base scenario is set to reflect the current status of the installation of small-scale SPV power plants in South Korea. In 2015, 6944 commercial SPV power plants were completed, and more than 90% of them were less than 100 kW. In addition, most of them were established in rural areas [58]. Therefore, suburb is selected as the installation location in the base scenario, and the installation scale is set 80 kW, which is close to 100 kW in the survey attributes. The private corporation and self-consumption levels are chosen as the levels of attributes of the operating body and electricity use, which are the preferred level of each attribute. The price is based on KRW 1000, the lowest price of the scale KRW 1000 to KRW 10,000. Depending on the installation location, the scenario is divided into Scenario A, Scenario B, and Scenario C. The other attributes are set to be identical to the base scenario. Table 4 summarizes four scenarios of future small-scale SPV power plant installations.

According to the scenarios established above, the public acceptance of changes in the additional electricity bill is simulated by calculating the choice probability between the base scenario and one of the three alternative scenarios. The results are described in Table 5 and Figure 2.

Table 4. Current and future scenarios of the installation of small-scale solar photovoltaic power plants.

Attributes	Base Scenario	Scenario A	Scenario B	Scenario C
Installation location	Suburb	Residence	City	Suburb
Installation scale	80 kW	80 kW	80 kW	80 kW
Operation	Corporation	Corporation	Corporation	Corporation
Electricity use	Self-consumption	Self-consumption	Self-consumption	Self-consumption
Price	KRW 1000	KRW 1000~10,000	KRW 1000~10,000	KRW 1000~10,000

Table 5. Simulation results for each scenario.

Additional Electricity Bill	KRW/Month	1000	2000	3000	4000	5000	6000	7000	8000	9000	10,000
Scenario A	South Koreans' acceptance (%)	72.36	71.83	71.37	70.73	69.40	67.06	63.42	59.80	56.71	54.32
Scenario B	South Koreans' acceptance (%)	73.01	72.60	72.05	71.19	69.63	66.90	64.01	60.82	57.09	53.74
Scenario C	South Koreans' acceptance (%)	50.00	38.25	34.34	32.97	32.37	32.07	31.90	31.80	31.73	31.69

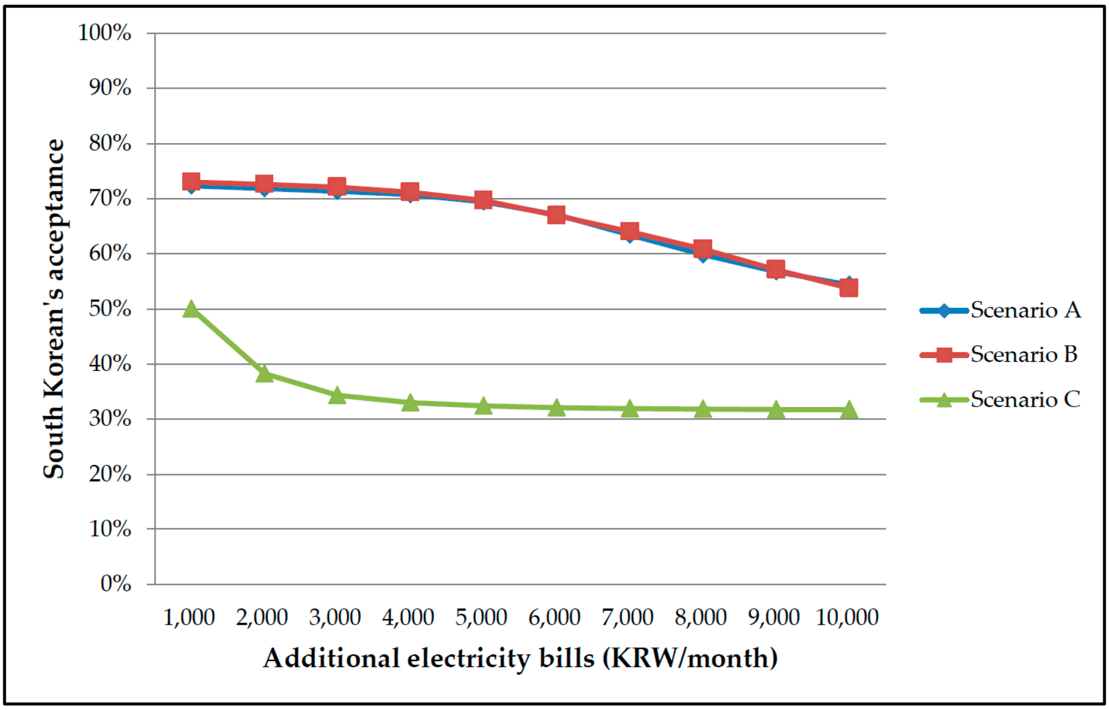

Figure 2. South Koreans' acceptance of each hypothetical scenario according to the additional electricity bill.

According to the results of the simulation, the higher the additional electricity bill, the lower the overall respondents' acceptance. However, it is found that respondents are in favor of installing small-scale SPV power plants in their residence or city if they typically have to pay the same additional electricity bill. Despite the higher additional electricity bill, the respondents' acceptance remains above the current state of 50%. This means that the respondents' acceptance of installation in residential areas and city areas is positive and the need for installation is high. As seen in the estimation results mentioned above, it is possible to predict that Scenario A and Scenario B are similar, because there is not much difference in preference between residence and city. In the case of Scenario C, as the additional electricity bill increases, the public acceptance decreases from 50% to 31.69%. This corresponds to the estimated result of the parameter in suburban areas having a negative value. Unlike other power plants that use renewable energy, SPV power plants do not seem to be considered as obnoxious facilities.

Therefore, when the government implements a policy to expand small-scale SPV power plants, it should actively consider installing them in residences or cities. As a result of the simulation, the increase in the electricity bill is still a critical factor that greatly affects the public acceptance. Therefore, it is necessary to conduct a more detailed analysis of the factors that contribute to the increase in the electricity bill due to the expansion of small-scale SPV power plants.

4. Conclusions

This study quantitatively analyzes the social preference for and public acceptance of the installation of small-scale SPV power plants in South Korea. To achieve this research objective, data collected through a CE questionnaire, a type of SP technique, are analyzed using a mixed logit model. The analysis shows that people considered the electricity bill, the operating body and the installation location to be more important than other attributes. The respondents prefer small-scale SPV power plants that are located in residential areas, have a large scale of installation, are operated by a private corporation and produce self-consumed electricity. The *MWTP* for these attributes are estimated to be KRW 4286/month, KRW 3712/kW, KRW 2885/month and KRW 3731/month, respectively.

As seen in the above results, the public's interest in safe and clean energy has increased and the perception of small-scale SPV power plants has changed positively. Considering the location of small-scale SPV power plants installation in accordance with the preference of the people, it is necessary to expand the installation around the residential area. The government should also come up with a system that grants various incentives to power generation operators to build small-scale SPV power plants that meet the public's preferences. Because there is the preferences heterogeneity for all attributes, the government should continue monitoring and try to change their attitude to potential opponents who do not like those attributes. The results of the simulation show that the public acceptance of installing small-scale SPV power plants in residential area or city area is maintained at over 50% despite the increase in additional electricity bill. As the choice of installation location is widened, it will be possible to supply small-scale SPV power plants with various sizes and shapes, and to develop the technology according to demand.

It is costly to install a number of new small-scale SPV power plants due to the higher cost of SPV power generation compared to the traditional fossil fuel generation [59,60]. Considering the cost will ultimately be passed on to the end-users of electricity, it is vital to gather public opinion on whether or not citizens are willing to pay for the installation. This is because the installation cannot be successful without public support in the long run, as public acceptance of renewable energy is becoming increasingly important [61,62]. Moreover, policymakers seek quantitative information about people's willingness to pay for the installation of small-scale SPV power plants. The purpose of this study was to provide such information to policymakers. In this regard, the results from the study are useful from the perspective of policy. In addition, this study provides quantitative acceptance according to the rise in electricity bill by predicting the public acceptance through simulations of installing small-scale SPV power plants.

However, the following issues should be considered when establishing policies. Since members of the public prefer private corporations to the government as an operating body, it is necessary to make efforts to recover the credibility of the South Korean government by supplementing the stable supply of SPV power and operation management. Alternatively, it may be possible to consider a policy that increases the participation rate of private corporations in planned SPV projects. The preference for self-consumption can be used as a basis for implementing the government's plans to increase the decentralized power grid, which can be self-sufficient on a regional basis. A decentralized power grid will enable improvements in local power independence.

Since there are few studies that have dealt with the social preferences of small-scale SPV power plants in the literature, it is difficult to compare our findings with the findings of other studies on this topic. However, new insights into the social preferences of small-scale SPV installations can be gained by comparing our results with data analysis of other countries, clarifying the differences and examining the factors that influence those gaps. These kinds of works could give us a new perspective on the social preferences of installation of small-scale SPV power plants. It makes academic and practical contributions from the following perspectives. First, it provides the basis for setting priorities for small-scale SPV power plant installation. Small-scale SPV companies can install SPV cells indiscriminately for profit. Therefore, to expand the supply of small-scale SPV power plants systematically, it is necessary to establish concrete policies reflecting the public acceptance. The social preference for each attribute of small-scale SPV power plant installation provides strategic implications for establishing initial and long-term plans. Second, it can provide implications for the calculation of a government subsidy. Since SPV modules are still expensive, the public's preference for and acceptance of small-scale SPV power plant installation are high, but it is not easy to install them. The subsidy payment policy plays an important role in increasing the installation of small-scale SPV power plants. In addition, this study has the academic meaning of applying a SP technique to small-scale SPV power plant installation to check its applicability and fill the gaps in the existing relevant studies.

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