

## Article

# Financial Feasibility and Social Acceptance for Reducing Nuclear Power Plants: A Contingent Valuation Study

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**Abstract:** Social acceptance of nuclear power has become a decisive factor in framing a sustainable energy policy. This study examines social acceptance for cancelling the construction of planned nuclear power plants (NPPs) and replacing them with other energy sources. The contingent valuation method (CVM) and cost-benefit analysis (CBA) are used to access the social acceptance and financial feasibility of such projects. Empirical analysis is based on the case of South Korea, where a similar policy is in progress under the new government. The CVM results show that a Korean household was willing to pay an additional KRW 1922.45/month (USD 1.80/month) for replacing seven 1-Gigawatt NPPs with other energy sources, which is about 3.5% of a household's current electricity bill. The CBA suggests that the annual costs of replacing this amount of nuclear power capacity with renewables or liquefied natural gas is KRW 1291.40 billion (USD 1.21 billion) or KRW 1180.38 billion (USD 1.11 billion) larger than its benefits, which amounts to about 3% of total annual electricity generation costs in South Korea. As the additional costs of nuclear power replacement cannot be fully covered by the mean willingness-to-pay of the current acceptance level, moderate levels of social resistance are expected if all the additional costs are passed on to the end-users.

**Keywords:** social acceptance; nuclear power; renewable energy; liquefied natural gas; contingent valuation method; willingness to pay

## 1. Introduction

Nuclear power is possibly the most controversial energy source because of the clear advantages and disadvantages that arise from its inherent technological characteristics. The current figures show that the amount and ratio of nuclear power have steadily declined worldwide. In 2017 there were 403 nuclear power plants (NPPs) worldwide, 35 less than the 2002 peak of 438. The total installed capacity was 351 Gigawatt (GW) in 2017, which is less than the 2006 peak of 368 GW. Annual nuclear electricity generation was 2476 TWh in 2016, about 7% below the historic peak of 2006. The share of nuclear energy in global power generation was 10.5% in 2016 after declining steadily from a historic peak of 17.5% in 1996 [1]. At the global level, it seems there is a social consensus for reducing nuclear power in the long-term. However, countries with a higher share of nuclear power are of the opinion that the electricity market cannot bear the rapid decrease in nuclear power as it would lead to a sharp increase in overall power generation costs. Therefore, the status of countries with operating NPPs

varies depending on the priority with regard to the advantages and disadvantages of nuclear power. For example, Germany has a firm policy to close existing units, while some countries including the US are either constructing new units or completing previously suspended construction projects [2].

Nuclear power is also considered a controversial energy source, and most issues can be broken down into three aspects. First, the economic advantage of nuclear power; that is, whether there are advantages from the perspective of generation costs. The unit cost of electricity from nuclear power is considered to be lower than other energy sources, but controversy grows as the external costs of electricity generation are widely recognized in recent years. Second, the issue of safety (or danger); that is, the probability of expected accident damage at NPPs such as explosions, melting of nuclear fuel rods, and nuclear fuel leaks. Radiation leaks from an NPP accident are treated as a much more serious issue than accidents related to other power plants, primarily because a nuclear leak has disastrous and widespread human and environmental consequences. This issue was outside public purview for a few decades after the Three Mile Island incident in 1979 and the Chernobyl accident in 1986, but the Fukushima disaster in 2011 sparked a controversy and the issue has reemerged again worldwide. Third, the issue of social acceptance of nuclear power, that is, evaluating public perception of nuclear power. As consumers rarely notice the difference in electricity quality depending on the energy sources, it has been assumed that they are not very sensitive to the type of energy source. Energy–environmental problems have recently emerged as an important public interest consideration, however, public participation and consideration of energy sources from a demand perspective are becoming increasingly important issues in the energy sector [3]. These three issues are interrelated, and each country determines its share of nuclear power considering these issues. Proponents of nuclear power emphasize advantages such as low cost of generation and low CO<sub>2</sub> emissions, while opponents highlight its disadvantages associated with safety hazards.

In sum, nuclear power has clear advantages and disadvantages due to its unique technological characteristics, and such advantages and disadvantages have a trade-off relationship. Therefore, it eventually becomes a matter of social consensus and social value judgments whether we take on the particular risks of nuclear power to receive its benefits, or replace it with other power sources. This implies that public acceptance and the image of nuclear power, not the technology itself, have become the core values for a decision on the use of nuclear power. Specifically, social acceptance of nuclear power is a decisive factor in devising a nuclear power policy.

This study examines public attitude toward the cancellation of a previously scheduled NPP construction and replacement of nuclear power with other energy sources. The main objective is to measure average social acceptance and net social benefit in monetary terms. The contingent valuation method (CVM) and the concept of cost–benefit analysis (CBA) are used as research methodologies, and empirical analysis is based on the case of South Korea, as it is an appropriate region to provide related policy implications for other countries. Besides, South Korea is one of the “big five” nuclear generating countries that account for 70% of all nuclear electricity generated globally [1]. This study has two marginal contributions compared with existing studies on social acceptance of nuclear power. First, we assume the replacement of nuclear power with other energy sources. As noted, public participation has increased in the energy market, and their knowledge of energy sources has also improved. Therefore, social acceptance for reducing nuclear power can be affected by the type of power source that replaces such reduced amounts. Second, on the basis of elicited willingness-to-pay (WTP), a CBA is presented to evaluate the possibility of replacing nuclear power from a financial aspect. Such analysis can provide practical implications for long-term electricity generation mix planning at the national level. Especially, as the South Korean government is moving ahead with its “energy transformation” plan with the aim of reducing a considerable portion of nuclear power, this study examines the potential for success from the aspect of social acceptance.

This paper consists of five sections. Section 2 briefly introduces the current status of nuclear power in South Korea, related issues, and summarizes existing studies on social acceptance of nuclear energy. Section 3 explains the method for eliciting public WTP, and describes the survey design

for data collection. Section 4 presents the results of empirical analysis; the mean WTP for nuclear power reduction is suggested and, based on this, financial feasibility of NPP reduction is evaluated. Section 5 concludes.

## 2. Background

### 2.1. Nuclear Power in South Korea: Current Status and Issues

Currently, nuclear power largely contributes to domestic power supply in South Korea, which is the main reason why this discussion is of such significance. Despite the geographical connection to the Asian continent, the power supply system in South Korea is isolated like an island because of the extraordinary political and military situation; namely, the division of the Korean peninsula. South Korea also imports about 95% of its primary energy as it lacks in natural resources [4]. Given this situation, nuclear power became an attractive alternative option to support rapid economic development. With such a historical and social background, nuclear power has played an important role in the South Korean domestic power supply sector. After the decision to introduce nuclear power in 1970, South Korea built and began to operate its first 600 MW NPP in 1978. Since then, there was a steady expansion of nuclear power. As of 2017, there were a total of 24 NPPs located in the four regions, but only 17 NPPs were in operation due to maintenance and suspension. Moreover, 5 NPPs were under construction (units 4, 5 and 6 of the Shin-Kori NPP, units 3 and 4 of the Shin-Hanul NPP) and an additional 4 new NPPs (units 1 and 2 of the Chunji NPP, units 1 and 2 of the Daejin NPP) were scheduled to be built at that time. Under this policy of nuclear expansion, South Korea's share of nuclear power in 2016 accounted for 21.8% of total installed capacity, and 30.0% of total electricity generation, the second highest ratio after coal-fired power among all available power sources [4].

However, South Korea's nuclear policy is currently experiencing a rapid change following the inauguration of the new government in 2017, as it has decided to pursue a nuclear-free policy in the long-term. The new government plans to reduce the number of NPPs from 24 in 2017 to 28 in 2022, 18 in 2031, and 14 in 2038 [5]. It has also clearly stated that the share of nuclear power in total electricity generation would be reduced to 23.9% by 2030 (in 2017, nuclear generated about 30% of the country's electricity), and would be replaced by renewables and liquefied natural gas (LNG) [6].

Meanwhile, public interest in NPP has grown significantly in South Korea. Recent public participation in the nuclear power issue is a good example that shows such increased public interest. In July 2017, the government had launched an ad-hoc committee to gather public opinion on whether to permanently halt the construction of two NPPs (units 5 and 6 of the Shin-Kori NPP), which were under construction at that time. About 471 citizens as public representatives had participated in this committee, and after gathering enough public opinion through a three-day discussion and a four-time survey, the final recommendations were submitted to the government in October 2017. The committee recommends resumption of the construction of two NPPs, and the ratio of people who believe that domestic nuclear power should be reduced or maintained were 53.2% and 35.5%, respectively. As such, as public interest and participation in nuclear power increases, social acceptance of nuclear power will have an immediate and strong influence on the South Korean nuclear power policy.

In sum, social acceptance of nuclear power has become an essential factor for a successful nuclear power policy in South Korea. However, the problem is that unlike economic advantage and safety, which continue to improve with advancements in technology, social acceptance is affected by a number of factors and its level shows differences depending on the time and method of investigation. For example, public opinion in South Korea was in favor of nuclear power during 2009, especially after winning a large-scale NPP project in the United Arab Emirates, but after the Fukushima disaster in 2011 it turned against nuclear power. This possible variability requires investigation of social acceptance of nuclear power, with a consistent method and at regular intervals. This study not only analyzes social acceptance of nuclear power in recent years but also applies an actual cost-benefit

perspective and provides meaningful implications for the South Korean government's future plan to reduce dependence on nuclear power.

## 2.2. Literature Review

There are many studies on social acceptance of nuclear power, and interest in this issue has been growing in recent years. Since 2010, related studies have been rapidly increasing and have introduced diverse perspectives on the issue. Examples include; proposing new indicators that quantify public acceptance of nuclear power [7], analyzing the impact of the Fukushima disaster on the acceptance of nuclear power [8–11], identifying public attitude on nuclear power using social media data [12], suggesting an international comparison of public acceptance of nuclear energy [13], and identifying the determinants of acceptance of nuclear power [14–19].

Besides the abovementioned studies, other studies having a closer relationship with this study estimated WTP for a situation regarding nuclear power and analyzed social acceptance in monetary terms. Most of these studies employed the stated preference method, such as choice modeling and CVM. In this section, we introduce the studies using CVM, as they can provide useful insights to our study because of methodological similarity.

Jun et al. [20] estimated the social value of nuclear energy and people's WTP for nuclear energy in South Korea. Respondents were divided into two groups: one group was provided information on nuclear energy such as safety hazards, economic, and environmental benefits; the other group was not given this information. Results show that each group has a mean WTP of USD 0.59/month and USD 0.35/month, respectively. This implies that the social value of nuclear energy increased when adequate information is provided to the public.

Liao et al. [21] analyzed Taiwanese WTP for nuclear power. The authors divided the respondents into two groups based on whether they supported the increase or decrease in nuclear energy's share in electricity generation, and elicited each group's mean WTP for its preferred policy. Respondents who supported the increase and decrease in nuclear energy's share in electricity generation was 223 and 241, respectively, and similar to each other. The median WTP of each group was USD 146.31/year and USD 164.85/year, respectively, which are also similar to each other. Based on these results, the authors concluded that Taiwanese did not support any dramatic increase or decrease in nuclear power, and claimed that the share of nuclear power should be maintained for a while.

Sun and Zhu [22] analyzed Chinese WTP for avoiding the construction of NPPs in their neighborhood. In order to analyze the impact of information about nuclear energy on WTP, respondents were divided into two groups comprising of people who were informed and those who were not informed of the pros and cons of nuclear power. The results showed that the mean WTP of respondents who did not have information was USD 0.1501/kWh, while the mean WTP of respondents who had such information was USD 0.1403/kWh. Based on these results, the authors suggested that comprehensive information would increase public support for nuclear power. Similarly, in their subsequent study, Sun et al. [23] and Sun et al. [24] found that distance of dwelling (buffer zone) from NPPs and the perception of security also influenced public acceptance of NPPs.

Yun et al. [25] investigated whether people's image of an NPP, their perception of safety, and scientific background related to their WTP for reducing risk in a nuclear power plant. Results showed that the mean WTP for all the respondents was about USD 17.014/month. After dividing the samples into several groups, the results showed that people with a higher scientific background and a good image of NPPs tend to have lower WTP. On the other hand, no clear relationship was found between the safety level and mean WTP.

Park et al. [26] analyzed Koreans' WTP for replacing nuclear power and fossil energy with renewable energy. It was found that each individual household was willing to pay USD 85 on average, and this figure corresponded to USD 16.1 billion of renewable energy value in South Korea. Further, it also turned out that a person who was younger, lived further from a NPP, a householder, and those with higher income preferred renewable energy to others.

Lee et al. [27] estimated people's WTP for replacing traditional energy sources such as coal-fired and nuclear power with renewable sources in Korea. The study results showed that Korean consumers were willing to pay an additional USD 3.3/month and USD 3.0/month on their electricity bill for replacing nuclear and coal-fired power with renewables, respectively. If these amounts are aggregated with total WTP for installing new photovoltaic capacity annually at the national level, then 372 MW of nuclear power and 339 MW coal-fired power can be substituted every year. The authors concluded that although there is a huge increase in Korean consumers' WTP for renewable energy, it is still lower than countries such as Japan, the UK, the US, and Italy.

From among the abovementioned studies, research studies conducted by Park et al. [26] and Lee et al. [27] are similar to our study, as they used CVM as a research method and suggested the notion of replacement of nuclear power with other energy sources. However, this study makes two marginal contributions that differentiate it from the other two studies. First, the two existing studies mainly focused on "increase in renewable energy" than "decrease in nuclear power." Although nuclear power and renewable energy sources are the main options in the future energy sector [28], it is unlikely that the reduced amount of nuclear power will be completely replaced by renewables. Therefore, it is more reasonable to open up the possibilities of replacing the reduced nuclear power with various other energy sources, and to examine the difference in WTP for the other energy sources. Second, through a CBA, this study quantitatively estimates the amount of nuclear power that can be replaced with other energy sources without incurring any financial losses. This will provide important new policy implications, which the previous studies did not contribute.

### 3. Materials and Methods

#### 3.1. Contingent Valuation Method: The Double-Bounded Dichotomous Choice Spike Model

It is relatively easy to economically evaluate market goods because they have a market price. Non-market goods do not have a market price, however, another approach can be used to access their value. The concept of CVM has been widely used to estimate the monetary value of such non-market goods by using stated preference data [29,30].

The CVM presents a hypothetical situation regarding a non-market good to respondents, and explicitly asks their WTP for accepting the situation. The common formats of eliciting monetary value in CVM are open-ended questions, bidding games, payment card questions, and dichotomous choice (DC) questions. Among them, the DC method has been most widely used where respondents are presented with a given price and they only have to make a judgment about whether or not to pay for it [31].

The DC format facilitates respondents' valuation task, minimizes non-response, avoids outliers, and reduces starting-point bias. It can be divided into single-bounded, one and one-half bounded, and double-bounded formats depending on the number of WTP questions. The double-bounded dichotomous choice (DBDC) asks the respondent his/her intention to accept the suggested status with the given price. If the respondent answers "Yes" (or "No"), the same question is asked using the higher bid price (or the lower bid price). The one and one-half bound dichotomous choice (OOHB DC) is similar to the DBDC, but if the response is "No", no further questions are asked. The single-bound dichotomous choice (SBDC) asks the respondent only one WTP question.

The DBDC formats are known to be more efficient than SBDC and OOHB DC as more information can be elicited about each respondent's WTP [32,33]. Specifically, the extra information gained from the follow-up questions of DBDC significantly improves the precision of the estimated WTP and these improvements are achieved without additional survey cost. Based on such advantages, we also use the DBDC formats to obtain data on respondents' WTP. Some CVM studies indicated that the responses to the first price may sometimes be inconsistent with the responses to the second in the DBDC and the OOHB can reduce the inconsistency of the DBDC. However, we have not found any evidence of inconsistency in our DBDC survey results.



The DBDC is currently the most widely-used WTP elicitation method and it has been applied to estimate WTP for nuclear power related situations. For example, Sun et al. [23] and Sun et al. [24] used the DBDC to estimate Chinese people's WTP to prevent a nuclear power plant from being constructed in their neighborhood. Specifically, they used a DBDC format survey that asks the respondents if they would pay a certain bid amount (Chinese Yuan) for electricity tariffs to avoid building a nuclear power plant and provides the follow-up questions based on their responses.

In our DBDC survey, respondents are asked whether they are willing to pay a certain additional amount on their electricity bills or not, if the seven 1-GW NPPs (corresponding to 52,122 GWh/year by assuming 85% of availability factor of an NPP; The average availability factor of an NPP was 84.82% in 2015 in South Korea [34].), which are scheduled to be built in the near future according to the national energy plan, are replaced with other power sources. If a respondent  $i$  answers "Yes" to the first bid of electricity bills ( $A_i$ ), the second bid ( $A_i^H$ ) will be twice larger than the first bid. If a respondent  $i$  answers "No" to the first bid, the second bid ( $A_i^L$ ) will be half of the first bid.

Some respondents may have zero WTP for the good which is subject to valuation. It means that respondents with *No-No* answers in the above DBDC format consist of two different groups: one is with zero WTP; and the other is with a positive WTP between zero and  $A_i^L$ . Therefore, respondents who answered *No-No* to the above DBDC format are given the third follow-up question: "Are not you willing to pay anything at all?" In sum, there are a total of five possible patterns of responses in our CV survey: "Yes-Yes", "Yes-No", "No-Yes", "No-No-Yes", and "No-No-No".

The DBDC CV spike model, which is used in this study, is a good alternative to allow a zero WTP response [35,36]. In this model, a Hicksian compensating surplus is induced using Hanemann's utility difference model [37]. A respondent's response can be considered as a function of his or her true WTP, which is a random variable denoted as  $C$  with a cumulative distribution function defined as  $G_C(\cdot; \theta)$ , where  $\theta$  is a vector of parameters. In this case, the probability of five observable response patterns can be represented as Equation (1).

$$\begin{aligned} P(\text{Yes} - \text{Yes}) &= P(C_i \geq A_i^H) = 1 - G_C(A_i^H; \theta) \\ P(\text{Yes} - \text{No}) &= P(A_i < C_i \leq A_i^H) = G_C(A_i^H; \theta) - G_C(A_i; \theta) \\ P(\text{No} - \text{Yes}) &= P(A_i^L < C_i \leq A_i) = G_C(A_i; \theta) - G_C(A_i^L; \theta) \\ P(\text{No} - \text{No} - \text{Yes}) &= P(0 < C_i < A_i^L) = G_C(A_i^L; \theta) - G_C(0; \theta) \\ P(\text{No} - \text{No} - \text{No}) &= P(C_i \leq 0) = G_C(0; \theta) \end{aligned} \quad (1)$$

To estimate the distribution of WTP, we assume that WTP is distributed as a logistic on the positive axis with  $\theta = (a, b)$ . Assuming respondents' choice for their utility maximization, the log-likelihood function of the DBDC CV spike model is represented as Equation (2) [36].

$$\begin{aligned} \ln(L) = \sum_{i=1}^N \{ & I_i^{YY} \ln [1 - G_C(A_i^H; \theta)] + I_i^{YN} \ln [G_C(A_i^H; \theta) - G_C(A_i; \theta)] \\ & + I_i^{NY} \ln [G_C(A_i; \theta) - G_C(A_i^L; \theta)] + I_i^{NNY} \ln [G_C(A_i^L; \theta) - G_C(0; \theta)] \\ & + I_i^{NNN} \ln G_C(0; \theta) \} \end{aligned}$$

where

$$G_C(A_i; \theta) = \begin{cases} [1 + \exp(a - bA_i)]^{-1}, & A_i > 0 \\ [1 + \exp(a)]^{-1}, & A_i = 0 \\ 0, & A_i < 0 \end{cases} \quad (2)$$

In Equation (2),  $I_i^{YY}$ ,  $I_i^{YN}$ ,  $I_i^{NY}$ ,  $I_i^{NNY}$ ,  $I_i^{NNN}$  are binary-valued indicator variables that inform which response the respondent will choose among the five response patterns. For example, if a respondent  $i$  answered "Yes-Yes",  $I_i^{YY}$  is 1 while the other indicator variables are 0.

The spike is defined by  $[1 + \exp(a)]^{-1}$  and it indicates the share of zero WTP responses in the sample. And the mean WTP is computed as  $(1/b) \ln[1 + \exp(a)]$  in a DBDC CV spike model [37].

We also utilize an additional model where  $a$  in Equation (2) is decomposed into  $a + x_i'\beta$  in order to analyze the effects of various covariates, such as respondents' sociodemographic characteristics and their attitude toward WTP for NPPs. Here,  $x_i'$  is the vector of the respondent's attitudes or socio-demographic variables and  $\beta$  is the parameter vector to be estimated.

### 3.2. Survey and Data Collection

The survey was conducted by a professional survey company (Gallup Korea). We only surveyed householders or their spouses who are liable for payment of the assumed increase in electricity bills. In order to provide sufficient information about nuclear power, we conducted face-to-face interviews, which offer higher flexibility and greater sample control than other survey modes and also enable complex questionnaire structures [33]. A sample was drawn using non-random sampling; purposive quota-sampling on the basis of respondents' gender, age, and geographical location, to maintain a component ratio that is representative of the actual population of Korea.

The survey consists of three parts. The first part includes a few preliminary questions, such as the respondent's satisfaction level with the electricity service, attitude toward environmental problems, nuclear power, and so on; all these factors may affect a respondent's acceptance of nuclear power. Such preliminary questions call the respondents' attention to the survey before the main CV questions, and enable us to examine the determinants of WTP for replacing nuclear power.

The second part includes key WTP questions in the CVM. Above all, the hypothetical situation of replacing NPPs with other electric power sources is described in detail in order for a respondent to fully understand the objectives of the survey. The description includes amount of electricity supply from nuclear power, number of NPPs, and the pros and cons of nuclear and other power sources, among others. Before asking the key WTP question, we require the respondents to state which power source they prefer as a substitute for seven NPPs, between fossil fuels and renewables. It is assumed that the seven NPPs will be replaced by the power source that the respondent chooses, and this is fully recognized by respondents. The final key WTP question is "Is your household willing to pay a certain additional amount of electricity bills for cancelling the construction of the scheduled seven 1-GW NPPs and replacing them with the power source that you prefer?" For a closer analysis, two types of initial bid amounts, that is, KRW 2000 (USD 1.87) and KRW 3500 (USD 3.28) are used. We take the US dollar equivalent as of January 2018 (USD 1 = KRW 1067.60) [38]. Those initial bids are selected by referring to the WTP and CV studies in the energy sector in South Korea [27,39,40]. This simple bid assignments based on limited information about the underlying distribution of WTP is most popular in practice because of its simplicity and lack of informational requirements. As noted in Section 3.1, the DBDC is used as an elicitation format, and the spike model is adopted in order to deal with the possibility that a respondent will have a WTP value of 0.

The third and last part inquiries about the respondent's socio-demographic characteristics such as gender, age, education, income level, and so on. This enables us to examine the impact of these variables on social acceptance of reducing nuclear power.

## 4. Results and Discussion

### 4.1. Preliminary Survey Results and Willingness-to-Pay Response

This section describes the main findings of the preliminary questionnaires. First, the degree of overall interest in electricity service was asked in a 5-point Likert scale (all the results in this section are measured in a 5-point Likert scale, unless otherwise stated). Nearly 75.3% of respondents answered "very interested," which confirms Koreans' close interest in the electric power sector. Moreover, the mean score of questions regarding the importance of environmental protection and the seriousness of climate change was 4.35 and 4.37 (1 = strongly disagree, 5 = strongly agree), respectively, so the respondents recognized the need for proper measures to the environmental problems. Next, a few basic questions were asked in order to outline public opinion on nuclear power. The mean score of

the question about whether nuclear power is dangerous was 3.69, which is close to the “agree (score 4).” The mean score of the question about whether nuclear power should be expanded in South Korea was 3.10, which is close to “neither agree nor disagree,” but its standard deviation was 0.85, which is larger than that of the other questions. This corresponds with the result of Huh and Lee [3] who found a larger heterogeneity in social preferences for nuclear power than for other energy sources.

In the main CV section, 400 respondents were divided into two groups, and one of the two types of initial bids was presented to the respondents in each group. Table 1 shows the distribution of respondents’ responses by initial bid amount. It is found in Table 1 that the number of respondents with *Yes-Yes* responses decreases and that of *No-No-(Yes or No)* responses increases, as the initial bid increases. For example, the ratio of *Yes-Yes* responses is 11.9% in the case of initial bids of KRW 2000 (USD 1.87) while it is a mere 1.0% in the case of initial bids of KRW 3500 (USD 3.28). On the other hand, the ratio of *No-No-(Yes or No)* responses is 32.2% in the case of initial bids of KRW 2000 (USD 1.87) while it nearly doubles (59.6%) in the case of initial bids of KRW 3500 (USD 3.28). This tendency proves that the quality of data obtained from our CV survey is appropriate for the WTP analysis.

The high ratio of respondents with *No-No-No* responses, 40.8%, deserves our attention. This implies that in South Korea there are many people whose utilities are not affected by the replacement or reduction of nuclear power. Zero responses are often found in DBDC-CV studies as a corner solution of consumers’ utility-maximization when the goods to be valued do not in any way contribute to the individual’s utility [36]. Therefore, the spike model is used in this study.

**Table 1.** Distribution of responses by bid amount.

Initial Bid (KRW)	Number of Responses (%)					Total
	<i>Yes-Yes</i>	<i>Yes-No</i>	<i>No-Yes</i>	<i>No-No-Yes</i>	<i>No-No-No</i>	
2000	24 (11.9)	70 (34.7)	43 (21.3)	5 (2.5)	60 (29.7)	202 (100)
3500	2 (1.0)	47 (23.7)	31 (15.7)	15 (7.6)	103 (52.0)	198 (100)
Total	26 (6.5)	117 (29.3)	74 (18.5)	20 (5.0)	163 (40.8)	400 (100)

#### 4.2. Estimation Results: Public Acceptance for Reducing NPPs

Two types of analysis models are used for eliciting WTP. Model 1 estimates the mean WTP and it does not consider various explanatory variables that may have potential impact on the respondent’s WTP. Model 2 includes the respondents’ socio-demographic and psychological characteristics to identify the determinants of the mean WTP. Table 2 shows the analysis results of the two models, which is the estimation result of the bid function represented as Equation (1).

**Table 2.** Estimation results of the two models.

	Model 1 (without Covariates)	Model 2 (with Covariates)
Constant	0.5470 *** (0.0941)	−2.5728 *** (0.9196)
Bid amount	−0.0005 *** (0.0000)	−0.0006 *** (0.0000)
Gender	−	−0.1887 (0.1858)
Age	−	0.0040 (0.0110)
Monthly household income	−	−0.0009 (0.0063)
Education	−	0.3121 (0.2017)
Type of alternative power source	−	0.7844 ** (0.3429)
Preferred method of payment	−	−0.6947 *** (0.1884)
Perceived seriousness about climate change	−	0.4397 *** (0.1370)
Perceived level of knowledge about nuclear power	−	0.1792 (0.1175)
Log likelihood	577.8588	560.7090
Spike	0.3666 *** (0.0218)	0.2995 *** (0.0640)
Wald statistics ( <i>p</i> -values)	281.7678 (0.0000)	21.8896 (0.0000)

Notes: Standard errors are reported in the parentheses; \*\*\*, \*\* indicate statistical significance at the 1%, 5% level, respectively; *p*-values correspond to the null hypothesis that all parameters are jointly zero.



First, in Model 1 (model without covariates), all parameter estimates are statistically significant at 1% level. Based on the Wald statistic, the null hypotheses and the parameter estimates are all zero and are also rejected at 1% level, which confirms the statistical significance of the model. The minus sign in the bid amount estimate means that a higher bid has a negative impact on the possibility of obtaining a “Yes” response, which is common in CV studies. Therefore, in the CV survey on nuclear power replacement, there is an increasing preference among respondents as the initial bid amount decreases.

The spike is estimated as 0.37, which is close to the ratio of *No-No-No* responses, 40%, in Table 1. This confirms the appropriateness of the spike model, and this suitability is also confirmed in Model 2. Therefore, policy makers should be conscious of people with zero WTP, specifically when interpreting WTP for nuclear power reduction and when devising related policies based on the results of the analysis.

Next, the estimation results for Model 2—the model with covariates—are reported in the last column of Table 2. To identify the determinants of the public’s WTP for replacing nuclear power, it is necessary to first consider the covariates which should be included in the model. Existing studies found that a variety of psychological, emotional, and socio-demographic factors influence the acceptance of nuclear power [14–19], and we select a few covariates with reference to these studies. Table 3 summarizes the basic statistics of the covariates included in Model 2. According to Table 3, respondents show overwhelming support for renewables as substitutes for nuclear power and prefer an additional amount in their electricity bill as a payment method. Respondents are also aware of the seriousness of climate change, and the wide variations are observed in their perceived level of knowledge about nuclear power. Among the various covariates, whether the knowledge about nuclear power is a determinant of social acceptance has been an important issue, and previous studies have presented different results and opinions [13,14,18,41]. According to Table 3, the calculated mean of perceived knowledge about nuclear power is slightly higher than average, which means most of respondents are not nuclear professionals. Such knowledge level of the survey respondents is appropriate for the study’s objective which is to analyze the acceptance of the general public for reducing nuclear power plants. We also intentionally excluded nuclear professionals and stakeholders belonging to the relevant companies or organizations when constructing the respondents’ sample, in order to focus on the analysis of laypeople’s acceptance.

**Table 3.** Definitions and sample statistics of variables.

Variables	Definitions	Mean	Standard Deviation
Gender	Gender of the respondent (0 = male; 1 = female)	0.50	0.50
Age	Age of the respondent	40.38	9.78
Monthly household income	Monthly household income of the respondent (unit: 100,000 KRW)	40.65	14.69
Education	Educational level of the respondent (0 = Less than high school; 1 = More than university)	0.60	0.49
Type of alternative power source	Which power sources do you prefer as a substitute for electricity from the 7 NPPs scheduled to be built by 2035? (0 = fossil fuel; 1 = renewables)	0.90	0.30
Preferred method of payment	If you have to pay a certain amount of money for replacing nuclear power with other sources, which type of payment method would you prefer? (0 = additional electricity bills; 1 = a new type of taxation)	0.44	0.50
Perceived seriousness about climate change	As of now, the problem of climate change is serious. (From strongly disagree = 1 to strongly agree = 5)	4.37	0.66
Perceived level of knowledge about nuclear power	I know well enough what nuclear power is. (From strongly disagree = 1 to strongly agree = 5)	3.42	0.82

Looking again at the estimation results of Model 2 in Table 2, the influence of each covariate on WTP is confirmed. According to the results, respondents who prefer renewables to fossil fuels as a substitute for nuclear power, those who prefer additional electricity bills to a new type of taxation, and those who see the seriousness of climate change have a higher WTP for nuclear power reduction and replacement. The impact of substituting power sources on WTP implies that when the Korean government pursues its energy transformation policy, there should be social consensus on the type of energy source that will replace the reduced amount of nuclear power. Therefore, potential opposition due to increases in the electricity bill can be partly relieved by replacing the reduced share of nuclear power with renewable energy sources. Specifically, the overall direction of the Korean government's energy transformation policy is appropriate from the perspective of social acceptance, as it plans to reduce the share of nuclear and coal-fired power and increase it with renewable electricity. Further, in the case of the payment method, the imposition of new taxes is not a good choice as it would not only entail social costs but also lowers the acceptance level. The payment vehicle has been an important issue in CV studies, as it offers the context for payment [42,43]. It seems that respondents prefer a familiar method of payment. This is partly because the use of levies on taxes is less common in countries other than the US [44]. In Table 2, it is interesting that respondents recognizing the seriousness of the climate change problem had higher WTP for nuclear power reduction because nuclear power has a low GHG emission intensity and is considered a good alternative to cope with climate change [45–47]. This result seemingly stems from the fact that people who are more cognizant of climate change have a higher preference for renewables over nuclear power. Unlike the aforementioned covariates, it is found that gender, age, income, education, and the knowledge level of a respondent do not make any statistical differences in WTP. This suggests that the Korean government does not have to focus on demographic factors when formulating publicity strategies for coping with possible social opposition to increases in electricity bills.

Finally, the monthly mean WTP for replacing nuclear power is calculated from Model 1, which is statistically significant at 1% level. On average, a Korean household is willing to pay an additional KRW 1922.45/month (USD 1.80/month) for replacing the seven 1-GW NPPs (52,122 GWh/year of electricity generation) with other energy sources (Table 4). This amount is about 3.5% of the monthly average electricity bill a family of four in South Korea pays (KRW 55,000; 350 kWh usages). According to the Korean government, electricity bills are expected to increase 1.3% by 2022 and 10.9% by 2030 [6]. Although several other factors such as general price level and rate of increase in wage growth should be considered, the social acceptance level fluctuates with time and different socio-economic events, and the possible increase in electricity bills from nuclear power reduction will not lead to problems in the short term but may provoke social resistance in the long term, based on the elicited WTP in this study.

**Table 4.** Willingness to pay estimates with 95% confidence interval.

Monthly Mean WTP per Household	Monthly Median WTP per Household	t-Value	95% Confidence Interval
KRW 1922.45 (USD 1.80)	KRW 1913.64 (USD 1.79)	10.52 ***	KRW 1639.23–2237.24 (USD 1.54–2.10)

Notes: The confidence intervals are computed by the use of Monte Carlo simulation method proposed by Krinsky and Robb [48] with 5000 replications; Figure 1 is the histogram of Monte Carlo simulation results; \*\*\* indicates statistical significance at the 1% level.

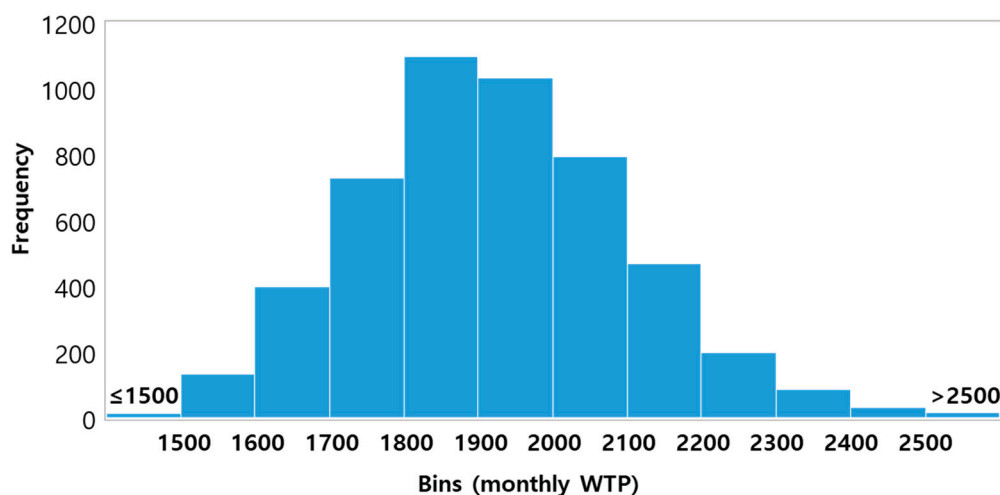


Figure 1. Histogram of Monte Carlo simulation results.

#### 4.3. Cost–Benefit Analysis: Financial Feasibility of Nuclear Power Plants Reduction

Although the mean WTP for reducing the number of NPPs is by itself important, the net social benefit at the national level may have greater significance to policy makers. Moreover, it is a major concern whether the replacement of nuclear power will be financially feasible or not. This section calculates the aggregated economic benefits of reducing NPP, and based on this, assesses the desirability and feasibility of replacing nuclear power with other energy sources.

The term ‘benefits’ used in this study means economic benefits which is the total economic value (TEV) of any change in wellbeing due to a policy or project. The net sum of all the relevant WTPs defines such TEV [33]. The economic valuation techniques that are mainly used in economics include revealed preference, stated preference, and benefit transfer, and CVM used in this study is one of the representative stated preference methods. Based on the theories of welfare economics, many previous energy-related studies adopted the method of calculating the aggregate benefits of a policy or project by estimating and aggregating the individual WTP [26,49–51].

Once the conditions of representativeness of the sample frame and a high response rate of the survey are met, the mean WTP can be aggregated into an economic benefit [31]. Further, the survey in this study meets these two conditions. If these conditions are met, the aggregation process is simple; the aggregated benefit is calculated by multiplying mean WTP by the total number of Korean households [33]. Nationwide, the total number of Korean households was 21.63 million in 2017 [52], so that the annual total economic benefit of reducing the seven 1-GW NPPs in Korea (52,122 GWh/year of electricity generation) is approximately KRW 498.99 billion (USD 467.40 million) (Table 5). Converting the units, this amount corresponds to KRW 71.28 billion/GW (USD 66.77 million), and KRW 9.57 million/GWh (USD 8.97 thousand/GWh) (=KRW 9.57/kWh).

Table 5. Annual economic benefit by substituting nuclear power in Korea.

Annual Mean WTP per Household	Number of Households (2017)	Annual Economic Benefit by Substituting Nuclear Power in Korea
KRW 23,069.42 (USD 21.61)	21.63 million	KRW 498.99 billion (USD 467.40 million)

As the unit cost of electricity from nuclear power is lower than that from other energy sources, there is a strong possibility of increase in total generation costs when replacing nuclear power with other sources in a fixed amount of domestic electricity demand. As described in Section 2.1, as the new Korean government plans to replace nuclear power with LNG and renewables, it is necessary to conduct an ex-ante evaluation of the costs and benefits from such a policy. This study uses the

unit price of settlement (UPS) to evaluate the Korean government's energy transformation policy from the public's perspective. If the electricity purchase cost of Korea Electric Power Corporation (KEPCO) is increased because of replacing the NPPs with other energy sources, the increased cost of KEPCO can be transferred to consumers. Moreover, since the UPS has been stable for a long time, we assume that the UPS will not be changed much in the future. In 2016, South Korea's UPS for electricity from nuclear, renewables, and LNG was KRW 67.91/kWh (USD 0.0636/kWh), KRW 102.26/kWh (USD 0.0958/kWh), and KRW 100.13/kWh (USD 0.0938/kWh), respectively [53]. In other words, the replacement of nuclear power with electricity from renewables or LNG costs KRW 34.35/kWh (USD 0.0322/kWh) or KRW 32.22/kWh (USD 0.0302/kWh), respectively. As the annual total economic benefit is KRW 9.57/kWh (USD 0.0090/kWh), the cost of replacing nuclear power with renewables or LNG are larger than the benefits at the current level of acceptance. The benefits–costs of replacing nuclear power with renewables and LNG are thus KRW −24.78/kWh (USD 0.0232/kWh), and KRW −22.65/kWh (USD 0.0212/kWh), respectively. In order for the mean WTP to cover the additional cost of generation for reducing NPPs, the UPS of renewable and LNG electricity should be lowered to KRW 77.48/kWh (USD 0.0726/kWh) or people's mean WTP should be increased.

Next, we calculate how much it would cost the Korean government to replace 52,122 GWh of electricity—the amount of annual power expected to be generated by the seven 1-GW NPPs—with electricity from renewables or LNG. The cost–benefit analysis is also conducted based on the results (Table 6).

**Table 6.** Cost–benefit analysis for replacing nuclear power in Korea.

Amount of Replaced Nuclear Power Generation		Aggregated Benefit	Replacement with Renewables		Replacement with LNG	
			Additional Cost	Net Benefit (B–C)	Additional Cost	Net Benefit (B–C)
Seven 1-GW NPPs	52,122 Gwh	KRW 498.99 billion (USD 467.40 million)	KRW 1790.39 billion (USD 1.68 billion)	KRW −1291.40 billion (USD 1.21 billion)	KRW 1679.37 billion (USD 1.57 billion)	KRW −1180.38 billion (USD 1.11 billion)

If the Korean government cancels the construction of the seven NPPs and replaces them with other energy sources, it will lead to KRW 498.99 billion (USD 467.40 million) of social benefits, which is calculated from the mean WTP of Korean households. On the other hand, if the corresponding amount of nuclear power generation is replaced with renewables or LNG, an additional cost of KRW 1790.39 (USD 1.68) or KRW 1679.37 (USD 1.57) will be required, which is calculated from the differences in UPS. Therefore, the annual cost of such replacement is KRW 1291.40 billion (USD 1.21 billion), or KRW 1180.38 billion (USD 1.11 billion) larger than its benefit. These amounts are about 3% of the total annual cost of electricity generation in South Korea, which is about KRW 42 trillion (USD 39.34 billion). Therefore, as the cost of replacing seven 1-GW nuclear power plants are larger than its benefits, moderate levels of social resistance are expected if all the additional costs are passed on to the end-users.

## 5. Conclusions

This study analyzed the social acceptance of canceling the scheduled construction of seven NPPs and using alternative energy sources for power supply and evaluated the financial viability of such planning. This study also examined the feasibility of the Korean government's energy transformation plan and suggested a methodological framework, which is applicable to other energy markets. The CVM with DBDC spike model is used to elicit respondents' mean WTP.

The results showed that an average Korean household was willing to pay additional KRW 1922.45/month (USD 1.80/month) for replacing the seven 1-GW NPPs with other energy sources,

which is about 3.5% of the current electricity bill. As noted in Section 3.2, this is the respondents' mean WTP when the seven NPPs are replaced either by fossil fuels or renewables depending on the respondent's stated choice. According to Table 3, however, most respondents preferred renewables to fossil fuels as substitutes for nuclear power. Therefore, the reported mean WTP can be interpreted as a similar amount to the South Koreans' mean WTP when NPPs are replaced with renewables. The estimation results of a model with covariates showed that respondents' experiential and psychological factors are more important than demographic factors in explaining their WTP. The annual total economic benefit of nuclear power replacement was approximately KRW 498.99 billion (USD 467.40 million). Cost–benefit analysis suggested that the annual costs of nuclear power replacement is KRW 1291.40 billion (USD 1.21 billion) or KRW 1180.38 billion (USD 1.11 billion) larger than the benefits, which is about 3% of the total annual electricity generation costs in South Korea. As additional costs of nuclear power replacement cannot be fully covered by the mean WTP of the current acceptance level, further efforts such as lowering the UPS of alternative energy sources and improving people's WTP for possible increase in electricity bills are desirable.

Several research limitations deserve to be noted. First, there is no choice but to mention the inherent limitations of the research methodology. The CVM uses stated preference data, which do not necessarily coincide with respondents' behavior in real-life situations due to their hypothetical nature [54]. The DBDC formats are also subject to some biases because of possible correlation between responses to the two bids. In this case, one-and-a-half bound DC can be an alternative [55]. Selection of the two initial bids in our DC CVM survey also needs to be addressed. The DBDC format has been proved to be sensitive to starting point bias [56]. We used a simple bid assignments approach based on its simplicity and lack of informational requirements. However, use of different method of bid set design [57–59] or a pre-testing can be considered as an alternative for a more elaborated initial bid set. Second, cost–benefit analysis is conducted in terms of suggesting an analytical framework and, thus, there is room for improvement by introducing additional cost–benefit factors and more elaborate assumptions. Specifically, we did not include elements other than direct generation costs; for example, a sunk cost of NPPs under construction, backward linkage effects of switching to other energy sources, and possible job creation, among others. Another factor to be mentioned is that the plan to reduce NPPs is only part of the Korean government's energy transformation policy (of course, reduction of nuclear power is at the core of the energy transformation policy in South Korea. Moreover, the situation in this study is similar to the Korean government's plan on reducing seven of the 1-GW nuclear power capacity from 27.5 GW in 2022 to 20.4 GW in 2030 [6]) and, thus, there will be additional causes for variation in electricity bills.

**Author Contributions:** All the authors played an important role in the study. J.W. outlined the methodology, developed the model, and revised the manuscript. S.L. took charge of making the survey questionnaire and gathering the data. Y.-G.L. investigated the current issues in energy markets and reviewed related literature. S.-Y.H. designed the study, interpreted the analysis results, and wrote the manuscript. All authors have read and approved the final manuscript.

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