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Original Article

The Cognitive and Economic Value of a Nuclear Power Plant in Korea

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ABSTRACT

We studied the value of a nuclear power plant by considering Koreans' willingness to pay (WTP) for neutralizing the various problems caused by building and operating a new plant. For this, we used a conjoint analysis and ordered logistic regression. We then compared the WTP estimates between various segment groups. The results revealed that each household was willing to pay an additional 99,677 Korean Won (KRW)/mo on average to resolve the negative impacts from a nuclear plant. Therefore, the yearly cognitive and economic value of a nuclear plant in Korea was about 19 trillion KRW. Through a segment analysis, we found that the more educated, younger, and poorer groups gave higher cognitive values than the less educated, older, and richer groups, respectively. Also, people who lived far from a plant gave higher values than people living near a plant, and people with more knowledge about or interest in nuclear energy gave higher values than people with less knowledge or interest. People who felt that nuclear energy is necessary gave higher values to nuclear energy than those who did not. Our results can be used as bases to set targets for promoting nuclear energy and pursuing a national project of building a nuclear power plant.

1. Introduction

The beginning of the 21st century has seen debates on future energies. Existing energy generation and fossil fuel use are the major sources of anthropogenic greenhouse gases being released into the Earth's atmosphere. This includes carbon dioxide emissions, which are the greatest contributor to global warming. In turn, a major source of carbon emissions is electricity generation. Electricity generation is mostly based on fossil fuels, and electricity generation from fossil fuels is responsible for roughly 40% of all carbon dioxide emissions. Long-term strategies for mitigating global warming will soon necessitate alternative energies.

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The world has also been concerned about the increasing carbon dioxide emissions. The United Nations [1] noted that climate change is one of the greatest challenges of our time and its adverse impacts undermine the ability of all countries to achieve sustainable development. The United Nations has thus presented policies for mitigating the global annual emissions of greenhouse gases by 2020.

Another important issue related to climate change in Korea at present is fine particular matter, or so called fine dust problems. Fine particulate matters penetrate through the bronchial tubes directly into the alveoli, into the bloodstream, and deep into the body, causing cardiovascular disorders. It is widely believed that one of the most important causes of fine particular matters in Korea is air pollution coming from China. However, we are not able to neglect pollution from local thermoelectric power plants. These plants are using carbon power resources.

To alleviate the threats of climate change and cope with the increasing demand for energy, low-carbon power is needed as the major supply to meet the country's future electricity needs [2]. Nuclear power has been highlighted because of its distinct economic and environmental advantages over other energy resources [3]. Therefore, nuclear power can be considered a promising alternative that can achieve both a stable energy supply and mitigation of climate change.

There are two types of low-carbon power generation sources: renewable energy and nuclear power [4]. Each has advantages and disadvantages as alternatives to fossil fuels. Although it has a controversial reputation, nuclear power is efficient and reliable [5]. It helps to reduce environmental degradation due to electricity-generation activities. For example, carbon dioxide emissions from nuclear power are much lower than those from fossil fuel power. Nuclear power is cheap, can be steadily supplied, and may have lower external costs [6]. Producing more nuclear power implies less dependency on foreign energy sources and a relatively sustainable supply, thereby reducing prices and increasing physical availability to ensure future energy security. Therefore, nuclear power is expected to be a promising alternative energy source in view of global warming and unstable energy supply, especially in South Korea. However, nuclear power entails risks, such as the environmental impact of radioactive waste, and damage to human health in the event of a catastrophe.

Renewable energy, as the other main alternative energy source, includes generation from natural resources such as solar heat, geothermal heat, and so on [7]. The main advantage of renewable energy is that it does not contaminate the environment and can be reused almost unlimitedly. Therefore, renewable energy, with its consistent availability and nonpollution, will be an effective and clean alternative energy in the future development of the world. For these reasons, renewable energy technologies are sometimes regarded as substitutes. However, in the technology field, renewable energy needs a particular solution to transform natural resources into useful energy forms and store the energy, but the current technologies have many limitations [8,9]. Also, economic feasibilities are considered the issues for the development of renewable energy [10]. Reddy and Painuly [11] noted that only a few renewable energy technologies, such as solar water heating and small-scale biomass power generation, can compete with conventional energy sources due to the generation cost.

People are worried about nuclear safety and risk of environmental destruction, especially after the Fukushima accident in March 2011. From the second half of the 2000s until this accident, nuclear power had been gaining popularity due to increasing concerns over global warming as a result of fossil fuel use [12]. However, this accident raised concerns regarding the trade-offs involved in replacing fossil fuels with nuclear power to meet climate change goals. In particular, people are troubled by the trade-off between the risks of nuclear power generation and the increased retail cost of other electricity sources [13,14]. Although the downside of nuclear power cannot be overlooked, it has an important role to play in slowing the pace of global warming without increasing costs. Thus, an important issue is the perceived danger of nuclear power and how people valuate it.

Judging the value and risk of nuclear power has two dimensions. First, the professional knowledge of specialists is important because understanding nuclear power requires various kinds of advanced knowledge. Second, the public's opinions and preferences are also important [15–17] because the public is subject to the risks that accompany any energy source [18]. Therefore, public opinions about an energy source cannot be ignored. Yet, relatively little is known about these social valuations [19], which crucially affect social acceptance management [18]. Empirical studies addressing the social acceptance of nuclear power have mostly been conducted from sociological perspectives or through comparisons among countries. Studies quantitatively evaluating the cognitive value of public perceptions of nuclear power, meanwhile, have been scarce. Hence, in the present work, we focused on estimating people's willingness to pay (WTP) to avoid building a nuclear power plant nearby, and evaluating public perceptions of nuclear power.

Concretely, this study aimed to evaluate the cognitive value of nuclear power in view of its social acceptance, in order to contribute to effective application of nuclear power policy. For this, we estimated the WTP for a nuclear power plant using the conjoint analysis method, considering three determinant factors (economy, safety, and environment). These determinant factors are important in understanding WTP for nuclear power [20–27]. Also, we aimed to suggest policy directions to promote the use of nuclear power by confirming the changes among various segment groups (demographic group, geographic proximity groups, and groups with different levels of knowledge and interest regarding nuclear energy).

Most related previous studies, except for that of Roe et al [22], have focused on the WTP for renewable energy. In the present work, we report WTP based on a consumer questionnaire survey and a statistical analysis. Nuclear power is a nonmarket commodity, the value of which cannot be directly determined by a market price. In this kind of case, the WTP can reflect public acceptance of a nonmarket commodity, because people are asked to valuate that product. We estimated the public cognitive value of nuclear energy, by measuring the WTP to reverse the negative consequences arising from the additional construction of nuclear power plants. Therefore, we can state that our study has originality in that we measure the monetary value of nuclear energy by connecting WTP and social acceptance of nuclear energy.

Also, we suggest some policy recommendations focusing on improvements to information transparency and public involvement, both of which help to lessen public resistance and promote the acceptance of nuclear power [28]. This study could be used by researchers, as well as policymakers, to promote the development of nuclear power in South Korea. The remainder of this study is organized as follows. Section 2 presents the results of a literature review. Section 3 describes the conjoint analysis method model used and the survey data collected. Section 4 presents the analysis results. Section 5 provides the main findings and conclusions.

2. Literature review

2.1. *Features of nuclear power*

Public concern regarding nuclear power began with the rise of the environmental protection movement in the 1970s. The Three Mile Island accident in 1979 and the Chernobyl nuclear catastrophe in 1986 caused social acceptance of nuclear power to fall to a very low level [17]. However, the importance of nuclear power was restored in the 2000s owing to global warming concerns and increases in oil prices [29]. Nuclear power is cheap, can be steadily supplied, and has low carbon dioxide emissions, thus having lower external costs [6]. Producing more nuclear power implies less dependency on foreign energy resources and fossil fuels, thereby reducing prices and increasing physical availability to ensure future energy security. However, nuclear power also generates nuclear waste [6,30] and entails accident risks [6,31,32]. The drawbacks of nuclear power include local and environmental opposition due to radioactive nuclear waste; the risks of nuclear weapons proliferation, terrorism, and serious nuclear accidents; the impacts of uranium mining; and the high costs of financing nuclear projects [33].

2.2. *Public acceptance of nuclear power*

There have been some studies on the public acceptance of nuclear power [34–37]. Bronfman et al [34] validated a causal trust-acceptability model for electricity generation and showed that social acceptance of an energy resource was directly related to perceived risk and social trust in regulatory agencies. Kidd [35] found that public acceptance was partly responsible for the underlying cost problem observable in the Western world. Richardson et al [36] discussed the safety-related issues associated with nuclear power and indicated how this had led to progress following accidents that had eroded public confidence. Song et al [37] indicated that perceived efficacy was most strongly related to social acceptance of nuclear power by examining the effects of perceived efficacy, perceived risk, communication quality, and trust on social acceptance of nuclear power in South Korea.

2.3. *Determinant factors of nuclear energy usage*

There have been studies on the various factors that affect energy usage decisions. Bae [38] listed six factors: environment pollution, regional economy, economic resources, environment friendliness, landscape change, and electricity supply and demand. The Korean Ministry of Knowledge Economy [39] discussed seven factors: safety, environment pollution, regional economy, asset value, environmental friendliness, diplomatic conflict, and electricity supply and demand. In addition, ethicality was put forward by Huh [40]. Before estimating the value of nuclear power, we conducted a pretest to find the determinant factors that most influence the usage of nuclear power. We were able to narrow these down to three factors in the present study: regional economy, safety, and environment. Because these factors were used to estimate the cognitive value of nuclear power in the present study, in this section we summarize the previous literature on each of these factors.

2.3.1. *Regional economy*

Nuclear power is hugely expensive to build, but very cheap to run; yet the economic efficiencies of nuclear power still look uncertain [41]. There have been many studies on the economics of nuclear power. Kazimi and Todreas [42] mentioned that the economics of existing nuclear power plants worldwide have been improved through increases in the efficiency of nuclear fuel use. Hewlett [43] examined the factors causing the escalation of operating and maintenance cost in a nuclear power plant in the 1980s and the subsequent leveling off of nonfuel operating and maintenance costs, finding that the escalation in costs was primarily due to increased regulatory activity by the Nuclear Regulatory Commission. Afanas'ev et al [44] reported on the economic efficiency of nuclear power plants by evaluating the generation cost compared to conventional technologies such as steam turbines. Mitenkov et al [45] examined the possibility of decreasing the capital cost of building a nuclear power plant by unifying the equipment and technological processes.

By contrast, previous researchers also tried to explain the factors that affect residents' attitudes toward nuclear power plants in terms of incentives to the local economy [46]. Nuclear-related facilities generate greater risks to local residents than to distant residents. Thus, it is possible that a group of local residents will oppose the construction of nuclear-related facilities much more strongly than the majority of beneficiaries who are willing to support it [47]. Therefore, the nation has to consider the group of people who reside especially near the hazardous facilities. For example, since the 1980s, the South Korean government made substantial efforts to find a site for a radioactive waste disposal facility. Those efforts failed, primarily because of protests by local residents concerned with the impacts of a waste disposal plant on the regional economy. Many countries use subsidies to compensate local residents [17]. Thanks to these subsidies and incentives, the development of nuclear-related facilities in rural areas may create job opportunities, thereby minimizing migration to urban areas [48]. It can also increase the availability of schools, senior residences, and other key public services. The development of nuclear-related facilities in rural areas can also generate extra income for landowners, and can be integrated with specific production processes [49].

2.3.2. *Safety*

From the layman's perspective, nuclear power is still a controversial energy source with many risky characteristics such as safety issues. After the Fukushima nuclear accident, the worst nuclear accident since Chernobyl, people began to seriously think about these issues. Many countries, including Japan, Germany, and Switzerland, decided to slow or even completely cease nuclear plant construction [50].

There have been some studies on the relationship between social acceptance and nuclear safety. Based on a survey and statistical analysis, Bennett [51] showed that the US has developed the safety review process over the past 30 years. Liu et al [52] established an assessment system consisting of five indices to quantify public acceptance of nuclear power. Lee and Harrison [53] studied the main attitudes and behaviors of working staff and the role of safety in three nuclear stations. Rumyantsev [54] proposed a method for predicting the safety of nuclear power; to increase the reliability of the safety predictions, he used quantile estimates of uncertainties. Chen et al [55] investigated the public acceptance of nuclear power in China, finding that people knew little about nuclear power or even misunderstood nuclear power safety. Li and Lin [2] reported on the history and current situation of nuclear safety goals.

2.3.3. *Environment*

Electricity generation is mostly based on fossil fuels, and fossil fuel electric generation is responsible for roughly 40% of all carbon dioxide emissions from human activity. Therefore, considerable reduction of carbon dioxide emissions can be achieved by changing a substantial fraction of electricity generating capacity from fossil fuels to environmentally friendly energy resources. Consequently, nuclear power has been emphasized due to its distinct economic and environmental advantages over other energy resources, including nonhydroelectric renewables [3]. In the near future, nuclear power is expected to be accepted as one of the most promising alternatives to both achieve a stable energy supply and mitigate climate change.

Economic growth based on the use of energy has the potential to cause environmental degradation [56]. There have been many studies regarding the relationship between economic growth and environmental pollution. Grossman and Krueger [57] and Selden and Song [58] found that economic growth causes environmental degradation. The results of Groothuis et al [47] contradicted the conventional view, finding that individuals have interests in the environment and are willing to pay for clean energy. Rashad and Hammad [59] presented a comparative assessment of the environmental and health impacts of nuclear power and other energy sources. They found that when comparing nuclear power with other energy sources for electricity generation, nuclear power can reduce the releases of environmental pollutants, because carbon dioxide emissions from a nuclear plant are much lower than those from other energy sources.

2.4. *Value measurement of nuclear power*

2.4.1. *WTP*

Nuclear power is a nonmarket commodity, and its value cannot be directly determined by a market price. WTP can be used to measure the value of this kind of nonmarket commodity. WTP can reflect public acceptance when people are asked to valuate a public or environmental product. It is widely used with social goods. Therefore, in this study, we used the WTP to measure the monetary value of what people are willing to pay to reverse the negative consequences arising from the additional construction of nuclear power plants.

A number of studies have included WTP analyses of electricity generation sources, including fossil-fuel, nuclear power, and renewable energy. Residents' WTP varied according to socioeconomic characteristics and environmental awareness [13,14]. Kato et al [46] reported that residents' attitudes depend on perceived benefits (or compensations) and perceived damage from nuclear power plant construction. Other studies explained changes in residents' safety perceptions of nuclear power plants in terms of public sector knowledge and information [60], and in terms of risk perception and emotional fear [61,62]. Roe et al [22] were the first to evaluate WTP for green electricity using a choice experimental design that included a mix of fuels. They found that greater WTP for emissions reduction stems from increased reliance on renewable resources, and lower WTP for emissions reduction stems from a reliance on nuclear power. Jun et al [17] noted that people in a country with a high level of support for nuclear power, and in which precise information about nuclear power was available, demonstrated a high WTP for nuclear power production. Although WTP for nuclear power was investigated in some previous studies, they differ from the present study in that they did not analyze the WTP of the determinant factors in detail. For example, analysis by Bae [38] of the WTP with six factors was only on wind power generation instead of nuclear energy. Huh [40] also mentioned the ethicality as a determinant factor that has to be considered as the social cost of nuclear energy generation. However, he did not conduct any statistical analysis for the value of nuclear energy by using this factor. Contrarily, we estimated not only the cognitive value of each factor, marginal WTP (MWTP), but also the total WTP. By using the total WTP, we can interpret the representative cognitive value of nuclear energy.

2.4.2. *Conjoint analysis*

Conjoint analysis, as suggested by Louviere [63], is a survey-research methodology used especially in the marketing literature to estimate the consumer's preference of multi-attribute commodities [64–67]. First, it was mainly used for estimating the value of commodities [63,68]. However, since the early 1970s, conjoint analysis has received considerable interest in both academy and industry as a method for measuring the value of nonmarket commodities [65,69,70]. This is because conjoint analysis allows researchers to consider synthetically the relationship of conflict between respondents' WTP and multiple attributes of the object by determining the WTP for various combinations of the attributes [71,72]. In particular, when the value of nonmarket commodities, such as nuclear and renewable energy plants, is analyzed, researchers have to consider various attributes, such as wildlife habitats, the residents' resistance due to safety concerns, and environmental change. By contrast, conjoint analysis can be categorized into the contingent choice method, contingent ranking method, and contingent rating method depending on the elicitation method used [73]. In this study, we employed the contingent ranking method. We suggested alternatives, each including attributes of safety, environment, regional economy, and WTP to respondents, and then had each respondent select a preference ranking from the most to least preferred alternative. Also, we followed the six steps generally conducted in conjoint analysis, as follows. In the first step, the researchers determine the research target, such as a public good. In the second step, the researchers conduct a comprehensive literature research to select attributes and payment methods that are measurable and easy for the respondents to understand, and then decide the level of each attribute. In the third step, researchers establish an experimental plan including a minimum of alternatives to select from, thereby allowing estimation of the full set of alternatives decided upon in the second step. In the fourth step, researchers design and write the questionnaire. In the fifth step, researchers collect meaningful data from the respondents through an on-site survey conducted in person. Lastly, the researchers interpret the results and draw conclusions through analysis of the collected data [67].

3. Data and measurements

Before estimating the value of nuclear power, we conducted a pretest to find the factors that most influence the use of nuclear power. As mentioned in Section 2, we extracted all kinds of possible factors based on the previous research. However, it was not possible to use all these factors. Thus, through the pretest, we tried to determine the most important factors to narrow the factors under consideration. The pretest included a survey of 81 total participants. We prompted participants to evaluate the importance of each factor by using a Likert-type scale ranging from 1 to 7. Through this pretest, we were able to find the factors that people consider most important in the choice of nuclear power. Eventually, we decided on three determinant factors (safety, regional economy, and environment) to consider in estimating the value of nuclear power.

3.1. *Data collection*

Table 1 lists the attributes considered in the conjoint analysis and their levels. The three determinant attributes (regional economy, safety, and environment) each had two levels: "same" and "degeneration". Here, "same" means that the attribute level is unchanged by the construction of an additional nuclear power plant, whereas "degeneration" means that the attribute level is deteriorated compared to the state prior to the construction of the additional plant. The WTP levels used came from the pretest: 20,000 Korean Won (KRW), 40,000 KRW, 60,000 KRW, and 80,000 KRW. Thus, a total of 32 ($2 \times 2 \times 2 \times 4$) alternative scenarios were possible. However, it is unrealistic to ask participants to rank all alternatives at once. Instead, we extracted the minimum of nine alternative sets from the total 32 alternatives by using "Orthogonal Design" in the SPSS software package version 21 (SPSS Inc., Chicago, IL, USA). This orthogonal design addresses the weakness of the revealed preference random utility model by isolating high correlations of individual choice attributes [74]. From the participants' point of view, even though the number of alternatives is reduced, ranking these nine alternatives might be still confusing. Therefore, we divided them into three question blocks, each consisting of three alternatives, and then collected the preference order from each block.

Table 1 – Attributes included in the conjoint analysis.

Attributes	Level	Description
Regional economy	Same (1) Degeneration (0)	Impact on the regional economy due to the construction of an additional nuclear power plant
Safety	Same (1) Degeneration (0)	Impact on the safety due to the construction of an additional nuclear power plant
Environment	Same (1) Degeneration (0)	Impact on the environment due to the construction of an additional nuclear power plant
WTP (KRW)	20,000, 40,000, 60,000, 80,000	Recovery costs we suggest in the survey

KRW, Korean Won; WTP, willingness to pay.

Table 2 shows one of three survey question blocks as an example. Each participant was asked to rank the three alternatives in the order of his or her preference.

Our survey was conducted online in March 2015 and received 1,550 responses. After excluding responses that were unreasonable or inconsistent, our final dataset consisted of 1,417 responses. We tried to solicit respondents evenly in terms of age, gender, and education level to reflect the actual population of South Korea; Table 3 lists the respondent distributions in these categories. The respondents represented the actual population distribution fairly well in terms of gender and age. We targeted adult respondents who were willing to pay additional tax for restoring the worsening conditions due to an additional nuclear power plant. Because our survey required a high level of participation and comprehension by the respondents, we used a specialized research survey company, Macromill Embrain, Seoul, South Korea. Thus, because our survey was conducted by a professional research company with a reliable respondent pool, the possibility of sample bias was reduced.

3.2. *Measurement*

For the conjoint analysis, we set up the utility function and then made a model used as a random utility framework. Through this process, we could estimate the WTP of each attribute. In this study, if we assumed that respondent i's utility function has a linear relationship with the individual or social characteristics related to the construction of nuclear

Table 2 – Example survey question block.

Question block 1.

Nuclear power has the advantages of high economy and low emission of carbon dioxide. Please assume that the construction of an additional nuclear power plant is needed due to increasing demand for electricity. However, there may be public concern about this nuclear power plan, such as negative impact on the regional economy, environmental contamination, and safety compared to other energy resources. To resolve these problems, the government is collecting additional monthly taxes and restoring the situations to their original states.
Now, we present the following list of alternatives. Please rank them in order of your preference.

Alternative card 1.
The construction of the additional nuclear power plant has the following impacts:
- Safety: same as before construction
- Regional economy: worse than before construction
- Environment: same as before construction
If you pay 80,000 KRW, the above impacts can be restored to the state that would exist if no additional nuclear power plant had been constructed.

Alternative card 2.
The construction of the additional nuclear power plant has the following impacts:
- Safety: same as before construction
- Regional economy: worse than before construction
- Environment: worse than before construction
If you pay 60,000 KRW, the above impacts can be restored to the state that would exist if no additional nuclear power plant had been constructed.

Alternative card 3.
The construction of the additional nuclear power plant has the following impacts:
- Safety: worse than before construction
- Regional economy: worse than before construction
- Environment: worse than before construction
If you pay 20,000 KRW, the above impacts can be restored to the state that would exist if no additional nuclear power plant had been constructed.

KRW, Korean Won.

Table 3 – Respondent distribution.

Classification		Frequency (N = 1,417)	Ratio (%)
Gender	Male	695	49
	Female	722	51
Age (yr)	20–29	311	21.9
	30–49	678	47.8
	≥ 50	428	30.3
Education	High school graduate	233	16.4
	College graduate or beyond	1,184	83.6

power plants, we can express respondent i's random utility model as follows:

$$U_{ij} = V_{ij} + e_{ij} = \beta x_{ij} + e_{ij} \tag{1}$$

Here, U_{ij} is respondent i's utility of choosing alternative j; V_{ij} is the function expressing each respondent's characteristic on the attribute of alternative, which is a deterministic variable part extracted from the survey; and e_{ij} is a random element. As mentioned above, we employed the contingent ranking method to estimate the respondents' WTP.

In the contingent ranking method, if respondent i preferred r_1 card, r_2 card, and …… r_J card in preference order of the alternative set C_i, U_{i1}, which means the respondent's utility, is always $U_{i1} > U_{ik}$ for all r_k cards excluding the r_1 card. If we assume that e_{ij} follows the Type I extreme value distribution [75], we can express the probability that respondent i selects card r_1 from the total of J alternative cards as follows.

$$\Pr(r_1|C_i) = \Pr\{V_{i1} + e_{i1} > V_{ik} + e_{ik}\} = \Pr\{V_{i1} - V_{ik} > e_{ik} - e_{i1}\} = \frac{\exp(V_{i1})}{\sum_{k=1}^{J}\exp(V_{ik})} \tag{2}$$

Similarly, we can express the probability that respondent i selects card r_2 from the remaining J−1 cards as follows:

$$\Pr(r_2|C_i) = \Pr\{V_{i2} + e_{i2} > V_{ik} + e_{ik}\} = \Pr\{V_{i2} - V_{ik} > e_{ik} - e_{i2}\} = \frac{\exp(V_{i2})}{\sum_{k=2}^{J}\exp(V_{ik})} \tag{3}$$

By repeating this process, we arrive at the following equation:

$$\frac{\exp(V_{i1})}{\sum_{k=1}^{J}\exp(V_{ik})}, \frac{\exp(V_{i2})}{\sum_{k=2}^{J}\exp(V_{ik})}, \frac{\exp(V_{i3})}{\sum_{k=3}^{J}\exp(V_{ik})}, \cdots \frac{\exp(V_{iJ-1})}{\sum_{k=J-1}^{J}\exp(V_{ik})} \tag{4}$$

For building up the generalization, we set R_{ij} to express the preference order that respondent i gives to the j-th card, and also set variable β_{ijk} to be 1 if $R_{ik} \geq R_{ij}$ and 0 otherwise. In this case, we can express the occurrence probability L_i of respondent i's selection order as follows:

$$L_i = \prod_{j=1}^{J}\left[\frac{\exp(V_{ij})}{\sum_{k=1}^{J}\beta_{ijk}\exp(V_{ik})}\right] \tag{5}$$

Therefore, the likelihood function can be expressed as follows:

$$L = \prod_{i=1}^{N}\prod_{j=1}^{J}\left[\frac{\exp(V_{ij})}{\sum_{k=1}^{J}\beta_{ijk}\exp(V_{ik})}\right] \tag{6}$$

We can obtain estimators of parameters by adapting the maximum likelihood estimation to Eq. (6) [76,77]. By contrast, we can standardize V_{ij} , which is the observable variable in the indirect utility function Eq. (1), as follows:

$$V_{ij} = \beta_1 z_{1,ij} + \beta_2 z_{2,ij} + \beta_3 z_{3,ij} + \beta_4 z_{p,ij} \tag{7}$$

Here, z_1, z_2, z_3 are attribute vectors, z_p is the price attribute vector, and β is the estimator of the parameter that has to be estimated. Now we can estimate the marginal WTP (MWTP) for each attribute by adapting Roy's identity as follows:

$$\begin{aligned} MWTP_{z_1} &= \frac{dZ_1}{dZ_p} = -\frac{\beta_1}{\beta_4} \\ MWTP_{z_2} &= \frac{dZ_2}{dZ_p} = -\frac{\beta_2}{\beta_4} \\ MWTP_{z_3} &= \frac{dZ_3}{dZ_p} = -\frac{\beta_3}{\beta_4} \end{aligned} \tag{8}$$

Table 4 – Results from the total sample.

	Safety	Regional economy	Environment	Cost
Coefficient	0.365*** (0.033)	−0.197*** (0.033)	0.171*** (0.033)	−0.000003401*** (0.000001)
MWTP (KRW)	107,321	−57,924	50,279	–
WTP (KRW)	99,677			
N	1,417			
Log-likelihood	4,246.123			

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.001$.
KRW, Korean Won; MWTP, marginal willingness to pay; WTP, willingness to pay.

4. Results and discussion

4.1. *WTP from the total sample*

Table 4 lists the results of the determinant attributes for the total sample. Here, all coefficients were estimated using Eq. (7), and each coefficient expresses the magnitude of the respondents' utility assignment to each aspect of nuclear power. The Log-likelihood value was 4,246.123, which is sufficiently high. Also, we could obtain a partial value by adopting the coefficients of Eq. (8). As a result, in Table 4 we present a partial value (MWTP) and a total value (WTP) estimated by summing all the MWTPs. The total WTP value was taken to be the cognitive value of the additional nuclear power plant.

The regional economy coefficient (−0.197) was negative, whereas those for safety (0.365) and environment (0.171) were positive, expressing the negative impact on surrounding areas due to the additional construction of nuclear power plants. These coefficients can be interpreted as follows. When there was no negative impact from nuclear power plant construction on safety or the environment, the respondents assigned higher utility levels. Also, the desire to recover safety was greater than that to recover regional economy or environment, comparing the relative magnitude of the coefficients among the attributes. By contrast, respondents did not choose “same regional economy” over “degenerated regional economy”, which is a puzzling result. In the case of cost, it had a negative coefficient as expected. This means that the lower the recovery costs for constructing an additional nuclear power plant, the higher the respondents' utility levels were. In this study, we estimated the respondents' WTP from the partial value (MWTP) of each attribution. As shown in Table 4, the partial value for safety was 107,321 KRW, that for regional economy was −57,924 KRW, and that for environment was 50,279 KRW. By summing these three MWTPs, we determined that the respondents were willing to pay 99,677 KRW monthly as an expense to restore the negative effects due to the construction of the additional nuclear power plant. Although the respondents had to pay the additional tax to restore the damage, they were willing to bear this tax to use the nuclear power. Therefore, the WTP was considered to be the respondents' cognitive value for nuclear power. If we divide 99,677 KRW by 3.18, which is the average number of people in each household in South Korea, we can calculate the monthly WTP per person. Then, considering the population of South Korea is 50 million, the total annual cognitive value of a nuclear power becomes approximately 19 trillion KRW (99,677/3.18 × 50 million × 12 months).

From the result of the total sample, we can say that an average Korean is willing to pay 99,677 KRW. This WTP value indicates the acceptance level of nuclear energy for Koreans. Now, we are to divide the total sample into various segments, because different groups may have different values about nuclear energy. Through analyzing for these differences, we wish to discuss ways to promote nuclear power generation later.

4.2. *WTP by segments*

4.2.1. *Demographic groups*

Having calculated the WTP of the total population, we estimated the cognitive values of a nuclear power plant among different population segments. First, we measured the WTP by different demographic groups; Table 5 shows the results for subpopulations of gender, education level, age, and household income.

Regarding gender, women's WTP (125,991 KRW) was higher than men's (84,756 KRW), and high-education respondents' WTP (103,804 KRW) was higher than the low-education respondents' (77,666 KRW). In addition, the 20s age group's WTP was 694,006 KRW, the 30s–40s age group's was 57,564 KRW, and the 50+ age group's was 2,337 KRW. The lower the respondents' age, the higher the WTP was. Lastly, the WTP of the respondents with low household income (191,000 KRW) was higher than that of the high household income group (62,200 KRW). In summary, we found that females, more educated people, younger people, and poorer people gave higher cognitive values than males, less educated people, older people, and richer people.

The results of the demographic analysis can be interpreted as follows. Highly educated people have greater chances of accessing professional knowledge about nuclear power. We can thus infer that they perceive higher cognitive value because they may not have excessive concern about nuclear energy and lower resistance to building new plants. In the case of age groups, people in the younger generation have just started their careers and may be poorer than the older generation, and thus they prefer lower electricity costs. Because nuclear energy would significantly reduce their electricity bill compared to other green energies, the younger generation and the poorer group have higher WTP for a nuclear power plant. When we consider these results together, we can say that males, less educated people, older people, and richer people should be the target for public campaign and for providing more information about nuclear power plants in order to

Table 5 – Results by different demographic groups.

Group	Classification		Safety	Regional economy	Environment	Cost	WTP (KRW)
Gender	Male ($N = 695$)	Coefficient	0.448***	−0.286***	0.216***	−0.00000446***	84,753
		MWTP (KRW)	110,448	−64,126	48,430	–	
		Log-likelihood		2,482.349			
	Female ($N = 722$)	Coefficient	0.285***	−0.111***	0.128***	−0.000002397***	125,991
		MWTP (KRW)	118,899	−46,308	53,400	–	
		Log-likelihood		1,718.496			
Education level	High school graduate ($N = 233$)	Coefficient	0.232**	−0.194**	0.147**	−0.000002382	77,666
		MWTP (KRW)	97,397	−81,444	61,713	–	
		Log-likelihood		722.479			
	College graduate or beyond ($N = 1,184$)	Coefficient	0.392***	−0.197***	0.176***	−0.000003599***	103,084
		MWTP (KRW)	108,919	−54,737	48,902	–	
		Log-likelihood		3,649.967			
Age (yr)	20–29 ($N = 311$)	Coefficient	0.827***	0.053	0.22***	−0.000001585	694,006
		MWTP (KRW)	521,767	33,438	138,801	–	
		Log-likelihood		1,327.634			
	30–49 ($N = 678$)	Coefficient	0.259***	−0.198***	0.154***	−0.000003735***	57,564
		MWTP (KRW)	69,344	−53,012	41,232	–	
		Log-likelihood		1,856.510			
	$\geq$ 50 ($N = 428$)	Coefficient	0.213***	−0.36***	0.157***	−0.000004279***	2,337
		MWTP (KRW)	49,778	−84,132	36,691	–	
		Log-likelihood		1,398.572			
Household income	Low ($N = 583$)	Coefficient	0.375***	−0.168***	0.175***	−0.000002***	191,000
		MWTP (KRW)	187,500	−84,000	87,500	–	
		Log-likelihood		1,633.472			
	High ($N = 834$)	Coefficient	0.359***	−0.217***	0.169***	−0.000005***	62,200
		MWTP (KRW)	71,800	−43,400	33,800	–	
		Log-likelihood		2,490.729			

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.001$.
KRW, Korean Won; MWTP, marginal willingness to pay; WTP, willingness to pay.

change the public cognitive value on nuclear energy. This can help lessen public resistance and promote the acceptance of nuclear power.

4.2.2. *Social groups*

4.2.2.1. *Geographical proximity*. The second type of segmentation analysis of WTP was based on social groups. Disputes regarding nuclear power plant construction have arisen from different social groups or individuals with specific personality traits, attitudes and preferences, and not least, cultural and geographic memberships [48]. In particular, the cause of the opposition group is mainly centered on the location of nuclear power plants, because nuclear-related facilities generally pose greater risks to local residents than to distant residents. Therefore, opposition from local residents who live near the nuclear facilities has been the major obstacle to the execution of nuclear policy. Generally, people oppose locating nuclear power plants in their neighborhood. To address this situation, many countries that use nuclear power have provided enormous subsidies to local governments. However, residents near nuclear power facilities are still worried about the potential danger from nuclear radiation. After all, people are willing to pay to avoid building a nuclear power plant nearby and prefer to choose other costly alternative power generation sources [78].

Table 6 shows the results of analyzing the subpopulations of respondents who live near to or far from a nuclear power plant. The WTP of respondents living near nuclear plants was 21,908 KRW, much lower than the WTP of those living elsewhere (123,762 KRW). Through these results, we inferred that people living in areas close to a nuclear power plant feel apprehension about their health, whereas people who live far from a plant feel relatively secure. This can be explained by prior studies indicating that a nuclear power plant might be responsible for health problems, such as thyroid cancer, experienced by residents nearby. In addition, recently, a court in South Korea adjudged the responsibility of nuclear power plants for residents' thyroid cancer due to long-term radiation exposure [41]. Considering these results, it is necessary for Korean governments to lower the resistance of local residents by paying appropriate compensations. At the same time, timely provision of enough and correct information about nuclear safety is also needed.

4.2.2.2. *Nuclear energy knowledge, interest, and necessity perception*. Antinuclear social atmospheres negatively affect nuclear policy and the nuclear development process [50]. Laymen in the field of nuclear energy tend to oppose it due to vague concerns about the safety of nuclear power. These concerns may come from ignorance and indifference about it. In particular, a lack of communication and information about nuclear power stimulates antinuclear activity. Jun et al. [17] found that the public preferred nuclear power when precise information was given to them. In other words, sufficient

Table 6 – Results by proximity segmentation.

Group Classification		Safety	Regional economy	Environment	Cost	WTP (KRW)
Near a plant	Coefficient	0.265***	−0.277***	0.136	−0.00000566***	21,908
($N = 200$)	MWTP (KRW)	46,820	−48,940	24,028	–	
	Log-likelihood		640.266			
Other residences	Coefficient	0.382***	−0.184***	0.177***	−0.00000303***	123,762
($N = 1,217$)	MWTP (KRW)	126,073	−60,726	58,416	–	
	Log-likelihood		3,709.765			

* $p < 0.1$,.
** $p < 0.05$.
*** $p < 0.001$.
KRW, Korean Won; MWTP, marginal willingness to pay; WTP, willingness to pay.

communication and information can reduce antinuclear attitudes. Countries where nuclear energy is well accepted are promoting policy transparency and effectively encouraging residents' participation in nuclear policy-making. These efforts could reduce public resistance to nuclear power and allow a steady pace of nuclear development [50].

We tried to measure respondents' nuclear knowledge and perception in three categories: nuclear knowledge level, interest level, and necessity perception. To segment the respondents into each category, we asked them the following questions. For nuclear knowledge level, we asked "Do you think you have enough knowledge about nuclear energy?" For nuclear interest level, we asked "Do you carefully and with interest follow topics related to nuclear energy through newspapers, TV, or other media?" For necessity perception, we asked "Do you think that nuclear power plants are necessities in our nation?" Table 7 lists the results of these segmentation analyses.

First, regarding the nuclear knowledge classifications, the WTP of respondents with greater knowledge was 249,875 KRW, much higher than the average WTP of all respondents (99,677 KRW). In other words, we can infer that more knowledgeable respondents gave higher cognitive value to a nuclear power plant than less knowledgeable respondents. This means that the more knowledge people have, the more they prefer nuclear energy. This result is consistent with that of the high-education group given in Table 5.

Second, regarding the nuclear interest classifications, the WTP of respondents with high interest in nuclear power was 117,965 KRW. This was higher than the average WTP of all respondents (99,677 KRW) and the WTP of the low interest group (20,925 KRW). We can infer that respondents with greater interest in nuclear power place higher cognitive value on nuclear power.

Third, regarding the nuclear necessity classification, the WTP of respondents who perceived that nuclear energy is necessary was 365,439 KRW, much higher than the average WTP of all respondents (99,677 KRW). These respondents place higher cognitive value on nuclear power.

Through the segment analyses, we found that respondents with more knowledge and more interest in nuclear energy had higher cognitive values on nuclear energy than opposite

Table 7 – Results by nuclear knowledge and perception segmentation.

Group	Classification		Safety	Regional economy	Environment	Cost	WTP
Nuclear knowledge level	Low	Coefficient	0.215***	−0.483***	0.145**	−0.000007524***	−16,348
	($N = 369$)	MWTP (KRW)	28,575	−64,195	19,272	–	
		Log-likelihood		1,399.473			
	High	Coefficient	0.417***	−0.098**	0.18***	−0.000001997**	249,875
	($N = 1,048$)	MWTP (KRW)	208,813	−49,074	90,135	–	
		Log-likelihood		2,978.031			
Nuclear interest level	Low	Coefficient	0.315***	−0.387***	0.181*	−0.000005209**	20,925
	($N = 179$)	MWTP (KRW)	60,472	−74,294	34,748	–	
		Log-likelihood		704.501			
	High	Coefficient	0.372***	−0.17***	0.169***	−0.000003145***	117,965
	($N = 1,238$)	MWTP (KRW)	118,283	−54,054	53,736	–	
		Log-likelihood		3,656.873			
Necessity of nuclear power	Unnecessary	Coefficient	−0.021	−0.263***	−0.041	−0.0000121***	−26,860
	($N = 297$)	MWTP (KRW)	−1,736	−21,736	−3,388	–	
		Log-likelihood		715.639			
	Necessary	Coefficient	0.468***	−0.177***	0.225***	−0.000001412	365,439
	($N = 1,120$)	MWTP (KRW)	331,445	−125,354	159,348	–	
		Log-likelihood		3,732.653			

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.001$.
KRW, Korean Won; MWTP, marginal willingness to pay; WTP, willingness to pay.

respondents. Therefore, we can say that the Korean government needs to educate people to increase public knowledge and interest about nuclear energy. At the same time, it seems to be necessary for the government to inform people of the current domestic energy situation.

5. Conclusion

Nuclear energy has significant advantages in terms of energy efficiency and eco-friendliness, which is why its use has been increasing continuously. At the same time, however, people have doubts about the safety of nuclear power due to nuclear accidents that have occurred in recent years. Therefore, we tried to measure the value of a nuclear power plant considering people's concerns.

The first purpose of this study was to estimate the cognitive value of a nuclear power plant, considering not only economic issues, but also cognitive issues about nuclear energy. Therefore, we looked for determinant factors that most affect people's perceptions of nuclear power. The value of a nuclear power plant was then measured by considering the values assigned to each determinant factor. The second purpose of this study was to find policy directions for encouraging nuclear power. After classifying survey respondents into various segments, we analyzed their differences in valuing a nuclear power plant.

After considering values for the determinant factors of safety, regional economy, and environment, we found that the total cognitive value of a nuclear power plant was 99,677 KRW monthly. The annual value of a nuclear power plant was thus approximately 19 trillion KRW (99,677/3.18 × 12 month × 50 million population).

Through a segment analysis by demographic groups, we found that the more educated, younger, and poorer groups gave higher cognitive values than the less educated, older, and richer groups, respectively. A segment analysis by social factors, such as geographical proximity and familiarity with nuclear energy, was also conducted. People who live far from a plant gave higher cognitive values than people who live near a plant; people with more interest in or knowledge about nuclear energy gave it higher values than people with less knowledge or interest. People who felt that nuclear energy was necessary gave higher values than those who did not.

We found that those who have higher cognitive values on nuclear energy are highly educated people and people with a high level of nuclear knowledge. In other words, if the public is well educated or informed with exact and timely information, they will better valuate nuclear energy. Therefore, to promote nuclear energy, it is important to make the public interested in nuclear energy and provide them with enough information in the current domestic energy situation.

Our results can be used as bases to set targets for promoting nuclear energy and pursuing a national project of building a nuclear power plant. These can be a useful guide to opinion leaders and policy makers in a sense that our results can reduce the scope of alternatives for promoting nuclear energy. For example, it would be easier to persuade females than males regarding the construction of a new nuclear power plant. Also, making people more knowledgeable and interested regarding nuclear energy might resolve many negative concerns. Efforts by government to communicate with people on issues related to nuclear energy would eventually cause people to give higher cognitive value to nuclear power.

We believe that this study transcends previous research regarding the measurement of a nuclear power plant by including the cognitive value. Our estimation included not only quantitative measures, but also people's real cognitive perceptions. Using our results, the Korean government may make energy policies considering nuclear energy's various social costs.

Our study had certain limitations. Although our sample size was large (>1,500), it is always better to increase the sample size to more accurately represent the actual population and to reduce any possibility of sample bias. The conjoint analysis that we adopted in this study may also have some problems. For example, the respondents may feel burdened in ranking the numerous different scenarios, and may find it difficult to accurately answer the questions. In future research, we will increase the validity of the nuclear power valuation by refining the number of factors that may affect the value of a nuclear power plant. Also, to demonstrate the robustness of this study, we should consider adopting several other methods in addition to a conjoint analysis.

Conflicts of interest

All authors have no conflicts of interest to declare.

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