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Original Article

Can Renewable Energy Replace Nuclear Power in Korea? An Economic Valuation Analysis☆

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ABSTRACT

This paper studies the feasibility of renewable energy as a substitute for nuclear and energy by considering Korean customers' willingness to pay (WTP). For this analysis, we use the contingent valuation method to estimate the WTP of renewable energy, and then estimate its value using ordered logistic regression. To replace nuclear power and fossil energy with renewable energy in Korea, an average household is willing to pay an additional 102,388 Korean Won (KRW) per month (approx. US $85). Therefore, the yearly economic value of renewable energy in Korea is about 19.3 trillion KRW (approx. US $16.1 billion). Considering that power generation with only renewable energy would cost an additional 35 trillion KRW per year, it is economically infeasible for renewable energy to be the sole method of low-carbon energy generation in Korea.

1. Introduction

Broadly speaking, there are two types of low-carbon power generation source: renewable energy and nuclear energy. Renewable energy sources are resources that can be used to produce energy continuously, and include solar energy, wind energy, biomass energy, and geothermal energy, among others [1]. The use of renewable energy sources is growing rapidly, but renewable energy currently accounts for only about 3% of the world's primary energy consumption [2] and supplies about 14% of the total world energy demand [3]. The worldwide share of renewable energy sources is expected to increase significantly from 30% to 80% by 2100 [4].

Nuclear energy is another low-carbon power generation method that accounts for approximately 20% of world electricity [5]. From the second half of the 2000s until the

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Fukushima incident (in March 2011), nuclear power had been gaining popularity due to increasing concern over global warming as a result of the use of fossil fuels [6]. However, Fukushima altered the public perception of nuclear power, and, as such, renewable energy technologies are rapidly gaining ground, supported by global subsidies amounting to US $120 billion until 2013. Renewable energy technologies are sometimes seen as direct substitutes for existing technologies, and their benefits and costs are conceived in terms of assessment methods developed for existing technologies. Such power generation units can provide small advanced-capacity additions to existing energy systems with short lead times and more flexibility compared with large, long lead-time units, such as nuclear power stations. Therefore, the development of advanced renewable energy technologies that serve as cost-effective and environmentally responsible alternatives to conventional energy generation is necessary [7].

After the Fukushima incident, many countries vowed to strengthen their renewal energy programs. For example, the German government announced that it would eliminate nuclear energy generation and replace it with renewable energy within 10 years, cut greenhouse gas emissions by 40% by 2020 and 80% by 2050, ensure renewables contribute 80% of Germany's energy by 2050, and ensure energy consumption drops of 20% by 2020 and 50% by 2050. It even has its own word, *Energiewende*, or "Energy Transformation." However, over the past 2 years, this plan has resulted in a 47% increase in the average family's energy bill [8]. Therefore, it is feasible that the rising cost of energy and people's reluctance to pay may be the biggest barrier to renewable energy replacing nuclear power and fossil fuels.

Nuclear and renewable energy have advantages and disadvantages as alternatives to fossil fuels. Nuclear energy has the public perception of being unsafe and renewable energy has economic feasibility concerns. However, long-term strategies for achieving global warming mitigation will soon necessitate alternative energy. Further, public measures that enforce market mechanisms that induce a shift from fossil-fueled to nuclear and/or renewable electricity generation will be required [9]. Therefore, it is necessary to determine whether or not renewable energy can be a better option than nuclear power as a means of low-carbon power generation.

Recently, the estimation of social cost concerning the stability and accident risk of the energy source has been important in various academic fields [10]. Therefore, the objective of this investigation is to examine whether or not renewable energies can be an economically feasible method for replacing nuclear power and fossil fuels in Korea. In this study, we used the contingent valuation method (CVM) and measure Korean households' willingness to pay (WTP) in order to estimate the economic value of renewable energy as an alternative to nuclear and fossil energies. In the next section, we discuss the importance of energy and the current energy situation in Korea. In the "Contingent Valuation Method" section, we explain our main methodology (i.e., CVM). In the "Data and Measurement" section, we elaborate on our data and measurements, followed by our results in the "Results" section. Finally, the "Conclusion" section presents the concluding remarks.

2. The Importance of Energy

In this section, we consider the factors that affect decisions on which energies should be used. At first we considered all kinds of possible factors based on previous research. Bae [11], for example, listed six factors, namely, environment pollution, regional economy, economic resources, environment friendliness, landscape change, and electric supply and demand. The Korean Ministry of Knowledge Economy [12] discussed seven factors, namely, safety, environment pollution, regional economy, asset value, environment -friendliness, diplomatic conflict, and electric supply and demand. In addition, ethicality was quoted by Huh [13]. Combining these factors together, we have 10 factors overall, including safety, environment pollution, regional economy, asset value, economic resources, environment friendliness, diplomatic conflict, landscape change, electric supply and demand, and ethicality. Among these, asset value, environment friendliness, and landscape change were removed through our pretest, because respondents thought they were either covered by other factors or less important. Therefore, we ended up with seven factors that affect the decision of energy usages as follows. These are described in the following sections.

2.1. *Environmental pollution*

Economic growth based on the use of energy has the potential to cause environmental degradation [14]. There have been many studies regarding the relationship between economic growth and environmental pollution. In particular, Grossman and Krueger [15] and Selden and Song [16] found that economic growth was associated with environmental degradation. In its early phase, economic growth causes environmental degradation. However, environmental conditions can improve after a certain level of economic growth has occurred. In several studies, this is described as a U-shaped relationship between environmental degradation and economic growth.

2.2. *Regional economy*

Since the 1980s, the Korean government has 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 implications that a waste disposal plant might have on the regional economy. Among various potentially hazardous facilities, nuclear-related facilities have been considered some of the most concerning to the general public. In 2005, however, the decision was made to construct the first Korean radioactive waste disposal facility, located in Gyeongju City. The decision was made based on the results of four candidate cities' local referendums, held in November 2005. In their referendum, Gyeongju's residents demonstrated general acceptance of the site, with nearly 90% of residents voting for construction of the facility [17–20].

Development and implementation of energy projects in rural areas can create job opportunities, thereby minimizing migration toward urban areas [21]. For example, in some rural regions, the investment in renewable energy represents a significant share of gross domestic product, up to 3% in Extremadura, Spain, in 2009. According to several case studies, such as those conducted in Abruzzo, Italy, the United Kingdom, and Canada, tax revenues have increased the availability of schools, senior residences, and other key public services. Renewable energy in rural areas can also generate extra income for land owners, and can be integrated with specific productive processes [22].

2.3. Economic resources

A number of studies have been performed considering net energy analysis for electricity-generation technologies, including fossil fuels, nuclear power, and renewable energy [23,24]. In Korea, the unit cost for generating electricity is presented in Table 1, based on data from 2014. The data show that nuclear power is the cheapest energy source. Despite the low cost of nuclear energy, however, the ratio of power production is highest for fossil-based energy sources. Nuclear energy is attractive due to its distinguished economic advantage over other energy sources [25]. Conversely, nuclear power plants are hugely expensive to build and very cheap to run, but the economics of nuclear power remains unclear, partly because its green virtues do not show up in its costs [26].

Recently, growing concerns over rising oil and gas prices, frequent supply disruptions, and the environmental impacts of fossil fuel use have diverted significant attention to African countries' potential to overcome past fossil fuel dependence [27]. Energy efficiency is a critical means to relieving pressure on energy supply and mitigating the competitive impacts of price disparities among regions. A renewed energy-policy focus, primarily on efficiency, is a prevailing theme in many countries [28].

2.4. Diplomatic conflict

In the energy industry, state-owned energy companies have generated controversy [29–32], as these companies have risen to power due to high oil prices, depleting reserves, and growing demand, particularly in Asia. When considering the growing awareness of climate change and a revival of resource nationalism, the state-owned energy company is an important factor in the perception of energy supply vulnerability [33]. In this situation, most countries attempt to reinforce their role in energy affairs [34–37].

2.5. Ethicality

Because it involves some people harming others, energy-derived climate change raises questions of ethicality [38]. However, how these people are related and how these damages come about depart significantly from our normal conception of an ethical dilemma. An ethical problem is one in which an individual intentionally harms another; both the individuals and the harm are identifiable, and the individuals and the harm are closely related in time and space [39]. Climate change is not a matter of a clearly identifiable individual acting intentionally to inflict harm on another individual closely related in time and space. Because people tend not to see climate change as an ethical problem, many are unmotivated to act with the urgency characteristic of our responses to typical ethical challenges [40].

Table 1 – Unit cost and ratio of each power production method in Korea (2014).

	Nuclear	Fossil	Renewable
Unit cost[a]	54.7 KRW[b]	134.5925 KRW	176.336 KRW
Ratio[c]	30%	66%	4%

[a] Unit cost data are from Electric Market Statistics in 2014, Korea Power Exchange (2015).
[b] 1,200 Korean Won (KRW) (http://epsis.kpx.or.kr/epsis/) is approximately US $1.
[c] Ratio data are from STATISTICS KOREA (http://www.index.go.kr/index.jsp).

2.6. Electric supply and demand

As mentioned in the "Introduction" section, since the high shock in oil prices in 1999, oil maintained a steady, high price for a long period [41]. According to Lee [42], oil prices exceeded the crisis level of oil supply in 1973, and they insist that the uptrend is continuing. Besides, according to the Green IT Promotion Council 2008[1], electricity consumption will steadily increase. In particular, Korea experienced an electricity shortage in 2013, demonstrating that the issue of electric supply and demand is becoming increasingly serious.

2.7. Safety

The world energy market has been altered many times, due in part to critical events and accidents such as the shale revolution in North America and the Fukushima nuclear accident in Japan [43]. Although the interest in and demand for a sustainable energy source is high, people are intimately related to the everyday risk that accompanies any energy source (i.e., electrical fires and gas accidents) [44]. Therefore, the safety of an energy source is an important issue that cannot be ignored.

3. Contingent Valuation Method

Market data are not available for public services or free services. In such situations, it becomes necessary to use a procedure that does not rely on market data. CVM has been proposed in the environmental literature for such situations [45], and is one of the most popular methods for analyzing and measuring the value of publicity [46]. CVM is a survey-based economic technique for the valuation of nonmarket goods and services. It is a technique to measure individuals' utility, and often represented as a stated preference model, different to a price-based revealed preference model. CVM has been widely used by government departments when performing cost–benefit analyses of projects impacting the environment. Today, it is widely accepted as a real estate appraisal technique, especially in contaminated property or other situations where exposed preference models fail due to disequilibrium in the market [47].

[1] The Green IT Promotion Council was established on 2008 as an industry-government-university partnership for promoting concrete action for achieving a balance between environmental protection and economic growth.

Typically, CVM asks how much money people would be willing to pay to maintain the existence of a nonmarket goods or services feature. CVM is typically measured using WTP, defined as the maximum amount of money that a user is willing to pay to adopt a good/service, or to avoid something undesirable. Several methods have been developed to measure consumer WTP.

In the past, CVM has been used for the estimation of WTP in several sectors: renewable energy and the factors that affect it [48–52], the evaluation of various renewable energy sources (e.g., wind, hydro, and biomass) [53,54], and the examination of payment form (e.g., collective or private) [55]. Bergmann et al [56] studied the attributes of renewable energy investments in Scotland using choice experiments. They found that the implicit price maintained a neutral impact on wildlife, and that WTP is sensitive to additional full-time jobs created by renewable projects. Alternative techniques for estimating WTP have been proposed and used in the marketing literature, including choice-based experiments such as conjoint analyses.

Generally, conjoint analysis and CVM can be adopted to estimate the WTP for renewable energy. However, conjoint analysis needs more respondents' awareness than CVM and also conjoint analysis has more comments about overestimation compared with CVM. For these reasons, the number of studies regarding renewable energy using conjoint analysis is smaller than the number of analyses adopting CVM. Therefore, we adopted CVM for estimating the WTP for renewable energy.

CVM establishment can be performed in five steps [57]. Step 1 involves selecting a research target, and defines the valuation problem and selects nonmarket resources. Step 2 is the construction of scenarios by creating a hypothetical market. When creating the scenario, we follow three stages. First, a scenario is constructed, which corresponds as closely as possible to a real-world situation. Because the scenario contains the reason for payment with standard market goods or services, researchers have to make the respondents understand the scenario fully. Second, it constructs a method of payment that fulfills conditions with respect to incentive compatibility, realism, and subjective justice among respondents. Third, it constructs a provision rule by which the good is to be provided, as a function of the stated value.

Step 3 involves the design of a survey questionnaire. First of all, researchers present the hypothetical scenario that was made in Step 2 to respondents, and then present the hypothetical payment mechanism and related stipulations. There are some payment mechanisms in CVM, such as open-ended questioning, bidding game, payment card, and dichotomous-choice questioning (Table 2). The bidding game method presents a series of questions until the maximum WTP is discovered. The payment card method presents the average expense of other goods, and induces respondents to provide their WTP for a particular research objective. It indicates a range of possible values, one of which is pointed out by the interviewee. Open-ended questioning leads the respondent directly to their WTP, without other options. Finally, dichotomous-choice questioning encompasses two similar methods, namely, single-bound dichotomous choice (SBDC) and double-bound dichotomous choice (DBDC). SBDC questioning provides little information; DBDC questioning is very similar to SBDC, but an additional follow-up question is required. A CVM researcher selects one for them and presents possible bidding mechanisms. Through these processes, the researcher elicits the respondents' WTP.

Step 4 conducts the survey written in Step 3. In-person interviews may be conducted with random samples of respondents. In general, a survey needs to be conducted two times. The first survey is a preliminary survey or pretest for finding the initial bid price. After the preliminary survey, researchers conduct the main survey. Step 5 analyzes the survey results by estimating the average WTP, constructing bid curves, and aggregating the data. Data must be entered and analyzed using adequate and appropriate statistical techniques. The CVM application procedure is presented in Table 3.

4. Data and Measurement

4.1. *Data collection*

Data for analyzing our research came from a survey that figured out WTP by presenting respondents with a virtual scenario using “only renewable power” instead of giving up all thermal power and nuclear power. The scenario used to make respondents understand this situation is as follows.

Renewable energy is 20% cheaper than nuclear energy (with regard to plant constructions costs), but it involves higher fees due its lower efficiency (about 20 times less efficient than nuclear energy). In addition, renewable energy has yet to resolve not only conflicts regarding noise (wind power) and ecosystem destruction (wind power and tidal power), but also the issue of where to build plants. To aid respondent comprehension, we also presented the German case as an example. We then asked respondents “Would you bear the

Table 2 – Contingent valuation method bidding mechanism type.

Method	Feature
Open-ended question	Respondents are asked to state their maximum willingness to pay (WTP) for the amenity to be valued
Bidding game	Respondents are asked a sequence of questions until maximum WTP is discovered
Payment card	Respondents are shown a payment card listing various dollar amounts, and asked to circle the one that comes closest to their own WTP
Dichotomous-choice question	Respondents are asked if they are willing to pay a single, randomly assigned amount on all-or-nothing basis (“yes” or “no” answer)

Table 3 – Contingent valuation method application procedure.

Step 1: Research target selection	• Define the valuation problem and select nonmarket resources
Step 2: Scenario selection	• Create a hypothetical market
Step 3: Survey questionnaire design	• Present a hypothetical scenario describing the change in the good to be valued
	• Present the hypothetical payment mechanism and related stipulations
	• Elicit the respondent's willingness to pay (bid elicitation procedure)
	• Collect information regarding respondents' socioeconomic background
Step 4: Survey	• Preliminary survey: Provide baseline initial bid for the main survey
	• Main survey: In-person interviews may be conducted with random samples of respondents
Step 5: Survey result analysis	• Data must be entered and analyzed using adequate and appropriate statistical techniques
	• Identify possible nonresponse bias

20,000 Korean Won (KRW) (or 40,000, 60,000, 80,000, 100,000), which is the additional electric fee, for developing renewable energy?" If the respondent answered "yes," we suggested double the initial cost. If respondents answered "no," we suggested half the initial cost. Furthermore, if respondents answered "yes–yes" (to the first 2 questions), we asked "How much would you pay?" For such question, we utilized a survey. We present a process diagram in Fig. 1.

The survey was conducted online in March 2015. We identified whether or not respondents followed the sequence of questions presented in the DBDC. Respondents who did not follow the sequence correctly were removed from the final analysis. Data were collected from a population of 1,525 respondents. We attempted to collect the sample evenly to improve data reliability. For this work, we controlled the number of survey participants to obtain a sample reflective of the total population of the survey area. In addition, we collected data from respondents corresponding to the population ratio of each city. As shown in Table 4, respondents were relatively well matched for gender, age, education level, and residence. We noted adult respondents who were willing to pay the additional fee for developing renewable energy. Because our survey required a high level of respondent comprehension, we asked the specialized research company, Embrain, to conduct the survey.

Although an in-person interview might make respondents participate in a survey more intensively than in a general survey that is without face-to-face contact, we used online surveys. This is because we wanted to know Koreans' general awareness about renewable energy. More importantly, we conducted the survey online because we needed as many respondents as possible. In addition, our survey was conducted by a professional survey company that could provide a reliable pool of respondents. Therefore, we can claim that the possible selection biases that may happen in a survey were minimized.

4.2. *Measurement*

WTP responses were elicited from DBDC questioning (Fig. 1). DBDC questioning required respondents to evaluate their WTP, given the repeated choices of whether the respondent would permit "only renewable power" for a particular additional cost. Five distinct additional cost ranges from a pretest were utilized. Each randomly received bid corresponded to one of the five additional cost ranges. Optimal bid design is an important issue in CVM. Clearly, the distribution of the chosen bids impacts the efficiency of the estimators, and should therefore be chosen after careful deliberation. A number of research groups have derived optimal bidding mechanisms [58–60]. To obtain optimal bid prices for our CVM survey, we conducted a pretest of 81 individuals.

These participants have various demographic characteristics such as job (student, office worker, government employer, etc.), age (from 20 years to 60 years), residential district (Seoul, Busan, Gyeonggi-do, etc.), and educational background. Therefore, the pretest sample size of 81 reflects the real-world population quite nicely. We explained our research objectives to these participants, and asked them to measure the value of renewable power in Korea. As a result of the pretest, we could get the distribution of WTP from a

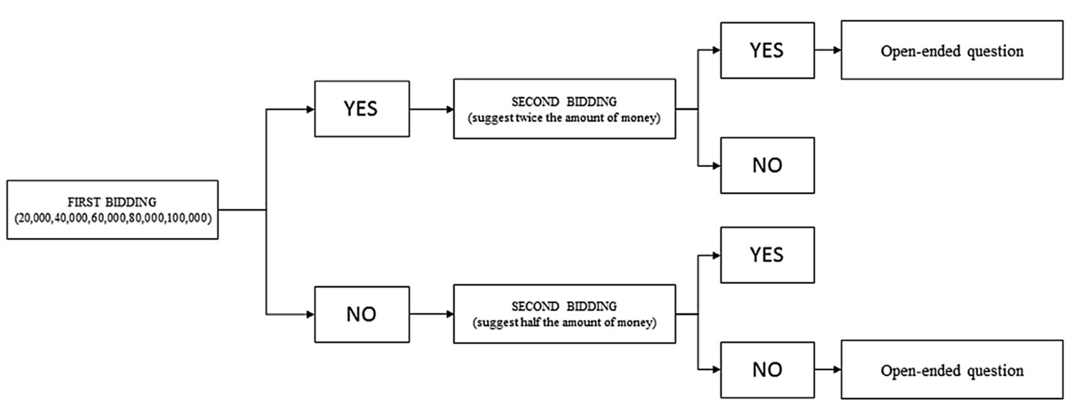

Fig. 1 – Diagram for double-bound dichotomous choice questioning.

Table 4 – Respondent distribution.

Classification	Frequency (N = 1,525)	Ratio (%)
Gender		
Male	784	51.4
Female	741	48.6
Age, y		
20–29	367	24.1
30–39	359	23.5
40–49	348	22.8
50–59	326	21.4
≥60	125	8.2
Education		
High-school graduate	246	16.1
College sophomore	263	17.3
Some college education	854	56
Graduate school or later	162	10.6
Residence area		
Seoul	276	18.1
Busan	170	11.1
Daegu	136	8.9
Incheon	188	12.3
Gwangju	65	4.3
Daejeon	77	5.0
Ulsan	38	2.5
Gyeonggi-do	193	12.7
Gangwon-do	52	3.4
Chungcheong-do	88	5.7
Jeolla-do	81	5.4
Gyeongsang-do	143	9.3
Jeju	14	0.9
Sejoung	4s	0.3

minimum of 0 to a maximum of 300,000 KRW. However, just one respondent chose 200,000 KRW and another one chose 300,000 KRW, and might be regarded as outliers. Therefore, based on the WTP of respondents derived from the pretest, we presented various bid prices (20,000 KRW, 40,000 KRW, 60,000 KRW, 80,000 KRW, and 100,000 KRW) in our survey.

To develop a framework for analyzing WTP based on these five bid sets, we utilized a random utility framework, similar to that developed by Hannemann [45]. First, we can write the utility function of an individual, j, as

$$u_{ij} = u_i\left(y_j, x_j, \varepsilon_{ij}\right) \tag{1}$$

where i takes a value of 0 for rejection of "only renewable power" (from the virtual scenario), but takes a value of 1 for acceptance of "only renewable power." y_j represents j's discretionary income and x_j represents the vector of relevant covariates that might affect the utility function (e.g., age, gender, education). The utility function contains some components that are unobservable to econometric investigation, and are thus treated as stochastic. ε_{ij} represents the unobservable components, represented as random variables with zero means.

If we present a respondent with an optional bid price (t_j KRW) for "only renewable power" from the virtual scenario, an affirmative answer implies

$$\Pr(yes) = \Pr\left[u_i\left(y_j - -t_j, x_j, \varepsilon_{ij}\right) > u_0\left(y_j, x_j, \varepsilon_{0j}\right)\right] = F(t_j) \tag{2}$$

$$\Pr(no) = \Pr\left[u_i\left(y_j - -t_j, x_j, \varepsilon_{ij}\right) > u_0\left(y_j, x_j, \varepsilon_{0j}\right)\right] = 1 - F(t_j) \tag{3}$$

Assuming additive separability of the utility function, we can specify a parametric utility function in the form of

$$u = \alpha x + \beta(y) + \varepsilon \tag{4}$$

to ultimately derive the following relation:

$$\begin{aligned}\Pr(yes_j) &= \Pr\left[(\alpha x_j - \beta t_j) > -\varepsilon_j\right] \\ &= \Pr\left[\alpha x_j - \beta t_j + \varepsilon_j\right] > 0\right]\end{aligned} \tag{5}$$

This gives us a simple way to estimate the mean WTP based on the answer to a single question (SBDC). However, this method abstracts the impact of income on WTP by assuming a constant marginal utility of income. To overcome this restriction, it is possible to directly model the WTP function by using a DBDC, where users are asked to respond to a series of sequenced questions following the initial bid [61]. A DBDC question presents respondents with a sequence of two bids and asks them if their WTP equals or exceeds that bid. The magnitude of the second bid depends on the answer ("yes" or "no") to the first bid. Denoting the initial bid as B1, a respondent would be asked whether or not they would permit "only renewable power" if it were priced at B1. If the answer is "yes," the respondent is presented with a new bid, BH, such that BH > B1. However, if the respondent's response is negative, they are presented with BL < B1. Hence, the four outcomes may be represented as follows:

$$\Pr(no - -no) = \Pr\left[WTP_j \le B_{1j} \text{ and } WTP_j \le B_{Lj}\right] = F(B_{Lj}) \tag{6}$$

$$\Pr(no - -yes) = \Pr\left[WTP_j \le B_{1j} \text{ and } WTP_j > B_{Lj}\right] = F(B_{1j}) - F(B_{Lj}) \tag{7}$$

$$\Pr(yes - -no) = \Pr\left[WTP_j > B_{1j} \text{ and } WTP_j \le B_{Hj}\right] = F(B_{Hj}) - F(B_{1j}) \tag{8}$$

$$\Pr(yes - -yes) = \Pr\left[WTP_j > B_{1j} \text{ and } WTP_j > B_{Hj}\right] = 1 - F(B_{Hj}) \tag{9}$$

where $\Pr(no - -no)$ means the probability of answer to "no" in the second question after answering to "no" in the first question. In this sense, $\Pr(no - -yes), \Pr(yes - -no), \text{and } \Pr(yes - -yes)$ mean the probabilities of each answer to the first and second question. The right-hand side is the equation for estimating the real value of the probability, where F represents the cumulative distribution function. Finally, Eqs. (6–9) represent the probabilities of observing a different response to each of the individual bids, and yield the likelihood function for estimating the mean WTP for the sample. Consequently, Eqs. (6–9) yield the following sample log-likelihood function:

$$\begin{aligned}\ln L = \sum_{i=0}^{n}\Bigg[&(no - no)\ln F\left(\frac{BLi - xi\beta}{\sigma}\right) + (no - yes)\left\{\ln\left[F\left(\frac{B_{1i} - x_i\beta}{\sigma}\right)\right.\right. \\ &\left.\left. - F\left(\frac{B_{Li} - x_i\beta}{\sigma}\right)\right]\right\} + (yes - no)\left\{\ln\left[F\left(\frac{B_{Hi} - x_i\beta}{\sigma}\right)\right.\right. \\ &\left.\left. - F\left(\frac{B_{1i} - x_i\beta}{\sigma}\right)\right]\right\} + (yes - yes)\left\{\ln\left[1 - F\left(\frac{B_{Hi} - x_i\beta}{\sigma}\right)\right]\right\}\Bigg]\end{aligned} \tag{9}$$

As mentioned earlier, the *(no–no)*, *(no–yes)*, *(yes–no)*, and (yes–yes) mean the probabilities of each answer to the first and second question. Therefore, the log-likelihood function is the total sum of each answer's probability in the total samples *n*. A variety of distributions, such as the lognormal, normal, and Weibull distributions have been proposed for modeling WTP. The parameters of these distributions can be specified as functions of covariates. The vector x_j is operationalized using specific control variables and relevant covariates. The coefficient estimates reveal the marginal impact of these covariates on WTP, and the mean WTP for the sample is estimated to be $E(WTP) = \bar{x}\beta$ in a spike model. The spike model uses additional valuation questions: one question asks whether or not the individual would like to contribute to the survey. Thus, it takes into account a spike at zero WTP, which is the truncation at 0 of the positive parts of the WTP distribution. Here, a spike is defined by

$$F(t_j) = \frac{1}{1+\exp(\alpha)} \tag{10}$$

The percentage of respondents' zero WTP among samples and mean WTP is estimated as follows:

$$WTP_{mean} = -\frac{1}{\beta}\ln[1+\exp(\alpha)](1+\exp(\alpha)) \tag{11}$$

The five bid sets (t_j) were in the 10,000–200,000 KRW range as follows: (20, 10, 40); (40, 20, 80); (60, 30, 120); (80, 40, 160); and (100, 50, 200), where each number represents (bid one, subsequent lower bid, subsequent higher bid). Based on the response to the first bid, the higher bid is presented if the response is "yes," and the next lower bid is presented if the response is "no." WTP is often impacted by individual attitudes and demographic characteristics. First, we asked respondents to consider the importance of seven energy issues (regional economy, electric supply and demand, environment, diplomatic conflict, safety, ethicality, and economics) in Korea. We then presented binary questions (i.e., whether or not respondents prefer nuclear energy to renewable energy), and multiquestions (i.e., how safe is nuclear power or renewable power in Korea?). In addition, we collected demographic information including age, gender, education, residence, presence or absence of a householder, monthly income, and electric light rates.

5. Results

When we conducted the main survey, we added another question concerning the interest in renewable energy. Fig. 2 shows the distribution of respondents' interest in and perceived necessity for renewable energy in the main survey. The respondents who were interested in renewable energy encompassed 83% (1,262 people) of total respondents, and 92% (1,399 people) answered that they felt renewable energy was necessary.

Table 5 is the frequency distribution of the DBDC responses. As mentioned earlier, we conducted DBDC questioning, which is one method of CVM analysis for estimating renewable energy.

Table 5 demonstrates that most respondents answered "no" and "no–no" at all cost levels. However, most respondents found renewable energy necessary in the early analysis (Fig. 2). Ultimately, we found that most respondents find renewable energy necessary, but do not want to shoulder the additional cost associated with renewable energy development. Table 6 presents the descriptions of the variables used in the survey.

Table 7 presents the descriptive statistics of variables that were used in the ordered logistic regression analysis. The regression analysis considered scale variables including nuclear interest, nuclear safety, renewable interest, renewable safety, important-local economy, important-electric supply, important environment, important diplomatic problem, important safety, important ethic, important economy, and dummy variables (gender, nuclear local, host, and preferred energy). In addition, we found the low correlation between variables through analyzing the correlation test presented in Appendix 1.

Table 8 presents the results of the ordered logistic regression using maximum likelihood estimation. Our model is statistically significant at a 1% level. The dependent variable is the preference for renewable energy. Respondents who answered

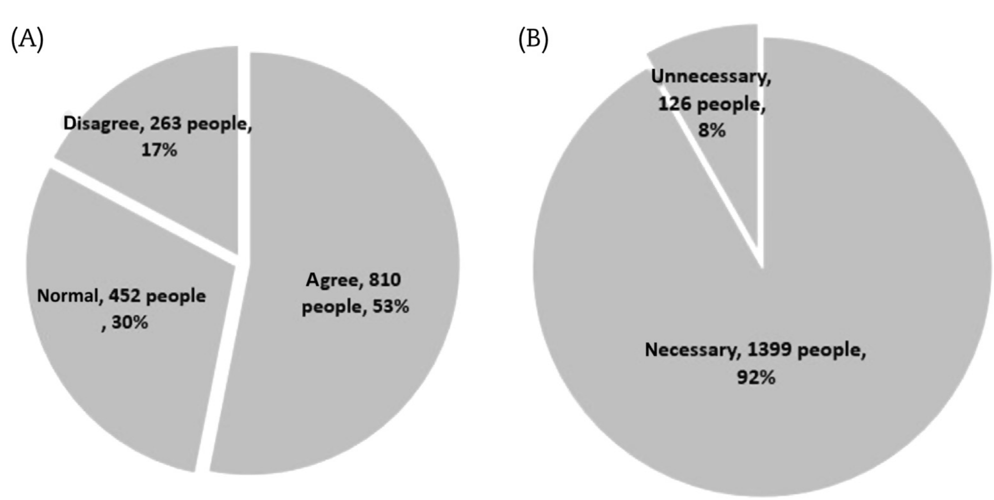

Fig. 2 – Respondents' interest in renewable energy. (A) Interest in renewable energy. (B) Necessity of renewable energy.

Table 5 – Frequency distribution of double-bound dichotomous choice responses.

Cost (KRW)	Respondents						
	Yes to the first question			No to the first question			Total
	Yes	Yes–yes	Yes–no	No	No–yes	No–no	
20,000	83	22	61	213	60	153	296
40,000	70	15	55	250	65	185	320
60,000	44	11	33	250	48	202	294
80,000	47	6	41	264	45	219	311
100,000	45	13	32	259	32	227	304
							1,525

KRW, Korean Won.

"yes–yes" to the first and second questions regarding WTP for developing renewable energy were given four points. Respondents who answered "yes–no" to the first and second questions were given three points. Following this perspective, two points were given to respondents who answered "no–yes," and one point was given to respondents who answered "no–no" (Table 5). Therefore, positive coefficients in Table 8 indicate that respondents prefer renewable energies.

The bid price coefficient in the third line is negative (Table 8). This indicates that when the suggested bid price decreased, the respondents preferred renewable energy ($p < 0.01$). By contrast, there was no correlation between either the preference for

Table 6 – Variable description.

Variable	Description
Renewable preference	Respondents' preference about the renewable energy inferred to the survey that we conducted
Bid price	Renewable energy development cost we suggested in the survey (20,000 KRW, 40,000 KRW, 60,000 KRW, 80,000 KRW, and 100,000 KRW)
Gender	0 if male, 1 if female
Age	Respondent's age
Education	Respondent's education level (elementary, middle, high, university, graduate university)
Residence	1 if respondent is a resident of a region with a nearby nuclear power plant 0 if respondent lives in other region
Householder	1 if respondent is a householder 0 if respondent is a family member
Nuclear preference	1 if respondent's preferred energy source is nuclear power 0 if respondent's preferred energy source is any other type of power
Nuclear interest level	The level of respondent's interest about nuclear 1–7 scale (1 = no interest, 7 = very interested)
Nuclear safety level	The level of respondent's feel about nuclear safety 1–7 scale (1 = unsafe, 7 = very safe)
Renewable interest level	The level of respondent's interest about renewable energy 1–7 scale (1 = no interest, 7 = very interested)
Renewable safety level	The level of respondent's feel about renewable safety 1–7 scale (1 = unsafe, 7 = very safe)
Income	Respondent's income (open-ended question)
Electricity bill	Respondent's electricity bill (open-ended question)
Regional economy	Respondent's feeling regarding importance of economic influence near the energy development region 1–7 scale (1 = minor, 7 = serious)
Electric supply and demand	Respondent's feeling regarding the importance of electric supply and demand near the energy development region 1–7 scale (1 = minor, 7 = serious)
Environment	Respondent's feeling regarding the regional environment impact near the energy development region 1–7 scale (1 = minor, 7 = serious)
Diplomatic conflict	Respondent's feeling regarding the importance of diplomatic conflict 1–7 scale (1 = minor, 7 = serious)
Safety	Respondent's feeling regarding the importance of energy source safety (critical accident risk or terror) 1–7 scale (1 = minor, 7 = serious)
Ethicality	Respondent's feeling regarding the importance of ethical issues (responsibility for future generation) 1–7 scale (1 = minor, 7 = serious)
Economics	Respondent's feeling regarding the importance of economy problems associated with the energy source (need for low energy costs) 1–7 scale (1 = minor, 7 = serious)

KRW, Korean Won.

Table 7 – Descriptive statistics.

	Minimum	Maximum	Mean	SD
Bid price	20,000	100,000	59,921.31	28,209.827
Gender	0	1	0.49	0.5
Age	20	69	40.34	12.699
Education	2	22	16.18	2.315
Residence	0	1	0.3	0.460
Householder	0	1	0.33	0.471
Nuclear preference	0	1	0.15	0.359
Nuclear interest level	1	7	4.69	1.285
Nuclear safety level	1	7	3.24	1.499
Renewable interest level	1	7	4.56	1.382
Renewable safety level	2	7	5.20	1.140
Income	1,000	90,000,000	2,561,976.59	4,682,099.839
Electricity bill	1,000	1,500,000	68,803.15	92,204.757
Regional economy	1	7	5.31	1.074
Electric supply and demand	1	7	5.76	1.069
Environment	1	7	5.98	1.065
Diplomatic conflict	1	7	5.17	1.092
Safety	1	7	5.87	1.138
Ethicality	1	7	5.57	1.132
Economics	1	7	5.67	1.099

All values are provided in Korean Won.

renewables, or the value of renewable energy, and "gender" or "education level," as these variables are not significant statistically. Because "age" and "residence" variables have a negative coefficient, we know that young respondents and those who lived far from nuclear power plants preferred renewable energy.

Table 8 – Result of ordered logistic regression analysis.

Variables	β
Constant	1.282 (0.648)[a]
Bid price	−0.00014 (0.000002)[b]
Gender	0.066 (0.130)
Age	−0.023 (0.005)[b]
Education	0.001 (0.024)
Residence	−0.205 (0.120)[c]
Householder	0.271 (0.147)[c]
Nuclear preference	−0.331 (0.174)[c]
Nuclear interest level	0.098 (0.057)[c]
Nuclear safety level	−0.07 (0.04)[c]
Renewable interest level	0.148 (0.056)[b]
Renewable safety level	0.157 (0.058)[b]
Income	1.953×10^{-008} (1.078×10^{-008})[c]
Electricity bill	1.211×10^{-006} (5.505×10^{-007})[a]
Regional economy	0.108 (0.066)[c]
Electric supply and demand	0.025 (0.07)
Environment	−0.08 (0.073)
Diplomatic conflict	0.06 (0.061)
Safety	−0.065 (0.067)
Ethicality	0.244 (0.068)[b]
Economics	−0.191 (0.064)[b]
Log-likelihood: 2,896.257	
Cox and Snell: 0.103	
Nagelkerke: 0.118	
McFadden: 0.054	
$p < 0.001$	

[a] Significance at the 5% level.
[b] Significance at the 1% level.
[c] Significance at the 10% level.

The positive coefficient of the "householder" suggests that heads of household primarily preferred renewable energy. Because the positive coefficient of "income" variable means respondents with higher personal incomes, these respondents preferred renewable energy. In addition, as we have a negative coefficient in the "nuclear safety level" and a positive coefficient in the "renewable safety level," the respondents who felt that renewable energy was safe (and conversely considered nuclear power unsafe) preferred renewable energy. Respondents with more interest in renewable energy preferred renewable energy, and respondents with more interest in nuclear energy understandably preferred nuclear energy. In the same vein, the negative coefficient of the "nuclear preference" indicates that respondents who do not like nuclear power prefer renewable energy.

Finally, as we consider the variables "regional economy," "ethicality," and "economics," we can interpret each variable as follows. First, in the case of the "regional economy" variable, when regional economy improves due to a nearby energy plant, respondents preferred renewable energy. Respondents who felt responsibility for future generations preferred renewable energy. Contrarily, the negative coefficient of "economics" indicates that people who are sensitive to economic feasibility did not prefer renewable energy. Other variables such as "electric supply and demand," "environment," "diplomatic conflict," and "safety" were not significantly related to the value of renewable energy.

The WTP survey is a suitable way by which we can estimate the value of nonmarket goods [62]. The value of renewable energy can be estimated in three ways. The first method is using an average (WTP mean) of the cumulative probability distribution estimated by setting the random cost from 0 to infinity [63]. The second method is the use of an average (WTP overall mean) [64], with the assumption that $\lim_{A \to 0} F_A < 1$ about the random cost (A). The last estimation is to use an average (WTP truncated mean) considering the minimum value (0 KRW) and the maximum value (Max.A, the maximum amount proposed). In general, the truncated mean is considered to meet the theoretical limitations and consistency, statistical efficiency, and total power conditions [65]. The equations used for the three WTP methods are presented in Table 9.

Table 10 presents the result of WTP estimation using parameters presented in Table 8. From the proposed equations, we adopted the truncated mean, because it includes the Max.A value that means the maximum bid price we proposed. This approach is one of the general estimation methods to estimate the WTP [66–68]. Through the truncated mean, we can have more effective results by estimating WTP using the limited interval data than using infinite data. In the case of our survey, we designed the scope of the bid price. This means that the bid price suggested in the survey has maximum and minimum values. Therefore, we can get the effective result from the truncated mean. By contrast, in our survey, there are 297 respondents who marked zero for WTP; 56% of 297 respondents answered that they made WTP the zero value due to having already paid enough taxes, regardless of the development of renewable energy. In addition, 19% of 297 respondents answered that they could not trust the government. They also made renewable energy value zero because renewable energy cannot be sustainable in supply and renewable energy is so expensive and so on. Therefore, because the truncated mean is the most accurate model (due to our survey design), we adopted that result for our main conclusion. The use of other WTP models does not qualitatively change our conclusions.

We estimated respondents' monthly WTP for developing renewable energy to be 102,388 KRW/household (approximately US $85). The standard error is 18,065 KRW and the 95% confidence interval is 66,398–137,796 KRW. An average household would pay this amount of money to replace thermal power generation and nuclear power generation with renewable energy. The Korean Bureau of Statistics maintains that there are 3.1862 persons/household in Korea. Based on these figures, we can calculate the yearly economic value of renewable energy in Korea. The total economic value of renewable energy replacing nuclear power and fossil energy is about 19.3 trillion KRW (approximately US $16.1 billion).

6. Conclusions

Although Korea has been solely dependent on fossil fuels since the industrial revolution, alternative energy is emerging as a major interest as issues of environmental pollution and energy limitations become increasingly prominent. Renewable energy, one type of alternative energy, is economically infeasible due to the high costs associated with electric power generation. However, it is difficult to say that renewable energy is not valuable. Because the public expects that renewable energy can reduce environmental contamination and resolve the safety fears of nuclear power plants, it is necessary to include qualitative analysis in the valuation method. Therefore, we estimated the economic feasibility of renewable energy considering not only quantitative costs, but also perceived benefits and costs. We used an online survey of 1,550 Korean individuals with help from the Embrain Research Center, and used CVM to evaluate renewable energy.

A typical Korean's maximum WTP to develop renewable energy instead of fossil fuels and nuclear power plants is 102,388 KRW/month. This WTP is used to calculate the value of renewable energy. The yearly value of renewable energy is about 19.3 trillion KRW; that is to say, additional investment in renewable energy is possible to supply national energy. Moreover, we recognize the importance of people's priorities with respect to important factors of energy generation, including regional economy, ethicality, and economics. First, people who are more sensitive to economic feasibility did not prefer renewable energy. By contrast, people with higher ethicality (e.g., those who feel a responsibility for future generations) preferred renewable energy. Heads of household responsible for family living are more interested in the development of renewable energy. We also found that people who live in areas near nuclear power plants demonstrated negative feelings toward renewable energy. It is interesting that individuals with negative perceptions of nuclear power and its safety prefer renewable energy. That is, people have opposing views regarding nuclear power and renewable energy.

Table 9 – WTP equations.

	WTP (mean)	WTP (overall)	WTP (truncated mean)
Equation	$-\frac{1}{\beta_1}\ln[1+\exp(\alpha)]$	$-\frac{\alpha}{\beta_1}$	$-\frac{1}{\beta_1}\ln\left[\frac{1+\exp(\alpha)}{1+\exp(\alpha+\beta_1 \mathrm{Max.A})}\right]$

WTP, willingness to pay.

Table 10 – Estimated WTP results.

	Mean	Overall	Truncated mean
WTP	198,129	193,524	102,388
Standard errors	30,225	29,610	18,065
95% Confidence interval	138,888–257,370	135,489–251,560	66,981–137,796

Data are presented in Korean Won.
WTP, willingness to pay.

Power production in South Korea was 550 billion kWh in 2014. Renewable energy accounted for 4% of that total, nuclear power 30%, and fossil fuels 66%. The annual total production cost of all energies was about 62 trillion KRW; the per-kWh production cost of renewable energy was 176 KRW; for nuclear power and fossil fuel, it is 55 KRW and 135 KRW, respectively [69]. Therefore, we can calculate the total production cost of renewable energy by using the production cost of renewable energy/kWh and total power production in South Korea when nuclear power and fossil fuels are totally converted into renewable energy. In this sense, we can say that the production cost will be approximately 97 trillion KRW (176 KRWR $\times$ 550 billion). This amount means that it needs 35 trillion KRW more than the expenses (cost) needed to generate the energy by using multiple energy sources in Korea (97 trillion KRW − 62 trillion KRW). Therefore, in Korea it may be difficult to produce all electricity with renewable energy, considering the current public perception of renewable energy. To increase the value of renewable energy, aggressive promotion is necessary to inform the general public of the benefits of renewable energy.

The value of renewable energy estimated in this study has significance academically, as the cognitive value of renewable energy (people's direct thoughts regarding renewable energy) is considered. Breaking the bounds of existing quantitative investigations, our paper considers public opinions about energy. Therefore, this is the first study for estimating the value of renewable energy by using econometric methods to reflect public opinion. It is true that our study has several limitations, the most significant being that every factor regarding renewable energy production is not reflected. There is also the possibility that CVM results might be overestimated or underestimated. However, the possibility of false results is, in a way, inevitable, because people sometimes answer survey questions differently regardless of their true WTP. Misunderstanding of the hypothetical scenario or survey questions may also lead to inaccuracy in results.

The results of our research will help the Korean government to execute more realistic budget planning by including various social costs for both quantitative and qualitative values. In future studies, we will increase the validity of measurement by refining a number of factors that may affect renewable energy value. In addition, we will verify the results of this study with various analytical methodologies, in addition to CVM.

Conflicts of interest

All contributing authors declare no conflicts of interest.

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Appendix 1. Correlation of variables.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Bid price (A)	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gender (B)	−0.018	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Age (C)	−0.001	−0.044	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Education (D)	−0.011	−0.119**	−0.069**	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Residence (E)	0.033	.030	−0.001	−0.047	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Householder (F)	0.020	−0.449**	0.417**	0.134**	−0.056*	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Nuclear preference (G)	0.010	−0.152**	0.047	0.008	−0.005	0.062*	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Nuclear interest level (H)	−0.007	−0.214**	0.224**	0.098**	0.040	0.161**	0.092**	1	–	–	–	–	–	–	–	–	–	–	–	–
Nuclear safety level (I)	0.021	−0.176**	0.193**	−0.037	−0.005	0.183**	0.343**	0.107**	1	–	–	–	–	–	–	–	–	–	–	–
Renewable interest level (J)	−0.029	−0.286**	0.204**	0.108**	0.019	0.204**	−0.027	0.646**	0.098**	1	–	–	–	–	–	–	–	–	–	–
Renewable safety level (K)	0.001	−0.251**	0.120**	0.124**	0.027	0.144**	−0.026	0.381**	0.000	0.481**	1	–	–	–	–	–	–	–	–	–
Income (L)	0.009	−0.123**	0.164**	0.150**	0.015	0.221**	0.073**	0.092**	0.083**	0.116**	0.054*	1	–	–	–	–	–	–	–	–
Electricity bill (M)	0.022	0.039	−0.025	0.080**	0.007	−0.079**	0.052*	−0.006	0.002	−0.020	−0.032	0.026	1	–	–	–	–	–	–	–
Regional economy (N)	0.036	0.056*	0.093**	0.003	0.011	−0.024	−0.021	0.169**	−0.051*	0.151**	0.230**	−0.012	0.047	1	–	–	–	–	–	–

(continued on next page)

— (*continued*)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Electric supply and demand (O)	0.026	−0.008	0.157**	0.027	−0.008	0.001	−0.006	0.234**	−0.045	0.201**	0.307**	−0.021	−0.002	0.555**	1	–	–	–	–	–
Environment (P)	0.004	0.117**	0.030	0.016	−0.009	−0.057*	−0.142**	0.119**	−0.223**	0.092**	0.219**	−0.051*	−0.046	0.468**	0.526**	1	–	–	–	–
Diplomatic conflict (Q)	0.025	0.058*	0.087**	−0.011	−0.019	−0.053*	−0.045	0.132**	−0.020	0.106**	0.116**	−0.041	0.005	0.439**	0.439**	0.427**	1	–	–	–
Safety (R)	−0.004	0.093**	0.042	0.058*	0.011	−0.069**	−0.115**	0.198**	−0.221**	0.125**	0.226**	−0.040	−0.009	0.422**	0.501**	0.573**	0.462**	1	–	–
Ethicality (S)	0.010	0.111**	0.065*	0.018	−0.030	−0.052*	−0.112**	0.160**	−0.149**	0.138**	0.177**	−0.037	0.000	0.403**	0.413**	0.584**	0.483**	0.591**	1	–
Economics (T)	0.011	0.051*	0.094**	−0.022	−0.011	−0.040	−0.007	0.137**	−0.037	0.106**	0.179**	−0.010	−0.025	0.485**	0.519**	0.486**	0.464**	0.460**	0.531**	1

* Significance at the 5% level.
** Significance at the 1% level.

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