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Reducing Environmental Impact of Coal-Fired Power Plants by Building an Indoor Coal Storage: An Economic Analysis

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Abstract: Coal-fired power plants have been identified as one of the major sources of air pollutants in the power sector. Most coal-fired power stations have large open-air coal stockpiles, which lead to a considerable amount of fugitive dust. The construction of an indoor coal storage is known to control coal dust; however, it requires significant upfront capital. Certain power utilities, including those in South Korea, are currently considering or are required to build indoor coal storages. This study analyzed the benefit and economic feasibility of indoor coal storages in coal-fired power stations. A contingent valuation method was used to elicit people's willingness to pay for the construction of new indoor coal storages. The results showed that, on average, a South Korean household was willing to pay KRW 59,242 (USD 53.97) in a lump-sum payment toward the construction of indoor coal storages at six coal-fired power stations (total storage capacity of 5.47 million tons of coal, with a site area of 1.15 million m^2). The resulting benefit–cost ratio of the project was calculated to be 0.52, which was not economically feasible. Thus, it is recommended that the South Korean government should focus on other cost-effective projects to improve air quality.

Keywords: closed coal storage; coal silo; coal shed; stated preference technique; monetary value; benefit–cost analysis

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1. Introduction

The environmental impact of energy use has received considerable attention [1,2]. Energy generation and conversion are closely related to various environmental problems such as air pollution, climate change, waste disposal, habitat destruction of species, and forest damage. Given that climate change has emerged as a major global issue, it is important to holistically understand the interrelationship between energy and the environment.

In recent years, numerous countries have promoted electricity generation using renewable sources [3]. On the other hand, traditional coal-fired power plants have been identified as the major cause of environmental problems, especially air pollution. Coal-fired power plants not only emit many air pollutants during the mining, transport, storage, and combustion of coal but also adversely affect groundwater, soil, and marine ecosystems. Therefore, from the perspective of environmental sustainability, it is necessary to reduce electricity generation from and prohibit any new construction of coal-fired power plants. However, there are advantageous as they generate electricity at low costs. In 2021, the share of coal in global electricity generation was 36%, which was the highest among all sources, although this share is expected to decrease in the long-run [4]. Moreover, a number of countries marked a return to coal-fired power in 2022 during the economic recovery from COVID-19 and as concerns rise about high natural gas prices and energy security [4]. Therefore, reducing the environmental impacts of existing coal-fired power plants is urgently important.

The literature on air pollution from coal-fired power plants has mainly focused on air pollutants that are emitted during combustion and those that remain after combustion (coal ash or fly ash) [5–8]. However, it should be noted that coal use can adversely affect public health and the environment at all stages [9]. A significant amount of air pollution is generated during the storage and handling of coal, especially from the wind blowing over uncovered coal stockpiles [10]. In fact, in most coal-fired power plants, vast amounts of coal stockpiles are placed in open air, where a significant amount of fugitive dust is produced and emitted. Therefore, it is necessary not only to reduce the pollutants emitted during or after the combustion of coal, but also to decrease the fugitive dust emitted during the transportation and storage of coal (mainly in an outdoor coal stockpile).

The coal stockpile of a coal-fired power plant can be located either outdoors or indoors. Outdoor coal storage requires a larger area and leads to a considerable amount of fugitive dust emissions, but it has the advantage of lower cost of construction and operation. On the other hand, an indoor coal storage, such as a shed, silo, or dome, has lower fugitive dust emissions and effective drainage control. Therefore, some countries are encouraging the use of indoor coal storage. Indoor or underground coal storages have already been in operation in a few countries, such as Japan, Germany, South Korea, and Finland. It is the most effective method for reducing fugitive dust from a coal stockpile. Among the different methods to reduce fugitive dust in mines and coal yards, the reduction efficiency of an indoor structure is 99% to 100% [11]. In principle, the construction of an indoor coal storage is justified only when the environmental benefits of reducing fugitive dust emissions are considered.

However, the construction of an indoor coal storage is expensive. Depending on the size and form of the structure, it can cost several hundred billion Korean Won (KRW) (about several hundred million USD). Therefore, it is important to understand the economic feasibility of the project, as public money is utilized to construct these indoor coal storages.

Against this background, the main purpose of this study is to estimate the economic benefits and calculate the economic feasibility of an indoor coal storage in coal-fired power plants. The reduction of coal fugitive dust is an environmental non-market good. Therefore, to elicit its monetary value, the public's willingness to pay (WTP) is estimated and determinants of the WTP are identified. To this end, the contingent valuation method (CVM) is used for collecting and analyzing the statement preference (SP) data for indoor coal storage. Additionally, based on the derived WTP, a simple cost–benefit analysis is conducted for the six planned indoor coal storages in South Korea.

2. Background

2.1. Literature Review: Environmental Impacts of Coal Stockpile

Most coal-fired power plants store large amounts of coal under open air. Unlike pollutants that are produced during or after coal combustion, there is relatively little interest in stationary coal stockpiles. Previous studies have analyzed the environmental effects of air pollutants or leachates from coal storage piles [12,13]. Additionally, Smit [14] analyzed the concentration profile of coal dust around a stockpile at a power station in Iowa.

Recent studies have examined the environmental impacts of coal storage and processing by focusing on coal stockpiles in power plants. Furthermore, they have identified the characteristics and factors influencing air pollutants from coal stockpiles. For example, Grossman et al. [15] monitored coal stockpiles in Israel's utility plants to report on their detailed characteristics, including temperature and types of gaseous emissions. They confirmed that toxic and fire hazardous gases were generated from open-air coal stockpiles, although some differences existed, depending on the shape, depth, and distance from the stockpile.

Kozinc et al. [16] studied a coal stockpile in a thermal power plant in Slovenia and analyzed the types of gaseous emissions and the factors influencing them. Their results confirmed that carbon dioxide, methane, dimethylsulfide, carbon monoxide, and oxygen were generated in the coal yard. Moreover, these emissions led to environmental problems such as dust, water pollution, and unpleasant odor.

With respect to the electric power generating stations in Tennessee, Muller et al. [17] characterized the impact of coal pile dust emissions on downwind air quality. Furthermore, they examined the influence of wind speed, humidity, air temperature, and turbulence on the concentration of dust. Similarly, Muller et al. [18] examined the effect of the bulldozer movement, which is a representative human activity in a coal yard, on coal dust emissions.

Kim et al. [19] studied the PM_{10} emissions from a coal storage yard in a thermal power plant. Their results revealed that PM_{10} emissions from coal yards were affected by several factors, including dust control measures, weather conditions, and the method and timing of coal loading and unloading. As PM_{10} emissions from coal yards are, relatively, higher during daytime (9 am to 8 pm), it is recommended to employ appropriate measures, such as watering, during that time.

Jha and Muller [10] examined the environmental and health effects of coal stockpiles in power plants, and converted the results to monetary terms. Although the methodology used was different, the aforementioned study was in line with this study, as it quantitatively measured the environmental cost of coal dust from coal stockpiles in a power plant. The storage and handling of coal in power plants can cause considerable local air pollution. Specifically, if the coal stockpile is increased by 10%, the average $PM_{2.5}$ concentration within 25 miles of the power plant will increase by 0.09%. Accordingly, the adult and infant mortality rates will increase by 1.1% and 3.2%, respectively. By applying the Value of Statistical Life approach to this increase in mortality, it was concluded that a one-ton increase in the coal stockpile in a power plant would lead to an air pollution cost of USD 197.

Studies related to water pollution in areas near coal stockpiles are rare. Cook and Fritz [20] examined the negative impacts of coal storage piles on groundwater. An analysis of the groundwater and surface water near a power plant in Indiana, USA, revealed that concentrations of sulfate and several metals and their hardness exceeded the standards. Considering the excellent buffering and dilution capacity of the soil in the region, it was confirmed that the leachate emanating from the coal pile can cause significant groundwater contamination.

In summary, most of the existing studies have focused on identifying whether air pollutants are emitted from coal stockpiles, characteristics of the emissions, and the factors affecting them. This study contributes to the literature by examining the economic benefit of the reduction in fugitive dust by constructing an indoor coal storage. Moreover, it analyzes the economic feasibility of the indoor coal storage and examines the validity of its derived benefit by comparing it with the results of similar studies, such as Jha and Muller [10].

2.2. Change to Be Valued: Indoor Coal Storage Facility

To reduce the adverse effects of fugitive dust from open-air coal stockpiles, various abatement measures are being applied in the field. Existing literature suggests water sprinkling, chemical dust suppression, and windbreak options as representative fugitive dust mitigation solutions [21–23]. Water sprinkling prevents the generation and scattering of coal dust particles in outdoor coal stockpiles and is currently the most used method. The windbreak method reduces fugitive dust by reducing wind speed; it mainly involves employing windbreak forests, fences, and walls. Surface stabilization includes chemical stabilization/treatment (spraying surface-active agents) and the installation of a surface cover (dust cover). Other possible methods, including fly ash treatment, compression by bulldozing, and a dry fog system, are also applicable.

On the other hand, there is limited interest in indoor coal storage, likely because of the high cost of construction. However, an indoor (closed) storage system is the most effective method for controlling coal dust. For example, the Commonwealth of Australia [11] revealed that the reduction efficiency of indoor systems was 99% to 100% for fugitive dust control methods in mines. This makes it superior to all other methods. Additionally, as compared to outdoor open stockpiles, the indoor system is advantageous in terms of noise reduction, low O&M cost, slow loss of heat content, and better esthetics [24].

However, an indoor coal storage has a few disadvantages. There is a higher possibility of self-heating and autoignition, and reduced access for corrective action when necessary [25,26]. Generally, the probability of autoignition in an indoor coal storage is somewhat higher. As coal has a high calorific value and many volatile components, the temperature rise due to heat accumulation and autoignition frequently occur when stored for a long time. It is known that autoignition occurs more frequently in an indoor coal storage because the temperature rise is faster than that in an outdoor coal stockpile. In the case of South Korea, there were nine fires caused by autoignition at three indoor coal storages during the five years from 2015 to 2019 [27]. Moreover, it requires larger upfront capital (construction cost) and O&M costs, relatively, depending on the size and form of the facility. In addition, safety issues of workers in indoor coal storage and the need to strengthen ventilation and monitoring can also be cited as disadvantages [24]. Therefore, it is critical to determine whether the environmental benefits of reducing coal dust can offset the relatively high costs of the facility. From this point of view, the benefit estimation and economic evaluation of building indoor coal storages have important implications.

Indoor coal storages have been in use since the 2000s. In the United States, although not for power plants' fuel, they have been used to store petroleum coke in St. Croix (Virgin Islands), Pittsburgh Marine Terminal in Pittsburgh (CA), and Los Angeles Export Terminal in San Pedro (CA) [28]. In Japan, the Misumi Coal Power Station is a representative example, where the world's first large-scale steel coal silo has been built and operated [29]. Additionally, China operates a dome coal storage system in the Houshi coal-fired power station [30]. In Europe, there are 200,000 tons of coal silo in Germany's Lünen Power Station [31] and 250,000 tons of underground coal storage in Finland's Salmisaari CHP power plant [24].

In South Korea, fine dust emissions have emerged as a nationwide concern and there are ongoing efforts to reduce air pollutants in the electric power sector. To this end, the construction of indoor coal storages in coal-fired power plants has been promoted. Among the twelve coal-fired thermal power stations in South Korea, the construction of indoor storages has been completed in five, while indoor systems have been partly introduced in three [32]. In particular, given the South Korean government's announcement of stricter regulations in May 2019, the promotion of indoor storage systems is gaining momentum. Amended regulations require that the six coal-fired power stations (Yeongheung, Boryeong, Samcheonpo, Dangjin, Taean, Hadong) should build indoor coal storages by 2024. However, it is argued that the amended regulations do not take into account the national coal power reduction plan and the practicality of the indoor system. Some power utilities that were supposed to shut down their coal-fired power plants are unsure if their facilities will remain unused or will be demolished after a short period of use. Therefore, estimating the benefits and evaluating the economic feasibility of constructing an indoor coal storage system can provide important information. This can also be beneficial to other countries that require similar decision-making.

3. Methodology

3.1. Contingent Valuation Method

This study uses the CVM to estimate the economic value of projects that build indoor open coal storages in Korea's major coal-fired power plants. It is relatively easy to estimate the economic value of goods traded on the markets because they have observable prices. However, it is difficult to assess the economic value of non-market goods, such as projects building indoor coal storages in coal-fired power plants. Therefore, this study applies CVM.

CVM is an economic valuation method that is used to estimate the monetary value of non-market goods, based on stated preference data [33]. It has a theoretical background in welfare economics. It can estimate both the use value and non-use value (i.e., existence value) of non-market goods. Accordingly, CVM has been widely used to assess the economic value of energy-related environmental goods, such as renewable electricity generation technologies [34–36], nuclear power plants [37,38], and carbon capture and storage technologies [39]. Using CVM, the economic value of energy-related environmental goods can be estimated in terms of WTP or willingness to accept (WTA). However, due to economic and psychological factors, a discrepancy exists between WTA and WTP, and WTA tends to be overvalued compared to WTP. Accordingly, in this study, the CVM was designed from the WTP perspective.

3.2. Double-Bounded Dichotomous Choice Spike Model (DBDC Spike Model)

CVM utilizes surveys to ask respondents to state the amount that they are willing to pay for the non-market goods that are being valued. There are many survey methods that elicit the respondents' WTP for the goods being valued, such as a bidding game (i.e., will you pay A; if not, will you pay A–B), payment card (i.e., which of these amounts would you choose?), open-ended question (i.e., how much would you pay?), and dichotomous choice (DC) question (i.e., if it costs A, would you pay for it? Yes/No). The most widely used method is the DC question, in which a researcher first presents a certain amount in a questionnaire, and then asks respondents whether they are willing to pay the amount; the respondents have to answer "Yes" or "No" [40]. The DC question method reduces the non-response rate because it simplifies the response. Moreover, it decreases the starting point bias and the likelihood of respondents exaggerating or reducing their WTP because the researcher sets multiple initial bids and presents them to the respondents.

Depending on the number of questions, the DC method is divided into a single bounded (SB) method and a double-bounded (DB) method. Compared to the SB method, the DB method improves the reliability of the point estimate, reduces its variance, and is statistically more efficient [41]. Currently, the double-bounded dichotomous choice (DBDC) method is the most widely used method in CVM studies. Thus, this study also uses the DBDC method to obtain data regarding the respondents' WTP.

The DBDC survey asks the respondents twice whether they are willing to pay a certain amount. In this study, the survey respondents were first asked if they were willing to pay a specified amount of additional tax toward the construction of indoor coal storages in Korea's major coal-fired power plants in order to reduce the problem of domestic fine dust and air pollution. If respondent i ($i = 1, \ldots, N$) answers "Yes" to the first presented additional tax A_i, the second presented additional tax $A_i^H (= 2 \times A_i)$ will be twice the first value. If respondent answers "No" to the first presented additional tax A_i, the second presented additional tax $A_i^L (= A_i/2)$ will be half of the first value. Among respondents who answer "No" to the first and second questions ("No"–"No"), those with zero WTP and those with positive WTP between 0 and A_i^L will be included. Therefore, this study identifies respondents with no WTP among respondents who answer "No"–"No" to the above questions by asking a third follow-up question (i.e., are you willing to pay anything at all?). Thus, the response patterns in our CVM survey are "Yes–Yes," "Yes–No," "No–Yes," "No–No–Yes," and "No–No–No." In this study, the DBDC CV spike model was used to model CVM survey response patterns [42,43]. Unlike the general DBDC CV model, this spike model considers the possibility that a respondent will have a WTP of 0.

The theoretical basis of the DBDC CV spike model is Hanemann's utility difference model [41,43,44]. In this model, the WTP of respondent i can be expressed as a random variable WTP_i, and its cumulative distribution function can be defined as $G_{WTP}(\cdot\,; \theta)$, where θ is a vector of parameters. Then, the probabilities for the five observable response patterns can be expressed as Equations (1)–(5).

$$\mathrm{P}(Yes - Yes) = \mathrm{P}\left(WTP_i \geq A_i^H\right) = 1 - G_{WTP}\left(A_i^H; \theta\right) \quad (1)$$

$$P(Yes-No) = P\left(A_i < WTP_i \leq A_i^H\right) = G_{WTP}\left(A_i^H;\theta\right) - G_{WTP}(A_i;\theta) \quad (2)$$

$$P(No-Yes) = P\left(A_i^L < WTP_i \leq A_i\right) = G_{WTP}(A_i;\theta) - G_{WTP}\left(A_i^L;\theta\right) \quad (3)$$

$$P(No-No-Yes) = P\left(0 < WTP_i < A_i^L\right) = G_{WTP}\left(A_i^L;\theta\right) - G_{WTP}(0;\theta) \quad (4)$$

$$P(No-No-No) = P(WTP_i = 0) = G_{WTP}(0;\theta) \quad (5)$$

To estimate this WTP distribution, it is assumed that the WTP is distributed as a logistic on the positive axis (log-logistic distribution) and $\theta = (a, b)$, as shown in Equation (6):

$$G_{WTP}(A;\theta) = \begin{cases} [1+\exp(a-bA)]^{-1}, & A > 0 \\ [1+\exp(a)]^{-1}, & A = 0 \\ 0, & A < 0 \end{cases} \quad (6)$$

Then, the log-likelihood function of the DBDC CV spike model can be defined, as shown in Equation (7), and the parameters can be estimated by maximizing it [43]. In this study, we used the statistical software R and its 'MaxLik' package to maximize the log-likelihood function and estimate the parameters.

$$\ln(L) = \sum_{i=1}^{N} \left\{ \begin{array}{c} I_i^{YY} ln\left[1 - G_{WTP}\left(A_i^H;\theta\right)\right] \\ +I_i^{YN} ln\left[G_{WTP}\left(A_i^H;\theta\right) - G_{WTP}(A_i;\theta)\right] \\ +I_i^{NY} ln\left[G_{WTP}(A_i;\theta) - G_{WTP}\left(A_i^L;\theta\right)\right] \\ +I_i^{NNY} ln\left[G_{WTP}\left(A_i^L;\theta\right) - G_{WTP}(0;\theta)\right] \\ +I_i^{NNN} lnG_{WTP}(0;\theta) \end{array} \right\} =$$
$$\sum_{i=1}^{N} \left\{ \begin{array}{c} I_i^{YY} ln\left[1 - \left[1+\exp\left(a-bA_i^H\right)\right]^{-1}\right] \\ +I_i^{YN} ln\left[\left[1+\exp\left(a-bA_i^H\right)\right]^{-1} - \left[1+\exp(a-bA_i)\right]^{-1}\right] \\ +I_i^{NY} ln\left[\left[1+\exp(a-bA_i)\right]^{-1} - \left[1+\exp\left(a-bA_i^L\right)\right]^{-1}\right] \\ +I_i^{NNY} ln\left[\left[1+\exp\left(a-bA_i^L\right)\right]^{-1} - \left[1+\exp(a)\right]^{-1}\right] \\ +I_i^{NNN} ln[1+\exp(a)]^{-1} \end{array} \right\} \quad (7)$$

where I_i^{YY}, I_i^{YN}, I_i^{NY}, I_i^{NNY}, and I_i^{NNN} are binary-valued indicator variables that indicate the five response patterns that were selected by the respondent. For example, if respondent i answers "Yes"–"Yes" in the CVM survey, I_i^{YY} will be 1; the other indicator variables will be 0.

In the DBDC CV spike model, the spike can be calculated by $[1+\exp(a)]^{-1}$ which indicates the share of respondents in the sample who have a WTP of 0. Then, the mean WTP can be calculated by $(1/b)\ln[1+\exp(a)]$ [44].

This study uses an additional model by replacing a in Equation (6) with $a + x_i'\beta$ to analyze the effect of the respondents' socio-demographic characteristics and environmental interest on their WTP; here, x_i' is the vector of variables for respondent i's socio-demographic characteristics or environmental interest, and β is the parameter vector to be estimated.

3.3. Survey Design and Data Collection

The survey was designed as follows: (1) Introductory section: questions were designed to ask the respondents about their interest in and perception of environmental issues; (2) Valuation section: contingent valuation questionnaires were designed to ask the respondents about their WTP for a project that builds indoor coal storages of major coal-fired power plants in Korea; (3) Final section: questionnaires were created to enquire about the respondent's demographic and socioeconomic characteristics. This is a typical CVM survey structure [45]. The demographic and socioeconomic characteristics of respondents (e.g., age, gender, income, and education level), as well as their level of environmental interest and perception, were surveyed because these factors were expected to affect their attitude and WTP toward the project.

In the valuation section, some biases may occur during the survey construction because of the hypothetical nature of the CVM. Thus, we tried to present a realistic situation to respondents and provide them with motivation to answer truthfully. Before the main contingent valuation questionnaire, respondents were provided with detailed explanations and visual content about the current coal-fired power plants in Korea, their outdoor open coal stockpiles, environmental problems caused by the operation of outdoor open coal stockpiles, and the benefits of a project that builds indoor coal stockpiles. Subsequently, respondents were informed of the possibility that their households may need to pay an additional tax for the project to build indoor coal stockpiles for the six major coal-fired power plants located in Yeongheung, Boryeong, Samcheonpo, Dangjin, Taean, and Hadong in Korea. In this study, we also assume that each respondent represents his or her household. The total coal storage capacity of the six coal-fired power plants is approximately 5.47 million tons, and the total site area is 1.15 million m^2.

For the DBDC survey, the initial bid amounts were divided into five types: KRW 10,000 (USD 9.11), KRW 30,000 (USD 27.33), KRW 50,000 (USD 45.55), KRW 70,000 (USD 63.77), and KRW 100,000 (USD 91.10); this was based on the project cost estimated by the government. The payment vehicle for the CVM survey was classified into lump-sum and annual (or monthly) payment, depending on the timing of the payment. For this study, the lump-sum payment is more appropriate because building an indoor coal storage is typically a one-time capital expenditure. Respondents were divided into five groups, and each group was presented one of the five initial bid amounts. Respondents who answered "No" to all of the aforementioned bid amounts in the first and second questions were asked whether they had no WTP for the project.

The survey was conducted online by a professional survey company (Gallup Korea) in May 2020. The respondents included 850 adults in Korea, aged 19–68 years. The purposive quota-sampling method that was based on the respondents' age, gender, and geographical region was used to maintain the component ratio of the actual Korean population. Table 1 summarizes the respondents' characteristics.

Table 1. Descriptive statistics of the respondents.

		No. of Respondents	Ratio (%)
Total number of respondents		850	100%
Gender	Male	447	52.6%
	Female	403	47.4%
Age	19–29	168	19.8%
	30–39	180	21.2%
	40–49	218	25.6%
	50–59	180	21.2%
	60 or higher	104	12.2%
Level of education	Less than high school	124	14.6%
	More than university/college	726	85.4%

Table 1. *Cont.*

		No. of Respondents	Ratio (%)
Average monthly household income	Less than KRW 2 million (USD 1822)	310	36.5%
	KRW 2–3 million (USD 1822–2733)	223	26.2%
	KRW 3–4 million (USD 2733–3643)	174	20.5%
	KRW 4–5 million (USD 3643–4554)	85	10.0%
	More than KRW 5 million (USD 4554)	58	6.8%

Note: KRW and USD denote South Korean won and United States dollars, respectively. We consider the USD equivalent as of 15 January 2021 (USD 1 = KRW 1097.69) (Bank of Korea; www.bok.or.kr (accessed on 15 January 2021)).

4. Results and Discussion

4.1. Survey Results

On enquiring about the degree of interest in environmental problems, 68.5% of respondents were found to be interested. On a 5-point Likert scale, 4 and 5 points were allotted if they were interested and very interested, respectively. Furthermore, 57.9% of the respondents found the current environmental issues of Korea to be at a bad level (1 point indicted very bad, and 2 points denoted bad).

With respect to the valuation section, to derive the respondents' WTP for the project that builds indoor coal storages of the six major coal-fired power plants in Korea, the respondents were divided into five groups. Each group was presented with one of the five initial bid values. Table 2 shows the distribution of respondents' responses, according to the initial bid amount.

Table 2. Distribution of responses based on bid amount.

Initial Bid Amount (KRW)	No. of Responses					
	Yes–Yes	Yes–No	No–Yes	No–No–Yes	No–No–No	Total
10,000	74 (42.3%)	37 (21.1%)	18 (10.3%)	7 (4.0%)	39 (22.3%)	175
30,000	47 (27.3%)	43 (25.0%)	15 (8.7%)	12 (7.0%)	55 (32.0%))	172
50,000	44 (24.4%)	30 (16.7%)	21 (11.7%)	18 (10.0%)	67 (37.2%)	180
70,000	21 (13.4%)	35 (22.3%)	24 (15.3%)	19 (12.1%)	58 (36.9%)	157
100,000	31 (18.7%)	26 (15.7%)	21 (12.7%)	26 (15.7%)	62 (37.3%)	166
Total	217 (25.5%))	171 (20.1%)	99 (11.6%)	82 (9.6%)	281 (33.1%)	850

As shown in Table 2, as the first bid amount increased, the number of "Yes–Yes" respondents decreased, and the number of "No–No"–"Yes–No" respondents increased. For example, the proportion of respondents who answered "Yes–Yes" when the first bid amount was KRW 10,000 was estimated to be 42.3%. However, when the first bid amount was KRW 70,000, the proportion of respondents who answered "Yes–Yes" was only 13.4%. Furthermore, when the first bid amount was KRW 10,000, the proportion of respondents who answered "No–No"–"Yes–No" was 26.3%, whereas it doubled to 53.0% when the first bid amount was KRW 70,000. These trends show that the quality of CVM data is suitable for estimating the WTP of households.

In particular, the proportion of respondents who answer "No–No–No" is high, at 33.1%. This implies that there are many respondents who think that a project that covers outdoor open coal stockpiles in coal-fired power plants has no impact on their own utility increase. These zero responses are often found in CVM studies when the goods being valued do not contribute to the respondent's utility under all the respondents' utility-maximization behavior [43]. Therefore, in this study, it is appropriate to use the DBDC spike model, which has the option to consider respondents with no WTP.

4.2. Estimation Results of DBDC Spike Model

In this study, two DBDV spike models were used. Model 1 did not consider covariates and it was used to estimate the average WTP of households. Model 2 included covariates of the respondents' demographic, socioeconomic, and environmental interest variables to identify factors that determined their WTP. Table 3 summarizes the definitions and statistics of the covariates used in Model 2.

Table 3. Definitions and sample statistics of covariates.

Variable	Definition	Mean	Standard Deviation
Gender	Respondent's gender (1= female; 0 = male)	0.47	0.50
Age	Respondent's age in years	42.91	12.90
Family	Size of the respondent's household (unit: persons)	3.09	1.19
Income	Monthly income level of the respondent's household (from 1 to 10)	5.00	4.06
Education	Respondent's education level in years	16.50	2.42
Interest in Environment	Interest in environmental issues (from 1 to 5)	3.81	0.75
Region	Whether respondent lives in the area* where the six coal-fired power plants (research target) are located (1 = resident; 0 = non-resident)	0.16	0.37

* Incheon, Chungcheongnam-do, and Gyeongsangnam-do, which are among the 17 metropolitan cities and provinces in Korea.

Table 4 shows the estimation results for Models 1 and 2. According to Model 1, all the parameters show statistically significant results at the 1% level. Moreover, the null hypothesis that all the parameter estimates are zero can be rejected at the 1% level, based on the Wald statistic. This indicates that Model 1 is statistically significant. The parameter of bid amount is negative at the level of significance of 1%, indicating that the probability of respondents answering "Yes" is lower when the bid amount is high. This is consistent with the results shown in Table 2. Furthermore, the spike parameters of Model 1 and Model 2 are estimated to be 0.3575 and 0.3540, respectively; they are found to be statistically significant at the 1% level. These estimated spike parameters are similar to the "No–No–No" response percentage shown in Table 2. This confirms that the DBDC spike models fit the data well.

According to the estimation results of Model 2, younger respondents and respondents with a higher interest in environmental issues are willing to pay more for a project that covers outdoor open coal stockpiles in coal-fired power plants. However, gender, income, education level, number of family members, and proximity of the respondents' residence to the six coal-fired power plants do not have statistically significant effects on their WTP. Therefore, respondents who are younger and more interested in environmental issues react more sensitively to the emission of pollutants from outdoor open coal stockpiles, and they are more likely to support the construction of indoor coal stockpiles in coal-fired power plants. With a gradual rise in public interest and the demand for a clean environment in recent years, it is expected that the economic value that the public assigns to indoor coal stockpiles in coal-fired power plants may increase in the future.

Table 4. Estimation results of the DBDC spike models (without and with covariates).

	Model 1 (Without Covariates)	Model 2 (With Covariates)
Constant	0.5864 *** (0.0683)	−1.1690 * (0.6031)
Bid amount	−0.000017 *** (0.00000086)	−0.000018 *** (0.00000089)
Gender	-	−0.1372 (0.1267)
Age	-	−0.0186 *** (0.0050)
Family	-	0.0115 (0.0554)
Income	-	−0.0054 (0.0173)
Education	-	0.0321 (0.0277)
Interest in Environment	-	0.5509 *** (0.0915)
Region	-	−0.0167 (0.1683)
Spike	0.3575 *** (0.0156)	0.3540 *** (0.0156)
Log likelihood	−1342.076	−1318.793
Wald statistics (*p*-values)	409.700 (0.000)	427.283 (0.000)

Notes: Standard errors are reported in parentheses; *** and * indicate statistical significance at the 1% and 10% levels; *p*-values correspond to the null hypothesis that all parameters are jointly zero.

Furthermore, the dummy variable that indicates whether respondents live in areas where coal-fired power plants are located does not have a statistically significant effect on the WTP for a project that builds indoor coal storages of coal-fired power plants in Korea. This demonstrates that the Korean public regards the environmental problems caused by outdoor open coal stockpiles of coal-fired power plants to be a national problem rather than a regional problem. Therefore, despite the geographical limitations of fugitive dust from outdoor coal stockpiles, the benefits of the project can be reaped on a national scale. This is because air pollutants, such as fine dust, have recently emerged as a national environmental issue in Korea, and coal-fired power plants have been identified as their major source. There could be support or opposition from the people at the national level as well as people living in the regions that directly benefit from the reduction in air pollution.

Moreover, the average WTP per household was calculated based on Model 1, and the results are shown in Table 5. The average WTP per household is estimated to be statistically significant at the 1% level. On average, Korean households are willing to pay about KRW 59,242.08 (USD 53.97) for the project that built facilities that cover coal stockpiles in Korea's six major coal-fired power plants.

4.3. Cost–Benefit Analysis

It is necessary to calculate the net social benefit to ensure the economic feasibility of implementing this project at the national level. To this end, the economic feasibility of this project was evaluated by calculating the aggregate economic benefit based on the average household WTP and comparing it with the project cost estimated by the government.

Table 5. Average willingness to pay per household.

Average WTP per Household	Confidence Interval
KRW 59,242.08 *** (USD 53.97)	95%: KRW 53,749.54–65,250.79 (USD 48.97–59.44)
	99%: KRW 52,053.46–67,271.26 (USD 47.42–61.28)

Notes: *** indicates statistical significance at the 1% level. The confidence intervals are computed by the Monte Carlo simulation method proposed by Krinsky and Robb [46] with 10,000 replications.

As the survey has sufficient conditions to represent the Korean population, the aggregate economic benefit can be easily calculated by multiplying the average WTP per household by the total number of Korean households [40]. According to the Korea National Statistical Office, the total number of Korean households in 2018 was 19.98 million. Therefore, the total economic benefit gained from the project is about KRW 1,183,657 million (USD 1078.32 million). Jha and Muller [10] reported that an increase of one ton of coal in the outdoor open coal stockpile can lead to an air pollution cost of approximately USD 197. Based on this result, the total benefit of the Korean project, having a scale of 5.47 million tons of coal (Table 6), is estimated to be USD 1077.59 million (KRW 1,182,860 million), which is similar to the result derived in this study. That is, it was found that the level of economic value that people perceive for the indoor coal storage is similar to the actual damage that the coal stockpile causes to people's health.

Table 6. Status of outdoor open coal stockpiles of Korea's six major coal-fired power plants and expected cost of building indoor coal stockpiles.

Coal-Fired Power Plants in Korea	Coal Storage Capacity (Thousand Tons)	Site Area (Thousand m^2)	Expected Cost of Building Indoor Coal Stockpiles
Incheon Yeongheung	880	170	KRW 530,000 million (USD 482.83 million)
Chungnam Boryeong	1270	250	KRW 490,000 million (USD 446.39 million)
Gyeongnam Samcheonpo	550	200	KRW 114,000 million (USD 103.85 million)
Chungnam Dangjin	730	140	KRW 470,000 million (USD 428.17 million)
Chungnam Taean	1140	220	KRW 143,000 million (USD 130.27 million)
Gyeongnam Hadong	900	170	KRW 530,000 million (USD 482.83 million)
Total	5470	1150	KRW 2,277,000 million (USD 2073.36 million)

Source: Cho and Oh [47].

According to the data from various media sources, the expected cost of building indoor coal stockpiles for six major coal-fired power plants in Korea (which is our CVM survey target) will be approximately KRW 2,277,000 million (USD 2074.36 million) (Table 6). Based on this, a cost–benefit analysis was conducted, as shown in Table 7. If the Korean government starts a project that builds indoor coal stockpiles for the six major coal-fired power plants in Korea, the cost is estimated to be KRW 1,093,300 million (USD 996.00 million), which is more than the benefit. The cost of this project is about 1.92 times that of the Korean people's WTP. Additionally, the benefit–cost ratio is 0.52, which is less than 1. Therefore, it is not an economically viable project. For this reason, social opposition is expected if the cost of the project is passed on to the public in a direct or indirect manner (e.g., increasing electricity rates).

Table 7. Cost–benefit analysis for the project of building indoor coal stockpiles.

Size of Coal Stockpiles	Aggregated Benefit (A)	Cost (B)	Cost–Benefit (B-A)	Benefit–Cost Ratio (A/B)
Coal stockpiles of six major coal-fired power plants in Korea (5.47 million tons of coal, the total site area of 1.15 million m^2).	KRW 1,183,657 million (USD 1078.32 million)	KRW 2,277,000 million (USD 2074.36 million)	KRW 1,093,300 million (USD 996.00 million)	0.520

It is necessary to consider the fact that the Korean government is actively increasing renewable energy and natural gas-fired power in the electricity generation mix, while gradually shutting down existing coal-fired power plants. According to the 9th Basic Plan for Power Supply and Demand, the Korean government plans to shut down all the coal-fired power plants that have been in operation for approximately 30 years, or it aims to convert them to natural gas-fired power plants by 2030. It is a national plan that contains Korea's comprehensive power policy, such as the basic direction of power supply and demand for the next 15 years, power facility planning, and power demand management. It is established and implemented every two years and occupies the most important position in the Korean power sector. The six coal-fired power plants that are the subject of this study are also scheduled to meet the same fate. In this situation, the construction of indoor coal stockpiles for coal-fired power plants will be redundant. From a social perspective, it would be ideal for the Korean government to carry out other projects that will be more cost-effective at reducing air pollution.

5. Conclusions

Given the impact of air pollution generated from the energy sector and the growing public interest in it, this study focuses on the fugitive dust generated from a coal storage yard in a thermal power plant. There is a need to reduce fugitive dust generated when storing and handling coal in outdoor coal yards. To this end, the construction of indoor coal storage has emerged as an effective measure. However, even though the construction of an indoor coal storage has environmental benefits, it requires a considerable amount of capital investment. Thus, this study calculated the benefits and costs of the project and assessed its economic feasibility.

The results showed that the Korean public was willing to pay KRW 59,242 (USD 53.97) per household to construct indoor coal storages at six coal-fired power plants (storage capacity of 5.47 million tons of coal, with a site area of 1.15 million m^2). They regarded the air pollution caused by the coal storage yard as a national problem rather than a local problem. It was also confirmed that only age and environmental concern had a significant effect on their WTP. The aggregate economic benefit of the six indoor coal storages was about KRW 1.18 trillion (USD 1.07 billion), which is far less than the estimated total cost of the project, which is estimated to be KRW 2.28 trillion (USD 2.07 billion). The benefit–cost ratio of the suggested project was 0.52, which is not economically feasible. Therefore, public resistance may increase if the cost of the construction of indoor coal storage is passed on to the public. Moreover, considering the South Korean government's plans to close most coal-fired power plants by 2034, the construction of new indoor coal storages could be a waste of public financial resources. The South Korean government should spend their budget on other cost-effective air quality improvement projects.

This study has some limitations. First, there are inherent limitations of the SP data. Although this study complied with the standard guidelines of the CV questionnaire and related procedure, the hypothetical nature of SP methods, which is one of the major weaknesses of the SP technique, still remains. Therefore, it is necessary to compare and verify the monetary value of indoor coal storage using other techniques. Second, as data were collected from a single source in a specific country, care should be taken when applying the results to other regions or contexts. Moreover, in this study, the current survey sample represents the entire Korean population, but if the study is conducted with people actually living near coal power plants, different results may be obtained. Thus, if a future study can be conducted using such a sample and compared with the results of this study, more meaningful policy implications will be drawn. Third, related to the cost–benefit analysis, future studies need to refine the cost estimation of indoor coal storages. This study presented a rough cost estimation based on the outline of the project; however, more accurate results can be derived if the exact type and size of the individual indoor coal storage is known.

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