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Regional Differences in Willingness to Pay for Mitigation of Air Pollution from Coal-Fired Power Plants in South Korea

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Abstract: This study examined whether people who reside in different regions of South Korea exhibit different WTP for the mitigation of PM2.5 emissions from coal-fired power plants by restricting their operation during the winter and spring when air pollution becomes severe. The eastern portions of the country are relatively insulated from the harmful effects of PM2.5 emissions due to northwest winds which cause air pollutants generated from coal-fired power plants to be carried out to the East Sea (Sea of Japan). Consequently, our sample group was divided into central, western, eastern, and southern regions, and a contingent valuation method, combined with a double-bounded dichotomous choice, was used to derive people's WTP for the mitigation of PM2.5 emissions. Our estimation results indicated that respondents who live in eastern regions showed a significantly lower WTP (about KRW 1280/month) than the mean WTP of other regions (above KRW 1337/month). Thus, we suggest that the current Seasonal Management System of PM2.5 emissions should be modified to consider regional differences. Statistical results from this study reinforce our suggestions—almost 78 percent of survey respondents support a revision of the current SMS policy and are in favor of a revised SMS policy—one that exempts eastern regions from a nationwide shutdown of coal-fired generation from December to March. Exempting coal-fired power plants in eastern regions from the Seasonal Management System might result in significant fiscal savings without a corresponding increase in nationwide PM2.5 concentrations.

Keywords: PM2.5 emissions; regional difference; contingent valuation method; willingness to pay; coal-fired power plants

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1. Introduction

South Korea experiences severe air pollution as measured by high daily average fine particulate matter (PM2.5) concentrations between January and March every year. PM2.5 is an air pollutant and is defined as particles that are 2.5 microns or less in diameter. Breathing in unhealthy levels of PM2.5 can increase the risk of health problems like heart disease, asthma, and low birth weight. Unhealthy levels can also reduce visibility and cause the air to appear hazy. In addition, PM2.5, which can be laden with lead and arsenic, can penetrate the lungs through inhalation and cause adverse health effects such as local and systemic inflammation. According to recent studies [1,2], nationwide actions to reduce energy-related emissions could significantly prevent premature deaths and provide tremendous economic benefits from a avoided in death and illness. Moreover, between 32% and 95% of the health benefits will remain in the region where pollution was eliminated. Among all OECD countries, South Korea has the highest PM2.5 concentrations, and according to an OECD report [3], Korea could suffer the highest GDP losses among the OECD countries as its poor air quality will lead to reduced labor productivity, increased health costs, and shortfalls in crop yields.

In Korea, the Comprehensive Action Plan on Fine Dust Management was implemented in 2017 whose goal is to reduce PM2.5 emissions by 30% by 2022 compared with the level in 2014 and to reduce the annual average PM2.5 concentration in Seoul to 17–18 μg/m^3 [4]. As a specific response to the air-quality disaster of 2019 (in March 2019, Korea experienced unprecedented air pollution as ultrafine particulate matter (PM2.5) concentrations increased drastically and remained at a significantly elevated level for one week), the Korean government decided to establish a "Seasonal Management System of PM2.5 emissions" (SMS) policy that temporarily shuts down a set of coal units or reduces their maximum power outputs between December and March of each year [5]. Figures A1 and A2 (Appendix A) provide additional information about the Korean SMS policy and the location of coal-fired plants in the country. This policy has been applied to sources of air pollution in the transportation, industry, power, and residential sectors. As of 2020, South Korea enforces regulatory limits on 11 air pollutants and 32 hazardous air substances. The Korean SMS policy can potentially reduce PM2.5 concentrations which can lead to benefits such as improved labor productivity, increased outdoor activities, and increased crop yields. However, such a policy can also engender corresponding losses—first, as coal-fired power plants cannot operate or operate with restricted capacity for four months every year, liquefied natural gas (LNG) plants must complement the insufficient electricity supply. As the electricity production costs of LNG power plants are significantly higher than those of coal-fired power plants, there is a resultant increase in electricity prices. Second, municipal tax revenue is reduced when coal-fired power plants are either phased out or operated below maximum capacity (local resource/facility taxes will not increase at the same proportion as the loss of revenue from idled coal plants). South Korean power plants are required to pay a per unit tax, the so-called "local resource and facility tax" (0.3 KRW/kWh), to corresponding local governments. It is estimated that the total local tax revenue losses would be approximately KRW 7 billion in 2021 (exchange rate in 2021 was USD 1.0 = KRW 1217.) (Korean Southern Power Corporation, 2021). Finally, a seasonal management policy can also result in the loss of local jobs as old coal-fired power plants are idled and then phased out.

The foregoing suggests that air quality management in South Korea is a complex problem—one that requires a nuanced understanding of the costs and benefits inherent in the seasonal management policy. In this paper, we examine whether individuals are willing to pay a higher electricity bill resulting from a substitution away from coal and into LNG. Although various socio-demographic characteristics such as education, income, age, sex, and awareness of the sources of air pollution can affect individual willingness to pay (WTP) for the net benefits stemming from environmental regulations, this study uniquely focuses on regional differences as an important antecedent of individual WTP.

Regional differences and variations play an important role in assessing the PM2.5 emissions and their dispersion in South Korea. The eastern portions of the country are relatively insulated from the harmful effects of PM2.5 emissions due to northwest winds which cause air pollutants generated from coal-fired power plants to be carried out to the East Sea (Sea of Japan). Figure A3 (Appendix A) illustrates this. Thus, the suspension or restriction of coal-fired plants in the eastern region of the country has a negligible impact on national PM2.5 concentrations. Yet, blanket enforcement of the SMS policy without accounting for regional differences results in excessive costs being borne by people in the eastern regions relative to the rest of the country. Some of these costs can take the form of a loss in tax revenue and loss of local jobs as coal plants are idled throughout the country. In other words, a one-size-fits-all SMS policy to manage PM2.5 emissions can result in sub-optimal economic outcomes and a misallocation of resources.

Given their relatively reduced exposure to PM2.5 concentrations, do people in the eastern regions of Korea have a lower WTP for clean air compared to the rest of the country? Our study will attempt to answer this research question by utilizing a contingent valuation method (CVM). In addition to considering the regional specificity of respondent residences, our methodology will also examine several socio-demographic variables—including education, income, age, sex, and membership in environmental NGOs. A goal of this study is to highlight that regional differences matter when estimating respondent WTP for air quality. We develop a framework to estimate differences in WTP based on the regional location of respondents even within the same country. To the best of our knowledge, there has been no study in this vein. WTP for environmental quality is a key parameter for policy design, but well-identified estimates of this parameter are barely available for air quality. The policy implications are straightforward: if the WTP of eastern residents is indeed lower compared to the rest of the country, then a "one-size-fits-all" SMS policy is inefficient and deserves to be revisited.

A second novelty of our study is that we provide the first revealed preference estimates of WTP for clean air, disaggregated by region in South Korea. We believe that the findings of our study are potentially applicable to other countries that are designing policies to address air pollution problems. Because environmental policies are not costless, the WTP methodological approach of our study helps address the issue of whether the benefit of a policy exceeds its cost, and therefore, enhances social welfare.

2. Literature Review: Contingent Valuation and Willingness to Pay

Contingent valuation (CVM) has been used to measure the values of environmental goods that do not have market prices [6]. The CVM constructs a hypothetical market that describes how potential consumers can buy environmental goods by providing information on the benefits and costs of purchasing non-market goods. This is a survey-based method which queries respondents directly on their WTP for environmental and public goods. However, the way in which the questionnaire asks people to respond with their WTP for the environmental goods can affect the reliability of the WTP.

Different formats of the CVM can be used to estimate WTP for non-market goods. Several studies use open-ended (OE) surveys [7–9] where respondents are directly asked to state their maximum WTP. However, the OE method can lead to large non-response rates, protest answers, zero answers, outliers, and generally, to unreliable responses [10]. In general, it is hard for respondents to value policies that they have little information on because these respondents are not used to thinking in terms of maximum WTP values.

Payment card (PC) approaches were developed as improved alternatives to the OE method. The PC approach also asks respondents' maximum WTP, but respondents are also provided with visual aids containing several monetary options for ease of valuation. Respondents can choose only among given values which reduces outliers and mitigates a starting point bias that can arise when the respondent is influenced by the initial numbers given as examples or as part of a range in the survey. Several variants of the payment card method have also been developed and empirically utilized by scholars among scholars [9,11–13]. However, the PC method is still vulnerable to range biases in cases where the respondent's true WTP is relatively low (high) compared to the lower (upper) bound of monetary values presented on the payment card. Additionally, the PC method can yield biased estimates of WTP such as a centering bias that is the result of respondent choices shifting toward the center of the range or an end-point bias which refers to the effects of various starting points of the payment card values [10,14].

Recent CVM studies have adopted the DC (dichotomous choice) approach, opting for either the single-bounded dichotomous choice (SBDC) method [15], or the double-bounded dichotomous choice (DBDC) method [16], or one-and-one-half-bounded (OOHB) DC method [17,18]. There are several advantages of the DC approach including ease of answering questions presented, absence of starting point bias, range bias, and biases arising from the strategic behaviors of respondents. In the DC approach, respondents are asked whether they are willing to pay a given amount (bid) for some public good by just answering Yes or No. The SBDC survey format is like a "take it or leave it" approach but in the DBDC method, the second highest bid is offered to the respondents if the answer was Yes, and the lower bid if the answer was No. There are a number of studies that have utilized the SBDC approach to estimate WTP of reduction in PM2.5 pollutions [9,15,19,20] as well as the DBDC method [21,22]. Some scholars have argued that DBDC is more efficient than the SBDC [23]; however, a recent study [24] used a Monte Carlo analysis to demonstrate that the difference between the two approaches tends to decrease as one increases the sample size.

Apart from above-mentioned methods, some studies used a variety of other methodologies such as the Benefit transfer (BT) method [25], the Principal component analysis [26], the Multi-parameter quantitative regression model [27], and the Multiple bound discrete choice approach [28].

A considerable amount of literature in the CVM space has directed attention to the differences between various CVM techniques. For example, Afroz et al. [9] compares methods such as OE, DC, and PC to note insignificant differences in the WTP values for higher fuel prices to minimize the concentration rates of SO_2, CO, NO_2, and PM in Klang Valley, Malaysia. Ardakani et al. [21] used the SBDC and DBDC methods to prepare a survey questionnaire to estimate the WTP of people for reducing air pollution concentrations via the application of an environmental tax in four distinct regions of Tehran (in four selected regions: Shahr-e-Ray, Shoosh, Haft-e-Tir, and Tajrish). The authors found that the average annual WTP of the respondents based on the DBDC method was higher than the corresponding WTP using the SBDC approach. Pertinent to our study, the authors also demonstrated a regional variation among the WTP results. The average WTP of respondents who lived in Tajrish was higher than that of respondents who lived in the other areas. However, they did not clarify the reasons for these regional differences in WTP.

According to several scholars, the DBDC approach [29–31] is an efficient CVM method. Hanemann et al. [23] conclude that the DBDC approach provides more certainty compared to the SBDC method. This conclusion is reinforced by Lusk and Hudson [32] who note that the DBDC approach led to greater accuracy for estimated coefficients and a lower mean squared error. For all of these reasons, we will adopt the DBDC methodology for our WTP estimation as detailed below.

Our exhaustive survey of literature as shown in Table 1 indicates that only one study based in Iran [21] has taken a similar regional approach to comparing WTP for improving air pollution. However, this study did not explore the reasons for the regional variations in respondents' WTP. Our study attempts to extend this line of research by providing a rationale for regional differences in the valuation of the PM2.5 mitigation policy.

Table 1. Extant studies on people's WTP for improving air quality.

Authors/ Publication Year	Air Pollution Type	Research Focus and Time Period	Method **	Actual Annual WTP	Annual WTP in USD *
Nguyen et al. (2021) [7]	Air quality improvement measures	Hanoi, Vietnam in May and June 2018	OE	VND 148,000 per person	6.45 per person
Rozan (2004) ** [25]	SO_2, CO, NO_2, and PM	Strasbourg (France) and Kehl (Germany) in January 1998	BT	FRG 465.3 per person	80.2 per person
Wang and Zhang (2009) [8]	PM	Ji'nan (China) in December 2005 and April 2006	OE	CNY 107 per person	16.6 per person
Tantiwat et al. (2021) [22]	Benefit from air quality improvement	Bangkok, Thailand June–October 2020	DBDC	THB 2275 per person	71 per person
Wei and Wu (2017) [11]	PM2.5	JingJinJi Region, China in 2015	PC	CNY 602 per household	93.3 per household
Ardakani et al. (2017) [21]	SO_2, CO, NO_2, and PM	Shahr-e-Ray, Shoosh, Haft-e-Tir, and Tajrish (Tehran) in 2015	SBDC	USD 5 per person	5 per person
			DBDC	USD 8.06 per person	8.06 per person
Kim et al. (2018) [18]	PM2.5	South Korean Urban Areas in June 2017	OOHB DC	KRW 5591 per household	4.9 per household
Ouyang et al. (2019) [26]	PM2.5	Shanghai (China) in 2017	Principal component analysis	USD 343.3 per household	343.3 per household
Wang et al. (2019) [27]	PM2.5	Beijing-Tianjin-Hebei (China) in November 2017 and January 2018	Multi-parameter quantitative regression model	CNY 59.8 per person	9.3 per person
Zahedi et al. (2019) [20]	GHG, PM	Catalonia (Spain) in May and June 2015	SBDC	EUR 88.9–177.5 per household	79.97–103.1 per household
Guo et al. (2020) [13]	PM, O3, NO2, and SO2	Zhengzhou, Pingdingshan, Zhumadian (China) in May 2016	PC over binary-choice	CNY 65 per person	10.1 per person
Pu et al. (2019) [12]	PM	31 provinces in China from December 2016 to February 2017	PC	CNY 275.39 per person	42.7 per person
Wang et al. (2020) [28]	PM2.5	Guiyang and Xingtai (China) September-December 2014	Multiple bound discrete choice	CNY 1448.4 per person	224.6 per person

* Reported WTP results were converted to 2021 USD based on exchange rates published by the International Monetary Fund's collection of development indicators (IMF, 2021): USD 1 = CNY 6.45; USD 1 = EUR 0.9; USD 1 = VND 22,938; USD 1 = KWR 1142.9; USD 1 = MYR 4.14; USD 1 = SEK 8.6; USD 1 = FRF 5.8; USD 1 = THB 31.99. ** Estimation methods: OE—open-ended; BT—Benefit transfer; DC—Dichotomous choice; PC—payment card; SBDC—Single-bounded dichotomous choice; DBDC—Double-bounded dichotomous choice; OOHB DC—one-and-one-half-bound dichotomous choice.

3. Materials and Methods

In this section, we first outline our methodology and then provide a description of the survey instrument utilized to solicit respondent choices.

As discussed above, this study adopts a CVM in conjunction with a DBDC technique to derive respondent WTP. The DBDC approach offers a two-stage bidding process to respondents [33,34]. With this method, the respondents have two options: "Yes" or "No." The second bid value is based on the first bid value, which can be lower or higher. Thus, if the respondents choose "Yes" to the first bid value, they will be given the higher value in the second bid. Alternatively, if the respondents choose "No" to the first bid value, they will face a lower value in the second bid. Hence, the DBDC method has four possibilities, which are "Yes-Yes", "Yes-No", "No-Yes", and "No-No."

Thus, suppose that amount of the first bid is *b1* and the second bid is *b2*, then each respondent will be in one of the following categories:

1. "Yes" to the first bid and "No" to the second, then $b2 > b1$, so $b1 \leq$ WTP $< b2$
2. "Yes" to the first bid and "Yes" to the second, then $b2 > b1$, so $b2 \leq$ WTP $<\infty$
3. "No" to the first bid and "Yes" to the second, then $b2 < b1$, so $b2 \leq$ WTP $< b1$
4. "No" to the first bid and "No" to the second, then $b2 < b1$, so $0 <$ WTP $< b2$

The estimation of WTP is based on the following linear function [34]:

$$WTP_i(Z_i, v_i) = Z_i\alpha + v_i \tag{1}$$

where Z_i is a vector of independent variables, α is a vector of parameters, and v_i is an error term with $v_i \sim N(0, \sigma^2)$.

We define b^1 as the first bid value and b^2 as the second bid value, and we also define $\varphi(X)$ as the standard cumulative normal function. We denote the answer of an individual by a dichotomous variable x_i, where $x_i = 1$ if the answer is "Yes" and $x_i = 0$ if the answer is "No." The probabilities that an individual will answer "Yes-Yes", "Yes-No", "No-Yes", and "No-No" to the two bid values can be expressed as $Pr\ Pr\ (y, y)$, $Pr\ Pr\ (y, n)$, $Pr\ Pr\ (n, y)$, and $Pr\ Pr\ (n, n)$, respectively. This is illustrated below via Equations (4)–(7).

Consider the following four probabilities:

1. The probability of the case: "Yes" for the first bid and "Yes" for the second bid

$$\begin{aligned} Pr\ Pr\ (y, y) &= Pr\ Pr\ \left(WTP > b^1, WTP \geq b^2\right) \\ &= Pr\ Pr\ \left(Z_i\alpha + v_i > b^1, Z_i + v_i \geq b^2\right) \end{aligned} \tag{2}$$

Applying Bayes rule $Pr\ Pr\ (A, B) = Pr\ Pr\ (B) \times Pr\ Pr\ (B)$ to Equation (2), we obtain the following:

$$Pr\ Pr\ (y, y) = Pr\ Pr\ \left(Z_i\alpha + v_i \geq b^2\right) \times Pr\ Pr\ \left(Z_i\alpha + v_i \geq b^2\right) \tag{3}$$

According to this case, the second bid value is higher than the first bid value, so we obtain $b^2 > b^1$, which leads to $Pr\ Pr\ \left(Z_i\alpha + v_i \geq b^2\right) = 1$, which then implies the following:

$$Pr\ Pr\ (y, y) = Pr\ Pr\ \left(v_i \geq b^2 - Z_i\alpha\right) = 1 - \left(\frac{b^2 - Z_i\alpha}{\sigma}\right) = \left(Z_i\frac{\alpha}{\sigma} - \frac{b^2}{\sigma}\right) \tag{4}$$

2. The probability of the case: "Yes" for the first bid and "No" for the second bid

$$\begin{aligned} Pr\ Pr\ (y, n) = Pr\ Pr\ \left(b^1 \leq WTP < b^2\right) = Pr\ Pr\ \left(b^1 \leq Z_i\alpha + v_i < b^2\right) = Pr\ Pr\ \left(\frac{b^1 - Z_i\alpha}{\sigma} \leq \frac{v_i}{\sigma} < \frac{b^2 - Z_i\alpha}{\sigma}\right) \\ = \left(\frac{b^2 - Z_i\alpha}{\sigma}\right) - \left(\frac{b^1 - Z_i\alpha}{\sigma}\right) = \left(Z_i\frac{\alpha}{\sigma} - \frac{b^1}{\sigma}\right) - \left(Z_i\frac{\alpha}{\sigma} - \frac{b^2}{\sigma}\right) \end{aligned} \tag{5}$$

3. The probability of the case: "No" for the first bid and "Yes" for the second bid

$$Pr\ Pr\ (n, y) = Pr\ Pr\ \left(b^2 \leq WTP < b^1\right) = Pr\ Pr\ \left(b^2 \leq Z_i\alpha + v_i < b^1\right) = \\ Pr\ Pr\ \left(\frac{b^2 - Z_i\alpha}{\sigma} \leq \frac{v_i}{\sigma} < \frac{b^1 - Z_i\alpha}{\sigma}\right) = Pr\ Pr\ \left(\frac{b^2 - Z_i\alpha}{\sigma} \leq \frac{v_i}{\sigma} < \frac{b^1 - Z_i\alpha}{\sigma}\right) = \left(Z_i\frac{\alpha}{\sigma} - \frac{b^2}{\sigma}\right) \tag{6}$$

4. The probability of the case: "No" for the first bid and "No" for the second bid

$$(n, n) = Pr\ Pr\ \left(WTP < b^1, WTP < b^2\right) = Pr\ Pr\ \left(Z_i\alpha + v_i < b^1, Z_i\alpha + v_i < b^2\right) = \left(Z_i\alpha + v_i < b^2\right) = \\ \left(\frac{b^2 - Z_i\alpha}{\sigma}\right) = 1 - \left(Z_i\frac{\alpha}{\sigma} - \frac{b^2}{\sigma}\right) \tag{7}$$

To estimate α and σ, we use maximum likelihood estimation, because Equation (4) through Equation (7) do not correlate directly with the probit model. Hence, we need to maximize the objective function to find the parameters as shown below:

$$\sum_{i=1}^{N}\left[D_i^{yy}ln\left(\left(Z_i\frac{\alpha}{\sigma} - \frac{b^2}{\sigma}\right)\right) + D_i^{yn}ln\left(\varphi\left(Z_i\frac{\alpha}{\sigma} - \frac{b^1}{\sigma}\right) - \left(Z_i\frac{\alpha}{\sigma} - \frac{b^2}{\sigma}\right)\right) \\ + D_i^{ny}ln\left(\left(Z_i\frac{\alpha}{\sigma} - \frac{b^2}{\sigma}\right) - \left(Z_i\frac{\alpha}{\sigma} - \frac{b^1}{\sigma}\right)\right) + D_i^{nn}ln\left(1 - \left(Z_i\frac{\alpha}{\sigma} - \frac{b^2}{\sigma}\right)\right)\right] \tag{8}$$

where $D_i^{yy}, D_i^{yn}, D_i^{ny},\ and\ D_i^{nn}$ are the dummy variables, they take the value of one or zero, which relies on the particular case for each individual.

To estimate WTP, $\hat{\beta}$ and δ are estimated using Equation (9) as follows:

$$\hat{\beta} = -\frac{\hat{\alpha}}{\hat{\delta}}\ and\ \hat{\delta} = -\frac{1}{\hat{\sigma}} \tag{9}$$

where $\hat{\beta}$ is the vector of coefficients associated with each of the explanatory variables and $\hat{\delta}$ is the coefficient for the variable capturing the amount of the bid. We can then estimate the WTP for individuals, which is given by the following:

$$E\left(\widetilde{Z}_i,\ \beta\right) = \widetilde{Z}'\left[-\frac{\hat{\alpha}}{\hat{\delta}}\right] \tag{10}$$

We describe our survey instrument next.

The Korea Research Survey Company (Seoul, South Korea. http://www.hrc.co.kr, accessed on 18 January 2023) conducted a preliminary review and several focus group interviews before conducting a final survey in July 2021. The survey was conducted online by sending a Uniform Resource Locator (URL) link to mobile phones through text messaging and e-mail. In total, we received 1502 completed surveys which corresponds to 21 percent response rate. More detailed information about the survey process is provided in Table 2.

The survey questionnaire consisted of four sections: the introduction contained socio-demographic information questions relating to age, region of residence, and gender. Then we provided information on coal-fired electricity plant closures by province. (Chungnam (30 units), Gyeongnam (14 units), Gangwon (4 units), Jeonnam (4 units), Incheon (6 units.) We also provided context on these closures by describing the Korean seasonal management system (SMS) policy for reducing PM2.5 emissions and gauged respondent awareness of the current state of this policy. The survey also queried respondents about their understanding of the benefits and costs of the SMS policy. The described benefits included an increased number of days with good air quality (from 13 to 28 days; a decrease in number of days with bad air quality (from 35 to 22 days); a reduction in PM2.5 emissions by 30 percent during the operation of the SMS policy from December to March of every year. Respondents were informed that the decline in PM2.5 emissions was not uniform across the nation. Central (central region includes Seoul, Gyeonggido, and Incheon metropolitan cities), southern (southern region covers Jeonnam, Gyeongnam, Gwangju, and Jeju municipalities), and western (western region includes Chungnam, Chungbuk, Jeonbuk, Daejeon, and Sejong municipalities) regions of the country saw greater reductions compared to the eastern region (eastern region covers Kangwon, Gyeongbuk, Daegue, Ulsan, and Busan metropolitan cities).

Table 2. Outline of the survey process.

Division	Content
Population group	Adult men and women 18 years old or older who live in South Korea.
Panel of sample	Korea Research Master Panel (about 590,000 people as of the end of June 2021)
Sampling method	Proportional allocation and extraction based on region, gender, and age
Sample size	1502 people
Sampling error	Based on random sampling with a 95% confidence level, the maximum allowable sampling error is $\pm$2.5%p.
Survey method	Web research (sending a URL through mobile phone text messaging and e-mail)
Response rate	Survey questionnaires were sent to 7129 people, and 1689 people responded to the survey. Ultimately, 1502 people completed the survey (21.1% of requests, 88.9% participation)
Survey period	13–18 July 2021
Survey agency	Korea Research Co., Ltd., Seoul, South Korea

The questionnaire also described losses associated with the SMS policy such as those stemming from electricity plant operation restrictions that included a decrease in revenue of electricity producers (about KRW 800 billion per year); a decrease in Regional Development tax revenues (KRW 7 billion); and a fall in local employment as plants were idled. The survey questionnaire also queried respondents about their knowledge of the origin of PM2.5 and whether respondents suffered from any diseases or symptoms related to air pollution.

The second section of the survey questionnaire detailed the regional spread of PM2.5 emissions in South Korea from December to March when the nationwide SMS policy was in effect. Figure 1 shows the change in the concentration of PM2.5 when the emissions from coal-fired power plants were reduced by 50 percent in January and March. The figure clearly indicates that the SMS policy was significant in reducing PM2.5 concentration in the central, western, and southern regions of the country but made only minor differences in PM2.5 concentration in the eastern region. The questionnaire explained that the eastern parts of the country naturally benefitted from the flow of northwest winds that discharged pollutants to the East Sea during December–March. The survey questionnaire then solicited respondents' views on the effectiveness of the current SMS policy that was applied nationwide and whether such a blanket policy should be modified to account for regional differences.

In the third section of the survey, respondents were queried about their WTP for the PM2.5 SMS policy via increases in their monthly electricity bills by explicitly considering regional differences between the eastern region and the rest of the country. Survey respondents were divided into five groups with different bids to apply the DBDC approach in estimating WTP. Table 3 presents the values of two-stage bidding. As stated, the total sample was divided into five groups, and each group was offered a different initial bid (KRW 100, 300, 500, 700, 900/month), as presented in column 2 of Table 3. We examined the responses to the first bids carefully. As indicated in the fourth column of Table 3, if the initial response was a "Yes", then we doubled the size of the bid. Similarly, we halved the size of the subsequent bid if the initial response was a "No".

Section 4 of the survey contained socio-demographic characteristics of the respondents, such as their educational backgrounds, household composition, residence type, monthly average income, their membership in environmental NGOs, and political preferences.

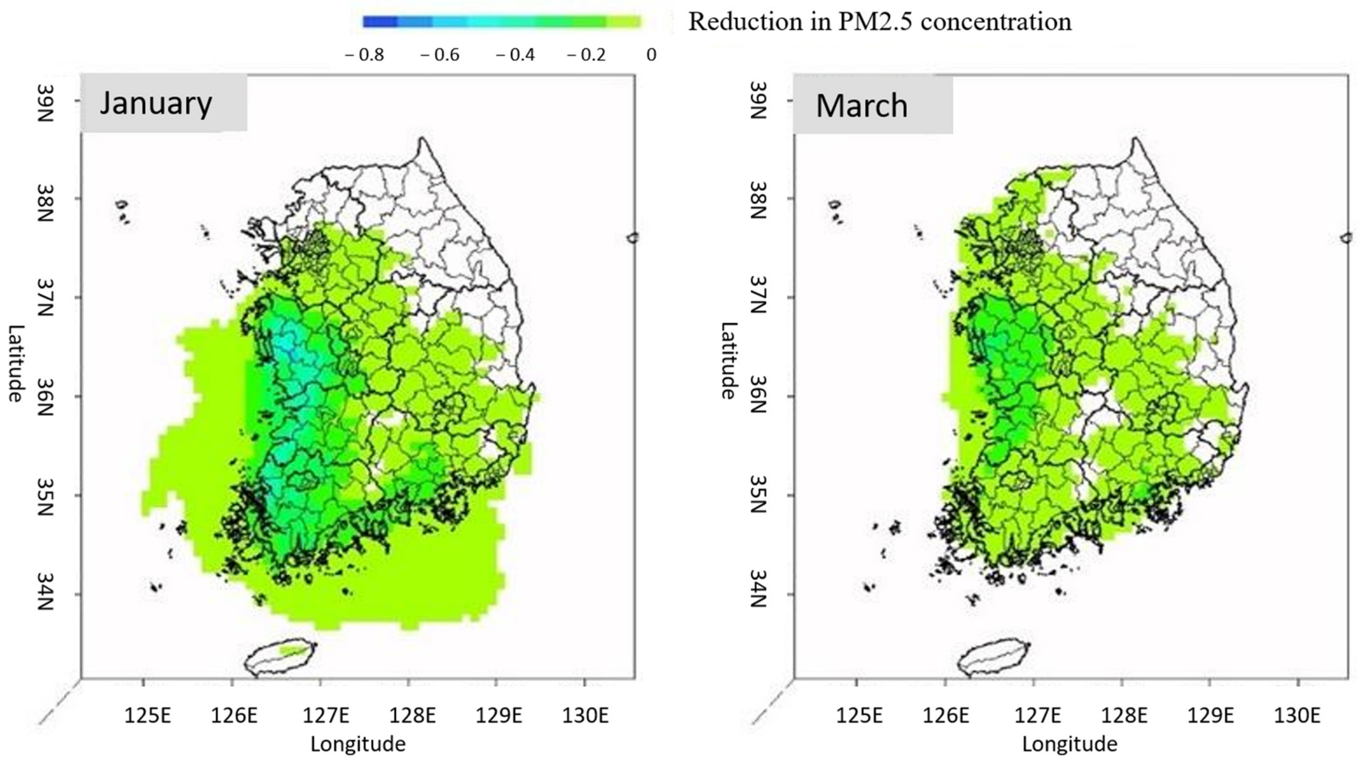

Figure 1. Contribution of SMS policy on the mitigation of PM2.5 accumulations.

Table 3. Suggested bids (we conducted focus group interviews to determine the appropriate initial bid range) in each stage for different groups (Units: KRW per month).

No.	Initial Suggested Bids	Suggested Bids for "Yes" Answer	Suggested Bids for "No" Answer
Group 1	100	200	50
Group 2	300	600	150
Group 3	500	1000	250
Group 4	700	1400	350
Group 5	900	1800	450

4. Results and Discussion

The basic statistics for the socio-demographic characteristics of the respondents are summarized in Table 4. An amount of 49.7 percent of our sample is male, and the rest identified as female. The average age of the respondents is 47 years old. About half of our respondents live in central regions such as Seoul, Incheon, and Gyeonggi, while about 30 percent of respondents reside in eastern regions including Daegu, Gyeongbuk, Busan, Ulsan, Gyeongnam, and Gangwon. Respondents who graduated college or had higher educational levels represented about 70 percent of the sample. Respondents' incomes are distributed relatively evenly, and the average respondents' monthly income is about KRW 3 million. Most of the respondents are not members of environmental NGOs. Regarding respondents' political preferences, 57.7 percent report they are neutral, 25.6 percent identify as progressives, while 16.7 percent report being conservative. Table 5 provides descriptive statistics (the actual survey questions of variables in Table 5 are provided in Appendix A (Table A1)).

The survey results indicated that two-thirds of respondents agreed that coal-fired plans ought to be shutting down from December to March to manage PM2.5 emissions. Specifically, survey results for SMS Effectiveness and SMS Effectiveness in eastern regions indicate that 66 percent and 63.5 percent of respondents, respectively, believe that the nationwide SMS policy is only slightly effective in reducing PM2.5. Sixteen percent of respondents in our sample believe that the current SMS policy is ineffective in the eastern regions and only six percent of respondents consider it ineffective nationwide. Finally, survey results indicate that almost 78 percent of respondents support a revision of the current SMS policy and agree that the current SMS policy should be modified by exempting the eastern regions of the country. The modifications to the SMS policy should allow for the normal operation of coal-fired power plants in the eastern regions, but the operations of coal-fired power plants elsewhere in the country may be suspended and/or restricted from December to March.

Table 4. Distribution of socio-demographic variables of respondents.

	Base = Total	Number of Respondents	Percentage
Total		1502	100.0
Gender	Male (1)	746	49.7
	Female (0)	756	50.3
Age	19~29 (2)	264	17.6
	30~39 (3)	231	15.4
	40~49 (4)	280	18.6
	50~59 (5)	295	19.6
	60 and over (6)	432	28.8
Region	East	379	25.23
	Others	1123	74.77
Shutdown acceptance	Strongly agree (1)	351	23.37
	Slightly agree (2)	653	43.48
	Neutral (3)	352	23.44
	Slightly disagree (4)	112	7.46
	Strongly disagree (5)	34	2.26
SMS Effectiveness	No effect (1)	92	6.13
	Slightly effective (2)	994	66.18
	Significantly effective (3)	365	24.30
	Very effective (4)	51	3.40
SMS Effectiveness in Eastern Regions	No effect (1)	242	16.1
	Slightly effective (2)	954	63.5
	Significantly effective (3)	276	18.4
	Very effective (4)	30	2
Modified SMS	Agree (1)	1168	77.8
	Disagree (2)	334	22.2
Income	<KRW 1,000,000 (1)	77	5.13
	KRW 1,000,000–1,500,000 (2)	57	3.79
	KRW 1,500,000–2,000,000 (3)	86	5.73
	KRW 2,000,000–2,500,000 (4)	126	8.39
	KRW 2,500,000–3,000,000 (5)	149	9.92
	KRW 3,000,000–4,000,000 (6)	273	18.18
	KRW 4,000,000–5,000,000 (7)	218	14.51
	KRW 5,000,000–7,000,000 (8)	295	19.64
	KRW 7,000,000–10,000,000 (9)	163	10.85
	KRW 7,000,000 and over (10)	58	3.86
Environmental Organization	Experience (1)	96	6.4
	Inexperienced (0)	1406	93.6
Political preferences	Very progressive (1)	45	3.00
	Slightly progressive (2)	340	22.64
	Neutral (3)	866	57.66
	Slightly conservative (4)	224	14.91
	Very conservative (5)	27	1.80

Note: Variable values in parentheses.

Table 6 shows respondent acceptance rates for the suggested bids in each group. As mentioned above, the five groups in our study were offered different initial bids. If a respondent answered “Yes” to the initial bid, he/she was offered a bid twice as high. Otherwise, a bid twice as low was offered. The acceptance rate for the first bid was the highest at KRW 100/month (74 percent of respondents), and the lowest was KRW 900/month (64 percent of respondents). Moreover, if the respondent accepted the first bid, the probability that he/she would accept the higher bid in the second stage was also high (above 70 percent of respondents in each group).

Table 5. Descriptive statistics.

Variable	Observations	Mean	S.D.	Min	Max
Gender	1502	0.497	0.5001554	0	1
Age	1502	47.106	14.80795	19	86
Region	1502	0.252	0.4344944	0	1
Shutdown acceptance	1502	2.218	0.9608627	1	5
SMS Effectiveness	1502	2.250	0.6148153	1	4
SMS Effectiveness in Eastern Regions	1502	2.063	0.6489458	1	4
Modified SMS	1502	1.222	0.415977	1	2
Income	1502	6.171	2.31051	1	10
Environmental Organization	1502	0.064	0.2446825	0	1
Political preferences	1502	2.899	0.7465746	1	5

Note: Gender (1—Male, 0—Female); Age (years), Region (1—East, 0—Others); Shutdown acceptance refers to the acceptance of suspending the operations of coal-fired plants (1—strongly agree, 5—strongly disagree); SMS Effectiveness is respondent opinion on effectiveness of SMS (1—Not effective 4—Very effective); Modified SMS refers to exempting the eastern regions of the country from the SMS policy (1—Agree, 2—Disagree); Income—categorical variable (1—less KRW 1,000,000, 10—over KRW 7,000,000); Environmental Organization—dummy for respondent experience with membership in an environmental NGO (1—Experience, 2—Inexperience); Political preferences gauges respondents' political views (1—very progressive, 5—very conservative).

Table 6. Acceptance rates of respondents for first and second bids.

First Bid (KRW/Month)	Acceptance Rate (%)	Second Bid (KRW/Month)	Acceptance Rate (%)
100	74.7	200	87.6
		50	18.4
300	70.3	600	84.4
		150	24.7
500	69.7	1000	72.2
		250	23.1
700	68.4	1400	77.7
		350	26.3
900	64	1800	77.1
		450	23.1

To estimate WTP, we constructed six different model specifications, as listed in Table 6. In the first three models, we estimated the mean WTP for the total sample (**Total 1**) (we utilized the user-written command in Stata "doubleb", as suggested in Lopez-Feldman [34], to estimate our models), respondents who live in the eastern regions of Korea (**East 1**), and respondents who live in the remaining regions (**Others 1**). Thus, we can compare how WTP differs in the total sample and different regions without any control variables. The next three models (**Total 2, East 2, and Others 2**) introduce control variables pertaining to age, gender, income, political preferences, membership in environmental NGOs, acceptance of the existing SMS policy, and opinions on the effectiveness of the SMS policy (see Table 7 for additional detail).

In case there are no control variables, the mean WTP is simply the estimated coefficient of beta. When control variables are included, the mean WTP is estimated by first multiplying the control variables' coefficient values and their corresponding means and then adding this to the estimated beta coefficient [34]. The estimation results for models without control variables (**Total 1, East 1, and Others 1**) indicate that the mean WTP in the eastern regions (KRW 1,082) is lower than in other regions (KRW 1.337). As described, models **Total 2, East 2, and Others 2** examine the impact of various control variables. Table 7 indicates that for the total sample (**Total 2**) and all regions except the East (**Others 2**), all control variables are statistically significant and have the same signs in both specifications. Specifically, older respondents with higher incomes, respondents who believe that the current SMS policy is quite effective, and those who are members of environmental NGOs have higher WTP for reduction in PM2.5 emissions. Our results also indicate that male respondents, respondents with conservative political views, and those who oppose the current SMS policy tend to have lower WTP. Respondents in the eastern regions of the country (**East 1** and **East 2**) have relatively lower WTP for reduction in PM2.5 via the existing SMS policy. The coefficient of income variable has a much lower value in model **East 2** compared to the total sample (**Total 2**) and other regions (**Others 2**), while the acceptance of the current SMS policy coefficient occurs with a significantly higher absolute value, indicating that in eastern regions, respondents' income has a lower effect on WTP for the existing SMS policy and respondents who oppose the suspension of coal-fired plants have much lower WTP compared to respondents from other regions of the country.

Table 7. Parameter estimation results.

Region	Total 1	East 1	Others 1	Total 2	East 2	Others 2
Age	-	-	-	9.368 ***	−2.273	13.45 ***
				(3.098)	(6.594)	(3.534)
Income	-	-	-	91.67 ***	70.80 *	94.06 ***
				(19.91)	(41.50)	(22.72)
Sex	-	-	-	−312.3 ***	−284.9	−331.6 ***
				(91.49)	(191.2)	(104.1)
SMS Effectiveness	-	-	-	306.6 ***	245.4	327.4 ***
				(82.38)	(180.4)	(92.49)
Shutdown acceptance	-	-	-	−265.1 ***	−432.4 ***	−210.4 ***
				(51.81)	(114.2)	(58.78)
Environmental Organization	-	-	-	605.0 ***	494.4	629.5 ***
				(197.7)	(417.2)	(224.2)
Political preference	-	-	-	−238.5 ***	−159.7	−267.0 ***
				(63.92)	(128.6)	(74.17)
Beta	1275 ***	1082 ***	1337 ***	987.3 ***	1783 **	755.5*
	(53.15)	(102.0)	(62.47)	(354.9)	(785.2)	(397.6)
Sigma	1522 ***	1606 ***	1492 ***	1441 ***	1536 ***	1401 ***
	(71.48)	(150.8)	(80.88)	(67.18)	(143.4)	(75.35)
Observations	1502	379	1123	1502	379	1123

Note 1: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Note 2: SMS Effectiveness is respondent opinion on effectiveness of SMS (1—No effect, 4—Very effective); Shutdown acceptance is acceptance of suspending the operations of coal-fired plants (1—strongly agree, 5—strongly disagree); Environmental organization refers to membership in environmental NGOs (1—participated, 2—never participated); Political preference gauges respondents' political views (1—very progressive, 5—very conservative).

Table 8 compares the WTP results of respondents in all six models. As expected, the lowest WTP results were obtained from respondents in the eastern regions (about KRW 1080/month), followed by the total sample (about KRW 1280/month), while the highest WTP for SMS revealed respondents who live in non-eastern regions (above KRW 1337/month) (The WTP estimation results obtained in this study are relatively higher than the mean WTP of KRW 5591 per year reported by Kim et al. [18]. This difference may be attributed to the survey conducted by Kim et al. [18] in June 2017, prior to the air-quality disaster of 2019 in Korea.) Interestingly, the inclusion of the control variables does not seem to significantly affect the mean WTP in all specifications. We also conducted a two-group mean comparison *t*-test to determine any significant differences between the means of the East and Other groups. According to the test results (Table A2), a mean difference exists only for the Income and Bid acceptance variables. This suggests that respondents from the eastern regions exhibit lower income and a lower bid acceptance rate. Therefore, the mean difference analysis corroborates the estimation results, indicating that people from the eastern regions have a lower WTP for the Seasonal Management System.

Table 8. Comparison of WTP results for total sample and for respondents who reside in the eastern region and other regions.

Model	Total 1	East 1	Others 1	Total 2	East 2	Others 2
Mean WTP	1275	1082	1337	1288	1087	1353

5. Conclusions

The air quality in South Korea has long been a serious public health concern. The key contributor to the nation's poor air quality is fine particulate matter (PM2.5). PM2.5 levels are impacted in complex ways, such as by weather conditions, external influences, and domestic emissions. The seasonal variation of PM2.5 in Korea is mostly affected by the operation of coal-fired plants especially during the winter and spring months. In response, a nationwide seasonal management system (SMS) to mitigate PM2.5 emissions from the operation of coal-fired power plants has been in operation from December to March every year in South Korea since December 2019. While many have studied the impact of this nationwide SMS policy on pollution, there is scant literature on assessing this policy from a WTP lens, especially one that considers regional differences. Our study attempts to fill this gap by examining the significance of regional differences in respondent WTP results for clean air via an increase in their electricity bills. We focus on the differences in WTP for the SMS policy among respondents who live in the eastern regions versus their counterparts in the rest of the country. The tempering influence of northwesterly winds during December–March in the eastern regions results in a dispersion of PM2.5 matter to the East Sea without impacting PM2.5 emissions inland.

For our analysis and assessment of the SMS policy, we employed a contingent valuation method (CVM) combined with a double-bounded dichotomous choice (DBDC) as a WTP question approach. Respondents were queried about their WTP for clean air via increases in their monthly electricity bills (the exact question was as follows: "Would you accept to pay an additional (50–1800) won per month to your electricity bill for 4 months from December to March every year, considering the benefits of increased visibility, greater access to outdoor activities, and improved health under the fine dust seasonal management system (SMS?")). According to our estimation results, the nationwide mean WTP for SMS was KRW 1275–1288 per month. However, it should be noticed that WTP for SMS in eastern regions was much lower (KRW 1082–1087/month) than in other regions (KRW 1337–1353/month). Due to meteorological differences, it is not surprising that our estimation results indicate that the WTP for clean air of respondents who live in eastern regions was significantly lower than the average WTP of all respondents in our sample.

Our estimation results also noted that respondents with higher education, higher incomes, and more progressive political preferences had a higher than the average WTP. Older and female respondents had a higher WTP. Respondents who were members of environmental NGOs also showed a higher WTP for clean air via an increase in their electricity bills. Of note is the fact that almost 78 percent of survey respondents support a revision of the current SMS policy and are in favor of a revised SMS policy—one that exempts eastern regions from a nationwide shutdown of coal-fired generation from December to March. Indeed, the policy conclusion emerging from our analysis is that the Korean government should revise its current SMS policy and accordingly emend it to consider regional differences in contributions of coal-fired power plants to PM2.5 emissions. Such a revision to the existing SMS might positively impact electricity producers' income, regional tax revenue, and local employment without any significant effect on nationwide PM2.5 concentration levels.

The Korean government has announced "Carbon Net Zero Emission by 2050" in 2020. Although coal-fired power plants are bound to be replaced by renewable electricity sources such as solar PV and wind power by 2050 in South Korea, the energy transition should be implemented efficiently and thoughtfully. In this regard, regionally differentiated restrictions on the operation of coal-fired power plants depending on the relative benefit and cost of the seasonal management on PM2.5 accumulation can help enhance the efficiency of current policy on clean air. Furthermore, most renewable electricity sources rely on intermittent and volatile solar PV and wind power in Korea, which can lead to instability of the electricity supply, but coal-fired power plants can complement the intermittency and variability of renewable electricity. Accounting for all these aspects can lead to more efficient control of coal-fired power plants, which will contribute to the effective long-term energy transition.

Our study contributes to the current literature on WTP for clean air by considering regional differences in respondent preferences. Our statistical analysis has implications beyond South Korea as it provides empirical evidence that the CVM methodology grounded in a DBDC approach may be useful in assessing respondent WTP for clean air. The government can use this study's findings as a guideline when allocating budgets to deal with air pollution.

We are also cognizant of the limitations of our study. A major drawback relates to methodological concerns associated with CVM methodology. Future research can utilize an attribute-based approach such as a choice experiment to understand preferences. Testing the modified SMS policy as described in this paper in a real-world setting would provide more information about the accuracy of the WTP values, and the potential impact of a *modified* SMS policy to improve air quality in South Korea.

Finally, in addition to coal-fired plants, the industrial sector and transportation also contribute to PM2.5 emissions. Isolating the impact of coal-fired plant restrictions on PM2.5 emissions from other contributory sources might be difficult. Alternate environmental policies could also influence respondents' valuation. Thus, estimating WTP for environmental policies, particularly those involving complex issues like PM2.5 emissions and their mitigation, might pose challenges for respondents.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

- Implementation period: From December of each year to March of the following year.
- Details of implementation: Suspension and restricted operation of coal-fired power plants.
- Regulation: Coal-fired power plants with high PM2.5 emissions are required to suspend coal power generation or restrict operational rates to reduce the supply of coal power within the range that can reliably meet electricity demand.
- Current status

	1st seasonal management program	2nd seasonal management program
Period	December 2019–March 2020	December 2020–March 2021
Suspension	8–15 units on average	9–17 units on average
	28 units in March	28 units in March
Operational restriction	26–46 units: capacity restriction Up to 49 units: operation restriction	26–46 units: capacity restriction Up to 37 units: operation restriction
	The remaining coal-fired power plants are limited to operating within 80% of maximum capacity.	

Figure A1. Description of the Korean Seasonal Management System (SMS).

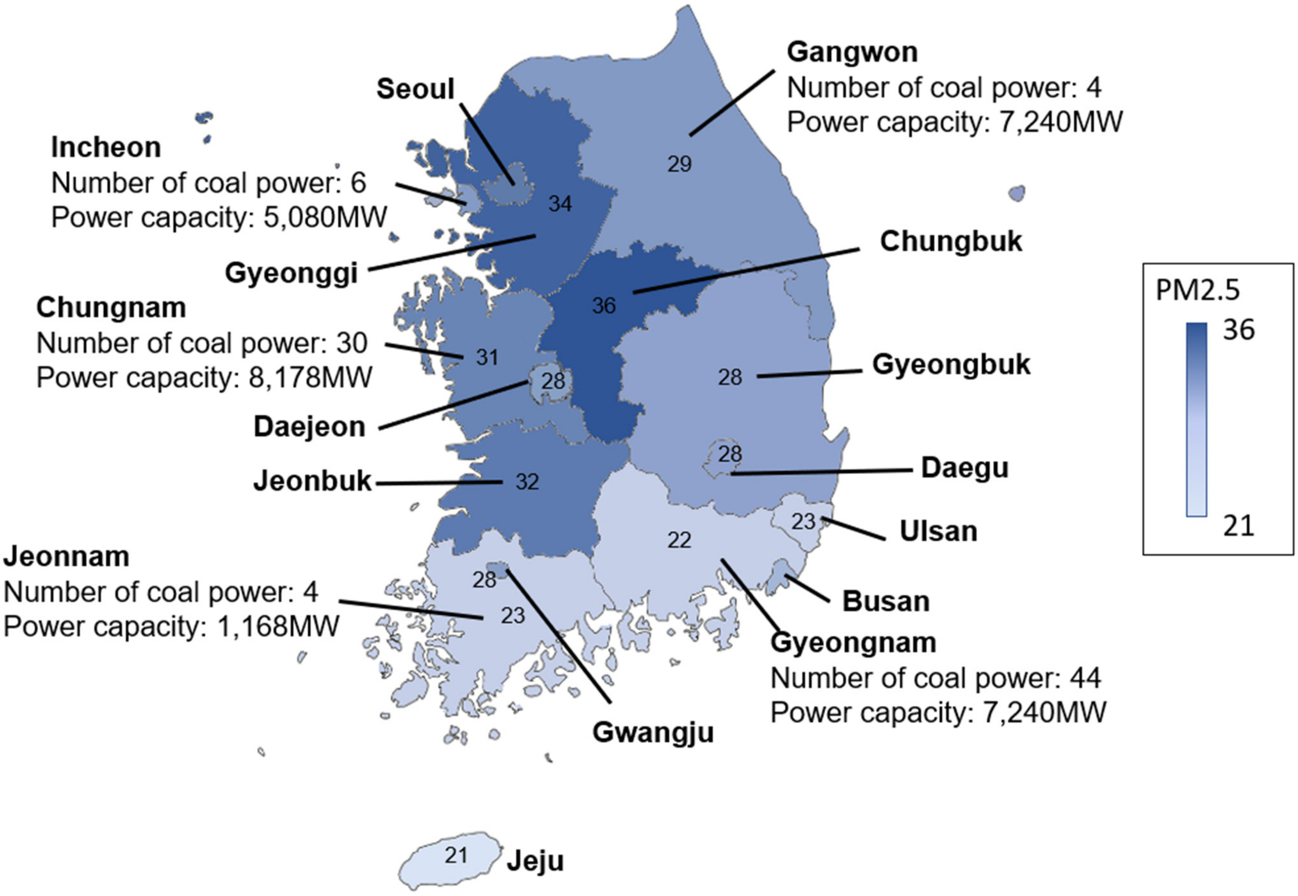

Figure A2. Provincial concentrations of PM2.5 (2021) (Unit: μm).

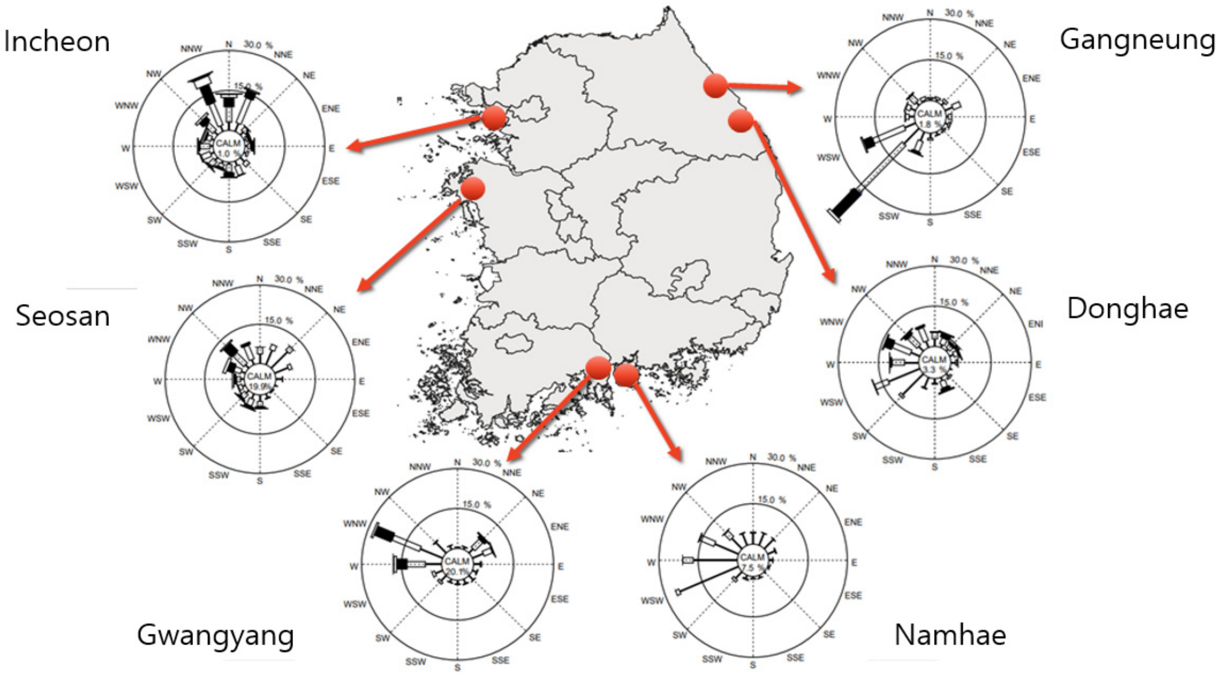

Figure A3. Wind direction in central, eastern, and southern areas December–March (Korea Environmental Economics Association, 2021, "Study on Introduction of Regional and Seasonal Management of Particulate Matter Emission", Final Report, Korea Southern Power Company).

Table A1. Survey questions.

1. What is your gender?
2. What is your age?
3. What is your current residential address in your resident registration?
4. What are your thoughts on suspending the operation of coal-fired power plants during the high fine dust season from December to March?
5. How effective do you think the current fine dust SMS, which involves shut-down or capacity restriction of all coal-fired power plants nationwide from December to March, is in reducing fine dust levels across the country?
6. How effective do you think the current fine dust SMS, which involves shut-down or capacity restriction of all coal-fired power plants in the Eastern regions (Gangwon, Gyeongbuk, Gyeongnam, Daegu, Ulsan, Busan) from December to March, is in reducing fine dust levels in the Eastern regions?
7. Do you support the improvement plan of suspending and capacity restriction of coal-fired power plants in the western region and maintaining normal operation in the eastern region under the fine dust SMS?
8. What is the monthly average income level of your household? (Please respond by combining all income, excluding taxes, including bonuses, interest income, etc.)
9. Have you ever participated in any citizen organizations related to energy or the environment?
10. What is your political orientation?

Table A2. Mean difference analysis.

Variable	Other	East	Difference
Income	6.274	5.865	0.409 ***
Age	46.75	48.16	−1.404
Gender	0.497	0.496	0.0008
SMS Effectiveness	2.253	2.240	0.013
Shutdown acceptance	2.209	2.243	−0.033
Environmental Organization	0.064	0.063	0.0008
Political preference	2.882	2.950	−0.068
Bid acceptance	3.075	2.839	0.236 ***
Observations	1123	379	

Note: *** $p < 0.01$.

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