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ABSTRACT

The South Korean government plans to reduce region-wide annual $PM_{2.5}$ (particulate matter with an aerodynamic diameter ≤2.5 μm) concentrations in the Seoul Capital Area (SCA) from 2010 levels of 27 μg/m^3 to 20 μg/m^3 by 2024. At the same time, it is inevitable that emissions from fossil-fuel power plants will continue to increase if electricity generation expands and the generation portfolio remains the same in the future. To estimate incremental $PM_{2.5}$ contributions due to projected electricity generation growth in South Korea, we utilized an ensemble forecasting member of the Integrated Multidimensional Air Quality System for Korea based on the Community Multi-scale Air Quality model. We performed sensitivity runs with across-the-board emission reductions for all fossil-fuel power plants in South Korea to estimate the contribution of $PM_{2.5}$ from domestic fossil-fuel power plants. We estimated that fossil-fuel power plants are responsible for 2.4% of the annual $PM_{2.5}$ national ambient air quality standard in the SCA as of 2010. Based on the electricity generation and the annual contribution of fossil-fuel power plants in 2010, we estimated that annual $PM_{2.5}$ concentrations may increase by 0.2 μg/m^3 per 100 TWhr due to additional electricity generation. With currently available information on future electricity demands, we estimated that the total future contribution of fossil-fuel power plants would be 0.87 μg/m^3, which is 12.4% of the target reduction amount of the annual $PM_{2.5}$ concentration by 2024. We also approximated that the number of premature deaths caused by existing fossil-fuel power plants would be 736 in 2024. Since the proximity of power plants to the SCA and the types of fuel used significantly impact this estimation, further studies are warranted on the impact of physical parameters of plants, such as location and stack height, on $PM_{2.5}$ concentrations in the SCA due to each precursor.

Implications: Improving air quality by reducing fine particle pollution is challenging when fossil-fuel-based electricity production is increasing. We show that an air quality forecasting system based on a photochemical model can be utilized to efficiently estimate $PM_{2.5}$ contributions from and health impacts of domestic power plants. We derived $PM_{2.5}$ concentrations per unit amount of electricity production from existing fossil-fuel power plants in South Korea. We assessed the health impacts of existing fossil-fuel power plants and the $PM_{2.5}$ concentrations per unit electricity production to quantify the significance of existing and future fossil-fuel power plants with respect to the planned $PM_{2.5}$ reduction target.

Introduction

Particulate matter of 2.5 μm in diameter or less ($PM_{2.5}$) is known to be a significant public health concern, especially affecting the elderly and youth (Dockery et al., 1993; Pope et al., 2009; U.S. Environmental Protection Agency [EPA], 2009; Kim et al., 2015). $PM_{2.5}$ consists of primary $PM_{2.5}$ directly emitted from sources and secondary $PM_{2.5}$ chemically formed from precursors emitted from various sources under conducive environmental conditions (North American Research Strategy for Tropospheric Ozone [NARSTO], 2004). Major precursors for secondary $PM_{2.5}$ include sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), and volatile organic compounds (VOCs) (Cohan et al., 2007; Hallquist et al., 2009; Robinson et al., 2007). Due to atmospheric dispersion characteristics, secondary $PM_{2.5}$ often results in regional air quality problems, including long-range transport (Liu, 2003; Abdalmogith and Harrison, 2005; Lim and Turpin, 2002; Polidori et al., 2006; NARSTO, 2004; EPA, 2009).

Poor air quality due to $PM_{2.5}$ becomes a more urgent policy issue when high $PM_{2.5}$ concentrations are prevalent in highly populated areas. For this study, we chose the Seoul Capital Area (SCA), which is one of the most densely populated areas in the world (United Nations, 2011). The SCA consists of three major jurisdictional areas, as shown in Figure 1: Seoul,

Incheon, and Gyeonggi-do. The population densities of Seoul, Incheon, and Gyeonggi-do are 16,592, 2659, and 1161 persons/km^2, respectively, as of 2011 (Statistics Korea, 2016).

In South Korea, many large fossil-fuel power plants are located near the SCA, as shown in Figure 2. These fossil-fuel power plants are major sources of SO_2 (e.g., coal-fired power plants) and NO_x (e.g., coal-fired power plants and natural gas–fired power plants). In 2010, coal-fired power plants, oil-fired power plants, and liquefied natural gas (LNG)-fired power plants produced 193,769, 25,356, and 95,147 GWhr, respectively (Electric Power Statistics Information System, 2011). Thus, a total of 314,272 GWh of electricity was produced by fossil-fuel power plants (Electric Power Statistics Information System, 2011). This accounted for 66.2% of the total

Figure 1. Location of the Seoul Capital Area in South Korea and modeling domains at horizontal resolutions of 27 km (outer box in the top panel) and 9 km (inner box with solid lines in the top panel). The SCA is denoted in the dotted line box of the top panel and shaded color in the bottom panel. Locations of $PM_{2.5}$ monitors used to evaluate model performance appear as block solid dots in the bottom panel.

electricity generated in South Korea in 2010. SO_2 and NO_x emissions from fossil-fuel power plants were 69,698 and 129,206 tons in 2010, respectively, according to the Clean Air Policy Support System (CAPSS) published by the National Institute of Environmental Research (2014). These emissions accounted for 17% of SO_2 emissions and 12% of total NO_x emissions in South Korea as of 2010 (National Institute of Environmental Research, 2014). Therefore, controlling emissions from fossil-fuel power plants is crucial to reduce the harmful impacts on society and to maintain good air quality in South Korea.

However, because of the current electricity generation infrastructure and the population's energy demands, it is not feasible to reduce electricity generation and, in turn, emissions from fossil-fuel power plants. In fact, South Korea will continue to produce larger amounts of electricity to keep up with socioeconomic demands such as the increased use of air conditioning and industrial activities (Korea Energy Economics Institute, 2013; Energy Information Administration, 2014). According to the "6th Electricity Supply Plan," the South Korean government plans to increase the electricity supply through 2027 by building new fossil-fuel power plants and increasing the use of existing fossil-fuel power plants near the SCA (Ministry of Knowledge Economy, 2013) such as Dang Jin Power Plant (4,000 MW) and Young Heung Power Plant (3,340 MW in 2010 and 5,080 MW in 2014). Although nuclear power plants and renewable energy sources may provide some alternatives, fossil-fuel-based electricity generation is unavoidable in the short term. Therefore, we expect South Korea will continue to experience increased SO_2 and/or NO_x emissions.

Nevertheless, it is imperative to strike a balance between electricity generation growth to meet future residential/industrial requirements and the development of an effective regional air quality management plan to protect public health. By implementing the "2nd Metropolitan Air Quality Control Master Plan," the South Korean government established plans to reduce region-wide annual $PM_{2.5}$ concentrations from 27 µg/m^3 in 2010 to 20 µg/m^3 in 2024 (Ministry of Environment, 2014). Since NO_x and SO_2 emissions from fossil-fuel power plants significantly impact the regional $PM_{2.5}$ air quality, the impact of emissions from additional fossil-fuel-based electricity generation on the air quality in the SCA needs to be understood and quantified. Several studies have looked into power plant emission impacts on $PM_{2.5}$ air quality on regions other than South Korea (Levy and Spengler, 2002; Kwok et al., 2013); the impacts were due to a single source (Kelly et al., 2010), or the study covered a
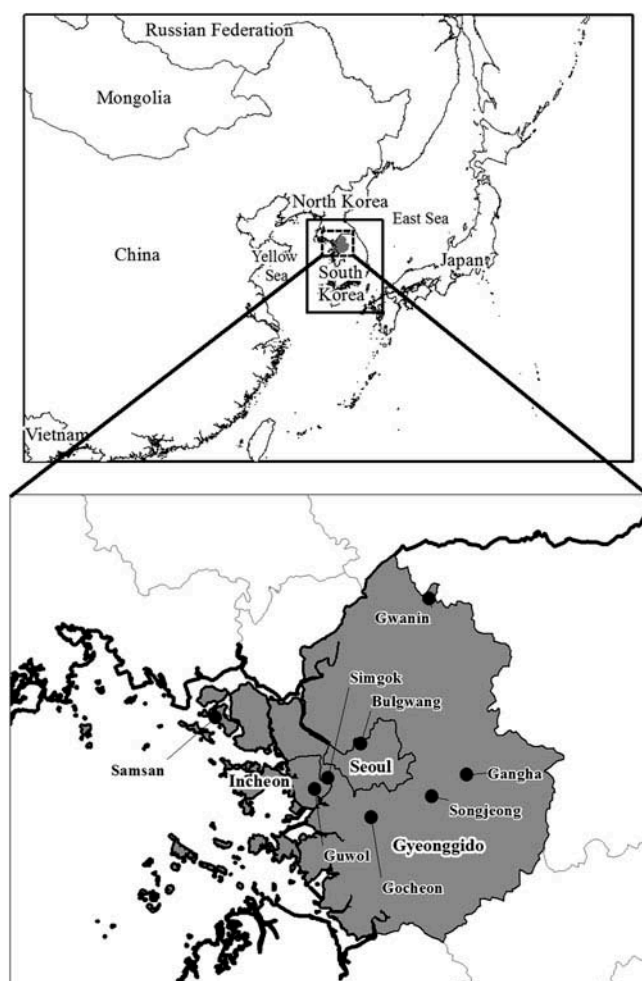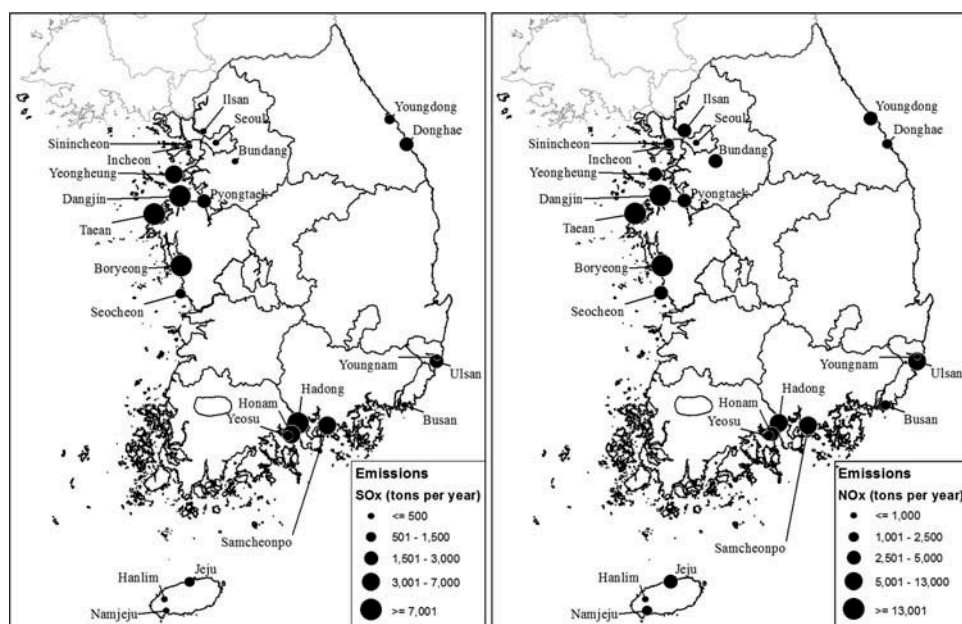
Figure 2. SO$_2$ and NO$_x$ emissions from fossil-fuel power plants in South Korea.

limited portion of the year (Lee et al., 2013). Thus, there is an obvious lack of information on additive fossil-fuel power plant impacts on the annual PM$_{2.5}$ air quality in the SCA. Therefore, our goal was to estimate the contribution of present and future fossil-fuel power plants to PM$_{2.5}$ concentrations in the SCA to support air quality planning that considers increased future electricity demand.

Methods

Modeling system setup

To assess the impact of fossil-fuel power plants, we configured the modeling domains, as shown in Figure 1. The boundary conditions of the 27-km domain run were prepared from the Community Multi-scale Air Quality (CMAQ) model default profile. The 9-km grid domain runs used boundary conditions extracted from the 27-km domain modeling outputs. We adopted the modeling domains and grids used for the "2nd Metropolitan Air Quality Control Master Plan." We also considered the recommendation for PM$_{2.5}$ modeling in EPA's modeling guidance, which is to use a grid resolution of 12 km or less (EPA, 2014). The modeling domain and grid configuration was to account for the possible interaction of foreign emissions from China, North Korea, and Japan with domestic power plant plumes. In terms of the modeling period, we performed 4-month simulations for January,

April, July, and October in 2010 to account for seasonal variations in the atmospheric environmental conditions in the SCA. To minimize the effects of initial conditions stemming from the profile, each monthly simulation included a 10-day spin-up period.

We used an ensemble forecasting member of the Integrated Multidimensional Air Quality System for Korea (IMAQS/K) (Kim et al., 2015). IMAQS/K offers various combinations of Weather Research and Forecasting (WRF)–Sparse Matrix Operator Kernel Emissions (SMOKE)–Community Multi-scale Air Quality (CMAQ) model sets. We used Model InterComparison Study—Asia (MICS-Asia) 2010 for foreign anthropogenic emissions (Carmichael and Wang, 2013), CAPSS 2010 for domestic anthropogenic emissions (National Institute of Environmental Research, 2014), and Model of Emissions of Gases and Aerosols from Nature (MEGAN) v2.04 for biogenic emissions (Guenther et al., 2006). The inventory species in CAPSS 2010 were NO$_x$, SO$_x$ (sulfur oxides), PM$_{10}$, PM$_{2.5}$, NH$_3$, VOC, and CO. We used SMOKE v3.1 to apply speciation profiles for detailed modeling species such as VOC and NO$_x$. In addition, we made spatial and temporal allocations of annual emissions to prepare model-ready emissions input files. We ran WRF v3.4.1 with initial conditions derived from the Final Reanalysis (FNL) data (National Center for Atmospheric Research [NCAR], 2015). Next, we ran the Meteorology-Chemistry Interface Processor v3.6 to prepare meteorological inputs for CMAQ. Details of the modeling system configurations are listed in Table 1.

Table 1. Configurations of WRF and CMAQ used in this study.

WRF		CMAQ	
Version	3.4.1	Version	4.7.1
Micro physics	WSM6	Chemical mechanism	SAPRC 99
Cumulus scheme	Kaio-Fritsch	Aerosol module	AERO5
Longwave radiation	RRTM	Boundary condition	Default profile for the 27-km domain
Shortwave radiation	Dudhia scheme	Advection scheme	YAMO
PBL scheme	YSU	Horizontal diffusion	Multiscale
LSM scheme	NOAH	Vertical diffusion	Eddy
		Cloud scheme	RADM

Estimation of the fossil-fuel power plant contribution

Figure 3 diagrams the approach we took to estimate the total contribution of fossil-fuel power plants to $PM_{2.5}$ concentrations in the SCA. First, we attempted to quantify the current contribution from existing power plants. Because large emission reductions of 50% or 100% can lead to overly changing the atmospheric chemistry in the model due to nonlinearity and, eventually, result in unrealistic predictions (Yarwood et al., 2007; Bartnicki, 1999; Dennis et al., 2008; Zhang et al., 2012), we adopted the de facto standard method used by the South Korean National Institute of Environmental Research (2012) to assess contributions. The method is a two-step procedure following the recommendation in Bartnicki (1999) to avoid the potential nonlinearity issue discussed above. The two steps are as follows: (1) calculate the sensitivity of 20%
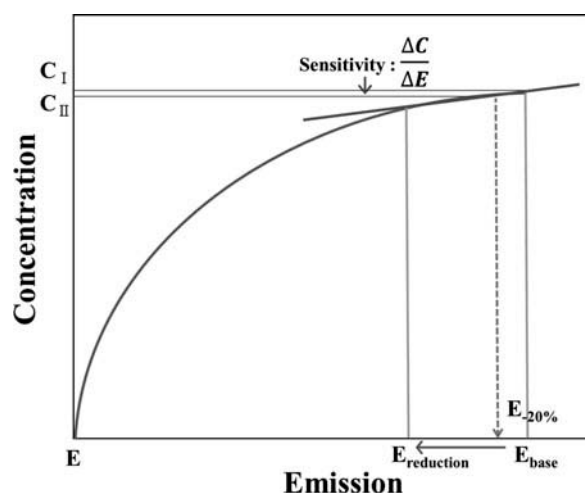

Figure 3. Plot of estimated contributions from fossil-fuel power plants. The contribution of existing fossil-fuel power plants was estimated by multiplying the modeled sensitivity of 20% emission reductions by 5.

emission reductions and (2) compute 5 times the sensitivity result from (1) to estimate the total contribution. We intended to use the estimated contributions to predict the potential impacts of anticipated increases in future power plant capacity/use.

Results and discussion

Model performance evaluation

Figure 1 depicts the locations of all $PM_{2.5}$ monitors in the SCA. All $PM_{2.5}$ monitors are equipped with measurement devices that operate on a continuous hourly basis. Due to data shortages, we could only rely on four monitors (Samsan, Gwanin, Gangha, and Songjeong) in January for the model performance evaluation. However, we used eight monitors for April, July, and October.

Using 27-km and 9-km modeling results, we calculated model performance statistics for all monitors in the SCA with equations suggested in EPA's newest modeling guidance (EPA, 2014). For meteorological inputs, we conducted model performance evaluations by examining the index of agreement and bias for temperature, wind speed, and wind direction at monitors in the SCA. All performance evaluation results are presented in Table 2.

Figures 4 and 5 show the time series and scatter plots comparing modeled and observed daily $PM_{2.5}$ concentrations. The model revealed that the best performance was in October ($R^2 = 0.843$). We observed that the model performance in the first half of July was poor, which resulted in a worse $PM_{2.5}$ prediction for the month ($R^2 = 0.419$) as compared with April and October. Again, there were many days with missing observations in January, as noted above. Therefore, the estimated model performance statistics for January not as significant for analytical purposes as that of the statistics for the other months. The goal of this study was to assess the contribution of existing fossil-fuel power plants with available emissions inventories with regard to daily and annual $PM_{2.5}$ standards. In South Korea, CAPSS is the best available domestic emissions inventory. Therefore, we conducted our analyses while recognizing that the model performance in July needs to be improved.

Fossil-fuel power plant contribution

Figure 6 shows daily average $PM_{2.5}$ concentrations at monitors in the SCA and contributions from fossil-fuel power plants. $PM_{2.5}$ concentrations were the highest in January among all four simulated months. The base model reveals a reading of 74.5 μg/m^3 on January 31, which is well above South Korea's daily $PM_{2.5}$ national

Table 2. Model performance statistics for 27-km and 9-km modeling results: temperature, wind speed, and wind direction (top) and PM$_{2.5}$ (bottom).

Variable	Statistics	27 km				9 km			
		Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
Temperature	Correlation coefficient	0.96	0.97	0.93	0.98	0.96	0.97	0.93	0.98
	Index of agreement	0.98	0.97	0.87	0.99	0.98	0.97	0.90	0.99
	Bias (°C)	−0.17	−0.96	−1.64	−0.50	−0.15	−0.75	−1.31	−0.47
Wind speed	Correlation coefficient	0.93	0.89	0.88	0.81	0.94	0.91	0.89	0.84
	Index of agreement	0.56	0.69	0.63	0.59	0.63	0.75	0.72	0.65
	Bias (m/sec)	2.28	1.75	1.24	1.74	1.85	1.43	0.94	1.43
Wind direction	Correlation coefficient	0.80	0.87	0.89	0.86	0.82	0.88	0.89	0.87
	Index of agreement	0.69	0.87	0.88	0.82	0.75	0.89	0.90	0.85
	Bias (degree)	40.7	19.9	14.0	−3.1	32.5	16.9	11.9	0.6

Statistics	27 km				9 km			
	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
Mean observed PM$_{2.5}$ (μg/m^3)	44.68	31.45	30.44	31.48	44.55	32.06	30.82	32.16
Mean modeled PM$_{2.5}$ (μg/m^3)	33.80	23.60	17.43	27.50	30.61	24.21	18.66	27.76
Normalized mean bias (%)	−24	−25	−43	−13	−31	−24	−39	−14
Gross error (μg/m^3)	0.28	0.25	0.46	0.20	0.33	0.25	0.43	0.20
RMSE (μg/m^3)	5.19	2.97	5.63	2.45	6.00	3.01	5.36	2.45
Coefficient of determination	0.53	0.81	0.38	0.82	0.49	0.79	0.42	0.84
Index of agreement	0.77	0.82	0.66	0.93	0.72	0.82	0.68	0.93

ambient air quality standard (NAAQS) of 50 μg/m^3. In the wintertime, long-range transport is often responsible for high PM$_{2.5}$ events (Kim et al., 2014). The largest contribution of fossil-fuel power plants, 2.7 μg/m^3, was estimated on July 10, which amounts to about 5% of daily PM$_{2.5}$ NAAQS. Although the overall modeled PM$_{2.5}$ concentrations in July were lower than other months, the contribution was still significantly larger than in other months because a large amount of secondary PM$_{2.5}$ is formed in July from precursors such as NO$_x$ and SO$_2$ emitted from fossil-fuel power plants. The estimated component-wide contributions of ammonium, sulfate, and nitrate were 0.63, 0.32, and 1.73 μg/m^3, respectively. Most power plants near the SCA are located in the south and southwest of the SCA. In January, modeled prevailing winds were northwesterly and modeled prevailing winds in July were southerly and southwesterly. This pattern is consistent with what has been reported in other studies (Kim et al., 2007, 2014; Streets et al., 2003). Because of the possible direct transport of power plant plumes to the SCA in July, a modeled response to the power plant emissions change was more evident in July than January.

As noted in the model performance evaluation result, however, the modeled PM$_{2.5}$ concentration was underestimated. Thus, we anticipate that the contribution would be more significant when model performance is improved. For the daily PM$_{2.5}$ NAAQS, it is usually more important to correctly predict high PM$_{2.5}$ days than average PM$_{2.5}$ values. Table 3 presents the maximum daily average PM$_{2.5}$ concentrations in the SCA and contributions from fossil-fuel power plants for the days showing maximum daily average PM$_{2.5}$ concentrations. The

highest daily PM$_{2.5}$ concentrations predicted in January and October were 74.52 μg/m^3 on January 31 and 63.00 μg/m^3 on October 11, and the fossil-fuel power plant contributions for these days were 0.28 and 2.14 μg/m^3, respectively. For October, fossil-fuel power plants contributed approximately 4% to the daily PM$_{2.5}$ NAAQS. As shown in Figure 6, most fossil-fuel power plant contributions originated from nitrate.

Table 4 presents the monthly average PM$_{2.5}$ at monitors in the SCA and contributions from fossil-fuel power plants. The largest PM$_{2.5}$ contribution from power plants occurred in July, and the smallest contribution was observed in January. At the same time, the highest monthly average PM$_{2.5}$ concentrations were modeled in January. Similar to the daily PM$_{2.5}$ concentrations, the model estimated the lowest PM$_{2.5}$ concentrations in July. However, we anticipate that the fossil-fuel power plant contribution in July would be much larger when the model performance is improved. We estimated the annual PM$_{2.5}$ contribution of 0.63 μg/m^3 from fossil-fuel power plants by taking averages of monthly contributions estimated for January, April, July, and October. This amounted to about 2.4% of the annual PM$_{2.5}$ NAAQS, 25 μg/m^3, in South Korea. Figure 7 shows the spatial distribution of fossil-fuel power plant contributions for the monthly average PM$_{2.5}$.

The results of this study will be useful for South Korean air quality managers to estimate the amount of emission controls needed to meet air quality standards in the SCA considering anticipated emission increases due to future energy supply plans. For example, we can estimate that the anticipated electricity generation with new fossil-fuel power plants according to the "6th Electricity Supply Plan" will be 120 TWhr
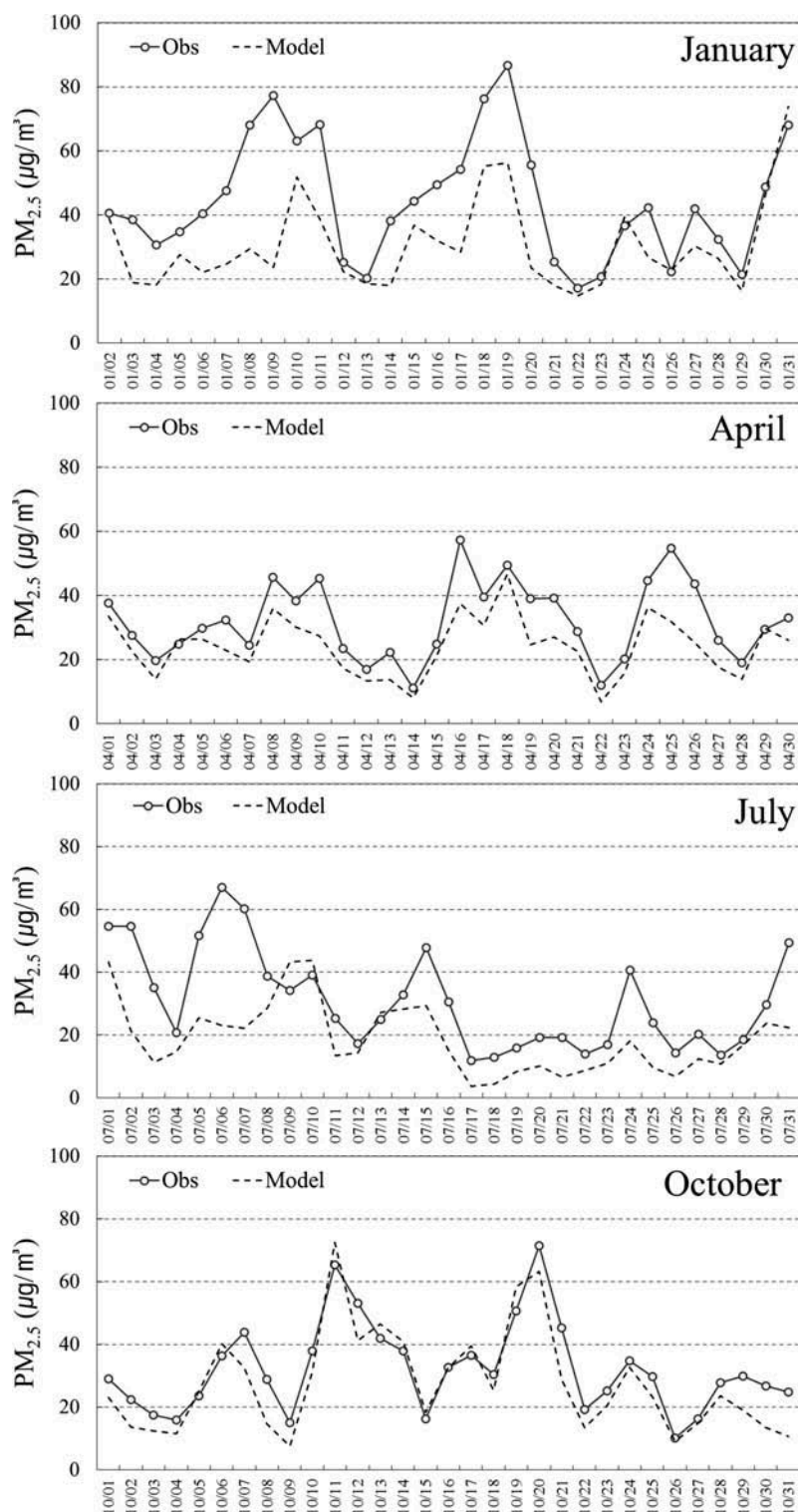
Figure 4. Time series of the daily average observed and modeled PM$_{2.5}$ concentrations at all monitors in the SCA.

by assuming a 90% capacity factor. Since the current contribution, 0.63 μg/m^3, results from 314,272 GWhr, we can estimate 2 μg/m^3 per 1000 TWhr. We expect a 0.24 μg/m^3 increase in PM$_{2.5}$ if increased power production occurs at the same locations and proportional to existing fossil-fuel power plants as of 2010.

According to the "2nd Metropolitan Air Quality Control Master Plan," the South Korean government plans to reduce region-wide annual PM$_{2.5}$ concentrations to 20 μg/m^3 by 2024 from the 27 μg/m^3 level observed in 2010. The estimated current annual contribution accounts for 9% of the reduction goal
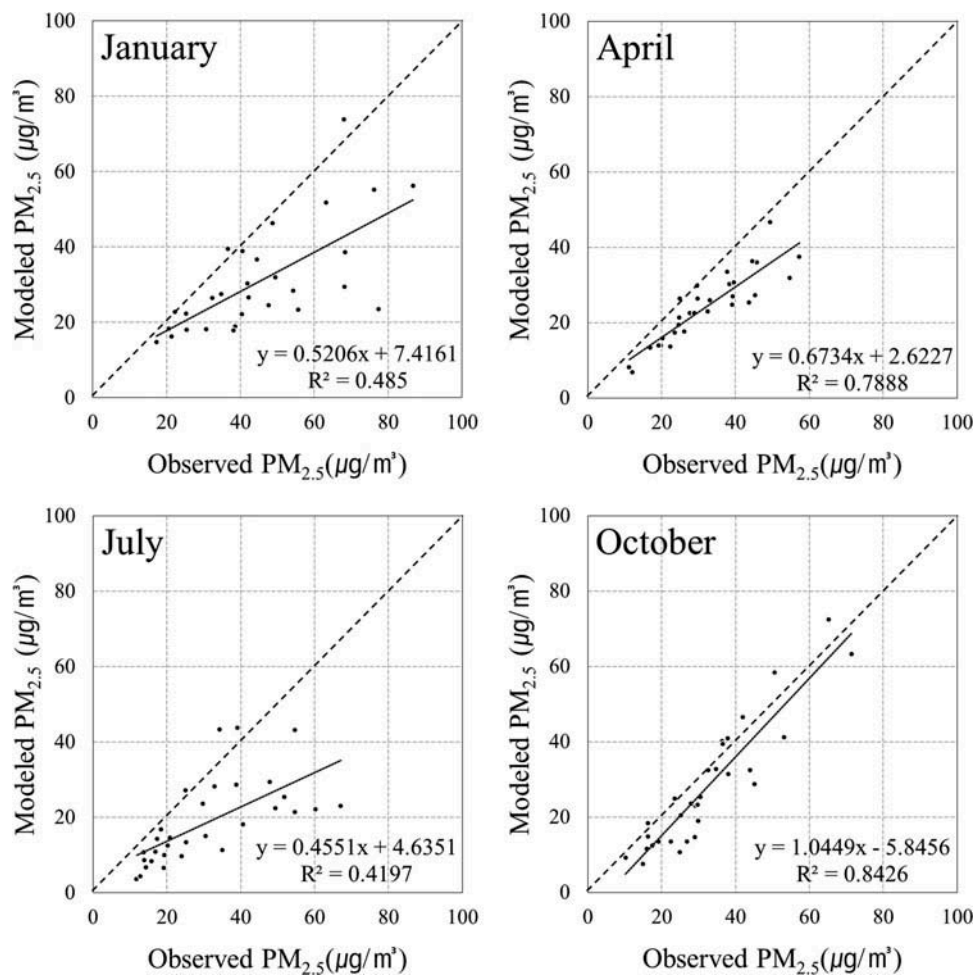
Figure 5. Comparison of the daily average observed and modeled PM$_{2.5}$ concentrations at all monitors in the SCA.

and the anticipated future incremental contribution would be 3.4% of the reduction goal. Thus, the total future contribution of fossil-fuel power plants would be 12.4% of the reduction goal of annual PM$_{2.5}$ concentrations by 2024. Using data available from Leem et al. (2015), we estimated an approximate premature death rate due to PM$_{2.5}$. The paper estimated that 14,915 (4275–26,017 with 95% confidence interval) annual premature deaths in the SCA are preventable if emission controls are in place to meet a PM$_{2.5}$ goal of 20 µg/m^3 as compared with the SCA-wide aerial average PM$_{2.5}$ concentration, 32.8 µg/m^3, resulting from a scenario in which no additional controls are in place in 2024. We approximated that the average premature death rate in 2024 will be 1169 persons per µg/m^3 by dividing 14,915 persons by 12.8 µg/m^3. Therefore, we conclude that the total PM$_{2.5}$ contribution resulting from existing fossil-fuel power plants, 0.63 µg/m^3, in 2024 would result in an estimated 736 premature deaths. We recognize that recent studies (Thurston et al., 2015, and references therein) indicate that different PM$_{2.5}$ constituents may have different health effects.

For this study, however, we followed commonly accepted information, such as provided by the EPA (EPA, 2009), which estimates premature deaths based on the total PM$_{2.5}$ mass. We acknowledge that, in the future, this paradigm can shift once scientific communities reach a consensus on the different effects of PM$_{2.5}$ constituents on premature deaths.

Conclusion

In this study, we estimated the contribution of domestic fossil-fuel power plant emissions to the surface PM$_{2.5}$ concentrations in the SCA, South Korea, where more than 25 million people live. We performed 4-month simulations for January, April, July, and October to account for seasonal variations in environmental conditions in the SCA. The maximum daily PM$_{2.5}$ concentrations in January, April, July, and October were 74.52, 42.05, 40.62, and 63.00 µg/m^3, respectively. Contributions of fossil-fuel power plants for these days were 0.28, 1.42, 2.69, and 2.14 µg/m^3, respectively. The average monthly PM$_{2.5}$ contributions from fossil-fuel power plants were
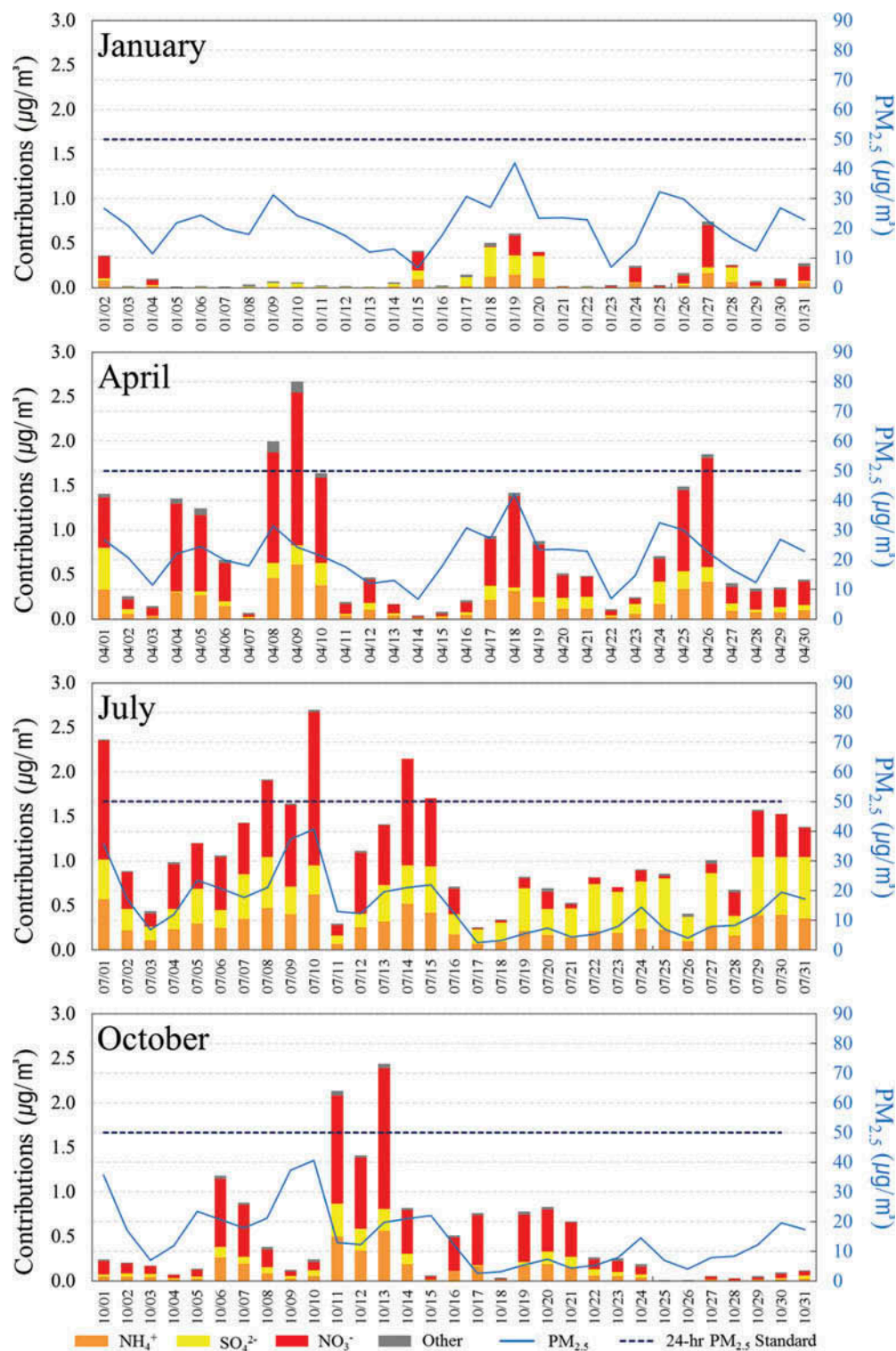
Figure 6. Daily average PM$_{2.5}$ concentrations at monitors in the SCA and contributions from fossil-fuel power plants.

0.16 out of 30.13 μg/m^3 in January, 0.76 out of 21.43 μg/m^3 in April, 1.11 out of 14.87 μg/m^3 in July, and 0.49 out of 23.77 μg/m^3 in October. The estimated annual average PM$_{2.5}$ contribution was 0.63 out of 22.55 μg/m^3. A previous study indicated that the relative contribution of foreign sources to the surface PM$_{2.5}$ in the SCA is about

25–30% (Kim, 2006). Figure 7 indicates that potential quantities of PM$_{2.5}$ transported to downwind countries are negligible. At the same time, we recognize that different atmospheric conditions can lead to non-negligible contributions to downwind countries such as Japan. Therefore, a long-range transport assessment is desirable.

Table 3. Maximum daily average PM$_{2.5}$ concentrations in the SCA and contributions from fossil-fuel power plants for days showing maximum daily average PM$_{2.5}$ concentrations.

Source	Maximum Daily Average PM$_{2.5}$ Concentration (μg/m^3)			
	January	April	July	October
SCA	74.52	42.05	40.62	63.00
Fossil-fuel power plants	0.28	1.42	2.69	2.14

Table 4. Monthly average PM$_{2.5}$ concentrations in the SCA and contributions from fossil-fuel power plants for days showing maximum daily average PM$_{2.5}$ concentrations.

Source	Monthly Average PM$_{2.5}$ Concentration (μg/m^3)			
	January	April	July	October
SCA	30.13	21.43	14.87	23.77
Fossil-fuel power plants	0.16	0.76	1.11	0.49

As of 2014, all coal-fired power plants are required to operate bag houses for fly ash and flue gas desulfurization to control SO$_2$ emissions. In addition, selective catalytic reduction devices to control NO$_x$ emissions have been mandated for all fossil-fuel power plants. These stringent controls are required for newly constructed fossil-fuel power plants as well. Therefore, we anticipate that the future SO$_2$ and NO$_x$ emission increments will be proportional to the planned electricity generation by assuming that the future fleet type mix and spatial distribution of fleets remain close to the current status. Based on the results of this study and the gross load of fossil-fuel power plants in 2010, we estimate that the annual PM$_{2.5}$ concentration increase in the SCA will be 2.0 μg/m^3 per 1000 TWhr due to additional electricity generation.

According to the "2nd Metropolitan Air Quality Control Master Plan," the South Korean government plans to reduce region-wide annual PM$_{2.5}$ concentrations to 20 μg/m^3 by 2024 from the 27 μg/m^3 level observed in 2010. The results of this study will be useful for South Korean air quality managers to estimate the amount of emission controls needed to meet air quality standards in the SCA considering
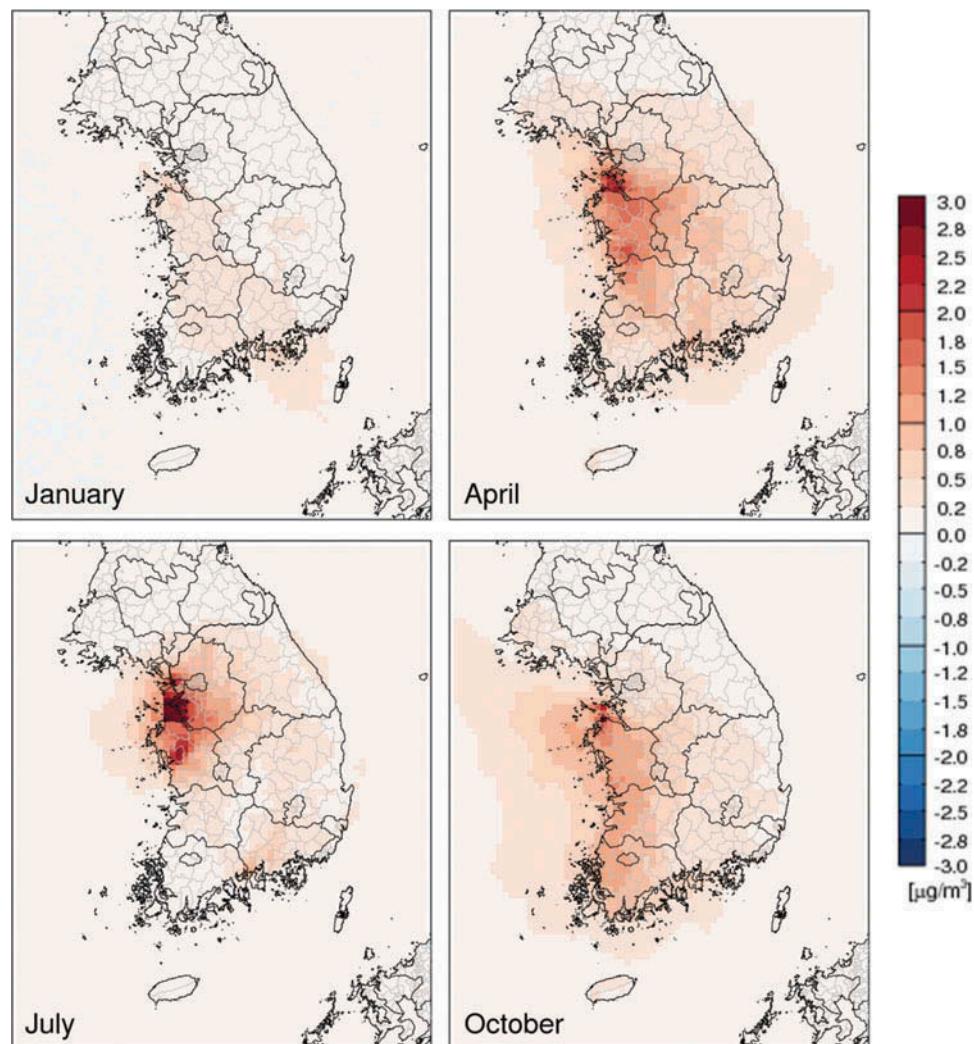

Figure 7. Spatial distribution of fossil-fuel power plant contributions for monthly average PM$_{2.5}$.

anticipated emission increases due to future energy supply plans such as the "6th Electricity Supply Plan." For example, we can estimate that anticipated electricity generation with new fossil-fuel power plants according to the "6th Electricity Supply Plan" will be 120 TWhr by assuming a 90% capacity factor. We expect a 0.24 μg/m^3 increase in PM$_{2.5}$ if increased power generation occurs at the same locations and proportional to existing fossil-fuel power plants as of 2010. Therefore, we estimated that the total future contribution of fossil-fuel power plants will be 0.87 μg/m^3, which is 12.4% of the target amount of the annual PM$_{2.5}$ concentration reduction by 2024, and premature deaths due to the existing fossil-fuel power plant contribution would be 736. In addition, we demonstrated that seasonal variations in PM$_{2.5}$ components need to be addressed in the future to meet daily PM$_{2.5}$ standards in the SCA. Finally, since the proximity of power plants to the SCA and the fuel types used significantly impact these estimations, further studies are warranted on the impact of physical parameters of plants, such as location and stack height, on PM$_{2.5}$ concentrations in the SCA due to each precursor. In addition, we recognize that the spatiotemporal limit of the current study on the impact of PM$_{2.5}$ concentration changes. We recommend that future studies include higher resolution modeling and observational analyses using remote sensing data.

Funding

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