

Debut of Particulate Matter (PM) in East Asia : Science-Policy Interface

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This study explores what drove the outstanding public concerns about particulate matter (PM) in China, Japan, and South Korea in the early 2010s despite constant improvement of air quality compared to earlier decades and how smog problems in China have awakened not only its own public but also those in its neighboring countries. To understand why then, this study investigates the role of scientific knowledge in the process of issue framing in East Asia and the interface between science and policy. It finds that the debut of PM in East Asia is a function of three components: increasing visibility of air pollution through smoggy days; the development of scientific consensus on causes and consequences of PM; and the enhanced communication between science and the public. It concludes that the science-policy interface is not a simple relationship between scientists and policymakers. Rather, science develops and transmits knowledge to create engaging relationships between the state and society. PM proves this triangular relationship between the state, society, and science.

Keywords: particulate matter, PM, science-policy interface, East Asia, China, Japan, South Korea

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INTRODUCTION

China recorded the highest average number of smoggy days in 52 years in its cities in 2013 with almost 30 smoggy days (China Daily, 2014). Many cities in Hebei province surrounding Beijing were included in the Ministry of Environmental Protection's list of 10 worst cities for air pollution (China Daily, 2014). Occurrence of smog or haze episodes can be characterized by particulate matter. Particulate matter (PM) is the sum of both solid and liquid hazardous particles suspended in air and may cause lung diseases. PM has been classified as PM₁₀ (particles with an aerodynamic diameter¹ of 10 microns or smaller, about one-seventh the width of a human hair) and PM_{2.5} (finer particles with aerodynamic diameter of 2.5 microns and smaller, about one-twenty-fifth or thirtieth of a human hair) for regulatory and scientific purposes (U.S. EPA, 1995). South Korea also experienced notable increase in the number of days with high PM density from 3 days in 2012 to 19 days in 2013 (Chung, 2014).

In tandem with this increasing pollution, media attention on this issue has increased since 2013 in South Korea and Japan. For example, 72 out of 422 press releases and correction reports of the Korean Ministry of Environment included the term, "fine particle," between October 2013 and February 2014 (Chung, 2014).

However, both Japan and South Korea have incrementally improved the conditions of PM since 2001 and 2004,

¹ Aerodynamic diameter is the "diameter of a uniform sphere of unit density that would attain the same terminal settling velocity as the particle of interest. This measure facilitates size comparison among irregularly shaped particles and refers to the physical behavior of the particles rather than the actual size" (Bell et al., 2004, p. 252)

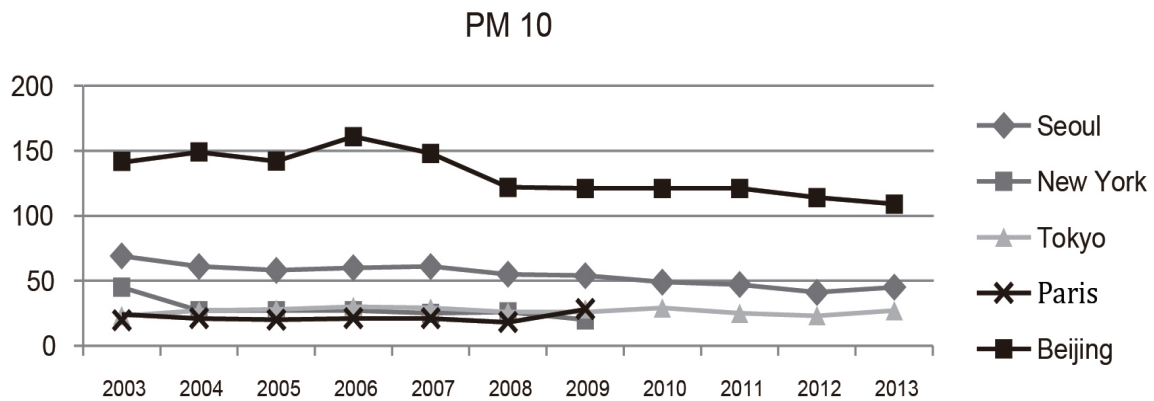


Fig. 1. PM10 concentrations in major cities

Source: Seoul Metropolitan Government, 2015. For Seoul, p. 72. For other cities, pp. 109-110.

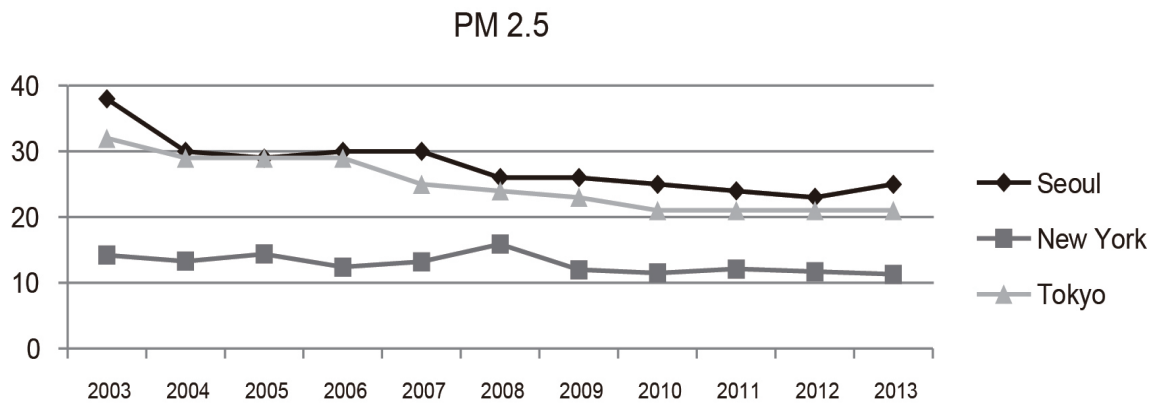


Fig. 2. PM2.5 concentrations in major cities

Source: Seoul Metropolitan Government, 2015. For Seoul, p. 72. For other cities, pp. 109-110.

respectively. Seoul Metropolitan Government and National Institute of Environmental Research of Korea have shown the long-term trend of PM concentrations in major cities (Figure 1 and Figure 2).

Despite continuous improvements of PM in Japan and South Korea, the mass media in East Asia have reported peoples' growing concerns about smog occurrence in China in the early 2010s. People believed that their air conditions had been jeopardized by smog from China, calling it a "Chinese smog bomb" in Japan (Johnston, 2013) and an "air raid" in South Korea (Ryall and Yoo, 2013). Chinese people also expressed their serious concerns about high occurrence of extreme smog episodes that lasted several months since the beginning of 2013, calling them "airpocalypse" and "airmageddon" (Leiva, 2014).

Japan established environmental quality standards for the suspended particulate matter in 1973, and South Korea established PM10 regulations in 1995. China also developed the limits for total suspended particulate under the National Ambient Air Quality Standard in 1996. However, the publics in three countries have only started to pay attention to the term of PM after China suffered from severe haze pollution events in the early 2010s.

This study examines what drove outstanding public concerns about PM in China, Japan and South Korea in the early 2010s despite constant improvement of air quality compared to earlier decades, and how smog problems in China have awakened not only its own public but also those in its neighboring countries. To understand why then, this study investigates the role of scientific knowledge in the process of issue framing in each country, and the interplay between science and policy.

ANALYTICAL FRAMEWORKS

Rolf Lidskog and Göran Sundqvist (2015) compared two different fields of studies on science-policy interface to explain when and how science influences policy. International Relations (IR) scholars argue that science and policy should unite only after scientific consensus has been reached among experts. The most peculiar statement would be that the “more autonomous and independent science is from policy, the greater its potential influence” (Haas and Stevens, 2011: 131). Contrastingly, scholars within the field of science and technology studies (STS) argue that science can be effectively influential not by being autonomous from the political process but by being attached to policy from the very beginning. Bruno Latour (1998: 209) asserts that “the more connected a scientific discipline, the better.” This study aims to examine these two approaches through the case of evolution of PM discourses in East Asia.

The epistemic community approach within IR studies was developed by Peter M. Haas in the late 1980s and early 1990s (Haas, 1989, 1990). For Haas, science, more specifically consensus-based science, plays an independent role for bringing about international agreements rather than playing a dependent role for serving national interests. Moreover, he argues that science can reshape state interests, and that epistemic communities who share common understanding of causal relationships and policy suggestions can act as the “transmission belts” for the transfer of knowledge to policymakers (Haas and Stevens, 2011: 131).

This approach contends that science and policy should be kept separate. It highlights that science must develop truth first, and then speak to power. In other words, science evolves on its own without interaction with policy, builds consensual knowledge among science experts, and then influence policy formation. This approach argues that these three phases should occur independently. If science involves in policy formation too early even before establishing scientific consensus, science can be viewed as scientific controversies rather than as a legitimate advocate for the environmental improvement.

Accordingly, this approach would contend that sufficient accumulation of scientific consensus on PM can explain why countries in the region have started to create and implement environmental policies regarding PM. Common understanding among scientists might have been made among scientists in the countries of East Asia before introducing policies regarding PM.

Unlike the epistemic community approach, science and technology studies present the coproduction thesis that highlights interdependent relationships between science and policy. Coproduction means that “uncertain or contested science can grow stronger in a conducive policy context, and a weak policy context can become stronger through the support of science” (Lidskog and Sundqvist, 2015: 6). Policy influences the production of knowledge and simultaneously knowledge supports policy. This approach argues that a dichotomy between knowledge and policy is not appropriate for making environmental improvement. As science does not have power, it requires interaction with other social actors.

Sheila Jasanoff called for the broader frames for the relationships between science and policy through the concept of civic epistemologies. For Jasanoff (2005: 255), civic epistemology is defined as “the institutionalized practices by which members of a given society test and deploy knowledge claims used as a basis for making collective choices.” Components of civic epistemology include availability of science, local policy formation and assessment, and local knowledge, and media and public perception of policy issues. Among them, Jasanoff emphasizes the public as the agency who participate in producing and applying scientific knowledge. She argues that citizens are “the primary audience for whom the state enacts its scientific and technological demonstrations” with criticizing the dyadic relationships between the state and science (Jasanoff, 2005: 248).

Along with civic epistemology, the civic science thesis also puts an emphasis on the “triangular interaction between scientific experts, policy-makers and citizens” as the citizen is an important actor in the science-policy nexus rather than just the recipient of policy (Bäckstrand, 2003: 25). Civic science is defined as the scientists’ efforts

to communicate scientific results with the public and enhance scientific literacy (Bäckstrand, 2003).

Thus, science and technology studies along with civic science approach would posit that recent policy formation in East Asia can attribute to the successful communication of science with the public through providing answering broad questions such as “what is the purpose; who will be hurt; who benefits; and how can we know?” (Jasanoff, 2005: 240).

The following sections will explain what measures three major countries in the region, China, Japan, and South Korea, had taken to tackle PM issues until the early 2010s. Next, it will investigate the two contrasting propositions derived from the epistemic community approach and science and technology studies.

PM IN CHINA

According to the Environmental Monitoring Department under the Chinese Ministry of Environmental Protection,² in 2015, air quality was monitored in 1,436 sites under national monitoring program in 338 cities at prefectural level and above. The most obvious evidence of a decline in air quality due to particulate pollution would be the increasing frequency of low-visibility days. Many studies examined particulate pollutions in developed regions of China, including the Beijing-Tianjin-Tangshan region.

According to a study on the characteristics of PM_{2.5} aerosols in an urban area, Chengdu, China in 2009-2010, major sources of PM_{2.5} included “coal combustion, traffic exhaust, biomass burning, soil dust, and construction dust emissions” (Tao et al., 2013: 1070). The seasonal variations of PM_{2.5} concentrations help us understand causes of its concentrations more clearly. According to Tao and his colleagues, the Chengdu area recorded the highest PM_{2.5} level in winter with 225 $\mu\text{g}/\text{m}^3$ on average, followed by 188 in autumn, 133 in spring, and 114 in summer (Tao et al., 2013). The combustion of fossil fuel and biomass burning for heating can explain the highest concentrations along with stagnant meteorological conditions that prevent pollutants from being diluted and dispersed in winter.

The number of annual hazy days in China increased from 2-4 days in the 1960s to 11-16 days in the late 2000s, which is almost five times of those in the 1960s (Ding and Liu, 2014). China created national ambient air quality standard (NAAQS) for PM₁₀ in 1996,³ but the increasing number of hazy days led the Chinese government take a new version of NAAQS in 2012 to replace its original NAAQS.⁴ The new standards include additions, stricter limits, and new contents. For example, 8-hour average concentration limit of ozone revision placed PM_{2.5} and O₃ in a core position to prevent and control air pollution. The annual standard for PM_{2.5} was set at 35 $\mu\text{g}/\text{m}^3$ for the first time in this new NAAQS.

The Five Year Plans, established in 1953, has been one of the most important governmental guidelines for the development in China. The environmental guidelines have been included since the sixth Five Year Plans for 1981-1985 (Wang, et al., 2013).

China has monitored the air pollution since the 1980s. The NAAQS, released in 1996, set air pollution index (API). In January 1997, the Committee for Environmental Conservation of the State Council required the 46 key cities for environmental protection to issue weekly air quality reports to the public as early as possible. All the 46 cities began to report the weekly API in June 1998. API was based on the monitoring results of three pollutants: total suspended particulates (TSPs), nitrogen oxide (NO_x), and sulfur dioxide (SO₂) (Wang, et al., 2013). In June 2000, major cities

²When the first session of the 13th National People's Congress revealed a plan to reorganize the entire government institutional structure in March 2018, China's environmental governance was drastically reformed. The Ministry of Ecology and Environment was established as a new environment “super ministry” because this new Ministry takes responsibility not only for pollution control but also climate change and emission reduction policies that the National Development and Reform Commission used to oversee previously (Lewis, 2020).

³The 1996 NAAQS set the standards for SO₂, TSP, PM₁₀, NO_x, NO₂, CO, O₃, Pb, B[a]P, and F. For more information, see <http://www.mep.gov.cn/image20010518/5298.pdf> (in Chinese).

⁴The newly revised standard has been jointly issued by Ministry of Environmental Protection (MEP) and General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) on Feb. 29, 2012 and has been implemented since January 1, 2016.

of China started to report daily API at the request of former State Environmental Protection Agency of China (later the Ministry of Environmental Protection) (Chen et al., 2016). The pollutants for monitoring included SO₂, PM₁₀ replacing TSP, nitrogen dioxide (NO₂) replacing NO_x. In 2011, cities started publishing the real-time hourly concentrations of the three pollutants on the National Monitoring Centers website (Wang et al., 2013).

This API was replaced by a new index called air quality index (AQI) in January 2013 after adopting the new 2012 NAAQS. The 2012 NAAQS added PM_{2.5}, ozone and carbon monoxide concentrations, comprising seven different indicators: the 24-hour average concentration of PM₁₀, PM_{2.5}, SO₂, NO₂, CO, the highest one-hour and 8-hour average concentration of O₃ for the monitoring of urban air quality. It also requested 74 major cities to provide the public with hourly real-time reporting in their local web platform and the national web platform of the Ministry of Environmental Protection from January 2013. The number of cities, participating in the national real-time web reporting system, grew to 190 in the beginning 2014 (Chen et al., 2016).

When the Chinese Ministry of Environmental Protection issued the new NAAQS on February 29, 2012, it also released the new Technical Regulation on Ambient Air Quality Index (AQI). In May 2012, the Chinese MEP required 74 cities to monitor the air quality based on the 2012 NAAQS and disclose the monitoring data publicly no later the end of 2012 (You, 2014).

Since 2006, China has set environmental goals for the Five Year Plan. The Communist Party of China (CPC) is another important platform to examine how the government treats environmental issues. The air pollution has been a part of the important political agenda of CPC. For example, in the 18th CPC in 2012, “ecological civilization was put alongside with economic, political, cultural, and social development to form a five-in-one overall development plan, for the purpose of leading to increased production, prosperity, and a good ecosystem” (You, 2014: 6).

The Ministry of Environmental Protection (MEP), the National Development and Reform Commission, and the Ministry of Finance issued the Plan for Prevention and Control of Atmospheric Pollution in Key Regions During the Period of the Twelfth Five Year Plan in 2012. This plan set goals for 13 key regions regarding PM₁₀ and PM_{2.5} as well as SO₂, NO₂, industrial dusts, and the VOCs. As a further measure, the MEP set the special emission limitation for air pollutants from “thermal power plants, steel and iron industry, petrochemical industry, cement, nonferrous metal industry, and chemical industry” as a new regulatory tool in 2013 (You, 2014: 7). The Chinese MEP also issued technical policies for the various requirements on technical innovation and economic incentives to reduce air pollution from heavy-pollution industries such as the cement industry, and steel and iron industry. These policies contributed to reducing PM_{2.5} concentration (You, 2014). The State Council endorsed these Chinese MEP measures. The national government has taken an active stance toward the air pollution control, particularly PM_{2.5} since the 2012 NAAQS.

These policy actions demonstrate that the national government of China cares about its legitimacy as well as its accountability to its people. Thus, to the Chinese national government, the achievement of high attainment rate of PM_{2.5} is “not only for environmental protection but also more importantly, for the governmental credibility” because it can show the national government’s willingness to respond to its people’s anxiety and concerns about hazy days and low visibility (You 2014: 7).

PM IN JAPAN

Japan has dealt with its own pollution problems from the early years of its industrialization in the late 1800s. National and provincial measurements, active public protests and lawsuits, responsible local government action, development of nuclear energy, and introduction of upgraded technology helped to turn the tide in the 1970s and 1980s. In particular, Japan’s farmers protested against copper smelters and other polluters that affected their lands and forests dating back to the 19th century Meiji era. Not only the farmers, but also the public demanded local governments to create and enforce pollution standards as early as the 1920 to fight against pollution from power

plants and chemical factories (Kurtenbach, 2015).

After experiencing severe environmental crises due to cadmium contamination, mercury contamination, and high concentration of sulfur dioxide, the Basic Law for Environmental Pollution Control was enacted in 1967. In particular, the Japanese government issued the Air Pollution Control Law in 1968 to protect victims from air pollution by providing the liability of business operators for environmental damages as well as to protect the environment from air pollution by controlling emissions including soot and smoke, volatile organic compounds, and particulates, by implementing measures against hazardous pollutants, and by setting maximum limits for automobile exhaust (Environment Agency⁵ later Ministry of the Environment of Japan, n.d.).

The Japanese government established environmental quality standards (EQS) in 1967 under the Basic Law for Environmental Pollution Control. This EQS set limits for five pollutants: SO₂, carbon monoxide (CO), suspended particulate matter (SPM), NO₂, and photochemical oxidants (Ox) (Kawamoto et al., 2011).

SPM refers to airborne particles with a diameter smaller than or equal to 10 micrometers. Even though it sounds like PM₁₀, Japan's SPM would be about PM₇ because of different collection methods. SPM particles are "collected with 100% efficiency at the 10µm cut point of aerodynamic diameter" whereas PM₁₀ particles are "collected with 50% efficiency at the 7µm cut point" (Wakamatsu et al., 2013: 183).

The EQS for SPM was established in 1973, setting the daily mean of hourly SPM concentrations as less than or equal to 0.10 mg/m³ and the hourly mean SPM concentration as less than 0.20 mg/m³ (Wakamatsu et al., 2013). SPM concentrations increased from 1980 to 1990, but they have decreased continuously owing to the promulgation of Automobile NO_x Law in 1992 and Automobile NO_x/PM Law in 2001, and the shutdown of a small incinerator in 1999 (Wakamatsu et al., 2013) (Figure 3).

However, cities in Japan endure hazy days in the early 2010s, partly due to "dust and pollutants drifting over

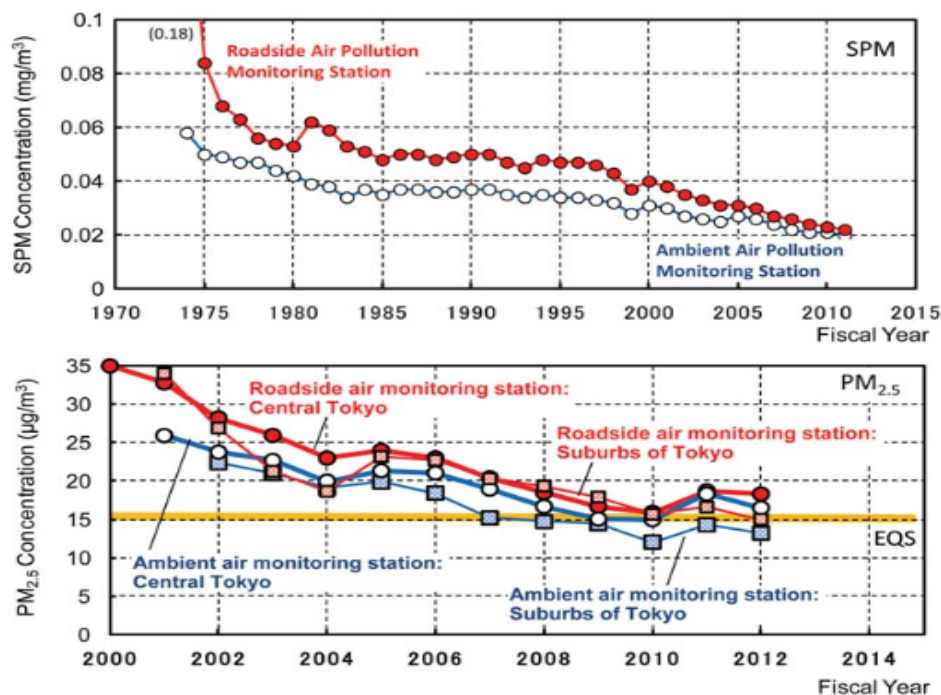


Fig. 3. Annual average concentrations of SPM and PM_{2.5} in Tokyo
Source: Wakamatsu et al., 2013: 184.

⁵The Environment Agency, reorganized to the Ministry of the Environment in 2001, was established in 1971.

from China” (Kurtenbach 2015). The EQS for PM_{2.5} was established in 2009, setting the annual standard as less than or equal to 15 $\mu\text{g}/\text{m}^3$ and the daily standard as less than or equal to 35 $\mu\text{g}/\text{m}^3$. As shown above in Figure 3, the concentrations of PM_{2.5} have fallen continuously but still exceeds Japan’s EQS.

PM IN SOUTH KOREA

South Korea established the Environmental Pollution Prevention Act in 1963 and the Environmental Conservation Act in 1977. However, its first comprehensive policy addressing ambient air quality under the Clean Air Conservation Act was established in August 1990 and came into force in February 1991 (Ministry of Environment of Korea, 2015a; National Law Information Center of ROK, 2005).⁶

Air quality standards for key air pollutants have been set since the late 1970s. After the first quality standards on SO₂ in 1978, standards for total suspended particles (TSP) along with carbon monoxide, nitrogen dioxide, ozone, and hydrocarbons were set in 1983. Standards for PM₁₀ were created in 1995, and standards for PM_{2.5} were enacted in 2011. The standards for PM₁₀ have been tightened throughout decades. The first PM₁₀ standards, enacted in 1995, were 80 $\mu\text{g}/\text{m}^3$ annually and 150 $\mu\text{g}/\text{m}^3$ daily, and were revised in 2001 as 70 $\mu\text{g}/\text{m}^3$ annually and 150 $\mu\text{g}/\text{m}^3$ daily. The standards were modified to 50 $\mu\text{g}/\text{m}^3$ annually and 100 $\mu\text{g}/\text{m}^3$ daily in 2007 (National Institute of Environmental Research, 2015a).

The Clean Air Conservation Act got amended in 2015 to introduce more comprehensive measurements for long-range transboundary air pollutions for the first time rather than tackling specific issues such as yellow dust (Kim, 2022). In fact, the Korean government developed its first 10-year “Master Plan for Improving Air Quality” in Article 7-5, newly inserted by Act 7779 in December 2005, and indicated its goals to improve air quality by reducing air pollutants and greenhouse gas (National Law Information Center of ROK, 2005). Article 7-5 indicates the necessity of “the close international cooperation” in tackling broad global or regional air pollution issues by mentioning only “climate changes” and “[o]ther matters necessary to improve air and environment” (National Law Information Center of ROK, 2005). This Act includes regulations on air pollutants including sulfur content in fuel resources (Article 26), scattering dust (Article 28), and volatile organic compound (Article 28-2), but does not mention anything transboundary pollutants.

The Korea Environment Corporation (KECO) has operated the national air pollution monitoring network and has provided the public with the information on the air pollution via the *Air Korea*, which is a real-time ambient air quality monitoring system, since December 2005 (KECO, 2015).⁷ It presents real time data on PM₁₀, PM_{2.5}, ozone (O₃), nitrogen dioxide, carbon monoxide, sulfur dioxide, and Comprehensive Air-quality Index (CAI), with four categories (Table 1). The CAI “aims to help the public easily understand air quality level and protect the health of people from air pollution” (Korea Environment Corporation Year Unknown, n.d.b). For example, for PM_{2.5}, the government set the ranges for each category: Good (1-15); Moderate (16-50); Unhealthy (51-100); and Very Unhealthy (above 100).

In addition to these national atmospheric policies, the municipal governments have also enacted their own policy measures. The Seoul Metropolitan Government enacted the “Special Act on the Improvement of Air Quality in Seoul Metropolitan Area” in 2003. It also formulated the First Seoul Metropolitan Air Quality Control Master Plan (2005-2014) in 2005 (Ho et al., 2021).

Seoul Air Quality Information provides forecasts, alerts, and citizen action plan instructions on four air pollutants:

⁶ For the full chapters and provisions, see the National Law Information Center of ROK. <http://www.law.go.kr/LSW/lsInfoP.do?lsiSeq=5001&chrClsCd=010203&urlMode=engLsInfoR&viewCls=engLsInfoR#0000>

⁷ KECO has also provided the monitoring information via the National Ambient Air Monitoring System (NAMIS) for the administrative organizations on both national and self-governing provincial levels since April 2004.

Table 1. Comprehensive Air-quality Index of South Korea

	PM _{2.5} /24hr	PM ₁₀ /24hr	O ₃ /1hr	NO ₂ /1hr	CO/1hr	SO ₂ /1hr	CAI
Good	0~15	0~30	0~0.030	0~0.030	0~2.00	0~0.020	0~50
Moderate	16~35	31~80	0.031~0.090	0.031~0.060	2.01~9.00	0.021~0.050	51~100
Unhealthy	36~75	81~150	0.091~0.150	0.061~0.200	9.01~15.00	0.051~0.150	101~250
Very Unhealthy	76~	151~	0.151~	0.201~	15.01~	0.151~	251~

Note: The category of “Good” indicates health effects as a “level that will not impact patients suffering from diseases related to air pollution”; “Moderate” as a “level which may have a meager impact on patients in case of chronic exposure”; “Unhealthy” as a “level that may have harmful impacts on patients and members of sensitive groups (children, aged or weak people), and also cause the general public unpleasant feelings”; “Very Unhealthy” as a “level which may have a serious impact on patients and members of sensitive groups in case of acute exposure” and a “level which may need to take emergency measures for patients and members of sensitive groups and have harmful impacts on the general public” (Korea Environment Corporation, n.d.a).

fine particles (PM_{2.5}), coarse particles (PM₁₀), ozone, and yellow dust (Seoul Metropolitan Government, 2015). Seoul city notifies the monitoring data of fine and coarse particles, and ozone acquired from NIER and issues alerts and action plan instructions when concerned for environmental hazards. For yellow dust, the Korea Meteorological Administration issues alerts and Seoul city issues action plan instructions (Seoul Metropolitan Government, 2015).

WHY THEN?

Despite constant improvement of air quality compared to earlier years, governments in East Asia initiated the PM forecast system in 2013. They also established environmental standards for PM_{2.5}: Japan in 2009, South Korea in 2011, and China 2012. To explain why the countries in East Asia spurred to take actions in late 2000s and early 2010s regarding PM_{2.5}, this study explores two propositions.

Epistemic Community Approach

Unlike the recent attention to PM in East Asia, numerous experts and scientists have studied PM since 1950s. The United States has measured total suspended particles (TSP), referring to particles sized up to 45µg/m³ since 1950. The United States Environmental Protection Agency adopted the first rule regarding TSP in 1971. The EPA introduced the first National Ambient Air Quality Standards for PM₁₀ in 1987 and for PM_{2.5} in 1997.

The Clean Air Act requires the EPA to establish National Ambient Air Quality Standards (NAAQS) for criteria pollutants such as particulate matter (PM) as well as lead, carbon monoxide (CO), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), and ozone and to periodically review and revise the criteria and NAAQS (U.S. EPA, n.d.). The first NAAQS for PM in the United States, issued in 1971 for TSP standards, were revised in 1987 to include criteria for PM₁₀ to protect human health from exposure to finer particulate matters that can be deposited in thoracic portions of the lower respiratory tract. Periodic reevaluation of new scientific information, published in 1996 and entitled “Air Quality Criteria for Particulate Matter,” provided key scientific bases to promulgate for new PM NAAQS decisions which retained the 1987 PM₁₀ NAAQS in modified form (from 150µg/m³ to 65 for 24 hours average, and from 50µg/m³ to 15µg/m³ for annual average) and added new standards for PM_{2.5} in 1997 (U.S. EPA, n.d.). Since then, three more reviews have been conducted in 2006, 2012 and 2020. These changes to the regulatory requirements demonstrate “an enhanced understanding of the potential health effects associated with particles of smaller size” (Bell et al., 2004: 253-254).

As the first country that adopted policies on PM, it would be meaningful to examine the development of scientific knowledge on PM in the United States. When the EPA promulgated NAAQS for PM_{2.5} in 1997, it relied on time-series studies of morbidity and mortality and on long-term cohort mortality studies (Board of Scientific Counselors, 2005).

However, there were many uncertainties at that time regarding the causal relationships between human exposure to ambient PM and the adverse health outcomes. To reduce these uncertainties, the U.S. Congress augmented the President Clinton's recommended EPA budget in 1998 with a supplemental budget in Fiscal Year 1999. The additional resources prompted EPA to accelerate investigation of PM-associated health outcomes and to "implement health risk reductions via scientifically defensible regulatory actions" (Board of Scientific Counselors, 2005: 3).

Intensive research activity by the Air Quality Management Work Group under the Clean Air Act Advisory Committee for nearly seven years yielded significant advances in the scientific understanding of PM. The Subcommittee found that its research program "has resulted in significant reductions in scientific uncertainty in critical areas, especially the distribution and dosimetry of inhaled fine and ultrafine particles, the relationship of ambient, fixed-site PM monitoring to real-world human exposures, the identification of susceptible subpopulations, the identification of biologically plausible mechanisms of PM toxicity..., the validity of PM epidemiological studies" (Board of Scientific Counselors, 2005: 4).

Based on these scientific findings, the World Health Organization issued "WHO Air Quality Guidelines" in 2005 to provide global guidance on limits for key air pollutants that pose health risks. In 2021, WHO revised the guidelines to address air pollution issues more rigorously (Table 2).

It can be argued that these results in the early 2000s along with the American initiatives have led the World Health Organization to announce standards for PM_{2.5} as illustrated above (Chen et al., 2016). This accumulation of scientific knowledge and consensus among experts around the world seemed to have prompted governments in East Asia to create air quality standards associated with PM_{2.5}.

Science and Technology Approach

Even though the Chinese MEP noticed the increasing PM_{2.5} concentration due to the rapid economic development and considered the necessity to measure and control PM_{2.5} under NAAQS, local governments did not support the Chinese MEP's plan to revise the existing 1996 NAAQS despite its centralized unitary political system. They were "afraid that upgrading the NAAQS, especially adding PM_{2.5} as a criterion pollutant, would make it harder to achieve attainment goals and harder to keep the speed of economic development, which is also an important criterion" in their political performance (You, 2014: 6). Thus, local government expressed strong opposition to the revision of the NAAQS. Accordingly, the "MEP had no sufficient political resources to add PM_{2.5} as a new criterion pollutant and upgrade the NAAQS; the final decision has to be made by the State Council, the cabinet of the Chinese national government" (You, 2014: 6).

The number of attainment days in a year is one of important indicators to evaluate local governments. API and AQI ranges from 0 to 500, indicating the higher the API value, the heavier the atmospheric pollution. To help the public understand and interpret the concentrations data of air pollutants, many countries and regions have used indices ranging from good to unhealthy. Since the 1970s, such indices have been developed. Air Quality Index (AQI),

Table 2. PM Standards in the World as of 2022

	Average	Korea	U.S.	EU	WHO 2005	WHO 2021
PM ₁₀	Daily	100	150	50	50	45
	Annual	50		40	20	15
	Daily	35	35		25	15
PM _{2.5}			12 (primary)			
	Annual	15	15 (secondary)	25	10	5

Source: Ministry of Environment of Korea et al., 2021: 402; WHO 2021

developed by the U.S. EPA, is the most commonly used index. For AQI, the concentrations of the six criteria air pollutants are monitored, and an Individual AQI (IAQI) for each pollutant is calculated. The maximum of all the IAQIs determines the AQI, and the air pollutant with the maximum among six criteria is defined as the “main pollutant” (Hu et al., 2015; You, 2014). The Chinese Ministry of Environmental Protection developed the Chinese AQI system in 2012, adopting this US EPA AQI approach but slightly revising the grading system (Table 3) (Hu et al., 2015).

The daily API under 1996 NAAQS and AQI under 2012 NAAQS not exceeding 100 is considered an attainment day. The attainment rate, or the number of attainment days in a year, is “a key index to evaluate the air quality of a city” (Chen et al., 2016). For example, Beijing calls an attainment day “Blue Sky Day”.

The differences of attainment rates before and after the adoption of the new 2012 NAAQS are significant. Chen and his colleagues compared the differences of attainment rates between API and AQI and showed significant discrepancies (Figure 4).

The 1996 NAAQS of China did not include PM_{2.5} as one of pollution criteria. Thus, cities in China were not officially required to monitor PM_{2.5}. As both the Chinese MEP and local governments knew that PM_{2.5} was the most problematic pollutants to cities in China, they were aware that the air quality attainment rate would be greatly brought down by the new NAAQS.

Despite the increase of energy consumption to support the rapid economic development, the number of attainment days of Beijing increased from 100 to 286 between 1998 and 2012 (Chen et al., 2016). In fact, the historical trend of API shows that China achieved a notable advance for the reduction of extremely heavily polluted days from 7% in 2001 to 1% in 2011 in all city average (Wang et al., 2013). The average PM₁₀ concentrations, regarded as the main pollutants, continually decreased between 2001–2011 thanks to the national sulfur dioxide controls during 11th Five Year Plan (2006–2011).

Citizens rather assumed “some deterioration in the atmospheric environment” (Chen et al., 2016: 50). The growing discrepancies between the public perception and government’s API due to the frequent haze occurrence have “forced the Ministry of Environmental Protection of China to release a new national ambient air quality standard” which is AQI (Chen et al., 2016: 50).

Chinese officials had been monitoring PM_{2.5} for years before the 2012 NAAQS adopted on a “pilot” basis, but they “had planned to wait until 2016 to start publishing those readings” (The Economist, 2012). However, on January 6th, 2012, Beijing city officials announced that they would start reporting PM_{2.5} monitoring data by month’s end, as they knew that “PM_{2.5} has been an important source of the discrepancies between official reports and the acrid, airborne reality” (The Economist, 2012).

Table 3. Chinese AQI

Grade	IAQI below	Daily average ($\mu\text{g}/\text{m}^3$)						Status
		SO ₂	NO ₂	CO*	O ₃ **	PM _{2.5}	PM ₁₀	
1	50	50	40	2	100	35	50	Very good
2	100	150	80	4	160	75	150	Good
3	150	475	180	14	215	115	250	Mild polluted
4	200	800	280	24	265	150	350	Moderate polluted
5	300	1600	565	36	800	250	420	Heavily polluted
6	400	2100	750	48	1000	350	500	Severely polluted
	500	2620	940	60	1200	500	600	

Source: The Chinese Ministry of Environmental Protection, 2012, 2016.

*Unit for CO is mg/m^3 .

** Data for O₃ is 8-hour peak average concentration, not daily average. When 1-hour average concentration of O₃ is higher than 800, the 1-hour average concentration is used to calculate individual AQI for O₃.

Mr. Ma Jun at China's Institute of Public and Environmental Affairs mentioned that it was the public outcry that led the authorities to act sooner to enhance transparency. He stated that “[w]ith amazing speed, this term of technical jargon, PM2.5, became a household word” because of the concern about health (The Economist, 2012).

The U.S. embassy at Beijing and environmental nongovernmental organization endeavored to help the public understand more about the effects of PM2.5 and its concentration in China through asserting that the 1996 NAAQS was outdated (You, 2014). The American embassy in Beijing started monitoring and publishing the air quality data of PM2.5 on April 8, 2008. PM2.5 data at four Consulates in Chengdu, Guangzhou, Shanghai, and Shenyang have also been published.⁸ All these readings from the American embassy and Chinese pressure groups “have been widely distributed over Chinese websites and social media, including the vastly popular Weibo microblog platform” (The Economist, 2012).

Once the Chinese government started to publish the monitoring data of PM2.5 since 2012, the vast differences between China's official readings and ones from other resources have become clear. For example, in January 2013, the American embassy showed $886\mu\text{g}/\text{m}^3$ for PM2.5 hourly concentration, but Beijing's own municipal monitoring center only acknowledged readings in excess of $700\mu\text{g}/\text{m}^3$ (The Economist, 2013).

Chinese authorities complained about the American embassy's independent monitoring and public reporting as official ones were often less dire (The Economist, 2013). The “side-by-side comparison of those competing data-sets” has become “a key feature of one of those mobile-phone apps” (The Economist, 2013).

This active communication between the public and science have prompted the Chinese government to take actions to reduce concentrations of PM. The Chinese government has not only decided to publish air quality data based on monitoring data but also have taken important policy measurements. Its 2013 Air Pollution Prevention Action Plan required the Beijing region, including Beijing, Tianjin, and Hebei, to reduce coal consumption growth by 2017. These regions needed to replace coal with “natural gas and non-fossil fuel energy by closing down excess iron, steel, cement, and other heavy-industry capacities” (Fortune, 2016). This plan displayed specific targets for coal consumption reductions: “13 million tons in Beijing, which aims to be completely coal-free by 2020; 40 million tons in Hebei; and 20 million tons in Shandong” (Fortune, 2016).

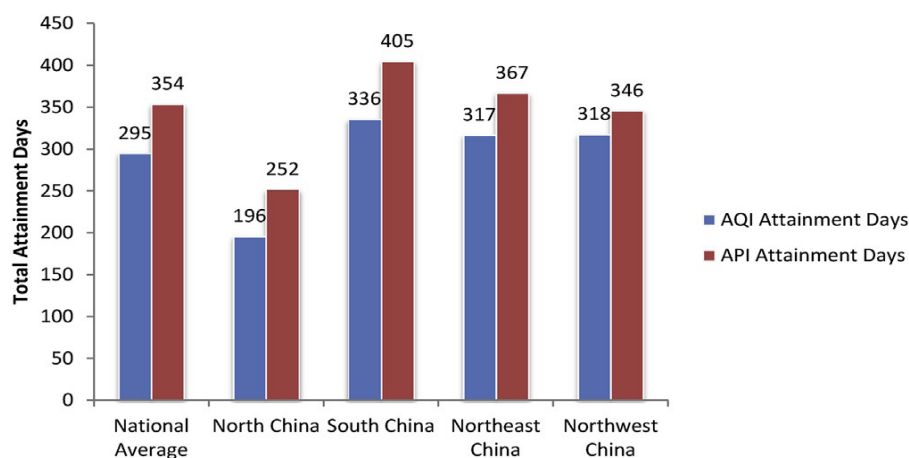


Fig. 4. Comparison of attainment days between API and AQI of China

Source: Chen et al., 2016: 52.

Note: Chen and his colleagues divided the 72 cities into 4 regions: North China (19 cities with warm-temperature dry climate); Northeast China (4 cities with mid-temperature humidity climate); Northwest China (8 cities, mid-temperature dry climate along the Tibet region); and South China (41 cities with subtropical and tropical climate).

⁸ See daily and historical data at <http://www.stateair.net/web/post/1/1.html>.

In tandem with measures for reducing absolute coal consumption, “China has also tightened its air pollution and environmental protection laws to both speed the transition to cleaner energy and to put powerful new tools in the hands of environmental officials and the public to fight pollution” (Fortune, 2016). These policies were not empty words. China has installed around “40% of the world’s newly added renewable energy power over the past five years and invested in clean and renewable energy that surpasses the U.S. and Europe’s combined investments” (Fortune, 2016).

It is notable that Chinese public anxiety about the increasing visibility of air pollution through frequent smog occurrence has pushed the Chinese government to take an earlier adoption of forecast system and actual policies. The role played by the U.S. embassy in Beijing is significant to get people aware of the specific degrees of air quality, as well as the difference between the data from the Chinese government and the American government.

The Japanese Ministry of Environment publishes real-time monitoring data of seven pollutants from its Atmospheric Environmental Regional Observation System and Spectral Radiation-Transport Model for Aerosol Species that Kyushu University forecasts the transport of air pollutants and dust and sandstorms from China (Japan Daily Press, 2013).

In the fiscal year of 2010 right after the regulations were set, 34 out of 46 monitoring sites exceeded the limits of the annual average of PM_{2.5} concentrations across the nation, but mostly were located in western Japan (Japan Daily Press, 2013). In March 2013, five prefectural governments in western Japan (Kumamoto, Yamaguchi, Oita, Nagasaki, and Shimane) issued air pollution warnings due to high concentrations of PM_{2.5}. In particular, the Fukuoka city government established stricter warning levels at 35 $\mu\text{g}/\text{m}^3$ than the central government’s warning level at 70 $\mu\text{g}/\text{m}^3$ (Japan Daily Press, 2013).

According to quantitative analyses on PM_{2.5} pollutants transported from China by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), the National Institute for Environmental Studies (NIES), and other organization, “the impact from transboundary air pollution in relation to the annual average concentration of PM_{2.5} in Japan is estimated to account for 50 percent at maximum” (Tanabe, 2013). A 5-month survey of 19 hospitalized youth (aged 8-15) patients with severe asthma showed some relationships between PM_{2.5} and human health through proving “the chances of experiencing symptoms rose by nearly 10 percent when the daily average of PM_{2.5} is above 24 micrograms per cubic meter” (The Asahi Shimbun, 2013).

However, the effects of China’s air pollution in Japan are not a recent phenomenon at all. The prevailing westerly winds from the Himalayas to the Pacific through China have carried various air pollutants towards Japan. Professor Toshihiko Takemurat at the Research Institute for Applied Mechanics of Kyushu University contends that “China’s air pollution rapidly worsened between the latter half of the 1990s and the first half of the 2000s. Since then, PM_{2.5} density has remained high,” and thus it is “not true that the density has recently surged” (Japan Daily Press, 2013).

Many would wonder why Chinese pollution, particularly PM, is “now suddenly an issue” even though “Chinese pollution in Japan is hardly a new phenomenon” (Johnston, 2013). It is argued that more availability of information on PM_{2.5} can answer this question (Johnston, 2013). The United States started publishing their monitoring data of PM_{2.5} concentrations in 2002, the European Union started reporting on PM_{2.5} in 2008 (The Economist, 2012), and Japan followed in 2009. Moreover, the increase of information on Chinese air quality through the American embassy and the Chinese government since 2008 and 2012 might have significantly enhanced public understanding of PM_{2.5}.

Interestingly, many people in western Japan believe that attention to PM_{2.5} is high “because the smog has finally reached Tokyo, drawing the attention of national politicians and the media, unlike past instances where Chinese smog was restricted mostly to Kyushu and western Honshu” (Johnston, 2013). Indeed, Tokyo is not an exception for the transported air pollution problems. Niroshi Tanimoto contends that China contributes to annual average PM_{2.5} around 40% in the Tokyo area as well as 60% in Kyushu (Galbraith, 2013). The air pollution levels of the cities of

Kawasaki and Chiba, close to the Tokyo area, have exceeded the safety standards (The Asahi Shimbun, 2013). It shows that pollutants drifting from China may reach farther east.

As public anxieties about PM_{2.5} from China have soared since 2013 when Beijing recorded severe pollution levels, many alarmed citizens are “accessing the Japanese Environment Ministry’s online data when the news media reported on the air pollution and smog smothering many Chinese cities” (The Asahi Shimbun, 2013).

This increased interaction between the Japanese public and science is important to understand the question of why PM_{2.5} has attracted public concerns. The increasing occurrence of smog events in not only western but also eastern Japan has awakened the Japanese public to notice the severity of air quality in Japan. More available data of air pollution in China from the American embassy in Beijing might have led the Japanese government to develop real-time data sharing with the public in regard to PM_{2.5} concentration in 2009.

The Korean government reports that about 30% to 50% of the annual PM concentrations in South Korea originated from China, but the percentages increase up to 60% to 80% for days with the high-level concentrations (NIER, 2015b). The Korean Ministry of Environment has released the air quality level of 16 areas around the World Cup Stadium since April 2002. The general public has gained access to air quality data on the nationwide outdoor air quality since December 2005 due to the increasing public interest in air quality.⁹

To respond to growing public anxiety about air quality, the Korean Ministry of Environment started to implement a pilot PM₁₀ forecast service system in the Seoul Metropolitan area during August 31, 2013 and February 5, 2014. However, municipal governments have provided forecast services on PM₁₀ concentration since the mid 2000s. The revised Ambient Environment Protection Law required the municipal cities to follow national standards of PM_{2.5}, rather than the municipal’s individual standards, set by National Institute of Environmental Research from February 2014. Accordingly, on February 6, 2014, the Korean central government has initiated the national full-fledged forecast system (NIER, 2015a).

However, Korean media (Yoon, 2015; Park, 2015; HanGeoRe, 2015) reported citizen dissatisfaction about this forecast system, due to the lack of accuracy and short-time span forecast. As the government’s official webpage for PM warnings and advisories did not provide any explanation or warning for smog impacts, the media asserts that some Korean citizens often visited the Japan Meteorological Agency to get more specific data. The Korean forecast system displayed only relatively simple information. Even though the Korean government has achieved the forecast accuracy aim of 80% in 2014 (NIER, 2015a), recording average 85.5% of ten regions, it is criticized that its accuracy rate significantly decreases to 57% for those days with high-level concentrations (Park, 2015; HanGeoRe, 2015).

The U.S. EPA has provided the two-day (today and tomorrow) forecasting service on O₃ and PM_{2.5} through *AirNow*, and the Department for Environment, Food, and Rural Affairs of the United Kingdom has provided up to five-day air pollution forecasts with 10 scales of air quality index bands from low to very high.¹⁰ The Japan Meteorological Agency also started 48-hour forecasting services on PM_{2.5} concentrations on March 22, 2013 with clear image and information.¹¹

NIER announced that it would make a gradual expansion of the forecast period from one day to two days. As the first step, it planned to add the PM₁₀ forecast for the weekends when it releases forecast on Friday from November 30, 2015. As the second step, NIER would release a national forecast without classifications of sub-regions for two-day period from April 2016. As the last step, NIER planned to release PM₁₀ forecast for each forecast regions from November 2016 (NIER, 2015b).

⁹ Seoul World Cup Stadium was built in 2001 for the 2002 World Cup, and official opened in November 2001. It is notable that the Korean Ministry of Environment started to release the air quality of areas nearby the World Cup Stadium on a real-time basis in April 2002 (Korea Environment Corporation, n.d.b).

¹⁰ For the United States, see <https://www.airnow.gov/>. For the United Kingdom, see <http://uk-air.defra.gov.uk/forecasting/>.

¹¹ For Japan, see http://www.tenki.jp/particulate_matter/

As such, the Korean public and media urged the Korean government to adopt more efficient and sufficient systems to inform the public about the air quality. The Korean government initiated the forecast services earlier than schedule through launching a pilot forecast system. The rising public concerns about PM might have placed the government under great pressure by the public who asks for more information on PM. As shown in the case of relying on Japanese information which some Koreans considered more useful, the public were not simple receivers of information given by the government. Rather, the Korean public seems to be willing to communicate with science in an active manner. The government acknowledges the dissatisfaction of the public on the accuracy of its forecast system (HanGeoRe, 2015) and tries to develop a more solid forecast system.

CONCLUSIONS

Countries in East Asia have shared air pollution concerns to a large extent because of the transboundary nature of air pollutants. Owing to downwind locations, Japan and South Korea have tried to establish an international framework that resembles a successful European experience through the Convention on Long-Range Transboundary Air Pollution (CLRTAP). International joint monitoring and modeling activities have been established through various channels since the early 1990s in Northeast Asia (Kim, 2014). Interestingly, their targeted substances for international efforts have changed over time, first with sulfur oxide in the 1990s, dust and sandstorms or yellow dust in the early 2000s, ozone in the late 2000s, and the most recently PM_{2.5} pollution (Tanabe, 2013).

This research asks why the region shifted their major concerns to PM_{2.5} in the early 2010s. The recent debut of particulate matter in East Asia is a function of three components: increasing visibility of air pollution through smoggy days; the development of scientific consensus on causes and consequences of PM; and the enhanced communication between science and the public.

Air pollution visibility led to increased public awareness and anxiety. Even though the Korean municipal governments had released the forecast data for PM₁₀ since 2005, the Korean public did not pay significant attention to PM₁₀, and there was little public discussion. They had been rather caught up by dust and sandstorms.

Along with the increasing visibility of pollution problems, this study argues that scientific consensus on the causes and consequences of PM has provided the public and media with information about why they had to be concerned about PM and how they could take precautionary measures in their daily lives. The accumulation of scientific knowledge, particularly on the relationships between PM and human health has led WHO to adopt formal guidance about the PM concentrations. Governments in East Asia do not pose a challenge to the existing scientific knowledge that informs us the causal relationships between the air quality and human health. The descriptions of PM including definition, causes, and consequences are consistent throughout different governments without significant disagreement. It can be argued that scientific knowledge has been embraced by the media, public and governments of the United States, Europe, and East Asia.

In addition to the development of scientific consensus, the science and policy interface is evident in the issue of PM in East Asia. The public in East Asia has been active in searching and sharing monitoring data to get informed about air quality and prepared for their daily activities. The “triangular interaction between scientific experts, policy-makers and citizens” has led governments in East Asia to take more active stances in a faster pace. The public with increased scientific literacy on PM has demanded their governments to create a better and earlier real-time monitoring data reporting system and the forecast services. Governments in East Asia including China have tried to respond to these public voices to prove their accountability to their people. The Action Plan on Environment and Health in 2007-2015, taken by the Chinese Ministry of Environmental Protection, points out the importance of “state environment health information share and service system” as for specific action plans. It states that:

Information is a fundamental factor for work regarding environment and health. Completely playing the role of information to offer *support for decision making* [emphasis added], management and research is guaranteed by sound information sharing and administration mechanisms. Set up information share service systems: utilize the Internet and governmental network resources, and the state monitoring database for environment and health; rely on the e-government platform; consult the standards of the World Health Organization and the United Nations Environment Program. (Chinese Ministry of Environmental Protection, 2008)

The increasing public awareness has worked as vehicles for science and policy interface in East Asia as the public has engaged in data sharing not only with science but also with politics through expressing what information they need more from the governments.

In addition to domestic efforts to solve the severe air quality issues, East Asian countries have cooperated through various channels. The first Tripartite Policy Dialogue on Air Pollution for China, Japan, and South Korea was held in March 2014 in China upon an agreement of establishing a policy dialogue on air pollution at the 15th Tripartite Environment Ministers' Meeting in May 2013 in Japan (Trilateral Cooperation Secretariat, 2014). The second Tripartite Policy Dialogue on Air Pollution was held in March 2015 in Korea to share policies and technologies for air pollution reduction. China's Ministry of Environmental Protection requested to focus on sharing policies and practices of volatile organic compounds and non-road mobile pollution sources that are the main causes of smog (Ministry of Environment of Korea, 2015c). China wanted to learn advanced policies and technologies from Japan and Korea.

In fact, the governments of China and South Korea started to share their data on real-time air pollution monitoring via private line in March 2015 and created a joint research team to investigate air pollutants in May 2015 (Ministry of Environment of Korea, 2015b). In addition, the two countries launched "Korea-China Fine Dust Reduction Project" in several steelworks in China in June 2015.

International efforts to cooperate as well as a myriad of domestic measures of the governments in East Asia would be necessary to solve PM that the people in the region have been suffering from. This research contributes to understanding the role of science and the sound relationships between science and policy. The public is not a passive receiver of scientific information and knowledge but an active seeker of better science and more affluent information. Thus, the science-policy interface is not a simple relationship between scientists and policymakers. Rather, science develops and transmits knowledge to create engaging relationships between the state and the society. The debut of PM in the early 2010s proves this triangular relationship among the state, society and science. It is suggested to examine the process of further development of policies about PM in East Asia after the debut of this issue as follow-up research.

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